Extracting Innovation:
An Integrated Material and Experimental Analysis of Early Distillation Technology and its Characterisation in South-Central Asia

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Abstract

In considering the position of technology within contemporary society, the concept of 'innovation' is integral in the creation of national, regional, and global narratives. This thesis addresses how early distillation - the selective evaporation and condensation of mixed substances - has been identified from archaeological evidence in South-Central Asia and associated with dialogues on the 'Hellenistic East' that are tied to traditional views on the influence of ancient Greek cultural and scientific innovations. The emergence of distillation marks a changing understanding of material properties, encompassing ideas on extraction, purification, and essences, and historically connected to proto-chemical explorations of matter. Yet primarily, distillation has been researched through a distinctly technically-led framework of explanation and empiricism. This thesis, therefore, challenges the widespread reconstruction of the 'Gandhāra still' as a key component within global chartings of distillation technology, used intermittently to both indicate processes of Hellenisation in South-Central Asia, but also reject ancient Greek origins for early distillation. First noted as 4th c. BCE – 4th c. CE ceramic remains from modern-day Pakistan, Afghanistan, and northern India, the characterisation of the 'Gandhāra still and tradition' is comprehensively evaluated in this thesis following recent reappraisals through a systematic material survey and targeted exploratory experimental studies. Results demonstrate how the 'Gandhāra tradition' and its constituent components are unlikely interpretations, both archaeologically and functionally, exemplifying how cultural concepts underpinning a limited view of 'innovation' have influenced interpretations of regional change, material classifications, and site function. Instead, through a holistic approach to technology, the body of analysis developed in this thesis reconsiders the technical practices and processes of innovation in early distillation by utilising insights gained from the experimental work. In doing so, an alternative view on the original 'Gandhāra still' archaeological evidence in South-Central Asia is presented that is distanced from its entrenched connection with distillation.

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Contents

Glossary, Abbreviations, and Orthographical Conventions

Distillation	Process of separating components or substances from a liquid mixture through selective boiling and condensation; predominantly undertaken using a ‘still’ (distilling apparatus).
Distilland	Material to be or being distilled.
Distillate	Material or substance formed from distilling and condensed from vapour; material concentrated or extracted distilling.
Early distillation	Phase of distillation technology and technical developments in distillation that predates the introduction of the alembic around 700-800 CE.
Proto-chemistry	Activities with some similarities (by contemporary standards) to modern chemistry; programme of methodical foundation for modern chemistry
Proto-distillation	Label for a series of technical developments that share some conceptual and thematic similarities with distillation
Proto-science	Activities with some similarities (by contemporary standards) to modern science; a field of research or understanding that acted in part as the conceptual foundations for modern science.

Orthographical conventions

- English translations of paper texts, titles, and journals in non-Latin alphabets are provided in square brackets “[ ]”
- Journals in Latin alphabets are not translated into English
- Individual author names are written in Latin alphabet if published in this way, institutions are in their native alphabet if published in this way, with English translation provided in square brackets “[ ]”
- Sites in South-Central Asia are frequently anglicised when translated in published research (e.g., ‘Shaikhan Dheri’ as opposed to ‘Shaikhān Dherī). Where a certain spelling is used in this text, it refers to how it is used in a specific publication. Alternative spellings of site and regional names are noted in the Catalogue.

Terminology conventions

- The region of *Punjab* is sometimes referred to as *Panjab* implicated by historical socio-political divisions and the preferences of certain authors. Where a specific spelling is used in this thesis, it is in direct reference to the original usage by an author and not a reflection of any political belief.
- The cultural groupings of *Scythians* and *Saka,* and *Parthians* and *Pahlava,* have historically been used interchangeably despite recognition of their geographic differences and incorrect previous ascriptions (see Tillisch 2008, pp. 5–16; Müller 2013). Where a specific term is used in this text (e.g., Indo-Scythians; the Saka, Scytho-Parthian, Saka-Pahlava etc.), it is in direct reference to how the relevant original authors have used a term and not necessarily agreed by the author of this thesis.

Abbreviations featured in the text

AIIT	Ancient India and Iran Trust
BGW	Black Gloss Ware
BMW	Black Metallic Ware
BSW	Black Slip Ware
hh:mm:ss	Hours : Minutes : Seconds (time values; e.g., 04:26:26)
ISMEO	Associazione Internazionale di Studi sul Mediterraneo e l'Oriente
NBPW	Northern Black Polished Ware
NRI	Needham Research Institute / the Needham Institute
NWFP	North-West Frontier Pakistan, now called Khyber Pakhtunkhwa
ORA	Organic Residue Analysis
PGW	Painted Grey Ware

List of Figures

List of Tables

Chapter One

Introduction

To study our material world is to analyse the relationships between humans, environments, and communities. Interrogating the social phenomena that guide the transformation and transmission of material resources - *technology* - is intrinsically a concern of how the material world performs, is understood, and can be utilised (see Pfaffenberger 1992; Ingold 2000, p. 312; Dobres 2010). The dynamic contexts of technology encompass how the creation of 'things' brings together individuals, organises social groups, and generates production strategies (Dobres 2000, 2010). Technologies, as a result, are interconnected *sociotechnical systems* (Pfaffenberger 1992) which illuminate, and are indicative of, world views, social dynamics, and changing human networks (Gosselain 2017, p. 292). Exploring the consolidation of *craft practices*, and their sequences of gestures and actions (e.g., Balfet 1991; Sellet 1993; Dobres 1999), reveals sociocultural details embedded in technical stages and material knowledge (see De La Fuente 2011). Correspondingly, such analyses expose the contexts in which social institutions, constructs, and identities emerge and can be reproduced (Pfaffenberger 1992). *Technological innovations* - the generation, dispersal, and adoption of new material practices (Sluiter 2017; Erb-Satullo 2020, p. 38) - do not, therefore, passively diffuse into new settings as 'better' ways of doing. Rather, innovation is a dynamic process that illustrates the technical, material, and social conditions that exist for practices to become accepted (Versluys and Sluiter 2023, p. 29). Through the cross-purposing of craft knowledge (see Brysbaert 2007, 2011, 2021) innovations respond to, and integrate with, existing social conditions (Sluiter 2017, p. 21). Societal changes happen through the "clustering" of technological practices, material understandings, and social activities that, therefore, enable innovations to become fully integrated into new social settings (Brysbaert 2020, p. 307).

This thesis takes a multifaceted approach to analysing technological innovation, its societal impacts, and the formation of technological practices through a specific and targeted case. While the pyrotechnologies of glass, ceramics, and metallurgy have dominated discussions on technical innovation (see McDonnell 2005; Erb-Satullo 2020), the selective control of evaporation and condensation through distillation is positioned as a significant material transformation process meriting detailed discussion. Ceramic vessels characterised as a *distillation apparatus* from South-Central Asia dated to the latter centuries of the 1st mill. BCE and early 1st mill. CE is one technological 'tradition' at the centre of associated dialogues of innovation and the origins of modern science (e.g., Needham et al. 1980; Park 2021). As a method of extraction, purification and material separation, several proposed origins of early distillation have been suggested, presenting the hypothesis that multiple independent versions of the technology emerged as new and 'complex' innovations.

During archaeological investigations throughout the 19th and 20th centuries in South-Central Asia, partly established ceramic typologies pertaining to local, imported, and seemingly 'Greek' vessels dated through the 4th c. BCE – 4th c. CE included elements of a distillation apparatus. One vessel characterised as a *receiver, receiver-condenser,* or *condenser* was identified (e.g., Marshall 1951; Dani 1966; Husain 1980), localised in the ancient region of Gandhāra that encompasses parts of modern Afghanistan, Pakistan, and the north Indian subcontinent (Figure 1). Deemed a component of the characteristic "Gandhāra still" and distillation "tradition" (e.g., Marshall 1951; Allchin 1979a, 1979b), the vessel has been shaped as integral in understanding the global development of distillation (e.g., Needham et al. 1980; Park 2021). However, this attribution has been only sporadically discussed aside from focussed critiques of specific elements such as translations (e.g. McHugh 2014, 2021) and experimental work that has aimed to show that the apparatus works (e.g., Butler and Needham 1980). Indeed, archaeological evaluations have been introduced (e.g., McHugh 2020)[1], but need developing to fully recognise the range of issues associated with such reconstructions and their pervasiveness.

Despite sitting at the geographic junction where eastern and western cultural ideas met, the apparatus periodisation coincides with the formulation of the 'Hellenistic East', broadly from the 4th c. BCE with a legacy lasting until at least the 4th c. CE. Here, the ancient region of Gandhāra has been used explore sociocultural interaction at the interface of multiple societies, situated around the Kabul and Indus rivers with the mountainous Swat and Bajaur Valleys to the north. Correspondingly, the region has traditionally been considered a context for the diffusion of cultural ideas from ancient Greece and the East Mediterranean into Central Asia (see Holt 1999; Mairs 2011, 2014; Manning 2014; Minardi 2018; Ball et al. 2019; Olivieri 2020a). Historically, the idea of innovation within such contexts has been closely aligned with select scientific connotations of technology (e.g., Woodcock 1966). Incubated through an enduring influence of Hellenocentric dialogues (e.g. Hadas 1959; Walbank 1981), material culture has been used to discuss sociocultural change in Central Asia, though often based such an interpretation in extensive references to ancient Greece (see Mairs 2011, 2014 for overviews). By extension, technology (if at all mentioned) has been viewed in a similar light.

[1] Accessing McHugh's critique (2020) of the Gandhāra still was delayed after its original publication due to the implications of the COVID-19 pandemic between 2020-2022.

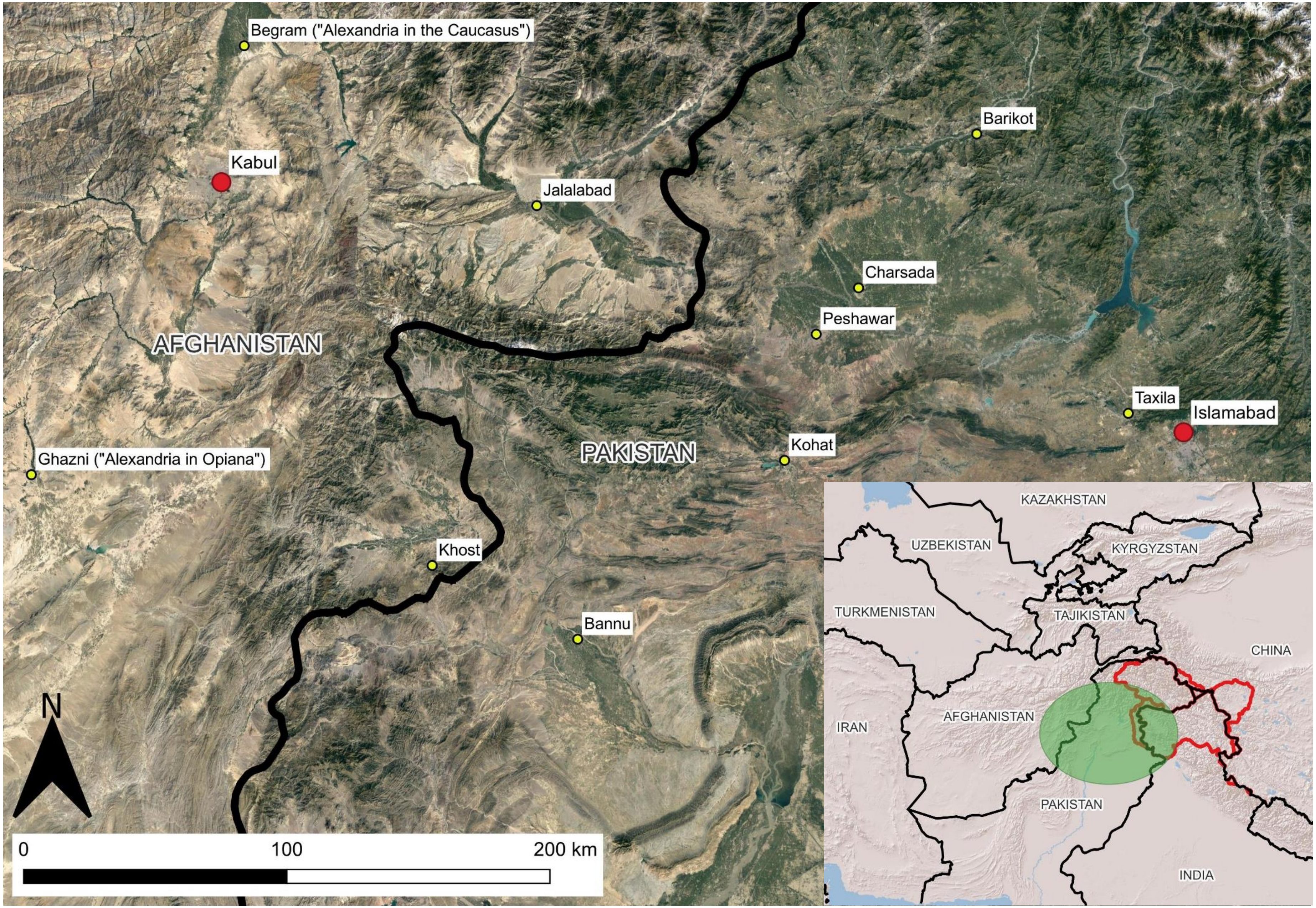


Figure 1. *Approximate region of Greater Gandhāra within Central Asia (insert) with select key sites and modern settlements.*

Major re-evaluations of Hellenisation in regions to the east of the Mediterranean have meaningfully addressed the degree to which dramatic sociocultural changes can be exclusively attributed to a single cultural origin (e.g., Rempel and Yoffee 1999; Petrie 2002; Vranić 2019). Reinterpretations of Gandhāra have followed, focussed on reviewing the extent of Greek influences in art, architecture, language, and stylistic forms of vessels (Petrie et al. 2008; Mairs 2014; Wallace 2016; Pons 2019; Olivieri 2020a). However, investigations of specific technologies, aside from some targeted studies on ceramic production (e.g., Iori 2018; Maritan et al. 2018, 2020), require further scrutiny. Distillation is no exception, and has been drawn into a debate on the influence of Greek intellectual and technological knowledge at the easternmost extremities of its contact (e.g., Egloff and Lowry 1930; Liebmann 1956; Rasmussen 2014). In South-Central Asian characterisations of distillation, questioning the cultural roots of the Gandhāra apparatus, and the materials being distilled, dominates discussions (e.g., Marshall 1951; Dani 1966; Husain 1980; Brancaccio and Liu 2009; Klimburg 2016). Here, the development of 'complex' technologies, including the emergence of modern chemistry, is traditionally presented as a move towards sophistication, indicative of cultural influences from Classical civilizations (e.g., Finley 1965; Ihde 1984, pp. 3–4). Considering how central such a conceptualisation is in modern Westernised views of civilization (see Haddad 2021), a comprehensive study of the Gandhāra tradition of distillation is required to bring interpretations of technological change in the region into a sphere of critical analysis. "The human factor", in understanding how new ideas, practices, and techniques are adopted and adapted (Sluiter 2017, p. 21), must be central in extrapolating the body of craft knowledge needed to integrate technological changes into regional and cultural contexts. Accordingly, distillation can be presented in a more nuanced format, which helps unravel the changing understandings of materials and their properties that contributed to the consolidation and adoption of an 'innovation'.

1.1 Research aims and scope

This thesis develops a critical perspective on interpreted early distillation practices in South-Central Asia through an evaluation of ceramic materials suggested for distillation and their wider technological contexts. The characterisation of early distillation in the region is explored though assessing its cultural ascriptions, connections to the 'Hellenistic East', and the influence of such a dialogue upon wider historiographies of technology. Pivotal to the study is a systematic material survey coupled with targeted exploratory experimental studies to evaluate reconstructions of suggested distillation apparatus in Gandhāra. In response, a series of preliminary considerations will be introduced to holistically reframe early distillation technology through ideas of craft practice, technical skills, and material knowledge. Such a view stems from a perspective on technology that embraces an understanding of relational concepts, cross-craft interaction, and changing human perspectives of materials. Through an interdisciplinary and multi-analytical experimental methodology, the capacity of early distillation is explored and generates a unique insight into fundamental considerations of the development of refined distillation techniques. Reappraising the suggested apparatus configurations within this integrated framework, and critically evaluating the body of interpretation, therefore, takes a multifaceted approach:

- Through a comprehensive material survey, produce a detailed synthesis of interpreted early distillation apparatus forms and components in South-Central Asia.
- Develop an enhanced critical evaluation of functional parameters that pertain to the characterised distillation apparatus (i.e., meaningful practical and technical observations on the process) through a series of exploratory experiments.
- Integrate the combined bodies of information into critiques of technical innovation in Gandhāra, 'the Hellenistic East', and the role of technology as an analytical tool within dialogues of sociocultural change.
- Generate a preliminary interpretation of early distillation as a change in human-material relationships, drawing from theoretical ideas on the sociality of technology and practice-based approaches.

1.2 Contextual and temporal setting

As a "space of constant dialogue" (Iori 2018, p. i), discussions concerning sociocultural, economic, and political changes during the 1st mill. BCE - 1st mill. CE transition in West and Central Asia are entrenched in concepts of innovation and mobility. These ideas have framed the transmission of fundamental developments in metallurgy, ceramic production, and glass manufacture (White 1984; Curtis 2005; Erb-Satullo et al. 2020). Considering such a sizeable geographic scope and temporal range, attempts to ascribe broad cultural phases to technological innovations have resulted in generalised connections with geographic areas and statements on cultural or civilization 'complexity' (e.g., Ihde 1984; White 1984; Assmann 2010).

Classical antiquity, linked to changes in the Graeco-Roman World, has continually served as an overarching framework for such technological ideas (e.g., Finley 1965; White 1984; Brun 2000). The *Hellenistic period* of classical antiquity, viewed in relation to the 'Greek World' during Greco-Macedonian domination (c. 330 – 30 BCE) (Haddad 2021, p. 3307), marks an extent of Greek cultural influence that instigated certain innovations and practices to diffuse globally. Within archaeology, *Hellenism* traditionally pertains to the analysis of shared aspects of material culture within the ancient Greek and Mediterranean ‘worlds’ (ancient Macedonia and the Aegean) (Vranić 2019, p. 144). This has been defined directly in relation to Greece (i.e., Hellenic cultural influences), but developed as cultural narrative from modern and Westernised views on the past (Dietler 2005; Prag and Quinn 2013; Thonemann 2016, p. 5). Hellenism is, therefore, rooted in the creation of European imperialist values, a contemptuous portrayal of Asia (i.e., Orientalism) (see Said 1978; Haddad 2021, p. 3308), and a Greco-Roman colonial “cultural ancestry” deemed the foundations of European-American culture (Dietler 2005, p. 34). Thus, as a recognised consequence of increased mobility outside the Mediterranean (Papadopoulos 2014, p. 180), *Hellenisation* - the adoption of Greek cultural and societal ideas - sees specific sociocultural diffusions and legacies as having stemmed from ancient Greece (e.g., Assmann 2010, p. 127). ‘Hellenisation’ emphasises the superiority and dominance of Greek culture through a simple transmission of objects and ideas (Langin-Hooper 2007, p. 145; Vranić 2019, p. 145), justified through comparing Mediterranean and Black Sea Greek diasporas to 15th-18th c. European colonisations (Papadopoulos 2014, pp. 187–188). Favouring a colonialist narrative, the enduring theory that the dispersal of a Hellenistic *koine* - Greek-rooted common language, customs, and culture - ‘carried’ technological ideas and influenced coinage and administrative structures (Olbrycht 2017, p. 195). This instigated a legacy of sociocultural changes as the basis of modern, globalised society (Haddad 2021, p. 3325), exerting a “profound influence in the construction of cultural capital and colonial ideologies in modern Europe and America” (Dietler 2005, p. 35).

Material culture as an indication of Hellenism was traditionally aligned strongly with the notion of ‘art’ particularly from an imperialist perspective (e.g., Woodcock 1966, p. 172). Hence, artistic differences more recognisable to European archaeologists, determined as sufficiently Greek and sophisticated by 19th century standards (i.e., Hellenistic features) have caused pre-set cultural concepts and connections to Greek artistic and technological techniques to underpin interpretations (Van Aerde 2018). The idea that Greeks aimed to diffuse their superior culture into less civilized and less culturally sophisticated regions that they encountered (see Yoffee 2005, pp. 153–159 for analysis) could be examined by connecting identified materialisations of high culture with contemporary understandings of high art, and thus the specific ethnic backgrounds of newly identified ideas (e.g., Tarn 1938; Woodcock 1966). Hence, in the consolidation of ‘Hellenisation’ within archaeological thought, critical ideas on interconnectivity across the Asian continent were largely overlooked.

Consequently, ‘Hellenistic periods’ have been demarcated in many regions seen to have experienced any degree of contact with the ‘Hellenistic World’ (e.g., de Codrington 1944, p. 82). Following early interest narratives (e.g., Banerjee 1919), Tarn’s seminal publication of

"The Greeks in India and Bactria" (1938) first fully set in motion the idea of a diffused Greek influence within South-Central Asia (Holt 1999, p. 9). The campaign of Alexander III of Macedon into Central Asia (334-323 BCE), and entry into Bactria and Gandhāra in 327-326 BCE, successfully conquered the Achaemenid Persian provinces within South-Central Asia[2], bringing them under nominal Graeco-Macedonian control (Mairs 2020, p. 3). This process is seen to have introduced Greek as a dominant written administrative language (Mairs 2014, pp. 10, 178). While existing local officials continued to administer their regions, the campaign instigated a growth of a new cultural influence expanding across parts of the Indian subcontinent through the construction of numerous urban settlements (Figure 2). However, the archaeology of the region was hardly known during early discussions (Mairs 2020, p. 1). Scholars nevertheless inflated Greek influence at its most eastern extent (e.g., Tarn 1938; de Codrington 1944; Woodcock 1966) driven by a "Western desire to exploit and build evidence on Eastern Hellenism" (Dani 1966, pp. 17–18). Largely as an exploration of multicultural contacts in the farthest areas reached by Hellenism (Antonetti and Biagi 2017, p. viii), the 'Hellenistic East' was presented in such accounts as the period of introductions of Western culture into Asia.

In the latter part of 4th c. BCE, Alexander departed the easternmost regions of his post-conquest empire (Stoneman 2019, pp. 37–38, 79), leaving garrison cities and immigrant communities that flourished and initiated a dispersal of 'Greek' characteristics in art, religion, and architecture. The succeeding Seleucid Kingdom maintained control in South-Central Asia, while modifying existing administrative structures and introducing new political foundations across their empire (Rempel and Yoffee 1999; Yoffee 2005, pp. 155–159; Coloru 2013). Though despite developing a network of settlements between the Mediterranean and Central Asia (Coloru 2013, p. 38), the Seleucid Kingdom eventually turned its attention elsewhere (Mairs 2020, p. 3). The 'Hellenistic Period' of kingdoms and polities that emerged after Alexander's departure and death (323 BCE), however, fragmented and developed at differing rates, far from the invariable view of 'Hellenisation'. Succeeding kingdoms established by Saka (Scythian) (see Tillisch 2008; Müller 2013 for discussion on terms), Parthian, and Indo-Scythian and Indo-Parthian rulers gradually pushed the last of the Greek rulers eastwards into the eastern Punjab until finally collapsing around 10 CE (Callieri 1995, p. 293). Regular disruption ultimately ended with the Kushan Empire, seen as a "Greek-speaking people" from the 1st - 4th c. CE (Pollard and Liu 2022, p. 2), which consolidated the region and brought political cohesion (Mairs 2011, p. 9). Collectively, this period became known as the "Hellenistic period of Indian history" (de Codrington 1944, p. 82).

[2] Parts of Bactria, Gandhāra, Arachosia, and Sattagydia satrapies.

Accordingly, chronological difficulties within Gandhāra have been routinely debated, contested, and revised (see Table 1), with only a handful of sites producing accurate dating information by which to corroborate cultural phasing of material culture. By the mid-3rd c. BCE, an effectively independent 'Graeco-Bactrian' kingdom was established and survived until approximately the mid-2nd c. BCE, followed by a seemingly new Graeco-Bactrian dynasty that embarked on a series of conquests into parts of Gandhāra by the 2nd c. BCE[3] (Mairs 2020, p. 3). Greater Gandhāra, as a recognised area, grew in importance in the 'Silk Road' at the confluence of India and China, retaining its links to the Mediterranean world (Pollard and Liu 2022, pp. 2–3). Subsequent dynasties that ruled over the dispersed and fragmentary territories became known conventionally as 'Indo-Greeks', defined specifically as Greeks from Bactria settling in Gandhāra after the Graeco-Bactrian invasions who adopted 'Indian' cultural practices until approximately 1st c. CE (Mairs 2011, p. 35). Yet despite Indo-Greek and Graeco-Bactrian being modern terms (Mairs 2020), both are traditionally seen to have ushered in political plans that encompassed urban foundations, resource and monetary reform, diplomatic power reorganisation, and warfare (see Manning 2014, pp. 8–9; Olivieri 2020a, p. 386). Hence, the impact of external imperial structures in Gandhāra and Bactria since the 6th c. BCE at the eastern edge of the Achaemenid Empire have been given less attention in research (cf. Petrie et al. 2008). Such structures provided the grounds for outside powers to influence social and political entities in the region (e.g., Curtis 2005; Magee and Petrie 2010; Minardi 2018).

Marking the chronological and geographic parameters of what constitutes the Hellenistic 'Easts', let alone their greater influence, is, therefore, difficult and misleading (Mairs 2011, p. 8). Yet defining the 'Hellenistic East', 'Greeks-in-the-East' and 'Hellenistic Far-East' as catchall groupings from modern stances (Petrie 2002, p. 86) became the focus when attention turned to archaeological remains (see Mairs 2011, 2014, 2020 for overviews). Such a conceptualisation is based in a limited archaeological lexicon that marks epistemological boundaries tied to theories of Orientalism[4], environmental determinism, and nationalism myths (Antonetti and Biagi 2017, p. vii). This is exacerbated by the long history of ascribing periodisations of cultural groups to a densely complicated region (such as 'Indo-Greek') when such terms derive from modern scholarship (Mairs 2020). Recording a history of the Indo-Greek kingdoms as products of Hellenisation is, therefore, "impossible in anything other than the broadest lines, and it would be irresponsible to give the impression that one could write it" (Mairs 2020, p. 3).

[3] Concentrated around 180 BCE.
[4] In which the 'East' is considered as "off-centre" from European progress (Said 1978, pp. 204, 220, 279).

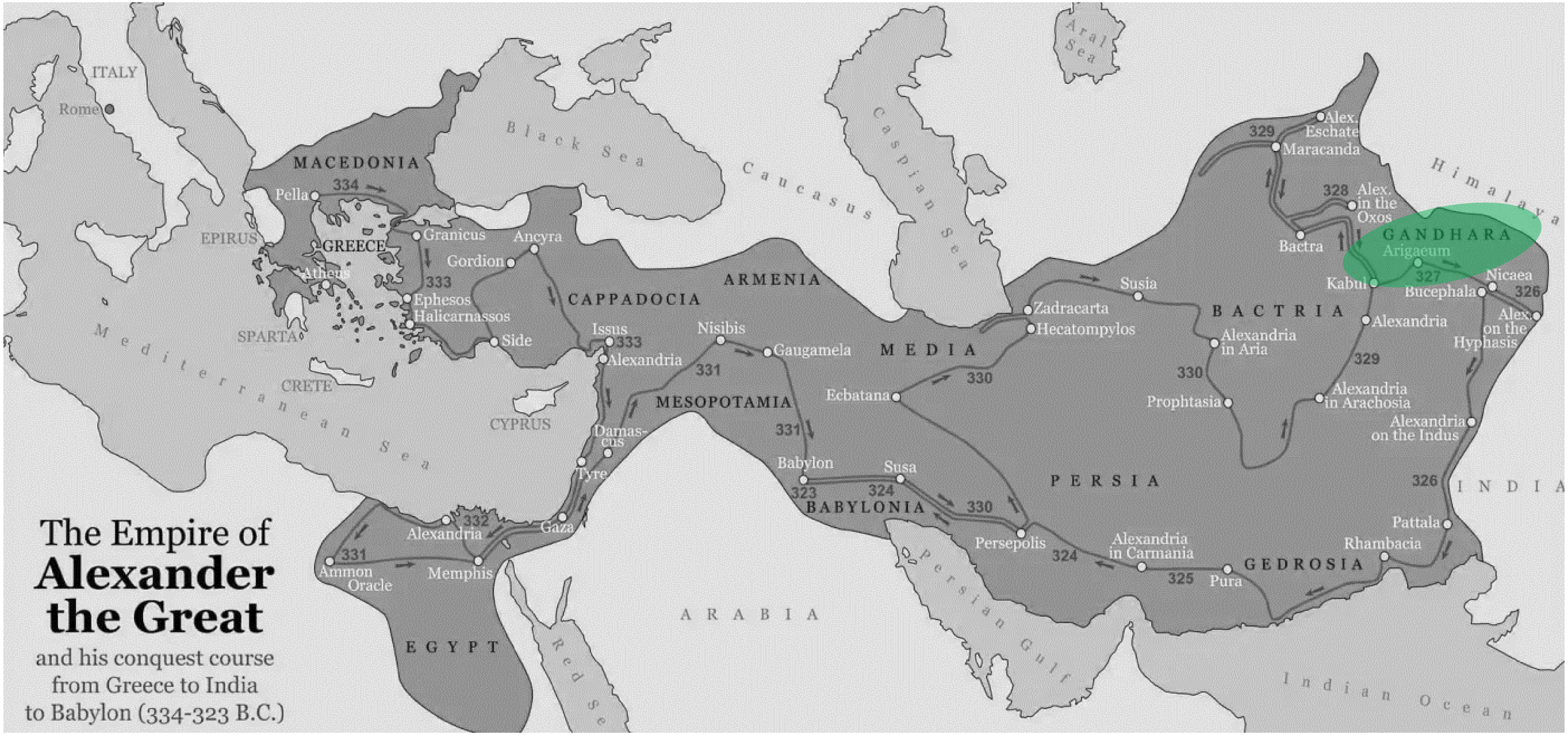


Figure 2. *The extent of Alexander III of Macedon's conquests by 323 BCE and route of Alexander III of Macedon's campaign into Central Asia. The approximate area of study region (Gandhāra) is indicated by the green oval (after Lyons 2015, fig. 1).*

Date range(s)	Broadly ascribed cultural phase and features	Other select attributed regional phases
Late 2nd or Late 2nd – early 4th c. CE (Dani 1966, pp. 24–25)	Late Kushan (Dani 1966, pp. 24–25) Late 4th c. CE, clear switch from figures of Greek mythology to casting images of the Buddha in copper-alloys (Pollard and Liu 2022, p. 3)	Barikot Macrophase 6 Phase IIIB, Kushan Charsadda Layers 14-15 (Dittmann 1984) Phase A, Period I, Late Kushana, Time of Vasudeva (Dani 1966) Bala Hisar, Charsadda Layers 14-15 (Wheeler 1962)
Mid 1st c. CE – early 3rd c. CE; Includes 93 CE (Dani 1966, pp. 24–25)	Middle Kushan (Dani 1966, pp. 24–25)	Barikot Macrophase 5 Phase IIIB, Kushan Charsadda Layers 14-15 (Dittmann 1984) Phase A, Period II, Middle Kushana, Time of Kanishka and Huvishka (Dani 1966) Bala Hisar, Charsadda Layers 14-15 (Wheeler 1962)
Early or mid 1st c. CE - 2nd CE (Dani 1966, pp. 24–25)	Early Kushan (Dani 1966, pp. 24–25)	Barikot Macrophase 4 Phase IIIB, Kushan Charsadda Layers 14-15 (Dittmann 1984) Phase A, Period III, Early Kushana, Time of Soter Megas, Wima Kadphises and Kujula (Dani 1966) Bala Hisar, Charsadda Layers 14-15 (Wheeler 1962)
c. 50 BCE – 90 BCE	Saka-Parthian, Hellenistic disappearing (Olivieri 2020a, p. 387) Late Indo-Greek / Saka-Parthian (Dittmann 1984) Saka (Scythian) and Indo-Saka, period of destruction and levelling at Shaikhān Dherī (Dani 1966)	Barikot Macrophase 3b (Olivieri et al. 2019, p. 154) Phase IIIA, Charsadda Layers 16-19 (Dittmann 1984) Phase B, Period IV A, Late Parthian (Dani 1966 Bala Hisar, Charsadda Layers 19-22) (Wheeler 1962)
c. 90 BCE – 80 CE	c. 111 BCE – 53 CE (2σ cal.) - Mature Barikot Urban Phase (Olivieri 2020a, p. 387) Late Indo-Greek / Saka-Parthian (Dittmann 1984) Indo-Parthian and Saka (Scythian)-Parthian Scytho-Parthian (Dani 1966)	Barikot Macrophase 3b (Olivieri et al. 2019, p. 154) Phase IIIA, Charsadda Layers 16-19 (Dittmann 1984) Phase B, Period IV B, Main Scytho-Parthian (Dani 1966) Bala Hisar, Charsadda Layers 16-18 (Wheeler 1962)
c. 150 – 50 BCE c. 182 BCE – 45 BCE (2σ cal.)	Indo-Greek pottery forms (first appearance), Greek script (Olivieri 2020a, p. 387) Indo-Greek (Dittmann 1984) Greek (Dani 1966)	Barikot Macrophase 3a2(post-250 BCE) - 3a.3 (post-150 BCE) (Olivieri et al. 2019, p. 151) Phase IIID Charsadda Layers 20-21 (Dittmann 1984) Shaikhan Dheri Phase C, Period V (A), Late Greek, Time of minor Greek rulers (Dani 1966) Shaikhan Dheri Phase C, Period V (B), Middle Greek, Post Meander time (Dani 1966) Shaikhan Dheri Phase C, Period VI, Early Time of Meander, Apollodotus I and Agathocles (Dani 1966) Bala Hisar, Charsadda Layers 19-22 (Wheeler 1962)
210 – 94 BCE (2σ cal.)	Mauryan(?), Indic, Graeco-Bactrian, and Greek pottery forms first appearance (Olivieri 2020a) Alexander-Mauryan (Dittmann 1984) c. 180 BCE, collapse of Mauryan dynasty (Behrendt 2007)	Barikot Macrophase 3a, Period 3a1 (Olivieri 2020a, p. 387) Phase IIC, Charsadda Layers 22-24 (Dittmann 1984)
c. 305 BCE – 180 BCE	369 - 201 BCE (2σ cal.) - Initial Barikot Urban Phase (Olivieri et al. 2019, p. 151; Olivieri 2020a, p. 387) 327 BCE – 326 BCE - Alexander III's campaign (Stoneman 2019, p. 79) Late Achaemenid (Dittmann 1984) Post-Achaemenid (Vogelsang 1988) Late 3rd c BCE, Emergence of Greco-Buddhist / Gandhāran art styles (Behrendt 2007)	Barikot Macrophase 2b (Olivieri et al. 2019, p. 151; Olivieri 2020a, p. 387) 3rd – 2nd BCE (Olivieri 2020b, p. 46) Charsadda Layers 14-28 (Vogelsang 1988) Phase IIB, Charsadda Layers 25-28 (Dittmann 1984) Bala Hisar, Charsadda Layers 24-34 (Wheeler 1962)
c. 530 – 330 BCE c. 543 BCE – 307 BCE (2σ cal.)	Achaemenid, Iranic, and Indic pottery forms (Olivieri 2020a, p. 387) c. 530 – 330 BCE - Gandhāra in eastern part of the Achaemenid Empire (Petrie et al. 2008, p. 1) Early Achaemenid (Dittmann 1984)	Barikot Macrophase 2a, Period 2a2 (Olivieri et al. 2019, p. 151; Olivieri 2020a, p. 387) Mid-1st mill. BC, Charsadda Layers 28-38 (Vogelsang 1988) Phase IIA, Charsadda Layers 29-32 (Dittmann 1984)
c. 654 – 307 BCE (2σ cal.)	Pre-Achaemenid (Vogelsang 1988) Achaemenid (Dani 1967)	Barikot Macrophase 2a, Period 2a2-2a1 (Olivieri et al. 2019, p. 151; Olivieri 2020a, p. 387) Phase IB, Charsadda Layers 33-38 (Dittmann 1984) Bala Hisar, Charsadda Layers 35-38 (Wheeler 1962)
c. 800 BCE - 450 BCE	Iron Age (?) (see Dittmann 1984, p. 159 for discussion) Achaemenid (Dani 1967)	Swat Period III, Phase VII - VI(II) (Dittmann 1984)
c. 1400 BCE – 800 BCE	Gandhāra Grave Culture Early Iron Age (Dani 1967)	Barikot Macrophase 1a-1b (Olivieri et al. 2019, p. 154) First half of 1st mill. BC, Charsadda Layers 39-51 (Vogelsang 1988) Phase IA, Charsadda Layers 39-51 (Dittmann 1984) Swat Periods V-VI (Dani 1967, pp. 22–40) Bala Hisar, Charsadda Layers 39-51 (Wheeler 1962)

Table 1. *Broad chronology of Gandhāra from Middle/Late Prehistory to Early Historic phases based on historical events and chronologies from sites in the Charsada area and site of Barikot (frequently used as models for dating in the region). Detailled chronologies allied to comprehensive absolute dating are few in number, hence references to specific straigraphic phases are given. The Barikot sequencing by Olivieri et al. (2019) and Olivieri* (2020b) *features more detailled phasing than presented in this overview. Where radiocarbon dates from Olivieri et al. (2019) are given, the calibrated standard deviation is also presented. Highlighted area roughly covers the period of* Gandhāra *distillation apparatus (depending on interpetation in individual studies).*

Over the last three decades, inherent biases of 'Hellenism' have been comprehensively discussed to re-evaluate dichotomous and binary views on social groups that experienced contact with the Mediterranean world (e.g., Yoffee 2005, p. 155; Filigenzi 2012, p. 112). Since the mid-20th century, research had begun to realise narratives on the 'Indo-Greeks' could not only be shaped by contrasting views on the dominance of Greek or non-Greek cultures (e.g., Narain 1957). Several major urban sites within Gandhāra are seen to exhibit evidence for Hellenistic occupation, Greco-Bactrian Kingdoms, and Indo-Greek Kingdom phases (Olivieri 2020a). Irrespective of modern political designations (Iori 2018, pp. i–iii), Gandhāra, as a frontier of Hellenism (i.e., the birthplace of 'Greco-Buddhism', its associated Gandhāran art style, and Greek-influenced local material practices) has been reapproached from several analytical stances (e.g., Petrie et al. 2008; Filigenzi 2012; Iori 2018; Van Aerde 2018; Pons 2019; Stoneman 2019; Olivieri 2020a; Pollard and Liu 2022). Postcolonial critiques (see Wenghofer 2021) have sought to understand the role of local agency in responding to the adoption and acceptance of new introductions away from emphasising the study of archetypal 'Greek' elements (Vranić 2019, p. 157). Here, in recognising the heterogeneity of 'East' (e.g., Mairs 2014; Minardi 2018; Stoneman 2019), continuities in regional practices and selective adaptations of Greek elements have emphasised the position of material hybridisation (Corò 2017, p. 5). Rather than focused on asking how regions such as Gandhāra became 'civilized' through Hellenisation, material culture is considered a dynamic and fluid representation of identity not limited by ethnic description (see Richey-Lowe 2021). West and Central Asia had well established regional trade and contact networks across the continent and beyond from at least the 3rd mill. BCE, most directly in South-Central Asia during the Achaemenid period preceding Alexander's campaign (e.g., Petrie et al. 2008; Manning 2014, p. 8; Boperarchchi 2017; Minardi 2018; Ball et al. 2019). Accordingly, responses by social groups in the region, during both times of conflict and relative peace, therefore, were not only contingent on imperialistic influences, but adaptive within their existing structures and conditions (Mairs 2014; Iliakis 2018; Olivieri 2018; Versluys and Sluiter 2023). While still influential, the idea of the 'East' as a tabula rasa that wanted to become Greek and adopt universal values of a Hellenistic *koine* (e.g. Rostovteff 1941) is too rigid (Callieri 1995, p. 305).

The influence of Hellenisation upon technological innovation is a concern that has filtered into global narratives on regional change in South-Central Asia. As a common foundation, the emergence of 'sophisticated' scientific methods have traditionally been understood from Eurocentric studies of technology that cite conceptual roots in the diffusion of ancient Greek technical developments (e.g., Gwei-Djen et al. 1972, p. 75; Wilson 1975, p. 54; Brun 2000, p. 277). Particularly, the interpretation of early distillation has undergone several significant chartings as a key element in the history of science resulting from evolving logical empiricisms

(Berthelot 1888; Levey 1959; Needham 1962; Forbes 1970; Needham et al. 1980; Kockmann 2014). Distillation is a separation and purification process that converts a liquid mixture or solution of substances into two or more distinct components (Chickos et al. 2016) (Figure 3a). Apart from a few exceptions, elements and compounds exist in an impure state. Separation processes, therefore, enable the transformation of raw materials into different products by purification. Accordingly, the principles of distillation conceptually underpin other separation processes, specifically extraction and purification. Distillation enriches, concentrates, and collects certain constituents of the source mixture - the *distilland* - into *distillate(s)* by partially evaporating the mixture and successively condensing its evaporated components, dependent on their boiling point and volatile characteristics (Kockmann 2014, p. 1) (Figure 3). Hence, in suggesting distillation as a complex "ancient practice" (Moran 2005, p. 12), previous studies have approached distillation as a concern rooted in elucidating its explicit cultural origins.

When articulated as a scientific principle, the underpinnings of distillation and its connections to the industrialisation of engineering are linked with Alexandrian Greece (Egloff and Lowry 1930; Forbes 1970; Moorhouse et al. 1972; Needham et al. 1980; Kockmann 2014) (Figure 3). This association assumes specific cultural origins for the creation of certain bodies of knowledge and practices. Equally, such treatment has prompted a push-back against a Greek-centric narrative (e.g., Mahdihassan 1972; Needham et al. 1980; Park 2021) but one centred on understanding technological and knowledge diffusion from specific locales (Rocha 2016). The perceived emergence of 'distillation apparatus' in the 2nd c. BCE Indo-Greek Gandhāra, incepted by Ghosh's (1948) and Marshall's (1951) archaeological excavations at Taxila, has sat on both sides of the debate (see Figure 3b); one line of interpretation aligning with the tradition of connecting distillation as an ancient Greek practice and another set to prove otherwise (e.g., Ghosh 1948; Marshall 1951; Dani 1966; Mahdihassan 1972, 1979; Allchin 1979b, 1979a; Husain 1993). Consequently, the identification of distillation with roots in 'Ancient India' was seen as a definitive move away from a Greek-centric idea of early distillation and placed the Gandhāra apparatus alongside those with clearly Greek (the Hellenistic or 'Alexandrian') and Chinese origins (see Figure 3c).

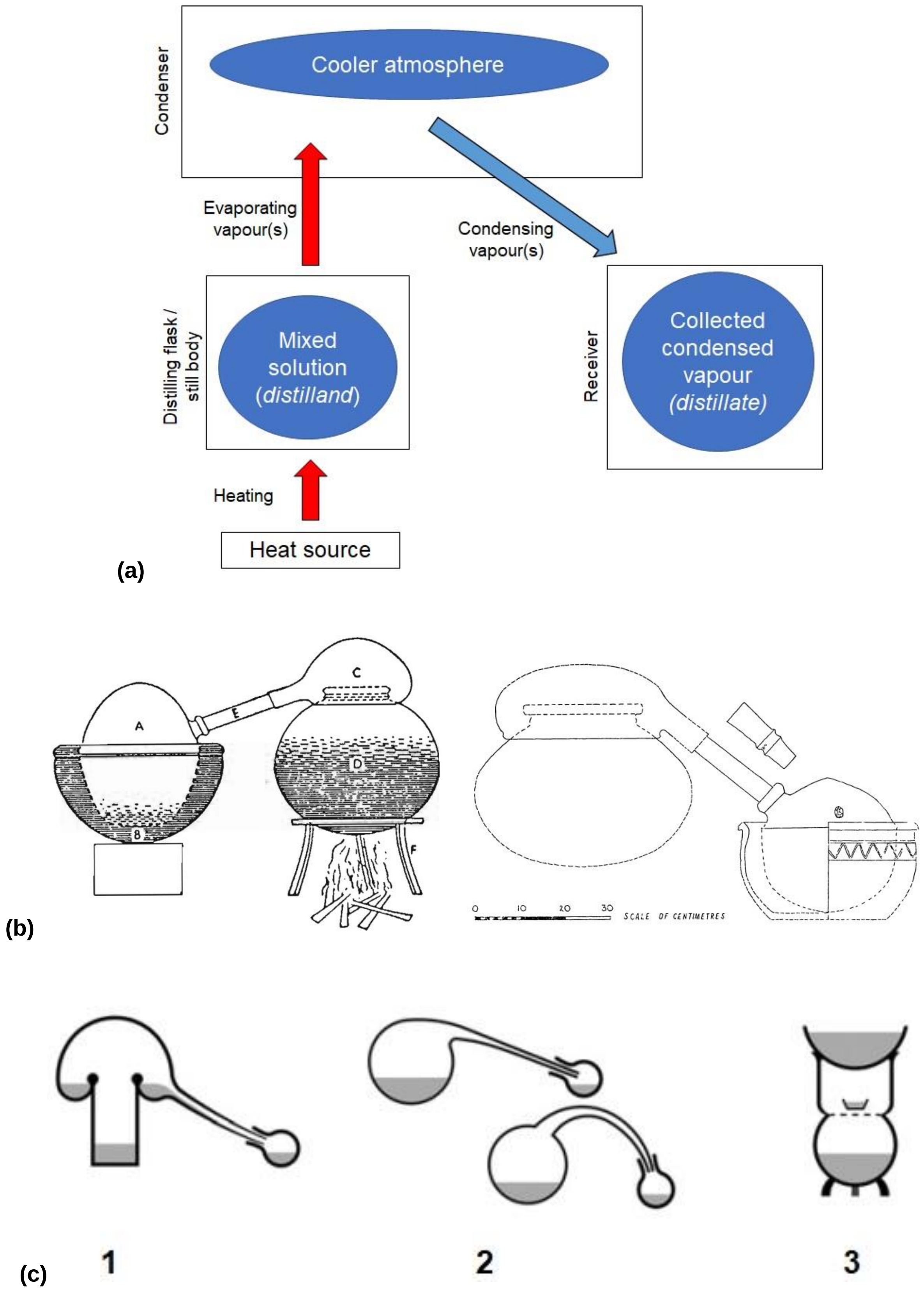


Figure 3. *The process of distillation and key reconstructions of early apparatus configurations.* ***(a)*** *Schematic showing the process of distillation and apparatus involved;* ***(b)*** *reconstructions of the "Gandhāra apparatus" from Taxila (left) (Marshall 1951, Pl. 125) and Shaikhān Dherī (right) (Allchin 1979a, p. 60);* ***(c)*** *examples of suggested key early still forms with distinct global origins (discussed further in Chapter 2):* ***1.*** *Hellenistic or 'Alexandrian' alembic still;* ***2.*** *Gandhāra still;* ***3.*** *'Ancient Chinese' still (Park 2021, p. 28, after Needham et al. 1980, p.81).*

Comprehensive explorations aiming to directly tie the provision, manufacture, and development of specialised equipment to residues of the products and processes conducted with apparatus have more recently been developed. This has previously been an often overlooked, but assumed, facet in reconstructing technological processes (Veronesi and Martinón-Torres 2018, p. 7346). Yet a stagnation of studies has significantly obstructed further exploration of early distillation apparatus, and particularly the archaeological evidence for it in South-Central Asia. Attempts to objectively classify distillation apparatus rather than critically evaluate previous characterisations, therefore, dominate. Hence, instead of proving the functional capabilities of models, the 'Gandhāra tradition' of distillation should be critiqued considering its fundamental connections to wide regional narratives. Distillation is a process that revolves around both the 'measurable' and abstract concepts of separation, extraction, purification, and material transformation, rooted in the capture and enhancement of certain properties. Conceptually different from those in the pyrotechnologies that begin with 'mixing' (e.g., Doonan and Day 2007), to explore the emergence of such a chemical technology within complex understandings of materials requires considering both technical practicalities and embodied craft skills. Thus, as the result of accumulated practical experiences when working with materials, objects, and resources (Pfaffenberger 1992; Ingold 2000, 2013; Dobres 2010; Kuijpers 2013, 2019), the emergence of early distillation can be more saliently explored through an analysis that moves away from assumed reconstructions. Rather than simply introducing new data, the renewed study of distillation and its adoption requires integrated archaeological approaches that utilise existing analytical techniques and datasets to revisit established interpretations (Erb-Satullo 2020, p. 36). From this stance, processes of innovation can be meaningfully reconsidered in South-Central Asia.

1.3 Methodological overview

This thesis utilises an interdisciplinary approach to develop a critical analysis of reconstructed early distillation technology and its origins in South-Central Asia, attuned to assessing how the Gandhāra tradition has been formulated and the plausibility of the reconstruction. By taking a view of technical innovation grounded in sociotechnical concepts, the thesis develops a series of preliminary ideas on the origins of distillation and its framing as a complete technological practice. In response, tentative reconsiderations of the archaeological materials and contexts related to distillation in the region can be offered, drawing from ideas on the sociality of technology. Crossing aspects of archaeology, chemical engineering, and insights of experienced practitioners in craft distilling, the methodological approach, therefore, comprises three related studies that promotes a re-evaluation of distillation technology, its characterisation in South-Central Asia, and innovations in early distillation:

- **Assess the archaeological characterisation and interpretation of early distillation technology within South-Central Asia through a systematic material survey.** Conducted through the consultation of archives, catalogues, and excavation reports (primarily from the Ancient India and Iran Trust), a detailed synthesis of interpreted distillation apparatus components, contexts, and configurations from South-Central Asia is presented.
- **Through experimental practice, evaluate the capacity and plausibility the interpreted early apparatus configurations from South-Central Asia and their functional parameters**. Split into two campaigns, experimental work both evaluates the functionality of the apparatus reconstructions through reconstruction and provides a series of practical considerations involved in early distillation technology. Preliminary experiments undertaken in a laboratory environment initially tests the reconstructions and subsequently directs a comprehensive exploratory experimental campaign within an 'authentic' setting. This approach establishes the functional parameters pertaining to the apparatus reconstructions, but also elucidates points of success and failure within the configurations. The distillery and distillers of Locksley Distilling Co. Ltd. acts as a consulting source throughout the project and provides training to hone the personal experiences and understandings of practical distillation. Experimental work is, therefore, carried out from the perspective of an experienced practitioner in distilling. Thus, generated insights and impressions come from an informed stance.
- **Formulate a preliminary body of technical concerns and material understandings involved in early distillation practices**. Utilising experiential impressions on early distillation practices gleaned from the experimental studies, technical decisions, choices, and observations involved in the experiments are unified with recorded observations to provide a means of articulating qualitive ideas through differing recorded insights on practice. Such a perspective introduces elements of understanding on fundamental ideas in early chemical technology, widening perceptions of materials, and critical views on the role of archaeological evidence in generating ideas on technical innovation.

The devised approach was partially due to the impact of the COVID-19 pandemic on how the project unfolded (limitations on research design resulting from the pandemic are addressed in relevant individual studies/chapters). However, the methodological approach, based on a material survey, two experimental studies, and grounded in a body of distilling experience, comprehensively analyses suggested reconstructions. Through the components of the survey and experimental studies, the original interpretations of the archaeological materials as distillation apparatus that have contributed to the creation of regional narratives and dialogues are re-evaluated. Further, a collation of evidence to critique a substantiated apparatus form and feature of distillation technology development has not been fully undertaken, especially in line with accounts on the expansion of technological activities.

Instead, the experimental work provides the basis for a reconstituted idea of early distillation as a technological practice, framed in sociotechnical concepts of innovation. Additionally, such a critique prompts a reconsideration of how the archaeological materials and contexts in question could be interpreted that equally engages with such a theoretical perspective. In turn, this body of information can support an enhanced critique of how technological reconstructions have been previously generated in Gandhāra and 'Hellenistic' epochs of South-Central Asia.

1.4 Wider research significance

As archaeology continues to be realigned and defined, so too must we consider approaches developed to understand the past in a critical light. It is vital that our studies of the past are shaped as a necessary component required to understand the record of change over time as well as the influence that the past has on our contemporary actions. The view of archaeology in Pakistan exemplifies such an issue, in that it is formulated from the legacy of European colonialist activities and 19th century scholarship (Petrie 2002; Van Aerde 2018), perpetuating a Westernised way of conducting archaeology, and deemed a pursuit of the social elite (Siddiqui 2018, p. 64). The study of Gandhāra, and the relationships that can be drawn with the region today, is largely still dictated by a dated perspective on archaeology and entrenched forms of interpretation. Due to the collapse of the USSR and recent political history in South-Central Asia, archaeological projects that cross the Gandhāra region have been undertaken by research teams from Pakistan, India, Afghanistan, Britain, France, Italy, Germany, Uzbekistan, and Russia and published inconsistently. Such studies are now largely outdated in comparison to bodies of archaeological research from other areas (Mairs 2011, 2014, 2020). This is exacerbated by the sporadic nature of data collection in the area leading to broad narratives on change from fragmentary remains and traditional modes of interpretation.

To simply use the volatile geopolitical status of South-Central Asia, however, as an excuse to gloss over problematic interpretations and sweeping superficial claims ignores work that has been done already to change this perspective Detailed archives have been maintained that act as comprehensive research records for the region. Recent interpretive turns in line with increased awareness of, and collaboration with, local scholarship (e.g., MAHSA 2022) have emphasised the utilisation and collation of existing datasets so that gaps in our current understanding can be addressed (Olivieri 2020a, p. 389). Extensive collections, such as the

Ancient India and Iran Trust and Needham Institute archives, should then be used to increase the number of targeted material studies in the region. This is a crucial step in increasing the number of practice-based ideas of technology in the region. Consequentially, doing so brings longstanding ideas related to technological and sociocultural change in South-Central Asia into a modern frame of relevance.

There is equally a broader concern over how archaeological interpretations of technological change are used as a narrative to justify modern policy decisions, whereby our interactions with the world versed in processes of innovation stem from glorious images of technological development (Rocha 2016, p. 20). Contemporary life is governed by the abundance of materials, where the perceived useable worth of the environment within the modern psyche is rooted in questions of 'value'. Accordingly, any discussion on technological innovation, change, and reconstruction is directly connected to how materials and their uses are seen in a contemporary light, following established patterns of being. Realising this introduces questions of sustainability, climate change, resource exploitation among others[5] into considerations of how archaeological reconstructions underpin modern attitudes.

Further, this approach challenges the view that archaeological remains hold an intrinsic value and act as the sole arbiter of what represents the authentic past (Mason 2008, p. 107). Craft practices, though previously marginalised cultural aspects, are curated as intangible cultural assets (see UNESCO 2022), and accordingly need to be integrated into our approaches to the interpretation of archaeological materials. Thus, a 'traditional' view of archaeology that centralises only the essentialist study of material remains neither offers the most holistic representation of the past nor recognises the role of heritage. While the recent global craft alcohol 'boom' represents an uptake in interest for distilling, finding connections with its origins and sense of authenticity within the production of alcohol (see Thurnell-Read 2014, 2019) presents an opportunity for archaeological research to be meaningfully integrated into understanding the foundations of the practice. This equally appreciates how modern artisans and practitioners in distilling can contribute to a 'bottom-up' approach on creating narratives on technological change (see Petty 2019). Hence, such conceptualisations of 'craft', their roots, and notions of innovation do not necessarily ascribe to modern justifications of large-scale development and material exploitation from ideas of technological change in the past. Understanding this dynamic engages with a critical perspective on past social practices not easily represented by material remains alone.

[5] i.e., concerns with societal, environmental, and economic ramifications.

1.5 Thesis outline

Following the contextual information presented here, Chapter 2 first outlines the principles of distillation in conjunction with an overview of how the emergence of early distillation has been chronicled. Additionally, methods employed in archaeological research to explore distillation are appraised. Chapter 3 then synthesises views on technological innovation as an archaeological study and develops an overview on how technology has been researched within South-Central Asia, with a particular focus on its association with processes of Hellenisation. Further, how technological innovation has been connected to proto-scientific concepts of materials will be outlined as a facet of developing 'complex' technologies, followed by the culmination of these issues in addressing how early distillation has been interpreted in South-Central Asia. Chapter 4 presents the material survey that collates reported ceramic distillation apparatus components and configurations from South-Central Asia, their chronology, and contexts. Following the survey, two experimental studies assess the distilling ability of the suggested configurations. Chapter 5 first presents a preliminary experimental study to determine basic working and operational factors of the apparatus configurations following established interpretation. This is furthered in Chapter 6 in an exploratory campaign aiming to establish a series of operational parameters of the Gandhāra apparatus, particularly addressing factors affecting its heating, cooling, and condensing abilities. Chapter 7 brings all these facets together in discussing wider implications of results from Chapters 4, 5, and 6. The discussion re-evaluates the archaeological evidence in Gandhāra for early distillation, in tandem with plausible interpretations of the materials suggested as distillation apparatus from South-Central Asia. Accordingly, preliminary ideas on the practice of early distillation, derived from experiential insights recorded during experimentation, will frame practical ideas involved in distillation within socially orientated perspectives on innovation. The thesis then concludes in Chapter 8 with a summary of the research findings and suggested directions for further research.

Chapter Two

The Archaeology of Early Distillation: An Overview of Prevalent Interpretations and Methodological Approaches

2.1 Introduction

Recording the development of distillation as a separation method has been of unremitting interest in the history of science (Kockmann 2014). In a romantic sense, distillation is presented as an rational shift in medicine to replace the "powders, syrups, and decoctions" of an earlier era (Forbes 1970, p. 109). Yet while encompassing a myriad of conceptualisations as a science, art, and craft, understanding the technical intellectualisation of distillation has dominated the field. This has predominately ascribed to a format popularised in the charting of innovations and echoing how archaeological materials traditionally have been treated in exploring early iterations of technologies (see Chapter 3). The subject, therefore, is vast and targeted studies have been conducted, focussed on geographic regions (such as Greece, South Asia, and China) and periods (mainly medieval and post-medieval contexts) (e.g., Moorhouse et al. 1972; Wilson 1975; Craddock et al. 1983; Voisenat 1995; Zizumbo-Villarreal et al. 2009; Zhou et al. 2014; Booth 2016; Veronesi and Martinón-Torres 2018; Belgiorno 2020).

Dedicated seminal volumes by Forbes (1948, 1970) and Needham et al. (1980) acted as the basis for such works by addressing distillation as a chemical process and diverging from sparse special-interest descriptions (e.g., Von Lippmann 1912; Egloff and Lowry 1930; Sherwood Taylor 1945; Liebmann 1956). Hence, charting the growth of distillation apparatus has taken precedence, with archaeological evidence used superficially to support grand narratives and maps of development by focusing on morphological changes in apparatuses and components (e.g., Needham et al. 1980). Finding connections between individual cases and apparatuses is inevitably a common direction of research, frequently culminating in a technological diffusionist narrative within historical accounts (e.g., Bruman 1944) or broad discussions attempting to synthesise extensive bodies of information (e.g., Park 2021, pp. 25–66). Secondary citing of early distillation without critical analysis has been a by-product of such an approach (e.g., Egea et al. 2015, p. 248; Spengler et al. 2020), which potentially perpetuates unproven perspectives. Thus, in emphasising the need to map technical change in apparatus features, regional studies that may provide more nuanced insights into distillation as a technology are pushed to a marginal position. By extension, individual cases are generally given less attention and reduced to a single descriptive interpretation.

Despite being stated as understood "empirically by the ancients" (e.g., Brun 2000, p. 277), the practice and adoption of *early* distillation remains a point of contention (Forbes 1970, p. 13). The acknowledgment of distillation as an old separation method is widely recognised (e.g., Blass et al. 1997), but lacks definitive archaeological evidence to support abstract literary descriptions of small-scale processes. While the earliest method for distillation is frequently attributed the Hellenistic cultural centres of the Alexandrian schools in the 1st and 2nd c. CE (Sherwood Taylor 1945; Holmyard 1957; Forbes 1970), earlier stages of proto-distillation are seen to have emerged in West and Central Asia several millennia before (e.g., Levey 1959; Schwartz and Hollander 2000; Belgiorno 2018a, 2020). Equally, the separation and isolation of specific materials and chemicals through distillation are deemed to have not been fully developed until centuries after, such as the development of alcohol distillation as a distinct method in the 12th c. CE (Rasmussen 2014, p. 79). Hence, a recognised roughly 1500-year gap exists between early recorded observations of natural phenomena related to distillation and comprehensive developments as the defining marker of the practice's roots (Blass et al. 1997, p. 434). Accordingly, charting the growth of distillation from a Hellenistic source through to medieval practices is a common introductory passage in scientific texts with references to medieval literature (e.g., Van Winkle 1967; Kockmann 2014).

Great emphasis has, therefore, been placed on integrating technical understandings, bodies of distilling knowledge, and recorded apparatus forms with the foundations of alchemical exploration and medieval underpinnings of theoretical science to suggest a clear trajectory of distillation development (e.g., Sherwood Taylor 1952; Ihde 1984; Léauté 1990; Moran 2005; Wilson 2006). Yet as a challenge to an ancient Greek or 'Classical' origin for distillation with ties to European records (Rocha 2016), cases for Chinese and Indian alchemical practices as the root of distillation developed with their own internal agency, as responses to prevailing Western narratives (Gwei-Djen et al. 1972; Mahdihassan 1972, 1979; Allchin 1979a, 1979b; Butler and Needham 1980; Needham et al. 1980). Subsequentially, globally pinpointing specific occurrences of distillation has embraced diffusionist principles from archaeology and anthropology (Rocha 2016, pp. 34–35) by employing and characterising artefacts to confirm the emergence of distillation apparatuses. Surviving archaeological examples then have been used to conclusively connect certain idealistic constructs. The implementation of archaeology within the exploration of distillation is often reduced to a vehicle for finding optimum vessel forms and essential parts for model apparatuses, amplified by preconceived narratives, approaches, and idealised reconstructions.

This chapter analyses the existing consensus on the archaeology of early distillation to provide a foundation for exploring how early distillation has been conceptualised in South-Central Asia and its connections to assumed processes of Hellenisation in the following chapters. Beginning with an understanding of the principles of distillation, a synthesis of primary established views on the origins of distillation and its conceptual parallels is presented. This includes outlining the existing case for Greek contributions to the development of distillation. Finally, current methodological approaches in archaeology used to study early distillation will be critically reviewed, culminating in a justification for evaluating the specific case of early distillation in South-Central Asia at the centre of this thesis.

2.2 Principles of distillation

As a separation and purification process, distillation relies on transforming a liquid from its condensed phase to the gas phase[6], then again condensing the vapour to return it to a liquid (condensed) phase (Chickos et al. 2016) (Table 2). Distillation therefore features within a number of contexts: alcohol production (separation of pure ethanol from fermented materials), metallurgy (transforming and condensing reducible metals as vapour), the concentration of acids, and desalinisation of seawater are some applications to obtain certain properties and products from mixtures (Veronesi and Martinón-Torres 2018, p. 7346). Identified evidence for early distillation and proto-distillation cross several craft and technological spheres and comes from multiple sources (see Appendix 2 for select examples). Beyond the process, the properties and limits of distilland materials are of equal importance. Under perfect conditions, the starting volume of distilland and final distillate would be the same if the distilland is a homogenous, predominately single-component solution (e.g., water), and was distilled in an efficient still with a continuous seal (such as in modern glass and metal stills) (Figure 4). Hence, as distillation enables the isolation of specific components in solutions or substances, and creates a concentrate of said component, the process exploits differences in relative volatility of components within the mixture but can only be used if components greatly differ in boiling point (Stichlmair and Fair 1998; EMBL-EBI Ontology 2022). Thus, the temperature difference between the distilland and the area in which it condenses must be great enough for the vapour to move from a hotter to a cooler, and higher to lower pressure, environment (EMBL-EBI Ontology 2022). Failure to do so results in a reflux action in which vapour condenses in the incorrect area of the still and returns to the distilling vessel (see Van Winkle 1967, pp. 194–195). This is sometimes purposefully initiated in distilled alcohol production so that the purest components are collected. Doing so requires an apparatus morphology that allows for the distillate to easily return to the heated distilland within the sealed system.

[6] Vaporisation; for a solid this is sublimation (Chickos et al. 2016)

Changes of state	Process	Description
Liquid → Gas	Evaporation	Physical process by which a liquid substance is converted to a gas or vapour
Gas → Liquid	Condensation	Process during which a gas undergoes a phase transition into a liquid
Solid → Gas → Solid	Sublimation	Direct transition of a solid to a vapour without passing through a liquid phase
Solid → Solid	Calcination	Heating material to high temperatures in oxygen to extract impurities or volatile substances
	Fixation	Chemical preservation of a substance to maintain structural and/or molecular features of that substance as they exist in the living entity
Liquid → Solid	Precipitation	Sedimentation of a solid material (a precipitate) from a liquid solution in which the material is present in amounts greater than its solubility in the liquid
	Filtration	Separation of suspended solids from a liquid or gas

Table 2. *Select chemical state changes and their processes linked to early material separation practices (after EMBL-EBI Ontology 2022).*

Figure 4. *A modern laboratory Thorpe still apparatus in use for alcohol by volume (ABV) analysis (right); the ethanol in the alcoholic red solution is vapourised, travels through the glass adapting pipe (moving from a hotter to colder atmosphere) and is then condensed in the cooler atmosphere maintained in the glass condenser before collecting into a receiving vessel below (photograph by the author).*

Distillation is dependent on enabling certain phase transitions when one state of matter changes to another though a thermodynamic system (EMBL-EBI Ontology 2022). This is centred on manipulating heat transfer in an appropriate way, and specifically utilising the physical process of transferring heat through boiling. As all substances are characterised by a relative vapour pressure[7], if the vapour pressure of the liquid matches that of the external pressure, then the substance will boil (Chickos et al. 2016). Hence, vapour pressure characteristics of the mixture are equally important, where vapour pressure can be supplied using a heat source to act as a separating agent (see Stichlmair and Fair 1998). By realising how multiple interfaces interact[8], manipulating thermal processing will then implicate distillation and how it can be employed (Manglik and Jog 2009, pp. 121001-4-121001–5). Accordingly, exploiting the differences between chemical and physical properties of individual components and understanding the temperatures at which different substances will turn to vapour, the separation of liquids from non-volatile solids and separating multiple liquids with different boiling points is possible through distillation (Table 3). When the rate of the vaporisation and condensation processes are the same, then a point of equilibrium is maintained[9], dependent on the temperature and the quantity of the liquid and vapour. In most cases, the distilling vapour will be compositionally different from that of the distillate (Chickos et al. 2016). Assumptions on vapour-liquid equilibria[10] subsequently dictate how the capacity of distillation systems within idealised systems and models are understood (see Kenig and Blagov 2014).

Compound, element, or material	Boiling point	Uses of distilled product
Methanol	64.7 °C	Fuel
Lead acetate (acetone)	77.1 °C	Solvent
Ethanol	78.23 ± 0.09 °C	Alcohol
Benzoin resin (benzene)	80.1 °C	Fuel
Water	100 °C	Purified water
Acetic acid	118 - 119 °C	Medical, used in early alchemy
Zinc	907 °C	Extracted pure zinc from ores

Table 3. *Boiling points of common compounds, elements, and materials that have an application when distilled (after Van Winkle 1967; Stichlmair and Fair 1998; EMBL-EBI Ontology 2022).*

[7] Pressure exerted by the substance against the external atmospheric pressure (Chickos et al. 2016; EMBL-EBI Ontology 2022).
[8] Region at which the contact of two homogenous phases causes thermodynamic or intensive properties to change from one phase to another (Chickos et al. 2016; EMBL-EBI Ontology 2022).
[9] i.e. no net flow of momentum, mass, and heat across phase boundaries (Stichlmair and Fair 1998, p. 6).
[10] Distribution of a chemical species between the vapour and liquid phases (see Van Winkle 1967).

As such, a suitable distillation apparatus (commonly called a ‘still’) is required to both vaporise and condense components, comprising of a distilling vessel containing the distilland (the still body) a condenser or means to condense vapour, and a means of collection - the receiver (Manglik and Jog 2009, pp. 121001–6). Consequentially, following the principles of heat transfer, different materials and their thermal properties of the still will directly influence the processes of distillation. Within a distillation system, lighter components[11] in the mixture will ‘boil off’ first to be condensed. Thus at various stages of the process, different components, and different concentrations of said components will be collected (Vogelpohl 2015, pp. 1–2). Mixtures and solutions, especially if not homogenous or proportional, will have a boiling range and thus through compositional changes subsequent mixtures will have their own singular boiling point (Vogelpohl 2015, p. 1). However, significant deviations from idealised models, such as through distilling solutions of ethanol-water azeotropes[12] cannot therefore be fully simulated (see Kenig and Blagov 2014, p. 413). Idealised models may accurately represent the process, though the complexity of variables involved[13] will directly implicate the process and produced distillates. While such a modern explanation is understandably detailed, the ability to evaporate and then cool vapours is relatively straightforward. Rather, the manipulation of a series of tools to control the process is key.

As distillation is a set of principles underlying a process, it is from these principles that multiple distillation processes have been developed for specific uses and with appropriate apparatus. Simple (or ‘pure’), dry, fractional, steam, vacuum, and molecular distillations have been adapted and mechanised for a variety of applications (Van Winkle 1967; Stichlmair and Fair 1998). Simple distillation[14] is the most common form of distillation (Vogelpohl 2015); vapour is directly and instantaneously channelled into the condenser, thus the distillate and vapour composition are identical (see Van Winkle 1967). Simple distillation is most effective when boiling points of the materials or liquids in the mixture are significantly different from one another (~ 25 °C difference) (Chickos et al. 2016). Thus, fractional distillation is used to separate the components in mixtures into fractions through repeated vaporisation-condensation cycles and successive distillation (or rectification) when boiling points are closer (Vogelpohl 2015, pp. 2–4). An example of this process would be in the production of rectified alcoholic spirits of an azeotrope of high ethanol content and water formed through repeated distillations to produce neutral spirits commonly from fermented grains or grapes. Used often

[11] Those with the lowest boiling point
[12] Constant boiling point mixture that when heated, the vapour and liquid phases are compositionally the same (see Kenig and Blagov 2014).
[13] e.g., still material, heating rate, distilland composition.
[14] When molecules transferred from the liquid to the vapour phase do not change prior to reaching the condenser (see Vogelpohl 2015).

as the basis for redistilled alcoholic spirits such as gin, understanding when and what to ‘cut’ or separate during distillation cycles is key to maximising the outcomes of distillation. However, monitoring vapour flow through a sealed unit such as a distillation apparatus is a major concern to prevent apparatus failure. In the example of alcohol distillation, as ethanol evaporates from a mixture, the pressure within the apparatus rises and is not a problem so long as a suitable method to condense will remove the ethanol at the same rate as it evaporates (Chickos et al. 2016). Imbalances between evaporation and condensation results in apparatus leaking, thus, strategies to vent in the region of condensation helps the vapour travel from the lower to the upper regions.

Hence, modified distillation processes to achieve separations under specific conditions[15], methods[16], and scales[17] have been developed to mitigate issues and modify outcomes (see Van Winkle 1967; Stichlmair and Fair 1998; Vogelpohl 2015). However, the application of the term ‘distillation’ within such contexts has often confused an understanding of the processes at work. Fractional freezing[18] monikered as “freeze distillation” in some circumstances is not distillation, but rather a crystallisation process[19]. Within alcohol production contexts, “freeze distillation” has been cited as the enrichment of an alcoholic product by partially freezing it and removing frozen material that is poorer in the dissolved material than is the liquid portion left behind, but is still not a distillation process (see Gwei-Djen et al. 1972). Similar can be said of dry distillation which specifically is the process of heating solid materials to produce gaseous vapours that could condense into liquids or solids, often to obtain liquids from wood and coal for the production of tars, bitumen, pitch, and resin (e.g., Groom et al. 2015; Kozowyk et al. 2017). Obviously, it does not start with a liquid solution, but conversely is used purely for solid materials as a distillation process (see Schwartz and Hollander 2000; Groom et al. 2015; Kozowyk et al. 2017).

2.3 Nexuses and established origins of early distillation

Distillation, from the Latin *destillare* (‘to drop down’ or ‘to trickle down’) (Forbes 1970, p. 71) has historically been used to label numerous extraction processes encompassing most purification and separation operations including filtration, crystallisation, and sublimation (see Forbes 1948, 1970 for overview). Considering such diversity, distillation is inextricably connected to how essences, vapours, and material composition are rationalised in early

[15] e.g., under a vacuum to lower the boiling points of the components in vacuum distillation.
[16] e.g., blowing steam through the distilland mixture to evaporate it in steam distillation.
[17] e.g., to separate, purify, and concentrate materials on a molecular level in molecular distillation.
[18] Separation of substances with different melting points.
[19] Solid forming by atoms or molecules organising into a crystal structure (EMBL-EBI Ontology 2022).

alchemical literature (see Sherwood Taylor 1952; Holmyard 1957; Moran 2005). While this flexibility of the term suggests a subjective foundation, distillation has mostly been explored as a chemical process rather than elucidating relational ideas underpinning its conceptualisation. Generated predominantly in the late 19th and early 20th centuries, charting distillation has been an exercise in illustrating progressive evolutionary stages or 'trees' of apparatus development (Figure 5), presenting either a physical developmental map or structural account. Despite being a niche subject, attempts to map distillation systematically were appraised as a model example of how the origins of modern scientific, engineering, and technological principles could be ascribed to specific cultural and societal nuclei. Translations of pre-18th c. CE medieval distillation 'handbooks' were heavily relied on, which drew ideas from ancient Greek and Egyptian rationalisations and theories on material composition, to explain the mystic alchemical connections to distillation (Ihde 1984, p. 11). This clearly contrasted modern chemical and physical principles of thermodynamics and liquid phase extraction that distillation was understood to be rooted in (Blass et al. 1997, p. 436). Hence, points of reference for researching the origins of distillation were largely divided into theoretical ideas and technical properties.

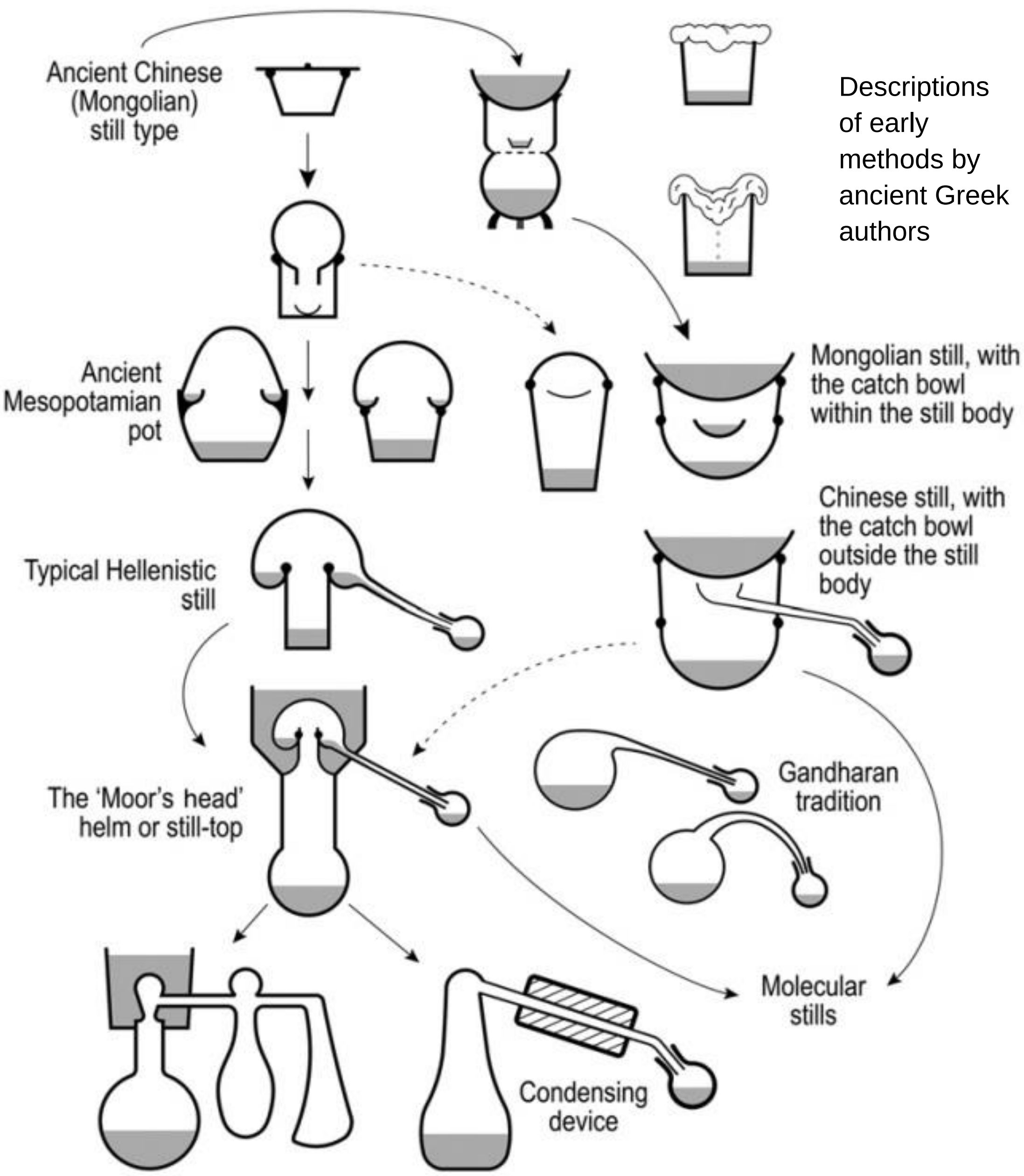


Figure 5. *Needham et al.'s (1980) evolution of the still (after Park 2021, p. 28, adapted from Needham et al. 1980, p. 81).*

The role of medieval sources in line with the development of alchemical practices, observations, and explanations, are therefore considered a substantial basis for 'modern' distillation, and emphasises the scientific prowess of certain ancestries from medieval translations (e.g., Berthelot 1888; Von Lippmann 1912; Diels 1913, 1965; Egloff and Lowry 1930; Sherwood Taylor 1945). In some respect, these are allied to later colonialist attitudes towards certain products such as alcoholic spirits (Fernandes 2014, p. 48). The body of information that currently exists on some of the earliest denoted origins for distillation, therefore, conceptualises the practice within a European-centric framework relying heavily on literary references and descriptions of distilling (e.g., Ihde 1984, pp. 18–19). Agricola's *De Re Metallica* (1556) for instance is one of the earliest comprehensive volumes on metallurgy and mining, but notably includes detail on the use of apparatus for distilling various substances such as zinc and nitric acid. The text has accordingly acted as a key source for determining the nature of established distillation practices. The same equally could be said of Brunschwig's *Liber de Arte Distillandi de Simplicibus* (15th – 16th c. CE) and Libavius' *Alchymia* (1596) when considered as first instructional books on distillation with clear connections to European alchemical practices that found their roots in Aristotelian and Pythagorean material concepts (see Browne 1948; Holmyard 1957; Bess 1985; Moran 2005) (see 3.4). Accordingly, labelling and relabelling of specific stages or still forms is common throughout existing dialogues, such as how early still configurations were later given specific cultural and ethnic ascriptions (see Figure 5). Accordingly, considering such a broad temporal frame, fragmentary references, and geographic distribution (see Appendix 2), 'early' in the context of charting distillation has often been sweepingly ascribed as 'pre-medieval'.

Consequently, accounts have relied on superficial explanations of processes as rational systems, presenting distillation as an established progression from methods of extraction, and tied directly to Alexandrian and ancient Greek philosophy as the foundation of modern science (see Chapter 3). Berthelot's work (1883, 1888), as one of the earliest identifiable attempts to unify such lines of thought, was based on extensive translation-centric studies of medieval and Greek alchemical texts. Subsequently, his ideas were consolidated, synthesised, and expanded, centred around specific technological and characteristic themes (e.g. alcohol and alchemy) by authors such as Diels (1913, 1965). Early distillation 'stages' were established in the early historiography of distillation through branches of science research, with a clear focus on connecting specific examples with an ancient Greek origin (e.g., Egloff and Lowry 1930; Barnes 1934; Sherwood Taylor 1945; Partington 1947). While it is accepted that distillation, by modern standards, was largely unknown at the time, the instrumentation and principles of distillation were seen to be described in the work of classical authors (Diels 1965; Forbes 1970, p. 13). Observable 'bridges' were, therefore, required to elucidate the earliest forms of distillation and how they may stem from ancient Greek descriptions. The pure distillation of alcohol frequently was a focal point of study, in part due to the popularity of alcoholic spirits, but also the assumed universal use of alcohol for multiple purposes (e.g., Berthelot 1883; Diels 1913; Wilson 1975; Léauté 1990; Egea et al. 2015). Ethnographic cases (particularly on alcohol distillation) were brought into such an enquiry through anthropological study to characterise "primitive forms" of distillation within a colonialist narrative on scientific progression, seen as models of early alcohol distillation (e.g., Lumholtz 1898; Montell 1937; Bruman 1944). Thus, developmental stages when discussing the formulation of distillation tended to be linked to explicit changes in scientific thought and concepts (e.g., Sherwood Taylor 1945, p. 182). Such stages were generated with an expanded understanding in the scientific community of Greek alchemical knowledge and its connection to the Arabic and European origins of Western science (Browne 1948; Sherwood Taylor 1952). This was deemed a form of proto-chemistry, where processes such as distillation were seen to have come from proto-scientific intellectuals with clear associations with both ancient Greece and modern scientific practice (e.g., Ihde 1984).

Hence, arguably as the first complete account that attempted to address the fragmentary nature of how distillation had been studied, Forbes' (1948) "A Short History of the Art of Distillation" (expanded in 1970) presented a linear and stadial account on distillation development stemming from multiple geographic origins. Needham's charting of early distillation apparatus in the 1980s as part of his vast "Science and Civilization in China" series[20], aimed to coherently map the functional and morphological growth of distillation apparatus (Needham et al. 1980, pp. 55–120). Here, Needham's work was largely conducted within a wider understanding of the development of science and desire to 'fix' dates to technological innovations, inceptions, and discoveries (Rocha 2016, pp. 14, 18). Alongside setting out a series of evolutionary steps expressed in a descriptive account, the work amalgamated distillation into other separation processes, synthesising previous studies and connecting lines of technical developments that led to distillation from several nuclei. As such, Needham saw distillation as a facet of knowledge diffusion and transmission, where the European form of alchemy had been impacted by Chinese alchemy (Rocha 2016, p. 33). No specific application of distillation has therefore taken precedence, however, the connections of the process to early alchemy and popularisation of alcohol distillation both have emphasised the role of refinement' as a technical study. Distillates within such consolidated studies are often placed into generic all-encompassing groups despite significant production differences (see Fernandes 2014, p. 47). Inevitably then, the study of distillation has prioritised understanding the process as a facet of determining the seemingly rational origins of modern science.

2.3.1 South-West Asia and the East Mediterranean

In discerning early methods of distillation, several cases have been suggested as the plausible earliest origins, connected to "ancient Mesopotamia", technological developments in South-West Asia, and sites in the East Mediterranean (Levey 1959; Platon 1971; Shelmerdine 1985; Schwartz and Hollander 2000; Belgiorno 2008, 2009, 2018a, 2018b, 2020; London 2016).

[20] Published from 1954 until as recently as 2016, following his death in 1995.

Within this broad geographic grouping, knowledge of extraction using water, as a grounding for ‘proto-distillation’, is considered one of the oldest techniques known to obtain aromatic essences from plants to mix with fats and oils to create medical ointments and cosmetics first noted in the 4^{th} mill. BCE and widely recognised by 1^{st} c. CE (Blass et al. 1997, p. 434). The representation and coherency of evidence to support such a claim is, nevertheless, ambiguous. In the “ancient Near East”, which Forbes attributed as Sumerian, Egyptian Assyrian, and Babylonian locales (1970, p. 11), refined substances may have been created through dry distillation processes, residue evaporation, or liquid inspissation as exemplified in the Egyptian medical papyruses from Luxor (1600-1550 BCE) (Forbes 1970, pp. 11–12; Kockmann 2014, p. 2). These were translated by Georg Ebers in 1872 and 1873, detailing medical formulae that comprised of early alcoholic solvents from beer and wine created through extraction methods (Blass et al. 1997, p. 433). This was however, a selective translation approached with preconceived ideas of processes and hypothesises, and arguably perpetuated in chartings of distillation technology.

It was not until the 1950s that a suggested extraction apparatus was comprehensively characterised from archaeological remains, principally connected to early essence and perfume manufacture. Levey’s “Ancient Mesopotamian Chemistry” (1959) detailed a Sumerian apparatus to control evaporation and condensation in the extraction of essential oils from herbs, based on a specific vessel form recovered excavations near Baghdad, Iraq and dating to around 3500 BCE (Levey 1959, pp. 32–35; Blass et al. 1997; Kockmann 2014, p. 3) (Figure 6). Such an idea generated an explicit typological classification of distillation apparatus. Twelve examples of the ‘channel rim jar‘, four of which were complete, were found at the site of Tepe Gawara, Iraq, spanning a period between 4200-3800 BCE (Levey 1959), with further recorded or interpreted specimens at five other sites (Belgiorno 2018b). Irrespective of confirming the vessel classification, very few instances of it have been noted, Yet Kockmann suggested that alcohol distillation under reflux and extraction from fermented substances would have been possible using such apparatus, and beneficial in the creation of essential oils or fragrances in order to yield a greater essence extraction (Kockmann 2014, p. 3). However, such an interpretation of the vessels and their use was ultimately a hypothetical idea. Thus, a definitive connection between form and use cannot be adequately proven, but it has become an accepted explanation and the starting framework for subsequent studies that aim to definitively prove Levey’s idea from a variety of archaeological methods (e.g., Belgiorno 2018b, 2020). Despite being a speculative interpretation, the roots of distillation in perfumes and essences may have been explored through such a process (Shelmerdine 1985; Reinarz 2014), though the inclusion of alcohol as a solvent used within the process here cannot be demonstrated.

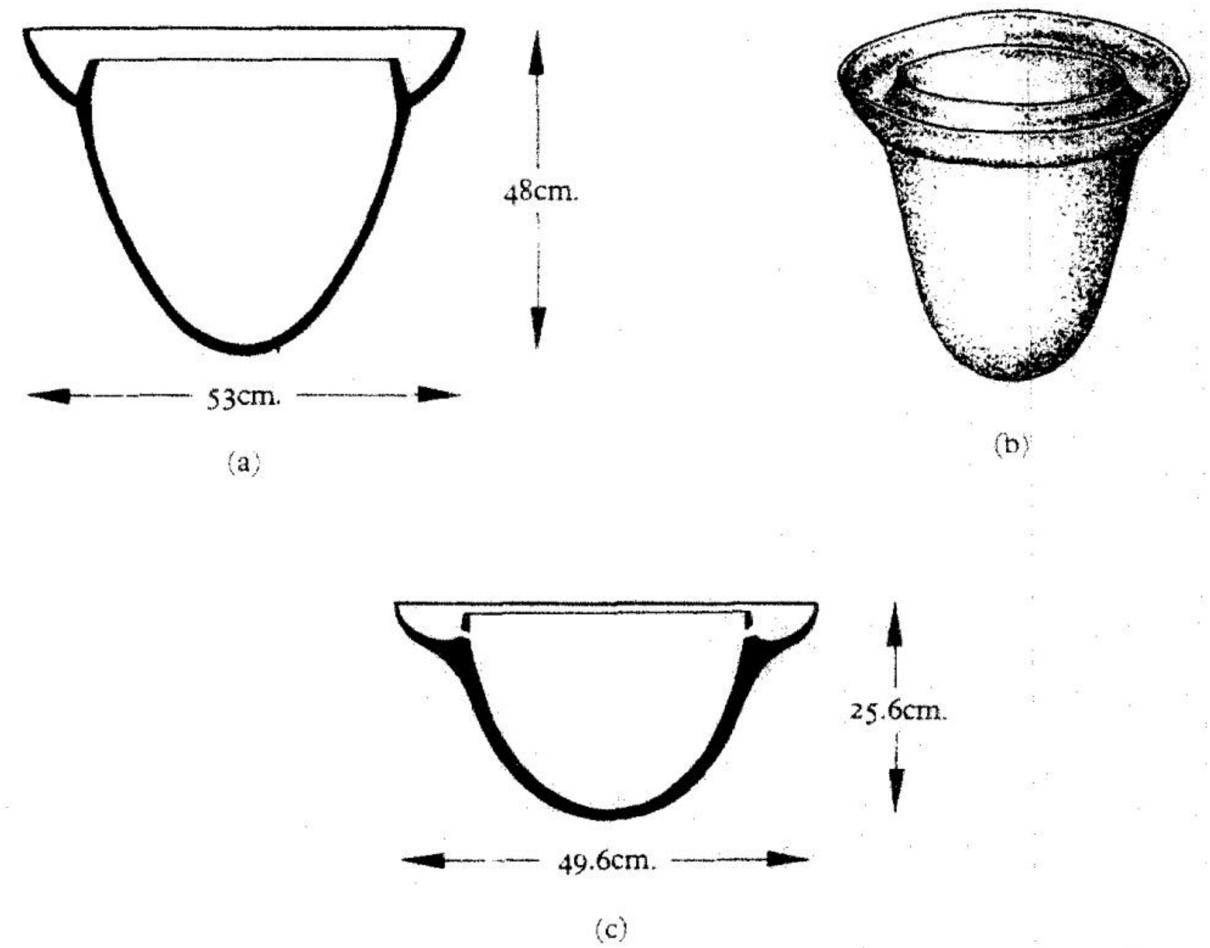


***Figure 6**. Tepe Gawara 'Mesopotamian channel rim jar' (3500 BCE) suggested as primary extraction apparatus (Levey 1959, pp. 33–35).*

As the East Mediterranean and its surrounding locales was then viewed as a nexus of distillation practices, other vessels in the region have been suggested as distillation apparatus to fit with the interpretation. Such ascription has ranged from Late Chalcolithic spouted open containers from Hujayrat al-Ghuzlan (London 2016, pp. 180–181) to Minoan vessels from Zakros seen as specialised apparatus for volatising aromatic essences over water or dry distillation (Platon 1971, p. 213). Further, wider studies on specific areas of sites, such as the interpreted perfumeries at Pylos (Shelmerdine 1985) and Pyrgos (Belgiorno 2008, 2016) have attempted to create coherent reconstructions of distillation involved in perfume manufacture (Belgiorno 2016). In tandem, the application of dry distillation as a conceptual precursor to refine bitumen (petroleum tar) from natural asphalt or oil shales in South-West Asia has equally been presented as evidence of 'proto-distillation' (Shelmerdine 1985, p. 57; Schwartz and Hollander 2000, pp. 83–84). Predominately represented by pottery with bitumen on the inside and/or outside, lumps of bitumen, and pieces of bitumen with 'melting' appearances from several sites in the region (Schwartz and Hollander 2000, p. 84), such evidence remains inferential. The combination though of identifying early bitumen processing and perfume manufacture has therefore presented such a broad region as a nexus of proto-distillation and its associated technologies.

Therefore, conceptualising ‘extraction’, as a central application of early distillation, has been a key idea when considering the function of certain items of apparatus found within geographic areas traditionally situated under the banner of ancient Mesopotamia. The earliest form, however, of extraction as an activity or practice has been connected to processes of water purification. Alongside seawater desalination, water purification is sporadically noted as a possible impetus for further distillation experimentation, but also the fundamental need for clean water within arid desert areas of South-West Asia (Mahdihassan 1972, p. 159; Needham et al. 1980, p. 60). Comparatively, desalination of seawater in post-medieval contexts is seen as testament to how a basic understanding of distillation has been employed for this purpose through exploiting natural fractional distillation processes in separating salt-water from drinkable fresh-water when at sea (Gwei-Djen et al. 1972, p. 99)**.** Hence, the earliest observations on water purification are seen by some as the foundation for understanding the process and manipulation of distillation (Sherwood Taylor 1952, pp. 39–46; Forbes 1970, p. 16). However, early archaeological evidence for water purification by distillation is sparse at best, and it is not clear as to how this led to what can be considered as ‘distillation’ and the development of apparatus specific for this purpose (e.g., Kockmann 2014).

2.3.2 Ancient Greece and the Alexandrian Schools

Interpretations of classical texts have been central aspects in illuminating the conceptual origins and applications of early distillation (see Appendix 3 for key textual references and passages). Texts, deemed as closely associated with ancient Greek proto-science and rationalisations of materials, processes, and techniques, have consistently been dated within the latter centuries of the 1st mill. BCE and start of the 1st c. CE through the Hellenistic “Alexandrian schools” (see 3.3). Extensive studies have been conducted on the subject, detailing more than what can be covered here, though it is worth recognising the scope of information available (e.g., Berthelot 1883, 1888; Von Lippmann 1912; Diels 1913, 1965; Egloff and Lowry 1930; Sherwood Taylor 1945, 1952; Partington 1947; Browne 1948; Holmyard 1957; Ihde 1984; Léauté 1990; Hankinson 2001; Moran 2005; Wilson 2006; Loyson 2009; Yfantis 2019; Dufault 2019; Yfantis and Yfantis 2020). Framed within wider questions on how chemical processes were understood, certain ancient works and writers are frequently repeated and built upon across the literature, especially in more recent analyses (e.g., Wilson 2006; Dufault 2019; Yfantis and Yfantis 2020). Distillation apparatus, in consequence, is commonly understood to have been developed as the earliest chemical instrument (Sherwood

Taylor 1945, p. 185) by specific ‘proto-chemists’ belonging to Alexandrian schools of philosophy, medicine, and literature (Kockmann 2014, p. 6; Rasmussen 2014, p. 79).

Fundamentally, key studies on the association between distillation and ancient Greek proto-science by Berthelot (1883, 1888), Von Lippmann (1912), and Diels (1913, 1965) accepted that “the ancient natural scientists came quite close to the proper understanding of the principle of distillation” (Forbes 1970, p. 13). Yet, while no full concept of distillation in a modern sense was known, lines of research in early distillation have often focussed on identifying passages or terms within texts that may allude to distillation (e.g., Egloff and Lowry 1930, p. 2063; Browne 1948, pp. 20–21). Textual information closely associated with ancient Greek proto-chemical explanations is therefore seen to stand as the most comprehensive indication of early distillation, rationalised as a discussion on the cyclical nature of water (Forbes 1970, p. 12). The frequently-referenced process of boiling and condensing seawater by Aristotle, Alexander of Aphrodisias, and Pliny is commonplace in many chartings of early distillation (Diels 1913; Forbes 1970; Mahdihassan 1972, p. 159; Wilson 1975; Shelmerdine 1985, pp. 12–13; Kockmann 2014). However, more detailed than a single reference to possible distillation, a passage by Aristotle in his *Meteorologica* (II.3; IV.9), and repeated in his *Historia Animalium* (IX.2) and *Phusike akroasis* (I.4), has been read as the earliest explicit reference to conceptualising distillation from the 4th c. BCE (see Appendix 3) (e.g. Berthelot 1883; Diels 1913; Liebmann 1956, pp. 166–167; Forbes 1970; Gwei-Djen et al. 1972; Wilson 1975, 2006; Hankinson 2001; Yfantis and Yfantis 2020):

“Saltwater when it turns in vapour becomes sweet and the saltwater does not form saltwater again when it condenses… I know this by experiment. The same thing is true in every case of this kind: wine of all fluids that evaporate and condense into a liquid state become water. They are all water modified by a certain admixture, the nature of which determines the flavour… If one plunges a water-tight vessel of wax into the ocean, it will hold, after 24 hours, a certain quantity of water, that filtered into it through the walls, and this water will be found to be potable, because the earthy and salty components have been sieved off.” (Aristotle, *Meteorologica* II.3, Trans. Lee 1952).

However, despite being integrated into later evolutionary models of distillation apparatus (see Figure 5), Aristotle’s account is surrounded by a complicated manuscript tradition and continuing debate on the meaning of individual words (Von Lippmann 1912; Forbes 1970, p. 15; Yfantis and Yfantis 2020). Interpretation of his account is therefore speculative (Forbes 1970, p. 14), compounded by continued assumed references to the practice and few confident mentions of distillation in later commentor’s works (see Appendix 3). Regardless, aspects of a possible method connected with Aristotle's description have been noted in Alexander of Aphrodisias's work (c. 200 CE), *Commentaria in Aristotelem Graeca: Meteorologica* (Liebmann 1956, pp. 166–167) (a commentor of Aristotle), mentioning that sailors: "...boil sea water and suspend large sponges from the mouth of a bronzen vessel to imbibe what is evaporated. In drawing this off the sponges, they find it to be sweet water" (I.20, Trans. Haydeck 1899). This is repeated in later accounts by Pliny (1st c. CE) in his *Naturalis Historia* (XXXI.70, Trans. Bostock and Riley, 1855), noting that fleeces would become moist with evaporated water and from this, fresh water could be wrung out suitable for drinking (Liebmann 1956, p. 167; Forbes 1970, p. 15). Such references subsequently have been used to bolster the evolutionary model of early distillation apparatus derived from specific ancient Greek texts.

However, intrinsic issues in how passages are interpreted prevent clear and sequential characterisations of early distillation to be identified, due in part to the abstract language detailed, but also considering that the figurative concepts throughout have historically been interpreted with an intention to identify distillation. Alternative interpretations of such a claim have, therefore, presented the observation as independent of distillation and related to other processes instead (e.g., Yfantis and Yfantis 2020, p. 169). Further, it has also been noted that the interpretation of such ideas as 'distillation' may have equally been confused with 'sublimation' (see Table 2) based on descriptions by Dioscorides in his *De Materia Medica* (I.42-63, Trans. Gunther 1933; after Goodyear 1655) (Liebmann 1956, p. 167). The divide between interpreting texts and tangible archaeological evidence for such forms of extraction therefore illustrates the difficulty in explicitly marking practices.

Issues associated with textual translations have not, however, prevented researchers from using ancient Greek texts derived from the Alexandrian schools as evidence for early alcohol distillation. While some pre-Greek theories on early alcohol distillation exist (Forbes 1970, pp. 1–12), it is from this context that a coordinated body of evidence explicitly on early alcohol distillation has been developed. Studies have ranged from translating specific words as representative of complete processes to using abstract or subjective interpretations of plays such as Euripides' "The Bacchae" (Trans. Buckley 2020, 755-8) as evidence of the use of distilled spirit in Dionysiac cult practices (e.g., Wilson 2006, pp. 47–48). However, Berthelot (1883, p. 85) first indicated that Theophrastus (stated as 4th c. BCE) described a high-alcohol 'wine' being used to ignite liquids for libations[21], though failed to provide any information on where this passage came from (see Appendix 3). Moreover, suggested translations such as

[21] Presumably, the assumption is that the liquid must be an alcoholic spirit due to the high ethanol content required for it to ignite.

Hippolytus' possible reference to wine distillation as part of Gnostic religious sect practices (1st c. BCE-1st c. CE), whereby 'to boil' was translated 'to distil' in ancient Greek (Hippolytus *Philosophumena* IV.31; Trans. Legge 1921) are commonly cited as evidence of the earliest instructions for alcohol distillation (Berthelot 1888; Diels 1913, 1965; Wilson 2006). Hence, it can be argued that the debate surrounding the earliest distillation of alcohol privileges the translation of specific ancient Greek terms (often only one word in a passage) as representative of a complete distillation practice.

The identification of the 'Hellenistic' or 'Alexandrian' still as a recognisable early distillation apparatus form does, however, connect with explicit illustrations of what have been interpreted as stills, and subsequently integrated into the evolutionary charting of distillation apparatus. Dioscorides' *De Materia Medica* (V.110; Trans. Gunther 1933 after Goodyear 1655) is considered to have first described a form of sublimation used to obtain mercury from iron and cinnabar, conjecturally reconstructed as apparatus configuration (e.g., Sherwood Taylor 1945, pp. 186–188) (see Figure 7). Crucially, such an arrangement was also identified as a clear illustration in later texts (Figure 8). Berthelot (1888) noted from his translations of manuscripts held in the St Marc Library, Venice (text MS Marc. 299) that 4th - 1st c. BCE distillation apparatus redrawn from 16th and 17th c. CE alchemical books detailing distillation equipment included Dioscorides' sublimation configuration, corresponding with ancient Greek descriptions (Egloff and Lowry 1930, p. 2063; Forbes 1970, pp. 20–28; Wilson 2006; Rasmussen 2014, p. 80) (Figure 7). Such configurations became known as Hellenistic or Alexandrian stills or *alembics*[22] consisting of a still body (cucurbit), a still head or 'cap', and a receiver made of glass or earthenware, heated by a sand, ash or water (*bain-Marie*) bath (Wilson 1975, p. 54).

Further descriptions of modified Hellenistic stills have been noted, such as the *tribikos* and *kerotakis* stills and the *bain-Marie* invented by Maria 'the Jewess' around 1st c. CE (a proto-chemist member of an Alexandrian school) (Partington 1947, p. 784; Forbes 1970, pp. 19–20), though understood through quotes by the later philosopher Zosimos (3rd c. CE) (*Mémoires Authentiques* VII.2; Trans. Mertens 1995) (Rasmussen 2014, pp. 79–80). It is however worth recognising that physical archaeological remains representing such components have not been identified, and equally that 'alembic' has been a term applied to characterise components of distillation apparatus of a considerably later date (see 2.3.4). Nonetheless, evolutions of the Hellenistic still have been reconstructed that developed into glass versions (see Figure 9). Berthelot's (1888) account of a 1st c. CE Greek text produced in Hellenistic Egypt on the

[22] Modified from the translated term '*ambix'* (Sherwood Taylor 1945, p. 187).

distillation of liquids and slow distillation of eggs possibly to create *theion hudor* (sulphur water; used to tint base metals and give the impression of gold surfaces) (Wilson 2006, pp. 17–21) utilised a glass *mastarion* ('breast-shaped') still head, otherwise recognised as the Hellenistic still form (Figure 12). Yet equally, the configuration has been given a possible 10th-18th c. CE range, with manuscripts illustrating devices for distillation, 'digestion', and sublimation (Yfantis 2019, p. 387).

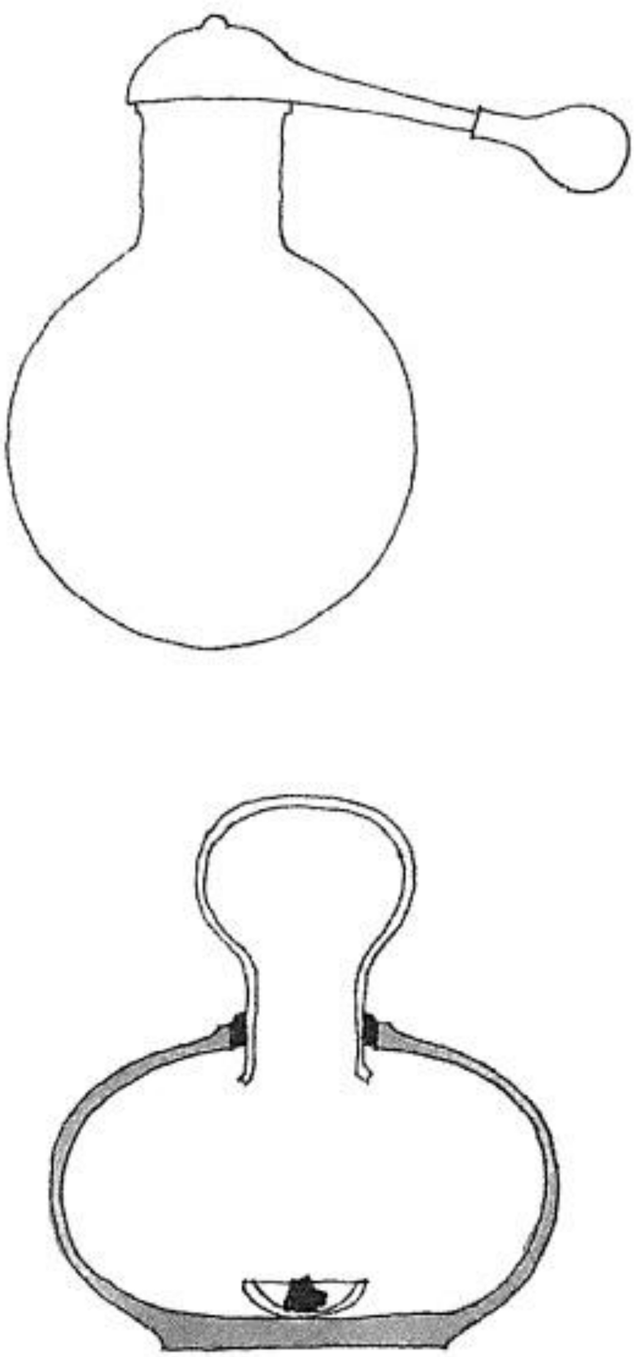


Figure 7. *Reconstructions from a description in MS Marc. 299 translated by Berthelot (1888) of glass 'Hellenistic' stills or alembics* ***(above)*** *and a similar apparatus for sublimation* ***(below)*** *(Wilson 2006, p. 22, fig. 1).*

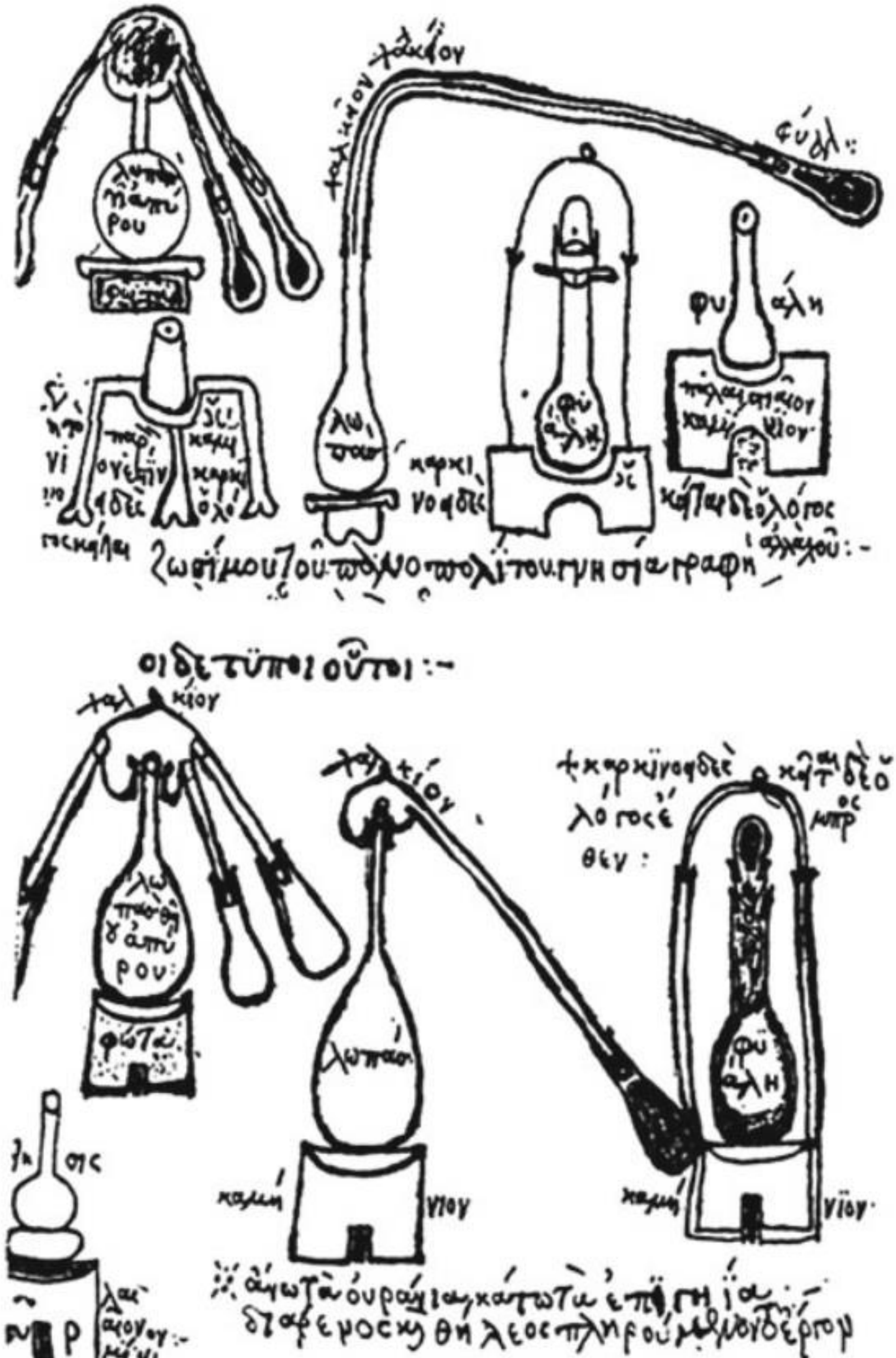


Figure 8. *Copies of illustrations of Hellenistic distillation alembics by Berthelot* (*Berthelot 1888, pp. 284–287).*

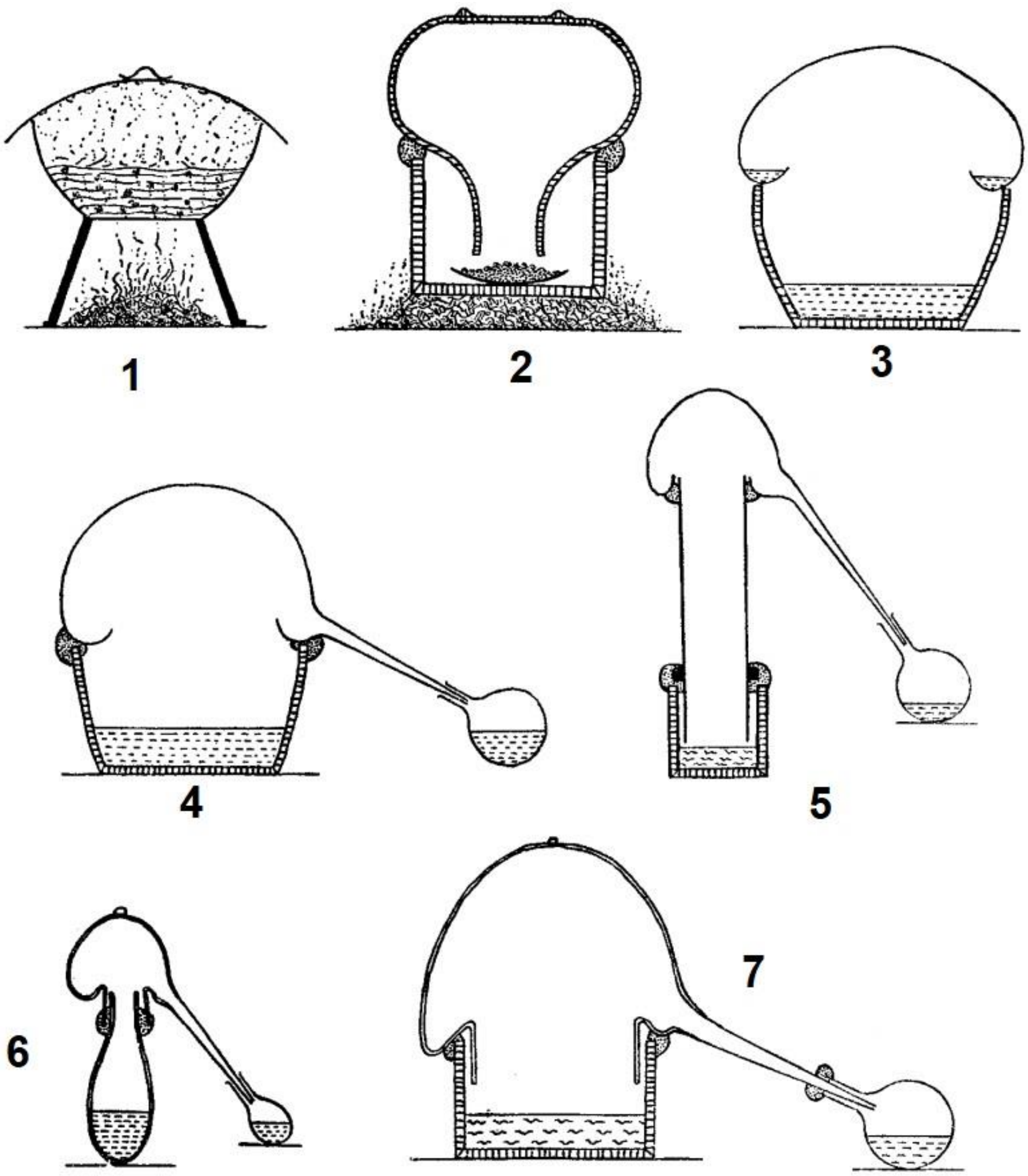


Figure 9. *Sherwood Taylor's (1945) stages of early still evolution in the 'Hellenistic still' (after Sherwood Taylor 1945, fig. 14, p. 201):* ***(1)*** *condensation collecting under pot lid;* ***(2)*** *sublimation apparatus;* ***(3)*** *turned-in rims on stills;* ***(4)*** *addition of a spout;* ***(5)*** *elevation of still head to help cool vapour and prevent boiling liquids "splashing over" (Sherwood Taylor 1945, p. 202)';* ***(6)*** *flask-like still body;* ***(7)*** *complete "Hellenistic" still.*

Irrespective of the fact that most original texts were lost, surviving through translated manuscript traditions or later reprints (Wilson 2006, pp. 18, 25), a selective reading of accounts and interpretations of illustrations has directed how a Greek origin is seen as a conceptual starting point to understand the abstract nature of distillation. Hence, while illustrations of Hellenistic apparatus detailed in manuscripts is a useful contribution, such depictions come from copies dating centuries later than originals and it is unknown how many times they have been copied, modified, and misinterpreted (Rasmussen 2014, p. 80). Regardless of affirmatively recognising such a complete reconstruction, significant disagreements between researchers on the translation and subsequent arrangement of individual components within the apparatuses highlights how these are not accepted classifications (e.g., NEEDHAM-1). Accordingly, the configuration, materials, and functionality of the earliest ancient Greek distillation apparatuses cannot be understood through such textual inferences when only conjectural interpreted and abstract references to distillation are noted. Moreover, working with the fragmentary textual descriptions is particularly difficult (see Appendix 3); dates and sources of ascribed Greek distillation apparatus are contentious and continually debated, with only some elements accepted within a unified consensus (see Forbes 1970 for overview). Thus, while there is a difference between noting references to distillation and identifying the apparatus, the two are often conflated and confused when it comes to developing a comprehensive body of understanding and prioritising what is relevant for establishing distillation within this context.

2.3.3 East Asia

In response to the enduring emphasis on establishing cultural origins of technological innovation, challenges to the idea that Greek civilization was the “cradle of science” (Rocha 2016, pp. 14–15) emerged within a greater global awareness of the historiography of distillation. Indeed, Needham’s “Science and Civilization in China” series comprehensively presented an extensive narrative on early distillation apparatus development from its earliest conceptual stages in East Asia (e.g., Needham 1962; Needham et al. 1980; Huang 2000). Correspondence during the production of the earliest volumes demonstrates a clear intent to place his evolutionary models of the ‘Mongol’ and ‘Chinese’ stills within the greater understanding of distillation technological development (e.g., NEEDHAM-2). In doing so, the dialogue presented an alternative origin of distillation technology based on early textual references to extraction processes, and connected branches of interrelated “Asiatic stills”, predominately ‘Mongolian’ and ‘Chinese’ still configurations (Needham et al. 1980, p. 55), (see Figure 5). Hence, the continued appraisal of Chinese texts as a source for identifying early distillation practices, and specifically evidence for previously elusive alcohol distillation, has been a key line of interpretation (Gwei-Djen et al. 1972; Needham et al. 1980; Shijian 1988; Dezhen 1988; Youpeng 1989; Bin 1992; Chengyuan 1992; Jinpeng 1993, 1994; Jiahua 1995; Haw 2006; Xi’an City Cultural Relics Institute 2009; Yong 2013; Jian 2016; Elias 2020). Evidence for both the ‘Chinese’ and ‘Mongol’ stills, however, similarly to other suggested still forms, remains fragmentary, but are demonstrated by both textual references and illustrations in some accounts (e.g., Gwei-Djen et al. 1972; Needham et al. 1980; Youpeng 1989; Elias 2020).

Within dialogues on the emergence of distillation in East Asia, morphologies of what are considered to be early stills used in China to facilitate alcohol distillation have been labelled as 'Mongol' and 'Chinese' stills. Characterised through a comparison between textual descriptions from approximately the 4^{th}-5^{th} c. CE, the name 'Mongol still' derives from ethnographic examples seen to replicate the continuation of a distilling tradition (Gwei-Djen et al. 1972, pp. 74–75). This is, however, a hypothetical connection generated in the early 20^{th} century (see Montell 1937; Bruman 1944, p. 426), considering that claims by Needham et al. (1980) classified the morphology from a stance that saw the configuration as an "…appellation [that] originated ethnologically, but the assumption is natural that this was the most primitive and ancient of the East Asian types" (Needham et al. 1980, p. 62).

Functionally, the 'Mongol' still was seen to differ significantly from the 'Alexandrian' still in that distillate condenses on the convex interior surface of a water cooled vessel to be collected in a small bowl as the distillate drips down (Gwei-Djen et al. 1972, p. 74). Therefore, the 'Mongol still' was deemed to originate from a different geographic locale other than ancient Greece (Gwei-Djen et al. 1972, p. 74). Furthermore, utilising a water-cooled condenser head within the configuration was noted as a vital feature (Gwei-Djen et al. 1972, p. 78), as this would (for some scholars) be a key factor in enabling alcohol distillation due to the smaller temperature differential between the boiling and condensing points of ethanol (Gwei-Djen et al. 1972, p. 74). Similar styles known as the Han (25-220 CE) and Jin (1125-1234 CE) Dynasty stills that operated in a similar way have also been noted as later replications or developments to the 'Mongol still' morphology (Haw 2006, p. 149), determined primarily from alchemical illustrations and descriptions of stills (e.g., Needham et al. 1980, pp. 69–70). Inevitably, the emergence of the 'Chinese still' was characterised through similar textual approaches, and also noted as the primary apparatus first to fully distil alcohol (e.g., Gwei-Djen et al. 1972; Needham et al. 1980; Jian 2016). As an evolved form of the 'Mongol' still, which includes a separate funnel arm to direct produced distillate into a receiver (see Figure 5), the 'Chinese' still was seen as a more efficient still (developed from at least the 5^{th} c. CE) as the configuration would not need to be dismantled to retrieve produced distillate unlike its 'Mongol' counterpart (Needham et al. 1980, p. 70). However, such explanations are conjectural and lack clear evidence of distilled alcohol to support reconstructions aside from a few references, let alone distinct 'Mongolian' or 'Chinese' still configurations (see Appendix 2 for select examples from China).

Though fragmentary, indications of alcohol distillation are chronologically linked to the Han Dynasty (25-220 CE) by several authors (e.g., Dezhen 1988; Jinpeng 1994; Jian 2016), alongside the use of the term 烧酒 [shōchū], recognised by some in texts as ‘burnt wine’ to indicate a metaphorical description of distilled alcohol (see Gwei-Djen et al. 1972). Archaeological evidence for plausible Han Dynasty distillation metal apparatus has been suggested, with explicit features that are seen to facilitate alcohol distillation (see Chengyuan 1992; Jian 2016) (Figure 10), though this remains a hypothetical explanation of an artefact form. Accordingly, in tandem with literary indications of shōchū as the earliest form of alcoholic distillation, the distillation of wine in the Han Dynasty is suggested to be a point of origin for the practice and connected to a specific, ethnically-labelled still form, despite the data being contentious (Jian 2016, p. 437). The connections between ancient China and early distillation technology have, therefore, largely derived from identifying references to metaphorical descriptions of supposed alcoholic spirits and descriptions of ‘appropriate’ apparatus forms to accommodate such a process. Detailed analysis of medieval Chinese texts and illustrations attest to the expansion of distillation into alchemical fields, with unique vessel forms required to carry out certain alchemical processes (e.g., Barnes 1934; Needham et al. 1980), more detailed than those noted in ancient Greek sources (see 2.3.2). However, finding evidence for alcohol distillation that undoubtedly emerged in China is still approached with pre-existing expectations on apparatus forms and certain translations of terms.

Figure 10*. Examples of proffered early metal distillation apparatus from China, possibly used for alcohol distillation. Han Dynasty bronze still (distiller) apparatus (left) (Chengyuan 1992, p. 174) and schematic of Han Dynasty copper distiller (right) (Xi’an City Cultural Relics Institute 2009, p. 8)*

2.3.4 Transition to distillation from ‘early’ distillation

The end of the ‘early’ phase of distillation has previously been correlated with the emergence of alchemy as a proto-chemical practice and perceived method of material transmutation from at least 800 CE (e.g., Holmyard 1957, pp. 47–56). Equally, a sizeable shift to large-scale distillation from small alchemical practices is noted to mark ‘comprehensive’ distillation or an understanding of the process with extensive detail (Craddock 1998, p. 1). Later archaeological evidence for zinc distillation at Zawar (Rajasthan) in India (14^{th} – 15^{th} c. CE) (see Craddock et al. 1983; Kharakwal and Gurjar 2006; Dey 2008; Alam 2020) and across South-West China (14^{th} – 17^{th} c. CE) (see Zhou et al. 2012, 2014) are, for example, seen to represent forms of industrialised distillation expanded considerably past an ‘early’ point. Hence, while early alchemical practices existed in Greece and China that may have involved distillation (see 2.3.2 and 2.3.3), the transition to ‘recognisable’ distillation apparatus is marked by developments in still morphology and tied to the emergence of medieval alchemical explorations. The role of specific apparatus forms to distil a range of materials, therefore, marked a consolidation of ideas surrounding the role of distillation, what it was seen to enable, and wider implementation of unique apparatus configurations.

The alembic, reported as widely in use by 700 CE (e.g., Kockmann 2014, pp. 6–7), is considered to have helped consolidate the scientific practice of distillation (Blass et al. 1997, p. 434). Taking its name from the Hellenistic still component (see 2.3.2), subsequent modifications to distillation apparatus[23] enabled finer essences within medicines, perfumes, and rose waters to be extracted. With the ability to extract purer forms of material properties, spiritual conceptualisations underpinning ‘magical’ elixirs were devised, central to early distilled alcoholic spirits such as *aqua vitae* (‘water of life’) (Wilson 1975, pp. 54–55, 2006, pp. 61–77). By the 9^{th} c. CE, alcohol distillation for medicine was more widely recorded by the proto-chemist Muhammed ibn Zakaryia Razi at a similar time when large elaborate stills were designed for rosewater, herbal compounds, and experiments into base metal solvents (see Forbes 1970). Further examples of 9^{th} c. CE Mamluk alembics at Quseir al-Qadim (Meyer 1992, p. 84), and 5^{th} - 8^{th} c. CE glass still heads later coined as ‘cold still heads’ (Sherwood Taylor 1952, fig. 12; Gwei-Djen et al. 1972, p. 74) denoted a shift to more recognisably modern distillation practices. However, a possible semantic and typological confusion between the labelling of alembics and ‘cupping glasses’ complicates such an attribution (e.g., Meyer 1992, p. 84). Equally, the distillation of alcoholic products such as wine to produce concentrated spirts during and before this period has been seen as unviable, primarily due to a lack of references to still cooling required to fully condense alcoholic vapour (Gwei-Djen et al. 1972,

[23] Such as glazing earthenware vessels (see Moorhouse et al. 1972).

pp. 75–76). This is compounded further by concerns of alembic efficiency, particularly considering that early examples produced in ceramic or glass are seen to have lacked the necessary conducting and cooling properties to enable continuous distillation (Ihde 1984, pp. 16–17). Regardless, identifying common still configurations, such as the alembic, has been a key feature throughout archaeological and historical research on distillation. To find complete alembics and their components across Greece, China, Mongolia, and the Indian subcontinent would then be seen as evidence of a commonality of distilling (e.g., Belgiorno 2018a, p. 20).

Due to the paucity of evidence and sparse explicit examples of distillation apparatus[24], great reliance has been placed on unifying archaeological materials with literary records, translated terminology, and etymological research, and confined to broad dialogues on technological change (e.g., Park 2021). This is to the extent that large-scale maps of distillation usage have been generated aligned with certain distilling 'traditions' but lack critiques of individual archaeological cases used to support textual inference. Connections to certain terms, specifically the Arabic word *araq* ("distilled alcoholic spirit") has been a feature of chartings of the transition from 'early' distillation to full pure alcohol distillation (Figure 11). Here, the use of the term 阿剌 [aji] in the post-Mongol Yuan Dynasty (1271 to 1368 CE) has been recognised as etymologically related to *araq*, thus acting as a marker of interconnectivity between Chinese and Arabic-speaking regions (e.g., Shijian 1988; Park 2021). However, other bodies of evidence to support such attributions are lacking. Archaeology holds a contentious position in such cases, predominantly employed as an indicator of the rise and exchange of technical practices. This reduces a complex technological system to an exercise in broadly identifying isolated elements unified within a grand narrative. Globally charting distillation technology diffusion and emergence through identifying archaeological representations of linguistic and illustrative commonalities has, therefore, been a predominant direction. Equally, it has acted as a broad framework by which to direct research, the application of analytical methods, and interpretations.

[24] Those recognised predominately pertain to medieval and post-medieval chronologies.

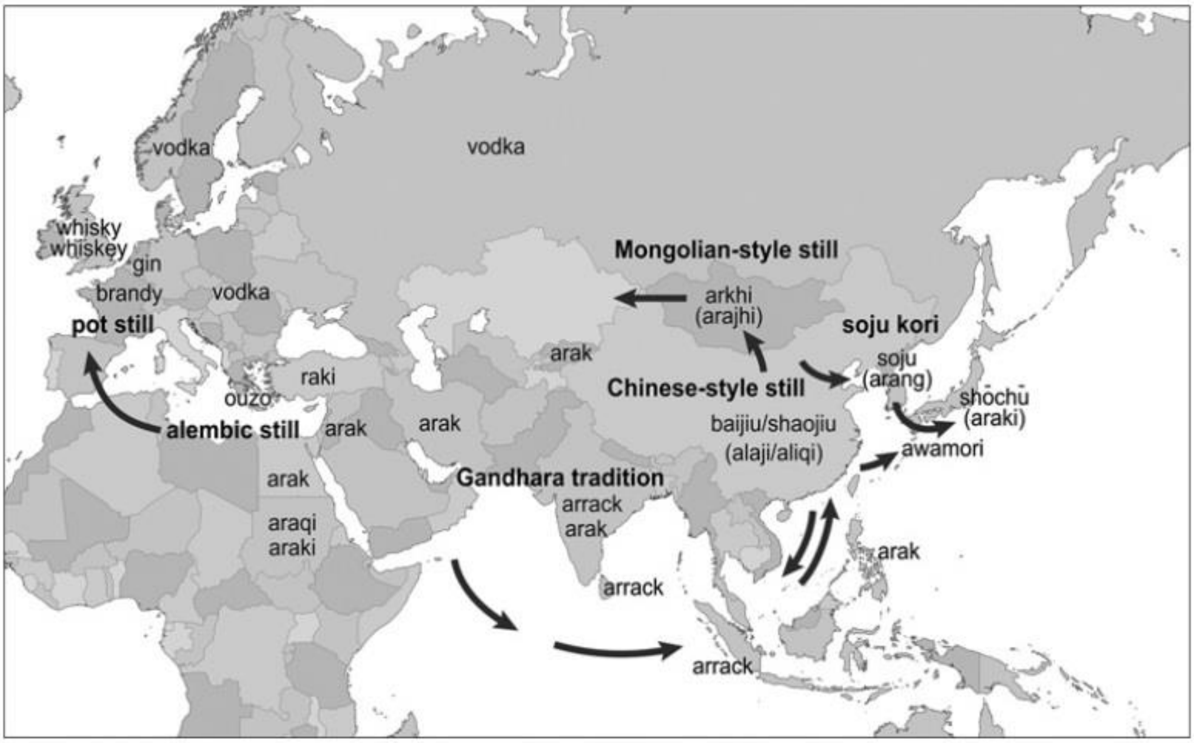


Figure 11. *Park's (2021) continental charting of distillation technology diffusions in characterisitic practice and apparatus traditions based on identified language adoption and change (Park 2021, p. 27).*

2.4 Archaeological approaches to early distillation

The view of early distillation as a series of distinct technological evolutions has direct connections with archaeological information, whereby piecemeal physical evidence and artefacts are directly related to conclusive apparatus examples. Conceptualising the bounds of early distillation is, therefore, partially a discussion reliant on defining the characteristics of core archaeological terminology when employed in such an essentialist format. Despite this direction, the role of apparatus within characterisations of technological change is frequently overlooked or disregarded (White 1984, p. 20; Veronesi and Martinón-Torres 2018, p. 7346). Accordingly, the predominant role of archaeology and material culture is to act as a body of evidence to prove conclusively the existence of such examples. Such a starting point is a major issue in the way research is directed: archaeological methods are applied to support a set interpretation and begins with a series of assumed functions for specific objects. In conjunction, the intangible nature of the components involved (i.e., essences and vapours) creates an additional intrinsic problem when dealing with the physical remains of the past to discuss early distillation. Thus, the question of apparatus and equipment becomes centred on its production, as this can be more conclusively determined aside from elaborating on what changes to apparatus material could enable in regards to distillation ability (see Veronesi and Martinón-Torres 2018, p. 7346). Evidently, a problematic line of interpretation therefore exists if early distillation practices are studied from archaeological remains alone. Bodies of research into early distillation then, while attempting to corroborate several lines of analysis, traditionally lend themselves to being approached as broader studies of object function and morphological capabilities of vessels. Archaeological studies have, accordingly, frequently utilised multiple methodological approaches by which to address this issue, introducing other insights on technological practices involved in early distillation.

2.4.1 Object form, function, and artefact distributions

Exploring function is an exercise as old as archaeology itself and underpins many areas of the field (Levin 1976; Coles 1979, pp. 11–12). The delineation of specific cultures ("The Beaker Culture"), debates around classifying vessels and wares (e.g. coarse wares, domestic wares, kitchen fabrics) (Trusty and Hruby 2017, p. 1), and categorisation (cooking, consumption, storage) exemplify the intrinsic position of object function in archaeology. Yet the articulation of function as an exploration of form has limited interpretation, whereby an artefact's shape, facets, and features are seen to directly equate to its function (Levin 1976; e.g., Biddulph 2008). Further, morphology-led approaches[25] have largely dictated traditional directions of object study (e.g., Binford 1965; see Hurcombe 2007, pp. 533–536). While methodical frameworks such as those proposed in use-wear analysis have been developed as a challenge to limited interpretations (see Van Gijn 2014 for overview), the creation of extensive material catalogues, and typological groupings spawned from them, demonstrates the legacy of such approaches. Assumptions about use, if based purely on how features appear, exemplify the often-limited value of essentialist approaches to archaeological materials. When extrapolated into explicit typologies, categorisations then become accepted uncritically (Trusty and Hruby 2017, p. 3) and dictate how artefacts are viewed. Postulating the function of physical features of objects is, therefore, directly associated with form, notable in ceramic studies where shape of vessels are commonly considered to contribute directly to the functionality of a vessel (Trusty and Hruby 2017, p. 2). In often seeking to objectively establish the nature of object function (Van Gijn 2014, pp. 167–168), one only needs to consider briefly the nature of typology and the impact that it has on core methodological directions taken in archaeological practice to realise how form-led archaeological research is.

Like other underrepresented technological contexts, distillation presents an ontological problem when evaluated through only a study of object function. Largely based on surviving medieval still examples (e.g., Moorhouse et al. 1972), archaeological contributions to charting distillation have frequently been considered to stem from what can be offered through determining object function, materialised as the positive identification of distilling apparatus

[25] "This thing looks like *x*, which would be beneficial for *y*, so it probably is used for *z*".

(see 2.3). Hence, identifying possible functional attributes of apparatus to enable distillation, and what said attributes can afford, is an approach related directly to the treatment of object function in archaeology.

Finding vessel forms and directly classifying them as distillation apparatus, therefore, begins with a preconceived and fixed idea of a model configuration, principally determined by modern knowledge of distillation (e.g., Marshall 1951; Levey 1959; Butler and Needham 1980; Belgiorno 2018a). Here, classes and sub-classes of vessels are frequently designated for specialist functions as understood through functional studies despite the intrinsic ability for seemingly 'specialised' pottery classes and forms to be multifactional and multifunctional (Olivieri 2018, p. 128). Direct issues in conceptualising what constitutes explicit distillation apparatus then complicates the matter further, especially when considering the magnitude of adaptions and improvisations to otherwise classified 'domestic' equipment that can be used for distillation (e.g., London 2016, p. 180). In turn, specialised glass and pottery distillation apparatus forms have been discussed in more depth within European medieval and post-medieval studies (e.g., Egloff and Lowry 1930; Moorhouse et al. 1972; Booth 2016; Veronesi and Martinón-Torres 2018), in comparison to what can be said about an 'early' stage of distillation.

In discussing variations in form, the diffusion of specific vessel types for distillation and 'traditions' of distillation practice has relied on identifying the distribution of specific archaeological finds. Artefact distribution studies that consider the interrelationships and patterns between identified morphological variations have been common in many bodies of archaeological research on technology (see 3.2). The study of distillation still morphologies has not been subject to such an approach in comparison to other vessel types (such as cooking vessels), plausibly due to their rarity and inconsistent representation (see 2.3). That said, the possible diffusion of the Tepe Gawara channel jar (see 2.3.1) as an early extraction apparatus has been suggested, though requires developing beyond a preliminary hypothesis (see Belgiorno 2018a).

Comprehensive and detailed material surveys of reported apparatus configurations and forms are, therefore, needed prior to interpreting any patterns of technological diffusion so that any reported observation can be fully evaluated beyond noting similarities in features. A complete material survey in this regard can act as a means to discuss and evaluate reoccurring patterns in apparatus components or configurations, but also provide a transparent catalogue of noted similar features that can be independently reviewed. However, this does not justify any ascribed use of a vessel (such as distillation) and further lacks complete interpretations of plausible technological diffusions. While more recent critical evaluations of artefact distribution have emerged through network approaches (e.g., Brughmans 2013; Knappett 2013; Donnellan 2020), these alone cannot be used to justify stated functions of artefacts, vessel forms, or reconstructed apparatus configurations.

2.4.2 Experimental archaeology

While the study of object function has often eluded a unified approach to interpreting early distillation, the idea that corporeal exploration can access the dynamics of technological practices has been championed as a suitable enquiry, understanding that the direct manipulation of materials and objects can help to reveal their uses. ‘Experimental archaeology’ emerged from this line of thought, frequently reconceptualised within the development of archaeology (e.g., Ascher 1961; Mathieu 2002; Bell 2009; Dungworth 2013; Paardekooper 2019). Before being considered as a means to ‘test’ certain hypothesises of archaeological interpretation, experimental archaeology at its most condensed realisation stemmed from principles first established by antiquarians as “any honest effort to understand ancient artefacts by actually working with them” (Coles 1979, pp. 11–12). Yet despite approaches to experimental archaeology consistently adapting (see Paardekooper 2019 for overview), it is an analytical tool often marginalised within the archaeological community, reduced to being positioned as an engaging demonstration for presenting the past to the public (Reynolds 1999, pp. 162–163). In comparison to perceived empirical approaches, the value of experimental archaeology has often been dismissed as “prejudiced” and “limited” bodies of information (e.g., McGovern and Hall 2016, p. 594).

Seminal texts, studies, and manifestos outlining experimental archaeology have frequently sought to re-establish the field. Following the term’s coining (see Ascher 1961), the works of John Coles arguably were the first comprehensive attempt to determine and define experimental archaeology, presented as his “rules of the game” (Coles 1973, 1979). Coles’ works essentially aimed to champion the usefulness of testing an archaeological interpretation, in response to entrenched interpretations on tool use, through practical replication and exploration (Coles 1973). However, within the changing post-processual landscape of archaeological thought, more dogmatic realisations of experimental archaeology arose. Peter Reynolds’ (1999) conceptualisation of experiment greatly emphasised the ‘testing’ element, but dismissed any interpretive aspect that was not rooted in hypothesis testing through hard scientific empiricism (Reynolds 1999, p. 164). By removing the human and subjective elements of past activity, Reynolds believed that only insights on past activity generated through vigorous testing were of value (1999, p. 163). His labelling of those who participated in living history demonstrations as possessing “character deficiencies” exemplifies this school-of-thought (Reynolds 1999, p. 162), particularly dismissive of the value of experience and experiential insights gained through ‘doing’. The legacy of such conceptualising has continued into modern experimental practice, where experimental replication and reproducibility are still accentuated in many studies (see Mathieu 2002 for overview; Petty 2019, p. 3). A consensus on what experimental archaeology aims to do, and the difference between certain ‘groups’ of experimental work, is, therefore, rarely comprehensively understood (cf. Paardekooper 2019). As a result, experimental archaeology has been dismissed and incorrectly deemed in some conceptualisations a branch of ethnoarchaeology (e.g., McGovern and Hall 2016, p. 594). Hence, the idea that experimental archaeology must prove theories, in the same scope and detail as in the scientific method, remains in several iterations of the practice (Petty 2019, p. 1). The divide between different ‘material knowledges’ by craftspeople and scientists further amplifies this issue (see Kuijpers 2019) and has influenced how technological studies have been approached through experiment. In turn, objective study (science) and experiential understanding (craft) are frequently seen not to sit together within experimental archaeology, despite the reality that experiential ideas feed directly into contexts of craft, craft practice, and craft learning at the heart of technological systems (Dungworth 2013, p. 15).

Considering the scientific milieu surrounding the study of early distillation (see 3.3), it is of no surprise that experimental approaches have featured since the inception of the subject. Many approaches predate the traditional foundational ideas of experimental archaeology, but ultimately such studies aimed to prove the appropriateness of reconstructed distillation configurations. Inevitably, when results from experiments have been published (e.g., Butler and Needham 1980; Belgiorno 2020; Stroud 2021), there is a heavy emphasis on process and function, predominantly addressing the capacity of apparatus for distillation. Thus, the idea that experiments should prove or disprove the viability for pure distillation (see 2.2) have significant representation in the body of experimentation, almost considered as necessary for charting apparatus. Alcohol distillation again was the focus of studying early distillation by experiment as demonstrative of an apparatus’ ability to achieve pure distillation. Investigations by Von Lippmann (1912) with the ‘Alexandrian still’ (see 2.3.2) addressed the viability for alcohol distillation, but had little success (Diels 1913; Gwei-Djen et al. 1972, p. 73). However, the ‘Alexandrian still’ method was successfully tested in the mid-20th century by Reti in a series of unrecorded experiments (see Gwei-Djen et al. 1972, n. 24), suggested it as the origin of the later 15th – 16th century CE ‘Rosenhut’ still for spirits distillation (Gwei-Djen et al. 1972, p. 73).

The trend for testing still viability and efficiency continued past early experimental work. Butler and Needham (1980), following Needham’s et al.'s (1980) scientific synthesis on the origins of distillation, undertook a set of experiments designed to test still efficiency of 'Mongolian', 'Chinese', 'Hellenistic' and 'Gandhāran' stills. Experiments largely aimed to determine the viability of alcohol disitllation through reconstructed glass working models of stills and using aqueous solutions of ethanol and acetic acid. Results showed that distillation with the 'Chinese' still was much slower than the 'Gandhāran' and 'Hellenistic' stills, with an functional capacity similar to a reflux condenser, considering that the collected distillation would often run back into the still body / distilling flask (Butler and Needham 1980, p. 70). As Needham's work was by its nature a scieintifc investigation, results produced specific operational comments on still efficieny, but were deemed by the authors to help determine where, and by whom, wine was distilled (Butler and Needham 1980, p. 69). The body of Butler and Needham's experiments emphasised the viability for alcohol distillation with the 'Mongol' still with no real specialised equipment or still head cooling (see Butler and Needham 1980, p. 72). This demonstrated the ease for distillation and alcohol distillation. However, the work clearly eschewed the question of the 'human' within technology and lacking a realistic or authentic setting for the distillation practice. Subsequently, the trend of using model working apparatus forms continued (e.g., Stroud 2021) and largely has been conducted through the guise of providing scientific legitimacy to the study of distillation technology evolution. The territorialism of scientists as the arbiters of their discipline's history, versus the dialogues created by archaeologists and historians, has, therefore, ultimately shaped experimental research on distillation to revolve around hypothesis testing (Fors et al. 2016, p. 88).

In the 2000s, experimental studies of distillation have continued rigid testing approaches to understanding early apparatus and its distilling abilities. Yet still grounded in assumptions on use, experimental practice has only emerged recently as a means to challenge historical claims on fundamental facets of distillation's history, such as alchemical practices (Fors et al. 2016, p. 87). A departure from this trend has been to evaluate some of the earliest suggested examples of distillation apparatus, both in terms of applications of distillation, but also in the wider historiography of the subject. Recent experiments on dry distillation have sought to explore the technological capabilities of early modern humans, extrapolated from exploring the production of early tar adhesives (e.g., Groom et al. 2015; Kozowyk et al. 2017). Further, functionality-led experimentation testing Levey's hypotheses on the channel rim jars from Ubaid Tepe Gawra (see 2.3.1) aimed to understand the functional dynamics of such apparatus and explain similarities with other examples across Europe and Asia (e.g., Belgiorno 2018a, 2018b, 2020). Utilising replica apparatus made using traditional methods and tools (Belgiorno 2018a, pp. 66–67), experimental campaigns used the channel-jar configuration apparatus to produce perfumed waters and essential oils (Belgiorno 2018a, pp. 30–33, 72–73). While the campaign demonstrated the importance of heat control within the process (Belgiorno 2020, p.

10) and the utilisation of materials underrepresented in the archaeological record (Belgiorno 2018a, p. 34), interpretation beyond technical considerations rooted functionality and assumptions on use is limited (Belgiorno 2018a, pp. 79–101, 2020, p. 10). Experiment then continues to be used as a vehicle to explore object function and technological diffusion based on assumed starting points.

More recently, experiment has been used in tandem with other archaeological lines of investigation, yet still tied to specific ideas on technical innovations in early distillation. In South American contexts, Zizumbo-Villarreal et al. (2009) tested if Capacha gourd and trifid vessels could be used as a distillation apparatus for producing alcohol in the Early Formative period (1500-1000 BCE) of Colima (Western Mexico), in line with a traditional method for cooking beans that employs the principles of evaporation and condensation (Zizumbo-Villarreal et al. 2009, p. 415). Notably, such an investigation also included insights from organic residue analysis (ORA; see 2.4.4) to provide supporting data (see McGovern 2019). However, echoing notions of technological diffusion, the experiments aimed to explore the similarities between Early Formative Colima vessels and Shang and Zhou Chinese steamers (1600-221 BCE) (Zizumbo-Villarreal et al. 2009), the latter postulated as a precursor to the 'Mongol' and 'Chinese' still types (Needham et al. 1980, p. 109). In proving that alcohol distillation was possible from an agave ferment using gourd and trifid vessels in a vertical configuration (producing distillates with an alcohol content of 20.5% v/v on average (Zizumbo-Villarreal et al. 2009, pp. 420–421), the aim of the research was to determine 'origins' rather than evaluate previous claims. Furthermore, ORA results from archaeological samples in comparison to modern replica samples generated negative indications of explicit biomarker compounds indicative of ancient alcohol distillation (McGovern 2019, pp. 4–7). Hence, the lack of excavated in situ articulated apparatus, comprehensive remains of a distillery, and confirmatory evidence to support the idea that distillation apparatus existed within this context (McGovern 2019, pp. 2–3) overshadowed insights gained through the experiments that could otherwise be used to comment on the functional parameters required for early distillation. The emphasis to understand a plausible connection between two apparatus configurations within the study therefore dominated, somewhat ignoring insights on early distillation as a complete technological practice.

Experimental methods, therefore, need to adapt so the human-centric decisions embedded in the earliest forms of distillation and proto-distillation can be understood by engaging directly with material composition and transformation at the interface where "material and maker meet" (Kuijpers 2019, p. 609). Seeing experiment as a facet of wider archaeological studies, rather than acting as independent endeavours offers a more meaningful role for experimental archaeology particularly when connected to studies of explicit materials and archaeological representations or signatures (e.g., material analysis data). Furthermore, gaining useful experimental results is difficult and sometimes impossible to plan for illuminating the intricacies of technological processes within a strict hypothesis-testing format. Hence, experimental studies must be attuned to the possibilities when things fail (Dungworth 2013, pp. 12–14).

Qualitative or quantitative approaches alone, however, are not helpful (Kuijpers 2013, p. 147). While experimental researchers have frequently used personal experience to produce general claims about technological processes, answers derived through such impressions alone often lack a desired level of accuracy normally associated with empirical measurement (Petty 2019, p. 2). Personal claims be neither universal nor objective (Kuijpers 2013, p. 143), though approaching technological reconstruction with specific quantifiable questions alone means that any result generated through experimentation will only address specific material properties and not the technology as a whole (see Dungworth 2013). Thus, as all experiences that underpin a practice are mediated by the senses (discussed further in Chapter 3), a methodology that understands and records ideas from impressions and experiences is necessary (Kuijpers 2013, p. 144). This should, however, be done in tandem with collecting measurable data so that subjective impressions can be correlated with possible physical and chemical changes to materials during an experimental reconstruction (see Kuijpers 2019). Thus, a holistic experimental methodology could provide avenues for exploration and error, engaging with wide groups of materials that extend beyond assumed applications for early distillation (Belgiorno 2018a, p. 19). Hence, the process of experimentation, and what is learnt through it, is just as important as experimental reproduction alone.

2.4.3 Ethnography and ethnoarchaeology

Since their earliest iteration, studies of distillation technology have recognised the interpretative value of ethnographic data to mitigate for the ambiguity of material evidence and paucity of final products. This is especially pertinent considering how experimental work largely addressed material and physical properties of early apparatus configurations, but not necessarily the practice (see 2.4.2). Accordingly, a comprehensive body of late 19th and early 20th century anthropological and ethnographic data on distillation (predominantly alcohol distillation) has been positioned as the conceptual basis for understanding how distillation may have emerged (e.g., Lumholtz 1898; Montell 1937; Bruman 1944). This has been used to support the interpretation of archaeological materials as examples of distillation apparatus (e.g., Zizumbo-Villarreal et al. 2009; London 2016). Thus, the emergence of ‘ethnoarchaeology’ as a subdiscipline has acted as a unifying context so that alternative practices away from preconceived ideas can be reconciled with unexpected archaeological results. The pervasive desire, however, to detail technological progression and evolution by researchers, combined with questionable colonialist legacies present in ethnographic research, underpins many interpretations of early distillation.

The “direct historical” approach is common within such a study and considers archaeological contexts as a historical and cultural constitute linked to the present (Gosselain 2016, p. 220). Imbued with connotations of ‘primitive’ activities in comparison to modern distillation practices, the body of evidence is often mobilised within diffusionist dialogues on the development of distillation and articulated through ethnic concepts such as Asiatic, Mongol, Filipino and Chinese still forms (Figure 12) (e.g., Bruman 1944). Archaeological interpretations emboldened such thinking, often supporting the idea that knowledge of distillation must be ancient and drawing from ethnographic examples. Observed distillation practices conducted by ‘primitive people’, and morphological similarities shared between stills in ethnographic cases and reconstructed apparatus configurations from archaeological evidence (e.g., Allchin 1979a, pp. 56–58) (Figure 13) were considered the link between past and present activities. That the technological progression mindset presented in many evolutionary chartings such as Needham et al.’s (1980) is silently guided by a dichotomy of modern and ‘primitive’ further indicates the limitations of such evolutionary maps. In this respect, the omnipresent idea of technological progression as a linear and stadial process acted as the basis by which to view ethnographic data as a comparative model for archaeological reconstructions.

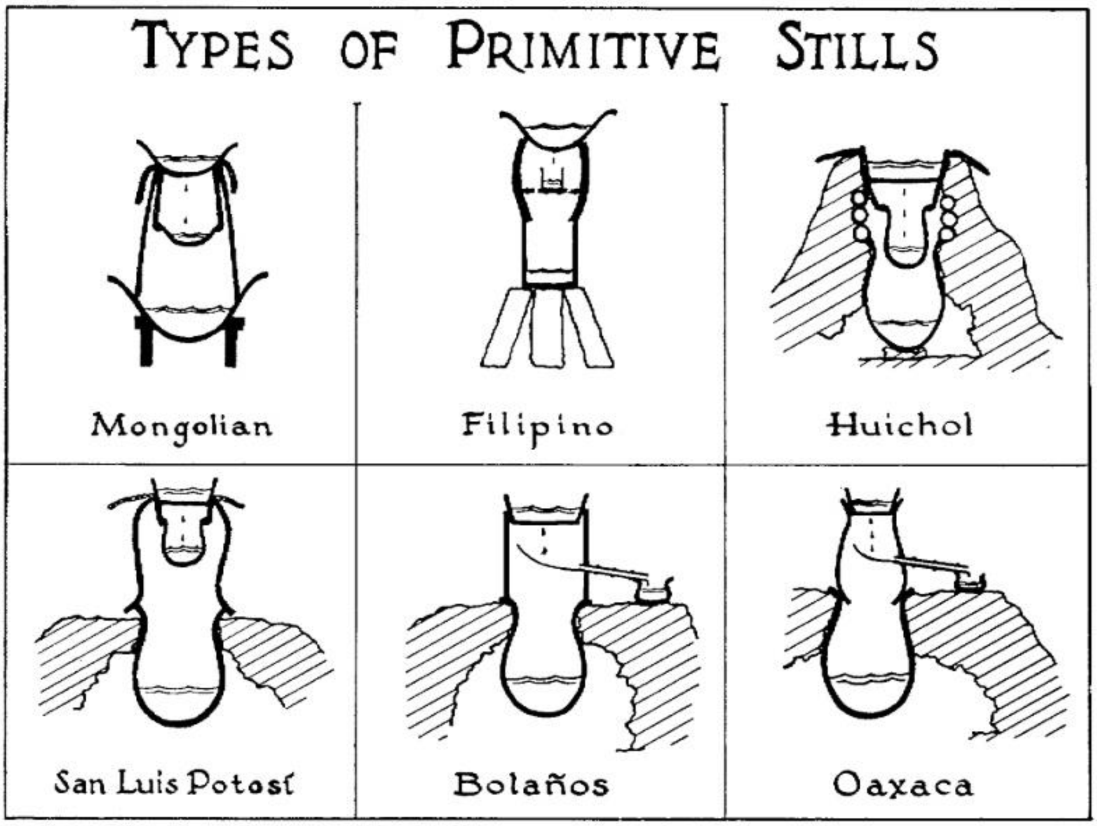


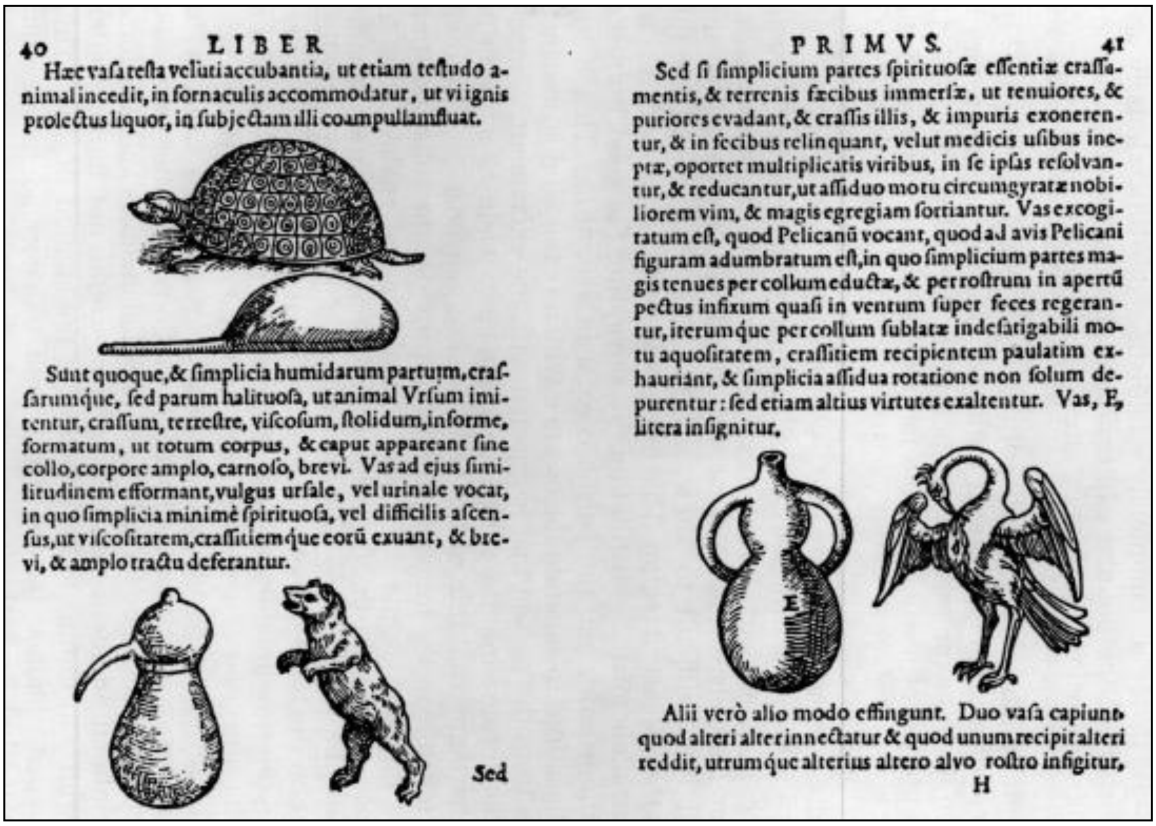
***Figure 12.** “Primitive stills of Asiatic derivation" according to Bruman (1944, p. 426) which utilise a vertical configuration of distillation apparatus.*

***Figure 13**. Still from rural India used to distil mahua flowers (Von Fürer Haimendorf 1943), seen to both exemplify ‘primitive’ distillation but also as a connection to the historical origins of the practice. Such has been the case in the creation of the ‘Gandhāra still’ tradition (see 3.5; Chapter 4).*

The application of ethnographic evidence in writing the history of early distillation then carries a series of caveats rooted in problematic perspectives and observations generated through a supposed study of contemporary human behaviour. Gosselain (2016) has robustly criticised the treatment of ethnographic data in archaeology, largely condemning the subjective and biased use of analogy to justify comparisons between ethnographic models and archaeological interpretations (Gosselain 2016, p. 217). Frequently, an emphasis on classifying 'premodern' people as fitting examples to match archaeological cases has driven such a comparison (Gosselain 2016, pp. 218–220). As seen in many studies aiming to establish the origins of distillation, the regular use of "primitive" to describe the process, apparatus used, and distillers themselves exemplifies the interpretative issues generated through ethnoarchaeological study rooted in logicisms and middle-range theories (Gosselain 2016, p. 216). Here, ethnographic accounts, when used as the basis for establishing nexuses of early distillation, have consistently grounded themselves in recording methodological rationalities alongside discussing concepts of technical prowess (e.g., Montell 1937; Bruman 1944, 2000). This is a familiar and common comparison used in ethnoarchaeological studies that attempt to characterise rationality and tradition, and subsequently the inevitable comparison with Westernised conditions (Gosselain 2016, p. 222). Hence, the common thread of creating a series of ethnographic observations, applying them to archaeological materials, and validating an interpretation of distillation apparatus features both in isolated cases and grander narratives.

It is, therefore, questionable as to what extent ethnographic datasets are effective for passing comment on early distillation practices. If, however, ethnographic data is used to provide information on how humans "adapt to changing circumstances without compromising craft, identity, or social position" (Gosselain 2016, p. 222), a different remit for such observations is established directly related to understanding the changing social contexts of technology. Thus, in moving away from an interpretation of ethnographic cases underpinned by problematic analogies, there is a place for such examples when looking at archaeological remains.

Particularly, the sheer range of subjective understandings of processes and the sensory, multimodal, and embodied skills involved in developing a practice can be elucidated as options for communicating a technological practice away from strict empirical mindsets. Illustrating this, the articulation of distillation processes and operation of apparatus in anthropomorphic terms has been recorded since the 17th century (e.g Porta 1608; Egloff and Lowry 1930, p. 2064) (Figure 14) and continues to be used in cottage-industry *kirsch* production in eastern France (Voisenat 1995, p. 320). Descriptions by distillers in rural France of how the distillation process is more akin to bodily functions than mechanical properties provide an alternative view on the entire technical process rooted in a vocabulary related to concepts of life, death, and the human condition (Voisenat 1995, pp. 316, 319–320). Thus, the recognition that interpretative directions must explore a network of relationships between techniques, product qualities, and the effects of the product upon the body (Voisenat 1995, p. 314), demonstrates the complexities within differing perceptions and experiences of distilling. Such an understanding clearly goes beyond normative ideas on technological development.



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Hæc vaſa teſta veluti accubantia, ut etiam teſtudo animal incedit, in fornaculis accommodatur, ut vi ignis prolectus liquor, in ſubjectam illi coampullam fluat.

Sunt quoque, & ſimplicia humidarum partuim, craſſarumque, ſed parum halituoſa, ut animal Vrſum imitentur, craſſum, terreſtre, viſcoſum, ſtolidum, informe, formatum, ut totum corpus, & caput appareant ſine collo, corpore amplo, carnoſo, brevi. Vas ad ejus ſimilitudinem efformant, vulgus urſale, vel urinale vocat, in quo ſimplicia minimè ſpirituoſa, vel difficilis aſcenſus, ut viſcoſitatem, craſſitiemque corũ exuant, & brevi, & amplo tractu deferantur.

Sed

PRIMVS. 41

Sed ſi ſimplicium partes ſpirituoſæ eſſentiæ craſſamentis, & terrenis fæcibus immerſæ, ut tenuiores, & puriores evadant, & craſſis illis, & impuris exonerentur, & in fecibus relinquant, velut medicis uſibus ineptæ, oportet multiplicatis viribus, in ſe ipſas reſolvantur, & reducantur, ut aſſiduo motu circumgyratæ nobiliorem vim, & magis egregiam ſortiantur. Vas excogitatum eſt, quod Pelicanũ vocant, quod ad avis Pelicani figuram adumbratum eſt, in quo ſimplicium partes magis tenues per collum eductæ, & per roſtrum in apertũ pectus infixum quaſi in ventum ſuper feces regerantur, iterumque per collum ſublatæ indefatigabili motu aquoſitatem, craſſitiem recipientem paulatim exhauriant, & ſimplicia aſſidua rotatione non ſolum depurentur: ſed etiam altius virtutes exaltentur. Vas, F, litera inſignitur.

Alii verò alio modo effingunt. Duo vaſa capiunt, quod alteri alter innectatur & quod unum recipit alteri reddit, utrumque alterius altero alvo roſtro infigitur,

H

Figure 14. *Extract from "De Distillationibus" by Porta (1608), comparing still types to animal morphologies, and incorporating operational guidelines that link the 'movement' of spirits within the stills to that of the animal, hence the appropriate still must be used depending on the matter of the substance being distilled.*

In reviewing the role of ethnographic evidence, an alternative idea on distillation apparatus is encouraged detached from logical and rational assumptions of technological innovation, and dismissing derogatory attitudes imbued in ethnoarchaeological interpretations. Fitting within a context of innovation, how a still is created from a myriad of understandings on materials, processes, and exploration can be discussed and not connected only to rationalised concepts of technical specialisation. Thematically running through ethnographic accounts of distillation, particularly as an activity within rural environments, secondary uses for vessels rather than specially made apparatus components often act as the formative elements of a configuration (e.g., Figure 15). Instead of justifying how certain vessels match archaeological materials as an element of a developed distillation apparatus, observations demonstrate how domestic vessels are appropriated for apparatus configurations. In many respects, this supports a theory of distillation emergence and innovation as rooted in experimentation, adaption, and exploration of materials, and tied to changes in object use. As such, the role of craft practice at the centre of ethnographic data on distillation clearly emphasises a need for 'practice' to be considered at the heart of technological studies. This is particularly significant considering the general lack of such a consideration within most artefact-centric and experimental studies of early distillation.

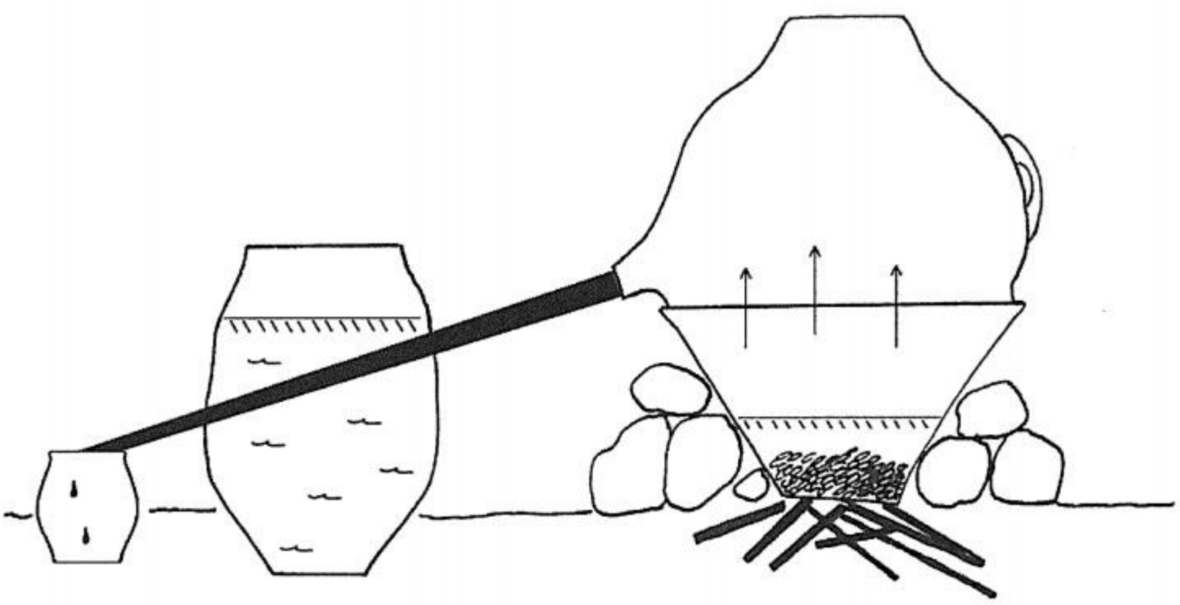


***Figure 15**. An illustration of a traditional still (lampikos) in rural Cyprus made from a series of adapted cooking vessels (unknown record date) (London 2016, p. 180).*

2.4.4 Organic residue analysis (ORA)

As the connection between visible form and assumed function has been disputed (see 2.4.1), other lines of analysis to determine object function and its connection to distillation have been introduced. Interpreting the presence and use of organic materials not easily recognisable in archaeological contexts has accelerated since the advent of acute identification analytical methods. Distillation have been drawn into this exploration (e.g., McGovern 2019), considered within frameworks of material science and organic chemistry. Organic residue analysis (ORA) is one established tool, influenced by the integration of analytical chemical methodologies to recover, detect, and characterise biomolecules representing a 'fingerprint' or 'biomarker 'of organic materials (Dunne 2017, p. 1). It is these indicative compounds and structures which aim to be identified in ORA and relate back to residues, organic products, and botanicals with compounds characteristic of particular plants or foodstuffs (Hopkins and Armitage 2012, p. 132).

Specific analytical instrumentation is employed in ORA to separate and identify absorbed compounds in a pottery sample and thus identify vessel contents and use as a recognisable residue. Chromatographic and mass spectrometry methods have allowed molecular-level recognition and resolution of complex residues, biological materials, and environmental substances to be evaluated (Evershed 2008a, p. 897). Through the coupling of gas- (GC) and liquid- (LC) chromatography with mass spectrometry (MS) instruments, the detailed separation[26] and subsequent characterisation[27] of samples has enabled discernible inferences on multiple biomolecular constituents to be provided (Evershed 2008a, pp. 897–898; Hopkins and Armitage 2012, p. 131). ORA, therefore, attempts to establish the origins of residues by matching compound chemical structures, distribution, and stable isotope composition (the biomarker) to extant material references (Evershed 2008b, p. 27). As such, ORA relies directly on matching chemical structures and distributions to a series of modern reference libraries of biomarkers and therefore suggest organic products or materials (Biers et al. 1994, p. 20; Dunne 2017, p. 2). Consequentially, the translation of this principle more broadly into the study of organic residues is ephemeral and constrained to descriptions of chemical properties (e.g. compound classes present), considering the complexity of chemical constituents that formulate residues (Evershed 2008a, p. 895).

The ambition of ORA to be a comprehensive method in determining substances that have been in contact with objects, however, presents a series of challenging issues that can undermine generated results. Analysing preserved in situ contents, visible surface residues, and absorbed organic residues through ORA has emerged as areas of interest in pottery studies (Evershed 2008b, pp. 26–27), mobilising ORA to be integrated into many archaeological questions (see Dunne 2017, pp. 15–17). Remnants of organic materials (the residues) are, however, often naked to the eye, but probably present in around 80% of all pottery assemblages (Brown and Brown 2011, p. 194). Hence, ORA has historically been limited to studying visible contents of pots or trace amounts of organic materials (Biers et al. 1994, p. 9) to connect residues, and thus products, with specific chronological periods and vessels (Brown and Brown 2011, pp. 193–194). The very nature of residues therefore limits what contexts can be analysed, such as within studies of distillation. Organic materials from archaeological sites are biological in origin, thus they will likely be heterogeneous mixtures,

[26] Chromatography.
[27] Mass spectrometry.

and increasingly more complex through human activities (e.g., food preparation) (Brown and Brown 2011, p. 195) and depositional impacts (e.g., decay) (Evershed 2008a, p. 897). Understanding how compound molecular structures change through degradation is imperative (Brown and Brown 2011, p. 195; Dunne 2017, p. 2), as is considering what other constituents are present in a residue, so that possible sources in the context of an artefact's origins and level of possible contamination can be confirmed (Evershed 2008a, p. 899). This is further complicated when considering the geographic variability in organic references and environmental conditions that impact residue and compound representation (McGovern and Hall 2016, p. 596), and variation in pottery fabrics (Evershed 2008b, p. 28).

ORA studies for distillation and proto-distillation are, therefore, few in number, limited only to single studies on perfume (e.g., Biers et al. 1994) and experimental comparative examples for alcohol distillation (e.g., McGovern 2019) (see 2.4.2). Regardless, previous ORA studies have claimed to have found evidence for early distilled spirits in the Mediterranean, notably a precursor to Greek ouzo represented as "brandy lactones" recovered from the Early Helladic Cemetery at Kalamaki (see Martlew 2004, p. 135). However, as pure distillates fundamentally do not contain organic materials[28], it is highly unlikely that distillates will be able to be identified through ORA methods. While not stated explicitly as a distilled spirit, the association made between residue and product lead researchers to the conclusion that the "Greeks might have been drinking a type of ouzo c. 3000-27000 B.C." (Martlew 2004, p. 135). Hence, because recognisable flavour constituents with modern ouzo were reported, it was assumed that the residue must indicate similar beverages. Such an assumption ignores how the process of distillation would affect the composition of a residue detectable by ORA. Accordingly, ORA methods offer options by which to consider plausible distillands and other contextual information, though not fully connected to the question of distillation as a transformative technological process.

Practical concerns with ORA methods cause additional considerations. Sample preparation, instrumentation calibration, and MS analysis is intrinsically a time consuming process (Hopkins and Armitage 2012, p. 132). Thus, multiple independent and complementary chemical techniques are often required when approaching archaeological samples (McGovern and Hall 2016, p. 603) and consequentially the approach to ORA continues to be applied as a method to recover and identify residues. While this is good in developing cases and arguing for the presence of indicative biomarkers, ultimately, it encourages origin-centric arguments over holistic interpretation and technical choices, despite the ability of ORA to identify some

[28] i.e., they consist of the most volatile compounds.

elements of technical processes (e.g., McGovern and Hall 2016, p. 609). The opportunity for ORA to provide insight on facets of craft practices has been suggested through analysing spatial distributions of residues in vessels[29] (e.g., Evershed 2008b), yet the process is often used as a way to pinpoint the origins or first uses of certain products. This furthermore places ORA in an uneasy position when it comes to the creation of historical knowledge and dialogue. Methods for ORA vary between laboratories (McGovern and Hall 2016, p. 595), largely influenced by instrumentation, funding, and staffing available. The ideal of creating an objective approach to determine the composition organic residues will, therefore, never be a neutral process, considering the perceived value and pedestalling of empirical instrumentation, direct connection this has with enabling analysis, and subsequently how this body of information feeds into archaeological interpretations (see 3.2). As such, ORA has been considered an empiricism, arrogantly placed above knowledge and experiences gained through other methods (e.g., McGovern and Hall 2016, p. 594); those without ORA deemed to lack the absolute explanation of archaeological patterns. Above all, however, recent meta-analyses have brought together critical reviews of fundamental biomarkers used in ORA that underpin many interpretations of liquids and residues (see Drieu et al. 2020; Whelton et al. 2021). As such, considering the questionable representation of distillands and distillates to begin with, how ORA can be useful for expanding the representation of distillation in the archaeological record is not well established.

2.5 Summary

Distillation has continuously been a difficult subject for archaeology due to the paucity of material evidence and ephemeral nature of final products. The archaeology of early distillation, however, despite being a topic imbued with complex understandings of materials, has historically been treated as an exercise in confirming and debating the origins of a chemical technology, irrespective of the technical practice required to complete such material transformations. The contribution of archaeology to the global narrative has, therefore, largely been reduced to reporting evidence of apparatus forms as a typological characterisation derived from hypothetical assumptions on object use. Hence, the role of archaeology (and the archaeologist) in reconstructing early distillation technology often is a supplement to structured evolutionary technological chartings (e.g., Needham 1962; Needham et al. 1980) declared as logical progressions (e.g., Kockmann 2014). This is in part a recognised issue, yet mostly as a facet of understanding the limits of the archaeological record and homogenising the idiosyncratic distinctions between individual practices and resulting products (e.g. Gwei-Djen et al. 1972; Needham et al. 1980; Huang 2000). Therefore, the appraisal of physical and

[29] Thereby revealing specific technical decisions.

engineering properties of artefacts is a longstanding feature (e.g., Butler and Needham 1980), but overwhelmingly ignores a holistic idea of distillation and critical evaluation of entrenched apparatus reconstructions.

Establishing clear origins of practices should not necessarily be a priority but remains largely the direction taken when experimental and object-centric studies have been utilised to support a preconceived model of distillation apparatus. Previous studies of early distillation then largely focussed on distinct material groups; how refined distillation technology allowed for the processing and purification of water, alcohol, metals, and other materials was a concern directly tied to morphological properties of apparatus components. Bolstered by interpretations of abstract comments and texts, it was these morphological changes that needed to be found in the archaeological record to provide absolute proof of distillation technology changes. Thus, the notion of determining a grand narrative on how the practice has developed on a global scale to chart the emergence of distillation is equally not a productive direction. In a limited scope, assumptions on what constitutes Chinese, Western, and Indian civilizations have clearly impacted the creation, charting, and trajectory of technological histories (Rocha 2016, p. 18). Such ethnic labels for practices, still morphologies, and distillation traditions have then formed the underpinnings of larger evolutionary explanations for technological changes in distillation. Consequentially, detailed discussions on the consolidation of specific technological practices are neglected, and little is realistically explored beyond identifying explicit developmental stages of apparatus. Dissecting individual cases of proffered early distillation can, therefore, provide more detailed insights on the role and development of such a practice in society but significantly must be determined from multiple bodies of evidence and away from attempts to find 'missing links' between apparatus forms within evolutionary tree models. This avoids an overreliance on literary sources, particularly considering the much higher representation of European medieval texts in comparison to other bodies of evidence (see 2.3). Combined, more nuanced ideas on craft interaction and technological practices, such as those concerning specialisation and dedicated apparatus, can transcend the study of distillation simply as an isolated technology.

The next chapter will evaluate how technological innovation has been treated as an archaeological study and introduce sociotechnical views pertaining to craft and practice. Specifically, it will address the way that technology has been researched within South-Central Asia and the 'Hellenistic East', connected to proto-scientific concepts of materials and the development of 'complex' technologies. Finally, the chapter will culminate in an overview of how early distillation has been interpreted in South-Central Asia.

Chapter Three

Analysing Technological Innovation in Hellenistic South-Central Asia

3.1 Introduction

The concept of 'Hellenisation' has experienced numerous critical evaluations in response to reviews of the creation of European and Westernised world values (Prag and Quinn 2013) (see 1.2). In understanding the eastern extent of Hellenism, the role that technological practices have in conceptualising the 'Hellenistic East' are paramount, amplified by how the region has been studied primarily by Western scholars as a Classics-oriented endeavour (Mairs 2014, p. 3). Technology, when viewed as an element of Hellenisation, has historically been explained as the product of diffusion from the core of the 'Greek world' to new regions (Vranić 2019) (see 1.2). Adoptions of, and changes to, new technological elements away from their original contexts, however, are affected by broader social changes (Erb-Satullo 2020, p. 38) and cannot depend on such an explanation. Accordingly, while efforts have been made to divert from a rigid view of Greek cultural influence in South-Central Asia for some time (e.g., Dani 1966; Callieri 1990, 1995; Olivieri et al. 2006; Petrie et al. 2008; Mairs 2014; Olivieri 2020a), the mobilisation of material culture as an indicator of Hellenism has traditionally dictated how technological changes and introductions are viewed in the region. This is most noticeable in the extensive usage of broad cultural, political, and imperial labels such as 'Indo-Greek' and 'Greco-Bactrian' (see Callieri 1995). Complete studies of certain material groups have, therefore, only recently emerged to challenge such a trend from primary archaeological data (e.g., Iori 2018; Olivieri 2018, 2020b; Callieri 2020). In tandem, both the limits of interpretation constraining the evidence at hand (Petrie 2002, p. 85) and the sporadic rate of investigations in West and Central Asia (Lund 2014, p. 297) have stalled the discussion of technology in greater detail. Thus, compounded by the colonial legacy felt in the region's archaeological research, and greater attention generally being paid to the archaeology of Greece (see 1.4), the potential of technology as a context in which to explore sociocultural change has not been fully utilised.

As studying any aspect of the archaeology of Gandhāra is fragmentary (see Olivieri 2020; Mairs 2020 for analysis), this chapter will set out how archaeology has treated technological innovation as a thematic concern. From this analysis, it will evaluate how material culture and technology have been employed within discussions on 'Hellenisation' in South-Central Asia.

To further outline the development of such an idea, understandings of materials during this period connected to proto-scientific thought will be contextualised within the interpretation of technological innovations and introductions. Finally, to demonstrate how this issue has manifested in an archaeological case, the chapter will close with an overview of the debate surrounding the emergence of distillation in South-Central Asia and how it has been connected to the legacy of Hellenism by some scholars.

3.2 Interpreting technological innovation

Within archaeology, the study of technology has undergone seminal shifts in methodological scrutiny, correlating with developments in analytical instruments, and drawing from a variety of disciplinary backgrounds (e.g., Lemonnier 1986; Hughes 1986; Balfet 1991; Pfaffenberger 1992; Sellet 1993; Ingold 2007, 1995, 2000; Dobres 2000, 2010; De La Fuente 2011; Kuijpers 2013; Delage 2017; Gosselain 2017; Erb-Satullo 2020). The broader history of technology is, however, largely guided by professionals interested in the origins of their respective disciplines, causing a predominantly internalist narrative (Hughes 1986). Consequently, the "Standard View", in that technological progression is believed to be a rational and inevitable system to satisfy certain logical needs (Pfaffenberger 1992, pp. 493–495), underpins how many archaeological interpretations are considered proxies for technological innovations (Bernbeck and Burmeister 2017). Finding evidence to pinpoint inventions, technological introductions, and their diffusions is, therefore, to connect technology to a grand narrative of the foundations of modern positivist, empirical, and scientific principles (see Jones 2002). Hence, as an assumed, universally understood concept, innovation and invention are frequently used as poorly defined rhetorical aspects tied to linear markers of social progress (Erb-Satullo 2020, pp. 37–38).

While stemming from diffusionist ideas of innovation that fully fit the image of the Standard View (e.g., Rogers 1962), the stadial development of complex material practices is deemed to equate to cultural sophistication, observable in the archaeological record. Through a modern determinist logic, technology is deemed to possess its own momentum and is directly indicative of complexity (Pfaffenberger 1992, p. 514). Within such a conceptualisation, technological innovations are presented as an inevitability that originate from sophisticated sources, and rooted in a scientific understanding of processes (Pfaffenberger 1992). Thus, explanations of technological change, such as through social constructionist, evolutionary, diffusionist, and behavioural approaches, entertain the Standard View by relying upon modern analogous models and their connotations of societal development (see Erb-Satullo 2020 for overview). The inception of metallurgy, for instance, has been presented as the inception of science (e.g., Childe 1930, pp. 2–3; Ihde 1984), formulated through a complex and specialised technology (Kuijpers 2013, p. 138). It is, however, contingent on the “persistent fallacy” of projecting a modern understanding of metallurgical value, processes, and systems onto the past (Killick 2005, p. 483). Thus, essentialist and economic conceptualisations of technology are embedded within how technological innovation is understood, and frequently used as a relatable starting point to discuss technological change (e.g., Brynjolfsson and McAffee 2016; Tegmark 2017). The concept of ‘innovation’ is, therefore, confined to developments in technology and science (Sluiter 2017, p. 23) that ignores the assimilation of “the new” into social groups as innovative introductions across every domain of life (Sluiter 2021, p. 244). As such, the view that innovations are facets of hierarchies of complexity relies on arranging “the past” into a rational system akin to “the modern”.

In consequence, technological chartings are entangled with nationalistic receptions, appropriations, and triumphalism (Rocha 2016, p. 20). Historical narratives of technological innovation frequently acts as the backbone for theorising the emergence of the Western world in ‘modernity’ and the 19th and 20th centuries (Versluys and Sluiter 2023, p. 32). Therefore, claims of where and when certain ideas or innovations were invented underpin glorious images of past national scientific histories to justify modern government decisions and activities (Raina 2015, pp. 61–62). External, economic, and ‘rational’ pressures are then frequently considered the context for producing material culture, where technical innovation is a means of environmental adaption (e.g., Binford 1965). Technology then acts as an explanatory model, analogous example, or indicator of social complexity commonly the result of necessity (see Pfaffenberger 1992). Consequently, it is viewed as an empirical and rational scaffold that supports stadial dialogues of societal change at the expense of recognising the fundamentally human elements at the centre of sociotechnical systems (e.g., Binford 1962, p. 218). Consequentially, the influence of Schumpeterian economic models and ‘R&D’ (Research and Development) growth systems present technological innovation in a modern guise as a systemic end in itself (Versluys and Sluiter 2023, p. 31). Hence, drawing on idealised visions of a glorious past, innovations are seen as indicative of ‘greatness’ to exemplify a national continuum of scientific and technological prowess as the cause of economic strength and modernity. The rhetorical framing of ‘innovation’ traditionally considers it a question of ‘complexity’ (and all its connotations), rather the result of conceptual associations created within social groups (Sluiter 2021, p. 257).

In tandem, technological innovation frequently has been determined in archaeology by identifying increasingly complex modes of material transformation. The archaeological tradition of mapping artefact typologies, chronologies, and distribution patterns emboldens such a stance by explaining how technological traditions diffused and evolved, rooted in particular ethnic identities connected to object forms (see Fernández-Götz 2013). Final products are, therefore, considered as a direct reflection of uniform cultural ideas within a technological process, expressed through the visual form of a single object. In doing this, the *reconstruction* of archaeological evidence has historically been undertaken corresponding to a rigid order of preferred diagnostic methods and evidence (see Bell 1994; Jones 2002; Barrett 2021). Reconstruction, in such a conceptualisation, is an exercise in recording physical and chemical absolutes as indicators of fundamental technical "truths" within positivist frameworks of analysis (Dobres 2010, p. 105). The view of reconstruction here separates the compositional values and function of artefacts[30] from the associations created between objects within a technological 'system' (Kuijpers 2019, pp. 605–606). Thus, in reconstructing technological innovations, materials, objects, and the processes leading to their creation are presented as existing in a disarticulated hierarchy structured by supposed absolutes (Hurcombe 2007; Ingold 2007; Kuijpers 2019, pp. 606–608). This ignores the plurality of innovations, the sociotechnical nature of technological systems, and fundamentally the social context in which they are integrated.

It is unsurprising then that seemingly objective procedures of measurement and quantification have been championed to explore archaeological remains (Barrett 2021, p. 39), used as the framework to analyse final products or objects, and designate specific developmental and technological stages (Ingold 2007, p. 9). Characterising technological innovation on both large and small scales[31] has become the preserve of "archaeological science". Technology is subsequently confined to frameworks of material science to study 'production' (Kuijpers 2013, p. 145), further embellishing the idea that technology can only be fully understood by technical specialists within set thematic discussion areas (Sherratt 2008, pp. 209–210). Here, 'production', applied widely in such a material analysis context, is often conflated and confused with 'manufacture', 'crafting', and 'technology' (Miller 2009, p. 5). In homogenising these ideas, reconstructions of technological processes reconcile contemporary ideas with past values through select rational principles that govern how artefacts are produced (Pfaffenberger 1992, pp. 495–502). Consequentially, the emphasis on obtaining what can be objectively measured from material culture has created essentialist perspectives on materials, perpetuating an idea of rationality to justify technological reconstructions. The interpretation of individual artefacts as components within complex systems, apparatus configurations, and manufacturing paraphernalia act as a crutch by which to re-assemble archaeological remains into idealised models and advanced technological stages.

[30] Often related to studies of production technology.
[31] i.e., from locating the introduction of completely new technological ideas to studying slight modifications to existing practices.

The human element embodied in technical choices, and thus materialised in the creation of things, is therefore rationalised in terms of societal 'needs'; the finished form of an object provides the justification for its creation (Pfaffenberger 1992, pp. 495–502). By centralising the observable parameters of material culture, moving between static material artefacts and dynamic cultural practices remains a one-dimensional process: an interpretative gulf to be crossed in which remains are the only indication of explicit systemic activities (see Pluciennik 2012). Tangible materials then are conceptualised as a telling representation of society's constituent parts, but reduced to measurable systems independent of seemingly observable human experience (Kuijpers 2019, p. 607). Inevitably, this approach can only generate explanations of archaeological patterns (Jones 2002, pp. 16–18). Thus, reconstructions of technologies are frequently the result of *explaining* archaeological remains, reassembled to match idealised and hypothetical technological production models, rather than *interpreting* the data (Townend 2007, p. 109; Barrett 2021, pp. 39–47). Projecting a modern understanding of process to rationalise how artefacts would 'fit' together and form complex technological systems reduces such items to single homogenised cultural labels. In result, preferencing the security of objective readings eschews humans and ultimately presents 'things' as produced through disembodied activities (see Ingold 2007). How the process of making influences the creation of societies is overlooked (see Ingold 1995, 2013). Accordingly, the complex social and human-centric processes at the heart of sociotechnical systems are reduced to a series of oversimplified models that favour quantitative values and explanations as the reasoning behind technology.

While the Standard View of technology presented the human body as an automaton passively moved by the mind to produce material culture, exploring embodied actions, gestures and *habitus* - the developed predispositions formulating the practices regulating technical actions (see Bourdieu 1990) - has provided a nuanced approach for exploring technology (see Dobres 1999, 2000, 2010). Central to this is understanding that people are the ontological start point for technology (Dobres 2010, pp. 104–106).. Accordingly, human understandings of materials and processes must be the point of orientation for interpreting technology (Pfaffenberger 1992) as humans articulate the creation of 'things' through bodily actions and skilled practice (Ingold 1995, 2000, pp. 312–323, 2007). Sociotechnical views of technology have, therefore, traditionally centralised *agency* (Dobres 2000, 2010) that understands how objects are dependent on social intentions and human interaction. Ultimately, "to understand agency is to understand how different humans, in different periods and places, could claim ownership over actions… agency is understanding conditions to allow humans to claim '*we did this*' or '*I did this'*" (Ribeiro 2021, p. 536). Agency, in such a context is the capacity of humans to act and make choices, acknowledging that individuals influence and shape their social reality through actions and decisions within social contexts. Social agency then evaluates how individuals or groups navigate and influence the social worlds around them. Accordingly, technology is, therefore, a total "social fact" (Leroi-Gourhan 1964, pp. 22, 26), comprising interacting sociotechnical systems.

As an analytical tool and conceptual framework, *chaîne opératoire* - the sequence of operations and bodily techniques to transform raw materials into objects - examines individual steps in technological processes and their links with sociocultural elements (Balfet 1991; Sellet 1993; Delage 2017, p. 159). Integral to the reconstruction of *chaînes opératoires,* 'practice' and 'agency' are often inseparable in archaeological dialogues that deal with questions of technology. Reconstructing *chaînes opératoires* sees human actions as the centre of technological sequences (see Leroi-Gourhan 1964, 1965, 1993). Unifying materials, tools, and actors within interconnected complex social practice of technology (Hughes 1986; Lemonnier 1986), *chaîne opératoire* directly links people to production, and the performance of production in a social context (Dobres 2000, pp. 154–156). 'Practice' as the enactment of techniques and technical gestures developed through learned craft practices, skills, and *habitus* is intrinsically human (see Bourdieu 1990; De La Fuente 2011) and organised through *chaînes opératoires.* Technological practice, therefore, presents outward materialisations of human beliefs, emotions, and experiences marking "prevailing worldviews, social values, and cultural attitudes about how to live in and act on the world. In turn, those beliefs and values both shaped and were reinforced through material and bodily routines of [artefact] manufacture and use" (Dobres 2010, p. 106).

Fundamentally, practice encompasses how environmental properties and human connections to materials comprise myriad experiences that are embodied, learnt, and communicated (e.g., McLuhan 1964; Gibson 1979; Reed 1996; Chemero 2003; Stoffregen 2003). Such experiences are reconciled through technological practices (Lemonnier 1986). Sensory experience, extending beyond visual and tangible qualities, reveals other dimensions of materials and their properties (e.g., Hurcombe 2007; Kuijpers 2013, 2019). Material engagement is therefore multimodal, and fields of sensory understanding (see Hamilakis 2013, 2021) act as mediators, points of control, and measures to guide and realise technological processes. In unison, that technological practices can have an affective quality (Hamilakis 2013; Massumi 2015; Harris 2016; Rizvi 2018) sees technology as a complex system that is "simultaneously adaptive and expressive" (Pfaffenberger 1992, p. 513). Hence, sensory experiences of, and engagement with materials, consolidate *craft practices* - the embodiment of learned skills, techniques, and tool use to manipulate material properties to initiate technological sequences. Sensory knowledge, in responding to changes in materials through crafting, therefore, helps guide the development of technique and skill. Approaching technology through understanding *cross-craft interaction* - the ways multiple crafts when studied together have technological and social impacts on each other via human interaction (Brysbaert 2011, p. 3) - enables studies of technology to illuminate the crossing of nodes in different material groups and their transformative processes. Studying individual *chaîne opératoires* is an often limited approach as they tend to be considered as a linear series of technical stages (Dobres 2010, pp. 108–110; Brysbaert 2011, p. 2). Doing so overlooks the interweaving of craft activities and the sharing of technological aspects within social practices (see Brysbaert 2007, 2014). Thus, human interactions between the places and spaces in which crafts are practiced allows for the exchange and sharing of knowledge, practices, tools, and techniques (see Brysbaert 2014). Practice, that centralises human agency and the interaction of humans and things (Dobres 2010, p. 106), brings attention to the dynamic nature of technological processes (Gardner 2021) and recognises that technical actions are rooted in human and social agency (Ribeiro 2021, p. 537). This requires borrowing and adopting craft knowledge from individuals, social groups, and technological spheres to formulate new and adaptive craft practices.

Accordingly, in reaction to essentialist principles in technology-related studies, the understanding of innovation has been revised to encompass sociotechnical concepts and practice-based approaches to technology. Tied to major European research programmes, innovation has recently experienced greater attention, re-evaluation, and disciplinary integration (e.g., Bernbeck and Burmeister 2017; Sluiter 2017, 2021; Versluys and Sluiter 2023). Critically, such approaches frame innovation as a process rather than a diffusionist or evolutionary model. Notably in the humanities, the "*Anchoring Innovation*" research agenda and cluster (funded by the Dutch National Research School in Classical Studies) has sought to reconsider how innovations become adopted within social groups (see Sluiter 2017; Versluys and Sluiter 2023). The concept of 'anchoring', or the "dynamic through which innovations are embedded and attached to what is perceived as older" (Sluiter 2017, p. 32) has accentuated how the social setting of new innovations are vital in their introduction and incorporation. This view emphasises how technological changes and introductions are socially embedded and creatively improvised practices (Versluys and Sluiter 2023, p. 28).

The conceptual basis of 'anchoring' is not necessarily a new concept within archaeology. Anchoring, however, accentuates concrete concepts as the stable basis for innovations to take root through activities, processes, and metaphors (Sluiter 2017, p. 32). Indeed, ontologies in modern, Western sociologies differ from those in the past and are shaped by contemporary capitalist models of growth (Bernbeck and Burmeister 2017, p. 9). The multitude of material conceptualisations, both tangible immaterial, are therefore, needed to be understood if an innovation is to be successfully integrated into a new social context. Hence, *acceptance* is key to the transferral and translation of objects, both in terms of assimilating newly acquired knowledge and the role of local knowledge in negotiation (Brysbaert 2020, p. 301). Innovations, therefore, are “[sociotechnical] practices that result from already existing practices” (Bernbeck and Burmeister 2017, p. 16) and not replacements for older technological systems. Thus, how innovations fit into both past and contemporary domains stems from how social groups connect the new to the familiar (Sluiter 2017, p. 23). Seeing new practices, objects, and techniques as embedded in such contexts become fully “anchored inventions” (Versluys and Sluiter 2023, p. 29). It is the importance of a local, social understanding in adopting and adapting objects, technologies, worldviews, processes, and practices (Brysbaert 2020, p. 301). Realising this sees technologies emerging as “clusters”, in that innovations are rarely one aspect in themselves, but rather a constituent part in a wider network of interacting sociocultural ideas and concepts (Brysbaert 2020, p. 302).

Evidentially, technology provides the conditions for social, cultural, and human transformations (Rizvi 2018, pp. 58–59); it is both a method to consolidate, and expression of, emotions, beliefs, and ideas. The resonation of sociocultural concepts through the practice of technology continues throughout societal changes “since system builders must draw on existing social and cultural resources” (Pfaffenberger 1992, p. 500). In realising archaeological information as the “surviving residues of things that people had lived amongst” (Barrett 2021, p. 138), material remains are given a meaningful role in interpreting cultural interactions within sociocultural contexts that underpin the emergence of technological innovations. In an absolute sense, archaeological remains should not be not explained and fitted to idealistic and hypothetical technical models through attempts “to impose some prior notion of order upon the world” (Barrett 2021, p. 138). The idea of ‘complexity’, often interwoven with ‘technology’ assumes levels of societal complexity required to instigate technological changes. Technological practices are, however, the accumulation of multiple interacting, changing, and modified sociotechnical systems (Dobres 2010, p. 105). This does not assume the superiority of a single material, technological grouping, or social context, providing instead detailed insights on the relationships between technology and society, and humans and materials.

Reconstructing technological innovation, therefore, requires a multifaceted methodology, interweaving multiple elements of sociotechnical systems. ‘Innovation’ is not rooted in rational revisions and notions of advancement nominally limited to material absolutes and discrete material groups (Ingold 2007, p. 3; Kuijpers 2013, p. 141). If technological innovations are principally the adoption of new practices, ‘things’, and their spread (Sluiter 2017, p. 21; Erb-

Satullo 2020, p. 38), human experience is, therefore, the mediator of technological practices through craft, technical skills, and multimodal sensory experiences. Seeing innovation as the social condition that allows practices to emerge develops a starting point from which to realise how technology influences human conditions. Through adapting and adopting bodies of technical knowledge, technological practices inform and influence one another (e.g., Brysbaert 2007, 2021; Fenn 2015). Hence, innovations emerge through changes to how materials are understood and manipulated. Frames of comprehension that borrow and adapt ideas from multiple *chaînes opératoires* and cultural interactions (see Brysbaert 2007, 2021) utilise mutual points of understanding by which to communicate such ideas (Sluiter 2017; Versluys and Sluiter 2023). In fostering a field of understanding that 'allows' the integration of innovations, existing crafts and communities of practice are integral to communicating and consolidating transformative material processes. Combining *chaîne opératoire,* cross-craft interaction, and agency approaches reveals dynamic overlapping social networks that adopt, adapt, or reject the production of goods, showing how the cultural dynamics of different social communities are embedded through daily activities (Brysbaert 2021, p. 199).

3.3 Technology and the 'Hellenistic East'

In viewing archaeological materials through the lens of 'Hellenisation' (see 1.2), Woodcock's "The Greeks in India" (1966) opened with a bold account extolling Greek influences in South-Central Asia, touching on technology, science and art: "…There were few parts of India into which the Greeks did not eventually penetrate… To India in general [the Greeks] gave their industrial techniques, their science of astronomy and the great school of Gandhara sculpture whose influence penetrated into the far corners of Asia." (Woodcock 1966, p. 13). Traditionally, archaeological evidence used to explore technology in South-Central Asia has been considered in terms of shared stylistic values connected to Greek cultural aspects, understood through the progression of particular cultural styles (Stoneman 2019, pp. 45–46; Maritan et al. 2020, p. 342)[32]. This perspective sees local elites imitating Greek models, interacting directly with Macedonian trading loci, or integrating technologies following Alexander's conquests and consolidation of the Greco-Bactrian and Indo-Greek states (Bernard 2011, pp. 81–83; Vranić 2019, pp. 145, 155). Hence, the notion that 'Hellenism' can be extracted from archaeological remains, following research trends in philology, historical geography, iconography, and historiography (Antonetti and Biagi 2017, p. vii), has been adopted to imply that technological

[32] Some examples: architecture and city layout (Colledge 1987; Mairs 2005), Greek inscriptions (Callieri 1995, p. 302), Hellenised and Graeco-Buddhist sculpture (Van Aerde 2018), Greek iconography on sculpture and 'toilet trays' (Callieri 1995, p. 304), coinage imprinted with Greek rulers (Haddad 2021, pp. 3316–3318), Hellenised terracotta figurines and those seen to depict Greeks (Filigenzi 2012, pp. 136–137), and Hellenistic stone seals and jewellery (Khan 1986, p. 184; Callieri 1995, p. 304).

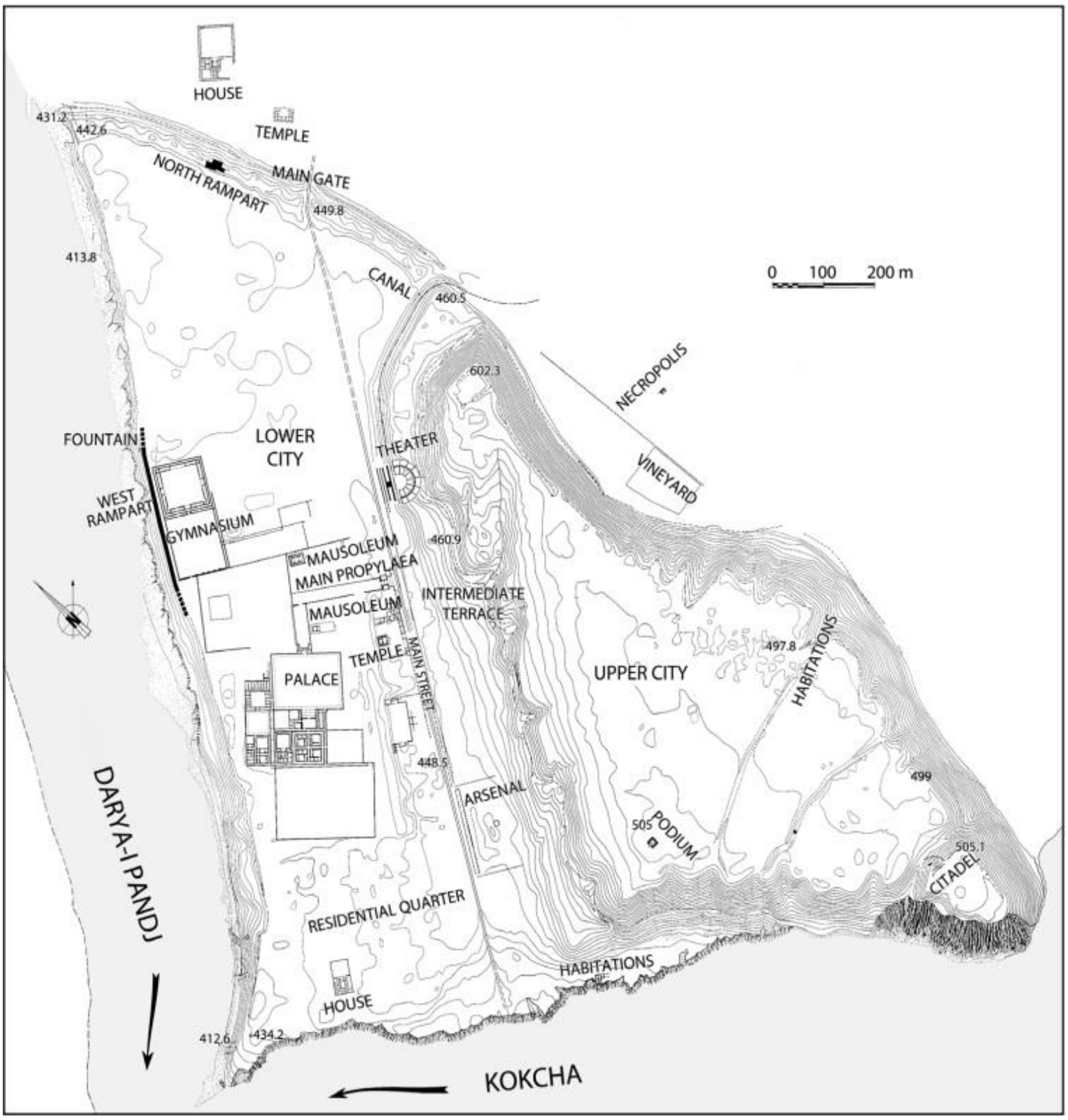
innovations, too, can be observed as specific 'Greek' cultural representations. Historically, such innovations are seen to have influenced society and culture through material introductions that display clear local Greek artistic and craft tradition (Mairs 2011, p. 14), driven by commercial structures linked to cultures west of the region (Callieri 1995, p. 293). However, using such evidence to discuss the transmission of technological ideas, practices, and techniques when represented purely by stylistic values is a one-dimensional interpretation. Unsurprisingly, even among challenges to such a monolithic narrative, the focus on style and form dominates in the consideration of technology, used to categorically mark ancient Greek influence in South-Central Asia (Callieri 1995, p. 239; Junker 2021, pp. 42–44).

Identifying change through archaeological materials in South-Central Asia is impacted by how material designations and typologies are applied across individual regions (see McNicoll and Ball 1996; Helms 1997, p. 68). Accordingly, Gandhāra and Bactria have acted as microcosms within which to explore the introduction of Greek innovations through identifying cultural influences underpinning technological introductions (e.g., Maritan et al. 2018, 2020; Pollard and Liu 2022). Yet the assumption that Greeks had a great stylistic influence on material culture (and therefore technology) (Dani 1966, p. 47) created a fragmentary, inadequate, and problematic body of evidence (Mairs 2014, p. 7). However, enduring chronological and geographical problems (Mairs 2011, p. 9) and a lack of definitive reference works (Stoneman 2019, p. 470) mean generalised statements on cultural groups, ethnicity, and identity have been frequently used (Mairs 2011, p. 8). Indeed, for a considerable period, Hellenistic materials were often viewed as a coherent and clear introduction in contrast to inconsistent Gandhāran 'Iron Age' (see Dittmann 1984, p. 159 for analysis). This was in part due to the study of the 'Gandhāran art style', which has been seen to incorporate prominent Hellenistic influences (e.g., Behrendt 2007; Pons 2019). Accordingly, reconsiderations of the connection between material culture and ethnicity have emphasised the dynamic nature of identity which cannot be seen as a representation in 'forms' (e.g., Mairs 2005, 2014; Wallace 2016; Lecuyot 2020; Richey-Lowe 2021; Wenghofer 2021). Binary cultural introductions, therefore, cannot be used to approach understandings of technological change in South-Central Asia.

Material representations of 'Hellenised' technological introductions, especially within major regional settlements, have shaped established ideas on sites and the activities undertaken at them. Excavations at the Greco-Bactrian royal settlement of Aï-Khanoum in modern Afghanistan between 1924-1979 declared the site as the first 'Greek' or 'Macedonian' (Colledge 1987, p. 140) city in the region (Mairs 2014, p. 1; Martinez-Sève 2014) (Figure 16a-b). Notably, it became a case study for developing a material reality of definitive 'Greekness' and Hellenisation at its easternmost extent (see Schlumberger and Bernard 1965) (Figure

16a). Founded in the 4th c. BCE by Seleucus I (Bernard 2011, pp. 86–87) and occupied until invasion by Saka tribes around 145 BCE (Ball et al. 2019, pp. 291–293), Holt's (1999, p. 41) description of 'Greco-Bactrian' Aï-Khanoum as cosmopolitan and "perhaps the most Hellenised place Klearchos [3rd c. BCE Greek philosopher] had seen since leaving the Mediterranean…" demonstrates how Aï-Khanoum marked the extent of Hellenisation for many scholars. In turn, connections to Greece and Hellenistic ideals in the city structured the study of Hellenism in the region (Ball et al. 2019, p. 291). Customarily, distributions of material culture with certain diagnostic attributes at Aï-Khanoum (i.e., Hellenistic features) has historically marked the regional influence of certain ethnic groups (Richey-Lowe 2021, p. 49).

Hellenistic features at Aï-Khanoum are multifaceted, encompassing a "…Macedonian palace, Rhodian porticoes, Coan funerary monuments, Athenian propylaea, Delian houses, Megarian bowls, Corinthian tiles, and Mediterranean amphorae." (Holt 1999, p. 44) (Figure 16a; 16b-i). However, only acknowledging the 'Greek' elements marginalises the multicultural environment of such an important regional settlement. Equally, the influences of a dynamic sociocultural setting upon the consolidation of technologies are equally overlooked. Instead, ascribing specific cultural styles is prioritised, representing 'features' as having a distinct cultural origin irrespective of mixed culturalisms. Local mud-brick flat-roof construction methods for the majority of the buildings (Ball et al. 2019, pp. 293–296) (Figure 16a-i), domestic architecture (Bernard 2011, pp. 91–92), and the "temple with indented niches" (Ball et al. 2019, pp. 302–303) particularly are noted as non-Hellenistic cultural styles. Rather, Hellenistic elements were introduced across the lifespan of Aï-Khanoum, such as the inclusion of Greek-style cult statues and added stepped *krepidoma* within the temple, displaying "the greatest degree of innovation" in architectural technology in the city (Bernard 2011, p. 92). The city then is deemed as a hybridised mix of 'Mesopotamian' / Iron Age Iran (Ball et al. 2019, p. 302), Achaemenid / 'Persian' (Bernard 2011, p. 93), and Greek architectural components (Colledge 1987, p. 144). Similarly, Aï-Khanoum's palatial and administrative complex cannot be standardised as 'Macedonian' in character (e.g., Holt 1999, p. 44), but incorporated Achaemenid neo-Babylonian layouts and local building materials alongside integrating Corinthian and Doric columns (Bernard 2011, pp. 88–89) (Figure 16a-ii). Further, quintessential Greek buildings, specifically the gymnasium and theatre, were integrated into pre-existing local structures and planning, adapted to the regional environment (Bernard 2011, p. 90). As a comparative example to 'spot' Greek elements at other sites in South-Central Asia, such as city layout and urban grid planning at Sirkap, Taxila (Colledge 1987, p. 150), Aï-Khanoum acted as a case to elaborate on the scale of adopted, or implemented, Hellenism across Bactria and neighbouring Gandhāra.




(i)


(ii)

Figure 16a. *Aï-Khanoum: Plan of the site (**above**; drawing by J. Liger and G. Lecuyot; in Martinez-Sève 2014) and architectural features **(below)**: **(i)** mudbrick house (Lecuyot 2020, fig. 25.2); **(ii)** Corinthian capital (Richey-Lowe 2021, fig. 2).*

(i)

(ii)

(iii)

Figure 16b. *Aï-Khanoum: Examples of material culture:* ***(i)*** *'Greek-style' amphorae (Schlumberger and Bernard 1965, fig. 27);* ***(ii)*** *bronze statue of Hercules from the "Temple of the Niches" (photograph by M. Prins; http://www.livius.org/pictures/afghanistan/ai-khanum);* ***(iii)*** *bronze coin of Diodotos II (c. 235-225 BCE) (photograph by the Classical Numismatic Group; https://www.cngcoins.com).*

The body of material culture from Aï-Khanoum has, therefore, been considered to represent modified and adopted technological processes at work in the city, but consistently viewed through artistic and stylistic principles (Figure 16b). Generalised statements have acknowledged the scale of technological systems at the site, such as alluding to metallurgical practices represented by the presence of casts for creating bronze statues and "Greek-style" metal vases (Colledge 1987, p. 145) (Figure 16b-ii). Cultural depiction then has been given most attention as a comparative model by which to explore the material constituents of ethno-cultural-identity at the site (Richey-Lowe 2021). Therefore, Aï-Khanoum, when predominantly seen as an 'art-centre' intimately connected to Hellenistic culture, has been presented as a locale that embraced elements of preceding Achaemenid traditions in creating a new artistic style which retained distinguishing Greek characteristics (Ball et al. 2019, p. 306). As promoted by scholars such as Tarn (1938), this perspective is connected to appraisals of artefacts as examples of 'Hellenised arts', due to the "force of a petrified tradition" (Filigenzi 2012, pp. 112–113) (see also 1.2). Form again is used to evaluate cultural identity as a process of assimilation, rather than a dynamic and adaptive process of acculturation. Hence, recent approaches to stylistic values of architecture at Aï-Khanoum have emphasised the limits of seeing cultural identities as expressed through material form, historically fixating on "our modern understanding of identities [as a] criterion of ethnicity" (Richey-Lowe 2021, p. 51).

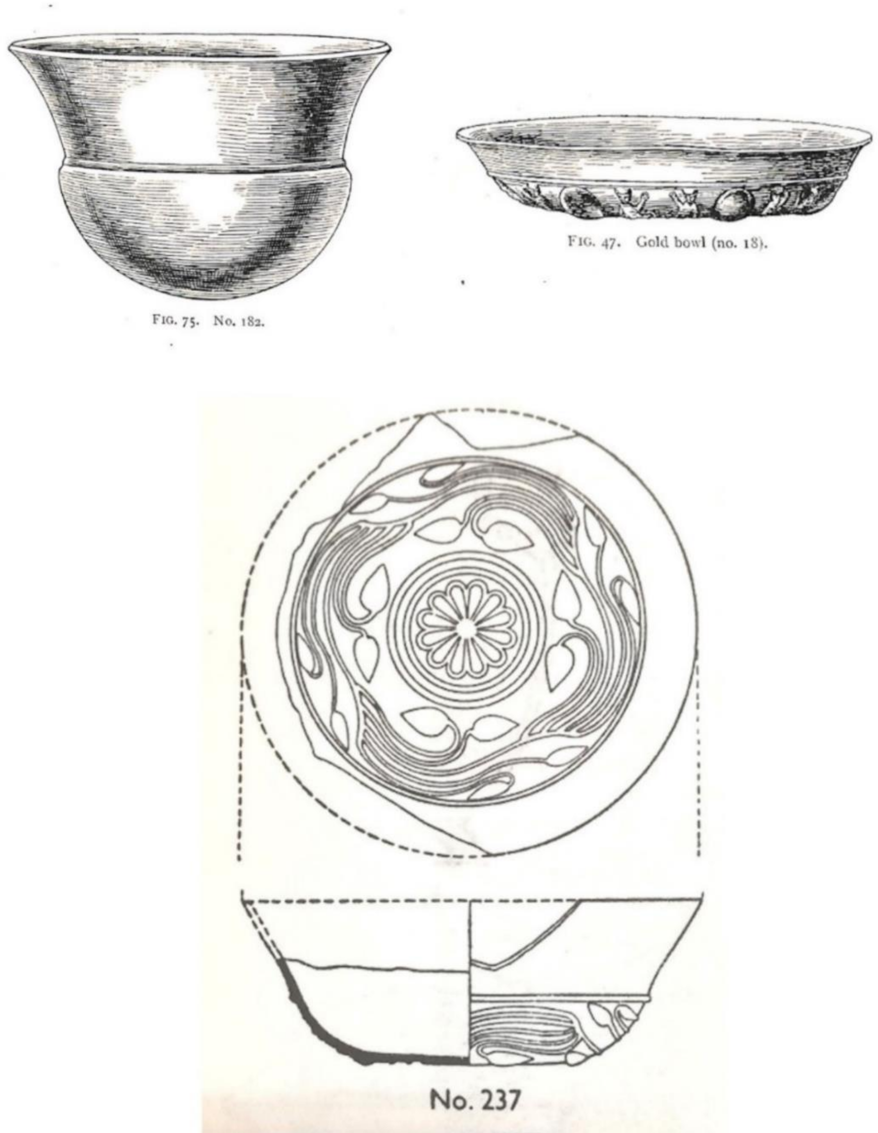
Exemplifying this trend, evidence used to illustrate the 'Hellenistic East' and its technological activities is dominated by numismatic studies and the craft of Gandhāran art. Broadly consolidated as a conduit of interpretation in the 18th and 19th centuries to understand "Eastern Hellenism", coinage and sculpture were deemed to denote the arrival of Greek craftsmen and traders into South-Central Asia, promoting "gradual Hellenisation" of local populations through material introductions (Dani 1966, p. 17), and depicting Greek rulers and elites (Minardi 2018, p. 131) (Figure 16b-iii). Thus, while distinct craft traditions are ascribed to both minting or striking coins and carving sculpture[33], the artistic emphasis imbued in sculpture and perceived centralisation of Greek economic structures symbolised by the circulation of certain coins set the tone for how technology was viewed as adjacent to the visual value of artefacts themselves. Equally, such a view overstates how Hellenistic coinage was viewed to have changed the 'eastern' economy (Holt 1999, pp. 33–35). Furthermore, contingent on what it privileged and when, how numismatic analysis is biased by the modern coin-collecting market is largely ignored, (Holt 1999, p. 107; e.g., Boperarchchi 2009). Equally, ambiguous terms such as 'Hellenised Orient', 'Hellenistic East' and 'Greco-Buddhist' used to label sculpture and 'Gandhāran art' categorically hold connotations of civilizing from a Hellenistic source (Filigenzi

[33] Thus, object forms are used to provide a connection to specific technological processes.

2012; Pons 2019). This is also true for how 'craft workshops' at Aï-Khanoum have been viewed as producing Greek prototypes and "locally produced imitations of Western objects" (Bernard 2011, pp. 101–102) (Figure 16b). Thus, the Hellenised state connected to the Indo-Greek and Greco-Bactrian kingdoms within South-Central Asia is seen as a dominant force of change through sculpture and numismatics, based on a direct ascription of cultural identities with a particular focus on stylistic values and forms of objects. 'Depiction' is, therefore a superficial representation of social, cultural, and political influences embedded in technological processes that lacks the nuance of understanding cultural interactions and preferences westernised *a priori* knowledge (Filigenzi 2012, p. 112). Hence, the processes and practices involved in technology, and the 'making' of material culture, continually are viewed through such a perspective on object form.

Aside from sculpture and numismatics, ceramics are undoubtedly the most abundant material group used to explore Hellenism through technological contexts (Figure 17; see Appendix 1 for notable examples from Gandhāran sites). In established approaches to pottery, 'Hellenistic' vessel introductions and emulations of luxury Hellenistic vessels in South-Central Asia are noted from 3rd-1st c. BCE (Olivieri 2018, p. 130; Junker 2021). Following 5th-3rd c. BCE Achaemenid (Iranian) introductions and contact with the Mediterranean from the 4th c. BCE (Maritan et al. 2020, p. 353), certain vessel shapes in South-Central Asia are considered to be found in the "ancient Greek ceramic repertoire" (Junker 2021, p. 44). Therefore, when used as archaeological markers for discerning the Hellenistic period and subsequent kingdoms in Bactria and Gandhāra, ceramic forms are employed to demonstrate the presence of Greek settlers (and particularly potters) across the Hellenistic world (Junker 2021, pp. 44–48). Such a line of thinking stems from the interpretation of Hellenistic pottery at Aï-Khanoum (e.g., Schlumberger and Bernard 1965; Bernard 2011, p. 102). With a focus on forms, styles, and shapes to suggest that "Greek settlers influenced and partly changed the Bactrian ceramic production" (Junker 2021, p. 44), the ceramic complex from Aï-Khanoum historically defined pottery production across South-Central Asia (see Schlumberger and Bernard 1965). This view reflects the emphasis placed on artistic ideals when studying material culture production as exhibited in the analysis of sculpture. Here, comparisons have been drawn between ceramic vessels from Gandhāra and both ceramic and metal Hellenistic vessels found across West and Central Asia (Figure 17a), despite many models lacking accurate provenances (e.g., Dalton 1926, pp. 82, 120). However, by adopting inferences from studies of ceramics at Aï-Khanoum as a framework for interpreting pottery production techniques (e.g., Marshall 1951; Wheeler 1962; Durrani et al. 1997), ceramic production in Bactria and Gandhāra is homogenised. Recognising the expression of Hellenistic tastes and influences in pottery through the appearance of new vessel forms continues the pervasive connection between vessel shapes, their uses, and perceived Greek antecedents.

Accordingly, traditional approaches to ceramics in South-Central Asia have seen pottery production as highly influenced by Mediterranean introductions, caused by the settlement of Greek immigrants (Junker 2021, pp. 42–44). The characteristic ‘fish-plate’ or ‘*plat-à-poisson*’ (created c. 5th c. BCE in Attica) is, for example, considered a key Hellenistic form realised across the Hellenistic territories (Rotroff 1997, p. 146; Bernard 2011, p. 102). Recognisable morphological differences in variations, both in Bactria (see Junker 2021 for analysis) and Gandhāra (see Iori 2018; Callieri 2020; Olivieri 2020b), are seen to suggest clear contrasts between Greek-Mediterranean examples and those from South-Central Asia (Figure 17b). Similar conclusions have been drawn from the identification of *krater*-like vessels at Aï-Khanoum, Barikot, and Bhir Mound (2nd c. BCE Indo-Greek and Saka-Parthian phases; see Appendix 1). Connected to a common Hellenistic form (e.g., Rotroff 1997, p. 139), such vessels are considered to have utilised differing morphological and finishing variations (e.g., Iori 2018, p. 77). Equally, Archaic, Classical, and Hellenistic ceramic ‘pot stands’ or *lásana* (λάσανα) (Morris 1981, p. 401) have been noted as emulated in Saka-Parthian to Early Kushan phases at Barikot, but stem from a Hellenistic origin (Iori 2018; Olivieri 2018, pp. 133–134) (Figure 19d). In the case of other recorded *lásana*-like examples across Gandhāra, such an attribution is not agreed upon so universally in comparison to fish plates and *kraters* (see Husain 1980; Petrie et al. 2008; Nasim Khan 2010a). Such examples illustrate how embedded references to Hellenistic nexuses are in evaluating ceramic technology, yet recent evaluations have noted the limits of such approaches. ‘Fish-plates’ from Bactria and Gandhāra, for instance, lack direct parallels with a consistent ‘Hellenistic’ forms (Junker 2021, p. 57). Furthermore, ceramic production techniques utilised in supposedly ‘Hellenistic’ forms were unique to certain areas, such as at Barikot in Gandhāra (Callieri 2020; Maritan et al. 2020, p. 351; Olivieri 2020b). Therefore, neither single ceramic repertoires, such as Aï-Khanoum, nor the spread of Hellenistic forms did not define regional pottery production. Indeed, local pottery production, such as at Barikot, adopted and integrated new introductions to match their local pottery techniques and traditions (Olivieri 2020b, pp. 395–396). Individual sites, therefore, were tied to broader trading networks in the region, with individual groups interested in vessel shapes that suited their needs (Junker 2021, p. 59).



(a)

(b)  **(c)** 

Figure 17. *'Hellenistic ceramics' in South-Central Asia:* ***(a)*** *Hellenistic moulded ware bowl from Bhir Mound, Taxila (No. 237; approx. 2nd c. BCE) (Marshall 1951, p. 434) seen as similar 2nd c. BCE – 2nd c. CE gold and silver bowls from "the Oxus" (Dalton 1926, pp. 82, 120);* ***(b)*** *'fishplate' from Kampyr Tepe (3rd c. BCE) (after Junker 2021, fig. 1);* ***(c)*** *Black Gloss Ware (BGW) from Barikot (c. 2nd c. BCE)* (after Maritan et al. 2020, fig. 2)

More recent studies of ceramics have approached technology on multiple scales (moving away from only object form) to address detail of production processes and technical choices (e.g., Iori 2018; Maritan et al. 2018, 2020; Olivieri 2018). Within early excavations of Gandhāran sites (see Appendix 1), Hellenistic embossed wares from Bhir Mound, Taxila dated to the Indo-Greek phases of the site (Pottery Group C) (Figure 17a), were noted as "Hellenistic in character" (Marshall 1951, p. 434) and produced through moulding techniques. While rooted in form and artistic style, recognising the use of an explicit method creates opportunities to understand the stages at which 'Hellenistic' influences became integrated within production sequences, such as replication moulding. Such a realisation dismisses a binary view on technological change as a product of Hellenisation. Equally, petrographic studies have further introduced unique insights on technical choices involved in pottery production, elaborating on material characteristics of wares (Maritan et al. 2018, 2020; Olivieri 2020b, pp. 363–382). Analysis of 2nd c. BCE to late 2nd c. CE black gloss ware (BGW), also known as black metallic ware (BMW), its fabric paste, and slip, from the Swat Valley in Gandhāra has been interpreted as sharing similarities with Attic black glaze pottery and local northern black polished ware (NBPW) (Maritan et al. 2020, p. 353) (Figure 17c). Following petrographic analysis, BGW was noted to cross Indo-Greek, Saka, and Kushan phases, leading the conclusion that technological change could be the result of either "progressive loss of technology … [or a] local attempt to reproduce a luxury ware with local availability of raw resources and firing technologies" (Maritan et al. 2020, p. 354). Consequently, the idea that the ware could share similarities with black glazed Attic pottery and local NBPW is still tied to understanding 'Hellenisation'. Such inferences can become problematic through questioning the ethnic identity of the crafters involved in the production of pottery and participants in the technological practices (Van Aerde 2018). This association may revert to determining if said people are itinerant Greek crafters or immigrants from Greek areas (Callieri 1995, p. 306) and the relationship that they have with the production process. Hence, the interpretation of Hellenistic ceramic production in South-Central Asia with influences from Mediterranean technological traditions cannot be grounded in an assumption of explicit 'Greek vessels' but also techniques (Junker 2021, p. 44).

With the introduction of new vessel forms, an accompanying integration of new food and drink habits are also seen to have emerged. In the 'Hellenistic East', vessel forms have been related to changes in wine consumption. The diffusion of Greek wine practices involving *kraters,* a Dionysiac cult, and iconographic depictions of wine consumption in Gandhāra are seen as representing Hellenised winemaking and drinking cultures (Figure 18) (e.g. Brancaccio and Liu 2009; Stančo 2012; Zysk 2021). Across South-Central Asia, such a practice is deemed to have influenced later Buddhist forms of wine production (Falk 2009; Zysk 2021, p. 67). Here, a connection has been drawn between cities with Hellenistic traditions and Dionysian festivals, where successors of Alexander through the Indo-Greek and Greco-Bactrian kingdoms promoted viniculture (production of grapes for wine) (Brancaccio and Liu 2009, pp. 223–224). Despite being extrapolated from only iconographic depictions (e.g., Figure 18a-b), connections with winemaking continued "… when the Kushan kings took control of Gandhara and Buddhism emerged there … viniculture and Dionysian traditions were still present in the region, as shown by images linked to the cult of the god Dionysus that were frequently incorporated into Buddhist sculpture" (Brancaccio and Liu 2009, p. 227). Thus, a form of Hellenised wine production in South-Central Asia is considered to have persisted.

Hellenistic wine drinking customs are seen to have bolstered pre-existing traditions in Gandhāra (Olivieri 2018, p. 133), represented by the prevalence of 'tulip bowl' drinking vessels (Figure 18c) that are considered an Achaemenid derivation (Petrie et al. 2008; Iori 2018, p. x). Achaemenid drinking customs that involved ceremonial wine decanters or *rhyta* since the 5th c. BCE (Petrie et al. 2008, p. 9) have also been noted as part of the Gandhāran wine culture (Figure 18d). Here, the aforementioned *lásana* 'pot stands' or "kitchen stands" (Olivieri 2018, pp. 133–134) have been interpreted in some accounts as Indo-Greek, Indo-Scythian, Scytho-Parthian, and Kushan clay *rhyta* (Nasim Khan 2007, p. 105, 2010a, p. 203; Petrie et al. 2008, p. 10). In tandem with Indo-Greek "wine jars" (Figure 18e), *kraters* of Hellenistic tradition (Figure 18f), and references to drinking customs (see Iori 2018, p. 123), the body of historical information is seen to represent a continuation of wine customs, modified by distinctly Greek introductions. In contrast, evidence for production is limited aside form fragmentary botanical evidence for grapes and vines (see Spengler et al. 2020) and few identified rock-cut wine presses in rural locations dated to the early centuries of the 1st mill. CE (see Olivieri et al. 2006). Hence, wine is firmly limited to the context of consumption, overlooking the complete winemaking process. Material culture, therefore, is seen as a representation of a full technological process, mostly by the presence of drinking vessels. Hence, seeing wine production as a complete process within Hellenistic South-Central Asia is currently lacking, represented only by isolated object forms.

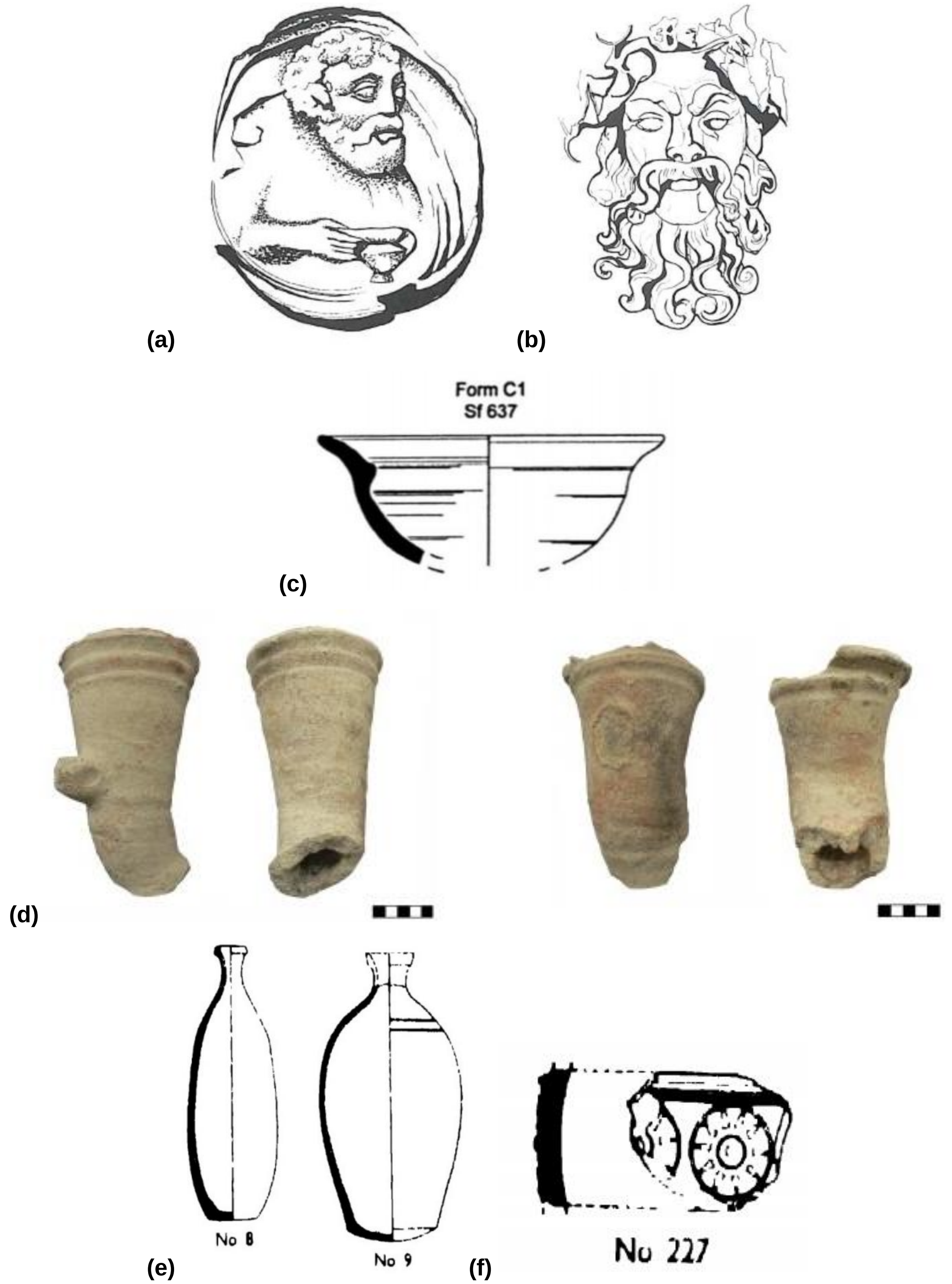


***Figure 18**. Examples of artefacts related to wine in Gandhāra: **(a)** Silver plaque of Dionysus (3rd – 2nd c. BCE) from Sirkap, (Marshall 1960, pl. 1; from Stančo 2012, p. 97); **(b)** bronze mask of Silenus (1st c. CE) from Begram (from Stančo 2012, p. 105); **(c)** Achaemenid 'tulip bowls' (c. 5th c. BCE) from the Bala Hisar, Charsada (Coningham and Ali 2007, p. 124); **(d)** clay 'rhyta' of 'kitchen stands' from Aziz Dheri (Petrie et al. 2008, p. 10; photos by M. Nasim Khan); **(e)** Indo-Greek oil or wine jars from Bhir Mound (Marshall 1951, pl. 121); **(f)** fragment of a krater from Bhir Mound (Marshall 1951, pl. 128). See original publications for scales.*

Simple paradigms of ‘Hellenism’ directly influencing the production of material culture is often overstated when viewed through diffusion-adoption and colonisation models (see Papadopoulos 2014). Historically, the concept of ‘Hellenised’ technology does not come from a direct ascription of technological processes as Greek, but rather from an accumulation of artefacts and architectural features idealised as quintessentially Hellenistic. Such approaches have ignored existing customs connected to the Mesopotamian-rooted Babylonian and Neo-Babylonian Empires, the Achaemenid Empire, and wider indigenous populations, instead reverting to static ideas of identity and concepts of orientalising (Yoffee 2005, p. 155). Recent studies have emphasised how cultural, political, and economic influences from a ‘Hellenistic’ source were fluid processes of adoption and response in Central Asia; disruptions were brief and social groups gradually assimilated cultural introductions as new expressions of identity (e.g., Wallace 2016; Iliakis 2018). In attempting to create large-scale reconstructions of ‘Hellenised’ cities from severely limited information (Olivieri 2020a, p. 392), frequent changes to Hellenistic Kingdoms, short-term developments, and specific border changes are unlikely to be viewed through marked changes within material culture groups (Lund 2014, pp. 297–298). Moreover, responses to wider societal changes are progressively, rather than immediately, revealed in processes of innovation (see 3.2). Accounting for local agency has demonstrated a more dynamic view of how the region responded to changing systems, military campaigns, and political administrations (e.g., Iliakis 2018, pp. 43–44). Therefore, different domains in ‘the Hellenistic East’, and the ways that people preserved senses of identity, social cohesion, and cultural belonging, were involved in a constant process of change and interaction (Sluiter 2017, p. 36).

Practice-based views of technology, that could offer detailed insights into such processes of change in Gandhāra, are still somewhat underdeveloped. Studies of material culture is predominantly approached through concepts of form (e.g., ceramics and wine production) and a focus on depiction and artistic styles (e.g., architecture, sculpture, and numismatics). Stylistic values of material culture and architecture, while a preferred approach in Gandhāran art studies and precise chronological approaches within art history (e.g., Behrendt 2007; Brancaccio and Liu 2009; Pons 2019), marginalises the multifaceted dimensions of materials and technology (see 3.2). Revitalised views of innovation, that recognise it as a process contingent on making connections with existing conditions, present opportunities to explore how crafting may have changed in response to new sociocultural encounters. Understanding this association distances narratives on Gandhāra from dichotomous views on cultural change.

3.4 Proto-scientific and material concepts in Hellenistic technologies

Historically, the spread of technological innovations from ancient Greece, seen as 'Classical' in their philosophical, astronomical, literary, mathematic, medical, and scientific roots (e.g., Loyson 2009, p. 1195), are deemed to represent a form of 'proto-science' and dispersal of the first conceptualisation of modern empirical knowledge. While a product of colonialist ideas on Hellenisation, the implication that Hellenistic centres of knowledge in Athens and Alexandria were focal points of scientific and technological diffusion is imbued with concepts of hierarchical civilization. Hence, such a flow of new ideas equally implies the dispersal of new technological, material, and scientific knowledge. Thus, the dissemination of proto-scientific Greek philosophy from the 3rd c. BCE is considered a significant achievement of the Hellenistic. This has been vital for defining major economic, sociocultural, technological and scientific changes (e.g., Yfantis 2019, p. 386) as the "…"authentic scientific investigation and revolution" of the Hellenistic age" (Haddad 2021, p. 3325). Correspondingly, such ideas feature in dialogues on how South-Central Asia became 'Hellenised' (e.g., Banerjee 1919; Woodcock 1966). The stance that specific technological innovations can have their roots traced to a proto-scientific conceptualisation of materials, with specific cultural connotations, historically has implicit connections with ancient Greece and Alexandrian philosophical knowledge (e.g., Loyson 2009). Grounded in recorded philosophical principles of science that endured as the prime understanding of the world within medieval alchemy until the 17th c. CE (e.g., Browne 1948; Holmyard 1957; Moorhouse et al. 1972; Ihde 1984, p. 25; Moran 2005), this exemplifies how complex technological practices were traditionally seen to have stemmed from a Hellenistic source of material understanding.

To conclusively deem proto-scientific ideas on material composition and their perceived properties as 'rational' (by modern scientific standards) is to ignore their abstract foundations and metaphorical comparisons by which to explain natural phenomena. Such understandings became the basis of elucidating chemical and physical transformative processes, but also the means to manipulate certain material properties. The opinion that observations by the 'Alexandrian Chemists'[34] discovered early forms of chemical practices and processes is prevalent (Sherwood Taylor 1952; Forbes 1970, p. 6). Here, explorations are distinctly allied to experimentation concerning the nature of changing matter by Greek philosophers and scholars of Byzantium, in Islam, and Europe (Sherwood Taylor 1952, p. 15). The Pythagorean doctrine of "four realms" (6th - 5th c. BCE), explanations of material composition such as Empedocles' "four elements" (5th c. BCE) - earth, water (liquid), fire, and air (odour or *pneuma*) - and their adoption by Aristotle and Plato (Wilson 2006, p. 28) were understandings of natural

[34] Circa 1st mill. BCE - early centuries of the 1st mill. CE.

processes that transcended absolutes of the material world. Other material properties, therefore, were seen to exist and able to be perceived, aside from physical and chemical ones, utilising metaphorical comparisons to explain environments and material worlds (Craddock 2016, pp. 199; 203–205). While such an understanding was decidedly abstract, the notion that the fundamental theoretical ideas guiding the creation of modern scientific knowledge had their roots in Ancient Greek metaphysics has perpetuated a connection between historical origins and modern concepts.

The position of intangible properties of materials largely indicated that 'things' in the universe including materials had a purest form (an essence), and that this property can be transformed, extracted, and captured (see Sherwood Taylor 1952; Holmyard 1957; Moran 2005). At the heart of Aristotle's *Natural Philosophy* is the idea that the physical consisted of a matter (e.g. iron, rust, bronze, sulphur) that assumes a 'form' carried through chemical and biological processes, controlled by the spirit or 'breath' - the *pneuma* (Sherwood Taylor 1952, pp. 16–17). The *pneuma* could be transformed (Sherwood Taylor 1952, p. 20), thus, the difference between gross matter (with tangibility) and matter for spiritual beings (such as smoke, vapour, air ether) was a key separation with the spirit being connected to heavenly bodies, seasons, and planetary hours (Sherwood Taylor 1952, p. 23). Therefore, specific atmospheric events provided the setting for transforming matter. Aristotle's elements of the terrestrial world had two separate 'exhalations' that can rise through the earth and can condense to form metals and minerals (Sherwood Taylor 1952, p. 20). Exhalations primarily composed of different amounts of sulphur (smoky earth) and mercury (watery vapour) (Moran 2005, pp. 25–26), caused by the sun's rays on ground to produce a dry exhalation as the basis for certain matters (Craddock 2016, p. 202). By exchanging one or both qualities, elements themselves could be changed into one another by what was seen by later alchemists as elemental transmutation and core to every process in the world; water (cold and wet) could under the correct circumstances become 'air' (hot and wet) (Moran 2005, p. 26).

Through the addition of nonmaterial, mystic, and intangible components as constituents of matter, a spectrum of material understanding with several shared themes was embellished by succeeding Greek philosophers (Craddock 2016, p. 197). Thus, the notion that materials were evolving and dynamic, and composed of different properties depending on their developmental stage, was an underlying concept in antiquity, established through personal experiences and observations (Craddock 2016, pp. 205, 218). Intangible qualities, sensory explanation, and unified concepts underpinning material knowledge provided a justification for how technological processes could manipulate materials, but equally acted as a metaphorical explanation of the natural world. Consequently, these perspectives represent a collection of embodied understandings of materials formulated through acquired experiences, accumulated interacting concepts, and sensory knowledge. The centrality this has in developing craft practices and understanding ‘anchored’ concepts for the adoption of innovations is key (see 3.2).

Previously, understandings of material and matter have been separated into the technical-factual and philosophical-theoretical (Ihde 1984, p. 3), possessed by the scientist and craftsperson as separate entities (Finley 1965, p. 32; White 1984, p. 12). The differentiation between how the ancient Greek sensorium was seen to govern the work of philosophers and the reality of understanding how materials performed by experienced craft practitioners (see Moorhouse et al. 1972, p. 80; Craddock 2016) is limiting. Further, the role of sensory experience in how material knowledge is developed (especially in tandem with the development of technologies) is symptomatic of how the Classics has treated the senses, primarily as elucidated through textual information (see Butler and Purves 2013). Therefore, whenever a connection is seen to be made with the Mediterranean world, science and technology are viewed in a reductive light, overlooking the reality that different values of technical knowledge were possessed by different people (Sherratt 2008, p. 210).

Connecting ideas from proto-scientific thought with specific innovations to identify the origins of technologies is a problematic association, considering the broad contexts of practices. Equally, this association is irrespective of the fact that textual references rarely comprehensively match an archaeological ‘reality’ (Erb-Satullo et al. 2020, pp. 413–414). Proto-scientific explanations of material composition do, conversely, demonstrate how material properties are understood through multimodal and multidimensional interactions. Equally, this represents the metaphorical expression of material properties at the heart of human-material relationships. The separation of technology as an active process from material culture as a series of static artefacts excludes how differing conceptual understandings of materials and their properties contribute to formulating new technological ideas. As a result, reconstructions of technology, and the means of affording material transformation through technological processes, cannot be explained through supposed proto-scientific rationalisations. Archaeological materials, particularly those tied to the ‘Hellenistic World’, cannot be reassembled to match hypothetical models of proto-science, and justify the diffusion of ‘scientific’ innovations from the geographic, societal, and cultural origins of certain ideas.

3.5 Early distillation technology, Hellenisation, and Gandhāra

The interpretation of archaeological artefacts indicative of early distillation in Gandhāra, traditionally cited as a technology with origins in ancient Greece and its own characteristic 'Hellenistic alembic still'. has been associated with specific cultural roots. Notably, the 'Gandhāra tradition of distillation and apparatus' has been identified as a series of ceramic vessels within previously ascribed Indo-Greek contexts (e.g., Marshall 1951; Allchin 1979b, 1979a; Husain 1980). As a technological introduction or innovation, the apparatus' development has been charted through an essentialist framing of materials and technology, centred on evaluating the origins of the reconstructed 'still' and its connections to explicit cultural ascriptions. This is compounded by the diverse cultural makeup of Gandhāra and how it has been researched. Tied to the complexities of understanding the influences of Hellenisation and the 'Greekness' of the Indo-Greeks (see Mairs 2014, 2020), the dialogue connects to wider concerns regarding the cultural histories of technology and science (see Rocha 2016; Kuijpers 2019).

The debate on whether distillation practices were conducted in South-Central Asia from an early date crosses archaeological and historical studies (see McHugh 2021). In literary works on alcohol in pre-modern South Asia, Sanskrit texts have been translated and interpreted as both explicitly and metaphorically referring to distilled beverages in the region (e.g. Oort 2002). This claim is, however, disputed by McHugh (see 2014, 2020, 2021) who maintains that the most secure description of distillation in a Sanskrit text dates to approximately 1200 CE, especially considering the ambiguity in translated terms (McHugh 2020, pp. 42–43). Therefore, the established discussion on archaeological evidence for early distillation in the region has been used in tandem to support the idea that distillation was practised before 13th c. CE, but acts as an interpretation developed independently of the literary study (McHugh 2020, p. 43).

John Marshall's (1951, 1960) excavations at Sirkap, Taxila first uncovered 'water-condensers' dating to the 1st c. BCE (Marshall 1951, pp. 420–421) as a component of a complete distillation apparatus or 'still'. Amalananda Ghosh's interpretation (1948) agreed with such a characterisation, and crucially supported an ascription of them as Indo-Greek or Indo-Scythian vessels (Ghosh 1948, p. 64; Marshall 1951, p. 420). Marshall corroborated his water-condenser with several vessels from vastly different strata and areas of Sirkap to demonstrate an explicit purpose for his supposed 'water-condenser' and assemble a full apparatus (McHugh 2020, p. 45). Thus, the complete 'still' was not uncovered in situ or as articulated components. Despite this, the water-condenser was further identified by Ahmad Hasan Dani during excavations at Shaikhān Dherī (Dani 1966), who labelled it as a 'Greek' vessel dating to the 2nd c. BCE (Dani 1966, p. 145). The characterisation here, while not explicitly referring to a definite Greek origin of the apparatus or developed as a product of Hellenisation, set in motion a discussion on the cultural roots of distillation in the region despite the weak interpretation to begin with.

Raymond Allchin equally supported Indo-Pakistan as a plausible nexus for distillation practices in his articles "India - the Ancient Home of Distillation" (Allchin 1979a) and "Evidence of Early Distillation at Shaikhān Dherī" (Allchin 1979b). In expanding the idea, Allchin enthusiastically championed Marshall's original interpretation (Marshall 1951, pp. 420–421). Within the studies, Allchin suggested that alcohol distillation was invented within Gandhāra, and not a product of external introductions to the region (Allchin 1979b, 1979a). His papers primarily synthesised previous evidence from Shaikhān Dherī (e.g., Dani 1966) in line with that of Taxila, and utilised data from excavations at supposed Indo-Greek and later sites across 'Ancient India' (Allchin 1979b). Claiming to have found over a hundred 'condensers' at the site, Allchin aimed to challenge the established idea that the process of distillation was understood by no one earlier than the "Greeks of Alexandria" (Allchin 1979a, p. 55). Instead, within a combined ethnographic-textual-archaeological study, he contested the idea that early distillation practices could not undertake alcohol distillation (Allchin 1979a, p. 56) and suggested a subcontinent-wide distribution of characteristic distillation apparatus forms instead of being a localised series of vessels (see Allchin 1979a, p. 61).

Indo-Pakistani science historian Syed Mahdihassan also agreed with Marshall's and Allchin's interpretations of the still (see Mahdihassan 1972, 1979), and expanded the periodisation of the morphological range of condensers to 4th c. BCE – 5th c. CE, further embellishing the stated indigenous origin for distillation. This was to the extent of noting several vessel typologies as possible components in the apparatus and a 'vertical' distillation apparatus unique to the Indo-Pakistan region that predated ancient Greek innovations (Mahdihassan 1972, 1979). Though Allchin's discussion recognised the limitations of the Taxila apparatus interpretation, the theory that alcohol distillation could have been conceptualised in "Ancient India" was promoted throughout, reclassifying the water-condensers as 'receiver-condensers' as specialised vessels to collect and store the distilled alcohol (Allchin 1979a, pp. 56–57). Allchin claimed that several stamped non-condenser pots at Shaikhān Dherī likely contained alcohol considering both the existence of the practice of stamping vessels in India and Afghanistan in the Later Kushan period, and the widespread identification of stamped Hellenisitc vessels (Allchin 1979b, pp. 161, 166). However, Allchin ended his description of the 'condensers' at Shaikhān Dherī by stating that he could add little to Marshall's view on the function of the condenser, except that they were used for liquid collection and were specialised for this purpose (Allchin 1979b, p. 773). Husain's 1980 thesis on the pottery of Shaikhān Dherī and subsequent thematic publications (Husain 1992a, 1993, 1995) bolstered a supposed range and longevity of distillation apparatus, aiming to demonstrate how established alcohol distillation as a technological practice was in South-Central Asia.

Identifying a direct connection between early distillation and cultural processes such as Hellenisation is, therefore, contentious, but not without its proponents. The existence of the still has been used to support the idea that the distillation of wine was occurring in 'Hellenised cities' in Gandhāra. Hence, distillation in South-Central Asia has been suggested as Hellenistic in origin (e.g. Greek and Indo-Greek), and subsequently widely adopted, modified, and administered through to the Kushan period as a Dionysian ceremonial practice (Brancaccio and Liu 2009, pp. 225–227). Considering then that wine production has been deemed symbolic of "a civilized people"[35] (Donahue 2016, pp. 605–606), connecting wine distillation to 'Hellenisation' compounds the view that distillation technology came from a culturally sophisticated source. This is at odds with the idea that the distillation of wine was a local innovation in Gandhāra, thus producing two polarising beliefs, but considered a key Gandhāra technological development in both accounts. Hellenistic connotations continued to feature even among those such as Allchin (1979b, 1979a), despite attempts to distance themselves from such cultural ascriptions. Most notable is how the interpretation of 'receiver-condenser' utilised morphological characteristics from the existing interpretation of the Hellenistic alembic still (see 2.3) as a comparison to justify a purpose as a distillation apparatus component (see McHugh 2020).

Consequently, a view that the Gandhāra still emerged independently in South-Central Asia within a 'mixed-Eurasian' environment has been presented, involving both Hellenistic (Western) and Chinese (Eastern) cultural influences in its evolution (Park 2021, p. 27). Moreover, such a view is supported by the body of evidence for early alcohol distillation in China from at least the 4th-5th c. CE that maintained cultural contacts with Gandhāra (e.g., Gwei-Djen et al. 1972; Needham et al. 1980; Youpeng 1989). Hence, the reconstructed configuration spawned from such a body of archaeological information became known as the "Gandhāra distillation tradition and still" in the wider historiography of science (e.g., Mahdihassan 1972, 1979; Needham et al. 1980; Park 2021), cited continually in secondary literature (Manglik and Jog 2009, pp. 1210011-6–7; Alam 2020, pp. 26–27; Olivieri 2022, p. 18). For many scholars, the Gandhāra still had become a key prototype for later medieval distillation apparatus examples but regardless stemmed from a questionable interpretation of

[35] Particularly, early 'Greek' colonists.

archaeological materials. McHugh summarised this sentiment, and noted how deeply entrenched the interpretation of the Gandhāra still had become: "…this epistemological momentum, shared among quite a diverse group of people will override any arguments I or others make *against* the idea, perhaps indefinitely" (McHugh 2020, p. 59).

3.6 Summary

It has long been understood that analysis of previous research in South-Central Asia must be integrated into broader work on the Hellenistic world rather than being considered as an isolated study (Mairs 2011, p. 8). Recent studies that have explored the dynamics of Gandhāra and Bactria have tended to move away from such a limited format; indeed, post-colonialist critiques of Hellenism have challenged simplistic diffusionist dialogues on cultural change in the region. Yet entrenched ideas of technological features, such as the view of a Gandhāra distillation apparatus, remain pervasive. Technological innovation sits at the centre of this concern, mostly reflecting contemporary views, and through an enduring tradition of seeing Greek technology as sophisticated and underpinned by intellectual thought. Such a rationalisation ties modern science and engineering practices to explicitly 'Greek' cultural impetuses. As such, artistic techniques (represented by stylistic values) are seen to equate to technological and technical choices. Thus, the combination of accenting high art, emboldened scientific prowess, and a constant return to debating technological diffusions as representative of cultural sophistication sets the tone for how archaeological evidence is viewed.

This view is diametrically opposed to how the idea of technology and innovation should be seen as complete sociotechnical processes used to transform both the social and material world. Such a view of technology is not rooted in correct, incorrect, or "social-coordination methods" of labour and ways of 'doing' (Pfaffenberger 1992, pp. 498–499), instead reframing how artefacts and technology indicate the cross-pollination of practices and material knowledge. Therefore, the idea of innovation needs to be discussed in the context of how a technological practice arises, is honed, and modified and not simply formulated from projecting modern interpretations onto archaeological materials. Thus, beyond treating the study of Gandhāra as an isolated subject based on cultural dichotomies and linear narratives, instead technology can be used as a context to explore the nature of change and not as a proxy representative of ethnic identities. The inclusive and polycentric nature of innovation goes against that typical notion that innovation is a "rational and predictable achievement leading to economic growth" (Versluys and Sluiter 2023, p. 39). Human factors and contexts of application are, therefore, needed to be considered. This provides a view of material knowledge that lends itself to a holistic idea of technological and craft practices; a human-centric concern that goes beyond the rigid assumptions of sophistication in art and science.

The following chapters will, therefore, be dedicated to analysing and evaluating the material evidence used to support the characterisation of the 'Gandhāra distillation tradition' (see 2.5). Through a detailed material survey (Chapter 4), reported instances of the Gandhāra apparatus will be critically assessed alongside evaluating identified distribution patterns of apparatus components across South-Central Asia. Chapters 5 and 6 will then evaluate the Gandhāra tradition through targeted experimental studies in response to issues identified through the material survey related to the practice of distillation. While meaningful ethnographic surveys and organic residue studies (as both experimental comparisons and targeted archaeological studies) were originally planned to help contextualise insights, these were abandoned due to implications from the COVID-19 pandemic (2020-2022). Instead, survey data and experimental results were used to generate new interpretations on both early distillation technology and the archaeological examples used to reconstruct the 'Gandhāra apparatus' through a practice-based approach to technological reconstruction.

Chapter Four

Material Survey

4.1 Introduction

Archaeological work throughout the 20th century instigated several major changes in charting early distillation practices with new lines of inquiry diverging from the established Western-centric narrative on distillation (see Chapter 2). The role of complementary bodies of evidence, in tandem with archaeological materials, was centralised. In one case, ceramic vessels from "Ancient India" were presented as the earliest conclusive evidence for a form of distillation practice (see Ghosh 1948; Marshall 1951; Mahdihassan 1972, 1979; Allchin 1979a, 1979b). Thus, South-Central Asia, and particularly Gandhāra, has been placed as a 'home' of an ancient distillation practice with an associated specific apparatus form (the 'Gandhāra tradition') (e.g., Ray 1956, p. 80; Brancaccio and Liu 2009; Manglik and Jog 2009; Vasani 2012; Klimburg 2016; Alam 2020, pp. 26–27; Spengler et al. 2020, p. 11; Park 2021). Such a theory was generated from reconstructed archaeological materials published during the flurry of excavations in post-independence Pakistan and India (e.g., Marshall 1951; Mahdihassan 1972; Allchin 1979a).

However, despite presenting a promising interpretive turn in how early distillation had been viewed, there has been limited critical consideration of the Gandhāra tradition and apparatus (see 3.5). Aside from noting issues in stratigraphic relationships between items of apparatuses, McHugh's critique (2014, pp. 32–33, 2020) largely focussed on how later translations of Sanskrit texts had been used to support a connection between morphologies of certain vessels and their role in distillation apparatus configurations (e.g., 2014, p. 41). Hence, while issues in the representation and stratigraphic relationships between elements of the apparatus in its original identification were highlighted (McHugh 2014, 2020), the widespread characterisation of apparatus, its distribution, and perpetuated relationships to archaeological contexts have not been addressed systematically. In addition, the prolonged legacy of the interpretation and wide reporting of the typology equally have received little consideration or been fully demonstrated. Thus, due to a distinct lack of critical examination, the Gandhāra apparatus has been taken as fact in summary reviews and non-targeted studies derived from secondary literature (McHugh 2014, 2021). When removed further from the original material, and citation of such work without critical analysis, references to the apparatus usually comprise a brief version of the whole case, condensed into a single sentence in introductory literature (e.g., Bancroft 2009, p. 26). Subsequently, the trend of identifying distillation apparatus and its specific forms has been embraced widely across the region (Figure 19). In Chapter 2, methods of analysis employed in interpreting early distillation were evaluated including how material surveys had been used to establish ranges of apparatus components and their ubiquity within a critical framework (see 2.4). However, longstanding assumptions on the function of certain objects and their widespread identification (as has been done in the interpretation of the Gandhāra distillation tradition) cannot be supported without consolidating the existing material.

This chapter presents the results of a detailed archive, catalogue, and material survey of interpreted distillation apparatus and characteristic components in the survey area[36] based on previous technological reconstructions. Results act as the dataset for the subsequent experimental research (see Chapters 5 and 6) to critique the presented reconstructions and configurations. The methodology and analytical direction will first be presented followed by the material pertaining to targeted sites, presenting a brief overview of the site interpretation and its research background (detailed discussions on the matter go beyond the remit of this thesis, hence citations and references are provided). This is followed by a discussion and description of the ascribed distillation apparatus, its attributed phasing, context, and key debates relating to the material. Finally, a wider discussion on how the interpretation of a distillation apparatus tradition or configuration had been generated will be offered.

[36] Parts of South-Central Asia encompassing southern Afghanistan, Pakistan and northern India previously designated as “Ancient Gandhāra”.

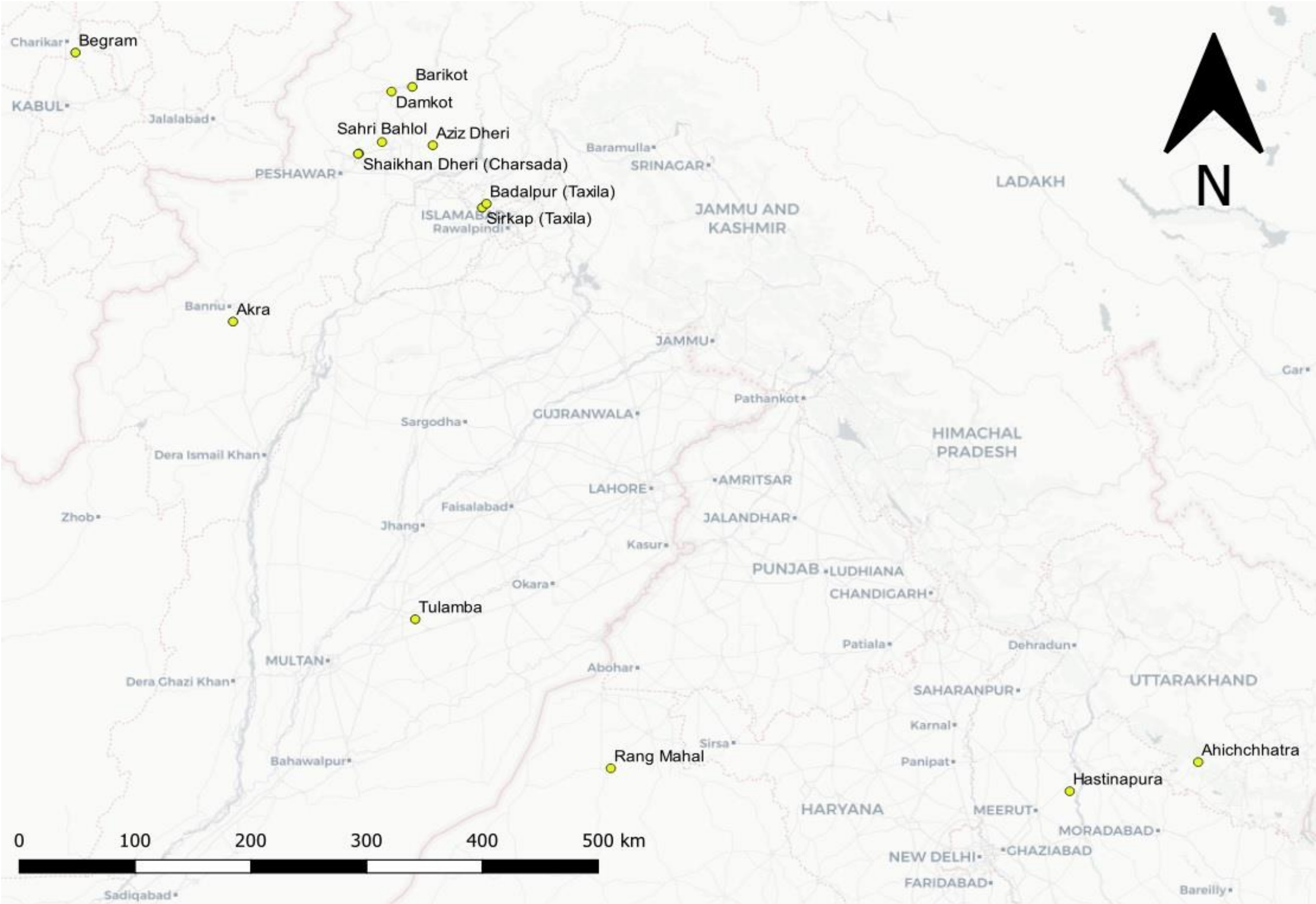


Figure 19. *Study area with sites mentioned in the text and catalogue. Base map from Esri (2022).*

4.2 Methodology

The material survey was conducted to establish the reported quantities of archaeological examples of distillation apparatus and their regional distribution. Archaeological research in the study region has been noted as difficult and inconsistent, complicated by the political and social history of Pakistan, Afghanistan, and northern India, and further affecting how results are reported even in peer reviewed journals (see Mairs 2020). As such, aside from Allchin's claim of widespread distillation apparatus across the region (see Allchin 1979a), there has been no full evaluation of the ceramic typology and characterisation relating to the Gandhāra tradition of distillation. While McHugh has presented a series of criticisms of the apparatus reconstruction (2014, 2020), a systematic survey of reported apparatus examples is required to understand the extent to which researchers have pushed the interpretation of evidence. In conjunction, the archaeological contexts of each item of interpreted apparatus from the sites have not been fully revisited or reconstructed since the 1990s (if at all). Thus, the quality of illustrations, standardisation of descriptions and classifications, and consistency of reports vary and significantly affects the understanding of context.

The survey made use of a large body of sources that consolidated a comparatively sparse number of reported distillation apparatus examples. Examples were divided into four major categories: the individual sites of Taxila, Shaikhān Dherī, and Barikot, and other isolated sites or examples. Categories were selected based on the significance of individual sites in the historiography of interpreting distillation apparatus in South-Central Asia, quantity of material present, and quality of representative examples. Archives, accessible museum collections, journal articles, and pre-existing datasets were consulted to both classify elements of proffered distillation apparatus configurations and contextualise the archaeological reconstructions. Original surveys, excavation notes, and correspondence held by the Ancient Indian and Iran Trust (AIIT) and Needham Institute (NRI) regarding specific excavations and archaeological sites were used in conjunction with site chronologies and stratigraphic diagrams to reconstruct the excavations where distillation apparatus had been reported. Many, however, were incomplete records with key information either missing or remaining unpublished (Figure 20). Equally, the inconsistency between individual researcher's plans, material reporting, and dating of features hindered site and excavation reconstruction. In many cases, excavation notes were a more complete record of archaeological contexts for certain sites (such as Shaikhān Dherī) that were integral in understanding why specific items were interpreted as components within an apparatus configuration.

By collating all surviving and reported examples, a range of the various distillation apparatus components, their interpretation, and an understanding of how reconstructions were formulated was developed. This derived from classified ceramic forms as distillation apparatus components, their associated features, and other connected archaeological remains pertaining to their characterised use. Still bodies and cooling basins that feature in most interpretations of apparatuses were not included due to their wide ascription as 'cooking vessels' and thus not explicitly considered as specialist components of a configuration (see 3.5). Dani (1966), Allchin (1979b, 1979a), and Husain (1980, 1993) all noted various quantities and classifications of individual apparatus components. However, Husain's typological categorisation (1980) was taken as a point of orientation by which to explore how the apparatus has been characterised as the most complete record of apparatus components. Note when an ascribed cultural name appears in the survey (e.g., 'Scytho-' or 'Saka'), it refers to the given name by the author in the citation that follows and is not necessarily universally accepted (see Glossary, Abbreviations, and Orthographical Conventions). Apparatus configurations and reconstructions were broadly grouped into three primary characterisations (see 4.3 for detail): Gandhāra still configurations and associated apparatus, vertical configurations, and other forms or examples of apparatus. Considering that a large proportion of references to distillation apparatus were secondary[37], returning to the original catalogues and records clarified the original vessel forms. Accordingly, an understanding of the morphological range of the apparatus components was developed.

The survey and its catalogue (see Catalogue) is, therefore, the first to identify, locate, collect, and evaluate all references and items of distillation apparatus from the region. In tandem, it re-evaluated the original archaeological materials, contexts, and excavations of certain sites believed to be central for early distillation. The survey began at the end of January 2019 with a preliminary research visit to AIIT, NRI, and the British Museum's South Asian Collection, followed by a study season in the summer of 2019 focussing on Shaikhān Dherī. The survey was planned to continue in 2020 to coincide with ongoing excavations at Barikot and conclude at the start of 2021 to overlap with the experimental campaign. The COVID-19 pandemic, however, prevented this progressing from March 2020 until the survey resumed in February 2022 for a considerably reduced research visit to both the AIIT and NRI. The cancellation of all archaeological work at Barikot through 2020 and 2021 coupled with global travel restrictions prevented any visits to excavation and museum collections in Pakistan to confirm or correct characterisations or designations. Categorisations, classifications, and quantities of specific features or items could not be confirmed with actual collections due to limits imposed by COVID-19 travel restrictions. The information recorded in the catalogue, therefore, should be corroborated with such collections to mitigate for inconsistencies in recorded materials from

[37] i.e., reinterpretations of previously excavated archaeological artefacts.

sites such as Shaikhān Dherī where accurate numbers of certain components cannot be easily ascertained. Hence, it is necessary to state that while the survey and catalogue stand as the most comprehensive collation of interpreted distillation apparatus and their archaeological contexts to date, it is possible that errors in ascribed cultural categorisation, periodisation, and item quantities exist.

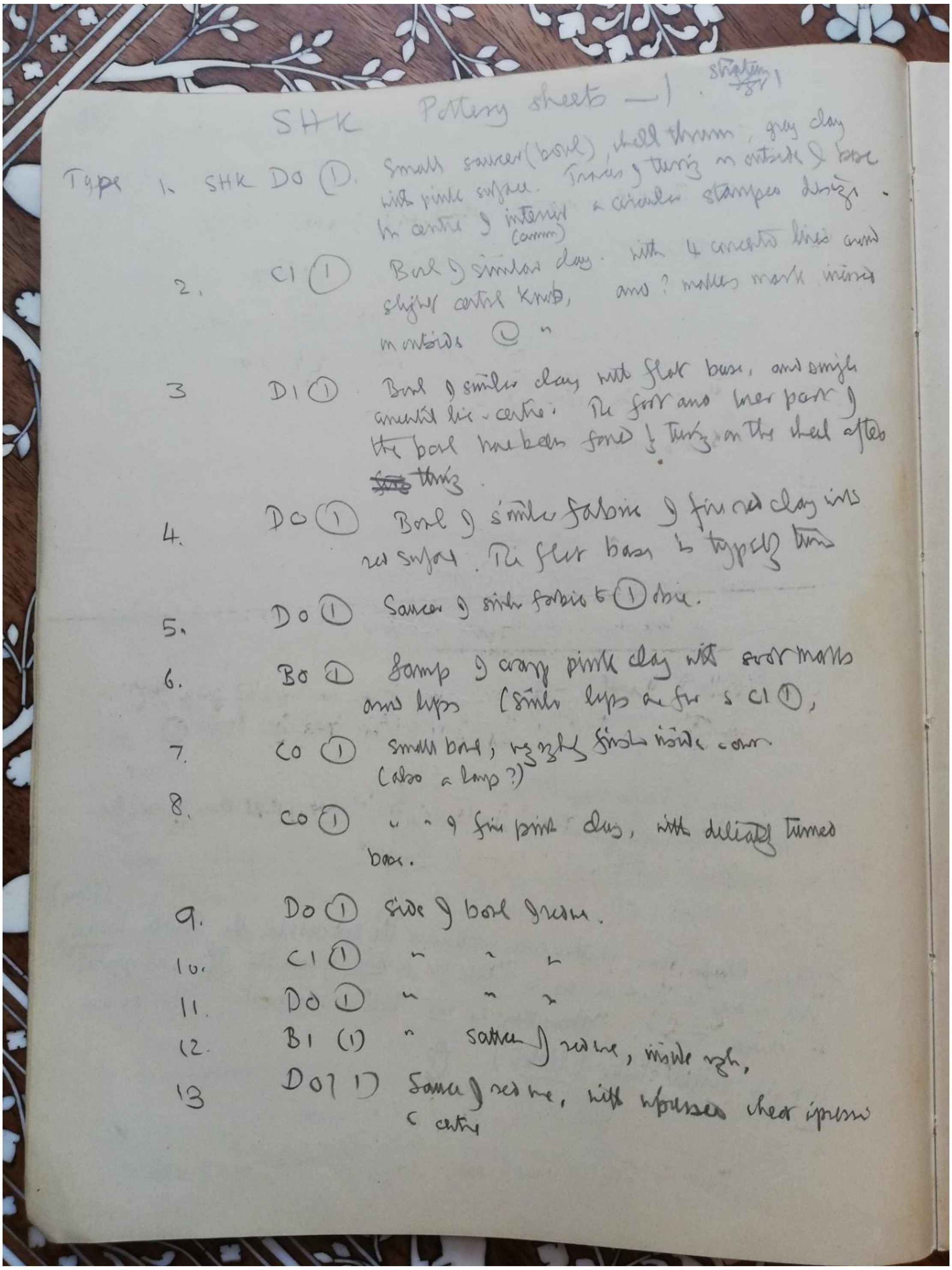


Figure 20. *Section of Allchin's site notes from the Shaikhān Dherī excavations in 1963 (ALLCHIN-1) pertaining to the distribution of pottery forms (by permission of the Ancient India and Iran Trust).*

4.3 Site and material analysis

The survey focusses broadly on the region of ancient Gandhāra and its connections to neighbouring areas. References by researchers have been followed where appropriate, with all items detailed in the Catalogue. Items listed as 'Cat. *x*' refer to individual numbered items in the Catalogue. The survey body centres three main sites that have aided the interpretation of distillation apparatus (Taxila, Shaikhān Dherī, and Barikot) and additionally includes several other sites that have presented or have reported evidence of distillation apparatus; Taxila arguably first provided evidence of a reported apparatus configuration, followed by a higher abundance of examples from Shaikhān Dherī, and most recently an accurately dated example of later apparatus evolution at Barikot. Each of the main sites is presented individually, with others collated in a more general discussion. Further detail on individual sites can be referred to in the Catalogue.

4.3.1 Taxila

The Taxila Valley encompasses several archaeological sites and monuments (Petrie 2013a, p. 652), noted predominantly for three successive mound cities that comprise "ancient Taxila" alongside a series of temples, Buddhist monuments, and monasteries (Marshall 1960, pp. 4–6) (Figure 21):

- Bhir Mound City; circa 6th – 2nd c. BCE (Achaemenid and Mauryan) (Marshall 1951, p. 83)
- Sirkap City; 2nd c. BCE - 1st c. CE (Greek/Indo-Greek, Indo-Scythian, Indo-Parthian) (Marshall 1951, p. 118)
- Sirsukh City; 1st – 5th c. CE (Kushan) (Marshall 1951, p. 217)

Presented as the first meeting point between Greeks and Indians in South-Central Asia (Beggiora 2017, pp. 240–241), and visited by Chinese pilgrims through the 5th – 8th c. CE (Marshall 1960), the area displays evidence of occupation from at least the 3rd mill. BCE (Petrie 2013a, p. 653; Stoneman 2019, p. 465). The Taxila landscape has yielded a diverse range of artefacts from the 6th-5th c. BCE to 5th c. CE, including an extensive group of items associated with established alcohol production and trade from at least the 5th c. BCE (Marshall 1951, pp. 406–407).

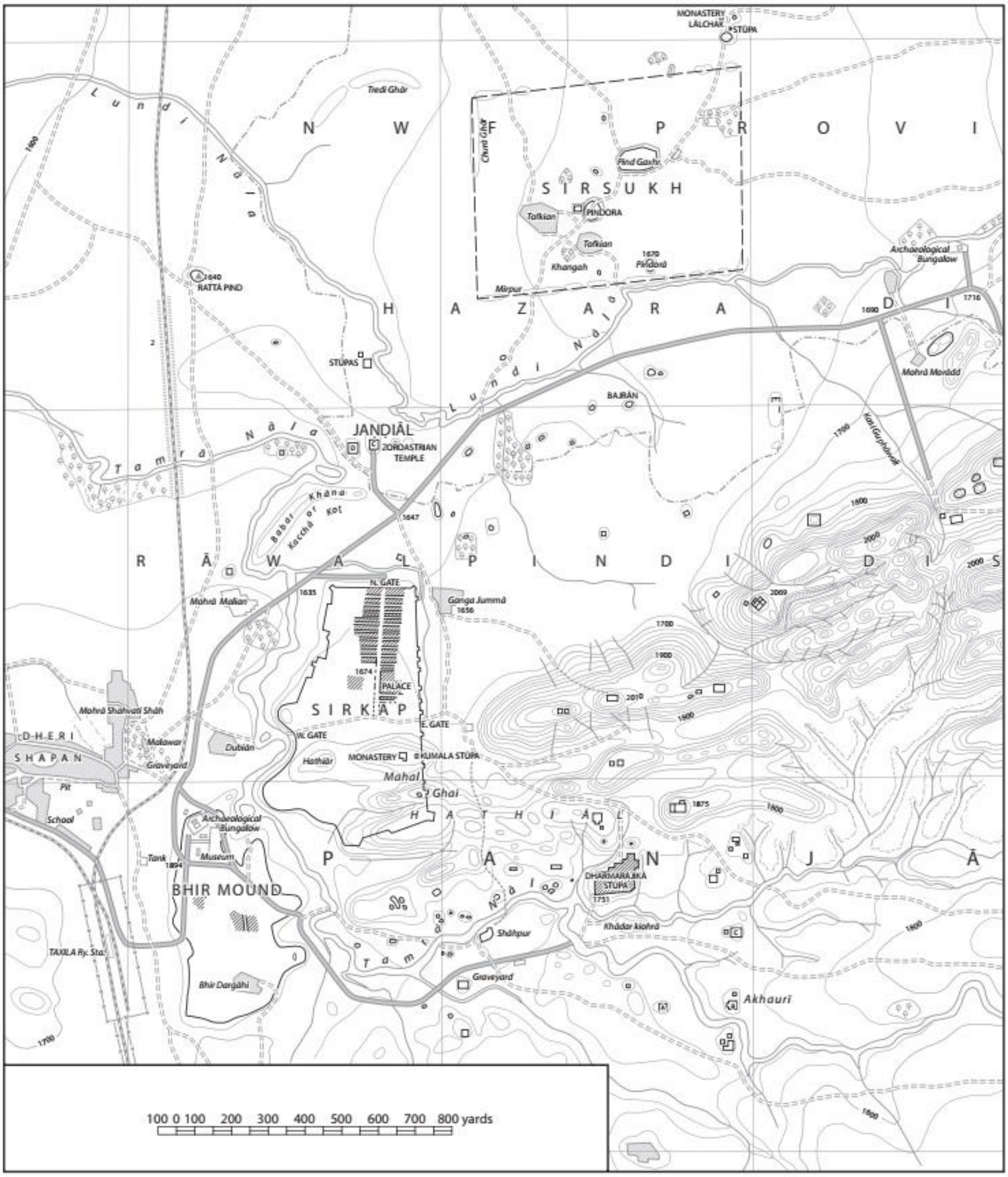


Figure 21. *Plan of Taxila showing the three main cities and excavated areas (Stoneman 2019 fig. 16.1, after Marshall 1960). The archaeological valley area of Taxila extends beyond what is depicted here.*

4.3.1.1 Relevant site chronologies, excavation history, and archaeological contexts

After the site was identified in the 19th c. CE by Sir Alexander Cunningham (Petrie 2013a, p. 653), the first comprehensive archaeological work was carried out by Marshall between 1913 and 1934. Marshall's excavations were more extensive at Bhir Mound and Sirkap (Mairs 2011, p. 36) and published several years later (Marshall 1951, 1960). Excavations by Ghosh in the 1940s (Ghosh 1948), and sporadic excavations continuing until relatively recently (Petrie

2013a; e.g. Khan 2019), built on what had been established by Marshall. Subsequent excavations predominantly challenged chronological or stratigraphic issues at individual Taxila sites first proposed by Marshall (Olivieri 2020a, pp. 391–393). The chronological and stratigraphic relationships between all the individual settlements have, therefore, been repeatedly debated, though due to the near-absence of radiocarbon dates, relative ceramic sequencing has been the predominant method of dating (Petrie 2013a). Hence, no consensus has been reached on phases and dating: a problem exacerbated further by the small number of ceramic vessels that have been used for relative sequencing (Petrie 2013a, p. 657).

While Marshall's work (1951, 1960) is entrenched in a culture history ideology (Petrie 2013a, p. 653) with little change in later revisions (see Dani 1986), Sirkap is traditionally seen as the clearest evidence of distinctly Hellenistic influences and Indo-Greek elements at Taxila. This is seen to be represented by a regular gridiron urban plan and surrounding fortification (Dani 1986, pp. 90–92) arranged in the first half of the 2nd c. BCE[38], contrasting the 'organic' arrangement of the earlier Bhir Mound (e.g., Marshall 1951, 1960, p. 65; Dani 1986, pp. 80, 83). Allied to numismatic studies of recovered coinage that helped define the chronology of the site, the combined evidence has led Taxila to be labelled a capital of the Indo-Greeks (Callieri 1995, p. 294). Despite being characterised as a 'Greek' urban feature through comparisons with the previous iteration of structural features (Mairs 2014, p. 62), the attribution of the stone fortification as Indo-Greek became accepted since Marshall's first impressions (Callieri 1995, p. 295). This is, however, disputed by recognising that the Indo-Greek urban architecture essentially remains unexplored. Thus, the Indo-Scythian and Indo-Parthian phases of Sirkap may have retained the same urban layout, burying the Indo-Greek city (Petrie 2013a, p. 660). Moreover, the Bhir Mound settlement was not fully abandoned by the Indo-Greek period, further complicating such cultural attributions (Mairs 2011, p. 36). Hence, despite their seeming 'completeness' Marshall's excavations are noted to have several chronological and stratigraphic inconsistencies (Callieri 1995, p. 294).

Subsequent work by Wheeler between 1944 and 1945 that remains partially unpublished (Mairs 2011, p. 36), more extensive work at Sirkap by Ghosh (1948), and more recent excavation and surface surveys have aimed to further characterise Indo-Greek evidence and imperial successions at Taxila (Callieri 1995, pp. 296–297; Mairs 2011, p. 36). Jandial C temple, outside the northern limits of Sirkap, is considered to resemble classical Greek architecture, marked by Ionic columns (Marshall 1960, pp. 87–89; Dani 1986, pp. 112–115; Callieri 1995, p. 299; Dar 1998, pp. 78–79). Corroborating numismatic evidence depicting

[38] c. 190 – 90 BCE; Marshall's Strata VI – V.

Indo-Greek rulers, therefore, has been seen to indicate a Hellenistic influence at Taxila (Marshall 1951, pp. 225–229). Further, Marshall's (1951) suggested 3rd or 2nd c. BCE Greek or Hellenistic embossed ware at Bhir Mound (Callieri 1995, p. 297) and "Greek black ware" (Iori 2018, p. 122) have been used to support such an association. However, as the excavated strata date to later periods, seemingly Indo-Greek material, and the grid-plan and fortifications, may be 'heirlooms' rather than in situ Indo-Greek remains (Mairs 2011, p. 36). In response, the aim to find Greek or Hellenistic objects in Taxila recently has been critiqued, instead identifying diverse craft techniques and materials in use in the city's workshops (e.g., Van Aerde 2018) (see Chapter 3). For Marshall's original catalogue of the site material, however (see Marshall 1951), established ceramic typologies and vessel functions relating to Indo-Greek or Greek activities were clear (e.g., Marshall 1951, pp. 411–413).

4.3.1.2 Characterised distillation apparatus

Research at Sirkap produced the first characterisation of early distillation apparatus with a clear (though debated) cultural phasing, largely attributed to a series of ceramic vessels dating to the 1st c. BCE, classed as Indo-Greek or Indo-Scythian material (Figure 22a). Eight items from Sirkap and two others from sites at Taxila have been characterised by previous researchers as connected with distillation (Cat. 1 to 10) (Figure 22b). However, the characterisation of one vessel as a 'water condenser' has a complex classification history. Ghosh first cites the classification of one vessel from Sirkap as a 'water condenser' (Type 73, Cat.1) (possibly a larger group of vessels though this is not clear) in his report on excavations at Taxila between 1944 and 1945 (1948, p. 68). In the same section, he notes how Marshall during the work had developed an interpretation of distillation apparatus similar to Type 73 (Ghosh 1948, pp. 64, 68), characterising his No. 127 and 128 as condensers (Cat. 2 and 3) and No. 129 as a condensing cowl or large spouted bowl (Cat. 5) (Figure 22b). Ghosh equally noted a "large spouted bowl with rounded base" at the site (Ghosh 1948, p. 67) (Cat. 4) in his records. Finally in completing his reconstruction, Marshall connected the two vessel types by ascribing his No. 210 and 211 (Cat. 6 and 7) as condensing tubes, and assumed an applied use of cooking vessels to act both as the still body and means to assist in cooling the apparatus. Thus, Marshall developed his distillation apparatus reconstruction from building on the unique morphology of specific ceramic vessels found in Block C and Palace Building K of Sirkap (Figure 22a). His description of the unit consisted of: "… a condenser (A) resting in a deep bowl of water (B); a condensing cowl (C) which fitted over the top of a handī containing water (D); a pipe (E) connecting A and C; and a tripod (F) on which the handī rested with a fire beneath it. The steam thus generated passed into the cooler A and was condensed." (Marshall 1951, p. 420).

Such an overview of a reconstruction may appear brief (Figure 22a), though the original classification and number of each vessel type is difficult to conclusively establish, due in part to the delayed publication of Marshall's work and differing typologies used by Ghosh and Marshall for the same site (see Ghosh 1948; Marshall 1951). While noting that they may be referring to the same vessel, Mahdihassan (1972, 1979) suggested that Ghosh's Type 73 (Cat. 1) and Marshall's No. 129 (Cat. 5) were from different areas and excavations, thus increasing the number of identified apparatus components. Regardless, it appears as the two are separate examples (rather than one a republishing of another), though this cannot be fully accepted. However, while Marshall clearly classified these components as 'water-condensers', he also noted that the precise use of the vessels was not known (Marshall 1951, pp. 420–421). Thus, it is important to note that the use of terminology in Marshall's account labels the found apparatus as 'water-condensers', which is ambiguous, and does not explicitly state that either the apparatus is used to condense water or is a condenser that relies on water. Despite this, Marshall stated that the likelihood of the apparatus being used for water condensing was "probable" (Marshall 1951, p. 420). Though Marshall did not claim that the apparatus could be used for alcohol distillation (it is unspecified why), accordingly labelling it as a 'water condensing unit' (Marshall 1951, p. 420). Other researchers, conversely, emphasised its suitability for alcohol distillation with a certain definitiveness (Mahdihassan 1972, p. 164, 1979); Mahdihassan justified this connection by comparing Marshall's reconstruction to the morphology of illicit stills operating in India at the time of his writing (Mahdihassan 1972, p. 163).

Further condensers have been noted at Taxila that differ from Marshall's 127 and 128, and Ghosh's 73 (Figure 22c and 22d); examples from Sirkap (Marshall's No. 47) (Cat. 8), Bhir Mound (Marshall's No. 46) (Cat. 9), and from Bādalpur (Cat.10). After Marshall's publications, the example from Bhir Mound (Cat. 9) and differing example from Sirkap (Cat. 8) were noted by Husain (1980) to be similar to identified vessels from Begram (Cat. 78-79), also tentatively labelled a condensing 'receiver' (Allchin 1979a, p. 61; Husain 1980, p. 141) (see 4.3.4). These are, however, significantly different from the commonality of Cat. 1-3, where Cat. 1 and 2 are morphologically the same vessel with a slightly angled spout in the upper section of the vessel and Cat. 3 is marginally more elongated with a spout perpendicular to the vessel. The Bādalpur example (Cat. 10) is essentially a flattened 'flask' with an upturned spout with no shared similarities (other than possessing a spout). Further, while such a connection could be accepted between vessels from the two sites, Taxila No. 46 (Cat. 9) and 47 (Cat. 8) are morphologically different themselves (No. 46 is squatter with a lower, wider, spout) and displays significant differing feature morphologies with the Begram examples (No. 46 is less conical with a more protruding spout).

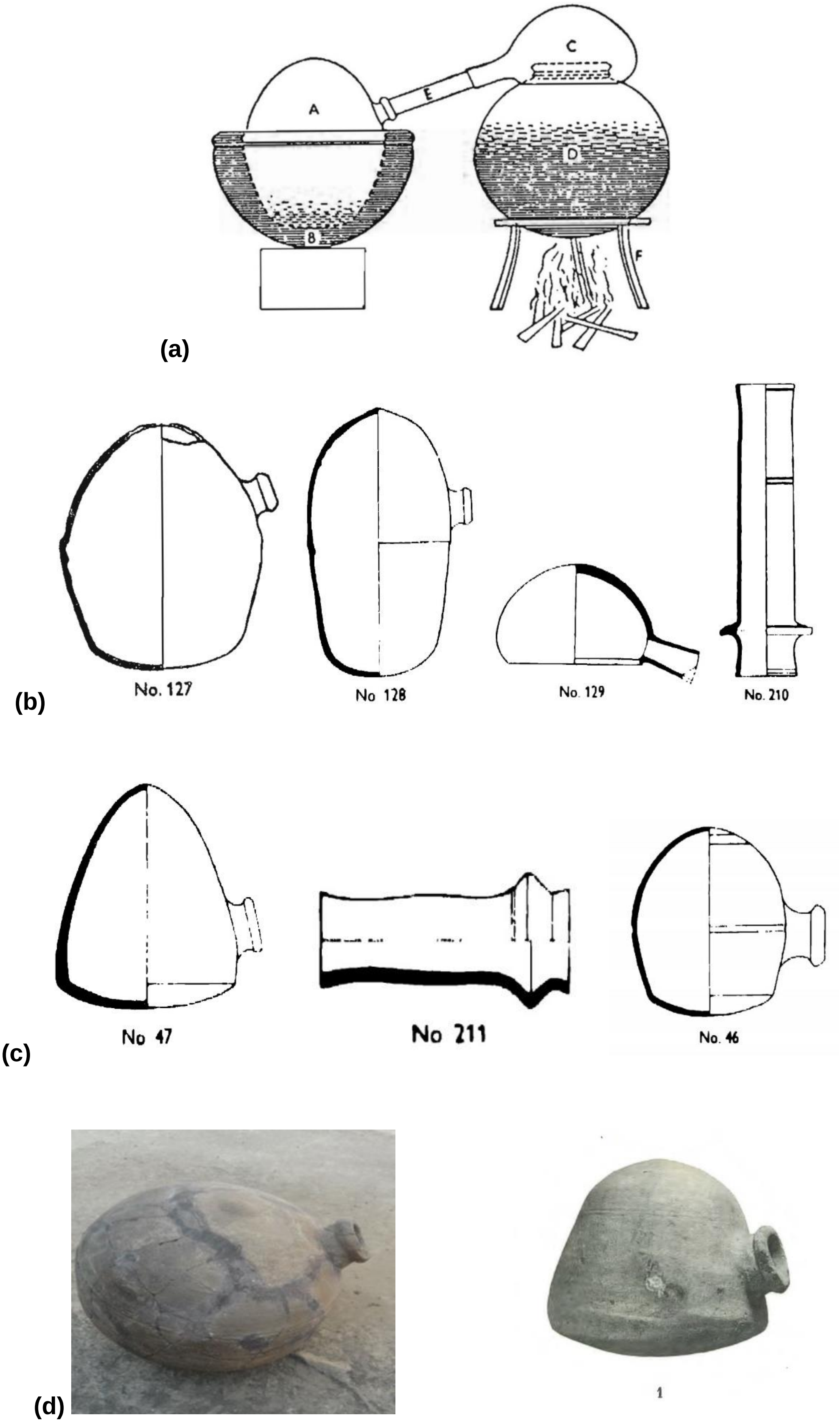


Figure 22. *Components of Marshall's reconstruction of 1st c. BCE distillation apparatus based on archaeological finds from Taxila, other reported examples from Taxila (Marshall 1951, Pl. 122-125), and their typological comparisons:* ***(a)*** *illustration of configuration;* ***(b)*** *individual components in the apparatus configuration (Cat. 2-3; 5-7);* ***(c)*** *examples from Sirkap No. 47 (Cat. 8), No. 211 (Cat. 7), and Bhir Mound No. 46 (Cat. 9);* ***(d)*** *comparative examples from Bādalpur (Cat. 10) (Khan et al. 2013, p. 73) and Begram (Cat. 78-79)(Ghrishman 1946, p. 193).*

4.3.1.3 Evaluation of interpretation

The initial apparatus reconstruction at Sirkap is underpinned by problematic elements of interpretation. Based on variation in the material alone and between each condenser 'form', it is hardly a coherent grouping to constitute a comprehensive and recognisable reconstruction. This extends to the differing morphologies in condensing tube and their associated flanges or fittings (Cat. 6 and 7), and their orientation within the reconstruction itself (see Cat. Sirkap photographs 1-3). Moreover, the fact that Marshall's original drawing (Marshall 1951, Pl. 125) differs from the configuration and used elements in museum displays (i.e. Marshall's No. 129 drawing as a still hood / condensing cowl versus the use of a vessel in the display akin to his No. 47) indicates that no consensus on the apparatus configuration truly exists. Equally, while Marshall's No. 127 (Cat. 2) and 128 (Cat. 3) are noted to be the same typological form (Marshall 1951, p. 420), No. 128 is more elongated in body morphology, and its spout is perpendicular to the body wall, indicating that these are different vessels.

Aside from the objects themselves, it is imperative to recognise that the complete reconstruction is contentious as the very few vessels Marshall had chosen to form the apparatus configuration were found in different locations and strata (McHugh 2014, p. 31) (Table 4; Figure 23). Specifically, the two 'condensers' were recovered from different parts of the excavated city, and the condensing cowl (Cat. 5) (though from the same 'Block' as one of the 'condensers' (Cat. 2)) was recovered from a different stratum and square, approximately 300 ft. from a condenser (McHugh 2020, p. 44). Such an association is exacerbated considering Marshall's sweeping classification of his strata II and III as Indo-Greek or Indo-Scythian (thus labelling his apparatus as such). This is an especially problematic classification as it is nearly impossible to claim Sirkap as 'Indo-Greek' (Callieri 1995, p. 297). Accordingly, while Marshall unified the select archaeological materials as an articulated apparatus, therefore presenting an interpretation of the artefacts as an apparatus configuration, it is not a convincing reconstruction based on the chosen examples.

Cat. number	Vessel / Item	Stratum	Location
2	No. 127, condenser or large closed vessel	Stratum III	Block C, square 47.77'
3	No. 128, condenser or large closed vessel	Stratum II	Block K, square 159.110
5	No. 129, condensing cowl or large spouted bowl	Stratum II	Block C, square 50.47
6	No. 210, smaller pipe	Stratum II	Block F, square 89.65'
7	No. 211, smaller pipe	Stratum III	Main Street, square 45.72'

Table 4. *Distribution of Marshall's characterised 'water-condensing apparatus' at Sirkap, Taxila (see Catalogue).*

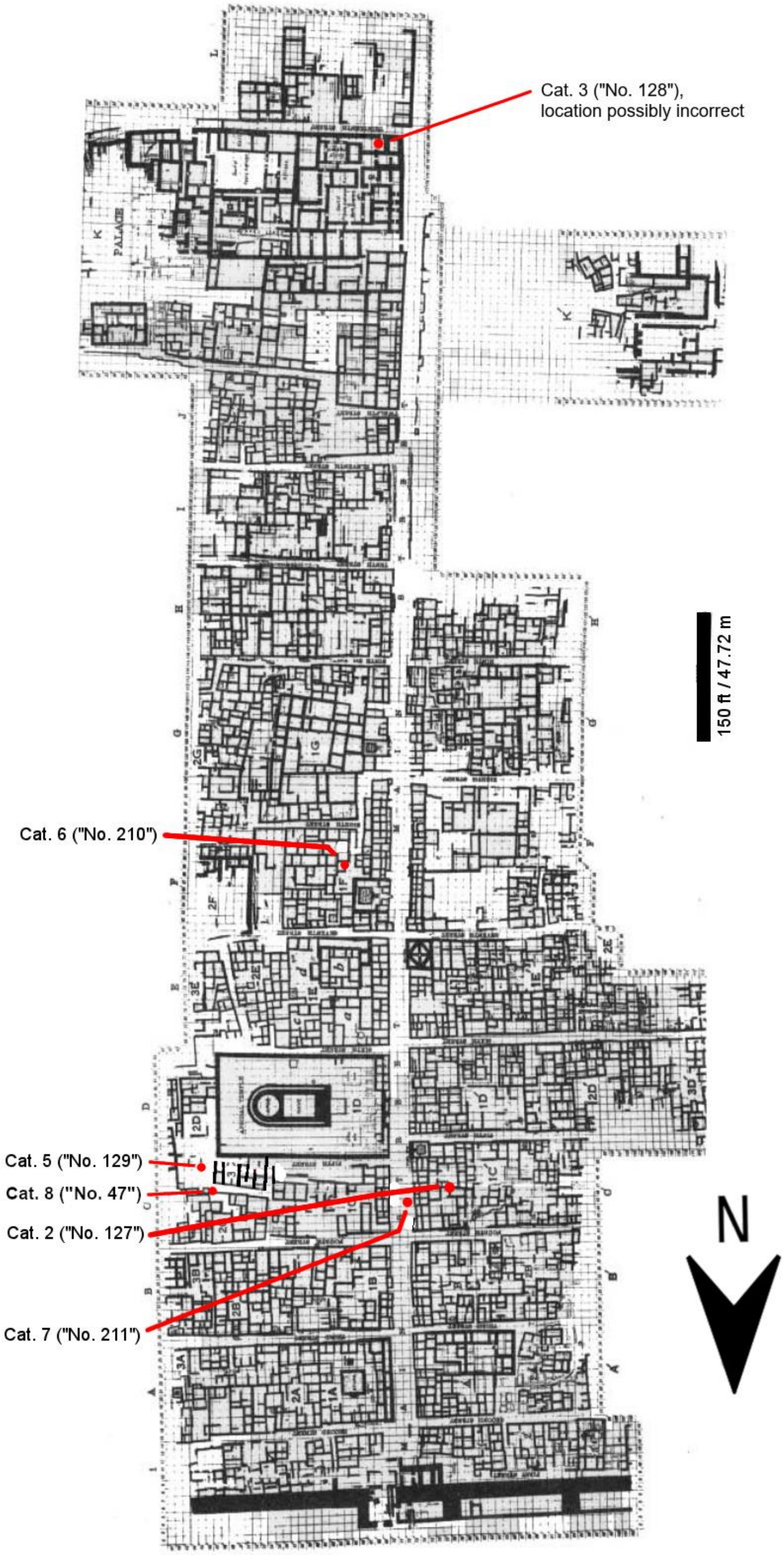


Figure 23. *Distribution of distillation apparatus at Sirkap (after Marshall 1960, fig. 2). Note locations of components are approximations due to the size of the excavation areas, making exact square identification difficult. Note that the scale is in feet (converted to metres) following the original excavation grid.*

4.3.2 Shaikhān Dherī / Shaikhan Dheri, Charsada / Charsadda

Following the characterisation of apparatus components at Taxila, archaeological research through the 1960s and 1970s helped formulate a specific 'Gandhāra tradition' of distillation. Particularly making use of interpreted evidence from the mound settlement of Shaikhān Dherī at Charsada, elements of the site's material and architectural remains were characterised as evidence of a distillation 'industry' (Allchin 1979a, 1979b; Husain 1980, 1992a, 1993). The wider Charsada area, marked as Pushkalavati / Peukelaotis, ancient capital of Gandhāra (Olivieri 2020a, p. 393), is stated as another example of a Greek presence and influence in South-Central Asia. Identified first by Cunningham in the 19th century (Petrie 2013b, p. 512), and its extents later defined in aerial photographs (Wheeler 1962, p. 12), Shaikhān Dherī is situated in the Peshawar Valley at the junction of the Kabul and Swat Rivers (Petrie 2013b, p. 512). Together with radiocarbon dating published in 2007 showing Charsada to be occupied from at least c. 1400 BCE (Coningham and Ali 2007), the site has been stated as an important regional centre throughout its occupation, rather than being a colonial outpost for successive regimes settling in Gandhāra (Mairs 2011, p. 37).

4.3.2.1 Relevant site chronologies, excavation history, and archaeological contexts

In a similar division to Taxila, Charsada consists of three primary 'city' phases constructed on mounds (Figure 24):

- The first Bala Hisar mound, first comprehensively excavated in 1958 by Wheeler following sporadic and unmapped excavations by H. W. B Garrick in 1882 and John Marshall in 1903 (Marshall 1904, pp. 146–154; Wheeler 1962; Coningham and Ali 2007, pp. 22–23). Wheeler viewed the Bala Hisar as having a 'Persian' foundation with defences erected in response to the Macedonian campaign in 327 BCE, as revealed during Marshall's excavations (Wheeler 1962). Early stratigraphic chronologies noted two main occupation phases: a mid-late 2nd mill. BCE and 6th – 2nd or 1st c. BCE. More recent surface surveys and excavations in the 2000s have further challenged this (e.g., Coningham and Ali 2007; Mairs 2011, p. 37).
- The second mound site of Shaikhān Dherī (Indo-Greek to Late Kushan) founded 2nd c. BCE, abandoned c. 3rd c. CE (Dani 1966, pp. 23–24), first confidently identified in 1958 from aerial photographs (Wheeler 1962), has been subject to comparatively less archaeological intervention (Mairs 2011, p. 37) (Figure 25).
- The third successive mound, Mirabad-Rajar-Mirziyarat / Mir Ziyarat, has been recognised as the final settlement at Charsada (Husain 1995, p. 79) (from around 4th or 5th c. CE to an undetermined period), but has not been investigated archaeologically

aside from recovering some Buddhist sculpture fragments and masonry pieces in the mid-1800s and early 1900s (Marshall 1904, pp. 154–160; Wheeler 1962, p. 2; Ali et al. 1997, p. 4).

As with the Taxila chronologies, ceramics have been employed across the Charsada sites to elucidate stratified periods and phasing prior to established radiocarbon dates (e.g., Dani 1966; Husain 1980, 1995; Ali et al. 1997). However, attributed cultural labels to certain ceramic forms, and their belonging to either 'Indic' (local/indigenous) or 'Aegeic' (imports from a distinctly Greek source or produced by immigrants from a 'Hellenic' region) corpuses has determined how Charsada's cultural continuity is viewed (see Petrie 2013b, pp. 516–517).

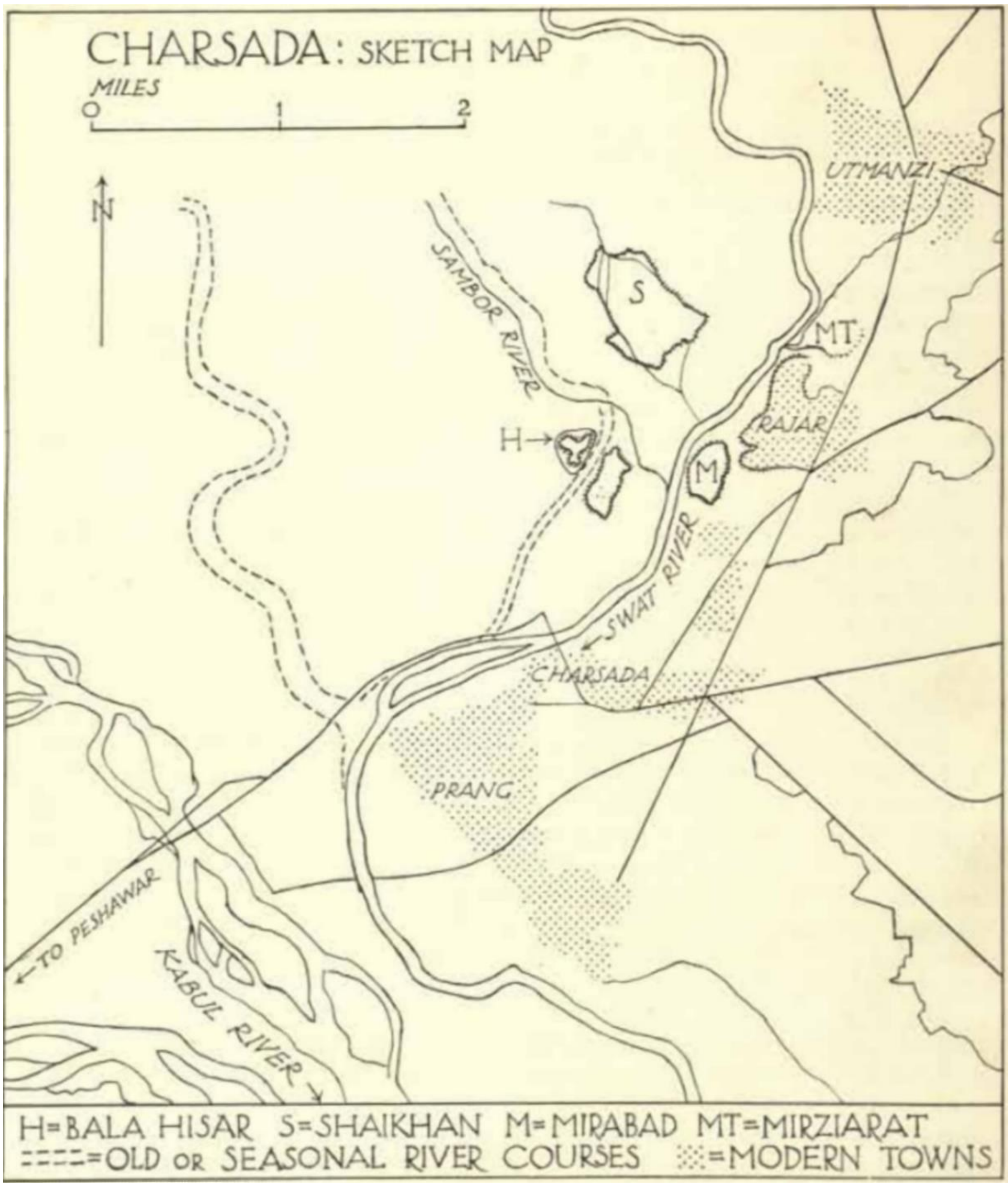


Figure 24. *Wheeler's (1962, fig. 1) sketch map of the mound cities around Charsada.*

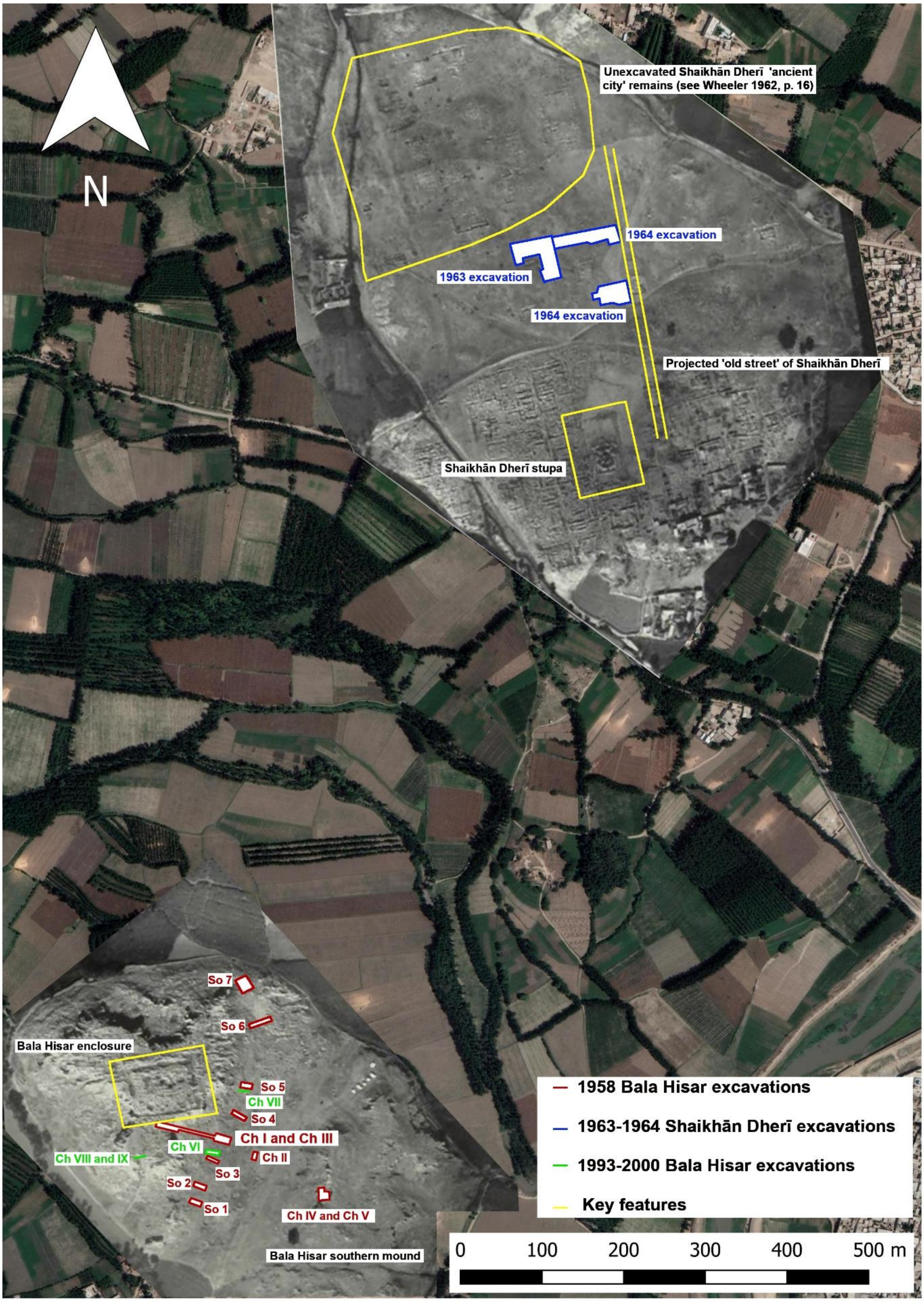


Figure 25. *Aerial photographs of part of Charsada showing the Bala Hisar and Shaikhān Dherī mounds, overlayed aerial photographs of the archaeological remains (Wheeler 1962, pl. 4, 15), key archaeological features, and recorded excavated areas. Aerial photographs show the extensiveness of the settlement before modern development (Wheeler 1962, pp. 16–17). Map by the author, base aerial photograph from Google Earth (2022).*

Considering its extensive size and archaeological potential, excavations at Shaikhān Dherī in 1963 conducted by the Universities of Cambridge and Peshawar, and exclusively by the University of Peshawar in 1964 (see Dani 1966; Husain 1995), aimed to establish the urban layout of the city and phases of occupation within the broader evolution of Charsada (Husain 1995, p. 81). Dedicated published work is limited to a few sources considering the short excavation period (Dani 1966; Allchin 1979b; Husain 1980, 1990, 1992a, 1992b, 1993, 1995). Archives, unpublished notes, plans, and draft chronologies are, therefore imperative to understanding the chronology of the site and how it has been formulated (e.g., ALLCHIN-3; Dani 1966; Husain 1995). Excavations at Shaikhān Dherī have been considered, however, a "more controlled" archaeological project than at the Bala Hisar, due to the comparatively shorter timeframe and its corroborated radiocarbon dates and coin finds (Petrie 2013b, p. 514). Regardless, Wheeler's evolutionary continuum at the Bala Hisar, determined through deep vertical excavation, specific pottery forms, and stratigraphic wall sections acted as the model for targeted excavation at Shaikhān Dherī (Olivieri 2020a, p. 394). Hence, the phasing of Shaikhān Dherī was established in parallel to Wheeler's chronology, though revised since the 1960s excavations to include a wealth of numismatic evidence (Mohammadzai and Khan 2011) (Table 5).

Initially for Wheeler (1962), the fortified urban layout of Shaikhān Dherī was comparable to the 'Greek' planning of Sirkap (Taxila) (Callieri 1995, p. 299). Corroborated with 2nd c. BCE Indo-Greek coinage (Callieri 1995, p. 299) foundational alluvial stratigraphic levels (Dani 1966), the theory has been maintained that Shaikhān Dherī was a refoundation of Charsada by the Greeks or Indo-Greeks between 2nd - 1st c. BCE, remaining occupied until the Kushan period (c. 4th-5th CE) (Husain 1995; Mairs 2011). The discovery of 'Hellenistic' terracotta figures and several other objects including an extensive ceramic assemblage supported such an idea, operating as evidence of Greek or Hellenised craftsmen at Shaikhān Dherī (see Callieri 1995, pp. 229–300, 305 for critique). Thus, to indicate a Hellenistic influence at Shaikhān Dherī, in contrast to the scant indications at the Bala Hisar, recovered ceramic forms with parallels to Hellenistic forms in western Asia (3rd - 2nd c. BCE), including fishplates, deep bowls with footed bases, jugs, and amphora, were attributed to the Indo-Greek period (Petrie 2013b, p. 518). However, key features, such as Shaikhān Deri's ramparts were not excavated (Dani 1966, p. 22; Olivieri 2020a, p. 396), rendering it difficult to establish the extent of the city. Nevertheless, based on targeted deep excavations and gridded excavation down to certain 'cultural phases' (Husain 1995, p. 83), Dani had reconstructed Shaikhān Dherī's abandonment as linked to gradual resettlement higher up the mound by the middle of the 3rd c. CE (1966, pp. 23–24). Over the course of the excavations, distinct areas, houses, and rooms were noted as a feature of the city's grid plan. However, the limited excavation periods and encroaching development of the modern settlement of Mirchakai Kalay since at least 1993 (see ALLCHIN-3) implicates the validity of any proposed hypothesises on the function of the site (Husain 1995, p. 84).

Despite this, notable finds such as a coin hoard in 2007 continue to encourage revisions of the occupation period of Shaikhān Dherī, potentially to as early as 5th c. BCE (Boperarchchi 2009, 2017). While collected coins from the original 1960s Shaikhān Dherī excavations had confidently depicted Greek and Indo-Greek rulers (see Dani 1966; Mohammadzai and Khan 2011; Boperarchchi 2017), re-evaluation of the hoard has suggested a pre-Greek presence at the settlement. Silver Achaemenid 'bent bars', virgin flans, and ingots dated to c. 5th - 3rd c. BCE have been found, potentially produced on site as local issues under Achaemenid rulers (Boperarchchi 2017, p. 20). It is the presence, however, of an imitation silver *tetradrachm* (Athenian owl coin) within the hoard dated to 380 BCE[39] that has revitalised interest on Shaikhān Dherī's direct connections with ancient Greece (Boperarchchi 2009, 2017, p. 18). This is especially notable considering the site's proximity to the centre of an important trade network at the time (Boperarchchi 2017, p. 20). Unfortunately, such finds cannot be corroborated with the original 1960s excavations considering that neither the findspot nor depth of the hoard have been recorded.

[39] Originals date to approximately 520 BCE (see Boperarchchi 2017).

Final phasing	Pre-1995 chronology			1995 and post-1995 chronology		
Phase and date range	**Period (see Dani 1966)**	**Stratum (see ALLCHIN-1)**	**Cultural period and source**	**Period (see Husain 1995)**	**Stratum**	**Cultural period, source, supporting numismatic evidence**
A: Kushan c. early to mid-1st c. CE – 4th c. CE (Husain 1995)	I	I II IIA III	Late Kushan; deep excavation (see Dani 1966, fig. 5)	1 / I	I II IIIa	Late Kushan; revised correlation. Coins of later Kushans including Vasudeva (see Husain 1995, p. 85)
	II	III IVA IVB	Middle Kushan; deep excavation (see Dani 1966, fig. 5)	2 / II	IIIb Iva Ivb	Middle Kushan; revised correlation. Coins of Kanishka and Huvishka (see Husain 1995, p. 85)
	III	V VI	Early Kushan; published correlation (see Dani 1966, p.25)	3 / III	V VI	Early Kushan; revised correlation. Coins of Kujula Kadphises, Wima Kadhises, Soter Megas (see Husain 1995, p. 85)
B: Scytho-Parthian (Saka-Parthian/Saka-Pahlava) c. mid-1st c. BCE – mid 1st c. CE (Husain 1995)	IV		Late Parthian; published correlation (see Dani 1966, p.25) Main Scytho-Parthian; published correlation (see Dani 1966)	4	VII VIII	Scytho-Parthian; revised correlation. Hoard of coins of Azes II (Husain 1995, p. 89)
C: Greek c. 130 – 115 BCE; 2nd c. BCE (Husain 1995)		VII VIII		5	IX	Late Greeks; revised correlation. Coins of late Indo-Greek rulers including Antialkidas, Heliocles and Philoxenus (Husain 1995, p. 89)
	IVA			6	X XI	Early Greeks; revised correlation. Coins of Menander, Apollodotus and Agathocles (Husain 1995, p. 89)
	IVB					
	V (A)	IX	Late Greek; published correlation (see Dani 1966, p.25)			
	V (B)		Middle Greek; published correlation (see Dani 1966, p.25)			
	VI	X XI	Early Greek; deep excavation (see Dani 1966, fig. 5)			
Pre-Greek/ Achaemenid c. 5th - 3 c. BCE (Boperarchchi 2017)				5th - 3rd c BCE (inc. 380 BCE)	Unknown	Achaemenid silver punch-marked bars, virgin flans and ingots, imitation Athenian *tetradrachm* (Boperarchchi 2017).

Table 5. *Collated chronologies for Shaikhān Dherī* (after Dani 1966; Husain 1995; Boperarchchi 2017).

4.3.2.2 Characterised distillation apparatus

In comparison to the characterisation and reconstruction at Taxila, the interpretation of distillation at Shaikhān Dherī has been greatly expanded. As the highest concentration recorded during the survey, 42 items from Shaikhān Dherī were characterised as distillation apparatus components by previous researchers (Cat. 11-52). In a series of targeted studies (Allchin 1979b, 1979a; Husain 1980, 1992a, 1993), the site has been positioned as displaying clear evidence of early distillation from Indo-Greek phases. This interpretation was determined from specialist ceramic vessels found in specific parts of the site and one area designated as a 'distillery' (Allchin 1979b; Husain 1993). While sharing similarities with the Taxila configuration, the interpreted apparatus components at Shaikhān Dherī spans multiple chronological phases (the broadest range being given as mid-2nd c. BCE – late 4th c. CE) (see Catalogue) (Figure 26a). This is complicated by conflicting chronologies and periodisation used across the literature (e.g., Husain 1995) and confused reporting of vessel quantities. Consequently, broad date ranges assigned to individual phases, stratigraphic sequences, and vessels, were originally suggested (see Dani 1966; Allchin 1979b; Husain 1980). Thus, subsequent research has relied on an equally broad periodisation to describe aspects of the characterised apparatus without a clear consensus:

- Dani first reported a 'Greek' "big pot for condensing water" in his publication on both excavation seasons at Shaikhān Dherī (Dani 1966, p. 145) (Cat. 11), agreeing with Ghosh's (1948) and Marshall's (1951, p. 420) typology at Taxila. Alongside Dani's (1966) characterisation, Husain (1980) delineated 'Greek' or Indo-Greek phases (Periods 6 and 5) as the earliest examples of apparatus components, specifically a still head (Cat. 14) and several receivers (Cat. 12-13) (see Figure 26b). These attributions were later clarified in his 1995 publication and in agreement with Allchin's work (1979a, 1979b).
- The next phase of the site (Period 4) contained three Scytho-Parthian or Indo-Scythian receivers (including Dani's previous reporting) (Cat. 15-17), which Allchin referred to as an "earlier type" apparatus component (1979b, p. 770) and Dani as a "water distiller" (1966, p. 160). A still head of drastically different morphology from the Indo-Greek example (Cat. 18) (see Figure 26c) was also attributed to Period 4 by Husain (1980). Crucially, this period was deemed the point at which a tradition of stamping receivers had started (Allchin 1979b, 1979a; Husain 1980).
- Early Kushan Shaikhān Dherī (Period 3), while producing a similar quantity of receivers as the previous two phases (Cat. 19-21), also introduced a new, rounder, and globular

style of receiver (Cat. 20-21). Morphologically different from receiver-condensers in Period 4, Period 3 carried the tradition of stamping (see Figure 26b).

- The Middle Kushan phase of the site (Period 2), however, saw a drastic increase in the number of receivers recovered, which morphologically had become squatter than their predecessors) (Cat. 22-41) (see Figure 26b). Period 2 also produced the only recorded condensing tube at Shaikhān Dherī (Cat. 42) (Figure 26d). The tube significantly differed from those recorded at Taxila in being thinner walled, shorter (c. 15 cm in length), and tapering to a point.
- The final Late Kushan phase of the site (Period 1) again produced several stamped receivers (Cat.43-52) though a number significantly smaller than the previous Middle Kushan period.

The characteristic feature of the apparatus - the ‘receiver’, ‘condenser’, or ‘receiver-condenser’ - has undergone several morphological evolutions and reinterpretations. Allchin concluded that pottery ‘condensers’ were used at the site from “the late Greek times onwards” (Allchin 1979b, p. 767). As a notably change, Kushan condensers could be distingished by their tendency to be stamped with a royal ‘tanga’ (insignia) (Allchin 1979b, 767-769), indicative of “licsensing” of distillied alcohol (Olivieri 2022, p. 18) (Figure 27). Husain (1980), however, had noted certain Indo-Scythian condensers with stamps (Cat. 16-17), which brings such an association into question. Allchin stated the ubiquity of the ‘condensers’ was indicative of regular replacements due to repeated use, and that stamped receiver-condensers were required for the storage and distribution of distilled alcoholic spirits (Allchin 1979b, p. 776). Hence for Allchin, condensers also acted as ‘receivers’ to collect and store produced distillates, though understanding this designation is not straightforward in his account (Allchin 1979b). Seemingly, the classification of ‘condenser’ may have been used interchangeably with ‘receiver’ throughout (ALLCHIN-1, Allchin 1979b, 1979a, Husain 1980). Allchin’s notebooks allude to a separation between ‘water condensers’ that might be stamped in line with Marshall’s designation, and stamped receiving vessels (ALLCHIN-1), though this is not clear in practice. Equally, recording examples as ‘condensers’ or ‘receivers’ differs within Allchin’s own work (e.g., Allchin 1979b, p. 757, 1979a, p. 59). Hence, the disparity between the classification of ‘condenser’ and ‘receiver’ exemplifies issues apparent in the reconstruction of the distillation apparatus.

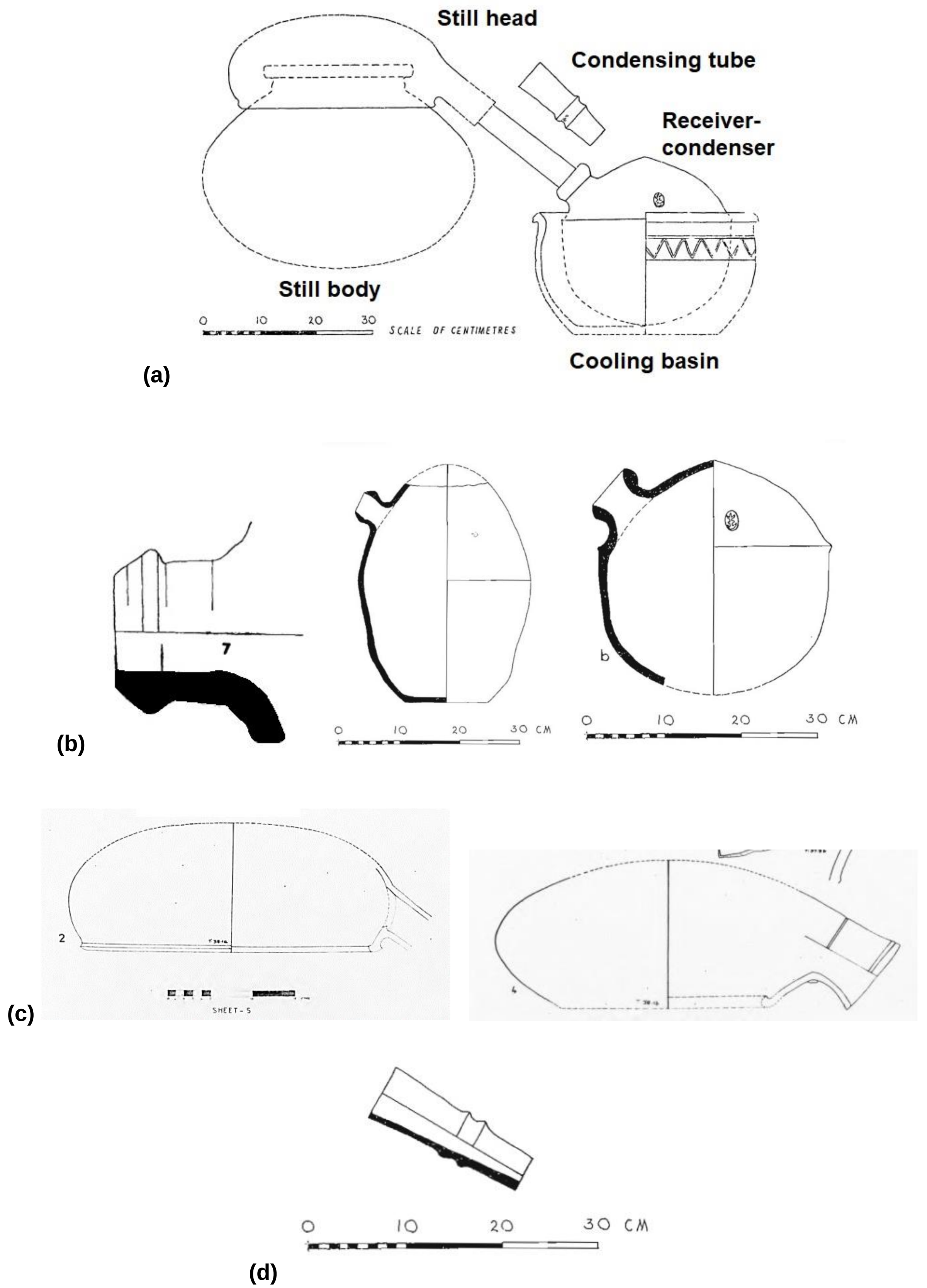


Figure 26. *Selected components of Allchin's 2nd c. BCE – 4th c. CE distillation apparatus from Shaikhān Dherī.* ***(a)*** *illustration of apparatus configuration (after Allchin 1979a, p. 60, 1979b, p. 773);* ***(b)*** *receiver-condenser examples (left to right): Dani's (1966, p. 145) "Greek water condenser" (Cat. 11), Allchin's "early [pre-Kushan] type" (1979b, p. 770) (Cat. 15) and "later [Kushan] type" (representative drawing) (1979b, p. 770);* ***(c)*** *example still heads: Husain's (1980) Indo-Greek (Cat. 14) and Scytho-Parthian (Cat. 18) still head;* ***(d)*** *Allchin's (1979b) Kushan condensing tube (Cat. 42). Other period-specific examples of components exist; see Catalogue.*

Figure 27. *Characteristic condenser or receiver spout with tanga stamp from Kushan phases at Shaikhān Dherī (ALLCHIN-4). The provenance of the sample cannot be ascertained, so no catalogue number is given.*

The underpinnings to Allchin's interpretation were, however, clarified to a degree by Husain (1980). What had been classified broadly as 'receivers' appeared to occupy the Indo-Greek to Late Kushan periods with distinctive changes to their morphology and more consistent use of the tanga mark stamp in the Kushan eras (Husain 1980, pp. 139–142) (Figure 27). Thus, it is important to note that Allchin's excavation notes make no clear distinction between 'water condenser' and 'receiver' during material recording per strata, and the label of 'receiver' and 'condenser' was used after the excavations. Allchin's excavation notes from 1963 recorded several 'condensing stills' in line with Marshall's classification recovered in upper strata in one weak concentration of the site (ALLCHIN-1, pp. 9, 15). Further, the record implies that the interpretation of the 'stills' may have been water condensing units and were stamped (ALLCHIN-1, p. 79). It can be, therefore, assumed that 'condensers', 'condensing stills', 'water condensers', and 'receivers' are all referring to the same typological forms with possible changing or differing ideas on how they should be classified and under what remit.

Unlike Marshall's account, which provides little on the context for his recovered apparatus components (see Marshall 1951), research at Shaikhān Dherī explored the purpose of the site's individual areas, their connections to distillation, and the distribution of the receiver-condensers (Figure 28). In conjunction with the recovered apparatus' evolution, two distinct excavated areas of Shaikhān Dherī were identified as a 'distillery with an open drinking area' at the heart of the city (Husain 1980, pp. 207–210) and 'House of Naradakha' (Figure 29). These elements were central for Allchin's discourse on the establishment of alcohol distillation in Gandhāra (Allchin 1979b, pp. 773–779). The distillery was found to be associated with (at the earliest) Indo-Greek or Scytho-Parthian architectural features of a complete room containing a hearth. Here, material remains indicative of winemaking and selling were found in association with receiver-condensers (Husain 1980, pp. 221–223). For Allchin, a mixed group of over 100 'condensers' was said to be within the disitllery, many stamped with tangas (ALLCHIN-1, p.25), alongside water pots and terracotta basins that Marhsall (1951) had categorised as condenser coolers in his reconstruction (Allchin 1979b, p. 774). Husain, however, clarified that Allchin's reporting of recording over 100 'condensers' was actually closer to 40 (Husain 1980, p. 139). Yet accurately confirming Husain's count is equally difficult and does not correspond with the reported numbers across his publications (see Husain 1980, 1993). Additionally, Allchin's assumption that tanga marked sherds were also likely candidates as disitlling receivers further complicates attempts to determine a clear number of the vessels (see Allchin 1979b). Conclusively, it cannot be stated if all stamps indicate reciever-condensers, or if stamps were used more widely on other vessels. Despite Allchin making a designation across the site between stamp-marked and non-stamped condensers (Allchin 1979b, figs 3–5), tanga marked spouts and stamped sherds, therefore, cannot be seen as representing receiver-condensers. This is particulay true of remains recovered from within the 'distillery'. Regardless, Husain (1980, 1993) agreed that the 'distillery' was confined to excavated areas D0, D1, E0, E1, F0, and F1, by Allchin's reconstruction, and although tentative, it clearly marked the area as being of special use:

"…The area was found to be scattered with a thick deposit of wood ash, particularly during the Late Kushana period. The pottery found here included large numbers of small, shallow bowls, many decorated with impressed designs of corn ears. Groups of these bowls were found still piled up, lying undisturbed among the debris. At the time we were inclined to believe that the area formed part of a potter's yard, or at least was adjacent to one, but this is now shown to be improbable. The density of pottery was less in the lower levels, but still greater than in other parts of the site. In a space of approximately 350 sq. m. over one hundred 'condensers' were found, dating from the Late Indo-Greek to Late Kushana times. Another class of finding particularly noted in the same area was a number of water pots with soot staining on their outer surfaces. Some of these may coincide with the Handis (cooking pots) proposed by Marshall as the second element in re-assembled distilling apparatus. Numerous examples of the third element, the T.C. basins which Marshall supposed to have been used as coolers for the condensers, were also found […] our feeling is that the pottery found there shows an otherwise unexplained emphasis on certain specialised types to the exclusion of others. For instance, the heaps of new cup bowls, and probably of other originally unbroken vessels, and the concentration of condensers. The […] interpretation must be in terms of an occupational use more directly linked to these special types, and this on balance we are inclined to accept as the most probable […] Reviewing the several possible interpretations we are inclined to conclude that the open space with its accumulated ash and debris, and its piled up drinking bowls, was used either for the manufacture or sale of alcoholic beverages, or for both, and that the 'condensers' were either simply wine vessels, or more particularly used in connection with the process of distillation." (Allchin 1979b, pp. 774–776).

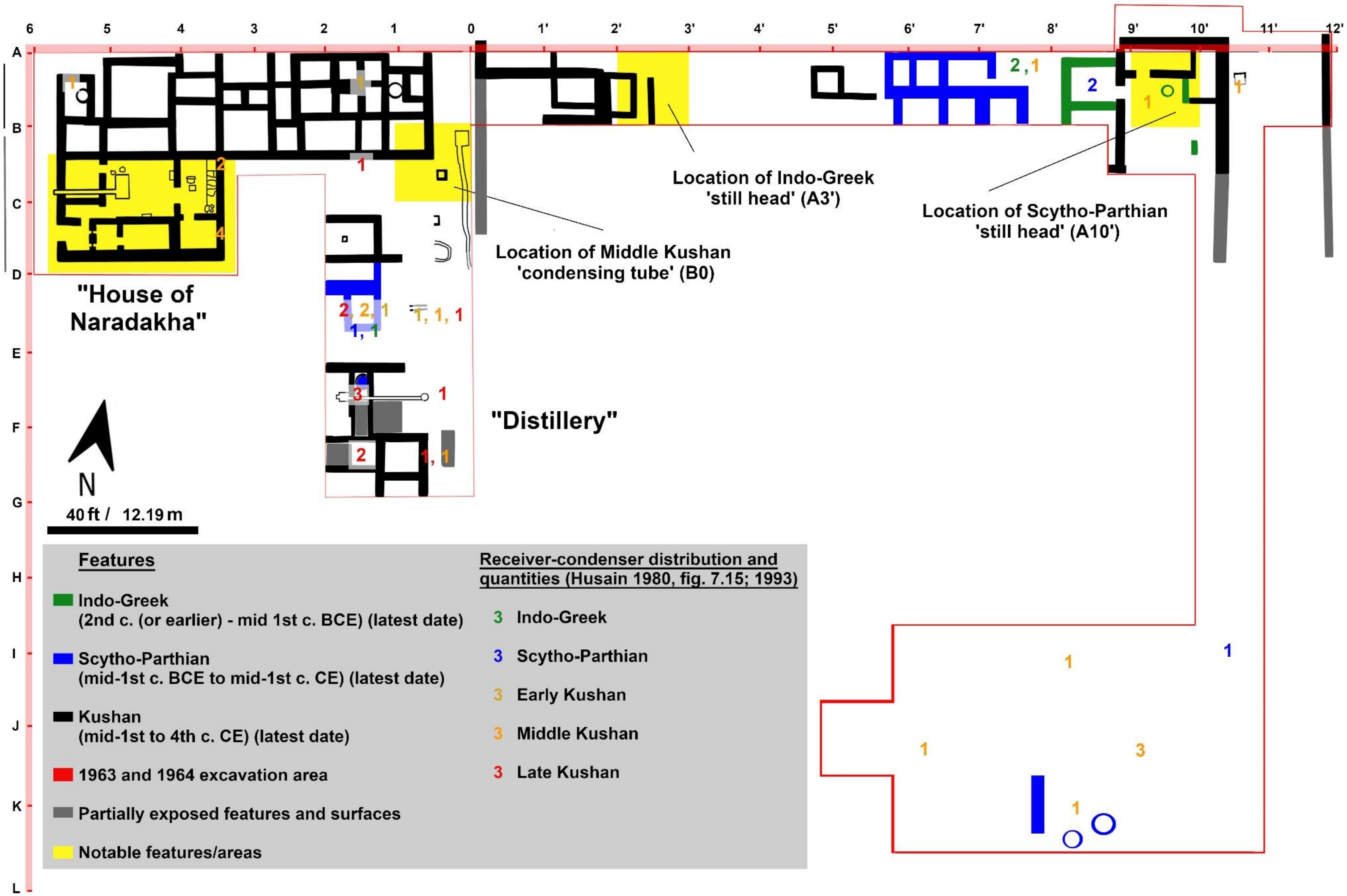


Figure 28. *Plan of Shaikhān Dherī showing the main features, excavated areas, and location of the suggested 'distillery' and 'House of Naradakha'* (after Dani 1966; Husain 1993, 1995) *(plan by the author). Note that the scale is in feet (converted to metres) following the layout of the original excavation grid. The 1963 excavated area grid uses the numbering system A1, A2, A3 etc. while the 1964 excavated grid area uses A1', A2', A3' etc.*

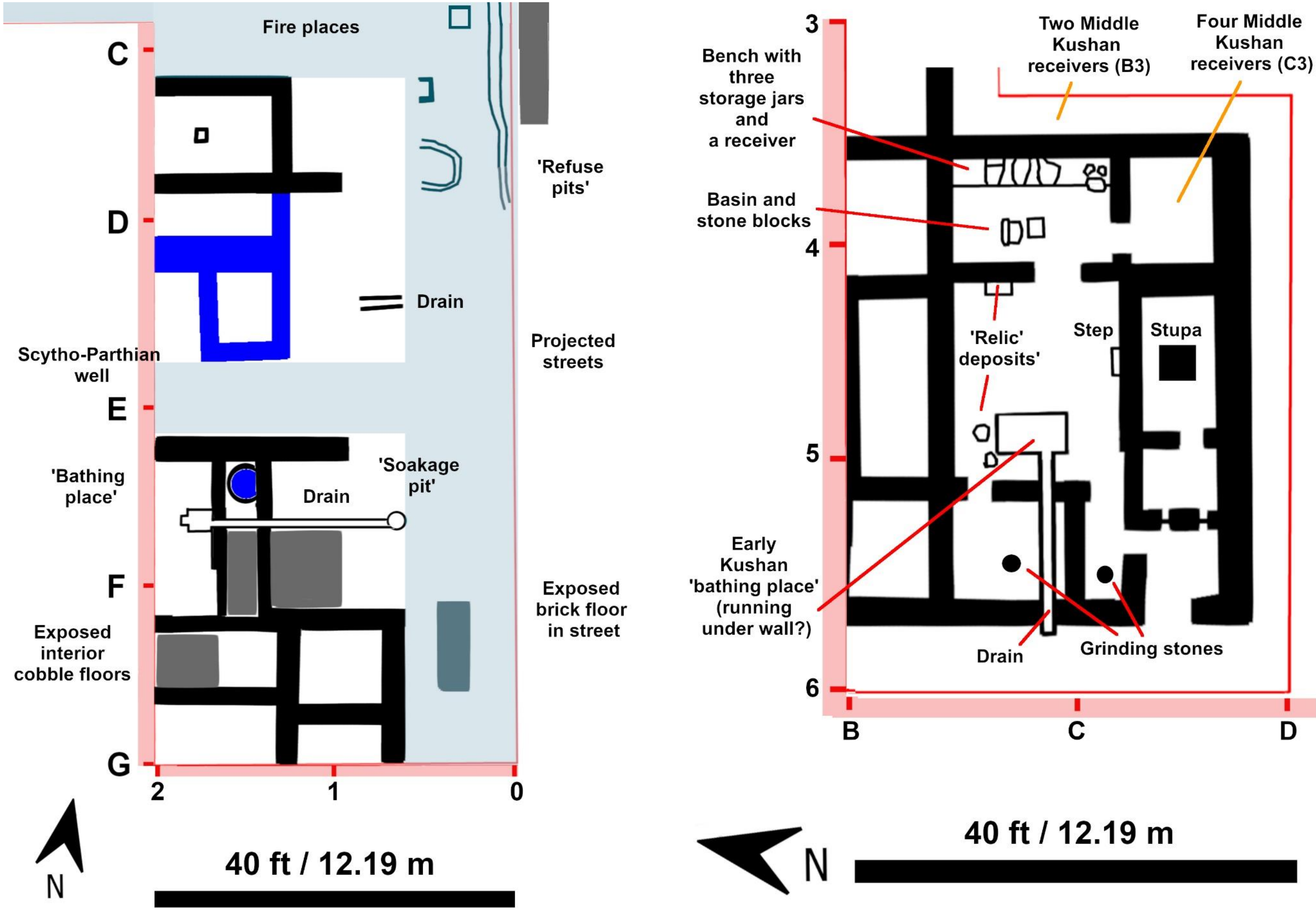
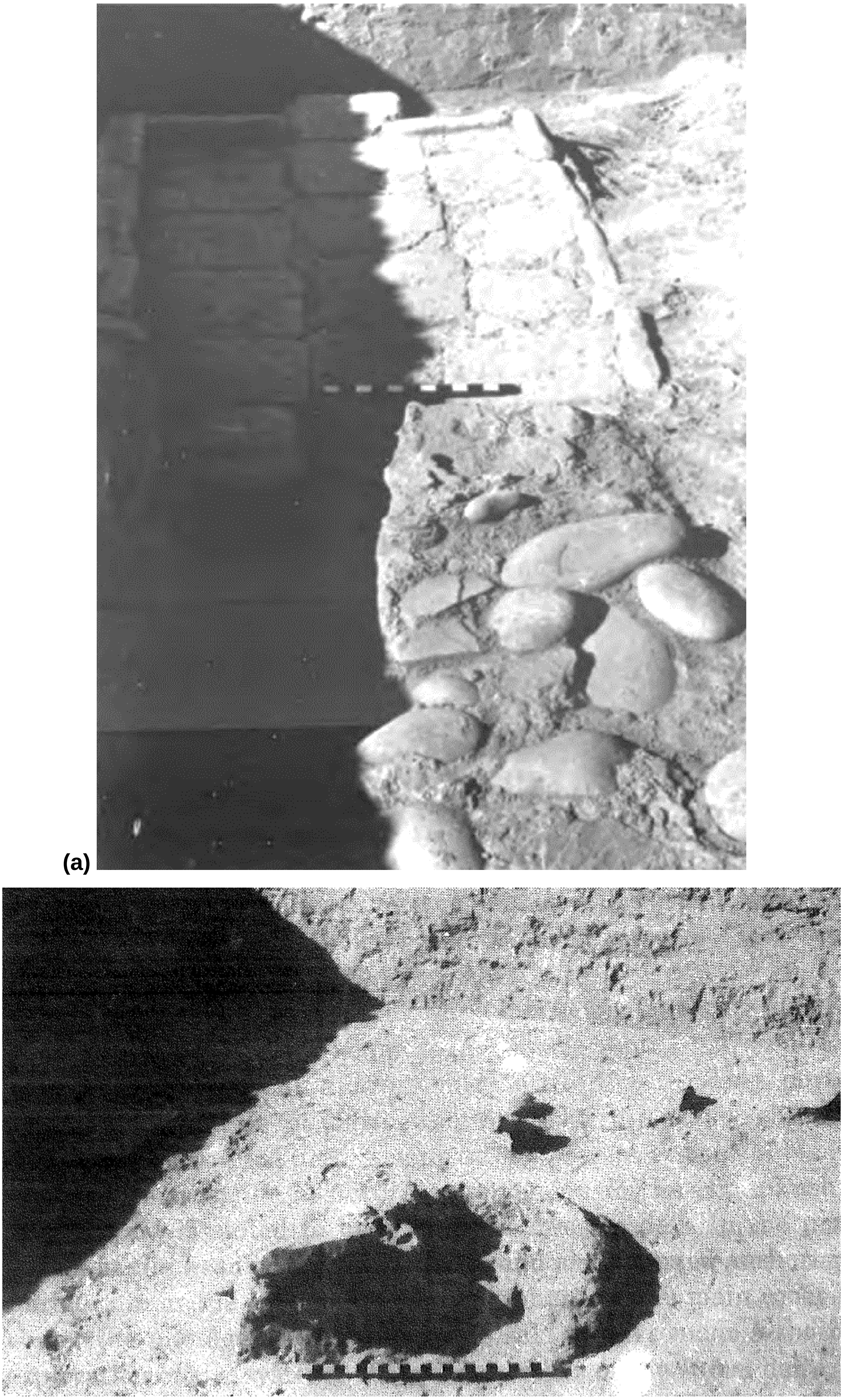


Figure 29. *Reconstruction of the 'distillery' (left) and 'House of Naradakha' (right) at Shaikhān Dherī based on descriptions, plans, and assemblages recorded by Dani (1966), Allchin (1979a, 1979b) and Husain (1980, 1992, 1993) (plans by the author). Note that the scale is in feet (converted to metres) following the layout of the original excavation grid.*

Husain built on the distillery interpretation in his targeted case study (Husain 1993), consolidating pottery from each square and cultural phase to develop a functional analysis of the rooms or building divisions. While agreeing with Allchin's interpretation, he noted certain discrepancies within the characterisation and reported vessel numbers. Notably, within Square E0 of the distillery, Allchin had recorded 16 receivers (ALLCHIN-1) while Husain noted four (Husain 1993, p. 303). This is a significant difference considering the distributed pottery within the single area (see Husain 1980), illustrating the ambiguity in the fundamentals of the receiver-condenser vessel characterisation. Furthermore, the connections that features within the area designated as the distillery and its surrounding locales have with distillation other than being recorded as involved in the distillation process are unclear (Allchin 1979b, 1979a). The noting of a 'bathing place' (a possible stone lined tank) in Square E1 as part of the complex (Figure 30a) is, for instance, not elaborated upon other than potentially suggesting a connection to distilled products considering its inclusion in the 'distillery' (see Husain 1993). Husain agreed with Allchin's interpretation, adding that alcohol distillation was "the only plausible explanation" (Husain 1980, p. 140), further noting that a room in Square C1 with its concentration of pottery and a fireplace (Figure 30b) must have held a function "similar to a pub in western society" (Husain 1993, p. 305). Hence, the area immediately around the 'distillery' was also used in the process of distillation (Husain 1980, p. 225).

The ritualistic 'House of Naradakha' at Shaikhān Dherī, identified as a 'Buddhist teacher's dwelling' (Dani 1966, pp. 28–29) or 'Buddhist urban shrine' (Allchin 1979b, p. 777) also acted as a feature connected to alcohol distillation at the site. Confined to areas B3, B4, B5, C3, C4, and C5, the 'House' produced Gandhāran sculptural remains in association with food storage paraphernalia (Husain 1992a). In the storeroom (Figure 31a), several Middle Kushan stamped condensers were found, alongside five large storage jars on an earth platform. Two grindstones, one in the centre of 'Room 31' and another in the western corridor (Figure 31b), were also noted, though no specific reason given for their presence. A second 'bathing place' dated as an Early Kushan feature was also noted within the structure (Allchin 1979b, pp. 777–778). Allchin noted in his interpretation a connection between the 'House' and ritualistic alcohol production or consumption (Allchin 1979b, pp. 778–779), though this was not a new interpretation with his publications; one receiver found along with storage jars on the platform was determined by Dani to be an configuration for measuring liquids (Dani 1966, p. 197). However, combined with the excavation of drinking bowls in the immediate area of the 'House', Allchin suggested that Shaikhān Dherī had a function specific to alcohol production and consumption, and that condensers were employed in either distillation process or for storing wine across the site, some in a ritualistic context (Allchin 1979b, p. 779).



(a)

(b)

Figure 30. *Features within the area of the 'distillery' seen to be connected to distillation: (a) the 'bathing place' in Square E1 (Husain 1980, pl. 9.3) and (b) fireplace or hearth in Square C0 (Husain 1993, p. 313).*

Figure 31. *Features within the 'House of Naradakha': (a) the storage room with jars on an earthen platform (looking north) where several Middle Kushan stamped receivers were found (Allchin 1979b, p. 778); (b) grindstone in the western corridor (Husain 1980, pl. 8.18); a second grindstone was found in 'Room 31' of the House.*

4.3.2.3 Evaluation of interpretation

Determining an accurate number of 'receivers' as the diagnostic element of the Gandhāra distillation apparatus at Shaikhān Dherī, despite being ascribed a range of names, cannot be accurately done. Constituent parts used to represent the receiver-condenser vary; receiver spouts, tanga-stamped sherds, and large-vessel body sherds have all been used to delineate the presence of a component (e.g., Dani 1966; Allchin 1979b, 1979a; Husain 1980, 1993). Thus, numbers between accounts vary. In the context of this survey, receiver numbers were derived from Husain's original study of the ceramics (1980) aligned and integrated with his later assessment of the evidence for distillation (Husain 1993). Numbers of components, regardless, vary depending on ascribed periods, especially in comparison to Dani's original report (see Dani 1966).

Within a re-evaluation of the ceramic assemblage by Husain (1980), the count of Indo-Greek receivers (three vessels) is higher than Dani's original classification (one vessel). Dani's 'Greek' Type 11 ("…big pot for condensing water"; Cat. 11) is the earliest example (Dani 1966, p. 188) and noted to have the same body morphology, spout angle, and approximate dimensions as Ghosh's Type 73 (1948, p. 64) (Cat. 1) and Marshall's No. 127 (1951, p. 420) (Cat. 2). Dani's Indo-Scythian receiver 'Type 16' ("large water vessel with single spout"; Cat. 15), was noted to have been "found on all the levels of the excavation" (Dani 1966, p. 197) and likened to Ghosh's ascription of a 'Type 73' (Dani 1966, p. 197). However, only one example was explicitly recorded by Dani (Cat. 15) alongside one "spout of a water distiller" ('Type 38'; Cat. 18) (1966, p. 160), categorised by Husain as a 'still head' (Husain 1980, p. 142). However, the classification of a 'Kushan' "large water vessel with spout" (Type 9; Cat. 19) by Dani (1966, p. 210) is not as easy to follow. Referring to the "water condensing" typology from Taxila (Ghosh 1948, p. 64), Dani did not make a differentiation between Early, Middle, or Late Kushan vessels within the configuration and equally did not draw the same parallels with Kushan vessels from Taxila to support his view (see Dani 1966, p. 210). Although, the sample does appear to be Early Kushan by association, due to excavated area and stratigraphy corresponding with Husain's count. However, the fragmentary nature of both the archaeological materials and interpretations themselves renders the current foundations of alcohol distillation ambiguous from the material evidence alone.

Accordingly, the proportionality of each component of the Gandhāra apparatus at Shaikhān Dherī varies, where only the receiver-condensers are represented across all periods (Husain 1980, pp. 139–141). Condensing tubes are represented by one Middle Kushan example (Cat. 42). Still heads ('Type 38') are confined to two ceramic examples (Husain 1980, Sheet 5.2), one Indo-Greek (Cat. 14) and another Indo-Scythian (Cat. 18) similar to those found by

Marshall (1951) (Husain 1980, pp. 141–142). This is, however, not a universal ascription. Here, the component Dani terms a 'water distiller' is likely to be 'still head' or 'cowl' noted by others (Dani 1966, p. 197). Husain explained the lack of these items in the Kushan era, and also the general lack of 'still heads' in comparison to receiver-condensers as having been replaced with wooden versions, which would not survive in the preservation environment of the site (Husain 1980, p. 142). No detailed information on this idea is, however, provided. Dating to his ascribed I-VI Periods[40], Allchin stated that the Shaikhān Dherī examples matched Marshall's condenser (though Marshall's was not stamped), though also noting that more had been recovered in 1964 but not recorded (Allchin 1979b, p. 793). Furthermore, while Allchin claimed that a number of stamped 'condensers' had been recovered from Shaikhān Dherī during the 1963 excavations, such an ascription has limited value in demonstrating the 'condensers' as explicitly distillation apparatus components. In attempting to support a connection between the practice of stamping and wider alcohol distribution networks, specifically wine and distilled spirits, (Allchin 1979b, pp. 757–758), such an association alone does not demonstrate the presence of complete apparatus. These issues combined show that no consistent pattern for other components of the apparatus can be recognised from the Shaikhān Dherī materials, but equally a clear number of receiver-condensers cannot be determined.

Allchin's (1979a, 1979b) and Husain's (1980, 1992a, 1993) designations of the 'distillery' and 'House of Naradakha' as places of distilling and alcoholic spirit storage are also contentious. In practice, such classifications were generated based on the presence of the 'receiver-condensers' in these areas. Aside from this, there is little to support the ascription of the 'House of Naradakha' as alcoholic spirit storage otherwise, considering the grounds for the 'receiver-condensers' being questionable, and more so for the 'distillery'. Other supporting distillery features are either lacking or not fully elaborated on. However, reassessing Shaikhān Dherī as a potential distillery site is near impossible today as the area appears to have been redeveloped from at least 1993, and possibly earlier (ALLCHIN-3).

4.3.3 Barikot / Bīr-koṭ-ghwaṇḍai

The excavations at the fortified urban settlement site of Barikot in the Swat Valley are considered one of the most comprehensive archaeological projects undertaken in Gandhāra, led by the Italian Mission to Pakistan (ISMEO) and conducted over several decades (e.g., Callieri 1990; Moscatelli et al. 2016; Olivieri 2018; Olivieri et al. 2019; Maritan et al. 2020). With extensive detailed analysis and accurate systematic excavation, seminal recent studies

[40] Allchin saw these periods as Early Indo-Greeks to Late Kushan (Allchin 1979b, 1979a).

on Barikot and its significance have explored how the city has changed and evolved over centuries (Callieri 1990, 2020; Iori 2018; Olivieri 2018, 2020b; Olivieri et al. 2019). Synthesising such a history goes beyond what can be detailed here, though its extensive ceramic record has been used as the basis by which to unify features with other sites in the region. Accordingly, the excavations have also produced several elements of the Gandhāra apparatus following characterisations at Taxila (see 4.3.1) and Shaikhān Dherī (see 4.3.2).

4.3.3.1 Relevant site chronologies, excavation history, and archaeological contexts

In recent years, Barikot has acted as a key archaeological site for evaluating the impact of Hellenistic cultural influences upon the Indian Subcontinent (Callieri 1995, p. 293) (Figure 32). Within broad historical narratives, the site is recognised as the 'Greek' city of Bazira/Beira mentioned by the historians of Alexander though such an attribution cannot be proven (Olivieri et al. 2019, p. 148). Evidence for distinct Hellenistic and Indo-Greek phases of the site have, however, been observed, represented predominately by a fortification wall dated to the 2nd c. BCE (Callieri 1995, pp. 302–304). As a result, Barikot experienced numerous turbulent changing empires between 500 BCE - 500CE, though like many archaeological sites in the region, its chronology has been determined by diagnostic sherds used to relatively phase the site within an exclusive context (Olivieri 2018, p. 124; Olivieri et al. 2019). Crucially in the last decade, the fortification has been, however, corroborated with radiocarbon dates and revised, providing more explicit dates for Achaemenid, Mauryan, and Indo-Greek phases in Gandhāra (e.g., Olivieri et al. 2019).

While the defensive fortification has been considered a typical Hellenistic example (Callieri 1995, p. 303), Barikot appears to have had its own localised pottery tradition contemporaneous to the fortification's earliest phase. Such a craft amalgamated forms common to other Graeco-Bactrian sites, such as those from Ai Khanum, but also integrated regional Swat protohistoric pottery traditions like the Northern Black Polished Ware (NBPW) (Callieri 1995, p. 304, Olivieri 2018, p. 128; see also Chapter 3). Pottery production techniques in Barikot appear to be the unique to the area with local innovations in manufacture and decoration that appear across the whole chronology of ceramics (Olivieri 2018, pp. 128–129). Equally, through contact the Mediterranean world since at least the 4th c. BCE, it has been argued that a form of imitated Attic black glaze pottery emerged at Barikot in the 2nd c. BCE (Maritan et al. 2020), signifying a perceived Greek influence at the site. This interpretation is supported by the identification of Hellenistic luxury forms in later periods (e.g. the Saka-Parthian phases of the site; 50 BCE - 50 CE) and replications of quintessentially Hellenistic pottery forms represented in the pre-urban contexts (Olivieri 2018, pp. 130–134).

Figure 32. *Locations of excavated trenches at Barikot (Olivieri 2020b, p.6; fig. 2).*

4.3.3.2 Characterised distillation apparatus

Eleven items from Barikot (Cat. 53-63) have been characterised in previous research as connected with distillation (see Callieri 1990, 2020; Moscatelli et al. 2016; Olivieri 2020b). Quantities of individual vessels at the site are noted to have been difficult to record due in part to crossover in reported numbers of fragments within single contexts (Callieri 2020, p. 6) and mixing of sherds following damage to the site storage during an earthquake in 2005 (Olivieri 2020b, pp. 10–11). Further, it is unclear if 'receivers and 'distillers' recorded in the 1990s (see Callieri 1990), and those on display in the Swat Museum (Cat. 56-58), are included in the most recent catalogues of pottery from Barikot (see Callieri 2020; Olivieri 2020b). Numbers of vessels detailed within the Catalogue, therefore, must be considered in the context of such an issue.

Most components derive from the Kushan era providing some semblance of period consistency despite being recovered from differently identified rooms across the site (Cat. 53-55; 57-60; 63). Further, it is worth noting that the non-receiver-condenser items, the 'boiler' (Cat. 53) and 'pipe' (Cat. 54), were found in different trenches (Trenches BKG 3 and 4). Only the pipe shares the same trench as a receiver-condenser (Cat. 59) (BKG 4), though both come from differing periods. The condenser from Temple B, Court 1710 (Cat. 60), is, however, of particular note (Figure 33) due to having been recovered in situ in the vicinity of a rectangular tank (Figure 34) (Trench BKG 11) (Moscatelli et al. 2016, p. 52; Olivieri 2020b, p. 35). This is deemed to have parallels with the 'House of Naradakha' from Shaikhān Dherī (see 4.3.2), considering that a quantity of receivers were also found next to a 'bathing place' (Moscatelli et al. 2016, p. 52). Furthermore, a 'Stele of Hariti' was also found in Court 1710 at Barikot similar to one in the 'House of Naradakha' at Shaikhān Dherī (e.g., Dani 1966, p. 29), seen to be indicative of ritualistic wine consumption practices in the building complex (Moscatelli et al. 2016, pp. 52–53). Moreover, the condenser (Cat. 60) reportedly matches Kushan and Late Kushan examples from Shaikhān Dherī (Period II/I) (e.g., Allchin 1979b, p. 769), justifying a comparison between the two sites and associations that the receiver-condensers have with such rectangular tank features. One museum collection specimen (Cat. 57) is also of Kushan date and displays a *tanga* (*tamgha*) stamp on the exterior (Callieri 1990, p. 686). Interestingly a 'mini condenser' (Cat. 55) was also recovered from the site that resembles the Indo-Greek receiver from Shaikhān Dherī, but is dated to the 3rd c. CE (Late Kushan) (Callieri 2020, p. 582). Indo-Greek (Cat. 61) and Saka-Parthian (Cat. 62) receiver-condensers, have, however also been recovered from Barikot from the same Trench (BKG 5), dating from the 2nd c. BCE to 2nd c. CE (Callieri 2020, p. 549), however, these are not explicitly recorded in the most recent pottery catalogue from Barikot (see Callieri 2020).

***Figure 33**. 'Condenser' from Temple B, Court 1710 at Barikot (Olivieri 2020b, p. 191).*

***Figure 34**. 'Receiver-condenser' from Temple B, Court 1710 found in situ alongside a tank at Barikot (photograph by Luca Maria Olivieri, in Moscatelli et al. (2016, p. 59)).*

4.3.3.3 Evaluation of interpretation

The typological classification of distillation apparatus at Barikot follows previous ascriptions from Taxila and Shaikhān Dherī. While the items do not necessarily offer anything different from what has been noted already in terms of morphology, the ‘mini receiver (Cat. 55) diverts from the trend and appears to be the only example in the region, though little can be said about the vessel’s function in relation to distilling. Further, the consistency of finding another Kushan receiver in context with a ‘bathing place’, like evidence from Shaikhān Dherī, strengthens the connection between these two elements. However, despite all components being found at Barikot, they are not in direct association with one another to justify a complete apparatus configuration. Furthermore, while a consistent pattern can be noted between the Kushan receiver-condensers, the same cannot be said for the individual Indo-Greek and Saka-Parthian receiver-condensers that have been recorded (Cat. 61-62).

4.3.4 Other isolated examples and characterised distillation apparatus configurations

In addition to the three main sites, several isolated examples of apparatus components have been reported since the Gandhāra reconstruction was first suggested, with various interpretations and morphological comparisons used to justify reported examples (Table 6). The majority of these were noted by Allchin as stamped and unstamped Kushan examples of receiver-condensers (1979a, 1979b) (Cat. 64-65, 67-68, 77-79), though these equally have been ascribed different periods, phases, and date ranges. Additional identified ‘still heads’ (Cat. 72-73, 76) have also been noted, though arguably have less date range and periodisation consistency. Furthermore, the ascription of specific cultural phases and date ranges is not agreed upon, with several researchers providing different periodisations of components. The chronological variability is, therefore, wide across examples from other sites. Moreover, certain components (e.g., Cat. 74-76) are given large chronological bounds; neatly connecting them to specific periods and cultural phases is misleading. Hence, as the date range of these sites and their individual chronological phases are vastly different, the justifications for classification are rarely elaborated on. Similarly, the volume of reported information from the sites varies, rendering complete evaluations of typological groups difficult to develop (see Catalogue references for detail on sites).

Period	Approximate date range	Site	Cat. number(s)
'Pre-Indo-Greek'	Pre-3^{rd} c. BCE	Brahmagiri	76
Indo-Greek	3^{rd} - 1^{st} c. BCE	Bala Hisar, Charsada	64
		Damkot	65
		Aziz Dheri	66
		Tulamba	67, 68
		Sahri Bahlol	69
		Akra, Bannou District	70
		Begram	78, 79
Indo-Scythian, Scytho-Parthian, and Saka	1^{st} c. BCE – 1^{st} c. CE	Aziz Dheri	66
		Begram	78, 79
Kushan	1^{st} – 4^{th} c. CE	Damkot	65
		Tulamba	67, 68
		Rang Mahal	77
		Bala Hisar, Charsada	64
Unknown (see Catalogue)	Unknown	Unknown	71
	6^{th} – 3^{rd} c. BCE	Hastinapura	74, 75
	2^{nd} – 1^{st} c. BCE	Bala Hisar	64
	300-200 BCE	Ahichchhatra	72
	100-350 CE	Ahichchhatra	73

Table 6. *Reported chronologies of other isolated apparatus components (see Catalogue for specific details on ascribed date ranges and periods). Note some items are repeated due to being allocated multiple date ranges and chronological ascriptions by differing researchers.*

The identification of other isolated components pre-dates Allchin's wide reporting in his dialogue on early distillation in South-Central Asia (1979b, 1979a). As a researcher into the origins of Indian science, Mahdihassan (1972, 1979) presented a review on the reconstruction of distillation apparatus from selected artefacts and archaeological sites as part of an explanation for their suitability in alcohol distillation. Here, he suggested that aspects of Marshall's distillation kit, particularly the still head or 'cowl', were in abundance across the region, evidenced by vessels from Sirkap (Cat. 4-5), Brahmagiri (Cat. 76), and Ahichchhatra (Cat. 72-73). Mahdihassan dated such vessels to various points in the 1^{st} millennium BCE, but failed to provide specific data to support this attribution (Mahdihassan 1972, pp. 163–165). His arrival at these comparisons, therefore, lacked necessary detail evidenced in the original literature. Ghosh and Panigrahi (1946), in publishing the excavation report on Ahichchhatra, first classified Mahdihassan's characterisation of a 'still head' as a spouted cooking pot with a burnt base dating between 300-200 BCE (1946, p. 43). Mahdihassan's explanation ignored detail such as the specific compositional and thermal properties of the cooking vessel and its sooted base, generalising the pot instead as a morphological form. Equally, there appears to be only one example of the still head from Ahichchhatra (300-200 BCE) that morphologically differs greatly from other examples noted through the survey (Cat. 72). This is hardly the “abundance” reported by Mahdihassan, but still presented as a widespread typological ‘fact’ (1972, 163-165).

This is not, however, an issue unique to Mahdihassan’s work. Within his interpretation of the material at Shaikhān Dherī, Allchin noted numerous sites that had evidence of characteristic, and in some cases regionally distinctive, receiver-condensers (Allchin 1979a, p. 61). Damkot (Cat. 65), Tulamba (Cat. 67-68), Rang Mahal (Cat. 77), and the Bala Hisar at Charsada (Cat. 64) were all noted to have examples, supported in part by the work of Husain (1980). In the most part, receiver-condensers within this group have been represented either by a single isolated spout fragment or body sherd, which could be considered as not reliably indicative of a complete, very specific vessel. It is only Rang Mahal (Cat. 77) that has provided the most complete example of a receiver-condenser, which shares morphological similarities (position of spout, body *tanga* stamping, and two-part body luting forming technique) with Kushan examples from Shaikhān Dherī.

Other forms of receiver-condenser have been reported that do not match the previous shared characteristics identified from Sirkap, Shaikhān Dherī, Barikot, and Rang Mahal. The examples from Begram in Afghanistan (Cat. 78-79), while noted as receivers, share very few morphological features with any other examples in the survey (squatter, wider spout, and lower spout position on the vessel wall), and were in their original interpretation identified as ‘churns’ (Ghrishman 1946, p. 193) (see also Figure 22d). The extensive *stūpa* and settlement site of Aziz Dheri (Nasim Khan 2007, 2010b, 2010a) has reportedly yielded several ‘condensers’ (G. R. Khan, pers. coms. 10th June 2019) (Cat. 66). However, further detail cannot be established. Two more samples of suggested distillation apparatus are also held in the British Museum’s collection from Akra (2nd – 1st c. BCE) (Cat. 70) and Sahri Bahlol (3rd-2nd c. BCE) (Cat. 69), both considerably different from one another. They are, however, strikingly smaller than any other characterised receiver-condenser form aside from the miniature variation at Barikot (Cat. 55). Allchin equally drew parallels between the example from Sahri Bahlol (Cat. 69) and the material from Shaikhān Dherī, classifying it as a ‘mini receiver’ and linked with another example held by the University of Peshawar (Cat. 71) (ALLCHIN-2, ref. Peshawar Uni).

Despite the issues with his identification of supposed apparatus components, Mahdihassan mentioned a different reconstructed distillation configuration that he dated to at least 300 BCE (and as early as 6th c. BCE), found across “Indo-Pakistan” (Mahdihassan 1972, 1979). The ‘vertical configuration’ replicated contemporary distillation units made of modified domestic vessels in Bihar, India (Mahdihassan 1979) including a specialist pot with a series of perforations in its base (Figure 35). The arrangement (and reconstruction) largely matched the ‘Mongol still’ apparatus as classified by Needham et al. (1980) (see 2.3.3), though instead it may be more reasonably generalised as a ‘vertical still’ configuration considering the lack of detailed functional analysis of the vessels. The vertical configuration was observed by Mahdihassan from work at the site of Hastinapura undertaken in the 1950s (Lal 1954, p. 58; Mahdihassan 1972, pp. 162, 165, 1979) (Cat. 74-75). Here, Mahdihassan reassigned what had previously been identified as a vessel classified for washing rice as a condensing unit (Mahdihassan 1979, p. 265) (Cat. 75). However, the reconstruction, using categorised ‘Period 3’ grey ware vessels (6^{th} – 3^{rd} c. BCE) (Lal 1954, p. 58) was ultimately speculative. In turn, his interpretation placed great emphasis on the plausibility of certain vessels for their use in creating a distillation apparatus, especially the condensing unit, without questioning if they had been used for this purpose. Still, the configuration was of interest to Allchin, who suggested that such an apparatus could have plausibly been widespread in the past considering the lack of non-specialist items required to create it (Allchin 1979, 56). However, even with showing promise, such an interpretation is circular, in that the idea relies on the adaption of domestic vessels and reuse of them rather than specialised distillation apparatus.

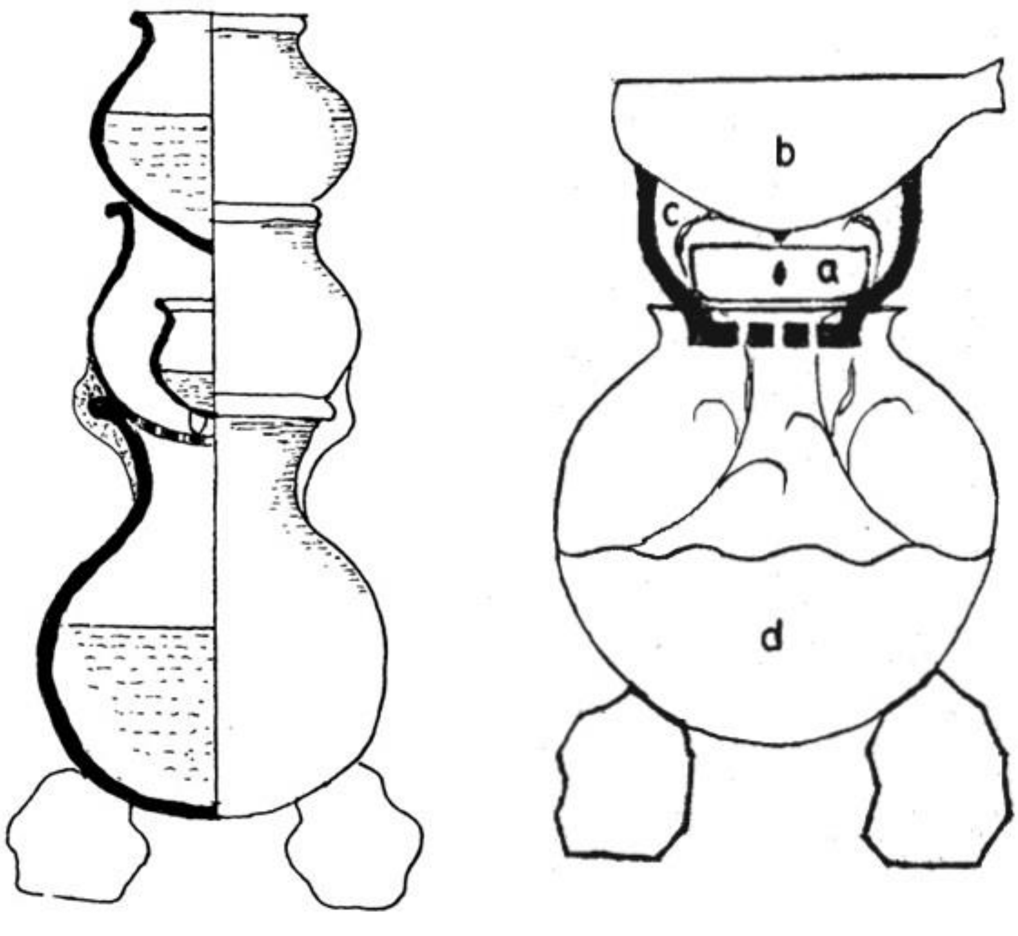
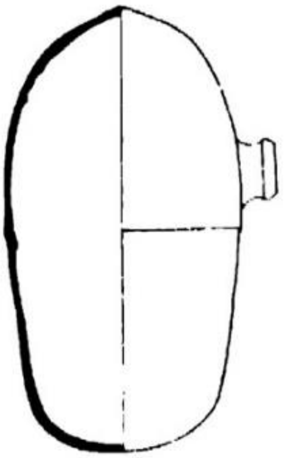


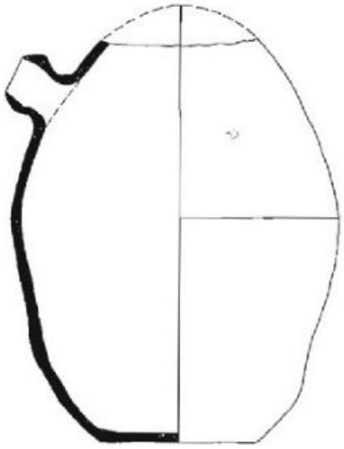
Figure 35*. Vertical still used for alcohol distillation noted in ethnographic accounts from India (left) (Allchin 1979a, p. 57) and possible still configuration based on archaeological remains from Hastinapura (300 BCE) (right) (Mahdihassan 1972, 1979).*

4.4 Discussion

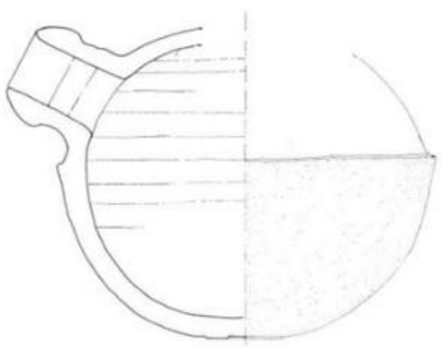
As evidenced by the survey, the range of what constitutes a distillation apparatus configuration, and its constituent parts, varies greatly beyond a consistent ‘Gandhāra tradition’ (e.g., Figure 36). While it is true that variability within technological traditions exist while maintaining a recognisable aspect (i.e., the ‘anchored’ concept) (see 3.2), the Gandhāra still apparatus has been determined from a single, non-standardised vessel (the receiver / condenser / receiver-condenser) that can neither account for a whole tradition alone nor represent it fully. The morphological variability in what constitutes the key components of the reconstruction (the ‘receiver-condenser’) across the region is substantial and varies greatly in reported numbers (Figure 36a-d). This trend began with inconsistently published characterisations by Ghosh (1948) and Marshall (1951), was continued and expanded by Allchin (1979b, 1979a) and Husain (1980, 1993, 1995), and finally adopted widely by the archaeological and science history communities (e.g., Needham et al. 1980; Park 2021). Expanding a single vessel form into a larger apparatus configuration is, therefore, a dubious association, particularly if vessels used in reconstructions significantly differ from original ascriptions. Other apparatus components apart from the characteristic receiver-condenser are much rarer and not in direct contextual association with the typological group (e.g., still heads and condensing tubes).Such a connection is weakened further considering the original range of suggested functions and characterisations of vessels that were later reinterpreted as receiver-condensers following Allchin’s expanded characterisation (Mahdihassan 1979; Khan et al. 2013; Moscatelli et al. 2016; Park 2021). Hence, a preconceived idea of a specific apparatus configuration has been repeatedly used to reconstruct distillation technology from a highly varied vessel form and inconsistent supporting finds (Figure 36e).

Information on vessel properties (e.g., clay fabrics, tempers) across all apparatus components, where detail is necessary for assessing their suitability for specific uses, is also lacking. Equally, pottery fabrics of vessels in the Taxila apparatus (see Figure 36e) varies greatly (along with morphology) and cannot be corroborated with the original reconstruction. Beyond paste colour groupings used at Shaikhān Dherī (see Husain 1980, 1990) and ethnographic comparisons on production techniques (see Husain 1992b), generalised descriptors (e.g., “red buff ware”) present in the existing interpretation of the vessels cannot account for the influence of different clays, surface treatments, and firing temperatures. While recent research in tandem with the Barikot excavations has improved understandings of local pottery fabrics and manufacture choices in Gandhāra (e.g., Iori 2018; Maritan et al. 2018; Olivieri 2018), such information cannot be directly translated to other key sites such as Shaikhān Dherī. The limits of material evidence, therefore, equally presents a series of concerns about vessel suitability that cannot be addressed.





(a) (b)



(c) (d)

(e)

Figure 36. *Demonstrating the material and morphological range in 'receiver-condensers' (see Catalogue for scales);* ***(a)*** *Marshall's No. 128 from Sirkap, Taxila (Marshall 1951, p. 420);* ***(b)*** *Allchin's earlier type condenser from square D1(9) stratum VIII, Shaikhān Dherī (Allchin 1979b, p. 770);* ***(c)*** *Allchin's (1979a, p. 61) identified receiver at Begram (Ghrishman 1946, p. 193);* ***(d)*** *receiver from Barikot (Callieri 2020, p. 550);* ***(e)*** *presentation of the original apparatus in Taxila Museum (photograph reprinted by R. Foss (https:/www.richard.foss.com); unknown original source/date). Note, an alternative 'still head' is used different from Marshall's original reconstruction (1951, p. 420).*

While the established typology by Marshall, Allchin, and Husain presents a 'standard form' of receiver-condenser, the archaeological evidence instead displays significant morphological variability. From the earliest classification at Taxila, a consistent form of 'receiver-condenser' did not exist. Indicatively, Sirkap Type 73 / No. 127 (Cat. 1 and 2) and No. 128 (Cat. 3) significantly differ in body morphology (No. 128 is elongated and not 'squat' like No. 127) and spout orientation (spout of No. 128 is perpendicular to the vessel wall) (see Figure 36a). Hence, the 'evolution' of receiver-condenser forms described by Allchin (1979b, 1979a) and Hussain (1980), while noting more examples of Marshall's No. 127 (e.g., Cat. 11 and 15), was conjectural as the foundation was not consistent to begin with. Moreover, linking back to the work at Sirkap, Allchin noted that Marshall had not provided adequate information on the association of the distillation apparatus components between one another, but was still satisfied that the strata were all datable to the 1st c. CE (Allchin 1979b, p. 771). Accordingly, correlations between date ranges, cultural periods, and specific form evolutions are not convincingly reliable. Equally, the condensing tubes noted at Sirkap, Barikot, and Shaikhān Dherī do not present a clear continuity, share few features, and have no morphological standardisation apart from being tubes (see Figures 22 and 26). Only the 'Kushan' receiver-condensers appear to be a consistent form and grouping, associated with examples from Shaikhān Dherī, Barikot, and Rang Mahal. These developed from pre-Kushan examples predominantly from Sirkap (Cat. 1-2) and Shaikhān Dherī (Cat. 11-13, 15-17), suggesting that this is a unique vessel characterisation. However, the notion of the 'receiver-condenser' is packaged with a presumptive idea about what distillation apparatus should look like (e.g., Allchin 1979b, p. 786). This association has prejudiced the way that sites such as Shaikhān Dherī have been interpreted (e.g., Husain 1993). The uncertainty in interpretation, discrepancy in vessels characterised (i.e. the differing reported numbers of receiver-condensers), and reporting of receiver-condensers from mixed and incomplete contexts brings the interpretation of a complete 'distillery' present at Shaikhān Dherī into question (e.g., Husain 1993), Thus, the classification of a 'receiver-condenser' has become an overstated loaded term.

In conjunction with issues highlighted in the characterisation of the archaeological materials, associated contexts, regional connections, and complementary supporting evidence used to justify the Gandhāra apparatus reconstruction are just as questionable. Here, lines of supporting information introduced after Marshall's original classification to bolster the interpretation of the Gandhāra still are largely unsubstantial. Allchin's translation of the Sanskrit word for 'elephant's trunk' in contexts related to alcoholic drinks (e.g., Allchin 1979a, p. 63) demonstrates how complementary evidence has been used, manipulated, and integrated to definitively 'prove' the existence of the apparatus. As critiqued by Oort (2002) and McHugh (2014, p. 32), Allchin had directly compared the preconceived Gandhāra still morphology to an elephant's head to suggest that visual representations of elephant-like configurations were directly related to contexts of alcoholic drinks. Further, the introduction of ethnographic data to support the Gandhāra still interpretation is clearly unreliable (see 2.4.3 for a critique of ethnography in early distillation studies). Allchin used ethnographic data from the late 19th and early 20th centuries to suggest that distilling alcohol was 'ancient' in South-Central Asia. The rationale here saw that "primitive people" would not learn more modern methods (e.g., Von Fürer Haimendorf 1943; Allchin 1979a, p. 56) and instead use stills closely resembling that of the Gandhāra still reconstruction (McHugh 2014, p. 32). Hence, for Allchin, ancient distillation practices operated as a "cottage industry" (Allchin 1979a, p. 56) in a similar way to how rural alcohol distillers operated prior to the establishment of European distilleries across South-Central Asia from around 1835 (Allchin 1979a, p. 56). Thus, the colonialist undertone in his argument is intensified further by false and biased assumptions embedded in the ideas derived from ethnographic accounts.

The spread of the Gandhāra still as a coherent tradition across South-Central Asia from major centres such as Taxila and Shaikhān Dherī to other peripheral areas which created their own distinctive variations is implicit throughout interpretations of the reconstruction though seldom explicitly stated (e.g., Allchin 1979a, p. 61). Hence, using data comparatively from sites with a high reported number of receiver-condensers (e.g., Shaikhān Dherī) versus those with one instance (e.g., Rang Mahal) to support such a narrative is misleading. This issue is then compounded by the problematic chronological discrepancies, ascribed cultural groupings, accepted certainty of the interpretation that are directly tied to the material. In turn, a legacy of typological characterisation has been created, justified through questionable applications of literary and ethnographic observations, and broadly adopted across the region to delineate further examples of apparatus components. Subsequently, sub-regional variations of a receiver-condenser within the Gandhāra tradition have been identified on an accepted but debateable interpretive basis.

The lack of detail relating to technical practice is equally unaccounted for within the existing interpretation of the Gandhāra distillation tradition. Such lines of evidence are useful in supporting reconstructions of technological practices based on archaeological materials and help illuminate the human dynamics of technology (see 3.2). Practice-based insights, however, are absent from current technological reconstructions of the 'Gandhāra still', apart from superficial explanations to justify a preconceived idea based on modern distillation processes. Notably, the varied modes of heating, while widely noted as vital for the success of distillation (see 2.2), are not elaborated upon. Marshall's reconstruction proffering the use of a tripod (Marshall 1951) and Allchin's lacking of a complete and detailed suggestion (Allchin

1979b, 1979a), therefore, do not provide sufficient information to draw conclusions on distillation ability. Detail on cooling strategies necessary to facilitate alcohol distillation (Gwei-Djen et al. 1972, p. 73) are equally as opaque, aside from references to cooling in a basin and through changing cold cloths to act as the condenser, again tied to ethnographic examples (Allchin 1979b, pp. 770, 784). This trend continues in how Mahdihassan (1972, 1979) created his vertical configuration interpretation and the assumed elements involved in its assembly, where superficial applications of ethnographic information were used to explain distillation apparatus within totally different environments and contexts (see Gosselain 2016, p. 221). Thus, the dominant explanation of the Gandhāra distillation tradition neither fully accounts for the implications of the craft practice that underpins the technology nor offers insight into technological innovations that stem from the practice itself. Such elements can only be understood through working directly with a complete reconstruction and not hypothesising on a series of disembodied artefacts. Hence, the acceptance of the 'Gandhāra tradition' narrative, its integration into regional archaeological work (e.g., Spengler et al. 2020), and consideration as one of many emerging distillation technologies (e.g., Needham et al. 1980; Park 2021) is prolific but grounded in a problematic synthesis of information and evidence.

4.5 Summary

The case of supposed early distillation apparatus in South-Central Asia represents many of the problems inherent in studies into early distillation more generally. It highlights the issues of starting from preconceived ideas on object function, relying extensively on textual and ethnographic evidence, and is indicative of archaeological problems that manifest themselves in discussions of technical innovation. The survey and compiled catalogue have demonstrated how a single interpretation underpinned by assumptions and speculative ideas has been widely applied without critical consideration. Instead, the body of work demonstrated the perpetuation and enhancement of a typological characterisation that has been repeated irrespective of the available archaeological evidence. How such a reconstruction shapes broader ideas on technological change in the region, and its place in formulating global narratives on the spread of innovations, should be recognised.

As such, the suggested early distillation apparatus in South-Central Asia should be scrutinised more thoroughly through active experiment to discern a set of parameters that could implicate the functionality of the reconstructed configurations. Allied to this, insights that can be gained into craft practice, sensory considerations, and operational dynamics that reveal themselves through use can be explored through such an experimental study. The following two chapters will, therefore, present critical operational concerns with apparatus reconstructions and preliminary ideas on early distillation practices. Established through working with suggested still reconstructions from Gandhāra, a holistic understanding of the craft dynamics behind using specialist apparatus can be developed that is not fixated on justifying a single interpretation of object function.

Chapter Five

Preliminary Experimental Trials

5.1 Introduction

In establishing how early distillation in South-Central Asia has been characterised from archaeological evidence, a series of preliminary experimental reconstructions were carried out to determine the viability of suggested apparatus configurations when following archaeological reconstructions and earlier experimental studies. In previous research, reconstruction has been frequently used to confirm, rather than evaluate, the interpretation that an early form of distillation developed in Gandhāra (e.g., Butler and Needham 1980). Moreover, the interpretation is primarily rooted in typological characterisations supported by hypothetical assumptions on use. This is not to conclusively state that reassembled artefacts could be a viable distillation apparatus configuration, but rather demonstrates how current archaeological evidence has not been approached through an adequate framework of critical evaluation (see Chapter 4). Thus, reconstruction has not practically tested fundamental assumptions on how the reconstruction operated. Hence, the focus on presenting distillation as a specialised activity in South-Central Asia correspondingly illustrates how experimental reconstruction is underutilised as an analytical tool for illuminating functional dynamics, technical details, and practical implications of early apparatus configurations.

Closely simulating interpreted configurations from Gandhāra as an initial exploration was first undertaken using appropriate ceramic materials, taking into consideration identified weaknesses in existing archaeological interpretation (see Chapter 4). The programme comprised a comparative set of water distillation runs using the prominent apparatus configurations from South-Central Asia - the vertical configuration suggested by Mahdihassan (1972, 1979) and Gandhāra still reconstructed originally by Marshall (1951) - to determine the distilling viability of the configurations. Preliminary water distillations using reconstructed ceramic apparatus aimed to identify the ability for different configurations to distil following the interpreted configurations within a controlled environment (i.e., a laboratory). Water was used for distillation as it is both cited as a use of the apparatus in question and in early distillation more widely (see Chapter 2). Alcohol distillation is, however, noted as a prominent use of the apparatus in the region and central to several interpretations of sites (see Chapter 4). However, strict regulations, laws, and constraints surrounding alcohol distillation in the United Kingdom has implications for exploring this option within conditions that would be relevant and ‘authentically’ appropriate (e.g., distilling alcohol outdoors and heated with a fire-lit hearth) (see Appendix 4 for specific UK distilling legislation). Therefore, by limiting research to water distillation as an exploratory context, and to maintain a series of variables for comparing the configurations, distillation run times were fixed, with temperatures of specific components in each configuration continually measured and using different distilland volumes in each run. This was deemed to be suitable to adequately establish the heating and heat retention properties of the apparatus and allowed a range of factors to be explored beyond just testing one variable per distillation run. As it was not the intention to determine conclusively if the configurations would work, multiple repetitions of each variable were not undertaken so that a series of potential issues could instead be identified within the limited timeframe of the project.

Additionally, conducting the preliminary study presented an opportunity to establish a means of gathering experiential impressions on early distillation practices that emerged through working with reconstructed ceramic configurations closely resembling archaeological examples and artefacts. Initial sensory and experiential factors that would be of use in aiding interpretation on the pragmatics behind early distillation helped to provide an idea on human actions and decision-making involved in early distillation. How the apparatus responded and changed through use was also noted, considering the recognised need to fully understand the nature of practice within technological interpretations (see Chapter 3). Furthermore, functional issues pertaining to distillation operation could be established to form a series of experiential and sensory interactions, indications, and implications for distillation that underpin the technological practice.

Testing parameters were informed in conjunction with experienced practitioners in distillation from Locksley Distilling Co. Ltd. Combined, this body of information determined the influence of time on distillation ability of the equipment and distillate volume, generating comment on the ability of each configuration to maintain a constant temperature and promote consistent vapour condensation. Factors implicating distillation rate and process with ceramic apparatus could therefore be ascertained and provide a comprehensive justification for further experimentation with insights brought forward to shape future experimentation.

5.2.1 Overview

The preliminary experimental trials aimed to establish factors that influenced the use of distillation apparatus configurations for water distillation. Experiments were undertaken in the Department of Archaeology’s Material Science Laboratory between April 2019 to July 2019 (creating the apparatus), and September 2019 to September 2020 (distillation trials). Due to the COVID-19 pandemic, experimentation and familiarisation with the apparatus was significantly delayed and had to be streamlined. Originally, a period of learning and familiarisation was planned to allow for specific functional foci to have been ascertained for targeted assessment within the preliminary study, such as detailed insights on heat exchange within the apparatus. Instead, this was abandoned in favour of using the preliminary study to identify plausible areas of assessment that would be centralised in the following stage of experimental study and identify broader functional parameters (see Chapter 6). Hence, considering the restructuring of the preliminary study, trials were divided into three stages following the construction of the apparatus:

1. Instrumentation trials to determine an appropriate measurement recording and apparatus heating strategy (see Appendix 5 for methodology and results).
2. Preliminary exploratory trials with the vertical apparatus, following its published reconstruction (Mahdihassan 1972, 1979).
3. Preliminary exploratory trials with the Gandhāra apparatus with its suggested condensing methods (see Chapter 4).

5.2.2 Creating the experimental apparatus

Working with experienced potters and ceramics specialists, replica versions of the distillation apparatuses were made for experimentation and certain technical impressions on manufacture were gleaned from this process to build an understanding of the practical issues surrounding the creation of the apparatus itself. Aside from specific individual components unique to each configuration (Table 7), both apparatus configurations used the same still body to save time during manufacture. The vessels (Figure 37) were made by the author with archaeologist and experienced potter Gareth Perry (Figure 38) as 1:1 scale replicas where possible using terracotta 20% sanded red (GVR20) clay and additional sand temper (calcite-free sharp sand, grain size ~ 0.2–0.63 mm). Vessels were left to dry for a week before firing so that any weaknesses in the ceramic could be noted. Vessel volumes and tube surface areas were calculated based on assuming a consistent shape across the whole vessel and therefore must only be taken as an approximation due to variations when creating hand-built and thrown ceramic vessels and varying vessel wall thicknesses (see Table 7).

Vessel	Configuration	Mass of clay used (kg) (approx.)	Dimensions (cm)	Volume (ml) (approx., as spherical bowl)	Drying time	Firing duration and temperature
Still body	Vertical and Gandhāra	7	19 cm wide (at rim), 31.4 cm (at shoulder), 30 cm deep, 1.6 cm wall thickness	Maximum capacity to rim of 13200 ml	7 days	1. Increase 100 °C every hour until reaching 600 °C 2. Increase 200 °C every hour until reaching 1050 °C 3. One hour settle and stabilisation period 4. Natural cooling period
Perforated mid-vessel	Vertical	2.5	20 cm wide (at rim), 10.4 cm deep, 0.8 cm wall thickness	2222 ml		
Spouted bowl (condenser)	Vertical	2.5	20.5 cm wide, 8.4 cm deep, 1.2 cm wall thickness	1696 ml		
Catch bowl	Vertical	1	10 cm wide, 3.3 cm deep, 0.7 cm wall thickness	148 ml		
Still head (body) (1)	Gandhāra	4	21 cm wide, 10 cm deep, 0.6 cm wall thickness	2256 ml		
Still head (body) (2)	Gandhāra	5	25 cm wide, 13 cm deep, 1.5 cm wall thickness	4342 ml		
Still head (body) (3)	Gandhāra	5	25 cm wide, 16 cm deep, 1.5 cm wall thickness	6072 ml		
Still head (spout) (1)	Gandhāra	0.5	5 cm wide, 14 cm length (cut down to 7 cm), 1.3 cm wall thickness	Min. internal surface area approx. 149 cm^2		
Still head (spout) (2)	Gandhāra	0.5	5 cm wide, 14 cm length (cut down to 7 cm), 1.3 cm wall thickness	Min. internal surface area approx. 149 cm^2		
Still head (spout) (3)	Gandhāra	0.5	5 cm wide, 14 cm length (cut down to 7 cm), 1.3 cm wall thickness	Min. internal surface area approx. 149 cm^2		
Still head (spout) (4)	Gandhāra	0.5	5 cm wide, 14 cm length (cut down to 7 cm), 1.3 cm wall thickness	Min. internal surface area approx. 149 cm^2		
Still head (spout) (5)	Gandhāra	0.5	5 cm wide, 14 cm length (cut down to 7 cm), 1.3 cm wall thickness	Min. internal surface area approx. 149 cm^2		
Still head (spout) (6)	Gandhāra	0.5	5 cm wide, 14 cm length (cut down to 7 cm), 1.3 cm wall thickness	Min. internal surface area approx. 149 cm^2		
Condensing tube	Gandhāra	0.5	4.8 - 3.5 cm wide, 15 cm length, 1.2 cm wall thickness	Min. internal surface area approx. 184 cm^2		
Receiver (1)	Gandhāra	5	Failed thrown vessel	Unknown		
Scaled receiver (2)	Gandhāra	5	17.5 cm wide, 22 cm deep, 1.1 cm wall thickness	8222 ml		
Basin	Gandhāra	Unknown (repurposed vessel)	32 cm wide, 27 cm deep, 1.5 cm wall thickness	21164 ml	Unknown (repurposed vessel)	Unknown (repurposed vessel)

Table 7. *Manufacture properties of replica experimental distillation apparatus components.*

(a) (b) (c)

Figure 37. *Components of apparatus configurations (experimental replicas):* ***(a)*** *vertical configuration;* ***(b)*** *drying vertical configuration individual components, top to bottom: still body, catch bowl, condensing vessel, and perforated vessel;* ***(c)*** *Gandhāra apparatus configuration (photographs by the author).*

Figure 38. *Select stages in the manufacture of the replica experimental distillation apparatus:* ***(a)*** *forming the top of the still body;* ***(b)*** *attaching upper and lower parts of the still body;* ***(c)*** *trimming the perforated vessel;* ***(d)*** *forming a still head spout and attaching it to the still head* ***(e)****;* ***(f)*** *forming the scale receiver (photographs by the author).*

The still body used in both configurations was made in two parts due to its size and as a projected form stylistically with the same capacity as those presented in the original reconstructed apparatuses rather than as a full archaeological replica (Figure 38a and 38b). This is because little information on the still body properties is given in the original vertical and Gandhāra apparatus reconstructions beyond recognising an appropriate cooking vessel for this purpose (see Chapter 4). Thus, a large water pot with cooking vessel properties was agreed as a suitable model for the replica, first throwing the top (shoulder to rim) and then the lower section and given a level base so that it would stand stable and flush on the hotplate.

According to Mahdihassan's interpretations and reconstruction (1972, 1979; see Chapter 4), the vertical distillation apparatus consisted of four individual domestic vessels arranged as a series of stacked pots. Thus, when making the reconstructed vessels, appropriate material properties of the vessels to support such a configuration had to be considered where archaeological data was not available. The perforated mid-vessel (to allow for vapour to rise through the configuration and support the catch bowl) and shallow spouted bowl used as the condenser were first made following the relevant archaeological examples. Wheel-thrown pots drawn out from their projected bases were first made slightly greater than the required dimensions to allow for shrinkage from drying and reduction during firing. Further, forming the perforated vessel before the others meant that all other vessels were fitted to its properties with slight adjustments (see Table 7). After it was thrown, the condenser vessel's spout was drawn out after a brief period of drying, and its convex exterior base[41] was rounded using a rib once the vessel was leather-hard. It was immediately noted, however, that because of its dimensions matching the archaeological example, the vessel would be sitting very low into the perforated mid-vessel. Therefore, distillate collection would be, presumably, more difficult as the condensing area would equally be considerably smaller and thus not be able to maintain a consistently cooler environment. Hence, to aid this process, two catch bowls were made to scale (Figure 37b) based on the reconstruction, one with an intermittent broken foot-ring and one without, so that vapour flow throughout the condensing area would be less restricted and hopefully increase the chance of a successful distillation. These were anticipated outcomes and significantly differed from the proposed reconstructed vertical apparatus (see Chapter 4 and Catalogue).

Detail on manufacture of the Gandhāra apparatus is known through Husain's targeted pottery studies from Shaikhān Dherī (Husain 1980, 1990, 1992b) (see Chapter 4.3.2). Several of the vessels used in the configuration were hand-built. For speed, however, it was decided that the

[41] Allows for distillate to gather at a central point and drip into the catch bowl below.

replica experimental vessels would be wheel-thrown where possible. The Gandhāra condensing tube was an exception to this, where archaeological examples morphologically varied across all sites that featured components of apparatus (see Chapter 4 and Catalogue). Furthermore, the means to connect the various components of the apparatus together varied too. Throughout the production process, however, it was noted that to create a tube small and long enough to fit two differing spouts perfectly was challenging. While potters in the past would have done this easily, the inconsistent morphology of the still head and receiver spouts across the whole region (see Catalogue) would require individually unique condensing tubes. Therefore, a 'standardised' ceramic tube which did not adhere to a single archaeological example was created to increase the likelihood of successful distillation, form an adequate seal to channel vapour, and streamline the production of apparatus. As such, the replica was made without external flanges and features exhibited on the examples so that the ceramic tube could be adapted depending on the needs of the experiment (see Table 7).

The manufacture of the receiver equally presented several challenges and key considerations. While experiments could have focussed on each individual receiver form, it was decided that later examples from Shaikhān Dherī would be used as the basis for the study as this was the most complete body of examples in comparison to earlier forms. The first attempt at forming the receiver followed archaeological methods in that two sections were thrown to scale separately then luted together with clay slip. The size of the vessel, however, caused the form to buckle under its own weight. Because of this, the subsequent receiver was made as a 1:2 scale model instead (see Table 7 for replica dimensions), thrown again as two sections and luted together with clay slip, and given a flat base to help support it in the basin. The basin was a recycled experimental vessel of correct dimensions and size to hold the scale receiver and thus be appropriate for the experiment. The receiver spout was then modelled on a later example also from Shaikhān Dherī and attached once the body was dry, cut and shaped from a larger clay tube.

The still head proved most challenging to form, as the drastic and inclined angle of the main body walls and rim would require supporting. The first attempt used an inadequate amount of clay to bring the rim and walls in enough and so had to be thrown again. The second attempt successfully produced the correct pot shape, though cracked during firing as the attached spout weighed down the wall and caused it to fracture (see Table 7). It also came to light that the angle of the rim was too everted (approximately 40°) to properly fit over the still body. The final attempt then was thrown with a less drastic inward curvature at the rim (approximately 20°) with its spout attached and fired successfully. That said, the production of the spouts individually proved difficult and required six individual attempts to be undertaken before a successful spout was made. This was because wheel-throwing a vessel appropriately narrow and tall was noted to be difficult and would often collapse during throwing due to its height and weight of wet clay. Equally, because the spout would require extra sand to act as an adequate temper and strengthen the spouts when firing, the third and fifth attempts failed primarily because the clay was either not homogenous enough[42] or too saturated with water to be worked and formed without needed to add excess sand. Before firing, however, it was anticipated that the head exterior would be trimmed at its top and upper exterior sides to round the outside base of the vessel and match the archaeological examples. However, because of the delicate fabric of the vessel, it was decided that this would not be done, thus the flat exterior base was produced on the final form (Figure 37c). This, theoretically, would not affect the distillation operation as the interior of the vessel was still concave, allowing the condensing distillate to run down the interior sides.

All vessels were fired above 900 °C as part of a stadial firing process (see Table 7) to ensure that they were watertight. Temperature fluctuations in kilns were mitigated through using a controlled heating method, though even in historical and archaeological cases regardless of geographic location, pottery kilns have been noted to consistently reach at least 700 - 900 °C (Gliozzo 2020, p. 28).

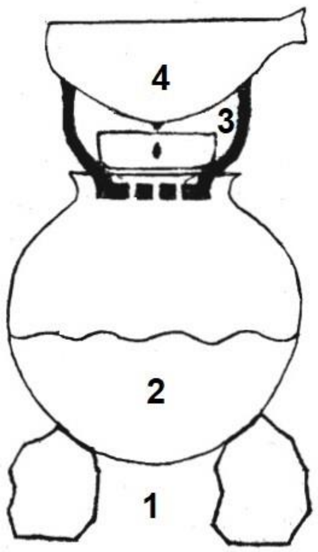
5.2.3 Methodology

Once the apparatus was made and instrumentation trials were complete (Appendix 5), a comparative preliminary experimental trial was undertaken using the vertical and Gandhāra apparatus configurations for water distillations to establish how both worked beyond their existing hypothetical reconstructions (e.g. Marshall 1951; Mahdihassan 1972, 1979). Both configurations had differing assembly and maintenance requirements considering their condensing methods. Further, the Gandhāra configuration runs used differing points of condensing (depending on the trial; see 5.3.2) due to ambiguity in the original interpretation (see Chapter 4). Thus, the trials also aimed to determine an appropriate way of condensing for each configuration.

Each distillation run lasted for four hours with a one hour cool down period. This was deemed sufficiently long enough to become familiar with the configurations, troubleshoot arising issues, and develop a detailed idea on how the physical properties of the apparatus would affect configuration heating and cooling abilities. Moreover, according to model systems, this should be a sufficient period to fully produce a measurable quantity of distillate (see 2.2).

[42] i.e., the sand was not mixed evenly.

Temperatures of the condenser, condensing chamber environment (condensing area), heat source, and distilland in the still body were all measured using Thermosense TW-KF3-1000 K-type fiberglass insulated welded-tip thermocouples (temperature range of 0 - 400 °C ± 0.75 % T) connected to a HH-520 thermocouple data logger (Figure 39) making readings at 2 second intervals to create a high-resolution dataset. Apparatus heating was maintained by a Lloytron E831SS hotplate (maximum temperature of 250 °C when under load) to both provide a consistent rate of heating and simulate the single point of heating exhibited in the original reconstructions. For each run, the hotplate started from its 'off' position and was increased to its maximum power (1500 W) immediately. Prior to use, distillation apparatus was soaked in water for 20 minutes so that the ceramic fabric was saturated to help contain liquids. The still body was then filled with the relevant distilland volume and sealed using clay and clay slip. Starting distilland volumes varied through each run: 2000, 4000, and 6000 ml distillands were used to understand the rate of heat transfer through each system and degree to which distilland could be distilled. Each volume was deemed adequate to be a minimum amount to distil in the replica still body and produce a sufficiently large and consistent distillate for measurement, equally representing the conversion rate of distilland to distillate. Further, instead of considering each run independently (as had been the case in the instrument trial), temperature data was analysed using IBM SPSS Statistics 26 using the data from each apparatus configuration. At the end of each distillation run, the hotplate with the apparatus was switched off. Temperatures continued to be recorded for a further 60 minutes to provide insights into heat retention. The distillate and remaining distilland were then collected and measured.



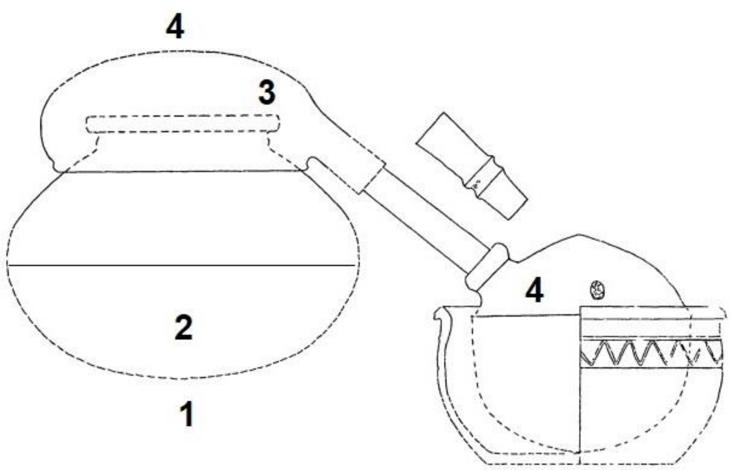


***Figure 39**. Thermocouple locations depicted here on drawings after Mahdihassan (1979) (left) and Allchin (1979b, 1979a) (right). **(1)** Heat source (in the case of experiments, a hotplate); **(2)** distilland; **(3)** condensing area; **(4)** condenser; Gandhāra apparatus utilises two points for the condenser depending on the trial (see 5.3.2).*

During the experimental trials, experiential insights were recorded at regular intervals and tied directly to the condensing strategies and interventions needed to maintain a fully pressurised environment for successful distillation (see Appendix 6 for recorded insights). These were noted at regular 15-minute intervals to help build the body of insights and determine elements of practice involved in conducting a successful distillation. Seals showing signs of breakage were periodically repaired when temperature readings were taken using clay and clay slip to maintain a consistent distilling environment. For the vertical configuration, still cooling was adjusted at 15-minute measurement intervals by manually adding tap water to the condenser[43] to maintain a consistent temperature, added until the condenser was full. Two alternative still cooling methods for the Gandhāra still were used, based on Allchin's reconstruction from ethnographic accounts (Allchin 1979b, pp. 773, 784). In the first 2000 ml run, cooling was provided through a damp cloth on the still head with the receiver placed in a water bath to promote a condensing environment, following the idea that still head cooling would be required for alcohol distillation (Egloff and Lowry 1930; Gwei-Djen et al. 1972; Allchin 1979a). The cloth was changed at each 15-minute interval and the water bath was manually topped up with tap water until reaching capacity (6000ml) prior to use. For the 4000 and 6000 ml runs, damp cloths were instead wrapped around the still head spout and ceramic tube connecting to the receiver, and placed on top of the receiver in line with ethnographic studies (Mahdihassan 1972; Allchin 1979b, 1979a).

5.3 Results

The results of both the vertical configuration and Gandhāra apparatus trials are presented here. Results are presented in subsections to display findings related to each stage of the experiment, and experiential insights related to each trial are recorded in Appendix 6.

5.3.1 Vertical configuration preliminary trials

Three water distillation runs were first carried out using the vertical configuration in the same arrangement as in the instrumentation trials (see Appendix 5) following the experimental methodology (see 5.2.3). Distillate and distillands were collected at the end of each 4-hour run and 1-hour cool down period (Table 8) and temperature recordings of individual components were compared (Table 9). It was noted that volumes of distilland remaining would be influenced by the quality of seals between components (e.g., vapour escaping and not condensing within the unit) and so would not be a fully accurate representation of percentage of converted distilland to distillate (see 2.2). All distillation runs appeared to have operated as intended but did individually present certain functional differences.

[43] Maximum capacity of 2000 ml.

Starting distilland	Distillate collected	Distilland collected	% of distilland distilled
2000 ml	43 ml	405 ml	2.15
4000 ml	32 ml	2550 ml	0.8
6000 ml	23 ml	2582 ml	0.38

***Table 8**. Remaining distillands and collected distillates post-distillation from trials using the vertical apparatus configuration.*

Measured component (distilland starting volume)	*n*	Minimum temp. (°C)	Maximum temp. (°C)	Mean temp. (°C)	SD
Heat source (2000 ml)	9001	20.5	383.1	252.8	83.3
Distilland (2000 ml)	9001	17.5	76.8	62.5	14.9
Condensing area (2000 ml)	9001	16.7	44.4	35.9	8.2
Condenser (2000 ml)	9001	18.2	25.9	22.5	2.5
Heat source (4000 ml)	9001	20.8	389.4	261.8	87.8
Distilland (4000 ml)	9001	19.6	77.8	61.2	14.7
Condensing area (4000 ml)	9001	18.4	40.8	33.4	6.9
Condenser (4000 ml)	9001	18.3	27.4	23.8	2.6
Heat source (6000 ml)	9001	21.1	398.2	260.7	86.5
Distilland (6000 ml)	9001	19.9	72.7	57.4	14.4
Condensing area (6000 ml)	9001	19.2	54.0	42.4	10.3
Condenser (6000 ml)	9001	19.4	26.0	22.7	2.3

***Table 9.** Measured temperatures of individual components within the vertical configuration.*

2000 ml of water distilland was first measured and decanted into the still body after soaking the apparatus for 20 minutes to improve the impermeability of the vessels. Once the apparatus was assembled and sealed, the hotplate was switched on and the data logger began recording. The hotplate quickly reached a maximum temperature of 383.8 °C before levelling off and maintaining a mean temperature of 252.8 °C (Figure 41). After noting damage, the body seal was repaired 75 minutes into the run, and further at 90 minutes, as distillate and water vapour were noted to be escaping through body seal. Seals maintained integrity after this repair for the remainder of the run, with the only other intervention being to fill the condenser to capacity at 150 minutes.

The 4000 ml distilland distillation run operated in a similar way and maintained similar temperatures throughout; the hotplate reached a maximum temperature of 389.4 °C and maintained a mean of 261.8 °C (Figure 41). Seals remained more consistent requiring fewer repairs throughout in comparison to the previous 2000 ml. One repair 30 minutes into the process was needed, though a less involved intervention than the two significant repairs conducted during the 2000 ml run. Towards the end of the run, vapour was noted to be escaping at one point of weakness in the seal, though no breakage could be identified. The condenser had to be refilled to capacity on two occasions, at 75 and 120 minutes, although no effect upon the condensing area was noted.

The 6000 ml run, however, presented several issues concerning seal maintenance throughout the run. When first noted at 75 minutes, seals were repaired again at 150, 210, and 225 minutes. Despite repair attempts throughout, and a superficial slip layer applied completely around the joins, vapour was still able to escape from the body seal (Figure 40). The relationship between such a point of fracture and distillate collection was not immediately apparent and could not be comprehensively identified.

Figure 40. *Slip layer applied over seals between body and condenser as an intervention to help maintain optimal distilling conditions (photograph by the author).*

Comparing the temperature readings between each run indicated how distilland starting volume influenced still operation and performance, notably at the early stages of the process. This is in relation strictly to the 4-hour distillation run time. Thus, it is possible that differing distillation run times would influence the temperatures measured within each component. Considering that heat sources were consistent with one another, the exception being that the hotplate during the 2000 ml run was operating at a consistently lower temperature than the 4000 ml and 6000 ml trials (see Figure 41), it can be assumed that a consistent temperature and heat rate was maintained throughout each run. This is because the hotplate operated under load and the total mass in the 2000 ml run was, accordingly, lower than the 4000 ml and 6000 ml runs. Yet despite each component maintaining temperatures at a similar average to one another (Table 9), evaluating the components irrespective of the heat source does display operational discrepancies between each run and starting distilland volume (Figure 42). Significantly, the still body atmospheric temperature in the 2000 ml distilland run came to a point of equilibrium faster compared to the other runs, which can be attributed to the lower volume of starting distilland. This association is reflected in the slow point of equilibrium exhibited in the 6000 ml run that maintained a temperature of 57.4 °C (Figure 42), several degrees lower than the 4000 ml and 2000 ml runs.

A similar trend was noted in the condensing area temperatures. However, the condensing area in the 6000 ml run maintained a significantly higher mean temperature (42.4 °C) than during the 2000 ml (35.9 °C) and 4000 ml (33.4 °C) runs (Table 9). That said, temperature fluctuations in in the condensing environment of the 2000 ml run were greater than the 4000 and 6000 ml runs (Figure 42), suggesting that the condensing area in the 2000 ml run was less consistent. It could not be ascertained, however, if such an inconsistency was directly affecting the volume and rate of distillate produced. Equally, the condensing area temperature lull during the 2000 ml run at 03:47:30 (43°C) to a low point of 39.7°C at 03:55:38 (which then recovered to ~ 43 °C) did not indicate a notable influence upon the other components or distillate produced (Figure 42). Furthermore, this lull could not be corroborated with any specific action, such as refilling the condenser or repairing seals.

Regardless of being unable to connect isolated temperature changes with specific operations during distillation, it is worth noting that temperature changes to the condensing area from 03:33:00 in the 6000 ml run over a 30-minute period could possibly be connected to the two episodes of repair to the body and condenser seals (Figure 42). However, despite the fluctuations and differences recorded in the condensing area, the condenser temperatures in all runs maintained similar mean temperatures at very similar points during the run. Although this is somewhat expected, the differing condensing area temperatures and starting volumes of distilland did not influence the condenser temperature throughout the runs. This is irrespective of the condensers being filled at different points within the runs, although the 4000 ml run condenser maintained a slightly higher mean temperature (23.8 °C) than the others. This intervention may be the cause of the moderately lower mean temperature of condensing environment (Table 9).

The configuration appeared to maintain temperatures consistently and was expectedly influenced by the volume of starting distilland. The rate of temperature drop in the still body (distilland temperature) once the heat source had been turned off was similar with the 6000 ml and 4000 ml runs. However, the 2000 ml run exhibited a sharper drop, which was equally reflected in the temperature drop rate of the condensing area (Figures 41 and 42). The condenser temperatures, as mentioned prior, indicated a similar rate of temperature decline irrespective of the other more drastic fluctuations and differences in components. That said, the rate of temperature decline of the 2000 ml condenser once the heat source had been switched off appeared to be somewhat sharper than during the 4000 ml and 6000 ml runs (Figures 41 and 42).

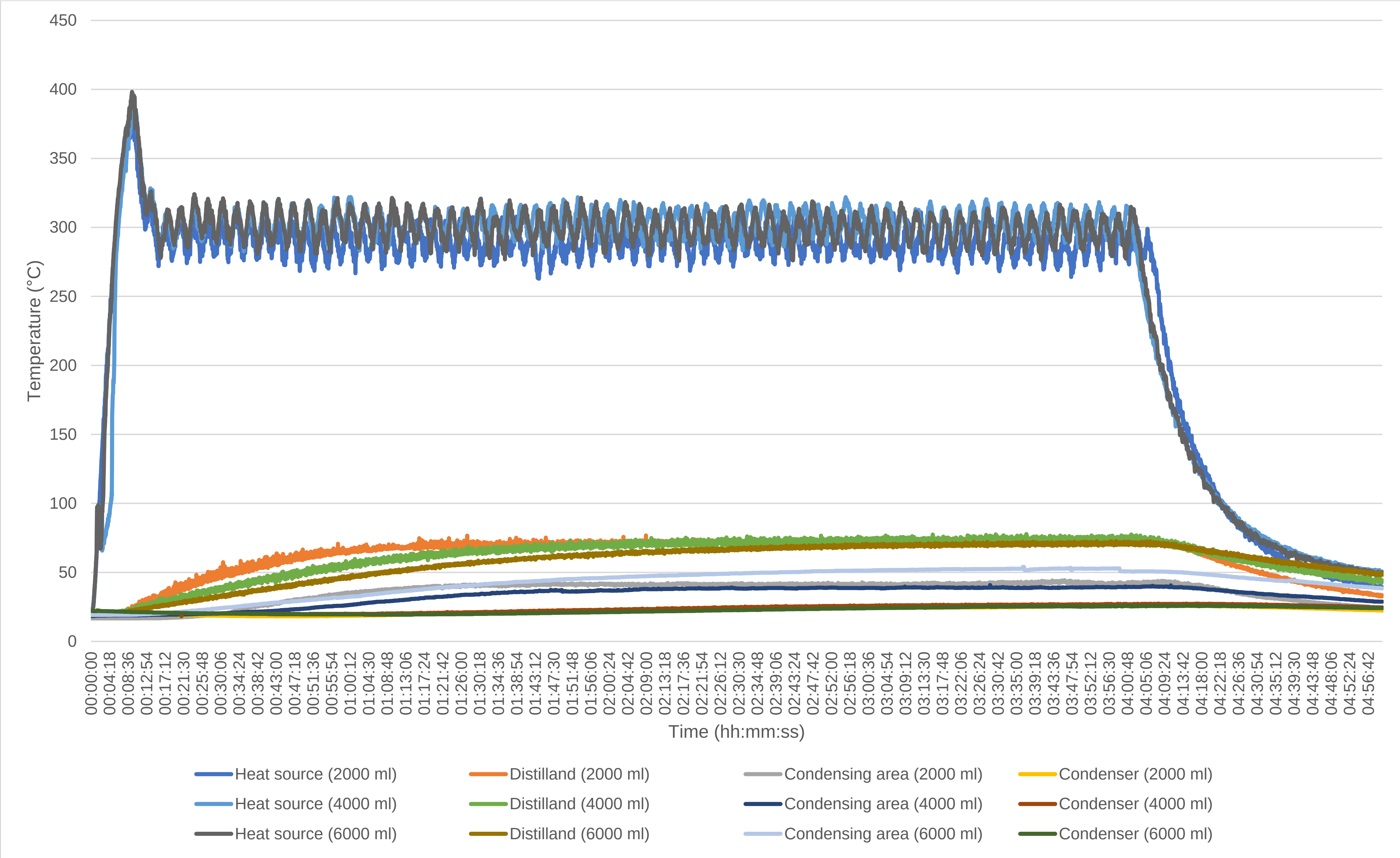


Figure 41. *Temperature readings derived from distillation runs with vertical configuration (all components). Volumes in brackets correspond to starting water distilland volume.*

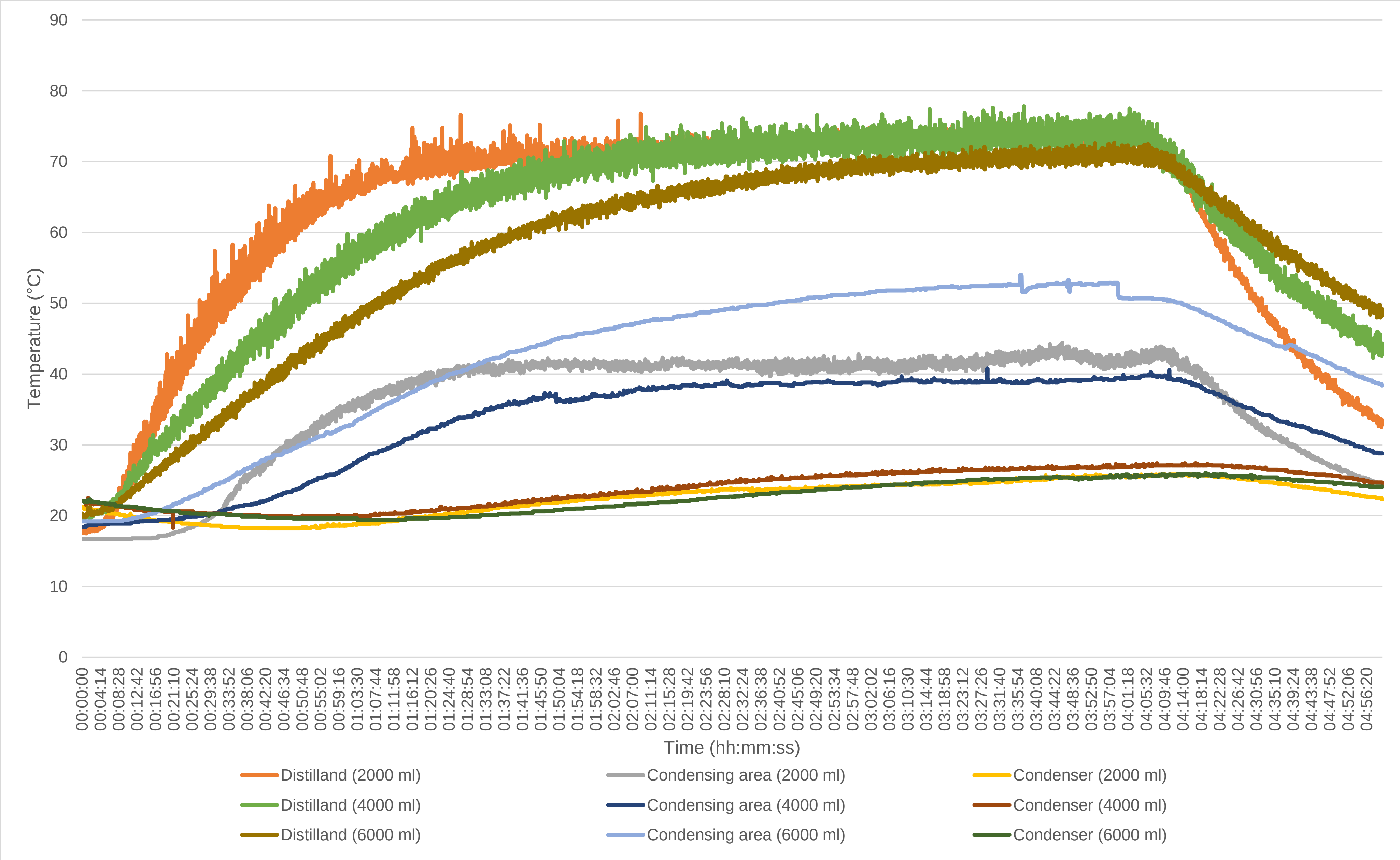


Figure 42. *Temperature readings derived from distillation runs with vertical configuration (distilland in still body, condensing area, and condenser).*

5.3.2 Gandhāra configuration preliminary trials

Three water distillation trials were carried out using the Gandhāra configuration following the established methodology and operation. Distillate and distillands were collected at the end of each run (Table 10) and temperature recordings of individual components were compared (Table 11). As identified in the instrumentation trials, other components were also analysed irrespective of the heat source readings, due to the large discrepancy between the heat source maximum temperature and those of the other components. In the same way as undertaken in the vertical configuration trials, the still body was first filled with the required volume of distilland and the cavity between the body and condenser (or in the case of the Gandhāra still, the still head) was sealed using clay. These were periodically repaired as in the vertical trials. It was noted from the start of the trial that the gap between the still body and still head was significantly greater in the Gandhāra configuration than the condenser and still body in the vertical configuration (see Figure 39). Instrumentation errors with thermocouples were noted (causing anomalous peaks and drops in temperature reading) as the probes were not isolated and rather prone to breakage due to their fragility and initial hotplate temperatures exceeded their tolerance (see Table 11). Equally, this probably caused certain thermocouple probes to cease reading in the 4000 ml run, earlier than in the 2000 and 6000 ml runs. Impacted components are indicated by the *n*-values in Table 11, so anomalous points were ignored when calculating descriptive statistics to normalise results. These are included in the raw data (see Supplementary Data) and Figures 43 and 44 to visually indicate where anomalies occurred.

Starting distilland	Distillate collected	Distilland collected	% of distilland distilled
2000 ml	0 ml	563 ml	0
4000 ml	9 ml	2477 ml	0.02
6000 ml	3 ml	4490 ml	0.05

Table 10. *Remaining distillands and collected distillates post-distillation from trials using the Gandhāra apparatus configuration.*

Measured component (distilland starting volume)	*n*	Minimum temp. (°C)	Maximum temp. (°C)	Mean temp. (°C)	SD	Affected data points (assuming complete run)
Heat source (2000 ml)	9001	20.8	434.8	261.5	93.4	None
Distilland (2000 ml)	9001	18.1	68.8	57.0	13.8	None
Condensing area (2000 ml)	7263	17.3	38.4	32.5	6.5	04:02:06 - 04:03:52/end (53)
Condenser (2000 ml)	9001	18.8	50.8	39.9	10.0	None
Heat source (4000 ml)	8633	20.5	390.7	234.1	101.9	None
Distilland (4000 ml)	8633	18.9	65.8	51.6	14.3	None
Condensing area (4000 ml)	8633	18.9	65.9	52.4	13.4	None
Condenser (4000 ml)	8633	18.8	21.4	19.1	0.4	None
Heat source (6000 ml)	8825	19.6	414.5	274.1	93.6	03:42:14 - 03:43:52 (47) 04:18:48 – 04:23:00 (127)
Distilland (6000 ml)	8998	17.1	68.7	52.3	14.1	04:18:48; 04:20:30; 04:17:58 (3)
Condensing area (6000 ml)	9001	17.6	53.3	40.8	10.0	None
Condenser (6000 ml)	8999	16.1	19.7	17.4	0.4	04:18:50; 04:20:30 (2)

Table 11. *Measured temperatures of individual components within the Gandhāra configuration.*

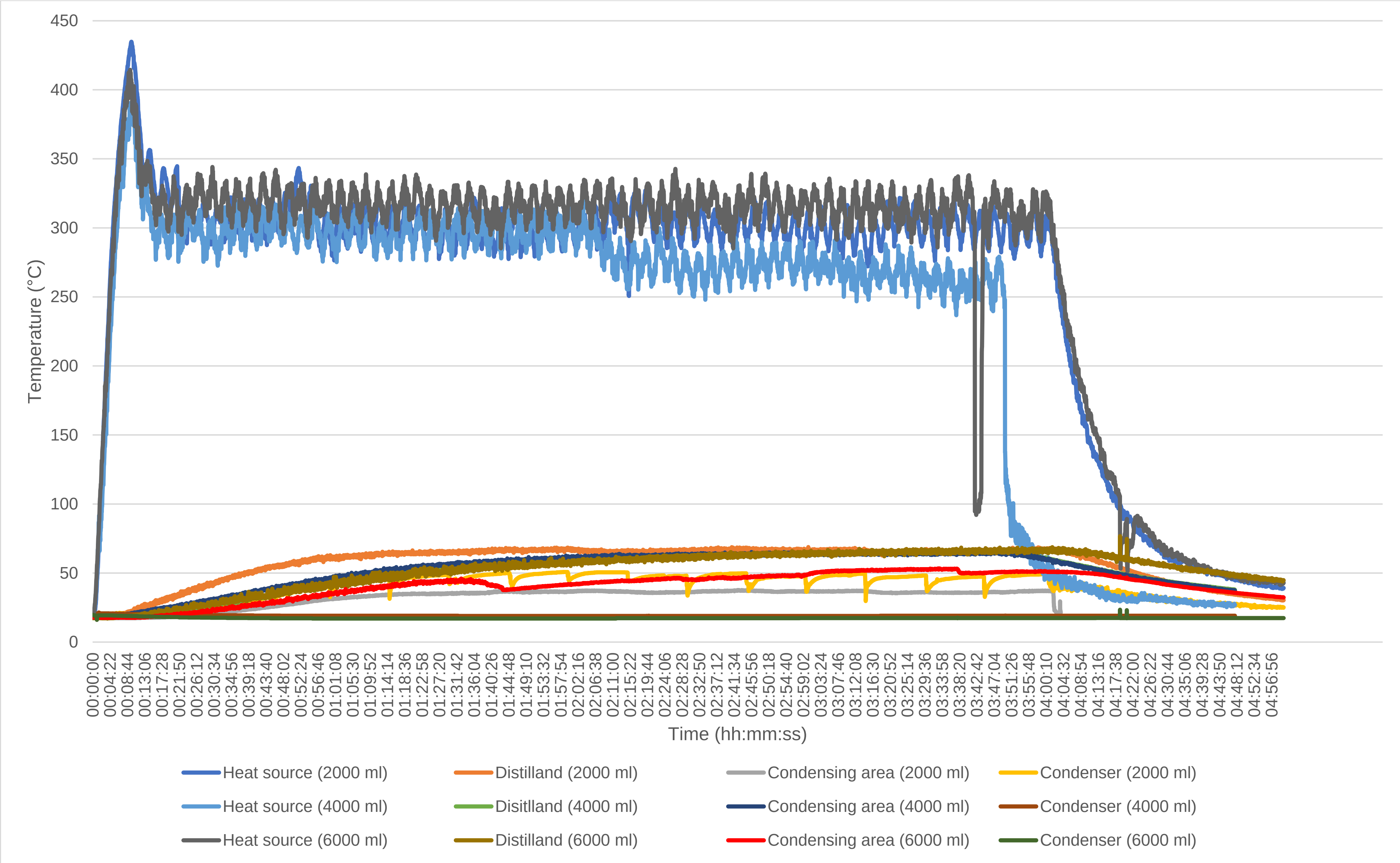


***Figure 43**. Temperature readings derived from distillation runs with Gandhāra configuration (all components), noting that the condensing methods are different for the 200 ml run. Volumes in brackets correspond to starting water distilland volume.*

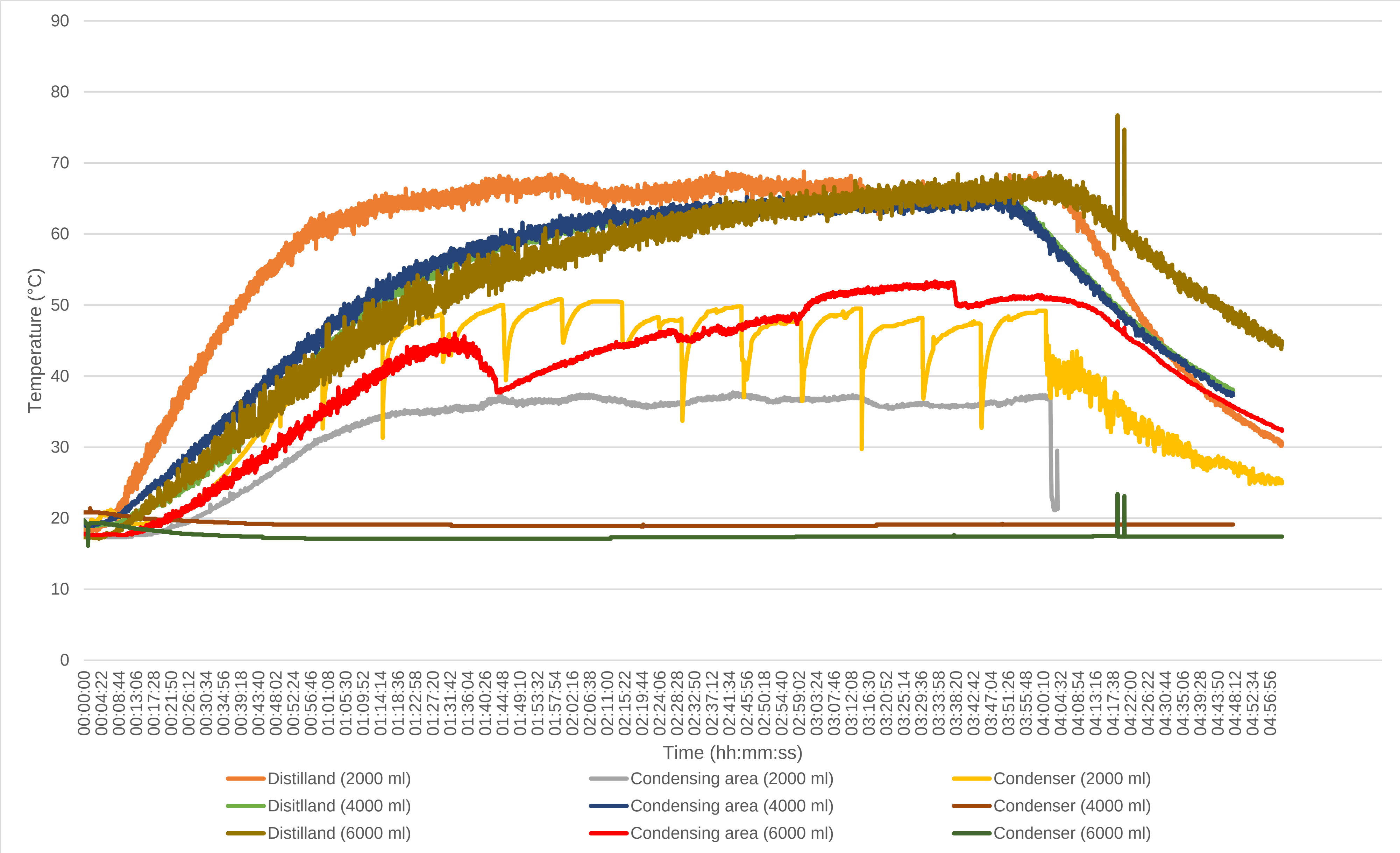


Figure 44*. Temperature readings derived from distillation runs with Gandhāra configuration (distilland in still body, condensing area, and condenser, noting that the condensing methods are different for the 200 ml run). Volumes in brackets correspond to starting water distilland volume.*

Unlike the vertical configuration trials, the potential of other functional parameters for distillation were explored considering the different techniques of cooling and condensing between the two apparatus configurations. The 2000 ml run tested the distillation ability of the Gandhāra apparatus configuration when using a still head cooling method through applying and changing a cloth on top of the still head, following the original notion that still head cooling was needed for alcohol distillation through manipulating the reflux action (see Egloff and Lowry 1930, p. 2074) (see Chapter 2). The 4000 ml and 6000 ml distillation runs had a different condensing areas and method, in that the receiver and tube was cooled to promote condensing, instead of having still head cooling as in the 2000 ml. With the receiver sitting in a basin of cold water, this configuration more closely mirrored Marshall (1951) and Allchin's (1979a, 1979b) interpretations of the original reconstructed water condensing apparatus and Gandhāra still (see Chapter 4). Further, cloth changes during the 2000 ml run were not replicated in the 4000 and 6000 ml runs, considering that the experimental set was exploratory and designed to create a group of primary insights and impressions. Condenser temperature was measured in the 2000 ml run directly on top of the still head where cloth changes were occurring and on the receiver in the 4000 and 6000 ml runs. Measuring the temperature of the condensing area inside the still in all runs provided a provisional level of comparability and repetition within each individual run.

At the beginning of each run, the appropriate volume of water distilland was first measured and decanted into the still body after soaking. Once the apparatus was assembled and sealed, the hotplate was switched on to its highest temperature, reaching similar temperatures to those recorded in the vertical configuration runs (Table 9). In the 2000 ml run, cloths on the still head were changed every 15 minutes alongside taking experiential and sensory observations (Appendix 6). Upon the distilland reaching 53.8 °C in the still body and the still head condensing area rising to 25.6 °C, damages to the seal between the still head and still body were visible 45 minutes into the run. After 60 minutes it became clear that the still was not operating in the way that had been hypothesised, possibly caused by problems with how vapour was condensing within the still head.

In the 2000 ml run a sizable volume of distillate or condensed vapour was escaping through the breaks in seals, suggesting that distillate was gathering in the channel created between the still body, seal, and still head (Figure 45). This was caused by inducing a reflux action at the top of the still rather than creating an adequately cool, lower pressure environment in the spout and tube that would have drawn the warmer vapour. The pattern continued to the end of the run, and significant breakages in the seal were noted from around 195 minutes. This issue may have been caused by the direct still head cooling. However, the trend repeated during the 4000 ml and 6000 ml runs with the cooling directed onto the condensing tube and receiver. Though noted later than in the 2000 ml run, distillate was seen to be escaping at 135 minutes (4000 ml run) and 165 minutes (6000 ml run). Seals were repaired early on into each run, indicating that the articulation and join were experiencing a high amount of stress during the trial, irrespective of the condensing method.

Expectedly, the constant cloth changes in the 2000 ml run were visible in the condensing area temperature readings and recording (reaching a maximum of 50.8 °C at 01:59:26) (Figure 44) and equally promoted a lower mean condensing area temperature (32.5 °C) than recorded in the 4000 (52.4 °C) and 6000 ml (40.8 °C) runs (Table 11). Condenser temperatures in the 4000 ml and 6000 ml runs stayed consistent, though the large discrepancy noted in the condensing area mean temperatures in the 4000 and 6000 ml runs is unclear and cannot be attributed to a single cause. Equally, the sudden drop in condensing area temperature in the 6000 ml run from 43.8 °C beginning around 01:35:02 (its lowest in this period of 38.7 °C at 01:47:06). Distilland temperatures in all runs were consistent and largely matched the same rates of heating as witnessed in the previous vertical configuration trial. The influence of starting distilland volume upon temperature increase was noted again, however, a slight depression in temperature recorded at 02:00:18 during the 2000 ml run could not explicitly be connected to any intervention or influence noted in the other components (Figure 44).

Figure 45. *Distillate / condensing vapour penetrating through the clay seal between the still head and body during the 2000 ml run with the Gandhāra apparatus configuration.*

5.4 Discussion

The preliminary experimental trials provided insights on the operational capacity of each apparatus configuration and highlighted certain functional implications stemming from both reconstructions. As the experimental runs were exploratory, any insights generated were limited in that identified functional parameters were not fully established, nor could be adequately demonstrated without comprehensive experimental repetition. Insights relating to distillation ability for each apparatus could still be highlighted and justify a selection of targeted parameters and variables related to specific technical decisions. The change to a more accurate measurement strategy using the thermocouple data logger, following the instrumentation trial, further demonstrated that future experiments should produce more accurate temperature change mapping.

However, while the basis of an improved understanding of the technical distillation ability of apparatus configurations could be developed, the 'replicability' of experiments is somewhat limited. Repetition of individual runs with set distillands[44] would be needed to confirm trends and provide reliable results. Conversely, considering the significant delays and disruptions due to the COVID-19 pandemic, and the decision that the next stage of experimentation should begin utilising the overview understood here, repetitions were not undertaken. Equally, the apparatus configurations may have operated more effectively if a different liquid was being distilled instead of water. Ethanol has a significantly lower boiling point than water (78.23 ± 0.09 °C) (see 2.2), so it could be argued that alcohol distillation could have been achieved within the system as the boiling temperatures had been reached within the still body throughout all the trials. Furthermore, the laboratory setting, and use of a hotplate, were already significant methodological choices in the experiments that had eschewed aspects of an 'authentic' setting. Therefore, the experimental trials, conducted in a laboratory environment, have substantial limits in replicating the material and technological conditions required to both evaluate the configurations and pass comment on technical practices involved in early distillation. Accordingly, the body of results here can be used to identify certain functional limits of the apparatus configurations as distillation equipment rather than determine the appropriateness for alcohol distillation.

Throughout the trials, elements of the experimental method were noted to have potentially affected the performance characteristics of the reconstructed apparatus, and therefore could be considered to have negatively influenced the evaluation of the configurations. Certain readings recorded in the temperature data spiked or cut off suddenly in specific trials (see

[44] e.g., multiple 2000 ml, 4000 ml, 6000 ml runs with each apparatus.

Figure 44). This was probably because the thermocouples used were not isolated at their end junctions, thus, using isolated thermocouples would be able to mitigate for most reading issues in subsequent experimental trials. Equally, heating the distilland via the hotplate in the experiments may have affected the ability for the cooling strategies to successfully induce distillation as the vapour may not have been produced at a constant and consistent rate due to the water distilland not fully reaching boiling point. Hence, a smaller scaled apparatus could be used instead as had been the done in previous experimental research on the configurations (e.g., Butler and Needham 1980) to potentially increase the chance of success and yields of distillate. However, as the trials were focussing on evaluating the proffered configurations holistically, experiments would only be relevant if a close direct material and scale reconstruction was used. While it is true that the receiver used in the reconstructed Gandhāra configuration was smaller, receiver-condensers vary in size according to their characterisation in the region (see Chapter 4). Thus, the scaled version was an appropriate option as most of the configuration then matched the archaeological materials, but still limits the replicability of the experiments if considered a model reconstruction of archaeological data.

Significantly high remaining water distillands in every run throughout the preliminary campaign, however, indicated that a longer distillation period than four hours would provisionally have produced greater volumes of distillate. This would have to be thoroughly evaluated, therefore, considering the differing condensing methods. Low yields of converted distillates in both configurations throughout all trials and over the 4-hour process (Table 10) may be the result of several interconnected issues. Converted volumes of distilland to distillate were very low across all runs, compared to model distillation systems that should fully distil close to 100 % of starting water distillands (see 3.2). While any distillates measured during the Gandhāra still trials could equally be residual water left over from soaking the apparatus at the start of each run, distillation time could have been insufficient to provide larger quantities of distillate. Hence, the still did not reach a point of efficiency and continuous distillation. Furthermore, considering the issues with the clay seals that were noted throughout the process, the still might have been unable to fully promote the right conditions for distilling. This could be tied to the high loss of distillate being 'boiled off' instead of fully condensing.

While the vertical apparatus did yield a measurable and greater volume of distillate than the Gandhāra apparatus, neither could justifiably be noted as 'significant'. Moreover, as vapour was escaping through seams at joins between components in both apparatus configurations, this failure suggested that vapour was not being condensed fast enough, contributing to the reflux action occurring within each system. This equally demonstrates that when runs were successful in the vertical configuration trials, a sufficiently large cooling surface was maintained (the underside of the condensing bowl) as opposed to the smaller tube interior in the Gandhāra apparatus. In tandem, it could be suggested that both apparatus configurations were getting too hot too quickly via the hotplate. Temperature readings, however, suggest that water distilland temperatures were not consistently reaching a high enough temperature to be fully distilled. This might be because heat was not distributed across the full surface of the still body exterior (as it was being heated directly at the base) and then transferring to the distilland. As such, it appeared that water vapour was slowly moving through both systems, cooling, and not being channelled for collection. This was either due to morphological issues with the configurations or that the apparatus was not maintaining a considerably and consistently cool environment to condense vapour in the correct parts of the still. Thus, the surface area of the condensers (i.e., the external surface of the condensing bowl in the vertical configuration and internal surface area of the condensing tube and still head spout in the Gandhāra configuration) might not have been large enough to consistently condense produced vapour. Hence, heating and condensing strategies, and the understanding of them, directly influenced the success of the distillation trials.

Poor conditions for distilling within the apparatuses could be due to the insufficient height difference between the top of the still head interior and base of the still body. This is needed to create a large enough condensing environment by increasing the temperature difference between the boiling distilland and cool condensing area. Accordingly, maintaining vapour balance and equilibria influences if a complete distillation could be achieved (see Chapter 2). In tandem, the localised point of condensing within each system may not have been suitable to promote adequate condensing processes. This is not so much a concern in the vertical configuration where the point of condensing was on the exterior base of the condensing vessel ('condenser'). Though in the Gandhāra configuration this is a major concern considering that the points of cooling must be along the still head spout and condensing pipe to increase the condensing surface area for vapour to travel and be channelled into the receiver. Thus, the temperature imbalances and potentially uneven rate of heat transfer would not have promoted optimal vapour condensation. Rather, differing atmospheric pressures within each apparatus prevented a point of equilibrium being reached within the systems.

Identified functional concerns with the Gandhāra reconstruction, therefore, bring the legitimacy of the interpretation into question. Fundamentally, the experiments identified how heat transfer within the system, if the still body is in direct contact with the heating source (hot plate) is contingent on the volume of liquid being distilled. Marshall's use of a tripod within his Gandhāra still reconstruction (see Chapter 4), therefore, both does not account for this factor, but equally places the still body too far away from a heat source to maintain consistent heat transfer.

Hence, issues observed in the experimental reconstruction of the Gandhāra still suggest that the vessels are not the most appropriate for distillation considering their inability to sufficiently provide a large enough area to both condense vapour and dissipate pressure build-up within the system. As suggested before, the still head and still body connection consistently leaked throughout all trials and acted as a channel to collect distillate rather than run off and condense via the still head spout and condensing tube. Further, maintaining seals during the Gandhāra apparatus runs involved far more attention than in the vertical configuration trials, suggesting that a clay seal was not sufficiently strong enough to sustain a fully pressurised environment in the correct part of the still (i.e., the condensing area). It is, however, likely that distillate was equally not adequately condensing outside of the still head or along the tube to run into the receiver. Revisiting sealant methods in future experimentation would be useful conduit of analysis; less porous materials with a greater elasticity and malleability that can withstand high pressures could potentially sustain stronger seals. Hence, it could be hypothesised that the distillation apparatus configurations would function better with fewer notable failures or fracturing seals at the junction of individual components.

Alongside the evaluation of technical makeup of the configurations, experiential insights generated through the preliminary experiments help identify practical craft contexts in which key technical skills could become embedded while formulating distillation. Usefully, the experiments demonstrated the intricate knowledge of temperatures, rates of heating, and pressurisation needed to enable distillation. Recorded experiential insights taken at set times throughout the course of each distillation run noted the influence of practical technical choices on distillation ability (Appendix 6). These had connections to plausible practical and technical concerns rooted in sensory indications and directly associated with the apparatus configurations. Here, in the vertical configuration runs, periodic refilling of the top condenser to maintain a cold environment and promote condensing was only done when the condenser had lost water, presumably through the fabric of the condenser absorbing water and evaporating from the surface. This promoted a cold environment for condensing as can also be seen in the temperature data for the vertical trials (Figure 42), once during the 2000 ml run and twice in the 4000 and 6000 ml runs (see Appendix 6). However, to promote a more consistent condensing environment (and therefore increase distillate yields), the condenser water would need to be replaced more regularly with sufficiently cool water that would only be done when it was deemed to have been too warm, rather than at regular intervals when it was visually noted to have lost water. Understanding when to change condenser water then is directly connected with sensory insights on temperature and developed knowledge on what constitutes ‘cool enough’ within this context. Hence, the temperature imbalances and lack of a sufficiently large enough temperature difference with the systems demonstrated how central practice and craft skill involved in the process was required to determine whether they could successfully distil.

However, in using the Gandhāra apparatus, most experiential insights collected across all the runs with the configuration predominantly were connected to repairing the apparatus at specific places as clay seams had failed, become saturated, or simply were not sustaining an environment where distillation could occur successfully and channel the collection of vapour. Consequently, it could be argued then that the experiential insights collected at specific points throughout the course of each run were only concerned with repairs and specific practical failures within each system. Such concerns are, regardless, associated with the technical knowledge and skills underpinning distillation more broadly and not necessarily unique to a single run. Here, both adequate cooling and heating strategies were needed to be employed and manipulated in the right way; low distillate yields may simply be the result of not realising a specific element of the practice with the apparatus, despite having a clear understanding of the issues at hand. Such an association reiterates the importance of embodied and developed craft knowledge through the honing of skills central to the formation of a technological practice.

The next stage of experimentation would, therefore, need to address heating and cooling strategies involved in early distillation practices, but also integrate a pragmatic approach to recording experiential insights, adequately providing a grounding to elaborate on skill, technique, and practice in early distillation technology. To implement a level of control within the next stage of experimentation, especially when experiential insights are substantial, the Gandhāra apparatus configuration would only be used going forward. This also would then generate a more detailed body of critique for evaluating the key component of the 'Gandhāra tradition' of distillation and its conceptualisation as a major technological innovation. Recording insights within a rigid and regulated structure during the preliminary experimental trials subsequently promoted a limited means of gathering a wider range of subjective concerns. This is especially true as technical practices are so varied and not limited by set recording strategies or what is deemed appropriate to record. Hence, focus should be shifted to addressing only one apparatus configuration within the next stage of experimentation, providing a consistent frame of reference to identify reoccurring experiential insights or technical choices.

5.5 Summary

Both the vertical and Gandhāra conjurations when tested in a limited and controlled environment exhibited few indications of promise to support the notion that the reassembled archaeological materials were appropriate for distillation. While the vertical configuration did produce a small volume of water distillate following their suggested operation in their original reconstructions, this does not adequately support the theory that the assembled archaeological artefacts would be appropriate distillation apparatuses. The fundamental design of the Gandhāra apparatus, identified through experimentation, markedly was seen to prevent distillation from occurring. In comparison, as demonstrated in ethnographic studies, vertical apparatus configurations clearly work (see Chapter 2). The preliminary experimental trials again showed this, though its archaeological representation in South-Central Asia is still questionable (see Chapter 4). In conjunction, the reconstruction of the vertical configuration from selected ceramic vessels in South-Central Asia by Mahdihassan (1972, 1979) was suggested in the preliminary experimental studies here to not be the most appropriate vessels to formulate a vertical configuration. As recognised by McHugh (2020), practically any set of ceramic vessels could be used to assemble a vertical configuration, as had been done in Mahdihassan's reconstructions (1972, 1979). Hence, in many respects, further experimental work with the vertical apparatus beyond what has been done here would mostly confirm that ethnographic examples of these stills worked (which principally were the model for the vertical configuration in Gandhāra).

The Gandhāra apparatus, however, was not a successful configuration when used under the testing conditions in the preliminary trials, plausibly due to the heat source used in the experimentation. Regardless, temperature imbalances, heat transfer, differing pressures, and optimal vapour condensation were all identified as plausible reasons as to why the apparatus was not enabling distillation when directly following the reconstruction. To this extent, it is difficult from these laboratory trials to conclude that either configuration was suitable for distillation aside from the limited success with the vertical configuration. As such, it can be stated that a more meaningful analysis of early distillation should centre on analysing nuances within the Gandhāra apparatus and its archaeological context, also considering its interpretation as a specific distillation 'tradition' (see Chapter 4). This then equally allows for an exploration of whether the configuration could work if appropriate alterations were made, and additionally provide a context to address elements of embodied practice and experiential concerns involved fostering a craft practice. The next chapter will, therefore, comprise an exploratory distillation experimental campaign in the field that evaluated specific functional issues with the Gandhāra apparatus and consolidate a body of insights surrounding early distillation as a complete practice.

Chapter Six

Exploratory Experimental Campaign

6.1 Introduction

In the previous two chapters, it has been demonstrated that reconstructions of ceramic distillation apparatus from Gandhāra are inconsistent, lack universal morphological features, and have not been sufficiently proven as viable. From the preliminary experimental study (see Chapter 5), the assumptions underpinning the earliest interpretation of the Gandhāra apparatus by Marshall (1951) confirmed that neither heating the apparatus from a single point, nor his explanation for still cooling, were adequate justifications to support his view. In tandem, if following the reconstructions, temperature imbalances, rate of heat transfer, differing pressures, and optimal vapour condensation were all identified as plausible reasons as to why both the vertical and Gandhāra apparatus configurations were not fully enabling distillation.

In this regard, as maintaining vapour balance and equilibria are required to achieve a full distillation (see 2.2), both adequate cooling and heating strategies must be employed and manipulated in a specific format to distil. While the condensing method suggested within the interpreted vertical configurations functioned plausibly, the means of condensing in the Gandhāra apparatus reconstruction were considerably more difficult to manage when followed directly (see Chapter 5). Combined, such elements related to the knowledge, skills, and craft practice of distillation have not been fully considered in any reiterations of the Gandhāra tradition (see Chapter 4 and Catalogue). They are, however, as recognised from the preliminary experiments, vital for formulating early distillation as a technological context (see 3.2). Hence, despite such initial critique, the assessment of configuration viability must be expanded further to build a deeper understanding of the practical issues at hand when working with such a reconstruction. This particularly pertains to issues of apparatus heating and cooling, and the parallels that this may have within a renewed view of early distillation practices. The preliminary experiments highlighted intrinsic issues in formulating a hypothetical reconstruction of a technology without full regard to materials and practice. Therefore, practical engagement with the apparatus through experimentation can help generate a body of insights that underpin formative methods, practices, and techniques in distillation.

In recognising the limits of experimental work when conducted in the controlled environment of a laboratory (see Chapter 3), this chapter explores a nexus of issues identified in the initial preliminary experiments by using an experimental methodology to establish if the Gandhāra apparatus can function within an ‘authentic’ setting. This did not not aim to replicate the distillation capacity of the Gandhāra apparatus, especially as alcohol is not being distilled. Instead, experiments generate an understanding of technical considerations, skills, and craft knowledge that could find parallels within other craft environments, and thus illuminate the conditions under which distillation could become adopted as an ‘innovation’ (see 3.2). Doing so also accommodates an exploration of the influence of a variable heat source upon the success of distillation and explores how the apparatus could better condense vapour, maintain temperatures, and achieve distillation. The combined practical factors and heat processes involved in heating the distilland to boiling temperature in the lower ceramic vessel (still body), maintaining an adequate cooling environment at a specific point, and condensing the resulting vapour at a point of distilling equilibrium are, therefore, key concerns. Furthermore, while the relationships explored here will be used to evaluate the success of distillation within the context of the Gandhāra apparatus, such concerns crucially help generate a body of experiential and sensory insights on the practice, craft, and conceptualisation of early distillation. This can in part only be fostered if qualitative observations and considerations are given equal attention as quantitative measurements. Hence, through a series of sequential experiments each examining different issues and responding to the insights collected from the previous, a body of critique on the influencing factors involved in early distillation and the Gandhāra configuration can be developed.

6.2 Archaeological context

The question of heating has frequently been approached as an assumed element of archaeological studies of technology: because metals, glass, and ceramic objects exist in the archaeological record, the correct temperatures needed to create such artefacts were achieved (McDonnell 2005, pp. 493–495). However, heat control and maintenance are complex, influential, and transformative methods that cannot be generalised or explained primarily as a proxy derived from the existence of artefacts (Miller 2009, pp. 101–103). Within the transformative context of chemical technologies, this becomes a central concern particularly in distillation due to the significant difference in temperatures between heat source and condenser required to induce the process (see 2.2). The evidence and remains of appropriate structures (such as hearths, ovens, and furnaces) are, however, difficult to identify, surviving only in fragmentary remains and rare examples, and complicated by the fluidity and non-standardisation of these terms (McDonnell 2005, p. 493). Thus, the lack of evidence of ceramic walls and features indicative of relevant heating structures equally renders any discussion on apparatus heating and cooling somewhat speculative, often through examining wider material production sequences.

Practical considerations of how heating and cooling are balanced to maintain a favourable distilling environment are central in understanding the parameters for distillation operation. This concern is key for achieving successful distillation: an appropriate fuel, temperature, and atmosphere within a suitable heating arrangement versus maintaining an adequately cool condensing environment is a balance that must be achieved. Differing direct and indirect heating modes and installations do vary in levels of control (Table 12). Hence, the use of a bonfire or open fire with virtually no control in comparison to a hearth and oven (while it may be obvious to state) can directly affect the performance and success of distillation processes. This extends to direct and indirect modes of heating; the use of a sand, water, or oil bath, which provide more consistent heating surfaces, indirectly heats at an even rate, and features heavily in the history of distillation development (see Chapter 2). Realistically, such indirect heating methods are not represented archaeologically.

Type	Effective operating temperature (°C)	Maximum temperature (°C)	Redox (balance between oxidising and reducing conditions)	Control
Bonfire	600 – 800	c. 1000	Predominately oxidizing	None
Hearth	800 - 1000	1300	Predominately oxidizing	Medium
Kiln/oven	600 - 900	1300	Predominately oxidizing	Medium

Table 12. *Properties and levels of control over bonfire, hearth, and kilns/oven high temperature structures (after McDonnell 2005, p. 496).*

Establishing variability in hearth and heating structures is an extensive study in itself. Across the existing body of research, divisions between domestic and technological heating configurations in Classical and Hellenistic settings has often acted as the basis for determining the purpose of hearths (e.g., Healy 1978; Tsakirgis 2007; Westgate 2015). This has been a longstanding concern in archaeology, since the identification of specific heating methods for explicit purposes is a common association between features. Extensive studies on domestic structures in Greece since the Bronze Age, and megaron buildings of Mycenaean palaces, established the division between installations for general heating (e.g., fireplaces and braziers) and configurations for cooking activities (e.g., cooking hearths), (Tsakirgis 2007, pp. 225–226; Westgate 2015). In analysing the designation of domestic and religious activities in the Greek household, the study of decorated ‘keyhole hearths’ from the Early Helladic / Early Bronze Age Aegean (c. 3100 - 2000 BCE) have particularly contributed to re-evaluating domestic and palatial spaces (e.g., Muhly 1984; Galligan 2013). From this basis, specific fuel sources of hearths on the ground (wood fired) and other structures such as braziers (charcoal) have equally been attributed to domestic or ritualising uses, as utilised in Classical and Hellenistic structures (e.g., Tsakirgis 2007, p. 229). Such designations accentuate the specific function of installations.

Conversely, ovens, furnaces, and hearths for ore roasting and refining have been the subject of more extensive archaeological study designating explicit stages in metallurgical processes from the 4th c. BCE and connected to metallurgical activities in the 'Mediterranean World'. Historically, the perceived 'evolution' of metallurgical furnaces for refining techniques, to the extent that specific clay pastes were used for specialist purposes (such as *tasconium* for cupellation crucibles) saw that explicit structures and areas associated with specific activities and apparatus was widespread (e.g., Healy 1978, pp. 152–153). This relationship has, however, been challenged in recent studies of metallurgical features across the Mediterranean area to show the longevity of activities prior to Hellenistic periods and multifunctionality of features: workshops at Kition (Cyprus) have been shown to be in use for an extensive period (1125 – 350 BCE) allied to the use of hearths for non-smelting metallurgical activities (Kassianidou 2016, pp. 73–74). Moreover, evidence from Iron Age sites in the Eastern Mediterranean have also demonstrated the cross-purposing of hearths, tied to considerations of how smithing hearths can also achieve the conditions to reduce iron oxides into iron metals (Erb-Satullo 2019, pp. 584–585). Equally, large metallurgical landscapes, such as Laurion in mainland Greece, have yielded extensive evidence for metallurgical installations since the Early Bronze Age and continuing to act as the "backbone of the Athenian economy" in the Classical and Early Hellenistic periods (Hulek and Nomicos 2022, p. 2). Particularly, the example of Laurion has provided indications of how lead-silver ore washing and concentrations structures occupied the same spatial and temporal setting alongside domestic hearths, cupellation furnaces, mine shafts, and a battery furnace (Hulek and Nomicos 2022, p. 6). Accordingly, these cases demonstrate how adaptions and applications of techniques across different metallurgical contexts provided the need for adapting and modifying specific heating techniques to achieve certain results (e.g., Erb-Satullo et al. 2020, pp. 414–415). The cross-purposing of hearths and heating features within long periods of time suggests that distinct 'specialisation' of manufacturing installations is not always required.

However, such information is connected to widespread refined metallurgical purposes and not directly to other specific technological spheres, such as distillation. Considerations of ceramic vessel properties and their heat retention abilities in bringing together all constituent parts of a practice is, therefore, required. Within Gandhāra, the relationship between suggested apparatus and heating structures is difficult to ascertain. As seen from the survey (see Chapter 4), the representation of hearth and heating structures within South-Central Asia during the ascribed chronology of the apparatus is difficult to unify with specific apparatus components.

Aside from a few fragmentary remains noted at Shaikhān Dherī (see 4.3.2), and speculation on heating strategies for distillation at Taxila (see 4.3.1), little can be stated on the connection between heating methods and characterised distillation apparatus. Conversely, cooling strategies for distillation have been proposed throughout the body of interpretation (see Chapter 4), presumably due to the documented central role of cooling involved in the process (see Chapter 2). Detail on ceramic properties, such as the use of calcareous or non-calcareous clays and their porosity that can directly affect rates of cooling, would be useful for evaluating such an association. In materials from Gandhāra, however, existing information lacks the necessary detail to discuss associations between vessel properties and cooling abilities (see 4.4). Accordingly, means of heating, and their connection with characterised distillation apparatus, is a question rooted in whether a specialised or adapted heating installation is required to adequately maintain a consistent heating and cooling (and hence distilling) environment.

In response, the previous instalment of experimentation questioned the validity of Marshall's (1951) suggestion of apparatus heating for distillation, in that a single point of heat from below the still body (*handi* cooking pottery type) when placed on a metal tripod was an implausible configuration to have enabled consistent heat transfer and thus continuous distillation (see Chapter 5). Marshall's reconstruction mirrored idealistic models of distillation, however transferring it into a setting with significantly more variability in heating, cooling, and properties of the apparatus itself than the model, ignores a large body of idiosyncrasies that emerge when conducted in an authentic setting. While borrowed from a different, but associated, craft context, the use of tripods and tripod pots over fires for slow heating of ingredients and oils for extraction in Mycenaean perfume manufacture has be deemed as an "obvious" configuration (Shelmerdine 1985, p. 50), though the appropriateness of this when dealing with different materials and volumes of distilland cannot be assumed. Equally, research on cooking traditions in the Late Bronze Age Aegean have demonstrated how the relationship between heating methods, pottery morphologies, and foodstuffs directly impacted produced results (see Morrison et al. 2015). More pertinently, tripod pots severely limited visual assessments and drastically slowed heating rates of foodstuffs during cooking, going against the traditional assumption that the tripod morphology aided fuel regulation through use (Morrison et al. 2015, pp. 119, 123). Furthermore, the existing body of evidence for metallurgical and domestic hearths across the wider Indian subcontinent exemplifies that such features exist and were widely adopted for certain technological contexts and with specialist uses (see Bari 2020, pp. 291–294). The recognised features within the region and understanding of distillation processes, therefore, reinforces why assumptions on the use of heating and cooling should not be perpetuated when viewed in the context of the ceramic distillation apparatus of Gandhāra.

Understanding the function of the ceramic assemblage of late 1st mill. BCE Gandhāra, regardless of if whether includes distillation apparatus, requires a deeper evaluation of the corresponding evidence for heating and pyrotechnological structures. The survey of proffered distillation apparatus components (Chapter 4) had already demonstrated a certain lack of evidence for explicit in situ heating configurations, which allows possible configurations that would have been appropriate for distilling to be meaningfully hypothesised. While the presence of sooted cooking vessels at Shaikhān Dherī suggested as still bodies creates a certain connection between specific temperatures and the vessels used (see Chapter 4), this alone does not indicate the use of a specific installation. Moreover, the original reconstruction by Marshall in using a tripod places the still body too far from the heat source and does not allow for the complete surface area of the still body to be heated (see 5.4). Thus, alternative proposed elements must be put forward if the interpretation will be fully supported including considering options that exist for heating in pre-Hellenistic South-Central Asia. As such, this acts as a comprehensive foundation by which to develop an exploratory experimental campaign, analysing both the impact of controlled heating and cooling methods upon distillation within this context and elements of distillation practice contingent on such factors.

6.3 Methodology

An exploratory experimental campaign was conducted to establish a range of interconnected and influencing functional parameters in distillation relating to heat sources, archaeologically appropriate features, ceramic vessels, and the complete Gandhāra apparatus. Following previous experiments that demonstrated how heating and cooling affected the success of distillations (Chapter 5), the exploratory experimental programme closely reconstructed the original setting of the Gandhāra apparatus to establish the validity of the original interpretation. While both water and alcohol distillation have been previously suggested as uses for the proffered Gandhāra apparatus (see Chapter 4), strict UK distilling laws and guidance prevent alcohol distillations being conducted outside of certain premises[45] (see Appendix 4 for detail on UK distilling legislation). Further, as suggested in Chapter 5, sufficiently heating a full-sized apparatus in the lab was difficult and experiments would only be relevant if a direct material and scale reconstruction was used. Accordingly, the exploratory campaign would not replicate a form of alcohol distillation but rather detail a series of practical, technical, and material concerns surrounding the Gandhāra apparatus reconstruction. Consequentially, the campaign

[45] e.g., commercial distilleries and laboratories.

focussed on water distillation, which acted as a sufficient comparative model though respective of the differing properties of alcohol versus water when distilled. Experiential insights were, therefore, recorded across all the trials to generate a body of information that that could illustrate specific elements of a craft practice involved in early distillation practices (Appendix 7).

Through distilling the same volume of water across all experimental trials, each individual distillation run was modified based on the previous so that influencing factors were securely determined, establishing how the distilling method could be improved. While previous experiments identified potential implicating factors in controlled heating of ceramic apparatus (see Chapter 5), the translation of this factor into an ‘authentic’ and archaeologically-informed setting was, therefore, needed. Further, the campaign addressed the appropriateness of certain heating configurations contemporaneous to the ascribed period of the apparatus for maintaining boiling temperatures of water and implications for distillation apparatus operation. Hence, due to the exploratory nature of the programme, and limited existing experimental data to use as a comparative model (see Chapter 3), each individual run was not repeated. However, the total number of runs provided a comprehensive dataset to inform a detailed critique of the functional properties of the ceramic apparatus and establish certain key features required to distil.

To first create a model for testing the reconstruction efficiency, determine a suitable mode for heating the apparatus, and simulate the use of heating the apparatus on a tripod over an open fire, a limited comparative experiment was undertaken (see 6.4.1). Two methods of heating water in a ceramic vessel were tested - on open fire, and in a hearth structure surrounding the lower half of the vessel - to establish a preliminary level of control over the rate of water heating. Temperatures of the heat source and heated water were recorded using CCPI sheathed K-type 3mm alloy 600 mineral insulated thermocouples (temperature range of 0 - 1250 °C approx. ± 0.4 %), coupled to a HH-520 thermocouple data logger. Wind speed and moisture were also recorded using reported data from the Meteorological Office (Met Office) as this could influence the rate of heating.

Each run followed the same testing procedure: 4000 ml of water was decanted into the ceramic test vessel with a lid and heated for at least 60 minutes, firstly over an open fire and then within a hearth structure. This was done to establish the rate at which a temperature of 90 °C + could be reached as a temperature point that would boil both water and ethanol, thus producing vapour to be condensed. This was done three times for each structure to generate an impression and understanding of consistency; it was unlikely that an accurate and precise average would be achieved due to the variation in the fire-based heat source. While starting temperatures of the heat source varied, fuel was continually added to increase the temperature for 60 minutes, after which the fire was then left to burn-down for a maximum of 60 minutes. Temperature recording, therefore, started once the fire was deemed to be relatively stable. Doing this while continuing temperature recording generated an impression of heat retention in the configuration and the ability of existing heating configurations as options to enable water and alcohol distillations.

As the second set of experiments, using 4000 ml of starting water distilland and placing the still body within an enclosed hearth, multiple distillations were carried out altering specific variables in distillation operation to establish if the apparatus could afford full distillations (Table 13; see 6.4.2 - 6.4.7). This was used to establish if optimal vapour equilibrium and conditions for distillation could be met, if water distillate could be produced following the reconstructions, and create a series of parameters and practical concerns connected with the how the apparatus was used. Aiming to not decisively prove an association through multiple repetitions, but rather create several impressions related to practice through the process of experimenting, mitigated for perceived issues with accuracy and data reliability. Because of the discrepancy between each method, individual trials (see 6.4) detail specific variables and methods related to each distillation run. Temperature of the heat source, distilland, atmospheric temperature in the still head (the region where hot vapour would first meet a point of condensing), and atmospheric temperature in the receiver were recorded again using the same method as described above (Figure 46). Apparatus was not soaked prior to use, however, unlike in the preliminary experiments (Chapter 5), as this was not deemed to have made a significant difference to the process. Once the fire in the hearth was lit and maintaining at least 400 - 500 °C, recording began, and the distillation run was deemed to have started. Fuel was continually added to increase and maintain the temperature for a set duration of time depending on the run, after which the fire was then left to burn-down for another set period, where the still was not monitored or tended to but continued to distil and record temperatures. This provided an impression of the apparatus's heat retention properties and level of control to change or maintain temperatures. After all experimental trials, apparatus components were photographed to produce a record of macroscopic use-alteration changes to the apparatus components (see Appendix 8).

Figure 46. *Location of thermocouples on reconstructed Gandhāra apparatus:* ***1.*** *Heat source (within hearth);* ***2.*** *Distilland (inside still body, below level of liquid and not touching ceramic interior);* ***3.*** *Still head (interior);* ***4.*** *Receiver (interior). The use of the hearth instead of a hotplate as employed in the preliminary experimental studies (see Chapter 5) allows for a greater surface area of the still body to be heated.*

Trial	Hearth	Duration of distillation (mins)	Duration of burn down (mins)	Sealant	Condensing strategy	Wind speed min. - max. (mph)	Ambient temperature min. - max. (°C)	Produced distillate (ml)	Remaining distilland (approx. ml)	Notes
1	Rock	120	30	Clay	Cold cloths (changed)	7-9	9-11	N/A	2750	Partial apparatus (without condensing tube and receiver), slow distillation
2	Clay	60	60	Clay	Cold cloths (changed) and basin replenished	4-7	7-12	146	2850	Success, small yield of distillate, seal burst, and pressure drop noted
3	Clay	60	60	Clay	Cold cloths (changed) and basin replenished	5-7	15-17	0	2910	Failed distillation
4	Clay	120	60	Clay	Cold cloths (changed) and basin replenished	4-8	21-28	0	2010	Failed distillation
5	Rock	60	60	Clay	Cold cloths (changed) and basin replenished	7-9	10-15	3	2950	Small success
6	Rock	180	60	Clay	Cold cloths (changed) and basin replenished	7-9	10-15	16	1010	Small success, very small yield of distillate

Table 13. *Properties of exploratory experimental distillation trials.*

6.4 Results

The results of both the individual experiments and comparison between all experiments are presented here. Experiments were undertaken periodically at the dedicated Department of Archaeology's experimental area at Beauchief Abbey, Sheffield, between May 2021 and May 2022. Results are presented in subsections to display findings related to each stage of the experimental campaign. Temperature readings of individual components are presented and discussed where relevant to each individual section. Note that hearth temperatures where listed are not representative of the average temperature of the hearth due to the fluctuating inconsistent temperature of a fire taken by a localised reading point of a thermocouple. As such, some hearth temperature plots are not displayed in temperature recording graphs but are found in the Supplementary Data if not relevant to the individual trial or experiment.

6.4.1 Water heating in ceramic vessel on open fires and hearths

Water heating trials over an open fire demonstrated the rate at which high temperatures of liquid boiling could be reached easily over an open fire. However, heating was largely uncontrollable. The runs were originally intended to be conducted sequentially to produce comparative averages between open fire and hearth heating (see 6.3.) Unfavourable weather conditions at the experimental area and subsequent mitigating decisions meant each run became a unique trial (Table 14). Instead of repeating the open fire and hearth heating tests, and exhausting more resources and time, it was decided that the need for a hearth was established, albeit the decision was rooted in experiential information rather than conclusive experimental data.

Run/trial name	Duration of run (mins)	Duration of burn down (mins)	Temperature start (°C)	Wind speed (min.-max.) (mph)	Notes
Open fire 1	90	60	135.6	13-16	Crack in vessel noted
Open fire 2	60	30	645.7	13-16	Abandoned early (01:10:45) due to crack in vessel
Open fire 3	60	30	121.1	4-8	Crack in vessel noted (00:10:00)
Hearth 1	60	30	183.2	4-5	Abandoned early (00:39:00)
Hearth 2	60	30	416	6-16	Abandoned towards end of burn down (01:22:00), though average taken for last 8 minutes
Hearth 3	60	30	432	6-12	Abandoned early (00:42:00)

Table 14. *Individual runs comparing heating water using a hearth structure and open fire.*

The first open fire test used the planned longer duration of run and burn down period. However, during open fire run 1, it soon became apparent that a break in the vessel base had emerged, possibly caused by all the water boiling off sooner than anticipated. It is likely, therefore, that the vessel had broken through direct thermal shock. The higher heats after 120 minutes (above 100 °C) are likely to be due to the thermocouple reading the vessel atmospheric temperature rather than water temperature. Open fire run 2 repeated this process with adjusted run durations, though at 54 minutes, it was noted again that the water vessel had cracked, and water had leaked from the base and lower exteriors. From this damage, the continual slow leaks from the test vessel were clearly influencing the thermocouple readings for the heat source and so the configuration of in the next trial was altered. Open fire run 3 repeated the previous experiment, though considering that leaks in the previous run may have influenced the heat source, the repaired vessel instead was placed upon a tripod of stones to elevate it from direct contact with the fire. However, a leak from the base and lower exteriors was noted early into the run at the 10-minute mark which again appeared. The hearth runs were primarily affected by adverse weather which meant that all runs had to be abandoned at points due to flooding at the experimental area or heavy rain affecting both the thermocouple reader and ability to maintain the fire within the hearth. As such, while it was anecdotally noted that the hearth was much easier to maintain, use, and control in comparison to an open fire, this could not be demonstrated in the temperature readings (Figure 47).

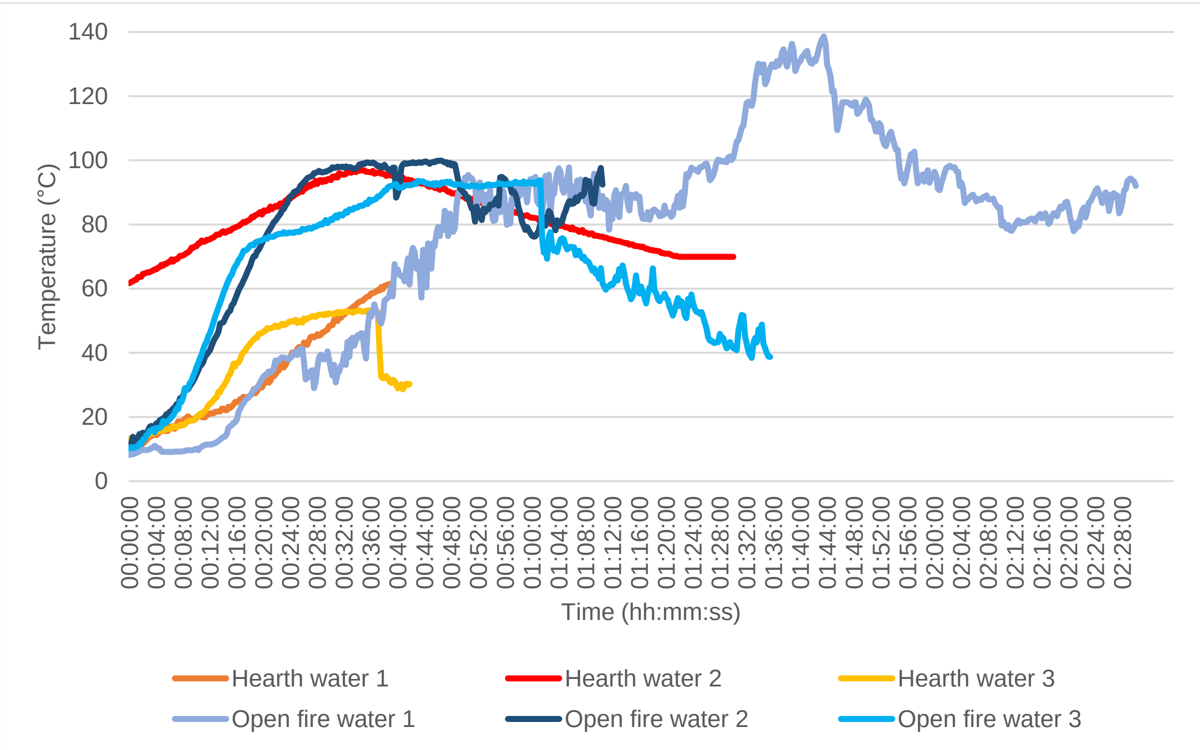


***Figure 47**. Water temperature readings from hearth and open fire heating tests (see Supplementary Data for raw experimental data).*

The brief, though largely unsuccessful, experiment justified a need for a hearth to both elevate the still body from direct heat and provide a stable, heat-retaining environment to better control temperatures throughout the apparatus use. While the temperature data across all the runs cannot necessarily be used to support the idea that the hearth provided a more gradual rate of heating (Figure 47), it could be stated that because the water in all the open fire runs boiled off far faster. This caused to fluctuating rather than gradual temperature increases, hence, the hearth acted as a more appropriate and rapid method of heating water in a controlled manner. Thus, a hearth is a preferable feature for the distillation apparatus. This does not necessarily pertain to a specific material (for instance the hearth could be made from clay or assembled rocks), but rather that a structure would be required. This was needed to be further established in the subsequent trials, ascertained through practical distillations.

6.4.2 Trial 1: Condensing vapour in a specific component of the still

Building on the previous body of experimental data, the first trial aimed to see if water vapour could be drawn through the still successfully and subsequently condensed at the end of the still head spout using a reduced version of the Gandhāra apparatus (Figure 48). This would demonstrate that the fundamental functional principal of the still worked, justifying further experimentation to establish how individual components of the reconstruction affected the performance of the apparatus. Once the fire was lit and steady, 4000 ml of water was placed into the still body, and the join between the head and still was immediately sealed with clay. It was then placed into the hearth and the thermocouple reader was set to record, with the still tended to for 120 minutes followed by a further 30 minutes of burn-down. To maintain and promote a localised cooling environment during the run, cold wet cloths were wrapped over the still head spout and replaced with new ones once they had warmed. Seals between joins were repaired when needed using more clay and a small ceramic bowl was placed under the spout to collect the distillate.

Distillate began to visibly collect at the end of the spout at least from 48 minutes into the run. Vapour could have been condensing earlier within the spout, though this was not noted. Distillate was produced very slowly as only a maximum of 5 ml of distillate was collected. This amount is, however, approximate as the distillate was collecting so slowly that much of it was absorbed into the catch bowl. Cloths were changed regularly with new cold ones once they were deemed to be too warm to maintain the condensing atmosphere in the spout, though were changed in an irregular pattern of intervals. Distilling almost slowed to a halt when cloths were either too warm or no cloths were on the spout during changeovers, suggesting that distillate production was not just vapour condensing when meeting the cooler atmospheric temperatures outside of the apparatus. Temperature readings within the still showed that heating was consistent and maintained boiling temperatures (Figure 49), though it was noted that if the still was too hot throughout then a suitable condensing atmosphere at the spout would not be concurrently maintained. As such, while changing cloths did not appear to affect temperature change within the still (Figure 49), instead it did directly implicate the flow of distillate produced.

Figure 48. *The reduced Gandhāra apparatus in use.* ***Top left:*** *The reduced apparatus built into the rock hearth;* ***top right:*** *distillate collecting at the end of the spout and dropping into the catch-bowl;* ***bottom:*** *securing the cloths around the spout to promote condensing (photographs by the author (top left and right) and Matthew J. Lester).*

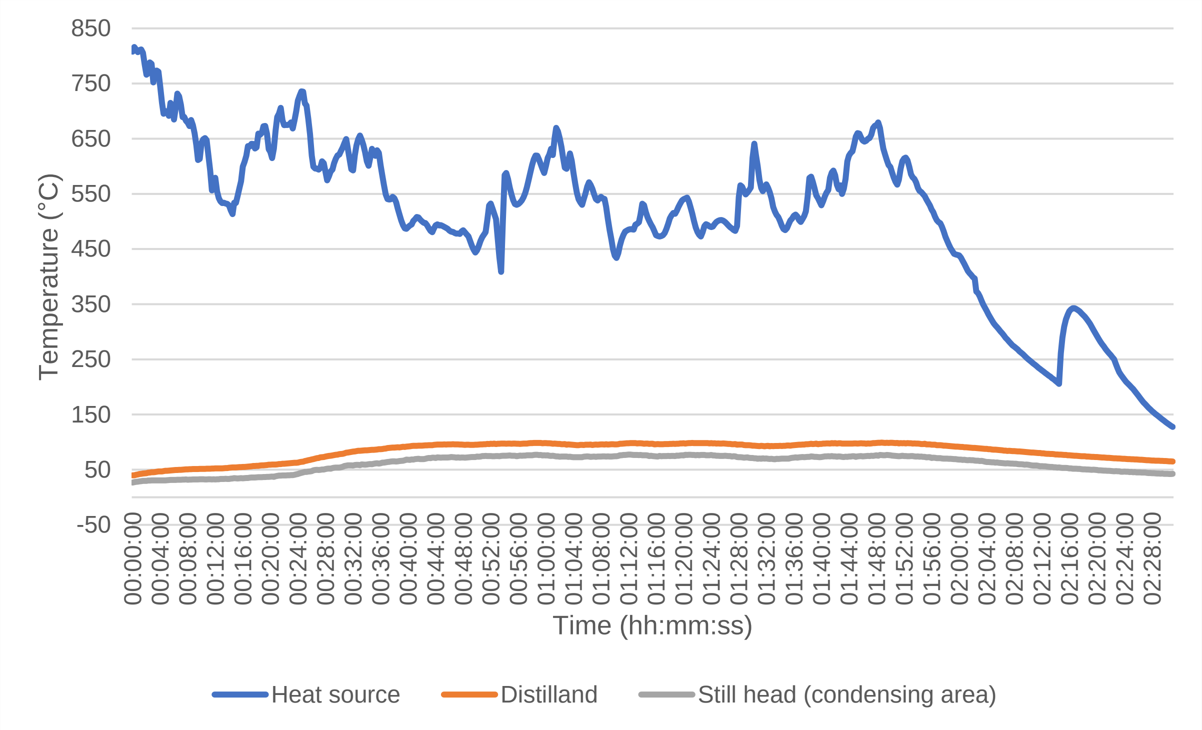


Figure 49. *Temperature readings derived from Trial 1 (all components; see Supplementary Data for raw experimental data).*

6.4.3 Trial 2: 60-minute run with full reconstructed apparatus

The first distillation trial with the complete apparatus proved successful, though yielded a low volume of water distillate. Trial 2, therefore, involved using the complete reconstructed apparatus to distil water. Once the fire within the hearth was lit and steady, 4000 ml of water was placed into the still body, and all joins between the components immediately sealed with clay. It was noted, however, as also observed in the preliminary experimental study (see Chapter 5), that the joins between the still head spout and condensing tube were not flush, which may inhibit vapour and condensing vapour flow. The thermocouple reader was then set to record and the still was tended to for 60 minutes followed by a further 60 minutes of burn-down. To maintain and promote a localised cooling environment during the run, water in the receiver basin was constantly replenished and cold wet cloths over the head spout and condensing tube were replaced with new ones once they had warmed, and seals between joins were repaired when needed using more clay (Figure 50).

Figure 50. *The complete reconstructed Gandhāra still in operation using a clay hearth to heat the distilland and cloths being changed along the condensing tube (photograph by Matthew J. Lester).*

Temperatures within the still quickly reached boiling point. The receiver and condenser were also cold enough to promote condensation based on the previous trials. However, at 00:36:45 into the run, the main seam between the still body and head burst, due to an excessive build-up of pressure. This caused the clay seam to fracture and the still head to become dislodged from the body. This is reflected in the sudden spike in receiver temperature readings (Figure 51) as hot vapour had built up in the system and not condensed quickly enough. Once the apparatus had been repaired, temperatures within the receiver recovered before the burn down period, though this incident indicated that the unit was able to maintain the correct pressurisation for promoting a distilling environment. This is also indicated by the distilland and still head condensing area reaching 100 °C prior to the seam burst. The apparatus explosion, due to a build-up of pressure needing to be released by some means, indicated that the system was not being cooled sufficiently, or the apparatus configuration did not possess a large enough condensing surface area to rapidly cool and condense the hot vapour.

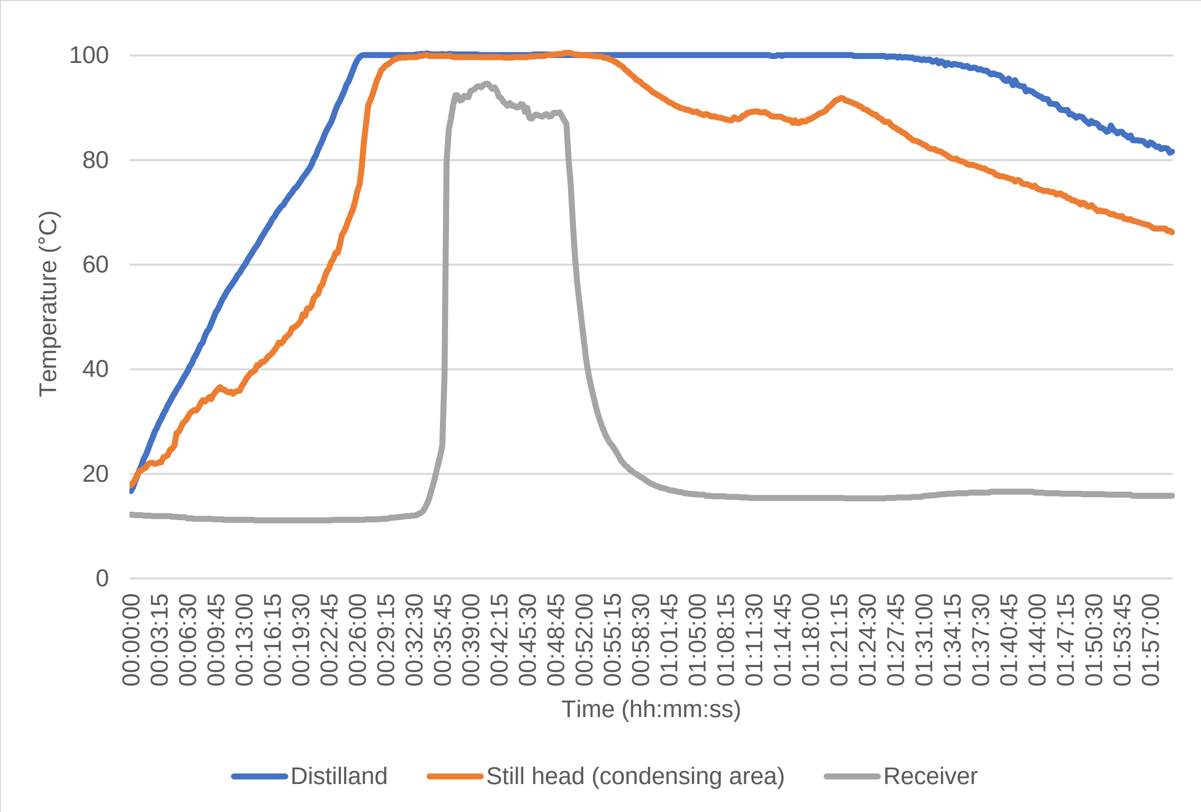


Figure 51. *Temperature readings derived from Trial 2 (without heat source; see Supplementary Data for raw experimental data).*

6.4.4 Trial 3: 60-minute run with full reconstructed apparatus

Trial 3 repeated the same protocol as Trial 2 (see 6.4.3), intended as a repeat experiment to demonstrate that the apparatus could consistently distil. However, ultimately it was a failed run yielding no distillate. The protocol was followed exactly as before, starting with 4000 ml distilland, and continuing for 60 minutes with a 60-minute burndown. Considering that the seal had burst in Trial 2, it was noted that a significant pressure build-up had occurred through the whole system. Thus, in Trial 3 the seal between the receiver and condensing tube was not closed using clay. Once the trial had commenced, while increasing gradually, temperatures of the distilland and condensing area dropped at 00:38:30, which did not correspond with a sudden change in temperature with the receiver (Figure 54). Fluctuations in the heat source temperature readings (see Supplementary Data) equally do not correspond to the sudden drop-off. Possibly, this may indicate that the system was not fully pressurised (i.e., too much heat and vapour were escaping) and, therefore, an adequate condensing environment was not promoted. It was, however, noted that condensed vapour was instead accumulating and penetrating through the clay join between the still body and head, possibly indicating full a reflux action occurring. Hence, vapour was only condensing at the top of the still and not in the spout and condensing tube was (Figure 52). Presumably, adequate pressurisation was not achieved through the apparatus to distil water, yet seams were continuously repaired using clay when breakages were noted (Figure 53), but ultimately the internal environment was not fully conducive for promoting distillation.

Figure 52. *Vapour condensing within the still head, collecting around the interior join between still head and body due to reflux, and then penetrating through the clay seam by saturation or escaping through seal cracks (photograph by Christos Giamakis).*

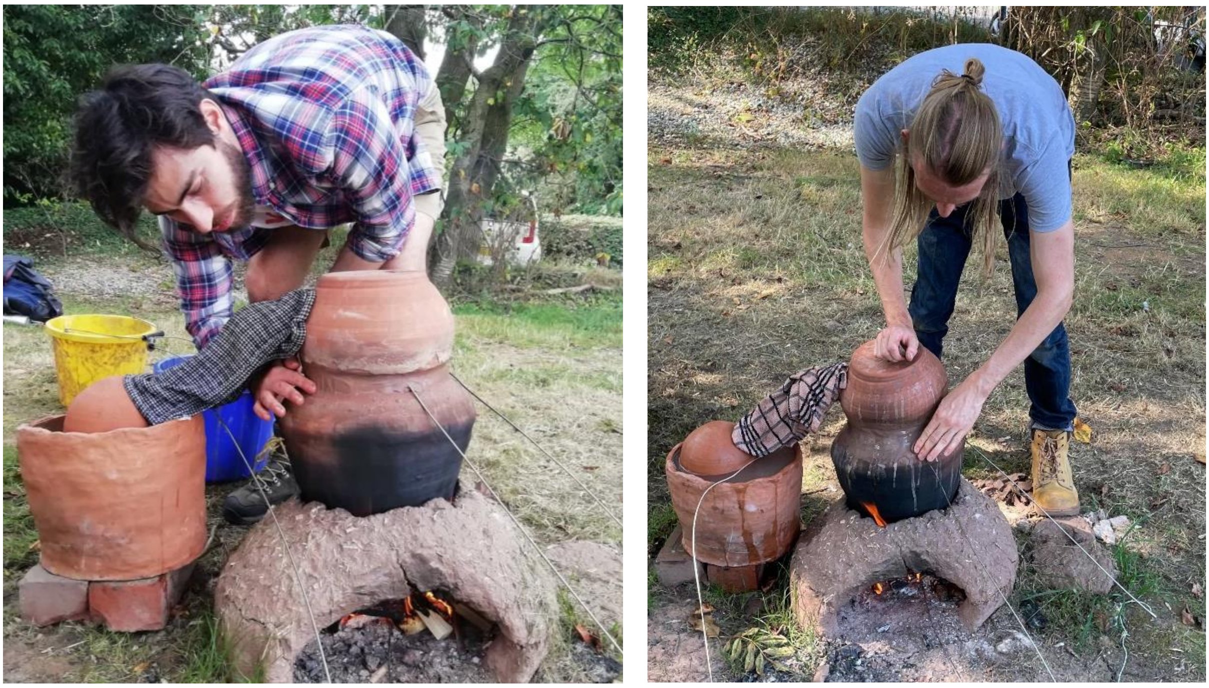


Figure 53. *Repairing seams between the apparatus components using clay and clay slip to maintain a pressurised atmosphere in the still (photographs by the author and Matthew J. Lester).*

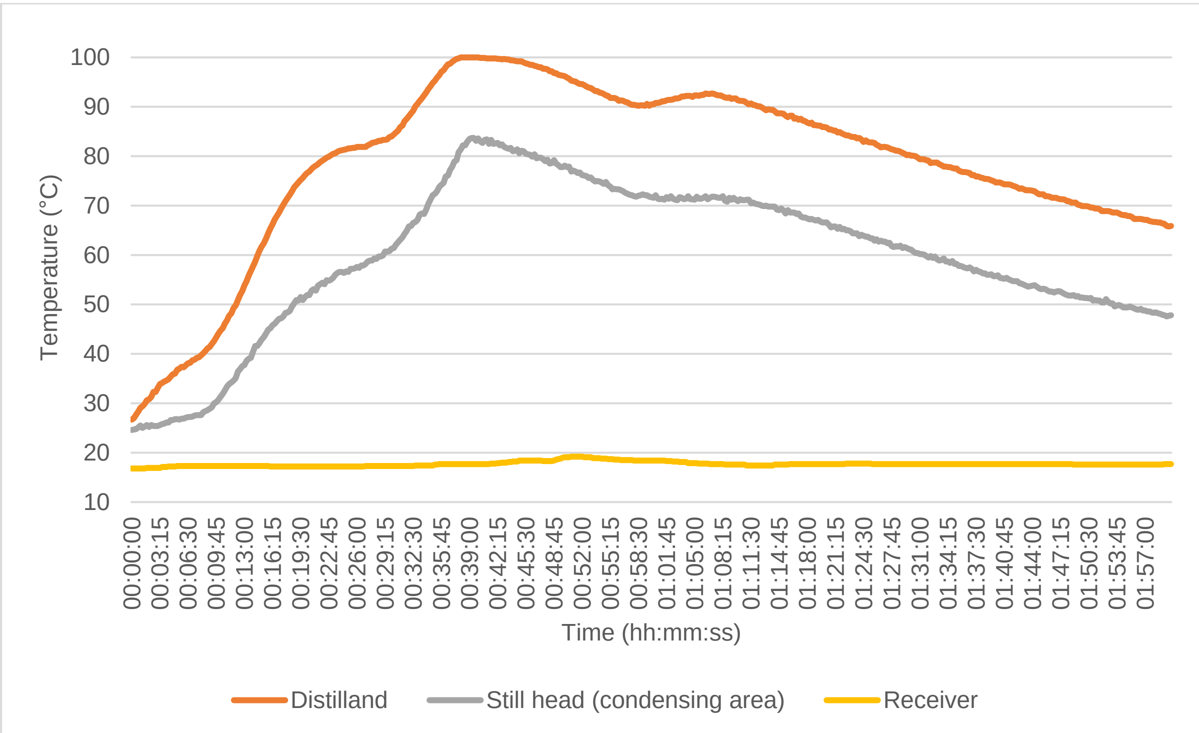


Figure 54. *Temperature readings derived from Trial 3 (without heat source; see Supplementary Data for raw experimental data).*

6.4.5 Trial 4: 120-minute run with full reconstructed apparatus

Trial 4 repeated the same protocol as Trials 2 and 3, though increased the run time by a further 60 minutes in response to the failed yield exhibited in Trial 2, and providing a longer period to diagnose and repair any faults. The trial started with 4000 ml distilland and continuing for 120 minutes with a 60-minute burndown. The join between the condensing tube and receiver was sealed using clay in response to the failed distillation in Trial 3, the distillation again failed, yielding no distillate. Temperature readings showed that the distilland and still head condensing area were not maintained or consistent throughout the trial. This was noted once 100 °C had been reached, and temperatures consistently declined at a regular rate during the burn down period (Figure 55) suggesting that the rate of heating and heat source may have affected the trial distillation. It was hypothesised that potentially the temperature, rate of heating, and size of the hearth fire during Trial 2 were higher than those in the current trial, particularly as it seemingly took longer to reach boiling point for the distilland, and fuel usage was slower or more gradual (Figure 56). While fuel consumption was not measured and such a observation is anecdotal, temperature readings of the heat source in Trial 2 and Trial 4 are significantly different, with the heat source in Trial 2 as consistently hotter. This may have been a contributing factor to the failure of the distillation trial, however, the two cannot be clearly connected or proven with the existing dataset. Equally, distillate appeared to have soaked through the seams particularly between the still head and body, though again it could be stated that clay was not the most appropriate material for a sealant between each component of the apparatus, contributing to the failed distillation. Trial 2 had, conversely, proved a success and so this could not be determined as the sole factor. It was noted, however, that the complete apparatus may have been getting too hot and that the differentiation between the still body and condensing area was not great enough to promote distillation. Additionally, the shape of the condensing tube, and the means by which it attached to the still head spout, could have been preventing vapour condensing in a part of the tube that would have allowed it to collect in the receiver.

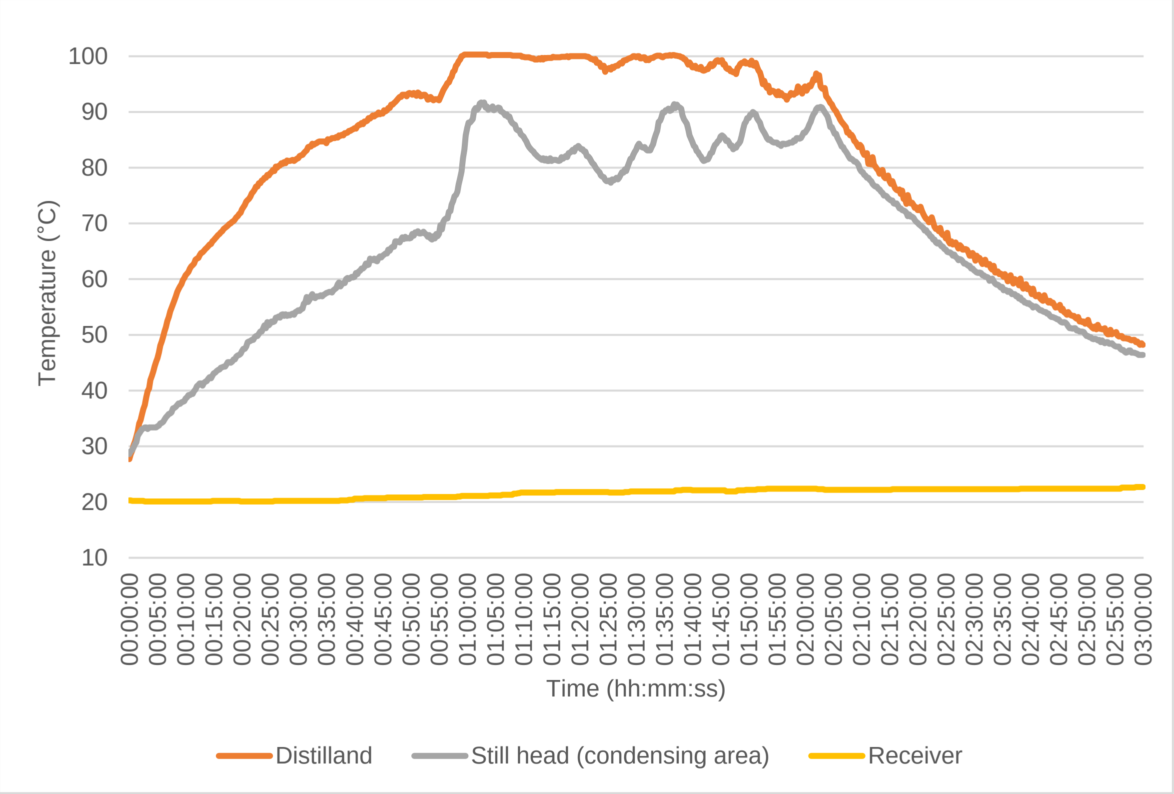


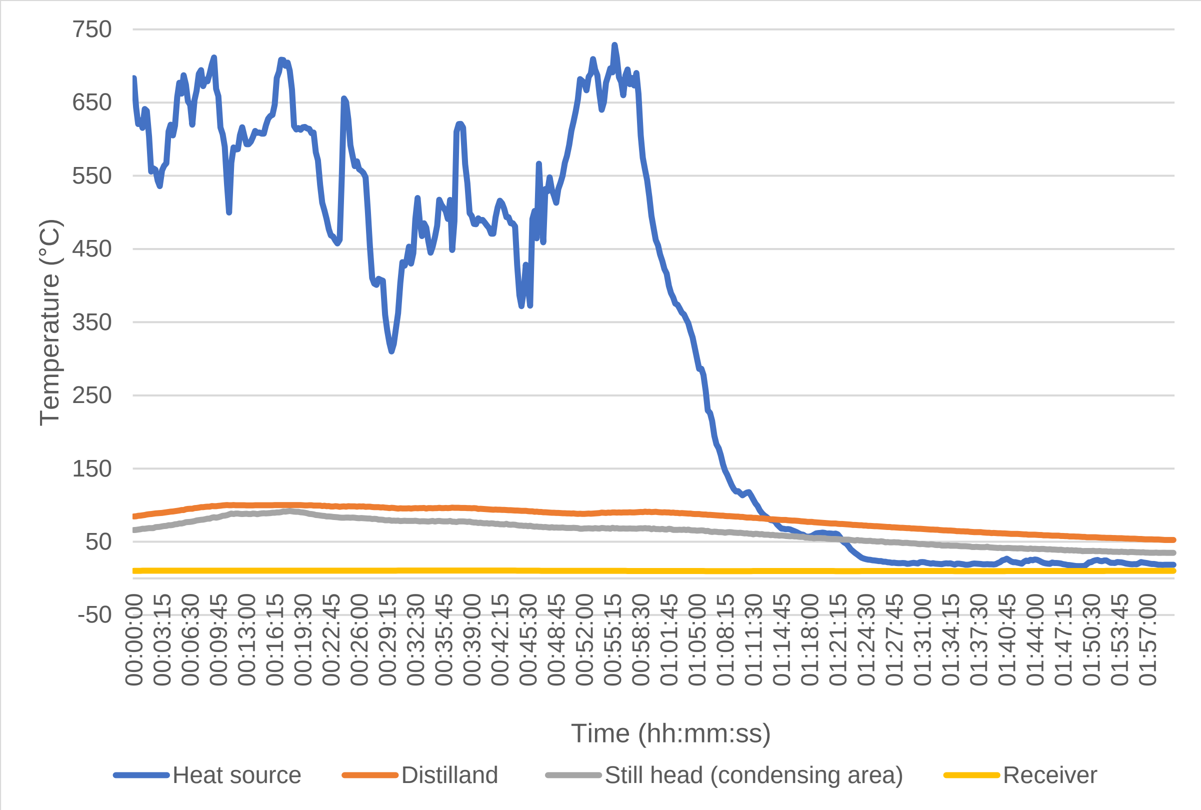
Figure 55. *Temperature readings derived from Trial 4 (without heat source; see Supplementary Data for raw experimental data).*

Figure 56. *Adding fuel to the hearth during Trial 4 (photograph by the author).*

6.4.6 Trial 5: 60-minute run while maintaining specific temperatures

In response to the potential issues highlighted in the previous trials, instead of beginning the trial by attempting to get the distilland to 100 °C so that it boils, Trial 5 aimed to ascertain the ease of maintaining the distilland and still temperatures at a temperature consistently lower than 100 °C). This, in principle, would prevent a refractory process occurring in the still (see 3.2), but still produce vapour to be condensed, and increase the temperature differential between the condensing area and distilland. This would have created a more conducive distilling environment. Using a rock hearth, once the fire was lit and steady, 4000 ml of water was placed into the still body. The still was then placed onto the hearth and the join between the head and still was immediately sealed with clay. When the distilland temperature of 80 + °C was reached, the thermocouple reader was set to record with the still tended to for 60 minutes followed by a further 60 minutes of burn-down. The aim then was to keep the distilland and internal atmosphere in the still head between 80 – 90 °C through cooling and monitoring the heat source in the rock hearth. To do this, the fire was periodically stoked (built up) and left to burn down gradually, considering that burn down stages in previous trials showed that distilland and still head temperatures dropped quickly when the fire was not tended (see 6.4.5).

Trial 5, however, ultimately failed as no distillate was produced. Furthermore, keeping the still at a consistent temperature proved very difficult (Figure 57), as the hearth retained heat well and kept the still body sufficiently hot even when the fire was almost fully extinguished. Such a correlation between the two factors cannot be easily established from the temperature readings alone as heat source temperatures did not correspond with drops in the still head and distilland temperatures (Figure 57). The variable temperatures recorded may be rooted in failing to keep the heat source fuelled adequately, but equally it could be that the condenser was not kept sufficiently cool or that the seal between the condensing tube and still head spout was inappropriate for the configuration. When the heat source was deemed to be too high, and thus heating the system too quickly, responding to this by letting the fire burn down (Figure 57) was not a consistently useful method of adjusting the heat in the system. The inability to maintain a consistent temperature within the system may be due to the heat retention properties of the hearth and ceramic apparatus. However, it might also have been affected by the operatives failing to react to crucial fluctuations in the heat source.



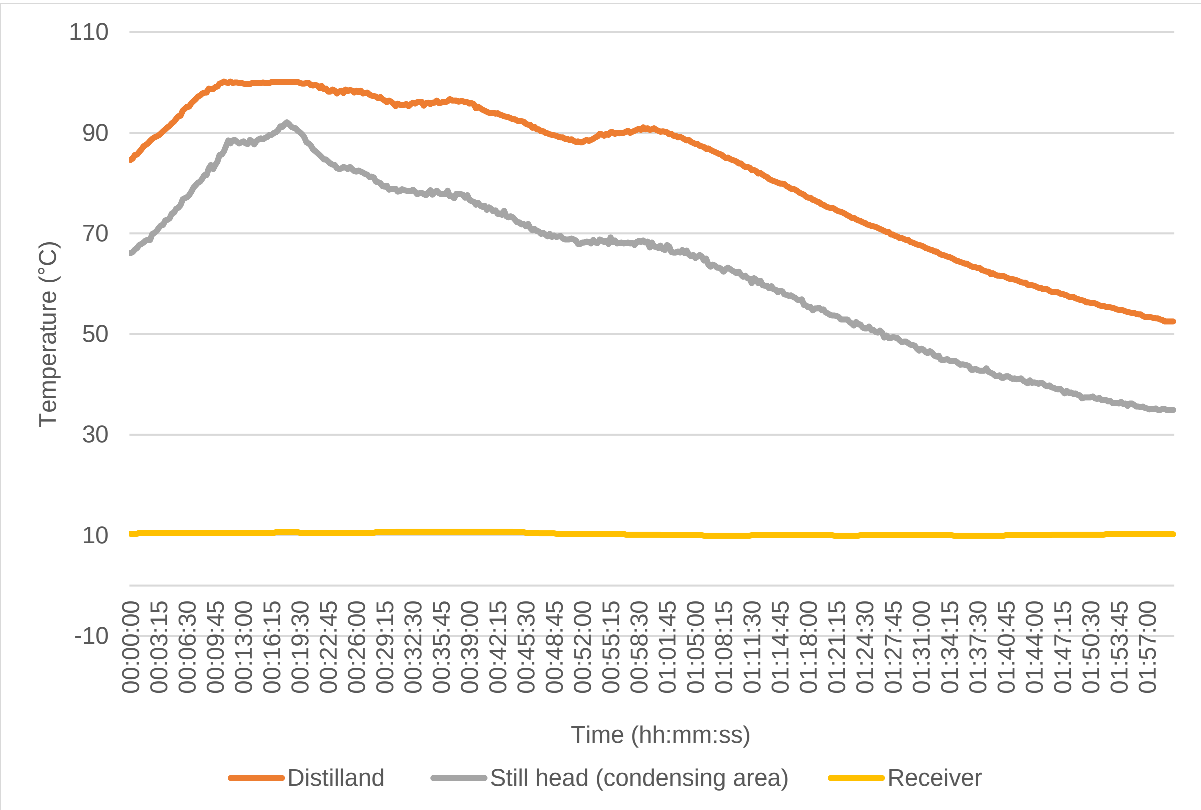


Figure 57. *Temperature readings derived from Trial 5 (with heat source (above) and without heat source (below); see Supplementary Data for raw experimental data).*

6.4.7 Trial 6: 180-minute run with clear condensing tube

Trial 6 used a similar protocol as the previous trials, though increased the run time to 180 minutes, offering a longer period of time to diagnose any faults in the system. It also aimed to develop insight into a long distillation that would theoretically been needed to fill the suggested capacity of the receivers (see Chapter 4). It was decided that a clear condensing tube fashioned from a plastic bottle would be used instead of the normal ceramic tube considering that failed distillations in the previous trials may have been caused by an inadequate join between the still head spout and the condensing tube. This would provide a means to observe one area of condensation during the distillation process, and perhaps identify any potential issues occurring in this crucial part of the apparatus. While not perfect, it was deemed suitable for identifying how the vapour and collected distillate could move within the system and could also help understand further potential parameters that would influence the distillation operation.

The trial started with 4000 ml distilland and continued for 180 minutes with a 60-minute burndown. A small volume of distillate was produced during the trial over the distillation period. Considering the previous trials, the heat source was kept at a consistently lower temperature so that the system would not be too hot and, therefore, close the temperature differentiation in the system between the boiling distilland and significant cooler condensing area (Figure 58). Equally, it was expected that this intervention would slow the rate of vapour production and pressure build-up within the system, avoiding seals bursting as had happened in Trial 2 (see 6.4.3), and steadily produce vapour at a manageable rate for the condensing tube. Within the tube, vapour was successfully condensing though unable to collect in the receiver due to the shape of the plastic tube. Instead, condensed vapour gathered within a recess at the end of the tube. Presumably within an internally smooth and shaped condensing tube unique to the apparatus, vapour flow through the system (if the tube were adequately cooled) would not have been inhibited. Regardless, the quantity collected was so small that it is difficult to see how the configuration was condensing successfully and consistently to be deemed an appropriate apparatus. In addition, the amount of distillate that was observed to be collecting along the tube was condensing close to the spout suggesting that the tube was not sufficiently cold to be condense vapour in the correct part of the still.

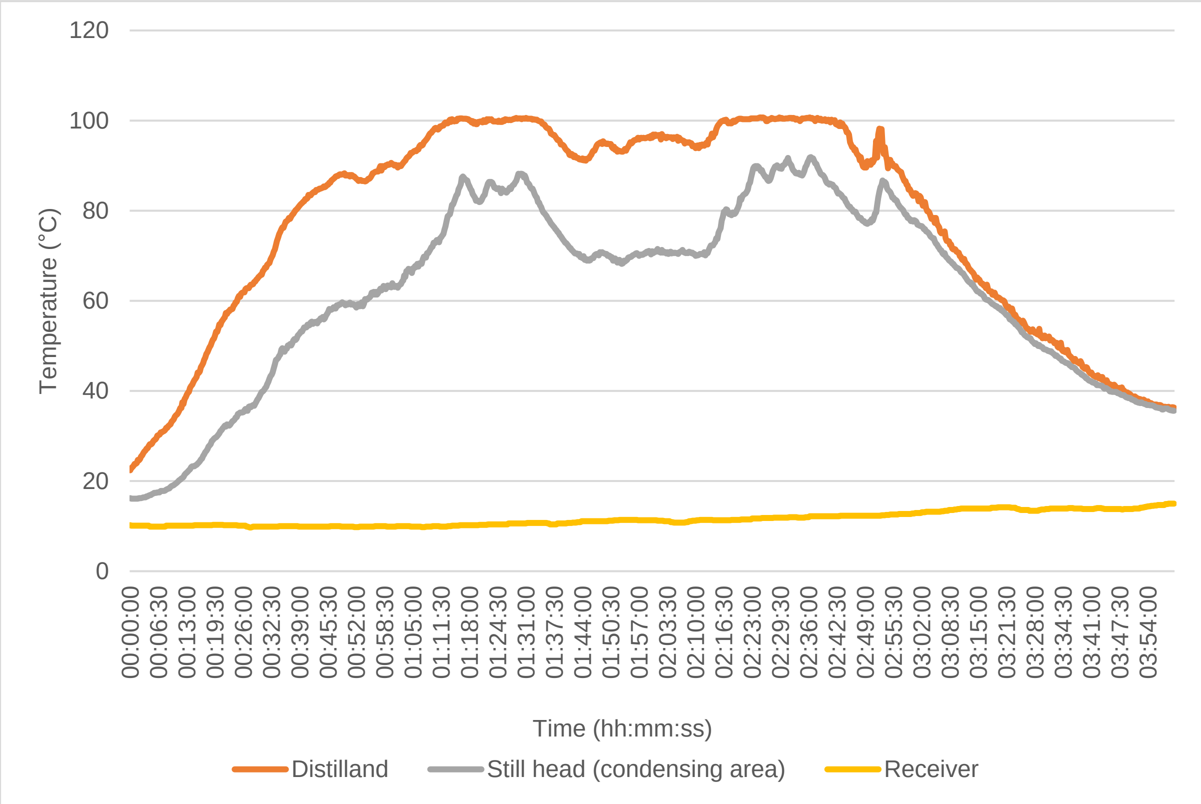


Figure 58. *Temperature readings derived from Trial 6 (without heat source; see Supplementary Data for raw experimental data).*

6.5 Discussion

The exploratory experimental campaign aimed to determine a series of functional parameters that would influence the use and operational ability of distilling with the reconstructed Gandhāra apparatus. As the first full exploration of such a pervasive reconstruction, the campaign demonstrated several potential issues that underpin elements of the proffered configuration, offering more insights into the considerations that may have arisen in the consolidation of early distillation practices. However, many of the inferences must be more comprehensively evaluated to connect any recorded observation to a potential fault, problem, or functional dynamic. Assessing the apparatus reconstruction in the most 'authentic' archaeological setting did also require accepting and responding to certain conditions of control. Conducting experimentation outdoors (i.e., not within a fully controlled laboratory environment) and the components used (such as a variable heat source) limits the replicability of the experimental campaign. Accordingly, the experimental campaign alone cannot be used as a model example to elaborate on the emergence of distillation technology as an invention. Instead, the variable conditions contextualised the evaluation of the reconstruction within questions of 'actualisation', or the reality of using the apparatus. As such, the campaign employed a methodology that generated the required insights for evaluating both the

Gandhāra reconstruction but equally developed a body of technical, practical, and sensory concerns that may have contributed to consolidating early distillation technological practices (discussed further in Chapter 7). This set of information is of greater relevance in considering material, technological, and craft concepts that would need to exist in order to accommodate distillation as a new innovation (see 3.2).

Water heating trials (Trial 1; see 6.4.1) demonstrated that different levels of control over heating methods would need to be accounted for, especially pertinent for distillation due to the central concern of vapour production rate (see 2.2). Evidently, a hearth structure provided a level control over heating rates despite varying wind speeds within each trial (see Table 13). This is not necessarily a universality, considering the range of heating methods used in distillation that are recorded in ethnographic cases and historical accounts (see Chapter 2). However, Trial 5 (see 6.4.6) particularly identified how failing to adequately respond to, and mitigate for, changes in the hearth temperature were plausibly affecting temperatures within other components in the configuration (see Figure 57). This was directly affecting any rate of distillation. Direct contact from the hearth fire with ceramic surfaces of the vessels (if not properly controlled) potentially damaged the apparatus (see 6.4.1). Thus, both vessel robustness and even rates of heating needs considering. Repeated firings after six trials were forming a layer of soot patina on the external surface of the still body (see Appendix 8). This indicated how sizable the fire was even with the controlled hearth. However, despite accurate and consistent readings of temperatures exhibited across all trials, considering that the thermocouple reader was making readings at every 15 seconds precisely, temperatures within the hearth would not have been accurately represented in the experimentation. Temperatures of a fire are ultimately not uniform and may have been affected by changes in wind speeds during different trials (see Table 13), though temperature readings of distilland across all trials suggested that heat distribution across the lower external surface of the still body was relatively even and consistent. However, one could suggest that a hearth structure or installation is required for configurations such as the Gandhāra apparatus and comprises an element currently absent from the assessment of the apparatus from South-Central Asia. Such an issue goes beyond this specific context, but comprises a more general concern within archaeology (McDonnell 2005, p. 493).

The ability of the apparatus to fully condense produced vapour, however, could be the greatest issue within the reconstruction. At the join of the still head with the still body in the Gandhāra configuration, the channel created failed to help direct condensed vapour into the receiver, but rather caused it to leak through the joins as noted in the previous preliminary experimental study (see Chapter 5). This is a repeated issue in all iterations of the Gandhāra configuration as still head morphology is not adequately considered, but significantly affects distilling ability (Figure 59). This is also not addressed within existing critiques (e.g., McHugh 2020). Therefore, throughout all the runs in both exploratory experiments and previous preliminary experimental campaign (see Chapter 5), a cyclical reflux process within the still head area was probably occurring (see 2.2). Any produced vapour and distillate instead of being channelled through the condensing pipe was, therefore, running down the interior of the head and collecting at the point where the head and body joined. Distillate then seeped out and was ultimately lost.

Regardless of the highlighted issues, distillate was collected after one successful distillation (see 6.4.3). Yields may have been increased if joins and connections between components, such as at the condensing tube and still head, were either more flush-fitting or made of a material other than clay. While this was noted in the previous preliminary experiments, including how a different material may have been more suitable as a sealant (see Chapter 5), clay seals did still promote a pressurised environment and thus adequate distillation conditions in some trials. Using different materials for sealing the apparatus could have helped promote better distilling conditions; ethnographic accounts have demonstrated a range of different sealant methods and materials, though equally several recorded cases use wet clay slip or mud (as used in the experiments) or no sealant at all (see 2.4.3). In tandem, this association demonstrates that ability of the apparatus to distil is not contingent purely on how separate components fit and join.

As Trial 2 (see 6.4.3) was a success and had maintained a pressurised environment throughout the system, this suggests that distillation was possible. However, volumes of distillate produced in trials when distillate was able to be collected (Trials 2, 5, and 6) were low in relation to the maximum volume of a representative receiver-condenser (see Chapter 4) and its smaller reconstructed counterpart. Hence, while condensation had occurred along the tube in Trials 2, 5, and 6 to produce a volume of distillate, in the other trials this was not the case. It could be argued, therefore, that a suitable pressurised environment and sufficiently cool atmosphere were not achieved constantly within the system. Equally, the constant need to repair seals was an omnipresent concern throughout each run, evidenced by the accumulation of clay upon the external ceramic surfaces at joining points. These may have created points of weakness or voids if old clay was not fully removed before a new seal was made (see Appendix 8). Consequentially, condensing conditions were not being met consistently in the Gandhāra configuration, and rather fundamental morphological issues with the apparatus neither promoted a good condensing environment nor were suitable for volumes of produced distillate from the configuration.

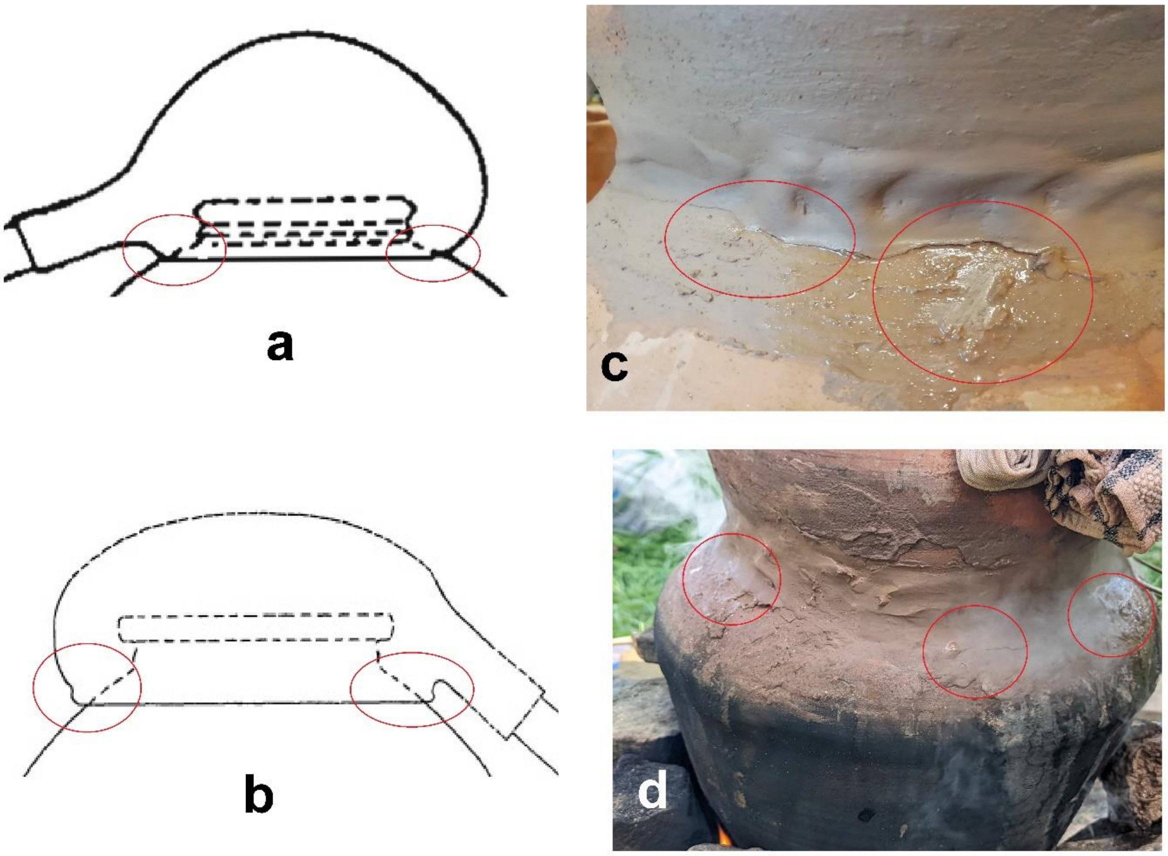


Figure 59. *The formed channel (red circles) between still head and body in the original Taxila (a) (after Marshall 1951, p. 420) and Shaikhān Dherī (b) (after Allchin 1979b, p. 773) Gandhāra still reconstructions, and leaking distillate from the channel (red circles) during the preliminary experimental trials (c) (see Chapter 5; photograph by the author) and Trial 6 of the exploratory experimental campaign (d) (photograph by Christos Giamakis).*

Therefore, evaluating vapour flow within the configuration was a key issue central to explaining why the system did not work. Firstly, the cold surface area of the condensing tube was too small for the volume of vapour building up in the system to be continuously condensed. While the replica tube was not a faithful reproduction of archaeological examples (see 5.2.2), the shape, size, and surface area of the experimental tube mirrored representative aspects of archaeological examples. Equally, as no typologically consistent tube exists (see Chapter 4) it is impossible to directly replicate all the tubes in a single experiment design. Modifying the end of the tube could assist condensing by partially blocking the ends to slow the vapour flow and thus condense more consistently. Moreover, creating a vent or hole at the top of the still head near the spout to let out any pressure build up would hypothetically prevent an explosion as was witnessed in Trial 2. This modification would also promote more consistent vapour flow throughout the system which, in tandem with an improved condensing or cooling method, could in theory yield higher volumes of distillate. However, modifications such as these are neither represented in the original archaeological materials (see Chapter 4) nor in other archaeological or ethnographic arrays (see Chapter 2). This again demonstrates the inherent issues in the Gandhāra apparatus reconstruction.

Therefore, experiments demonstrated how condensing tubes, as the principal point of cooling suggested in the original reconstructions (see Chapter 4), are far too small to process the amount of vapour produced. The most salient solution would be to heat the distillate at a much slower rate, though if too slow then no distillation would occur. However, as demonstrated in Trial 2 (when vapour producing was too fast) and Trial 5 (a too slow rate of vapour production), achieving such control even with a hearth structure is challenging. The question of vapour flow throughout the whole system is, therefore, largely forgotten in previous interpretations (see Chapter 4). Indeed, the correct pressurised environment and cooling points can be achieved within the configuration to an extent (see 6.4.3). This is also contingent on creating a large enough temperature discrepancy between the heating distilland and cooling method, which even during the coolest ambient temperatures recorded during Trials 1 and 2, was not being consistently achieved. While the experiments did not replicate distilling alcohol, the rate of heating within the system would have greatly impacted the ability for it to be able to distil materials with a significantly lower boiling point than water. Hence, the multifunctionality of the Gandhāra apparatus cannot be discussed (as had been done in early dialogues on distillation) without reconsidering properties of materials being distilled. This establishes a greater range of considerations that are often overlooked in archaeological reconstructions.

Achieving a ‘perfect’ testing environment for the reconstruction was not the goal of the study, considering that a series of plausible influencing parameters were to be determined rather than repeatedly proving that the apparatus could work and why. Here, the original reconstructions as suggested configurations exhibited archaeological materials and features of apparatus do not correspond to one another. The lack of a flush connection between the condensing tube and still head spout notably highlights the practical issues with the original reassembly of the apparatus (see Catalogue and Chapter 4). Accordingly, the fundamental arrangement of individual vessels to create the Gandhāra apparatus is not suitable beyond showing some resemblance to model distillation configurations. To some degree, it is therefore impossible to fully ‘test’ the configuration. Instead, the body of experimental data emphasises the types of technical and material knowledge required to formulate a functional apparatus and enabling distillation.

6.6 Summary

The experimental campaign identified several practical issues and influencing parameters that could affect how the reconstructed archaeological materials are considered as distillation apparatus. This is rooted primarily in how certain elements of the apparatus are joined together and fitted, such as the condensing tube and the still head. Equally, fundamental components of the apparatus as depicted in the reconstructions are not suitable for forming a functional apparatus, namely at the join between the still head and body. Such a concern could be mitigated for within different apparatus configurations. However, based on the reconstructions alone, it is difficult to support the idea that the archaeological materials arranged in this way are suitable as a distillation apparatus.

In response, the exploratory experimental process illuminated several insights and practical concerns that would govern the practice of early distillation particularly when conducted with ceramic vessels. Particularly, control over rate of heating, achieving large enough temperature differences between heated distilland and condensing points, cooling strategies, and embodied sensory knowledge pertaining to when changes within the system must occur are some considerations that arose during the experimental campaign (see Appendix 7). While these were identified and recorded, such experiential insights tie to wider discussions of skill, training, and learning that become embodied through repeated practice. Taken from the experimental trials, these cannot be simply used to elaborate on the emergence of early distillation technology. Instead, such sensory and technical information reveals human considerations on process and practice that would help establish distillation within a social context.

Therefore, the next chapter will unify what can be gleaned from the material survey and experimental studies to generate a series of insights on the existing interpretation of ceramic vessel forms as distillation apparatus. Based on this body of information, a renewed understanding of the ceramic distillation apparatus from Gandhāra will be offered. Finally, a series of preliminary ideas will be presented on the technical, craft, and sensory basis needed to consolidate distillation as a technological practice and innovation.

Chapter Seven

Discussion

7.1 Introduction

The archaeology of early distillation has historically been viewed as a problem that can only be addressed through a technical framework of analysis. Simultaneously, such an association emphasises existing evolutionary models of technological change and provides an explicit link that is followed in searching for the origins of distillation. While the idea that distillation diffused into regions from a single point has been challenged in recent scholarship (see Chapter 2), the focus on establishing explicit origins for distillation technologies has distorted how innovation is understood. When generated from such a perspective, specific reconstructions of distillation traditions, such as the 'Gandhāra still', rely on assumed and preconceived ideas that stem from modern intellectualisations of chemical processes (see 3.5). Here, the emphasis on understanding the empirical foundations of distillation has marginalised a complete interpretation of early distillation as a human-centric technological practice (see Chapter 3). Attempts to connect the supposed Gandhāra tradition of distillation with its ancient Greek roots, despite being re-evaluated over several decades, exemplifies how entrenched this approach is. Further, it is a concern that mirrors the legacy of research traditions in South-Central Asia that aim to find 'Greeks-in-the-East'. While robustly deconstructed in recent archaeological studies, such historical perspectives remain in the interpretation of technology and materials (see Chapter 3). Thus, the typologically classified apparatus components, and their associated activities characterised as 'distillation', have been viewed in a limited context and ascribed cultural groupings. The interpretation of technology, therefore, and its contributions to exploring cultural interaction and change in Gandhāra as a nexus of dense human interaction, is yet to be fully utilised.

The discussion presented in this chapter will draw together the key ideas and results from the thesis to argue for a preliminary view of early distillation as a complete technology from a practice-based approach. Subsequently, new perspectives on archaeological materials previously associated with early distillation in South-Central Asia will be proposed. Through the material survey, as the first to consolidate all examples of apparatus within the region (Chapter 4), and exploratory experimental studies (Chapters 5 and 6), the claim of early distillation in South-Central Asia can be effectively challenged and dismantled. Additionally, through the experimental aspects of the evaluation, a renewed interpretation of early distillation and its relationship with concepts of innovation can be discussed. Embracing an understanding of early distillation technology as an emerging sociotechnical context, a preliminary interpretation will be presented that engages with concepts of ‘anchored’ innovations, technological clusters, and craft practices (see 3.2).

This discussion will first evaluate the methodologies that were used to conduct the material survey and individual experimental studies, addressing their appropriateness to critique the ‘Gandhāra tradition’ of distillation (see 7.2). From this position, the chapter will reconsider archaeological materials and sites in South-Central Asia that have been connected to early distillation (see 7.3) by offering an alternative view on what they could represent (see 7.4). Subsequently, the experimental results and insights generated through the experimental studies will be used as a foundation to present a preliminary interpretation of early distillation as a sociotechnical practice (see 7.5). Hence, the emergence of early distillation will be reframed as a changing relationship between humans and materials, drawing from existing theories on innovation and sociotechnical practices.

7.2 Methodology evaluation

The unified material and experimental approach taken to evaluate early distillation technology and the ‘Gandhāra tradition’ of distillation has provided a meaningful framework by which to comment on a longstanding and assumed interpretation. It was achieved, however, only by allowing qualitative and quantitative data to be gathered simultaneously and therefore unify measured observations with subjective ideas on practice. As such, by working directly with the reconstructions and collecting empirical data through the experimental studies, the functional capacity of the Gandhāra apparatus could be fully critiqued. This was done first by considering functional elements of the vertical apparatus, as a suggested alternative of distillation apparatus in the region (see Chapter 4), before fully exploring a series of variables that could affect the performance of the Gandhāra apparatus within an ‘authentic’ setting. By abstracting the essential features of the archaeological reconstructions before experimentation, and reproducing and reworking elements of configurations, it is hoped that a nuanced perspective on the effectiveness and functionality of the Gandhāra apparatus has been developed. Equally, this process generated a body of knowledge on the practice of early distillation with direct connections to explicit technical decisions. This is key to fully understanding the practical and technical dimensions forming the technology of early distillation, even if the reality of the Gandhāra tradition of distillation is questionable. Thus, considering the multifaceted approach taken here to analyse the manifestation of early distillation technology within the Gandhāra region, it is key that each individual element is evaluated alongside the study as a coherent whole. From methodological evaluations within the discussions of Chapters 4, 5, and 6 respectively, a strong case can be made to present the merits of integrated analyses when interpreting technological contexts.

As the foundation for evaluating the Gandhāra still and distillation tradition, the material survey brought together a myriad of resources and reassessed typological ascriptions tied to the fundamental components of the suggested configurations. The construction of the apparatuses have undergone some discussion from this perspective before (e.g., McHugh 2014, 2020). In response, a systematic evaluation of the components was needed to establish the breadth of the issue. Both the suggested (but generalised) vertical configuration and specialised features of the Gandhāra apparatus were represented in the survey dataset, despite research historically focussing on identifying 'receiver-condensers' (see Catalogue). However, the body of original research, which may have alluded to spatial insights on other apparatus components, did not emphasise such relationships clearly for evaluation in the material survey. Potentially, therefore, any observed patterns could be only conjectural when discussing the distribution of full apparatus configurations. That said, because the original records of the excavations were consulted to generate the survey data, the dataset was sufficiently complete through utilising additional archive material that supported reports, publications, and ultimately the interpretation of apparatus configurations. Such a body of information, as a critical study itself, provided a robust foundation to support targeted experimental work and definitively challenge the accepted idea of the archaeological materials as a distillation apparatus.

As established in Chapter 3, the role of experimental work in conceptualising early distillation has been to support, rather than evaluate, the viability of configurations. It could be stated that the application of previous experimental methods has been somewhat irrelevant and ignored their potential value as a methodological tool to critique broad claims and perpetuated narratives (see Chapter 3). The experiments conducted within this study are, therefore, the first to comprehensively test the viability of the Gandhāra tradition of distillation. Preliminary experimentation first tested the two apparatus configurations (vertical and Gandhāra) directly following their respective interpretations and operation. Despite operating in a laboratory setting and using a modern heating device, the preliminary experiments recognised a suite of issues with the reconstructions, such as heat transfer across the still body surface area and seam leakage between components. This allowed for the exploratory experimental campaign to directly address variables in a detailed approach that related to fundamental function parameters involved in distillation, such as heating and cooling. Furthermore, the exploratory experimental campaign demonstrated how distancing experimental research from rigid hypothesis-testing structures is beneficial for creating nuanced ideas on early distillation, in contrast to the existing format of experimental work (see Chapter 2). This was effective for simultaneously exploring multiple variables and influencing factors, and increasing the angles of critique, but also developing an idea on how distillation could be enabled within the limits of the apparatus. While it could be stated that the lack of multiple repetitions of individual trials through both experimental studies brings the accuracy of any results or insights into question, multiple runs with each apparatus allowed for a substantial understanding of functionality and associated issues. Moreover, because the studies aimed to establish a range of influencing factors, the sequence of tested variables and trialled apparatus acts as a substantial body of results by which to further existing critiques of apparatus configurations. This was done both within a controlled laboratory environment to first establish a potential range of issues and then in a more 'authentic' open-air setting. Appropriately, certain specific functional elements could be discussed, framed with the expectation of understanding detail of the technical decisions and craft practice involved in early distillation.

Data recording through both sets of experiments made use of empirical measurement coupled with experiential and sensory insights. Through the course of conducting the preliminary experimental trials, an appropriate measurement strategy was determined including specific variables and locales on the configurations that should be measured during the distillation processes. Taken forward into the exploratory campaign, this allowed consistent impressions to be drawn from each isolated trial, connected to specific functional parameters that influence the process of distillation. Despite the lack of repetition, consistent observations on issues within the configurations, and during each process, could be determined. The methods of gathering subjective observation data did, however, differ in each study. Chapter 5 took a systematic approach to sensory and experiential insights, recorded at regular intervals, whereas Chapter 6 instead had a more progressive approach to recording ideas and concerns as they arose. Doing so diverged from rigid recording strategies, rendering insights directly relevant to individual emerging issues. This allowed closer connections with concerns of technological innovation to be made, where adaptions and modifications are noted through active practice (see Chapter 3). As a result, the combined methodological approach was appropriate for analysing the manifestation of distillation technology in South-Central Asia, and equally comprises an understated but fundamental component needed to analyse the viability of any technological reconstruction.

7.3 Deconstructing distillation apparatus in South-Central Asia

In capturing the impact of the 'Gandhāra still', McHugh's statement that the "famous reconstruction of a still haunts much of the secondary literature" (2014, p. 41) aptly represents the legacy and hold of a single interpretation of innovation. The contribution of such an idea has equally structured the understanding of technological introductions in South-Central Asia and, by extension, the origins of certain inventions. While a familiar rationalisation, the reliance on modern scientific models for reconstructing technology skews the view of archaeological evidence to fit a certain narrative from a series of stances underpinned by preconceived ideas on object function (see 2.5). Accordingly, this thesis has illustrated the uncertainty surrounding evidence for early distillation in South-Central Asia and its questionable connections to technological introductions from the 'Mediterranean World'. In response, and by expanding McHugh's recent critique (2020), the combined analysis developed in the material survey and experimental studies deconstructed the constituent parts of such an established interpretation. Critically, as the weak explanation and distribution of vessel forms as apparatus components was systematically demonstrated, the characteristic 'receiver-condenser' can now be assessed independently of 'distillation'. In conjunction with the fundamental practical issues that arose during distillation operation within an authentic archaeological setting, the conceptualisation of the 'Gandhāra tradition' as a facet of grand distillation chartings can also be addressed. Hence, in reviewing the archaeological materials through the material survey and experimental programme, the Gandhāra apparatus interpretation raises questions about what the materials, and their associated contexts, may represent. Such a systematic study has methodically assessed key patterns of how the Gandhāra still has been recorded within the archaeology of South-Central Asia, also allowing for a re-evaluation of the 'receiver-condenser' vessel form.

In Chapter 4, the archaeological evidence for the suggested distillation apparatus from across Gandhāra was set out in conjunction with key elements of alcohol production activities. This demonstrated the disproportionate representation of the apparatus across Gandhāra, the inconsistent morphologies of characteristic components (above all the 'receiver-condensers'), and fragmentary regional patterns used to justify a wide distribution. Despite variability in receiver-condensers being presented as an 'evolution' (predominantly determined through evidence from Shaikhān Dherī), the fundamentally different forms cannot attest to a consistent tradition. Alongside the limited number of specialised apparatus components, the distribution pattern observed across the whole South-Central Asian subcontinent is, therefore, problematic. In conjunction, the correlation drawn between the 'receiver-condenser' typology and specific architectural features at Shaikhān Dherī, representing a 'distillery' and alcohol market, cannot be used as a comparison with other sites such as Barikot (see 4.3.3). Here, the only confident connection that can be made between items is that a specific form of receiver-condenser ('Kushan') may be associated with a specific feature ('bathing place') (see 4.3.2.2). While the in situ receiver-condensers within the Shaikhān Dherī 'distillery' are vessel forms with arguably the most secure contextual associations to support a presupposed use (see 4.4), this cannot be used as an association to support the existence of auxiliary buildings that underpinned a regional industry.

Across South-Central Asia, significantly differing contexts, stratigraphic relationships, and chronological phases of the receiver-condensers and apparatus components brings into question any recognised pattern in previous research. In tandem, the original components of the Gandhāra still reconstruction by Marshall (1951) were found in very different contexts and strata at Taxila (see 4.3.1.2), but regardless used as the basis of future ceramic typologies in Gandhāra (see Catalogue). The lack of standardised features present in components other than the receiver-condensers (e.g., condensing tubes, still heads) suggests that these are neither specialised vessels for an apparatus nor unique to distillation. Here, underrepresented components were assumed to have been replicated in perishable organic materials (such as the still heads/cowls or condensing tubes) to account for the lack of key items (see 4.3.2.3; 4.4). This association is underpinned by the assumption that certain features did not survive and therefore are not represented (e.g., Husain 1980). While it is true that the archaeological record is biased in terms of "what makes it in" (Hurcombe 2007, p. 536), assumptions used to prop up how apparatus configurations would have worked cannot be used to explain away the lack of certain features simply by stating that they have not survived. Accordingly, the receiver-condensers cannot be used as a proxy to explain the distribution of the Gandhāra apparatus or distillation technology across South-Central Asia, considering the inconsistent morphological variety and assumptions used to support their reconstruction.

The experimental elements studies, despite their accepted limitations, furthered the body of critique of the Gandhāra apparatus reconstructions, illustrating why they do not function as expected. The approach taken here moved away from previous experimental work that aimed to prove the applicability of the configurations (e.g., Butler and Needham 1980) and did not default to a line of reasoning that accepted the reconstruction at face value. Although most of the distillation trials unsuccessful, Trial 2 in the exploratory campaign did produce a significantly measurable amount of water distillate in comparison to the other trials, as did the vertical apparatus configuration used in the preliminary experimental study. Despite recognising the low yields produced and long duration of time needed to fill the receivers (if they were for storing distillates as originally suggested), such a critique should not default to concepts of rationality. To do so would be as inappropriate as supporting supposed rationality underpinning the assumed Gandhāra apparatus to begin with. Key functional considerations for distillation largely omitted from the original apparatus reconstructions were, therefore, evaluated as facets of a complete system rather than assumed elements. Initially, the preliminary experimental study in Chapter 5 showed how heating methods in the reconstructions had been significantly overlooked. Generalisations, such as Marshall's hypothetical use of a tripod as a single-point of heating within his reconstruction (1951, p. 420), were identified as unsuitable grounds for claiming the existence of the Gandhāra distillation apparatus (see 5.3.2). This overlooked concern was further exemplified by replacing the single-point heat source with a purpose-built hearth that provided a more consistent and powerful heat source, adequately heating the volume of distilland in the still bodies (see 6.4 and 6.5). These insights together highlight why heating in distillation systems must be fully considered rather than assumed, but equally exemplifies how heating structures require more detailed evaluation within archaeological research.

Experiments demonstrated how altering modes of heating subsequently affected rates of heat exchange in configurations, and therefore required adequate methods of cooling (see 6.5). Recognising this connection simultaneously identified another overlooked consideration in previous research. Notably, the inability to fully cool vapour, following suggested methods and reported issues with pressurisation (see 6.4.3), is a fundamental issue with the Gandhāra configuration. A consistently recorded reflux action (see 2.2) in the apparatus (see 5.3.2; 6.4.4) indicated a temperature imbalance within the configuration. As the configuration was neither adequately cooled nor morphologically suitable to sufficiently cool the volume of vapour produced (see 6.5), the still was not able to properly function. Such an element is vital to understand when exploring early distillation apparatus; the debate surrounding when certain apparatuses were able to afford specific material distillations is dependent on explicit factors such as how heating and condensing methods are implemented. Previously, neither heating nor cooling had not been properly addressed in interpretations of the original archaeological materials from South-Central Asia (see Chapter 4).

Aside from heating and cooling methods, the material basis of the configuration presents several practical concerns. Pottery stills have been noted as less efficient than their glass and metal counterparts (see Chapter 2). In tandem, porous unglazed and unslipped ceramic interiors, such as those exhibited in the Gandhāra apparatus components, inhibit the movement of vapour or liquids within the still, which reiterates the implausibility of the Gandhāra tradition. While agreeable in principle, simply stating that the ceramic material of the stills is the primary influencing factor would be incorrect. Rather, fundamental practical issues connected to the selection of archaeological materials for the Gandhāra apparatus reconstruction demonstrate that it cannot accommodate distillation. Principally, the 'flushness' of connections between components at both ends of the condensing pipe (e.g., 6.4.4 and 6.4.5) was identified as a possible factor causing a significant loss in collected distillate. This was both through loss distillate through leakage, but also did not provide a sufficiently large and continuously sealed cool surface area to condense produced vapour. A different sealant material would have partially mitigated for loss, though collection ability is contingent on how components fit together, while sealant helps maintain a conducive distilling environment (see 2.2). Fundamentally, the issue directly affects the performance of the configuration and ability to collect distillate, rooted in the selection of ceramic vessels that would not change if a different sealant material was used. Leaking was exacerbated by the reflux action occurring within the still head at the top of the system that prevented vapour from cooling fast enough in the correct place (see 6.5). This caused excess distillate to run back into the still body, but also to collect in the channel created between the still head and body. Thus, the volume available for condensation (i.e., the maximum size of condensing area within the system) directly influenced the ability to distil but would vary depending on the design of the still head. As each suggested still head appears to be a different size (see Chapter 4; Cat. 4, 5, 14, 18, 72, 73, 76), the universally accepted idea that such vessels comprised a specialised component is implausible. This observation supports McHugh's opinion on the remarkability of the still head and why the form is not overly unusual (see McHugh 2020, p. 45), and underscores the need for such a component to be tailored to other still components in an apparatus configuration.

How experimental methodologies are utilised as tools within the analysis of technological innovation is, therefore, a key consideration. As a replication of a historic apparatuses within chartings of distillation technology, experimental studies have tended to aim for a comprehensive demonstration of how and why interpretations of vessels are suitable for distillation (e.g., Belgiorno 2020). This is especially true when evaluating chemical technologies and accounting for their archaeological underrepresentation. Combining the material and experimental analyses, the process of reconstructing a 'rationalised' Gandhāra distillation tradition (as undertaken in the original archaeological interpretations) was unsound from its first formulation. By assuming certain roles for ceramic vessels and failing to evaluate their suitability, the configuration was a hypothetical reconstruction that ignored any archaeological issues in favour of following set models. In previous experimentation (see Chapter 2), the shape of the Gandhāra apparatus had been shown to operate fully when using glass working models (see Butler and Needham 1980). Such an approach, despite fitting neatly within the protocols of the laboratory, does not match the archaeological origins of the interpretation and presents serious practical concerns when used in an 'authentic' environment. While levels of authenticity in technological reconstructions are debatable (see Chapter 3.2), the experimental analysis in conjunction with the material synthesis demonstrated how previous experimental work was illogical in aiming to prove the existence of the still as a concept. This project challenged such an association by using ceramic vessels and archaeologically appropriate sealant materials (e.g., clay slip) which in turn led to the identification a suite of practical issues within established functional parameters. Thus, while the errors in the Gandhāra distillation tradition now can be noted in the archaeological interpretation, technical decisions revealed through direct practice and engagement methodically identified the reasons why the apparatus could not realistically function.

The charted emergence of early distillation globally, and specifically the Gandhāra tradition, has exhibited a tendency to tie fragmentary information, such as brief literary references, with archaeological materials to support an unproven idea. Realising this has substantial ramifications for how the global development of distillation is viewed. Markedly, further dismissal of the 'Gandhāra tradition' disrupts global chartings such as Park's linguistic spread and how it matches distinct apparatus forms (e.g., Park 2021, p. 27). Misuses of applying one fragmentary idea (ascribed hypothetical technological traditions) to support another (proposed linguistic spread of a single word to represent 'distilled alcoholic spirit') ultimately ignores nuanced details on technological practices, innovations, and networks. While taking comfort in satisfying grand narratives on change, large-scale diffusion models cannot possibly account for all instances of early distillation, let alone evaluate all constituent parts. With such fragmentary archaeological evidence for distillation, we must, therefore, avoid a reliance on distribution maps of technology within linear models of practice.

7.4 Reinterpreting the 'receiver-condensers' at Shaikhān Dherī

With this critique in mind, it is worth reflecting on the nature of the objects previously deemed to be 'receiver-condensers'. This requires a reconsideration of their archaeological contexts away from the ingrained connection with distillation. Similar evaluations of other components within the suggested Gandhāra still (such as the suggested condensing tubes and still heads) should also be undertaken. However, due to their comparatively low numbers and morphological diversity, this would require a full review of the complete archaeological datasets and contexts, which goes beyond the scope of this thesis. Equally, more detailed understanding of ceramic fabrics (e.g., calcareous and non-calcareous clays), surface modification, and inclusions from Shaikhān Dherī would aid interpretations and effect suggested uses of vessels. While some elements have been summarised before and explored in relation to other sites in the region (e.g., Husain 1980, 1990; Iori 2018), the level of detail needed to understand a connection between material properties and pottery uses requires further research. Accordingly, interpretations of vessel and site functions are provisional.

Currently, as far as can be established, the highest concentration of receiver-condensers with recognisable shared characteristics and relatively consistent chronological sequence was recovered from the excavated areas of Shaikhān Dherī (see Chapter 4 and Catalogue). Such a connection is, however, hindered by the limited excavated areas. Regardless, this association renders them somewhat unique with a recognisable pattern, suggesting a possible connection between both the ceramic form and the site itself. Principally, a consensus even amongst advocates of the 'Gandhāra still' considers the 'receiver-condensers' as storage vessels of sorts, with stamping being introduced to the vessels from the Indo-Scythian/Scythian/Saka periods of the site onward (see 4.3.2). As a storage vessel or 'barrel' (possibly as a pottery mimic of wooden versions), the idea that they could contain grape wine is justifiable. Positive evidence for wine production and consumption (see Chapter 3) clearly suggests extensive wine culture, wine-related imagery, and artefacts within the South-Central Asian regional sphere (see 3.3). This is the strongest association between the typological form and a possible function, also considering the unique form that may indicate that it contained an equally unique product. As the vessel grouping is morphologically unique (see 4.4), this would suggest in turn that the forms would be reserved for a particular use. However, it would be worth stopping short of suggesting the possibility of a grape 'syrup' being made through pasteurising or boiling wine (e.g., Brancaccio and Liu 2009; McHugh 2020, pp. 53–55). This is due to the lack of evidence for this process aside from a brief textual interpretation possibly dated to the 5th c. CE (Brancaccio and Liu 2009, p. 226; McHugh 2020, pp. 54–55). Equally, evidence of hearths beyond scant remains needed to facilitate a large-scale process, and thus warrant the number of unique storage vessels at Shaikhān Dherī, is also lacking.

Instead, it could be argued that the body of information from Shaikhān Dherī displays evidence for a localised style of wine production that utilised a unique form of storage vessel. Equally, in reframing the 'receiver-condensers' as 'unique wine vessels', opportunities emerge to challenge the dominant Hellenisation framework that frequently structures approaches to wine production in South-Central Asia. Here, the study of wine material culture and iconography historically emphasised the connections that this had to ancient Greek antecedents or imperial elites (see 3.3). While the limits of the available archaeological information mean such interpretations are tentative, the consolidation of wine production in the region around Shaikhān Dherī could be viewed as an indication of how a production process endured and was adapted during centuries of political upheaval.

Dated roughly 4th c. BCE – 4th c. CE, the morphological continuum and regional distribution of the 'wine vessel' signifies a technological tradition that persisted and was built upon during multiple changing regimes. This is represented by the morphological sequence of the vessels across the excavated areas at Shaikhān Dherī, initiated around c. 3rd - 2nd c BCE (see 4.3.2), and in the comparatively small distribution of actual 'unique wine vessels' across the region (see 4.4). Considering the few early (i.e., “Indo-Greek”) examples from Shaikhān Dherī, and other sporadic reports such as those from Sirkap (see 4.2), such evidence may represent a small, localised form of wine storage at the sites. Wine was then distributed by other means further afield such as in wine skins, which are depicted in 2nd c. BCE iconography (e.g., Stančo 2012, p. 97). Worldwide traditions of using wooden containers since the 4th mill. BCE to store liquids (see Bevan 2014, p. 388) attest to the range of perishable materials that could also have been used. Accordingly, the increasing number of ceramic wine vessels at Shaikhān Dherī demonstrates how a localised production practice grew in scale corresponding to increasing political stability. Such a perspective provides a salient approach for integrating the archaeological remains into questions of cultural change and interaction, rooted in viewing wine production as an independent, local development within the region.

Expanding on notions of trade and exchange do, however, have their limits. It is difficult to accept that the vessels were traded with liquid inside in most cases, as suggested originally by Allchin (1979b, 1979a) and supported by McHugh, despite his criticism of the ‘still’ interpretation (2020). Conversely, survey data indicates the opposite (see Chapter 4); high concentrations of the ‘wine vessel’ at Shaikhān Dherī in comparison to any other site in the region, and limited finds elsewhere, signifies that the vessel had limited distribution. While this pattern is partly due to recording and excavation bias, exceptional cases, such as the Kushan example from Rang Mahal (Cat. 77) cannot be used as evidence of a wide network of trading the vessels. Concepts borrowed from other contexts of trade systems equally have limited applicability. As ceramic amphorae for wine from the Mediterranean region predominantly used for the storage and transportation of perishable foodstuffs across seas (see Bevan 2014), such an attribution cannot simply be projected onto the landlocked Gandhāra and the mound settlement of Shaikhān Dherī. In this respect, if trade administration is to be considered, distribution models cannot be relied upon as the primary mode of analysis.

Hence, within a dynamic system of trade, local wine production changed in accordance with newly formed sociocultural frames of reference. Supporting such an idea, seeing the ‘bathing place’ features within the excavated areas at Shaikhān Dherī (see 4.3.2.2) as facets of the wine pressing process, such as simple press bases (e.g., Frankel 2016, p. 553), provide a stronger connection with the role of the vessels as ‘wine vessels’. This is an important element that was previously overlooked when the vessels were considered as components of a distillation apparatus. While earliest production of wine may have occurred in and around the earliest ‘bathing place’ (i.e., in the ‘distillery’), the later Kushan press feature in the ‘House of Naradakha’ then represents a possible expansion of production. This also saw a changing relationship between foodstuff production practices and newly consolidated cultural ideas, introducing the evidence of religious iconography found in the 'House' alongside other production features such as the grindstones and large storage vessels (see 4.3.2). This may therefore be the root of a connection between similar features at Barikot (the 'unique wine vessel' found in situ with another 'bathing place') (see 4.3.3). Accordingly, the transformative significance of 'bathing place' structures at Shaikhān Dherī and Barikot highlights the fluid conceptualisation of a production system while adapting and modifying sociocultural contexts.

At Shaikhān Dherī, the process of centralising wine production, initiated from the site's earliest phases, first consolidated existing wine production practices and then modified them in response to later external cultural influences. The continuation of a familiar but changing form of wine storage container, therefore, could indicate the assimilation of new practices associated with wine that came from external sources away from the Shaikhān Dherī locales. Significant morphological changes, and the wider introduction of vessel stamping during the Kushan periods (c. 2nd – 5th c. CE), represents the institutionalisation and adaptation of a pre-existing, but not homogenous, culturally-ascribed technological practice during a period of political stability. Thus, on a local level, wine was amalgamated into a common cultural idea across the region with the Kushan political entity but had developed from a long and repeated technological practice consolidated at Shaikhān Dherī. Such an indicator of cultural continuity, rather than as a typological marker tied to specific cultural phases, places greater emphasis on the social context of production on a local scale. This perspective resonates with recent holistic perspectives on the assimilation of innovations in society (see 3.2) by centralising the context in which practices developed and the conditions for integration. The autonomy of those producing the wine is at the centre of discussions on technology, rather than simply being the result of political regime changes or external influences through processes such as 'Hellenisation'.

Charsada, as a well-established settlement area, was a key focal point in Gandhāra, evolving over centuries and throughout its changing mound settlements (see 4.3.2). Considering that Shaikhān Dherī may have been occupied from the 5th c. BCE and had an Achaemenid presence that pre-dated an Indo-Greek fortification, the city's proximity to regional trading networks further underlines the idea that it retained prominence despite sudden regional political changes. Such importance may have begun during the enlargement of the neighbouring Bala Hisar citadel settlement (see 4.3.2.1), though Shaikhān Dherī was positioned differently, orientated around manufacturing communities. Thus, beginning during the "Indo-Greek" phases of the settlement, the production and storage of wine at Shaikhān Dherī, as a centralised technological practice, acted as a cultural 'touchstone' that was adapted to the influence from changing regimes. With changing politics came changing cultural ideas ascribed to production but built upon a longstanding tradition of wine at Shaikhān Dherī, exemplified by its unique storage characteristic. Centrally, wine was produced and stored in vessels unique to the site, but distributed on a regional scale by different methods, mostly retaining unique vessels at Shaikhān Dherī. Despite growing institutionalisation of wine production through the Kushan era, the further expansion of Buddhism within Gandhāra prompted another change in how wine production was coordinated. This would account for the increasing number of 'rural' wine presses that have been noted in Gandhāra dated from the 5th c. CE and considerably fewer unique wine vessels at Shaikhān Dherī (see 3.3). Accordingly, the site seemingly retained its position as a central wine producing area for centuries. associated with a technological sequence that enhanced its regional character cultural plurality.

7.5 Reconstituting early distillation: a preliminary understanding

Together, the material survey and experimental studies together identified specific ways in which the established explanation of technological innovation in the Gandhāra region, rooted in traditional ideas on cultural influences through Hellenism, is problematic. Realistically, however, the studies alone cannot be used to provide a detailed reinterpretation, history, or reconstruction of early distillation. While the experiments contributed new data and observations on technical considerations involved in distilling practices, they are too far off from understanding the reality of early distillation. This is especially true in contexts of alcohol distillation, which have been central in discussions on the origins of the practice (see Chapter 2). Moreover, while recent reconsiderations have changed how we view technology (see 3.2), it could be argued that such methodological tools cannot be used to analyse distillation, as the process is not easily represented in the material record. This concern could prevent nuanced discussions on the underpinnings of distillation technology, such as addressing craft and skill, as has been done in other material groups (e.g., Kuijpers 2013, 2019). Instead, the body of experiential, technical, and sensory insights realised through repeated exploratory distillation experiments acts as a contribution in exploring the formation of the practice of early distillation. This will not decidedly reconstruct a complete technological entity, but rather extrapolate the conceptual basis for a method of material separation and purification. Equally, while 'proto-distillation' could be considered as a separate question, by extension, similar technical and material concepts in the foundations of early distillation bridge both technological contexts. Doing so connects with a view of innovation that recognises how existing concepts in technological contexts enables the adaption and adoption of new material ideas within a different social setting.

Embodying a holistic idea of technology and innovation (see 3.2), anchored concepts as the basis for distillation to emerge and become integrated in social contexts are key considerations. In seeing distillation as a dynamic 'technological cluster' that unified multiple technical skills, sociocultural ideas, and material concepts, the process marks a consolidation of ideas related to changing understandings of material properties and their purist forms. This is where experiential information is most useful: generating information through human experience on how intangible materials (by archaeological standards) can be tied to specific technical choices (e.g., vapours, essences, and liquids) reveals potential links with other craft spheres. Doing this considers early distillation not in a reductionist way and superseding an older technological system, but rather integrated within existing craft understandings and communities of practice. Such a view positions humans as the driving factor for developing distillation and integrating it as an 'innovation' into new sociocultural contexts. The technical and craft practice of distillation is then regarded as equally important as its engineering properties. In combining empirical measurements of processes with subjective, experiential bodies of sensory and technical information, detail in technological systems and practices can be revealed that is not represented by tangible evidence alone. Thus, through a practice-based perspective of technology, we can consider the conditions and concepts that led to early distillation practices to emerge and become accepted into new sociocultural contexts.

The experimental trials in this study, while not necessarily producing consistently successful distillations, illustrate craft considerations involved in the consolidation of early distillation practices. Fundamentally, these were subjective impressions of what was needed to be done and changed to successfully evaporate and condense the distilland, collected as a distillate. This is a series of concerns required to extrapolate the skills and technical consideration in distillation that can only come from accumulated experiences in distilling, and involving experienced distillers as part of the research process (see 1.3). In a practical sense, the experimental studies together (while centred on critiquing an existing interpretation) deconstructed a distillation process into individual stages and examined the functional parameters within each one. This could be structured as a provisional early distillation *chaîne opératoire* (Table 15), comprising technical, sensory, and bodily actions involved in its practice. By understanding individual technical stages for distilling with the reconstructed configurations, a comprehensive body of experiential and technical insights was developed (see Appendices 6 and 7). This can be linked directly to questions of craft practice (the embodied and developed skills required to distil). Certainly, considering technological practices within the confines of a single *chaîne opératoire* can be detrimental to how such social contexts are understood (see 3.2). Yet the lack of critical work on examining distillation as a social practice, instead of a technical method, implicates what can be confidently stated.

This view, however, does not segregate distillation into separate material groups as has been traditionally done (e.g., alcohol distillation, metallurgical distillation etc.). Rather, the practice of distillation, with connections to specific technical decisions, knowledge, and skills, can be directly connected with observations that emerged through the course of the experimental studies. Technical and practical concerns, rooted in qualitative experimental insights, therefore formulates a preliminary body of information on the craft practice of early distillation.

Stage in production sequence (*chaîne opératoire*)	Phase changes and chemical processes involved	Functional parameters: technical choices and skills related to craft, sensory indicators and embedded practical knowledge involved	Related experiments and possible archaeological proxies
1. Creating and selecting distilland	Fermentation (alcohol), raw material processing, botanical processing (medicines, perfumes)	• Individual bodies of technical knowledge connected to solvent manufacture (e.g., alcohol) and selection • Botanical selection • Individual bodies of technical knowledge connected to solvent manufacture (e.g., alcohol; botanical selection)	• Evidence for processed raw ingredients and materials
2. Creating and assembling apparatus	-	• Appropriate selection of materials to create an adequate condensing environment. • Individual bodies of technical knowledge connected to vessel manufacture • Technical knowledge related to vessel modification for adapting certain components for an apparatus configuration • Learnt knowledge on modifying equipment and ways to do this	• Exploratory experimental campaign • Modified vessels
3. Sealing and connecting apparatus components	Creating a pressurised environment to support vapour flow through system (see Chapter 3)	• Choice of sealant and understanding its material properties • Learned experience in forming a seal (i.e., the physical movement involved) • Knowledge of material consistency for creating a consistent seal and repairing as needed	• Preliminary experimental campaign • Exploratory experimental campaign • Possible residues of sealants
4. Heating distilland	Heat transfer within still body from vessel to distilland	• Fuel supplies and rate of heat build-up to evaporate liquids • Areas of heat concentration ('hot-spots') within system and mitigation of them during the process • Rate of heating managed to allow for gradual rather than rapid heating and subsequently cooling vapour; sensory knowledge to 'know' when system is hot enough	• Heating trials • Preliminary experimental campaign • Exploratory experimental campaign
5. Vaporising and evaporating distilland components	Vaporisation and evaporation; liquid or solid into gas	• Audible changes within system (boiling) • Pressure build-up and depressurisation of system when deemed necessary	• Preliminary experimental campaign • Exploratory experimental campaign
6. Condensing distilland components and collecting distillate	Condensation	• Strategy for cooling methods, embedded ideas on how to tell if components are too cold/hot • Selecting specific distillates ('cuts') as they are produced and indications on when to create purist distillate • Body of sensory information to differentiate temperatures of components	• Preliminary experimental campaign • Exploratory experimental campaign
7. Storing distillate	Bacterial infection and foodstuff spoilage	• Preservation conditions, body of knowledge on storage conditions and effects from changing seasonality • Knowledge on sealant methods and materials for long-term storage and subsequent applications	• Consistent collections of vessels • Possible residues of sealants

Table 15. *Proposed chaîne opératoire for technological practices related to early distillation.*

Effective views of early distillation technology should, therefore, engage with notions of practice, craft, and their relationship with functional parameters involved in processes of extraction and concentration. While providing a context for interpreting the practice of distillation as a series of technical concerns (see Table 15), seeing distillation as the product of cross-craft interaction (e.g., Brysbaert 2014) raises questions of how knowledge is shared, the cross-application of tools, and the borrowing of techniques from other craft spheres. Craft practices are rooted in understandings, rationalisations, and indications of how processes 'work'. In many respects, such conceptualisations can be associated with individual stages involved in distillation *chaînes opératoires* (Table 15) to unify a technical choice with a sensory indicator and practical knowledge. Hence, changing perspectives on material composition connects sensory knowledge to specific technical choices, thus forging cultural parallels with other human experiences (see 3.2). Considerations of cross-craft interaction at each stage of the provisional distillation *chaîne opératoire* illuminates where conceptual and embodied technical knowledge from other craft spheres could be introduced (see Table 15).

Early distillation relied on points of orientation by which to conceive the ability to remove a non-tangible material property, central in realising how distillation is fully the product of cross-craft thinking. This cannot be explained simply as material knowledge from either an artisanal or scientific perspective (e.g., Kuijpers 2019). Technological practices, and their wider sociotechnical systems, are not essentialist constructs governed by absolutes and rationality; they are formed from relationships between humans and materials that resonate with other understandings, symbolic representations, and dialogues. Ethnographic and historical evidence on distillation have emphasised the role of anthropomorphic metaphors, religious language, and relationships to bodily movements in the consolidation of distillation (see 2.3; 2.4). This includes metaphorical concepts of matter connected to wider sociocultural meanings, enacted within the experimentation and adaption of objects to achieve material transformations. Particularly, the adaption of domestic vessels in creating apparatuses exemplify both the ease of distilling (nominally framed as a sophisticated, scientific method) and modification of existing conditions or equipment through embodied human knowledge of distillation. Accordingly, distillation emerged as tool within a dialogue on material transformation, drawing on familiar cultural constructs. As an active demonstration of how distillation became integrated into a new social context, humans assembled apparatuses in *response to* changing material understandings, rather than being *constructed for* distillation.

Due to sparse information and isolated cases on early distillation (see Chapter 2), the exact contexts in which early distillation emerged are not certain. This does limit, to an extent, what can be said on how distillation was adopted in different social contexts and as a component within "clusters" of multiple technological systems. Interrogating the connections that distillation shares with other craft practices, however, allows us to place early distillation as a mediator within wider conceptual changes of matter, such as those in proto-scientific and alchemical thought (see 2.3.4; 3.5). Away from associations with classical and medieval contexts, this recognises how distillation is rooted in the practice of reconfiguring the properties of materials through separation and purification of an 'essence'. Stages of vaporising and condensing within the *chaîne opératoire* of distillation (Table 15) are a conceptual opposite to theoretical understandings in metallurgical processes that saw how different materials could be brought together and reforged; where material meanings are destroyed, mixed, and transformed in the metallurgical crucible, distillation extracted and refined. Fundamentally, existing bodies of metallurgical and pyrotechnological knowledge would be required to make such a distinction. That is not to say that distillation, therefore, could only emerge within such sociotechnical environments, but rather that similar clusters of technological references, practices, and knowledge would be needed. The practice of distillation then is not simply a self-supporting system based in inherent technical knowledge, but the adaption of conceptual understandings from other crafts, and the adoption of such knowledge into a dynamic sociocultural context. To see early distillation as a practice rooted in new understandings of material properties accepts that formal apparatus changes and modifications are not the sole driver of change, instead rationalising such an understanding within existing human-material relationships. Experimentation with how to extract, concentrate and preserve a material property - both tangible and immaterial - derived from a wider network of sensory, material, and social concepts that would be needed to articulate a transformational process in distillation practice.

Without modern explanations to describe chemical processes (see 2.2), sensory indicators as embedded knowledge connects the emergence of distillation with widening understandings of materials and their properties. Together with the body of ethnographic studies on distillation (see 2.4.3), the experimental studies exemplify how sensory knowledge is a principal component for developing distillation practices as both a practical means to control, but also articulate, key stages in the process (see Table 15). Naturally, across the experiments, the most obvious way to tell if a system was functioning was to note if distillate was produced. This had limited success, but with repeated practice, a consistent balance could be reached. While this was done on a regular timed basis in the preliminary experimental studies (see Chapter 5), deciding when to cool the system in response to noting when components became too hot became a more appropriate intervention (see Chapter 6). How the components felt, the size and consistency of the heat source, the change in sound when the distilland reached boiling point all helped monitor the process (see Appendix 7). Determining when to intervene with the distilling process was, therefore, rooted in sensory information and developed through accumulated experiences.

Learned experiences in the development of skills build technical abilities by unifying and adapting craft knowledge from multiple sources of technological understanding. Within the experiments, while the lack of produced distillate may indicate failure, understanding heat management to prevent pressure build-up and damage to the apparatus configuration (see 6.4.3) illustrates how experience accumulates as the basis for adapting practices. Such observations are rooted in sensory engagement, enhancing existing knowledge of a craft practice, and demonstrating the role of failure through experimentation during the development of a technology. In response, decisions on when to change cooling cloths, add more fuel, and repair seals became innate decisions that emerged through doing. Such a body of information combines ideas on heat exchange, heating rates, and cooling, embodied through sensory information and responding to changes in the apparatus through use. Consequently, across both experimental studies, steadily producing vapour so that it could be consistently condensed was monitored simply in feeling the condenser components and judging if they were cool enough (see Table 15 and Appendix 7). This is the basis of formulating skills in a practice and applying knowledge from other technological remits to adopt a new process. As such, the craft practice of distillation was realised as a set of sensory indicators, embedded technical knowledge, and learnt technical choices. From a basis of ‘extraction’, technical experiences and sensory insights from other craft contexts create adaptable interacting material ideas, formulating a sensory field of understanding as the basis for a craft practice. Here, the connections between how the selective extraction and condensation of components can be monitored and modified through sensory indicators are unified through a complete practice. Different conceptual connecting points between multiple interacting craft spheres relate directly to a cross-pollination of technical decisions and ideas.

Early distillation practices were therefore structured around adaptive and adoptive perceptions of suitable components to change, capture, and purify perceived properties of materials. These may have been tangible elements, such as essential oils or purified components, but equally more metaphorical concepts such as explanations of material composition. This is the ‘knowing’ of how to change a vapour back into a liquid or solid in distillation through a sequential process, articulated in sensory information and a unique lexicon to communicate such a perspective on material composition. Innovations then in early distillation are related to changing perspectives of materials and experimenting with how to manipulate such a transformation. To access the breadth of understandings of distillation is to engage widely with considerations outside of modern scientific principles; a comprehension seen in some circles as a misunderstanding of material composition prior to scientific empiricism (e.g., Kockmann 2014, p. 1). Thus, in reframing how early distillation innovations are seen, such traditional attitudes are dismissive of fundamental elements at the core of how early technological processes were understood and articulated.

Reconceptualising forms of apparatus in early distillation should depart from traditional views of how the technology developed. In preliminary experimental trials, the vertical configuration distilled successfully and more consistently than the Gandhāra reconstruction. This was previously established, considering that the vertical configuration, despite being presented as an archaeological reality, derived from ethnographic rather than archaeological data (see Mahdihassan 1972, 1979; see 4.3.4). Consequentially, considering that other 'early' examples of distillation apparatus (such as evidence tied to ancient Greece) have not been subject to the same level of evaluation undertaken in this project, it is likely that early distillation apparatus is more heterogeneous than previously understood. In tandem, the 'vertical configuration' demonstrates the ease by which a distillation apparatus could be assembled from appropriate domestic vessels and how existing vessels can be easily adapted to assemble a distillation apparatus (see Chapter 5). When seen in conjunction with the accumulated practical and sensory knowledge in the craft practice and technological sequence of distilling (see Table 15), further modifications to an assembled apparatus from common household vessels could be adopted easily. While the cross-use of domestic vessels as distillation apparatus components is unlikely to be demonstrated archaeologically, such an example displays intrinsic connections to the social context and spatial setting of early distillation. Equally, attempting to chart distillation development from an 'early' phase will inevitably exclude a large body of information due to the transient nature of apparatus configurations.

The transition between conceptualising distillation and its later specialisation does not have to be treated as a series of evolutionary stages as proffered in previous studies of technological change. Such early innovations in apparatus creation seemingly had fewer ties to specific morphological changes in vessels to create 'specialist' distillation vessels until much later in the technology's history (700-800 CE; see 2.3.4). Regardless, in furthering the hypothesis that distillation had multiple origins (see Park 2021), the emergence of forms of distillation brought about a changing human-material relationship that saw material properties and their affordances in fundamentally different regards. This ultimately was rooted in a sensory-mediated craft practice and technological process, and further acknowledges how crafts and technologies with their own local, dynamic 'languages' can influence the modification and adaptation of such a process. Therefore, the introduction of comprehensive distilling practices was brought about only through directly working with materials in several contexts and adapting knowledge of heating, cooling, and object potential, and communicated through a myriad of perceptions of materials and the environment. Anchored ideas in other material concepts, that introduced material and technical information from other craft spheres, provided the necessary conditions to allow for distillation to be adapted into different groups as a material separation method. As such, distillation within such a conceptualisation further transformed humans, their sociocultural milieu, and the relationships they formed with their environment. Realising this both benefits a greater understanding of how material components and processes can be manipulated, but equally the potential effect of processes such as distillation upon the cohesion and construction of sociocultural concepts.

7.6 Summary

Modern views on technology have traditionally structured innovation as a linear trajectory of societal progress and change. Recent holistic approaches to technology have demonstrated the limits of such dichotomous ideas, instead recognising how innovations are both social and technical phenomena within clusters of entwined sociocultural, socioeconomic, and ideological changes. Early distillation has historically been conceptualised from a technical mindset, in that it is a 'problem' that can only be addressed through evaluating the functional and engineering properties of hypothetical configurations of archaeological evidence. Here, existing narratives on distillation as an efficiently improved chemical process have emphasised a form of idealised knowledge as the intellectual basis for its development and from certain geographic points. The re-assembling of the Gandhāra tradition and still exemplifies this attitude, but the same could be said for other interpretations of early distillation apparatus whereby studies aim to prove the existence of early distillation within large-scale dialogues of technological change. If we remove such limits from how distillation is viewed, and introduce a body of understanding of sensory, material, and practical choices involved in distillation, we can begin to expose the dynamic nature of distillation as a craft practice as an active component in the formation of social constructs. This recognises that distillation marks a conceptual transformation in how humans understood, and related to, material properties. Early distillation technology, as the result of learnt sensory indicators and accumulated technical knowledge enacted through a complete craft practice, is directly connected to human experimentation with materials and matter, enacted through the adaption and adoption of new material concepts and the means to separate them.

In exploring sociocultural interactions in South-Central Asia, technological practices, and their realisation as reconstructions in archaeological research, have historically received less attention compared to an analysis of object forms. The assembly of the 'Gandhāra still' within this geographic and temporal context has been conducted from a similar emphasis on form (see McHugh 2020). Subsequently, a dogmatic view of certain artefacts as distillation apparatus components has eclipsed the possibility of other interpretations of what the 'receiver-condensers' are. The systematic evaluation by material analysis and experimental testing in this thesis have shown how the interpretation itself is problematic, but also why it fundamentally does not work. Moreover, the legacy of the Gandhāra still interpretation demonstrates the extent to which technological reconstructions can be reliant on hypothetical re-assemblies derived from modern understandings of chemical and physical processes. However, inconsistencies in its typological characterisation, differing degrees of representation, and considerable practical issues in the reconstruction brings the reality of the Gandhāra still and tradition into doubt, despite the sizeable number of proponents championing the interpretation. Consequentially it does not seem grandiose to suggest from the combined analysis (and building on previous critiques) that the 'Gandhāra tradition' of distillation did not exist. This significantly disrupts established chartings of early distillation (e.g., Butler and Needham 1980; Needham et al. 1980; Park 2021) and illustrates why relying on hypothetical reconstructions of technological innovations from such a staunch technical standpoint misrepresents original archaeological evidence.

More attention must be paid to critically evaluating existing technological interpretations with a degree of honesty that accepts that such pervasive ideas within the creation of the region are potentially flawed. Seeing the vessels as a form of wine storage, instead invites further reviews of typological ascriptions of archaeological artefacts in South-Central Asia. Such reframing places wine production in Gandhāra within holistic ideas on sociocultural interaction. By understanding 'innovation' as rooted in the adoption and acceptance of new practices, views of technology that had previously limited discussions regarding cultural change and integration in Gandhāra can be reorientated. Accordingly, the next, and final, chapter will conclude the thesis in summarising what has been produced from the project and suggest directions for future research.

Chapter Eight

Conclusion

8.1 Summary of findings and research products

The case of early distillation, and specifically the 'Gandhāra tradition', has been a product of preconceived ideas, hypothetical models, and an overwrought interpretation of historical evidence. It exemplifies how technological innovation in distillation has largely been treated in archaeology, and more widely in the history of science. From a beginning in which fragmentary spouted vessels were classified as 'water condensers', to their wider identification across South-Central Asia as alcohol distillation apparatus, to integrating the Gandhāra tradition into narratives of scientific development, and finally acting as an integral component of the 'grand narrative' of distillation technology diffusion, the enthusiastic championing of narrative over critical analysis has been centralised within regional debates on cultural origins of scientific ideas in South-Central Asia. Therefore, the longstanding tradition in South-Central Asian archaeology of searching for elements of 'Hellenistic' influences, defining the cultural impetuses of developments, and determining local origins of distillation have fostered a limited scope for discussing technology within the region. Conversely, deconstructing such monolithic narratives generates positive re-evaluations of established ideas, providing a more holistic perspective on early distillation and materials from Gandhāra previously interpreted as distillation apparatus. This can be seen through the conclusions derived from this thesis:

- The 'Gandhāra apparatus' did not exist. McHugh's scepticism for the reconstruction noted categorical issues with the original interpretation (McHugh 2014, 2020). In support, the material survey developed in this project systematically demonstrated the lack of assumed 'specialist' features of the apparatus, morphological inconsistencies throughout recorded key items, and disproportionate distribution of characterised 'receiver-condensers'. This critique was furthered by experimental studies that identified issues with the functionality of the apparatus. Equally, experiments demonstrated how working models used in previous experiments (e.g., Butler and Needham 1980) are not appropriate modes of experiment to support interpretations of apparatus configurations.
- The 'Gandhāra apparatus', when reconstructed using authentic archaeological materials, ceramic vessels, and contexts, is unsuitable for distilling. While alcohol was not explicitly tested during the experimental trials, consistently high internal temperatures within the system, the inability of the reconstruction to adequately cool produced vapour, and lack of control of heat sources were noted as potential issues for enabling alcohol distillation. This

is not to say that an apparatus similar in configuration to that of the Gandhāra reconstruction would be unfunctional, as has been identified in ethnographic cases. Rather, archaeological evidence to support it is lacking and that vessel forms selected for the reconstruction are unsuitable.

- While a satisfying narrative, emergence-and-diffusion technological chartings of distillation are largely hypothetical, inaccurate, and not meaningful interpretations of technological change. When discussing technological change and innovation in any context, focus should be placed on targeted studies which can enable a thorough examination of previous interpretations. Exemplifying this, the Hellenistic influence that has been projected onto interpretations of distillation-related materials in South-Central Asia through cultural categorisation is overstated, correspondingly inviting a renewed study of how distillation technology has been previously seen to diffuse from a Hellenistic 'core'.
- Conversely, as highlighted in the experimental analysis of the Gandhāra apparatus, a new view on early distillation should be developed that emphasises the direct relationship between human, physical choices and manipulating a chemical process. This is rooted in a body of technical understandings, sensory knowledge, and indicators to monitor and modify processes. Early distillation and proto-distillation are technologies consolidated through a multitude of craft practices that incorporated understandings of how to manipulate vapours, essences, and 'invisible' properties of materials. Rather than working with physical and tangible matter, early distillation marks a change in human-material relations that recognised a new potential of raw materials and a different dimension of materials. While what has been outlined here is a provisional reinterpretation of early distillation technology, this thesis has set the grounds for a stronger, sociotechnical-led approach to be cultivated.

Throughout the course of this project, it has been demonstrated how technological reconstructions correspondingly have significant ramifications on the view of technological progress and its connotations in a contemporary light. In writing global technological histories, the notion that innovation is tied directly to sociocultural revolutions in stadial terms rather than appraising the social environment, setting, and practices of technology has clouded impressions of cultural and indeed ethnic identity. While the desire to create rational evolutionary models of innovation aligns with scientific mindsets, the origins of specific facets of civilization when seen as representations of sophistication (i.e., practices) stems from legacies in research that preferences hypothetical interpretations of archaeological materials. The case of Gandhāra distillation technology, and study of early distillation within South-Central Asia, exemplifies the manifestation of hierarchical perspectives on cultural practices and their relationship with concepts of technological innovation. Such an attitude is, conversely, poised to change. Seminal turns within archaeology, both to fundamentally revisit its position in contemporary society and within archaeomaterials research more generally, are beginning to engage with the idea that archaeology is a study of change. It is the principles of archaeology that can become enshrined to elucidate the impact of interactions - human, material, and environmental - from physical remains and derived from its unique perspective on time. It is only then through integrated methods of study that established dialogues can be reappraised to correct the errors and negative legacy of certain narratives. Hence, the assumption that specific 'traditions' of practice can be reassembled as idealistic configurations from fragmentary archaeological remains, and thus represent significant technological innovations, is deeply problematic. Innovation, when applied broadly as a term to invoke notions of hierarchical social sophistication, cannot simply be expected to be extracted from archaeological materials, but must be framed within human-centric dialogues of technological practice. It is such elements of accumulated knowledge, directly embedded within technological practices, that can greatly contribute to renewed ideas on innovation and change away from hypothetical models and assumed rationalities at the heart of reconstructions. The combined body of research in this thesis has, therefore:

- Produced a detailed critical evaluation of an enduring interpretation of a distillation apparatus and 'tradition' through material survey and experimental practice.
- Generated the first unified synthesis of characterised 'receiver-condenser' typologies within the Gandhāra region.
- Produced the most complete targeted analysis of a technological characterisation in Gandhāra and collated archaeological data at specific sites to support it.
- Collected and reconfigured the historiography of excavations at Shaikhān Dherī with a particular focus on the site's characterised 'receiver-condensers'.
- Comprehensively challenged the global narrative of distillation from one of its earliest cases and reassessed its connections to 'Hellenisation' and ancient Greek origins of certain technological practices.
- Provided the groundings for a nuanced approach to early distillation that centres multifaceted and multimodal perspectives on materials and technical practices through accumulated human experiences.

8.2 Impact of research and its context

Distillation today has transformed into a global cultural phenomenon. The contexts of manufacture and material transformation continue to thrive, and advances in distillation operation within chemical engineering continue to refine and push the question of what an application of distillation can achieve. The 'gin boom' since the early 2010s in Europe and North America has shown that a renewed interest in the craft of distilling is of equal importance as the scientific and empirical absolutes of the process. Opportunities for craft practitioners - distillers - to become closer to their roots of their craft through unifying their own embodied knowledge of the practice with archaeological research promotes interdisciplinary and co-production methodologies to further develop the relevance for critically exploring the nature of change over time. This extends what can be taken from the historiography of science, but equally embraces an idea of heritage and its influences that ties to modern placemaking and senses of authenticity at the heart of craft practice.

It can be stated that the integrated material survey and experimental study undertaken in this project, therefore, highlighted the restricted perspective offered by the current models of archaeological interpretation. The idea of distillation with its roots in ancient Greek innovations, while perhaps plausible from a conceptual point, does not have direct archaeological backing. Instead, this thesis has demonstrated the flaws in interpreting distillation traditions from excavated materials and the legacy of such an idea. Compounded by a series of experimental insights into the practice's nuances, the existing narrative on early distillation has been demonstrated as precariously influential in how technology and its connotations of civilization is viewed. Hence, sweeping cultural ascriptions used to claim materials practices, technologies, and innovations as Greek, non-Greek, Indo-Greek etc. are not helpful when exploring the connections and movements of ideas throughout the 'Hellenistic East'. While there is certainly a discussion to be had on how different cultural groups influenced one another since the expansion of Greek colonisation, it cannot be done by either identifying nexuses as proxies for change or large characterisations of knowledge diffusion. Technology evidently is a context by which to explore human interactions with their environment, asking how technological practices mediated different and changing behaviours. The existing body of evidence then from South-Central Asia can be revisited from such a perspective to bring about nuanced discussions on the nature of change within the region.

8.3 Proposals and directions for future research

This project has provided a detailed grounding for further research directions that crosses several thematic areas:

1.) Investigating aspects unable to be addressed due to COVID-19:

- Expand the material survey to include localised reports of 'receiver-condensers', and follow-up with published research and internal archaeological reports.

- Comprehensively reconstruct, and subsequentially re-evaluate, the material record from Shaikhān Dherī to offer a stronger interpretation on activities at the site and connections with greater regional networks (e.g., connections with materials from Barikot).
- Re-evaluate chronological ascriptions of ceramic assemblage from Shaikhān Dherī by using recent radiocarbon dated ranges from Barikot as a comparative model; doing this can help realign ascribed date ranges for previously characterised apparatus components.

2.) Expanding the scope of analysis:

- Integrate material composition information relating to the ceramics of Shaikhān Dherī (e.g., clay sources, tempers, variability in manufacture techniques) with the proposed reinterpretation of the site to enhance discussions on cultural change across the 'Hellenistic' epochs in South-Central Asia.
- Undertake a structured experimental programme using differing alcohol concentrations to explore the limits and remits of alcohol distillation operation with proffered early ceramic apparatus configurations, but crucially not looking to confirm the distilling ability of apparatus.
- From the starting point suggested in this project, develop detailed frameworks to shape research directions of technology within South-Central Asia during suggested periods of 'Hellenisation' that embraces a holistic, sociotechnical, view of technology.

3.) Furthering early distillation studies:

- Develop an integrated programme of research on early distillation technology as a technological practice that introduces complementary lines of evidence in a meaningful way (e.g., ethnography, craft practitioners).
- Develop wider detailed frameworks to shape the study and research directions of early distillation in all its applications that includes complementary integrated analyses and not isolated studies.

Catalogue

The following catalogue lists all previously cited and attributed elements of specialist distillation apparatus by scholars (pre-January 2023): note that these are not universally agreed but instead a collation of interpretations. Detail on how the survey was conducted and the methodology use to collate this catalogue can be found in Chapter 4. While ascribed dates and cultural phases have been attributed to a single source, multiple authors have published on the material from some sites individually (e.g., Shaikhān Dherī). The arrival at apparatus components characterisations will, therefore, have come from a multiplicity of ideas and perspectives. Alternative names and spellings for sites are noted accordingly (e.g., Charsada / Charsadda). References listed in the catalogue are found in the main bibliography.

Items are sorted by site apart from those from Shaikhān Dherī that are divided into their ascribed periods, due to the high number of reported examples in comparison to other sites. Periodisation for examples from Shaikhān Dherī are derived from Husain's (1980) original pottery typology (based on dates and chronology determined by Dani (1966)) and not the later published chronology (Husain 1995) as the 1995 chronology does not correspond to the original cultural periodisation of the archaeological examples of distillation apparatus.

Elements such as still bodies and cooling basins that feature in most interpretations of apparatuses are not included here due to their wide ascription as 'cooking vessels' and thus not explicitly considered as specialist components of a configuration (see Chapters 3.5; 4).

Description of catalogue features

Each item within the catalogue uses consistent features. Where certain parameters are not known or cannot be ascertained, this is indicated.

Item

Catalogue number referenced throughout the text and project.

Original classification

The original classification of the archaeological example by report authors or excavators.

Ascribed use

Item's connection to a specific reconstruction of distillation apparatus and its ascribed use within the reconstruction. Detail on how the reconstructions were formulated is described in Chapter 4.

Date range

Previously allocated date range for the item. References to the first allocated range are provided when known; those without references are commonly recognised date ranges. A single ascribable reference, however, cannot be confidently ascertained.

Original ascribed period

Original ascribed cultural period for the item. References to the original ascribed period are provided when known; those without references are commonly recognised periods for the item. A single reference, however, cannot be confidently ascertained or ascribed. Citations connect to chronologies ascribed to individual items and are not universally agreed upon.

Stratigraphy

Ascribed stratigraphic phase from the item's excavation. References to the original ascribed stratigraphic layer are provided when known; those without references are commonly recognised stratigraphic layers for the item, though a single reference cannot be confidently ascertained or ascribed.

Description (with original citation(s))

Descriptions of item by given researchers and a reference or citation.

Manufacture and fabric

Reported fabric and manufacture methods of the item including a reference or citation.

Drawings and photographs

Published and unpublished drawings and photographs of the item. Where there are multiple examples or items of the same vessel type at one site (unless stated) presented drawings or photographs should be taken as representative for typological example.

Context and description

Brief overview of the site and the materials relating to the distillation apparatus reconstructions.

Sirkap, Taxila, Khyber Pakhtunkhwa, Pakistan

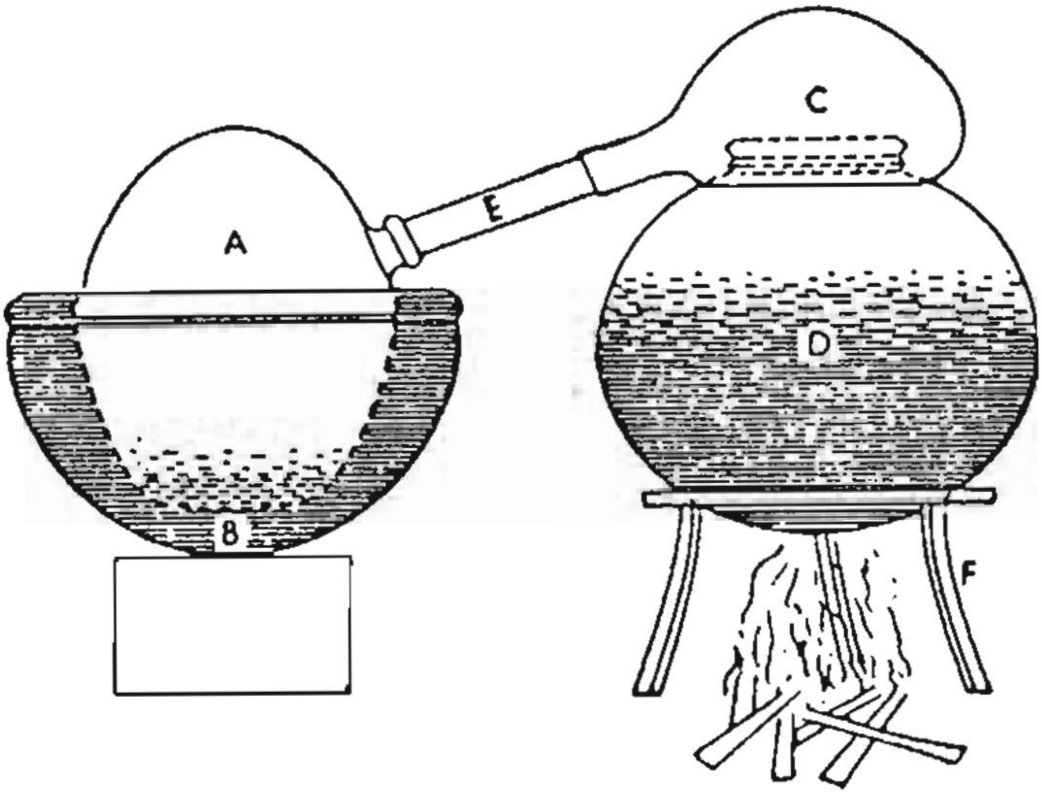
Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
1	Condenser or large closed vessel	Gandhāra still, receiver	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum III (Marshall 1951)	"Type 73 is a large close vessel save for a small spout on one side. It is made of two pieces luted together; the line of seam being marked by a conspicuous ridge. It is a highly specialized type but occurs occasionally throughout the occupation of the site. It may be part of an apparatus for condensing water" (Ghosh 1948, p. 64)
2	Condenser or large closed vessel	Gandhāra still, receiver	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum III (Marshall 1951)	"No. 127. Sk. '14-311, Blck C; sq. 47.77; stratum III. Condenser made of very coarse red sandy clay mixed with lime and *bajri*. Height 15 in. Thin walls. Cf. p193 *supra.* Pl 125, No. 127." (Marshall 1951, p. 420)
3	Condenser or large closed vessel	Gandhāra still, receiver	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum II (Marshall 1951)	"No. 128. Sk. '15-1090: Block K; sq. 159.110; stratum II. More domical at top than No. 127. Height 17.25in. Reddish brown, coarse sandy clay, with lime and *bajri.* Cf. p. 180 *surpa.* Pls. 125 no 128:129, u." (Marshall 1951, p. 421)
4	Large spouted bowl	Condensing cowl (still head), Gandhāra still	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum II (Marshall 1951)	"Type 74 is a large spouted bowl with a rounded base and represents the condensing cowl of the series described under Type 73. A tube is assumed to connected its spout with that of a vessel of Type 73. It is of a light-red ware of medium or coarse fabric and is treated with red slip both inside and out. This is a rare type but occurs sporadically throughout the occupation of the site" (Ghosh 1948, p. 67)
5	Large spouted bowl	Condensing cowl (still head), Gandhāra still	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum II (Marshall 1951)	"No. 129. Sk. '24-1176; Block C; sq. 50.47'; stratum II. Condensing cowl of good red clay with dark red wash. Rim much incurved. Diam. 13.25 in. Cf. p 149 n. 2 *supra.* Pl. 125, no. 129." (Marshall 1951, p. 421)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
6	Smaller pipe for uncertain purpose	Condensing tube, Gandhāra still	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum II (Marshall 1951)	"No. 210. Sk '12-688; Block F; sq. 89.65'; stratum II; length 10.87 in. Red clay without wash. Prominent flange 1.5 in. from one end, the other slightly splayed. Cf. p. 166 supra (Pl. 127, no. 210) (Marshall 1951, p. 429) "V3, Pipes Pl. 78.3. Drain pipes similar to 519, found in the upper layer of the last Indo-Greek Period, come from Sirkap" (Iori 2018, No. V3)
7	Smaller pipe for uncertain purpose	Condensing tube, Gandhāra still	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum III (Marshall 1951)	"No. 211. Sk ''14-956; Main Street; sq. 45.72'; stratum III. Length 6.12 in (Annual Report of the Archaeological Survey of India (1914) Pl. XXI, 36). Coarsish red clay mixed with some *bajrī*" (Marshall 1951, p. 429) Reference given by Marshall (1951, No. 211) to the *Annual Report* does not correspond to any relevant material. "V3, Pipes Pl. 78.3. Drain pipes similar to 519, found in the upper layer of the last Indo-Greek Period, come from Sirkap" (Iori 2018, No. V3)
8	Water bottle for pack animal	Receiver, Gandhāra still	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum II (Marshall 1951)	"No. 47. Sk. '25-697; Block C; sq. 46-47. Of exceptionally coarse sandy clay mixed with much *bajri* and burnt to red on outside only. Diam. 11.7 in." (Marshall 1951, p. 412) "Identical [receivers to those recorded at Begram] are reported from Taxila" (Husain 1980, p. 141)

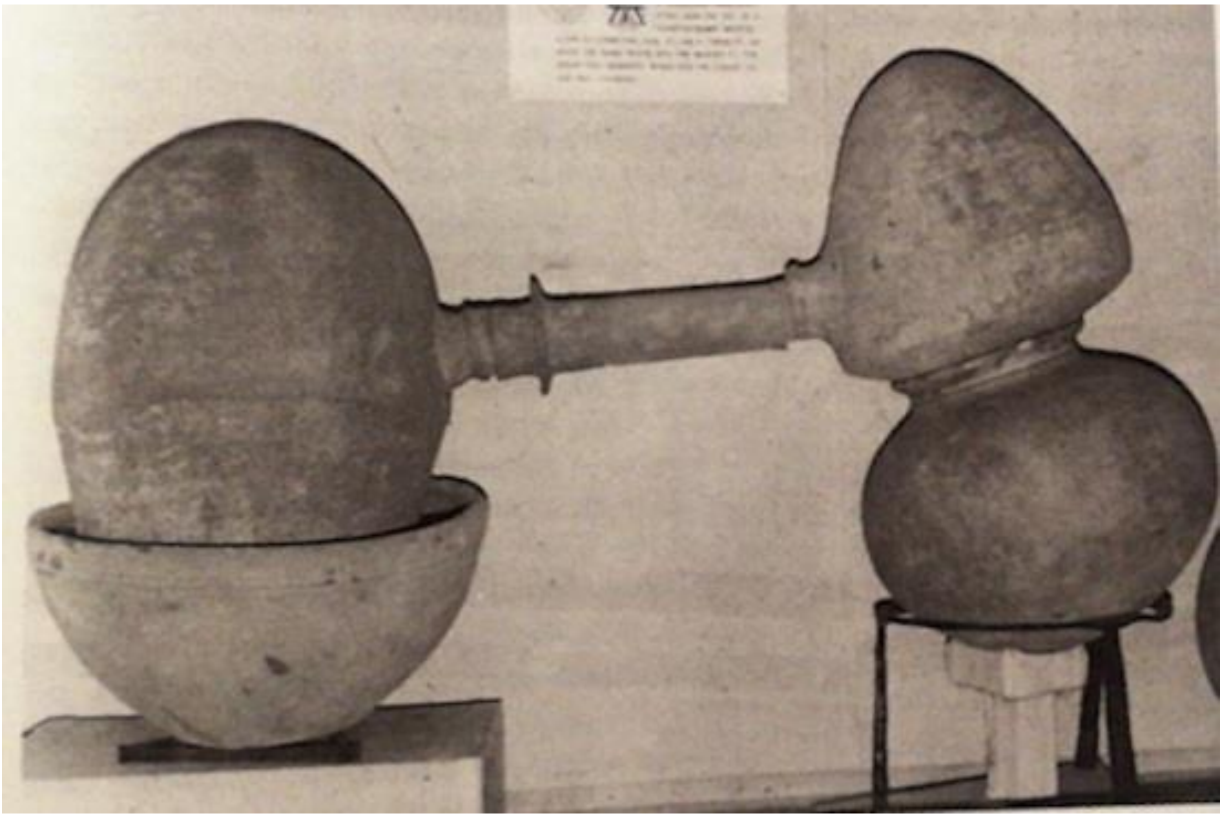
Manufacture and fabric

- Type 73 ; No. 127 - very coarse red sandy clay mixed with lime and *bajri* (Marshall 1951, p. 420)
- No. 128 - Reddish brown, coarse sandy clay, with lime and *bajri* (Marshall 1951, p. 420)
- Type 74 ; No. 129 - Reddish brown, coarse sandy clay, with lime and *bajri* (Marshall 1951, p. 421)
- No. 210 - Red clay without wash (Marshall 1951, p. 421)
- No. 211 - Coarsish red clay mixed with some *bajrī* (Marshall 1951, p. 429)
- No. 47 - Exceptionally coarse sandy clay mixed with much bajri and burnt to red on outside only (Marshall 1951, p. 412)

Drawings and photographs

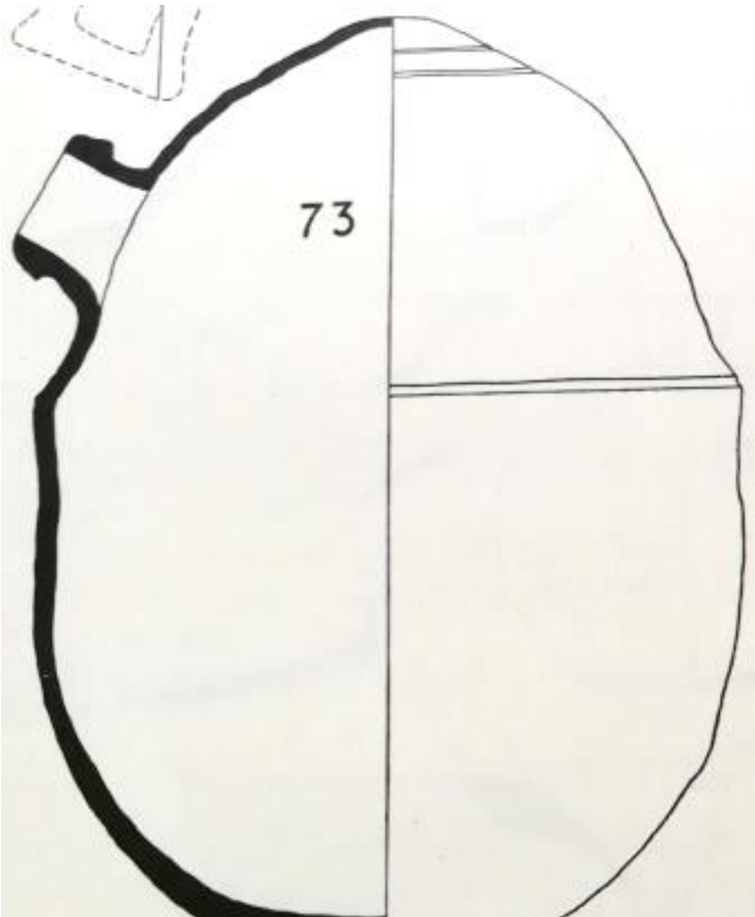


1. Original depicted reconstruction of the Taxila apparatus by Marshall (1951).

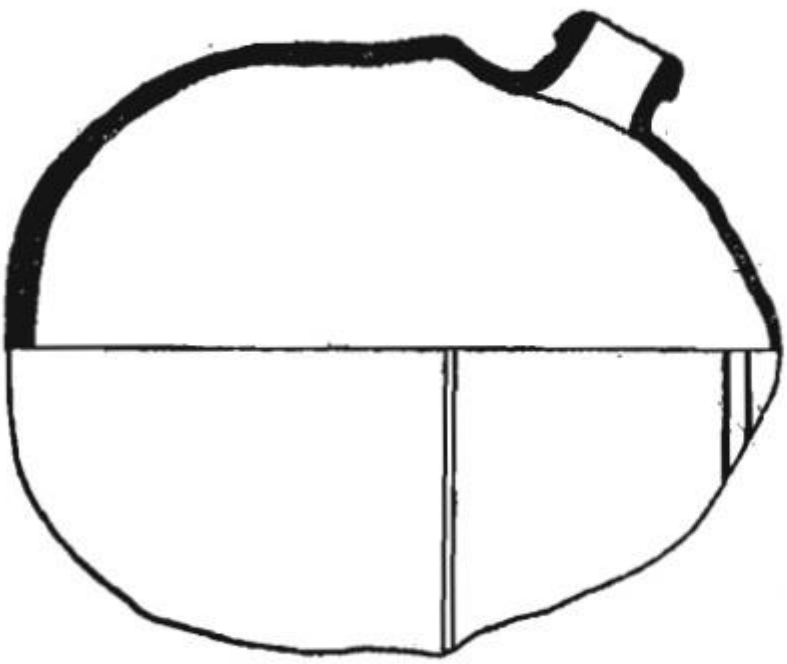


2. Presentation of the reconstructed apparatus in the Taxila Museum (photograph by P. Rovesti, unknown date).

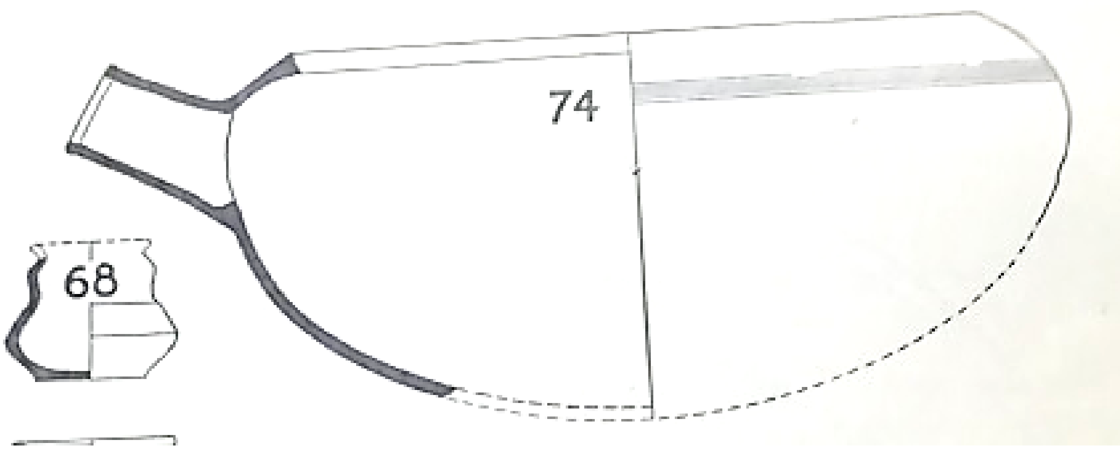
3. Presentation of the reconstructed apparatus in the Taxila Museum (photograph reprinted by R. Foss (https:/www.richard.foss.com); unknown original source, unknown date)



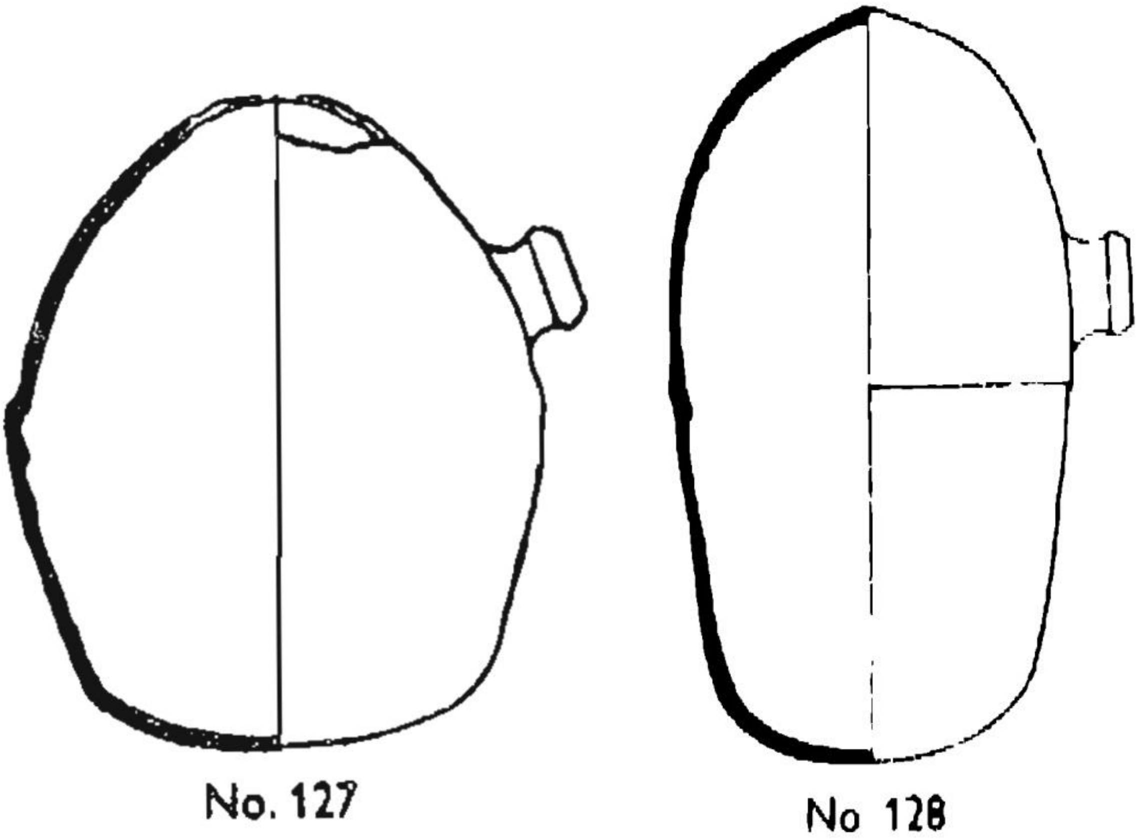
4. Ghosh's Type 73 (1:8 scale from original print publication) (Ghosh 1948, p. 65)



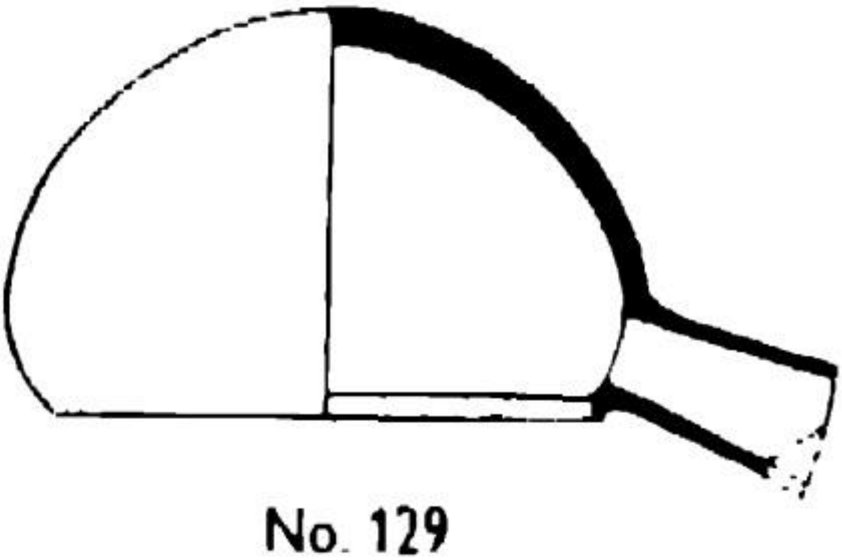
5. Redrawing of Ghosh's Type 73 with different orientation by Mahdihassan (no scale) (Mahdihassan 1972, fig. 44).



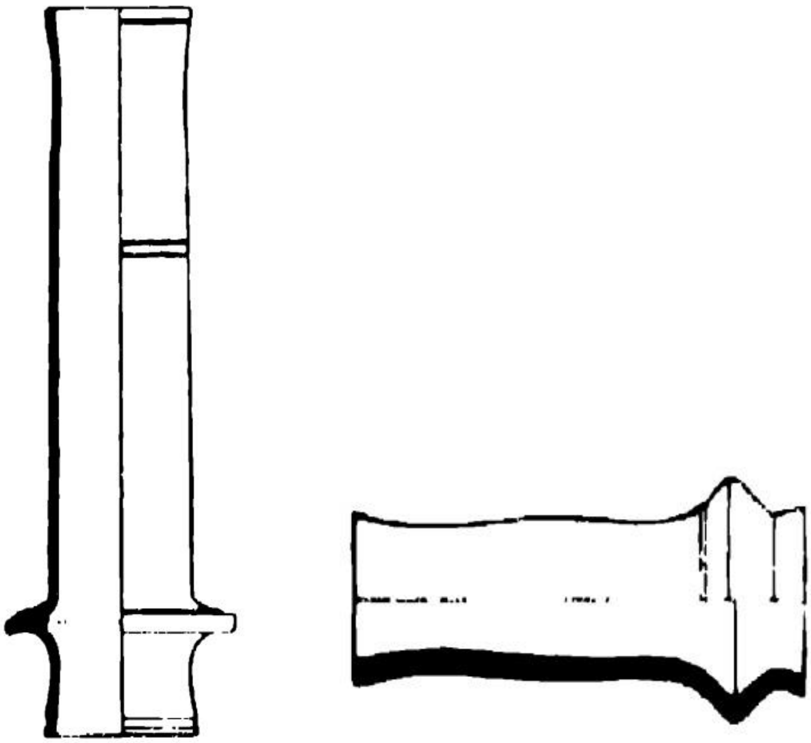
6. Ghosh's Type 74 (1:4 scale from original print publication) (Ghosh 1948, p. 65)



7. Drawing of No. 127 and 128 (no scale, dimensions given in (Marshall 1951, pp. 420–421))

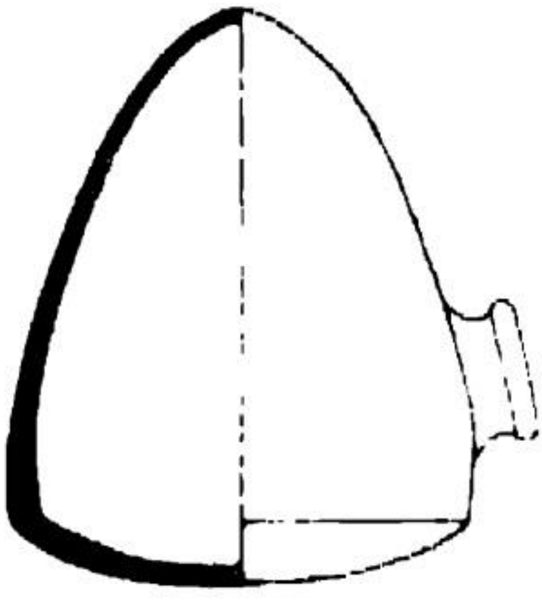


8. Drawing of No. 129 (no scale, dimensions given in (Marshall 1951, pp. 420–421))



No. 210 No 211

9. Drawings of No. 210 and 211 (no scale, dimensions given in (Marshall 1951, p. 429)).



No 47

10. Drawing of No. 47 (no scale, dimensions given in (Marshall 1951, p. 412)).

Context and description

Detailed evaluation of the Taxila material can be found in Chapter 4.

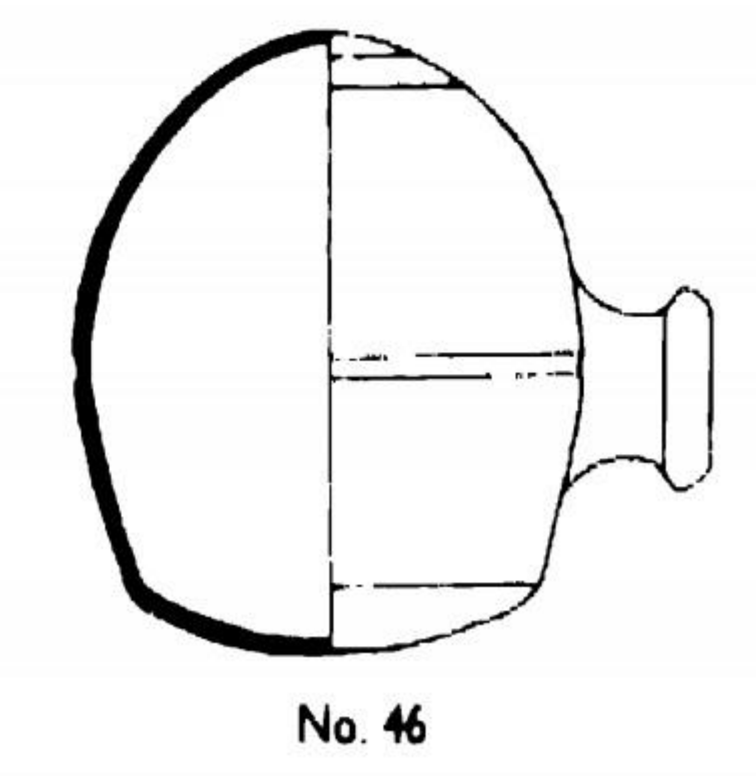
Bhir Mound, Taxila, Khyber Pakhtunkhwa, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
9	Large water bottle for pack animal	Receiver, Gandhāra still	1st c. BCE	Indo-Greek or Indo-Scythian	Stratum II (Marshall 1951)	"No 46. Bm. '20-578; sq. 29.33' From soak-well of stratum II. Water-bottle of coarse sandy clay, reddish buff in colour, slightly convex on inner side. Diam. 9.25 in." (Marshall 1951, p. 412) "Identical [receivers to those recorded at Begram] are reported from Taxila" (Husain 1980, p. 141)

Manufacture and fabric

- No. 46 - coarse sandy clay, reddish buff in colour (Marshall 1951, p. 412)

Drawings and photographs



1. Drawing of No. 46 (no scale, though dimensions given in (Marshall 1951, p. 412)) (Marshall 1951, Pl. 122).

Context and description

Detailed evaluation of the Taxila material can be found in Chapter 4.

Bādalpur, Taxila, Khyber Pakhtunkhwa, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
10	Water condenser	Condenser, Gandhāra still	Unknown	Unknown	Unknown	(Khan et al. 2013, pp. 65–80)

Manufacture and fabric
Unknown

Drawings and photographs

1. Characterised water condenser from Bādalpur (Khan et al. 2013(?); Khan 2019) (no scale).

Context and description
As an element of the greater Taxila environment, the Bādalpur monastic complex consists of a main *stupa* and associated features (Khan et al. 2013). Much of the archaeological material is ascribed as "Gandhāran", though unclear what exactly it pertains to aside from the broad 'ancient' characterisation (Khan et al. 2013; Khan 2019). A "wide variety of pottery, iron nails, bones, terracotta bangles, storage jars, bowls, plates, oil lamps, water condensers and potsherds were recovered and preserved" (Khan 2019, p. 73) during the 2012-2013 excavation season, and the 'condenser' was photographed in Khan (2019) though without any further detail (possibly originally published in Khan et al. (2013) though this source could not be obtained). While the original paper that published the condenser cannot be found (cf. Khan et al. 2013), it is worth noting that the photographed condenser does not match those of any other site let alone Sirkap, Taxila (see also Chapter 4 for evaluation of the Taxila material).

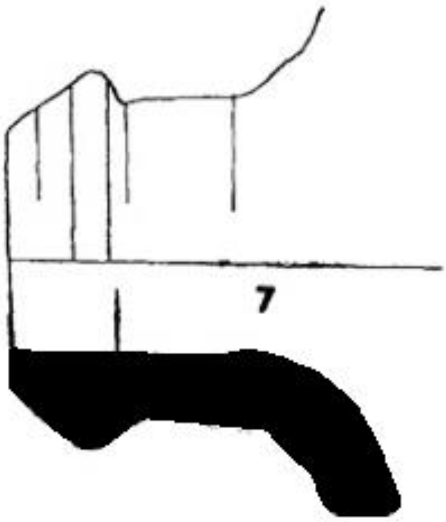
Shaikhān Dherī, Charsada / Charsadda, Khyber Pakhtunkhwa, Pakistan (Indo-Greek)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
11	Spout of big pot for condensing water	Receiver, Gandhāra still	mid-2nd c. BCE (Dani 1966, p. 25; Husain 1980)	Greek (Dani 1966) Indo-Greek (Husain 1980)	Period 1, A8' (7) (Dani 1966, p. 188; Husain 1980) Period 6-5 (Husain 1995)	1964 excavation grid area "Type 11, spout of a big pot for condensing water, same as Ghosh No. 73" (Dani 1966, p. 188) "Type 37, 33 max diam., red coarse. Moulded. Receiver" (Husain 1980, Sheet 5.1) "Three [receivers] from the Indo-Greek period" (Husain 1980, p. 139)
12	Receiver	Receiver, Gandhāra still	mid-2nd c. BCE (Dani 1966, p. 25; Husain 1980)	Greek (Dani 1966) Indo-Greek (Husain 1980)	Period 1, A8' (Husain 1980) Period 6-5 (Husain 1995)	1964 excavation grid area "Type 37, 33 max diam., red coarse. Moulded. Receiver" (Husain 1980, Sheet 5.1) "Three [receivers] from the Indo-Greek period" (Husain 1980, p. 139) "Recorded type – a receiver" (Husain 1993, p. 297)
13	Receiver	Receiver, Gandhāra still	mid-2nd c. BCE (Dani 1966, p. 25; Husain 1980)	Greek (Dani 1966) Indo-Greek (Husain 1980)	Period 1, D1(15) (Husain 1980) Period 6-5 (Husain 1995)	1963 excavation grid area "Three [receivers] from the Indo-Greek period" (Husain 1980, p. 139) "Type 37, 33 max diam., red coarse. Moulded. Side fragment of a receiver; provided with a large spout" (Husain 1980, Sheet 5.1)
14	Still head	Still head, Gandhāra still	mid-2nd c. BCE (Dani 1966, p. 25; Husain 1980)	Greek (Dani 1966) Indo-Greek (Husain 1980)	Period 1, A3'(11) (Husain 1980) Period 6-5 (Husain 1995)	1964 excavation grid area "Type 38, 34.3 rim, 39 max diam. Red medium, red slip and turning finishing, throwing in a shaping dish, side fragment of a still head provided with a large spout" (Husain 1980, Sheet 5.2)

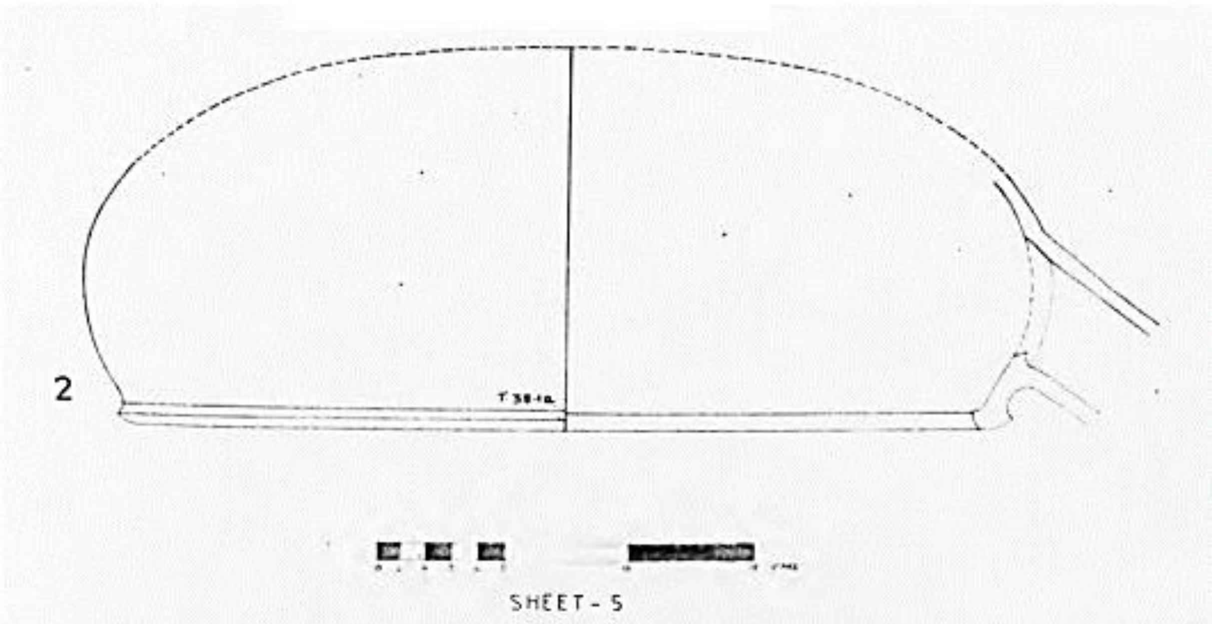
Manufacture and fabric

- Type 11 - Red ware (Dani 1966, p. 188); Type 37 - red coarse ware, moulded (Husain 1980, Sheet 5.1)
- Type 38 - Red medium, red slip and turning finishing, throwing in a shaping dish (Husain 1980, Sheet 5.2)

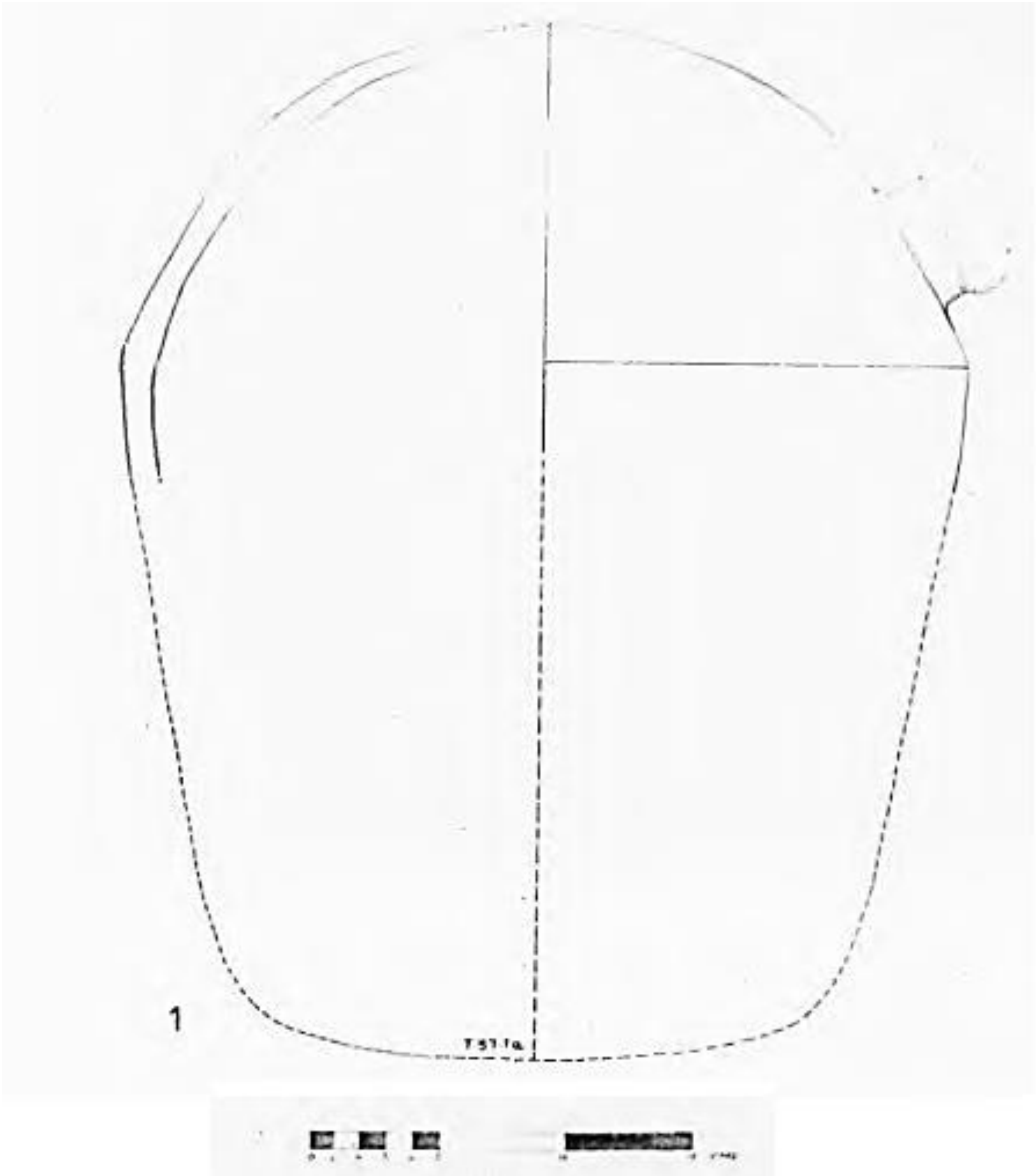
Drawings and photographs



1. Dani's drawing of his ascribed *"Greek… spout of big pot for condensing water"* (Dani 1966, p. 145).



2. Husain's drawing of his Indo-Greek still head (Husain 1980, Sheet-5)



3. Husain's drawing of his Indo-Greek receiver (Husain 1980, Sheet-5)

Context and description

Detailed evaluation of the Shaikhān Dherī material can be found in Chapter 4. See Husain (1995) for the most recent evaluation of site periodisation and chronology that may challenge what is listed here.

Shaikhān Dherī, Charsada / Charsadda, Khyber Pakhtunkhwa, Pakistan (Indo-Scythian/Saka, Scytho/Saka-Parthian, and Indo-Parthian)

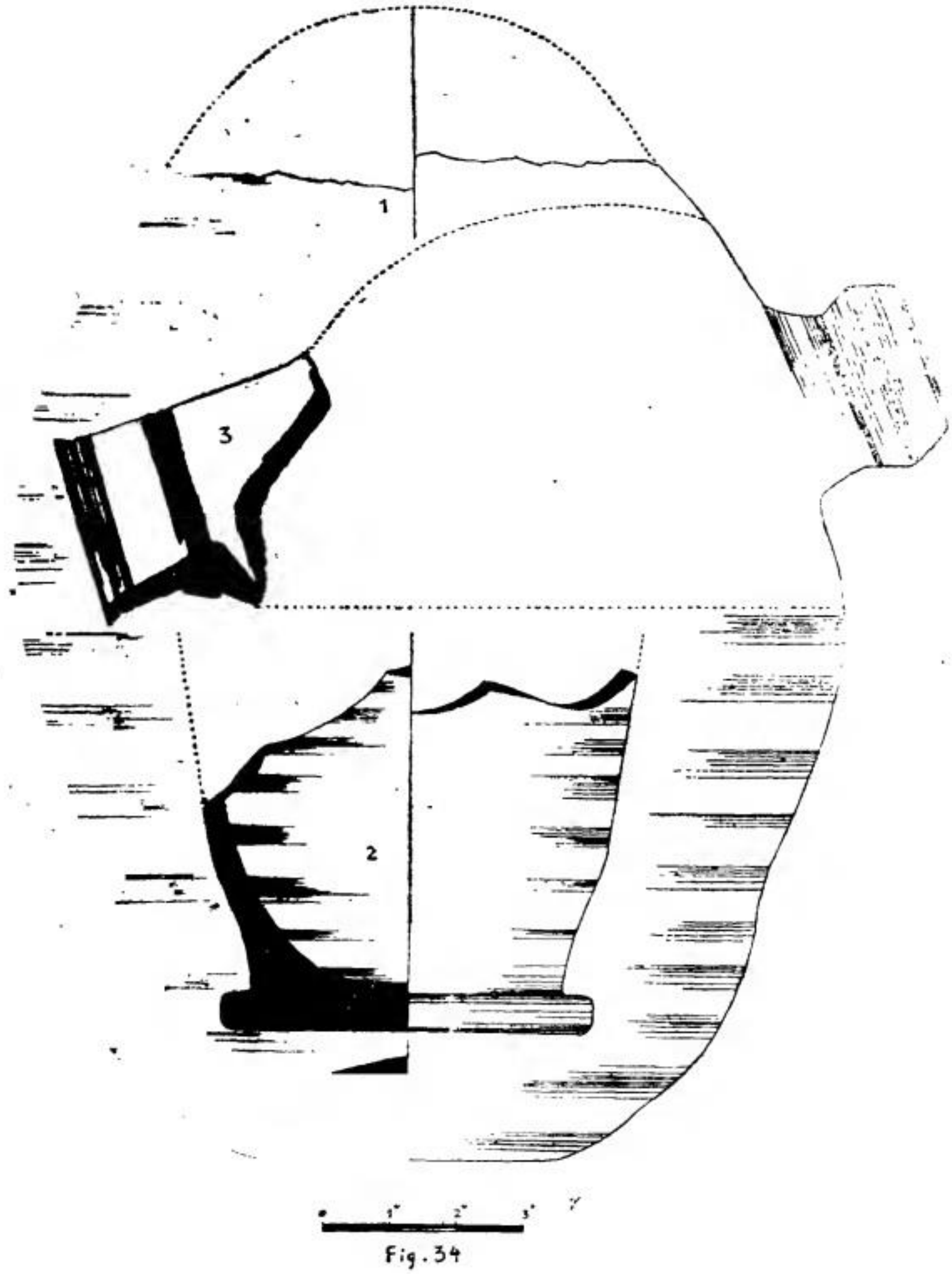
Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
15	Large water vessel with single spout	Receiver, Gandhāra still	mid-1st c. BCE – mid-1st c. CE (Dani 1966, p. 25; Husain 1980)	Indo-Scythian Scytho-Parthian (Husain 1993, p. 296)	Period 2, D1(9) (Husain 1980) Period 4 (Husain 1995)	1963 excavation grid area “Type 16, No, 1. It is a large water vessel with a single spout to one side, the vessel being made in two parts luted together” (Dani 1966, p. 197) “Type 37 - 33 max diam., 43.5 interior height, red coarse, flat base, moulded, an elongated receiver with a large spout in the upper half” (Husain 1980, Sheet 14.1) “Three [receivers] from the Scytho-Parthian period” (Husain 1980, p. 139) Drawing (Type 16 No. 1) (Dani 1966, p. 160) “Recorded type – a receiver” (Husain 1993, p. 296)
16	Receiver	Receiver, Gandhāra still	mid-1st c. BCE – mid-1st c. CE (Dani 1966, p. 25; Husain 1980)	Indo-Scythian Scytho-Parthian	Period 2, A9’(6) (Husain 1980) Period 4 (Husain 1995)	1964 excavation grid area “Red coarse, moulded, spout of a receiver with stamped *tanga* mark on the shoulder” (Husain 1980, Sheet 14.2) “Three [receivers] from the Scytho-Parthian period” (Husain 1980, p. 139) “Reg. no. 1127. The impression is close to the median seam and spout. It consists of a rectangular ground containing a wine jug with pedestal foot, high handle and raised lip...” (Allchin 1979b, p. 793)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
17	Receiver	Receiver, Gandhāra still	mid-1st c. BCE – mid-1st c. CE (Dani 1966, p. 25; Husain 1980)	Indo-Scythian Scytho-Parthian	Period 2, I11' (5) (Husain 1980) Period 4 (Husain 1995)	1964 excavation grid area "Red coarse, moulded, spout of a receiver with stamped *tanga* mark on the shoulder" (Husain 1980, fig. Sheet 14.3) "Three [receivers] from the Scytho-Parthian period" (Husain 1980, p. 139)
18	Water distiller	Still head, Gandhāra still	mid-1st c. BCE – mid-1st c. CE (Dani 1966, p. 25; Husain 1980)	Indo-Scythian Scytho-Parthian	Period 2, A10'(5) (Husain 1980) Period 4 (Husain 1995)	1964 excavation grid area Drawing (Type 18 No. 3) (Dani 1966, p. 160) "Type 18 No. 3. Spout of a water distiller with grooves at the spout and buttons below the spout" "Type 38 - 19.5 rim diam., 33cm max diam., 16 interior height, red medium with red slip, wheel and turning. A large spout of a still-head provided with two imitation buttons on the lower joint" (Husain 1980, Sheet 14.4)

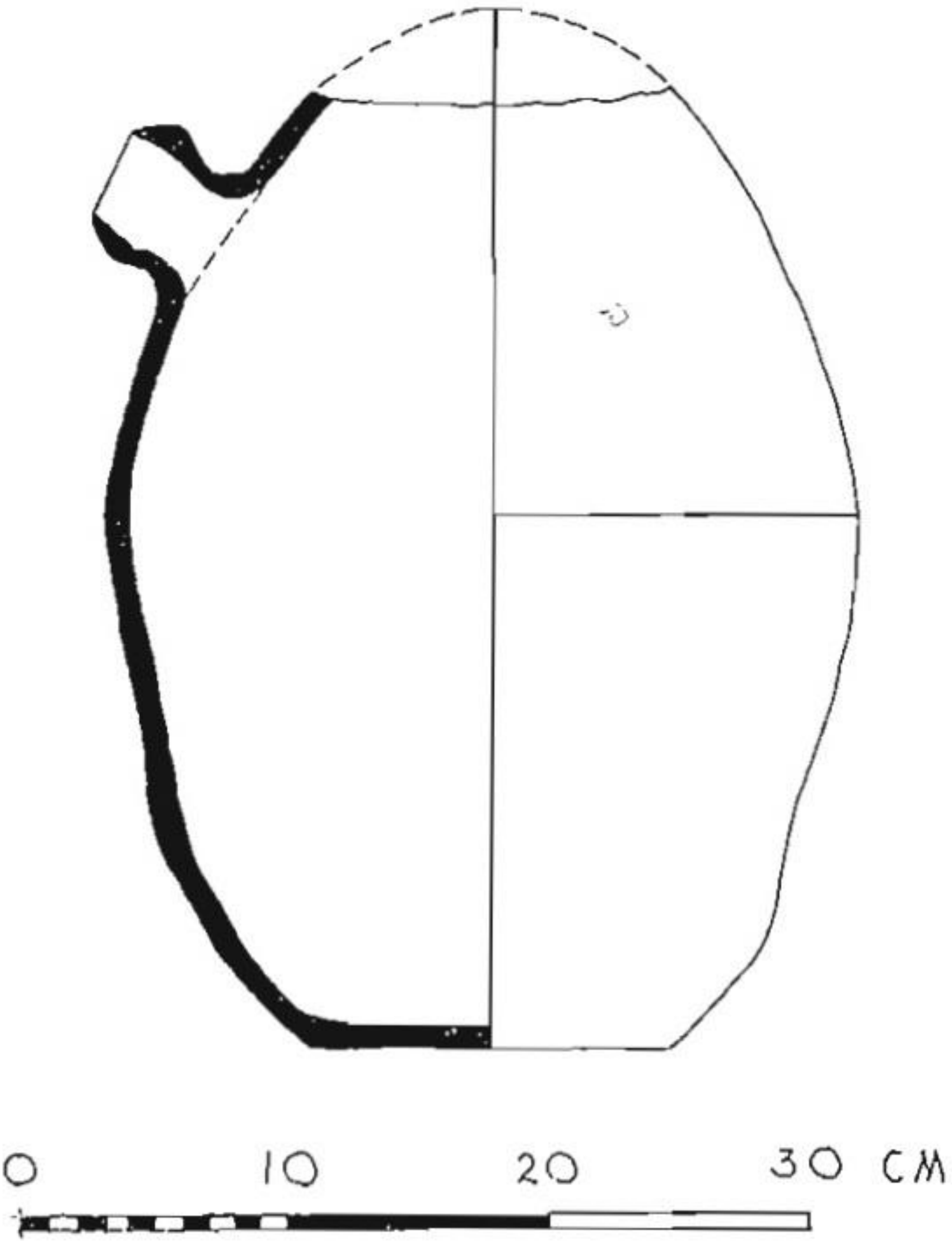
Manufacture and fabric

- Type 16. No. 1 - Red ware, two parts luted together (Dani 1966, p. 197); Type 37 - red coarse ware, moulded (Husain 1980)
- Type 18. No. 3 - Red ware (Dani 1966); Type 38 - , red medium with red slip, wheel and turning (Husain 1980)

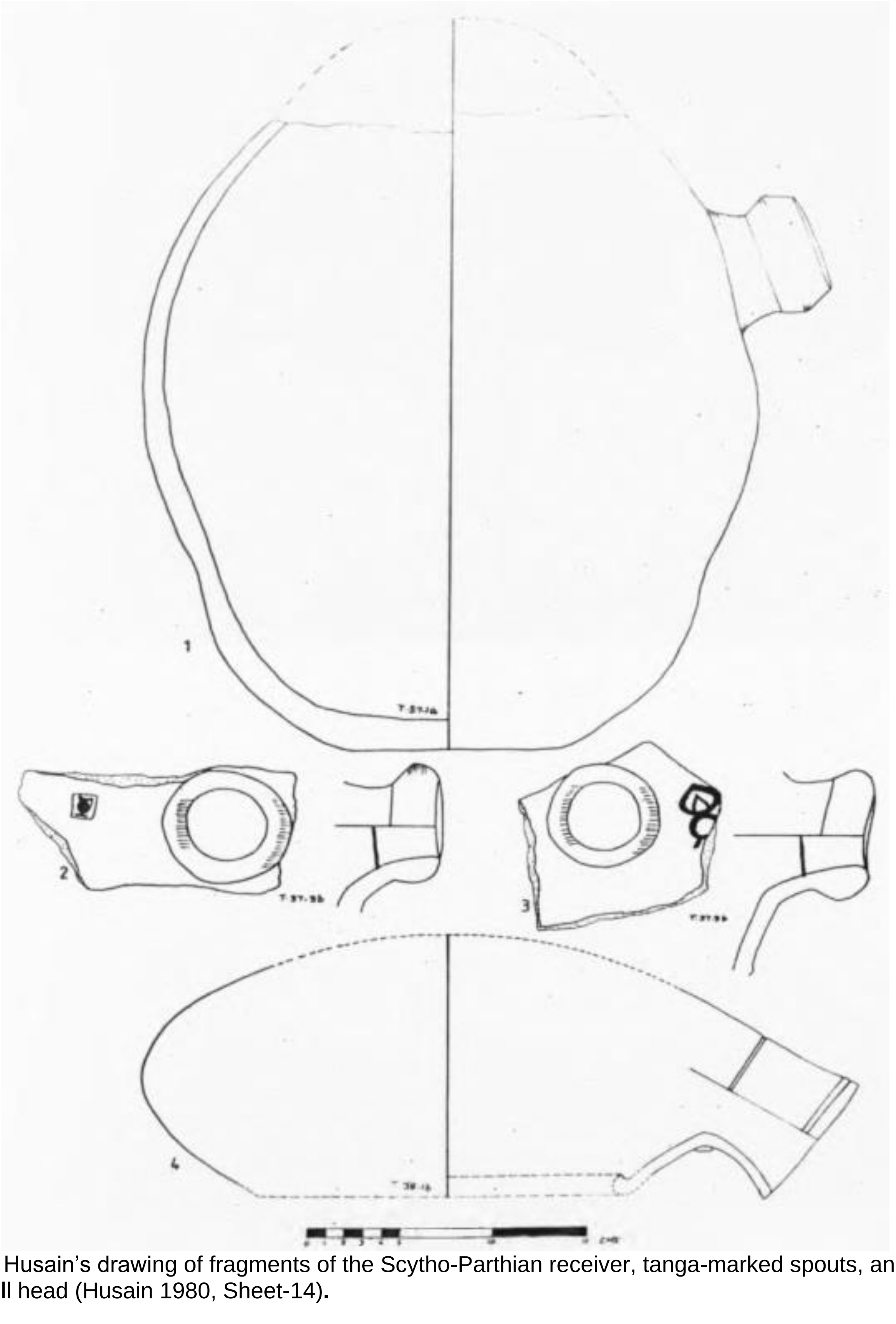
Drawings and photographs



1. Dani's drawing of his ascribed 'Scytho-Parthian' 'water vessel' (No.1) and 'water distiller' (No. 3) (Dani 1966, p. 160).



2. Allchin's "earlier type condenser from square D1(9) stratum VIII" (Allchin 1979b, p. 770)



1. Husain’s drawing of fragments of the Scytho-Parthian receiver, tanga-marked spouts, and still head (Husain 1980, Sheet-14).

Context and description

Detailed evaluation of the Shaikhān Dherī material can be found in Chapter 4. See Husain (1995) for the most recent evaluation of site periodisation and chronology that may challenge what is listed here.

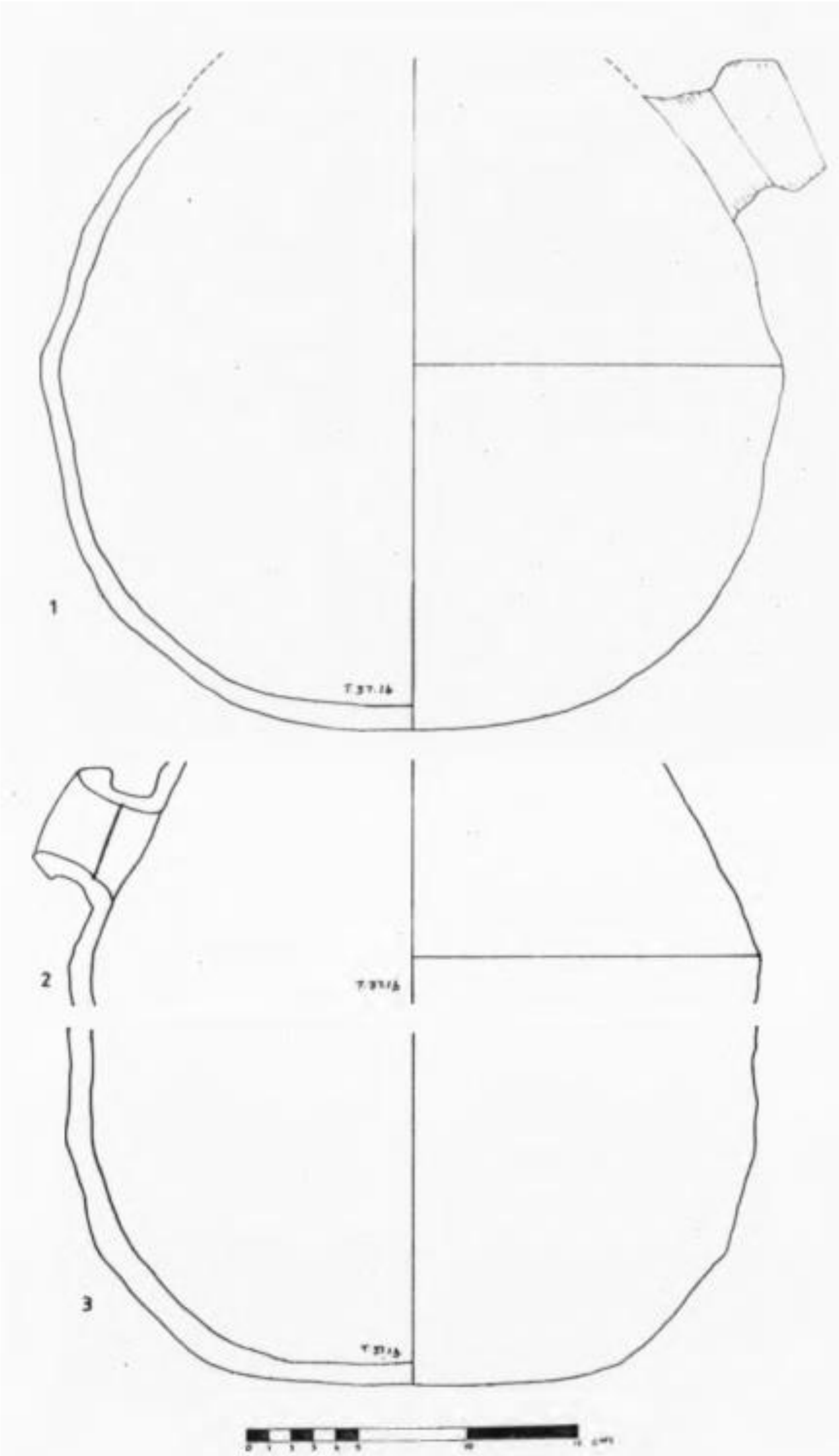
Shaikhān Dherī, Charsada / Charsadda, Khyber Pakhtunkhwa, Pakistan (Early Kushan)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
19	Large water vessel with spout	Receiver, Gandhāra still	Early-mid 1st c. CE(?) (Dani 1966, pp. 24–25; Husain 1980)	Kushana (Dani 1966) Early Kushan (Husain 1980)	A2 (5) (Dani 1966) Period 3, A2 (Husain 1980) Period 3 (Husain 1995)	1963 excavation grid area "Type 9, No. 1. It is a large water vessel with a spout of the same type as illustrated earlier." (Dani 1966, p. 210) "Three [receivers] from the Early Kushan period" (Husain 1980, p. 139) Drawing – Type 9, No. 1 (Dani 1966, p. 180)
20	Receiver	Receiver, Gandhāra still	Early-mid 1st c. CE(?) (Dani 1966, pp. 24–25; Husain 1980)	Early Kushan (Husain 1980)	Period 3, D0 (Husain 1980) Period 3 (Husain 1995)	1963 excavation grid area (Husain 1993, p. 294) "Three [receivers] from the Early Kushan period" (Husain 1980, p. 139)
21	Receiver	Receiver, Gandhāra still	Early-mid 1st c. CE(?) (Dani 1966, pp. 24–25; Husain 1980)	Early Kushan (Husain 1980)	Period 3, D1 (Husain 1980) Period 3 (Husain 1995)	1963 excavation grid area "Three [receivers] from the Early Kushan period" (Husain 1980, p. 139)

Manufacture and fabric

- Type 9; Type 37 - Coarse red ware, moulding formed (Husain 1980, Sheet 22)

Drawings and photographs



1. Husain's drawing of several examples of the Early Kushan receiver and excavated fragments (Husain 1980, Sheet-22) **.**

Context and description

Detailed evaluation of the Shaikhān Dherī material can be found in Chapter 4. See Husain (1995) for the most recent evaluation of site periodisation and chronology that may challenge what is listed here.

Shaikhān Dherī, Charsada / Charsadda, Khyber Pakhtunkhwa, Pakistan (Middle Kushan)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
22	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, D0 Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area (Husain 1993, p. 294)
23	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, D1 (Husain 1993, p. 296) D1(4) (Husain 1980) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area “Type 37.2a - [rounded base] receiver of globular form, 30.2 cm by 29.1 cm” (Husain 1980, Sheet 31.1) Not recorded on Husain (1980), Frequency Chart 7.4
24	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, D1 Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area (Husain 1993, p. 296)
25	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	F0(5) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area Not recorded on Husain (1980), Frequency Chart 7.4 (only one example is recorded from ‘F’) “Twenty [receivers] from the Middle Kushan period” (Husain 1980, p. 139)
26	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	A5(2) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area Not recorded on Husain (1980), Frequency Chart 7.4 “Twenty [receivers] from the Middle Kushan period” (Husain 1980, p. 139)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
27	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	B3(2) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area “Twenty [receivers] from the Middle Kushan period” (Husain 1980, p. 139)
28	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	B3(2) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area “Twenty [receivers] from the Middle Kushan period” (Husain 1980, p. 139)
29	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	C3(2) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area Not recorded on Husain (1980), Frequency Chart 7.4 “Twenty [receivers] from the Middle Kushan period” (Husain 1980, p. 139)
30	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	C3(2) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area Not recorded on Husain (1980), Frequency Chart 7.4 “Twenty [receivers] from the Middle Kushan period” (Husain 1980, p. 139)
31	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	C3(3) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area Not recorded on Husain (1980), Frequency Chart 7.4 “Twenty [receivers] from the Middle Kushan period” (Husain 1980, p. 139)
32	Receiver	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	C3(3) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area Not recorded on Husain (1980), Frequency Chart 7.4 “Twenty [receivers] from the Middle Kushan period” (Husain 1980, p. 139)

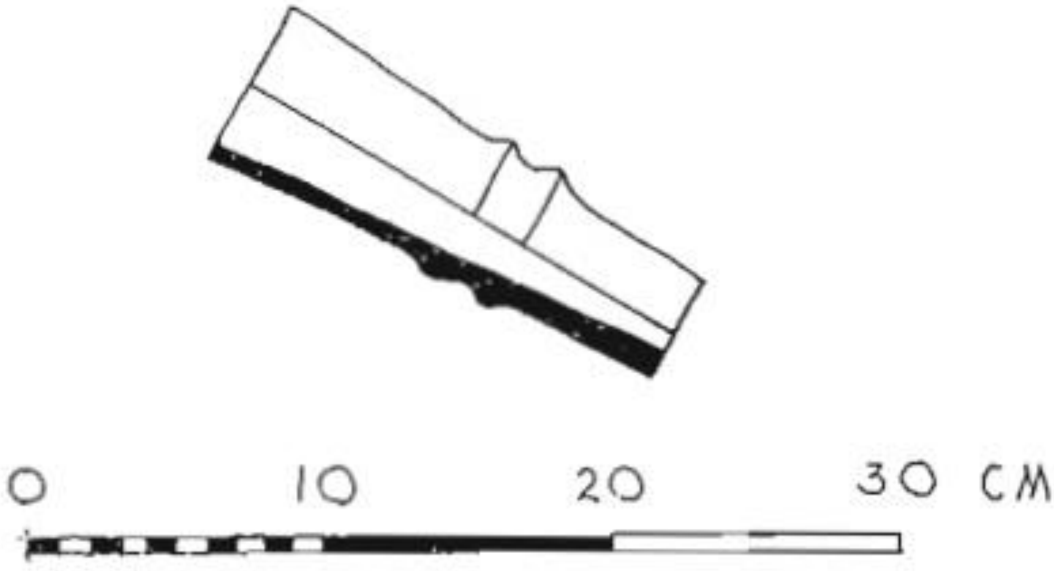
Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
34	Spout of receiver with a stamped tamga mark	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, J10'(1) (Husain 1980) Period II (Allchin 1979b) Period 2 (Husain 1995)	1964 excavation grid area "Type 37.3b – spout of a receiver with a stamped tamga mark" (Husain 1980, Sheet 31.3)
35	Spout of receiver with a stamped tamga mark	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, A10'(1) (Husain 1980) Period II (Allchin 1979b) Period 2 (Husain 1995)	1964 excavation grid area "Twenty [receivers] from the Middle Kushan period" (Husain 1980, p. 138) "Type 37.4b – fragment of a spout of a receiver with a stamped tamga mark" (Husain 1980, Sheet 31.4)
36	Spout of receiver with a stamped tamga mark	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, I9'(1) (Husain 1980) Period II (Allchin 1979b) Period 2 (Husain 1995)	1964 excavation grid area "Twenty [receivers] from the Middle Kushan period" (Husain 1980, p. 138) "Type 37.4b – fragment of a spout of a receiver with a stamped tamga mark" (Husain 1980, Sheet 31.5)
37	Spout of receiver with a stamped tamga mark	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, J10'(1) (Husain 1980) Period II (Allchin 1979b) Period 2 (Husain 1995)	1964 excavation grid area "Type 37.4b – fragment of a spout of a receiver with a stamped tamga mark" (Husain 1980, Sheet 31.6)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
38	Spout of receiver with a stamped tamga mark	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, K9'(2) (Husain 1980) Period II (Allchin 1979b) Period 2 (Husain 1995)	1964 excavation grid area "Twenty [receivers] from the Middle Kushan period" (Husain 1980, p. 139) "Type 37.4b – fragment of a spout of a receiver with a stamped tamga mark" (Husain 1980, Sheet 31.7)
39	Spout of receiver with a stamped tamga mark	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, Stratum VII, A11'(5) (Allchin 1979b) Period II (Allchin 1979b) Period 2 (Husain 1995)	1964 excavation grid area "Reg. no. 752, datable to our period IV, stratum VII. The impression is beside the spout. It is incomplete, but shows a circle surmounted by another, incomplete circle containing a triangle. The mark is larger than any other example…" (Allchin 1979b, p. 793)
40	Spout of receiver with a stamped tamga mark	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, A8'(2) (Husain 1980) Period II (Allchin 1979b) Period 2 (Husain 1995)	1964 excavation grid area "Twenty [receivers] from the Middle Kushan period" (Husain 1980, p. 139) "Type 37.4b – fragment of a spout of a receiver with a stamped tamga mark" (Husain 1980, Sheet 31.8)
41	Spout of receiver with a stamped tamga mark	Receiver, Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, J10'(1) (Husain 1980) Period II (Allchin 1979b) Period 2 (Husain 1995)	1964 excavation grid area "Type 37.4b – fragment of a spout of a receiver with a stamped tamga mark" (Husain 1980, Sheet 31.9)
42	Condensing tube	Gandhāra still	Mid-late 1st c. CE (Dani 1966, pp. 24–25; Husain 1980)	Middle Kushan	Period 4, B0(3) Period II (Allchin 1979b) Period 2 (Husain 1995)	1963 excavation grid area "5.6 max diam., red medium. A pottery tube, probably part of the distillation unit" (Husain 1980, Sheet 32)

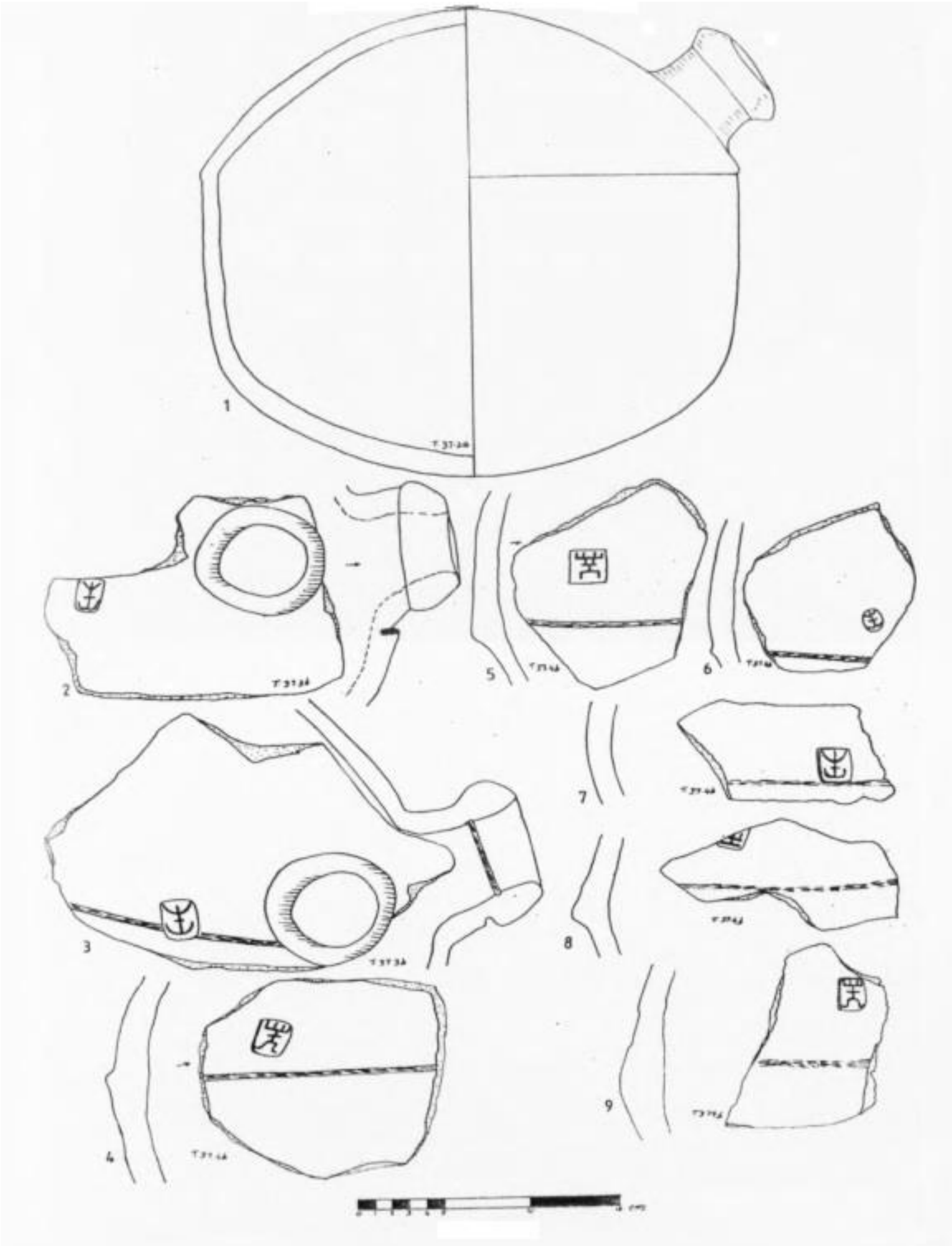
Manufacture and fabric

- Type 37.2a - Coarse red ware, moulded (Husain 1980)
- Type 37.3b and 37.4b - Coarse red ware, moulded and stamped (Husain 1980)

Drawings and photographs



1. Drawing of condensing tube by Allchin (1979b, p. 770) from Square B0(3).



2. Husain's drawing of several examples of the Middle Kushan receiver and excavated fragments (Husain 1980, Sheet-31) **.**

Context and description

Detailed evaluation of the Shaikhān Dherī material can be found in Chapter 4. See Husain (1995) for the most recent evaluation of site periodisation and chronology that may challenge what is listed here.

Shaikhān Dherī, Charsada / Charsadda, Khyber Pakhtunkhwa, Pakistan (Late Kushan)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
43	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, D0(3) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area Counted (Husain 1993, p. 294) “Side fragment of a receive; stamped tamga on the shoulder” (Husain 1980, Drawing 39.6) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138)
44	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, D1(2) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area (Husain 1993, p. 294) Counted (Husain 1993, p. 295) “A receiver of globular form; stamped tamga mark on the shoulder” (Husain 1980, Drawing 39.1) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138)
45	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, D1(3) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area (Husain 1993, p. 295) “Fragment of a receiver with a stamped tamga” (Husain 1980, Drawing 39.4) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138)
46	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	E0(2) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area Counted (Husain 1993, p. 294) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138)

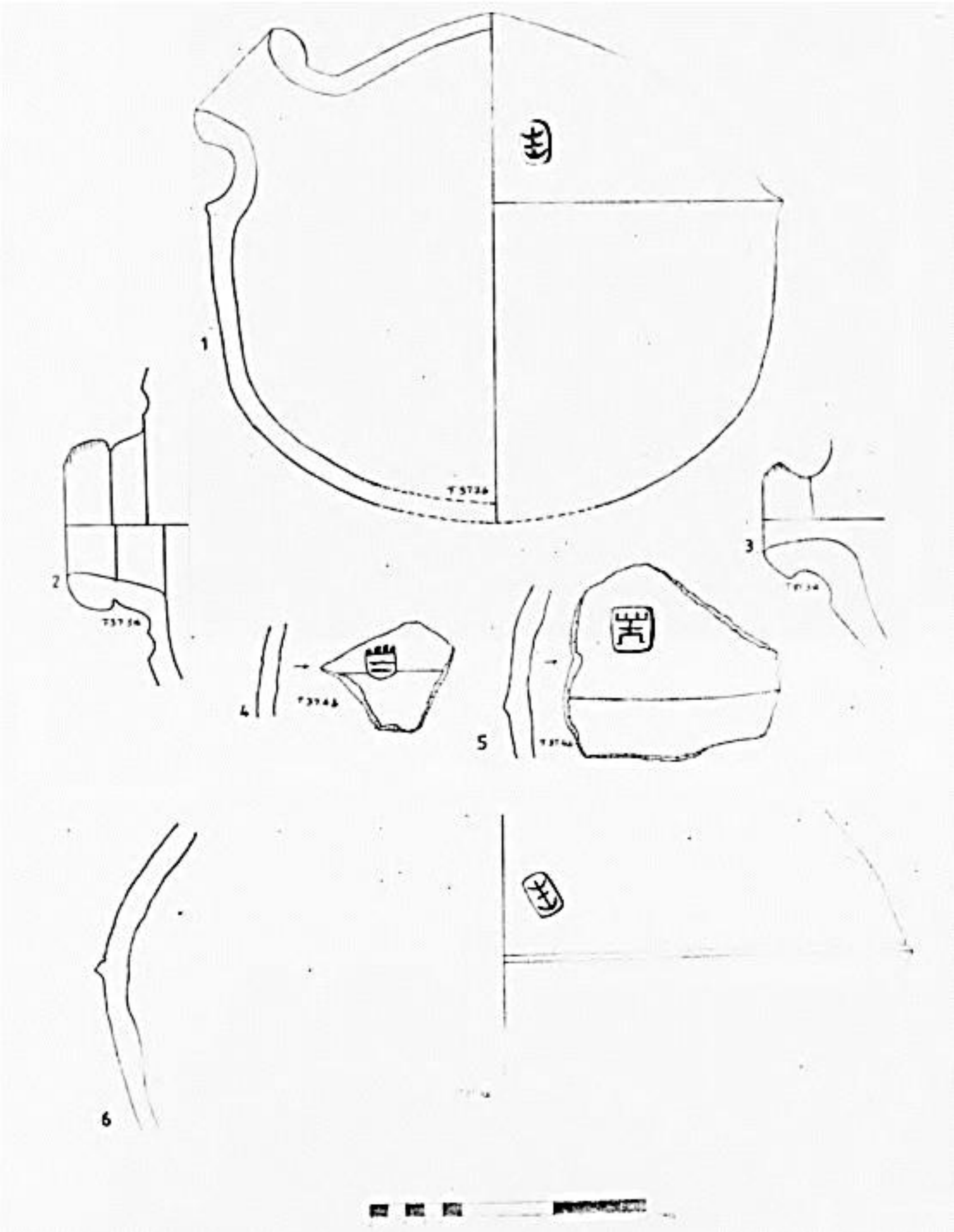
Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
47	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, E1(2) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area Counted (Husain 1993, p. 299) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138) Not recorded on Husain (1980), Frequency Chart 7.5
48	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, E1(2/3(?)) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area Counted (Husain 1993, p. 299) “Spout of a receiver” (Husain 1980, Drawing 39.3) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138)
49	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, F0(3) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area Counted (Husain 1993, p. 300) “Fragment of a receiver with a stamped tamga” (Husain 1980, Drawing 39.5) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138)
50	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, F1(3) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area Counted (Husain 1993, p. 301) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138)
51	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, F1(3) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area Counted (Husain 1993, p. 301) “Twelve [receivers] from the Late Kushan period” (Husain 1980, p. 138) Not recorded on Husain (1980), Frequency Chart 7.5

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
52	Receiver	Gandhāra still	Late 2nd-3rd or 4th c. CE (Dani 1966, p. 25; Husain 1980)	Late Kushan	Period 5, B1(1) Period I (Allchin 1979b) Period 1 (Husain 1995)	1963 excavation grid area "Spout of a receiver" (Husain 1980, Drawing 39.2) "Twelve [receivers] from the Late Kushan period" (Husain 1980, p. 138)

Manufacture and fabric

- Type 37.2b - Coarse red ware, rounded and moulded (Husain 1980)
- Type 37.3a - Coarse red ware, rounded and moulded (Husain 1980)
- Type 37.4b - Coarse red ware, rounded and moulded, stamped (Husain 1980)

Drawings and photographs



1. Husain's drawing of several examples of the Late Kushan receiver and excavated fragments (Husain 1980, Sheet-39) **.**

Context and description

Detailed evaluation of the Shaikhān Dherī material can be found in Chapter 4. See Husain (1995) for the most recent evaluation of site periodisation and chronology that may challenge what is listed here.

Barikot / Bīr-koṭ-ghwaṇḍai, Khyber Pakhtunkhwa, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
53	V1.1 boiler (?)	Still body? Receiver / condenser? Gandhāra still	3rd c. CE	Late Kushan	Trench BKG 3 Room 5 Layer 85 Phase 2b Macrophase 5 (Callieri 2020, p. 549)	Form 298. “298 BKG 305 (85) 2b/5” V1.1.(?) Boiler (?). Horizontal lateral mouth, round (flat) rim. Gritty bottom. With appliqued handle? Missing.” (Callieri 2020, p. 549)
54	V1.3 pipe	Condensing tube, Gandhāra still	2nd c. CE	Kushan	Trench BKG 4 Room 27 Layer 574 Structural period VI, Macrophase 4 (Callieri 2020, p. 549)	Form. 1732 “1732 BKG 427 (574) VI/4 V1.3(?) Pipe. Provided with flat ring and pipe tail for coupling” (Callieri 2020, p. 549)
55	MV8 mini receiver / miniature distiller	Gandhāra still(?)	3rd c. CE (Olivieri 2020b, pp. 38–41)	Late Kushan (Olivieri 2020b, pp. 38–41)	Trench BKG 5 Room 13 Layer 2653 Structural period VII Macrophase 5 (Callieri 2020, p. 582)	Swat Museum Inventory No. BKG 1680, Display No. 576 (Olivieri 2020b, p. 10) “*BKG 1680* BKG 513 (2653) VII/5 MV 8 (V.12) Condenser (cf. 1411 Plate 189.1). Hollow inside. Flat base” (Callieri 2020, p. 582)
56	Distiller	Receiver/ condenser, Gandhāra still	Unknown	Unknown	Unknown	Swat Museum Form No. BKG 2541, Display No. 575 (Olivieri 2020b, p. 10) Noted to be from an area not discussed in 2020s volumes, but on display (Olivieri 2020b, p. 10)

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
57	V1.2 receiver / condenser “V2.1 distiller” (Iori 2018, pp. 249, 274) Receiver	Receiver/ condenser, Gandhāra still	1^{st} – 2^{nd} c. CE (Callieri 1990, p. 683)	Kushan	Trench BKG 2, Room 11 Layer 205 (Callieri 2020, p. 549) 5^{th} – 6^{th} Period (Callieri 1990, p. 682)	[Inventory No.] Form 1411, partially complete Also Inv. No BKG 917(?). Could be Swat Museum example from 1990s “1411 *BKG 211 (205)** V1.2 Condenser. Ribbed top; gritty bottom. Oblique lateral mouth, round (convex) rim. Rounded base… From the same layer comes another condenser Inv. No. 916” (Callieri 2020, p. 549) “Receiver for distillation, of brownish buff ware…may be classed half-way between the earlier and later types… one of two recovered specimens (found in the same room) shows a Kushan *tamgha* impressed near the spout” (Callieri 1990, p. 686)
58	V1.2 receiver / condenser “V2.1 distiller” (Iori 2018, pp. 249, 274) Receiver	Receiver/ condenser, Gandhāra still	1^{st} – 2^{nd} c. CE (Callieri 1990, p. 683)	Kushan	Trench BKG 2, Room 11 Layer 205 (Callieri 2020, p. 549) 5^{th} – 6^{th} Period (Callieri 1990, p. 682)	Inv. No BKG 916. Could be Swat Museum example from 1990s “1411 *BKG 211 (205)** V1.2 Condenser. Ribbed top; gritty bottom. Oblique lateral mouth, round (convex) rim. Rounded base… From the same layer comes another condenser Inv. No. 916” (Callieri 2020, p. 549) “Receiver for distillation, of brownish buff ware…may be classed half-way between the earlier and later types… one of two recovered specimens (found in the same room) “ (Callieri 1990, p. 686)

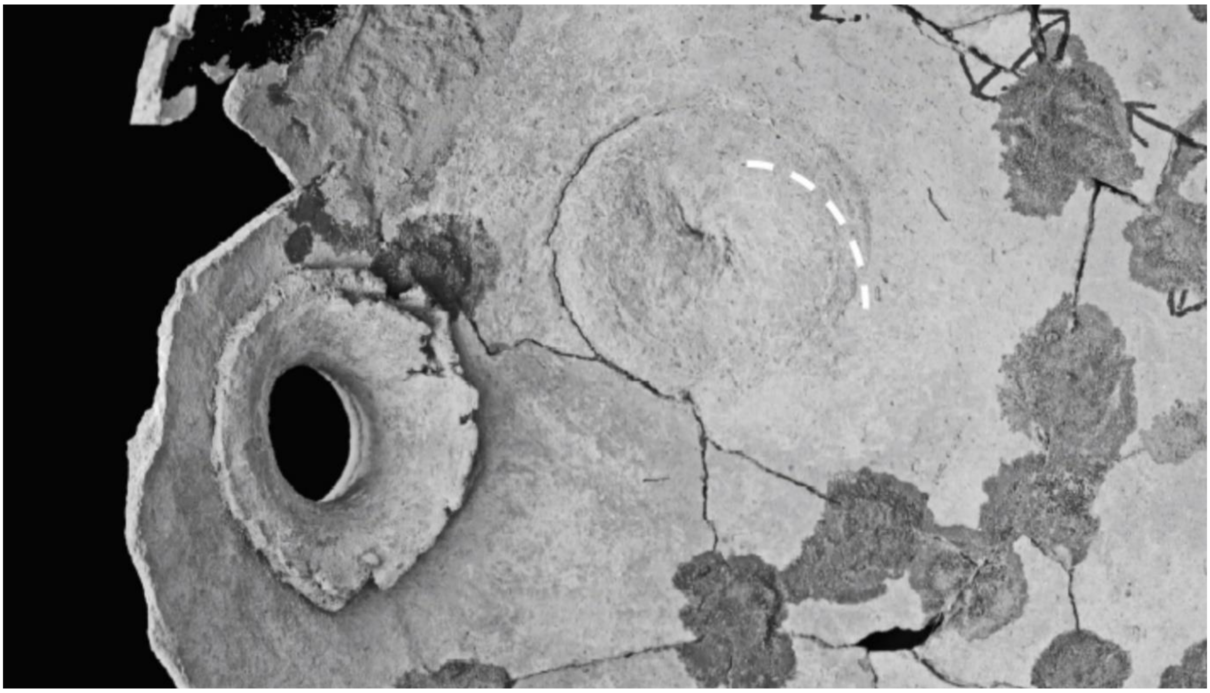
Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
59	V1.2 receiver / condenser "V2.1 distiller" (Iori 2018, pp. 249, 274)	Receiver/ condenser, Gandhāra still	3rd c. CE (Olivieri 2020b, pp. 38–41)	Late Kushan (Olivieri 2020b, pp. 38–41)	Trench BKG 4, Room 21, Layer 30, Structural period VIII, Macrophase 5 (Callieri 2020, p. 549)	Form 1725, partially complete "1725 BKG 421 (30) VIII/5 V1.2 Condenser. Plain top; gritty bottom. Oblique lateral mouth, round (flat) rim. Thick concave base." (Callieri 2020, p. 549)
60	V1.2 receiver / condenser "V2.1 distiller" (Iori 2018, pp. 249, 274)	Receiver/ condenser, Gandhāra still	3rd c. CE (Olivieri 2020b, pp. 38–41)	Kushan - Late Kushan (Moscatelli et al. 2016, p. 52)	Trench BKG 11 Temple B Macrophase 5b (Olivieri 2020b, p. 192) Trench BKG 11 Temple B, Court 1710 Macrophase 5 (Olivieri 2020b, p. 191)	Trench BKG 11 (Temple B) (Olivieri 2020b, p. 192) "…perfectly matches the coeval ones collected from the Kushan and late Kushan layers of Shaikhan-dheri…" (Moscatelli et al. 2016, p. 52) Condenser in situ "in Court 1710" (Moscatelli et al. 2016, p. 59) "Close to the tank, a distiller was documented in situ" (Olivieri 2020b, p. 35)
61	V1.2 receiver / condenser "V2.1 distiller" (Iori 2018, pp. 249, 274)	Receiver/ condenser, Gandhāra still	2nd c. BCE – 1st c. CE (Olivieri 2020b, pp. 38–41)	Indo-Greek (Callieri 2020, p. 549)	Trench BKG 5 Room 26 Layer 2768 Structural period III Macrophase 3a (Callieri 2020, p. 549)	Related to form 1725, partially complete (Callieri 2020, p. 549) "Condenser. Plain top; gritty bottom. Oblique lateral mouth, round (flat) rim. Thick concave base." (Callieri 2020, p. 549)
62	V1.2 receiver / condenser "V2.1 distiller" (Iori 2018, pp. 249, 274)	Receiver/ condenser, Gandhāra still	1st c. BCE-1st c. CE; 1st-2nd c CE (Olivieri 2020b, pp. 38–41)	Saka-Parthian (Callieri 2020, p. 549)	Trench BKG 5 Room 17 Layer 2773 Structural period IV Macrophase 4	Related to form 1725, partially complete (Callieri 2020, p. 549) "Condenser. Plain top; gritty bottom. Oblique lateral mouth, round (flat) rim. Thick concave base." (Callieri 2020, p. 549)
63	V1.2 receiver / condenser "V2.1 distiller" (Iori 2018, pp. 249, 274)	Receiver/ condenser, Gandhāra still	4th c. CE (Olivieri 2020b, pp. 38–41)	Kushan-Sasanian/ Post-Kushan (Olivieri 2020b, pp. 38–41)	Macrophase 6	"One specimen from BKG 11 Macrophase 6" (Olivieri 2020b, p. 192) Photograph or drawing(?) in Olivieri (2014)

Manufacture and fabric

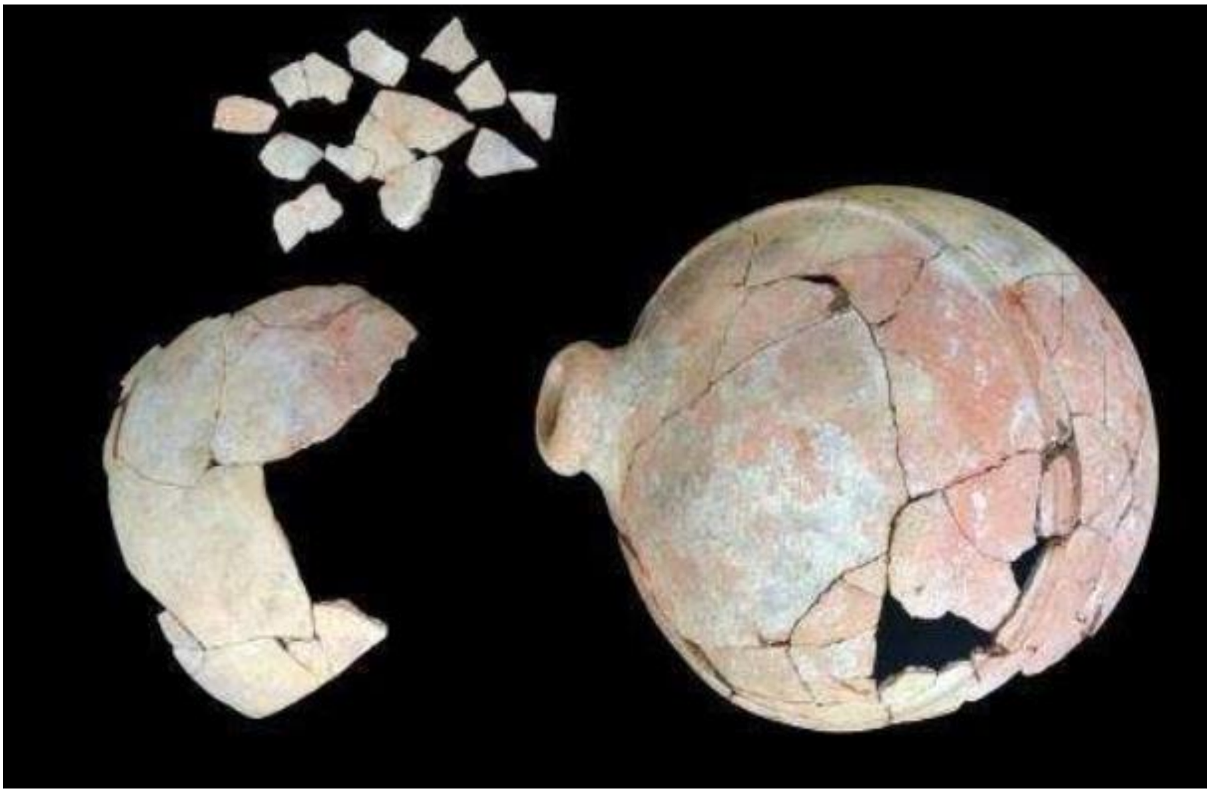
- V1.1 - Y/Bf coarse pottery, lime ,mica, quartz, few organics, non-slip wheel-thrown, mouth applied separately (Callieri 2020, p. 549)
- V1.2 - Y/P coarse pottery, joining two halves through moulding, mouth wheel-thrown and attached separately (Olivieri 2020b, p. 191); wheel-made red-slipped red ware (Moscatelli et al. 2016, p. 52); Y coarse, lime, mica, quartz inclusions, not slipped, coiling, moulding, mouth applied (Callieri 2020, p. 549)
- V1.3 - Red ware, O/R, lime, mica, quartz inclusions, slip(?), coiling and ring applied (Callieri 2020, p. 549)
- MV8 - O fine ware, thick red slip, handmade (Callieri 2020, p. 582)

Drawings and photographs

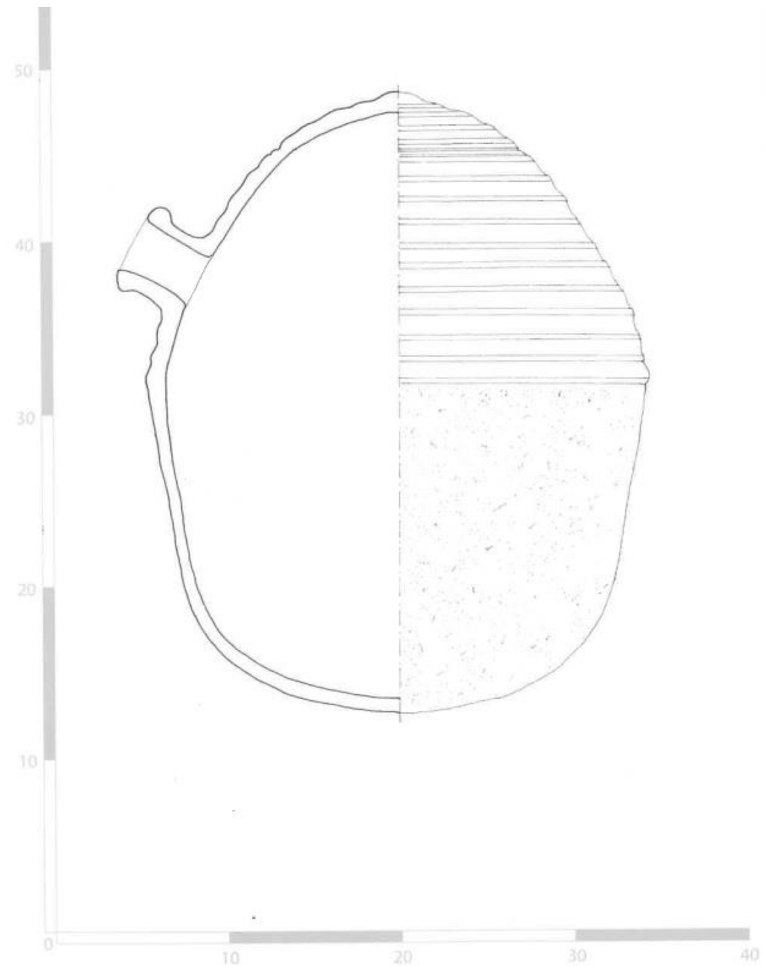
1. Condenser from BKG 11 (photograph by C. Moscatelli and E. Iori (in Moscatelli et al. 2016, p. 61; Olivieri 2020b))



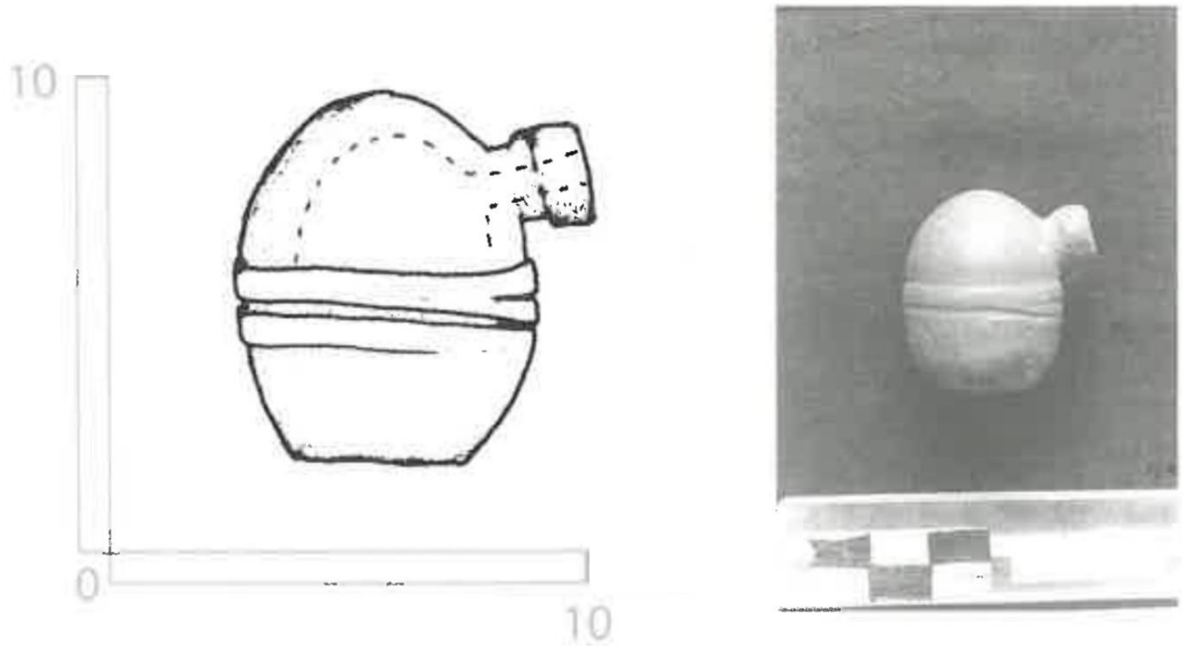
2. Interior of condenser from BKG 11 Temple B (photograph by C. Moscatelli (in Olivieri 2020b))



3. All fragments of condenser from Court 1710 (photograph by E. Iori (in Moscatelli et al. 2016))



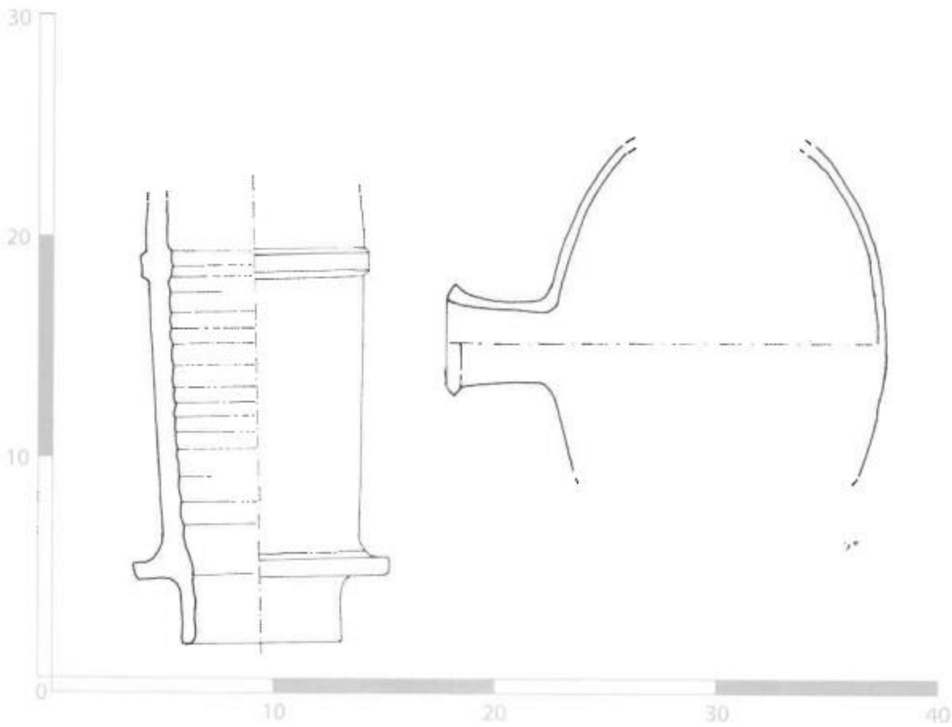
4. Drawing of an example of a condenser that matches item 1411 (Callieri 2020, p. 549)



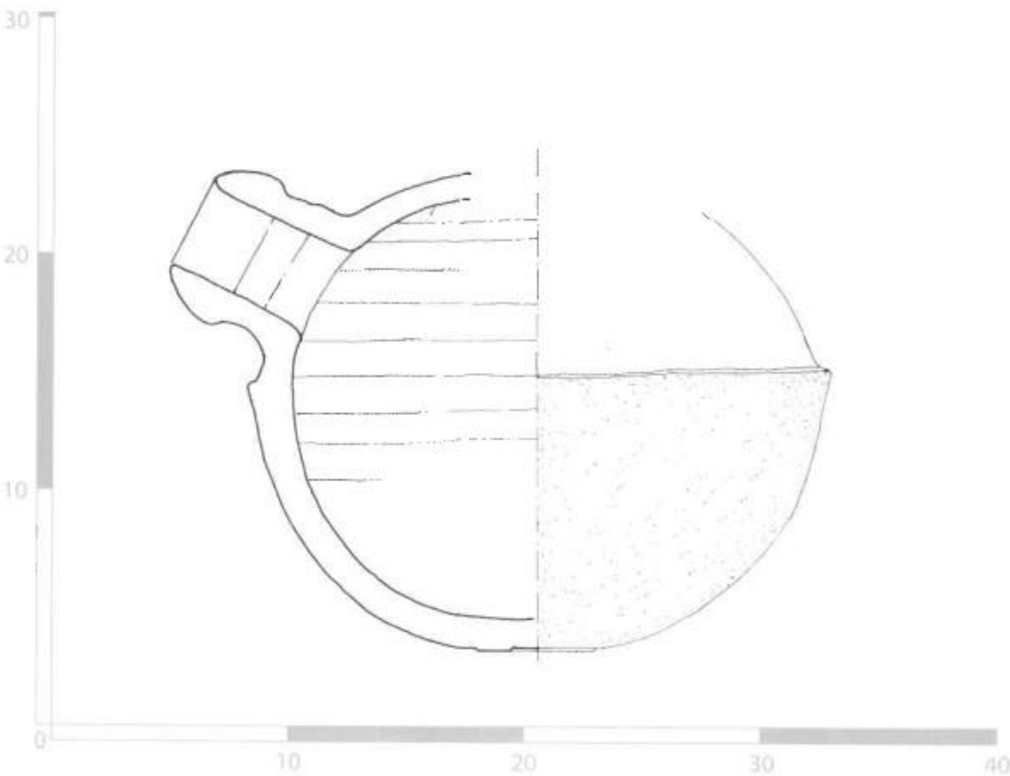
5. Drawing and photograph of “mini receiver” (photograph by Luca Maria Olivieri (Callieri 2020, p. 582)).

6. Spout with *tanga* stamp on BKG 917 (photograph by P. Callieri (Callieri 1990, p. 686)).

7. Condensing pipe (Form 1732) (photograph by E. Iori (Callieri 2020, p. 567))



8. Drawings of condensing pipe (Form 1732) and boiler (Form 298) (Callieri 2020, p. 550)



9. Drawing of receiver (Form 1725) (Callieri 2020, p. 550)

Context and description
Detailed evaluation of the Barikot material can be found in Chapter 4.

Bala Hisar, Charsada / Charsadda, Khyber Pakhtunkhwa, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
64	Spouted vessel or water jar, receiver	Gandhāra still	2nd - 1st c. BCE	Indo-Greek(?) Unknown	Unknown	"Receiver - spout of receiver" (Allchin 1979b, pp. 793–794) (Allchin 1979a, p. 61) Photograph (Husain 1980, pl. 6.1)

Manufacture and fabric
Unknown

Drawings and photographs

1. Husain's photograph of "…a receiver's spout lying on an exposed section of the Bala Hissar- Charsada." (Husain 1980, pl. 6.1).

Context and description
The Bala Hisar is recognised as the earliest city or settlement at Charsadda, its earliest phases dating to the beginning of the 1st mill. BCE (Ali et al. 1997, pp. 14–15). Historically, the site's chronology has been devised through historical accounts and ties to the campaign of Alexander the Great as outlined by Wheeler (1962), but effectively challenged and determined more recently (Coningham and Ali 2007; Olivieri 2020a). Intensified fortification of the site corresponds roughly to a point in the middle of the 1st mill. BCE and continued to be focus of activity through the 1st mill. CE (Ali et al. 1997, p. 15). Elements of Hellenistic material have been noted at the site, particularly a terracotta moulded head on jug identified as Alexander the Great dated to 2nd c. BCE (Callieri 1995, p. 300), contemporaneous to the ascribed period of an identified receiver spout (Allchin 1979b, pp. 793–794, 1979a, p. 61, Husain 1980, pl. 6.1). Aside from the single reporting citation and photograph of the receiver spout as found (Allchin 1979b, pp. 793–794, Husain 1980, pl. 6.1), the accuracy of the typological characterisation cannot be confirmed.

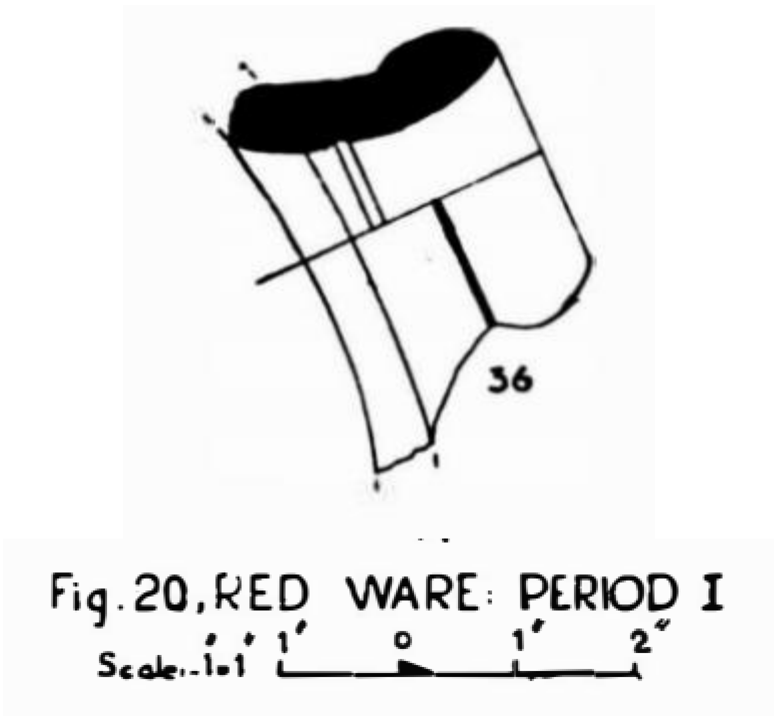
Damkot / Damkot Hill, Chakdara, Khyber Pakhtunkhwa, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
65	Narrow-mouthed vase with collared rim	Receiver, Gandhāra still	Up to and including 1st c. BCE	Pre-Scytho-Parthian (Rahman 1969, p. 108)	Period 1	"No. 36 – top of a narrow-mouthed vase" (Rahman 1969, pp. 194, 220) "Receivers- spout of receiver, red ware" (Allchin 1979b, p. 794) "Kushana (Kushan)" (Allchin 1979b, p. 794)

Manufacture and fabric

- No. 36 - Red ware, wheel thrown, no slip (Rahman 1969, pp. 194, 220)

Drawings and photographs



1. Rahman's drawing of *"Number 36. Top of a narrow-mouthed vase with collared rim.* (Rahman 1969, p. 220)*.*

Context and description

Damkot is seen to have its earliest occupation dated to the first half of 1st mill. BCE (Rahman 1969, p. 108). The pottery chronology during ascribed to the period is noted to be similar to that of the assigned Balambat III and Timargarha III phases of pottery typology at each site respectively (Rahman 1969, p. 218) though steadily went into decline. During roughly the 1st c. BCE – 1st c. CE, the site was then seen to be reoccupied by successive Scytho-Parthian and Kushan rulers (Rahman 1969, p. 109). It is to either this period or earlier that the receiver spout is recorded (Rahman 1969, p. 220; Allchin 1979b, p. 749). Allchin specifies the No. 36 form as a receiver at Damkot, though questions the assigned periodisation (Allchin 1979b, p. 749).

Aziz Dheri, Khyber Pakhtunkhwa, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
66	Unknown	Gandhāra still	c. 1st c. BCE	Indo-Greek or Indo-Scythian	Unknown	Condensers (no citation)

Manufacture and fabric
Unknown

Drawings and photographs
None

Context and description
The stūpa and settlement site of Aziz Dheri is one of the most sizeable anthropogenic features in the Gandhāra region that has been investigated archaeologically since 1976 (Nasim Khan 2007, pp. 71–72) and seen to display an uninterrupted cultural sequence from at least the Indo-Greek to the Islamic Period (Nasim Khan 2010a, p. 1, 2010b). Despite only ~10 % of the area being excavated (Nasim Khan 2010a, p. 1), the site's chronology has been established through Indo-Greek or Indo-Scythian (circa 1st c. BCE) to post-Kushan or Early Islamic numismatic evidence (Nasim Khan 2010b, pp. 2–3.) Summaries of trench allocations and catalogued finds have also been recorded (Nasim Khan 2010a, 2010b). Recovered from stratigraphic deposits and debris fills, the numismatic evidence is, however, subject to error through redeposition and incorrect stratigraphic and poor contextual recording (Nasim Khan 2007, p. 73, 2010b, pp. 1–2). Several 'condensers' have reportedly been recovered from Aziz Dheri (G. R. Khan, pers. coms. 10th June 2019), however this cannot be independently verified; excavations have been seldom published with a few exceptions as reports (e.g. Nasim Khan 2007) and a partial three volume catalogue (Nasim Khan 2010a, 2010b). The first volume of the series, however, with vital detail on the mixed material from the excavations (G. R. Khan, pers. coms. 24th July 2019) remains to come into fruition (as of March 2022). The published ceramics catalogue from Aziz Dheri (cf. Nasim Khan 2010a) equally does not display any prior attributed distillation apparatus forms.

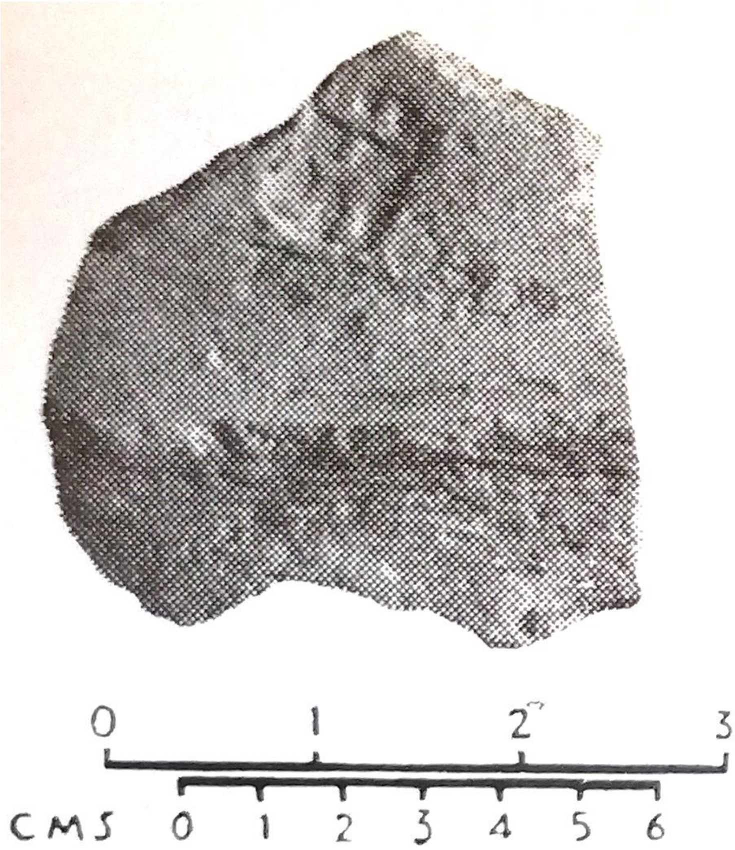
Tulamba, Punjab, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
67	Miscellaneous pot sherd with relief	Receiver, Gandhāra still	1st c. BCE – 3rd c. CE (Mughal 1967, p. 27) 6th – 7th c. CE (Allchin 1979b, p. 794)	Period IIB Greek / Indo-Greek (?) (Mughal 1967) Middle Kushan (Allchin 1979b, p. 794)	T1B-327, IA, Layer 38	"No. 1. – A pale-red ware piece, thick-bodied showing a crude human figure, perhaps impressed with a rectangular seal." (Mughal 1967, p. 58) Photograph (Mughal 1967, pl. 13) "Central seam of receiver with tanga impression (Allchin 1979a, p. 61)"
68	Jar	Receiver, Gandhāra still	1st c. BCE – 3rd c. CE (Mughal 1967, p. 27)	Period IIB Middle Kushan (Allchin 1979b, p. 794)	TLB IA, Layer 38 (Allchin 1979b, p. 794)	"No. 9 - Fragment of a jar" (Mughal 1967, p. 85) Drawing (Mughal 1967, fig. 26. No. 9) "Spout of receiver" (Allchin 1979b, p. 794)

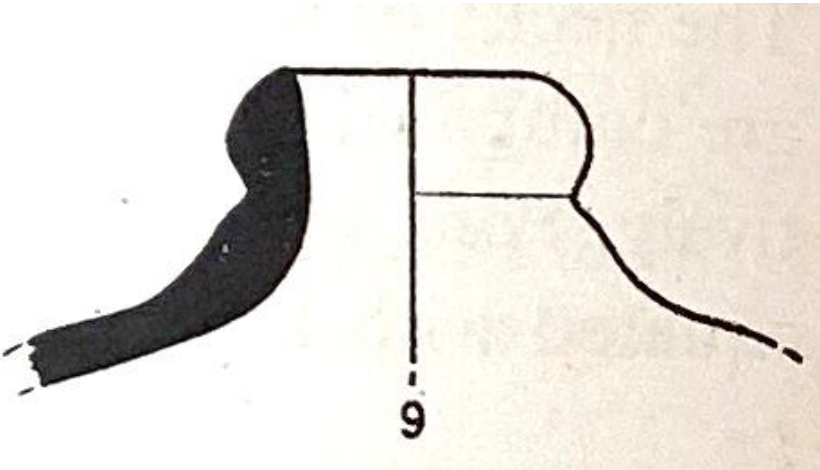
Manufacture and fabric

- No. 1: Pale-red ware, thick bodied (Mughal 1967, p. 58)
- No. 9: Pale-red ware, unevenly-fired, coarse fabric and externally-thickened rim (Mughal 1967, p. 85)

Drawings and photographs



1. Photograph of sherd No. 1 with stamp (Mughal 1967, Pl. XIII)



2. Drawing of rim sherd No. 9 (Mughal 1967, fig. 26)

Context and description

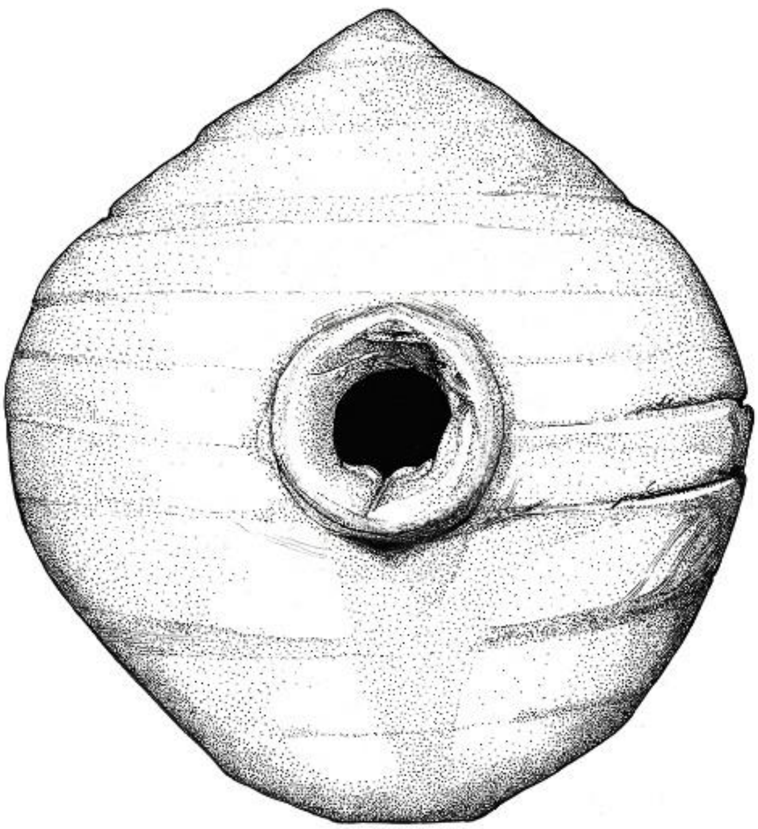
Excavations at the mound settlement of Tulamba between 1963 and 1964 (Mughal 1967, p. 16) suggested that the site had an Indo-Greek foundation dating to at least the 2nd c. BCE (Mughal 1967, pp. 20–21). Further, the site displayed a similar phasing to that of Sirkap (Taxila) and Shaikhān Dherī with Indo-Scythian/Saka, Scytho-Parthian, and Kushan levels (Mughal 1967, pp. 27–28). Allchin (1979b, p. 794) claimed that both 'receiver-condenser' fragments are dated to the Kushan era, though Mughal (1967, p. 58) suggested that they could be Indo-Greek fragments.

Sahri Bahlol / Seri Bahlol / Sahr-i Bahlol, Khyber Pakhtunkhwa, Pakistan

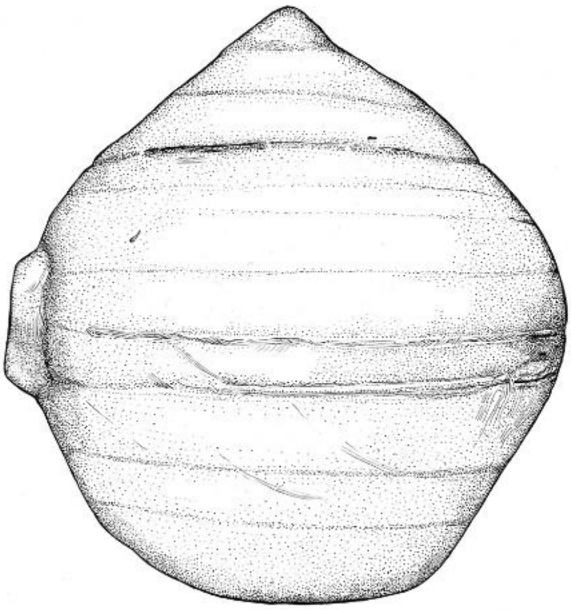
Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
69	Still container	Still, Gandhāra still(?)	3rd - 2nd c. BCE	Parthian(?)	Unknown	"Container (distilling?). Made of red slipware pottery (red)" (British Museum Catalogue 1880.1925)

Manufacture and fabric
- Red slip ware (British Museum Catalogue 1880.1925)

Drawings and photographs



1. Illustration of item 1880.1925 (front) (drawing by Maria Marinou)



2. Illustration of item 1880.1925 (front) (drawing by Maria Marinou)

3. Photograph of item 1880.1925 (from front) with scale (photograph by the author; by kind permission of the Trustees of the British Museum)

Context and description

The Buddhist monastic complex of Takht-i-Bahi and neighbouring city of Sahri Bahlol has been noted as occupied between 1st c. BCE and 7th c. CE, with the earliest cultural phases ascribed as Parthian and Kushan (UNESCO 2003, p. 91). The item was presumably found in the city area, though this cannot be confirmed. The apparatus is considerably smaller than other comparable examples and equally greatly differs morphologically than those at Taxila, Shaikhān Dherī, and Barikot. Allchin however noted that the form may share similarities with examples at Shaikhān Dherī and a preserved example in Peshawar University(?) (ALLCHIN-2, ref. Peshawar Uni.). The vessel reportedly comes from the site (though it is unclear where) and the original source of the collection cannot be established. The orientation of the vessel for distillation is unclear, as is how it would be possible to use, but drastically differs in form and size in comparison to any other example of apparatus. The vessel walls equally are considerably thinner than other examples, and the purpose of the exterior red slip in relation to distillation is not clear other than acting as a protective layer to help waterproof the vessel. Interior surfaces furthermore are not slipped, though it is possible that it has deteriorated. Equally, the collection's history is ambiguous, and its source has not been determined beyond an ascribed name.

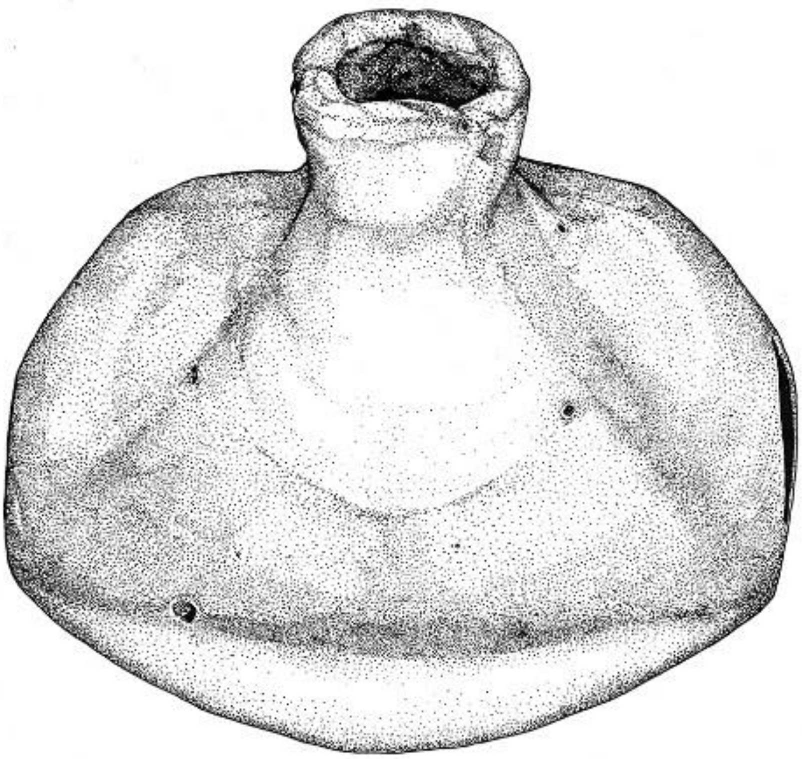
Akra, Bannou District, Khyber Pakhtunkhwa, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
70	Spouted vessel	Still	2^{nd} - 1^{st} c. BCE	Unknown	Unknown	"Spouted vessel, possibly used during the distilling process, made of red pottery and containing a pebble" (British Museum Catalogue 1880.3435)

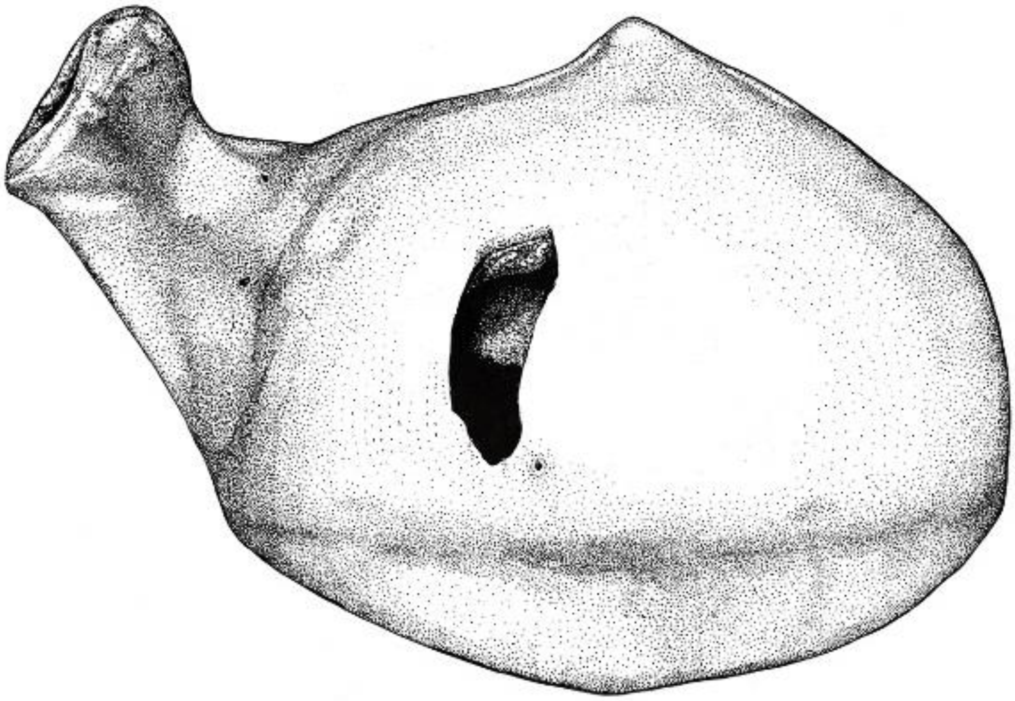
Manufacture and fabric

- Red pottery, exterior red slip(?) (British Museum Catalogue 1880.3435)

Drawings and photographs



1. Illustration of item 1880.3435 (front) (drawing by Maria Marinou)



2. Illustration of item 1880.3435 (side) (drawing by Maria Marinou)

3. Photograph of item 1880.3435 (from top) with scale (photograph by the author; By kind permission of the Trustees of the British Museum)

Context and description

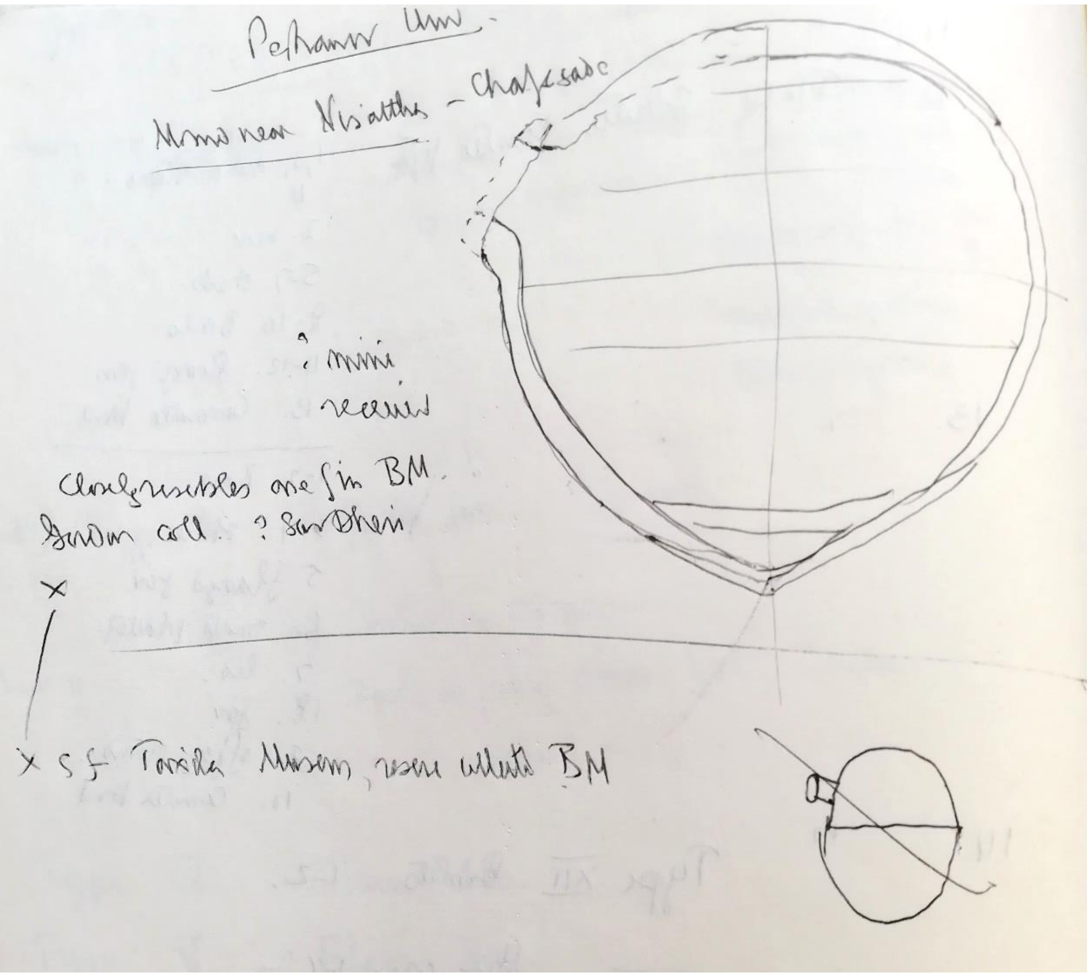
The Akra (Akara) mound is one of the largest historic sites in the Bannou region situated on the bank of the Lohra Nulla river that runs through the middle of the mound (Khan 1986, p. 184). It can be dated approximately to c. 250 BCE based on the presence of Indo-Greek coinage and equally has produced a pendant depicting Hercules (Khan 1986, p. 184). The vessel reportedly comes from the site (though it is unclear where) and the original source of the collection cannot be established. The orientation of the vessel for distillation is unclear, as is how it would be possible to use, but drastically differs in form and size in comparison to any other example of apparatus. The vessel walls equally are considerably thinner than other examples, and the purpose of the exterior red slip in relation to distillation is not clear other than acting as a protective layer to help waterproof the vessel. Interior surfaces furthermore are not slipped, though it is possible that it has deteriorated. While a rough 2nd-1st c. BCE date range has been noted, it cannot be confirmed as the context by which they were collected and stored is undetermined, through the exterior red slip is consistent with other 2nd c. BCE Indo-Greek examples from Gandhāra (see Iori 2018; Callieri 2020; Olivieri 2020b).

Unknown location, Khyber Pakhtunkhwa, Pakistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
71	Mini receiver	Receiver, Gandhāra still	Unknown	Unknown	Unknown	(ALLCHIN-2, ref. Peshawar Uni)

Manufacture and fabric
Unknown

Drawings and photographs



1. Sketch by Allchin (ALLCHIN-2, re. Peshawar Uni) of a ‘mini receiver’ (by permission of the Ancient India and Iran Trust).

Context and description
Sketch of a ‘mini-receiver’ possibly held by Peshawar University. Notes by Allchin (ALLCHIN-2) connect it with an example in the British Museum, presumably Item 1880.1925 (British Museum Catalogue). It is unclear if this is an independent example of another item.

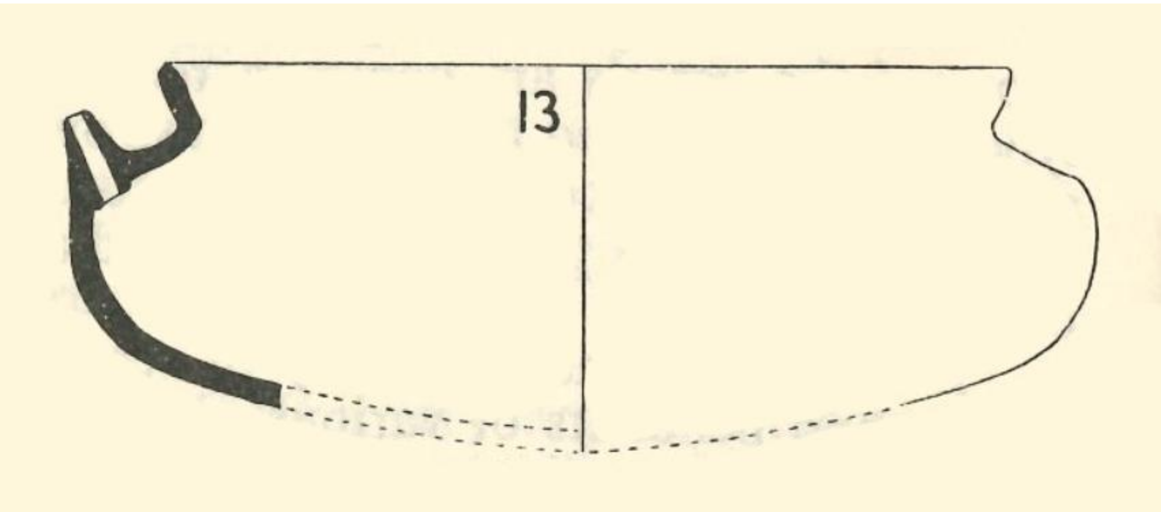
Ahichchhatra, Uttar Pradesh, India

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
72	Spouted (cooking?) vessel	Still head, Gandhāra still	300 – 200 BCE (Ghosh and Panigrahi 1946)	Unknown	Stratum VIII (Ghosh and Panigrahi 1946, p. 40)	Type 13 "…found with a burnt base… a short slightly out-turned rim and a small spout probably meant as an outlet for vapour." (Ghosh and Panigrahi 1946, p. 43) Drawing (Ghosh and Panigrahi 1946, p. 42) Still head interpretation (Mahdihassan 1972, p. 165)
73	Lipped bowl	Still head, Gandhāra still	100 – 350 CE (Ghosh and Panigrahi 1946)	Unknown	Stratum IV (Ghosh and Panigrahi 1946, p. 40)	Type 34 "lipped bowl" (Ghosh and Panigrahi 1946, p. 46) Drawing (Ghosh and Panigrahi 1946, p. 44)

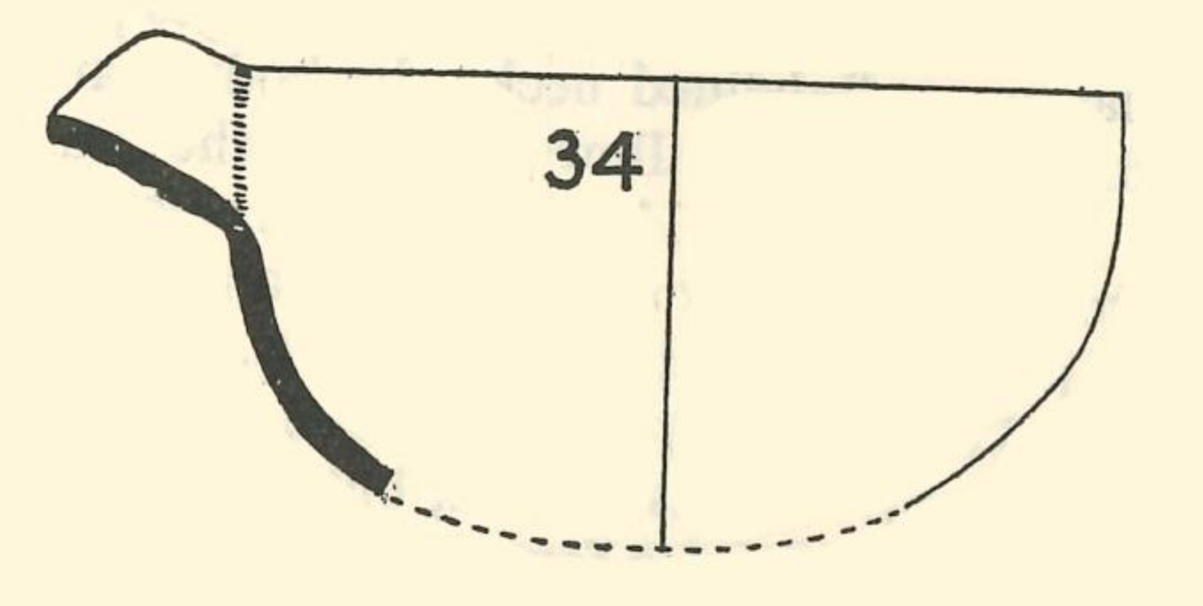
Manufacture and fabric

- Type 13 - light grey ware (?) (unclear/unspecified) (Ghosh and Panigrahi 1946, p. 43)
- Type 34 - Unspecified

Drawings and photographs



1. Ghosh and Panigrahi's Type 13 (1:4 scale from original print publication) (Ghosh and Panigrahi 1946, p. 42).



2. Ghosh and Panigrahi's Type 34 (1:4 scale from original print publication) (Ghosh and Panigrahi 1946, p. 44).

Context and description

The extensive historic city of Ahichchhatra was excavated and surveyed throughout the 1940s, though unlike many projects during this period, its pottery assemblage received detailed analysis from an early stage (e.g. Ghosh and Panigrahi 1946). Occupation of the site remained continuous from the last few centuries of the 1st mill. BCE (considered by some to not have a 'prehistoric' period (e.g. Ghosh and Panigrahi 1946, p. 38)) until 1100 CE. Two vessel forms from the assemblage (13 and 34) were deemed as suitable components of a distillation apparatus by Mahdihassan (1972, p. 165). Type 13 was originally described as "…cooking vessels in the early period… always found with short rims or no rim at all, a deficiency which must have been a serious handicap in use" (Ghosh and Panigrahi 1946, p. 43). Mahdihassan was critical of the original interpretation of Type 13 noting that where the spout originally was described as a vapour outlet was actually an "outlet for alcohol vapours" (Mahdihassan 1972, p. 165). According to Ghosh and Panigrahi, Type 34 "completely disappears in all the higher levels. It is perhaps strange that so convenient a device as the protruding lip should have been abandoned by the later potters, who are generally found to retain utilitarian devices of obvious value" (Ghosh and Panigrahi 1946, p. 46). Speculatively, the Ahichchhatra Type 34 is the same vessel as Wheeler's Brahmagiri Type 34 (cf. Wheeler 1948, p. 226), though Mahdihassan (1972, 1979) neither draws an explicit comparison between the two in reconstructing the apparatus nor references the morphological connection to the apparatus.

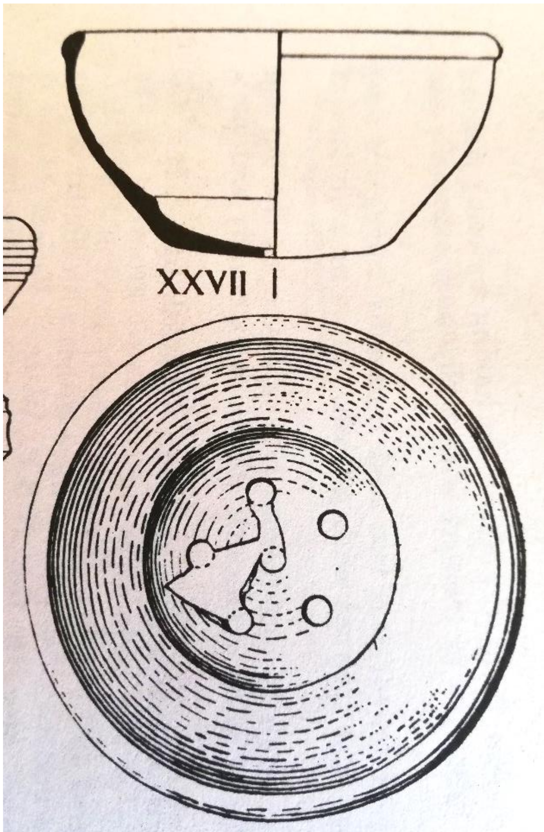
Hastinapura, Uttar Pradesh, India

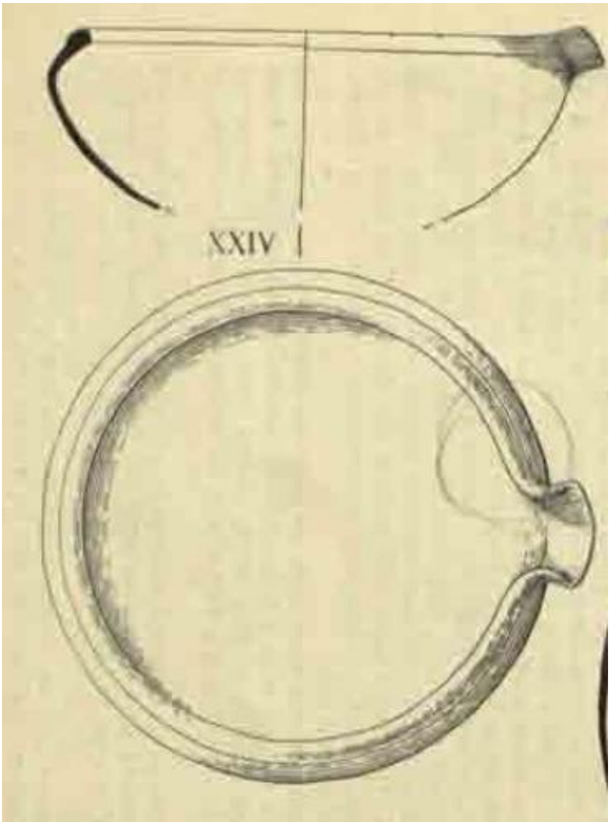
Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
74	Perforated vessel	Condensing area, vertical still	6th – 3rd c. BCE (Lal 1954)	Unknown	Mid-level Period 3 (Lal 1954)	"basin… with six perforations (Type 27)" (Lal 1954, p. 57) "Vertical still" (Mahdihassan 1972, pp. 165–166)
75	Bowl	Condenser, vertical still	6th – 3rd c. BCE (Lal 1954)	Unknown	Mid-level Period 3 (Lal 1954)	"basin…with an inturned externally round-collared rim (Type 24)" (Lal 1954, p. 57) "Vertical still" (Mahdihassan 1972, pp. 165–166)

Manufacture and fabric

- Type 27 / XXVII - grey ware, medium fabric (Lal 1954, p. 59)
- Type 24 / XXIV - grey ware, medium fabric with internal and external dark grey slip (Lal 1954, p. 57)

Drawings and photographs





1. Lal's drawings of Type 27 (left) (1:4 scale from original print publication) (Lal 1954, p. 58)
2. Lal's drawings of Type 24 (right) (1:4 scale from original print publication) (Lal 1954, p. 58)

Context and description

Dedicated excavations at Hastinapura began in the early 1950s. In response to previously established periodisations (cf. Gordon 1958; Wheeler 1959), the excavations partly aimed to determine the stratigraphic chronology of the characteristic painted grey ware (PGW) noted across Central and South-Central Asia, and delineate an ‘Iron Age’, proto-historic or early historic period (Lal 1954). Accordingly, since the first publication of the site excavations, the ceramic assemblage has acted as a comprehensive example of the remits and range of vessels ascribed to this period. From such a basis, a vertical distillation apparatus configuration was observed by Mahdihassan created by arranging and reconstructing vessels from the site (Mahdihassan 1972, pp. 162, 165, 1979), particularly reassigning what had previously been a vessel classified for washing rice as a condensing unit (Type 24) (Mahdihassan 1979, p. 265).

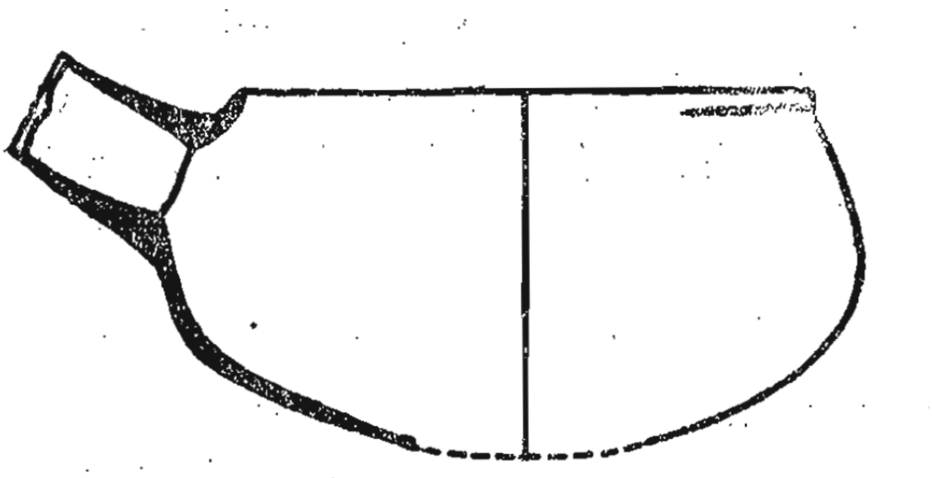
Brahmagiri, Karnataka, India

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
76	Spouted vessel	Still head, Gandhāra still	1st mil BC – 2nd c. BCE (Wheeler 1948)	Stone Axe Culture IA (Wheeler 1948)	Br 17, 21, 22, 23; Sub-phase IA (Wheeler 1948)	"Type 34 spouted vessel" (Wheeler 1948) "Cowl or hood of a still; domestic vessels linked to distillation kit" (Mahdihassan 1972, p. 165)

Manufacture and fabric

- Handmade and burnished, coarse grey fabric with thin terracotta-red slip (Wheeler 1948, pp. 222, 224).

Drawings and photographs



1. Wheeler's drawing of Type 34, ascribed to the Brahmagiri Stone Axe Culture IA (1:4 scale from original print publication) (Wheeler 1948, p. 226)

Context and description

Excavations at Brahmagiri began in 1945 by Mortimer Wheeler, which revealed megalithic tombs, stone axes, microliths, painted pottery, and other pottery groups in three main 'cultures' (Wheeler 1948, p. 181). Within the ascribed 'Stone Axe Culture IA' (early 1st mill. BCE – 2nd c. BCE) (Wheeler 1948, p. 202), Mahdihassan drew a connection between Wheeler's vessel group 'Type 34' and Marshall and Ghosh's still head/hood/cowl from Taxila, dating it as 300 years older (1972, pp. 165–166). Type 34 was a spouted vessel where spouts later became "a familiar feature throughout the 'IB' phase of the Brahmagiri Stone Axe culture" (Wheeler 1948, p. 224)). For Mahdihassan, the Type 34 at Brahmagiri was undeniably a part of a Taxila-style distillation apparatus based on a comparison of drawings. However, the chronological and stratigraphic disparities between the two sites challenges such an association. Equally, it is worth noting the differing spout lengths, concave profiles, and angle of spouts between both items.

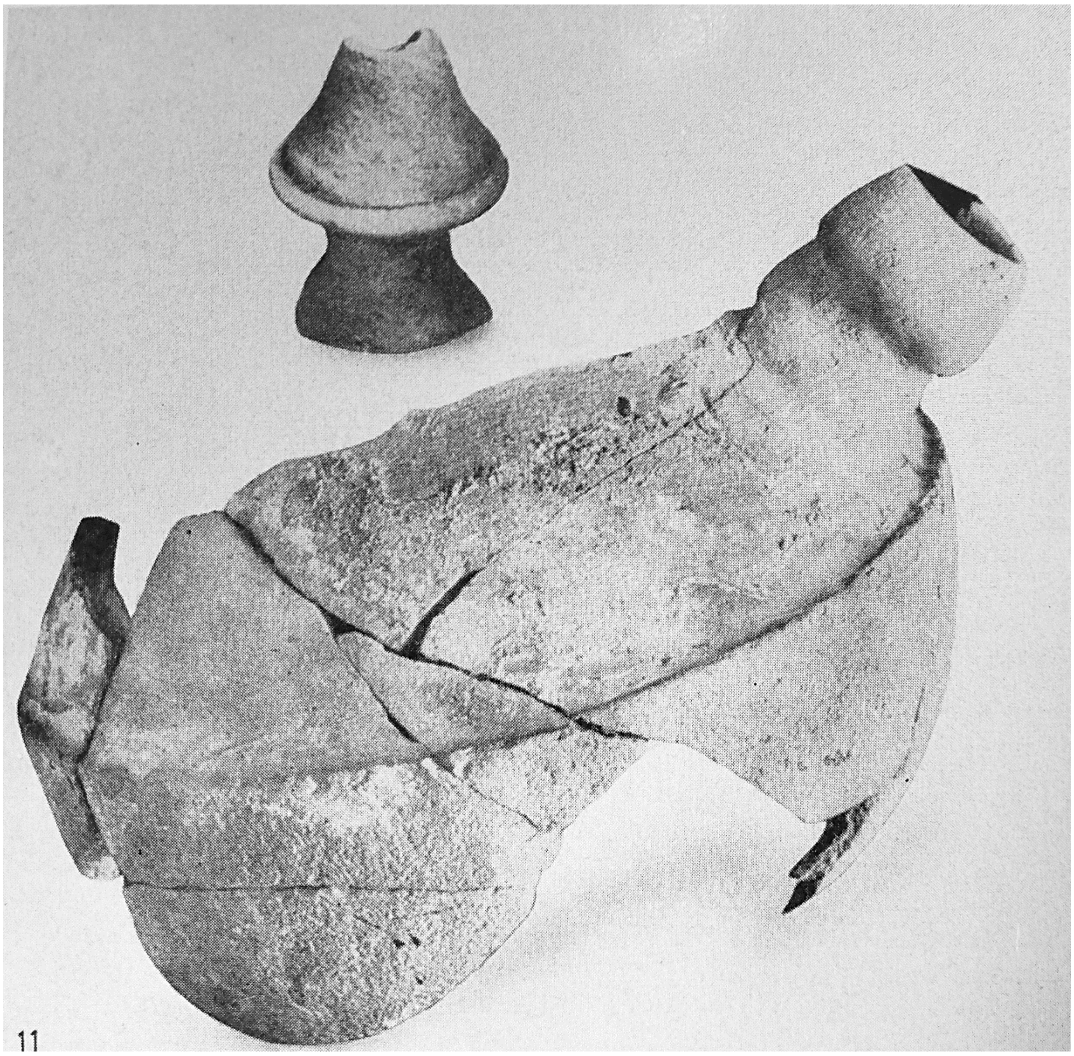
Rang Mahal, Rajasthan, India

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
77	Spouted jar	Receiver, Gandhāra still	2nd - 1st c. BCE (Rydh 1959) **1st c. CE** (Allchin 1979b, p. 771)	Late Kushan(?)	Trench 1, Square B10 (Rydh 1959)	"Spouted jar, variant 4l " (Rydh 1959, p. 110) 'Receiver' (Allchin 1979b, p. 61)

Manufacture and fabric

- Variant 4I - Red ware, wheel thrown

Drawings and photographs



1. Photograph of a spouted jar (no scale) (Rydh 1959, pl. 48, No. 11)

Context and description

The larger site within the double-mound settlement of Rang Mahal in northern India was primarily excavated by the Swedish Archaeological Expedition in the 20th century, denoting three major settlement periods derived from its pottery sequence (Rydh 1959, p. 43). As one of the more complete 'receivers' in the catalogue, the Kushan example was fully contextualised, however little is discussed regarding its in situ location and morphological relationships the vessel shares with other examples outside of Rang Mahal (cf. Rydh 1959, pp. 146–147). The archaeological features within the area do not fully correlate with those at other sites where receivers are found (e.g., Shaikhān Dherī and Barikot), though shares the closest resemblance with Kushan examples from Barikot in terms of the spout angle and its position on the vessel wall. No scale is provided with the Rang Mahal example to compare with those found at other sites.

Begram / Bagram (Ancient Kapisi / Kâpici), Parwān Province, Afghanistan

Item	Original classification	Ascribed use	Date range	Original ascribed period	Stratigraphy	Description (with original citation(s))
78	Churn(?)	Receiver, Gandhāra still	2^{nd} - 1^{st} c. BCE(?) (Ball et al. 2019)	Greek or Scytho-Parthian(?) (see Ball et al. 2019)	Unknown	"BG 314 - Churn(?)... decorated with two incised lines… height 21.4 cm(?), width at base 24(cm?)" (Ghrishman 1946, p. 193) Receiver (Allchin 1979a, p. 61)
79	Churn(?)	Receiver, Gandhāra still	2^{nd} - 1^{st} c. BCE(?) (Ball et al. 2019)	Greek or Scytho-Parthian(?) (see Ball et al. 2019)	Unknown	"BG 358 - Churn(?)... decorated with two incised lines… height 21.4 cm(?), width at base 24(cm?)" (Ghrishman 1946, p. 193) Receiver (Allchin 1979a, p. 61)

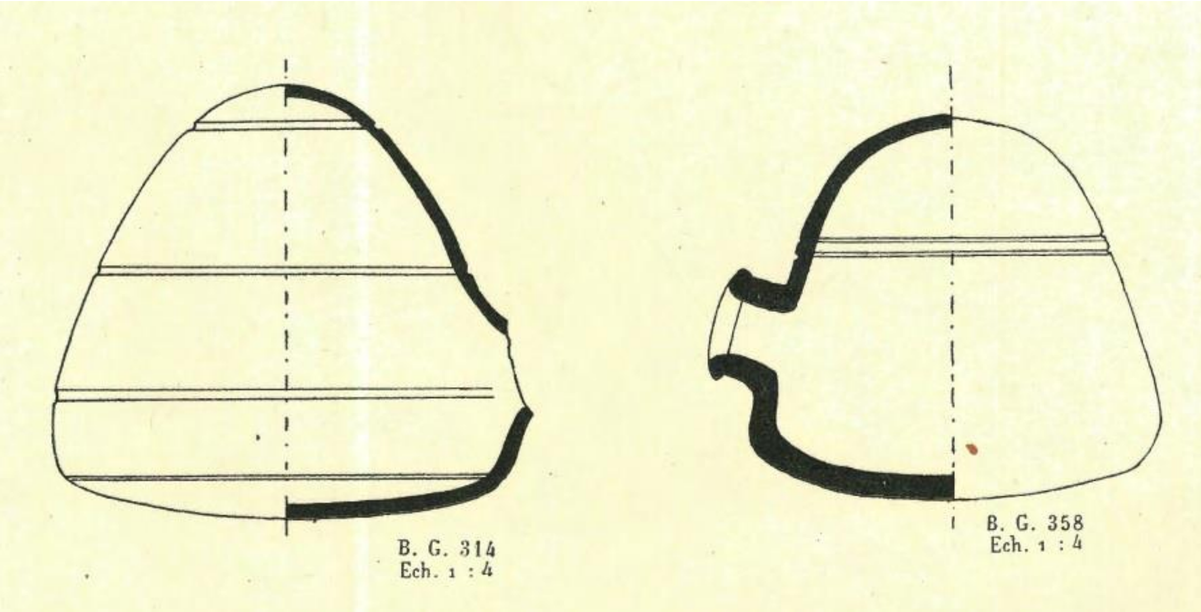
Manufacture and fabric

- BG 314 - Brown fabric
- BG 358 - Brown fabric

Drawings and photographs

1

1. Photograph of BG 358 (Ghrishman 1946, pl. XIV)



2. Drawings by Ghrishman (1946, pl. XXXVIII) (1:4 scale from original print publication).

Context and description

The earliest period of the site has been ascribed to 2nd c. BCE – 2nd c. CE (Ball et al. 2019, pp. 287–288). Grey-ware pottery in the phase reportedly parallels that of the lowest levels at Shaikhān Dherī (Greek and Scytho-Parthian phases) (Ball et al. 2019, p. 288). The recorded receivers were noted by Allchin (1979a, p. 61) and repeated Husain (1980, p. 141): an interpretation based on published material by Ghrishman (Ghrishman 1946, Pl. XXXVIII, No. 314, 358). The form differs greatly from other identified receivers-condensers, and the ascribed periodisation is unclear if it pertains to the vessels.

Appendix 1. Collated examples of ‘Hellenistic’ or ‘Greek’ pottery and ceramic, forms, imports, and influences from select sites in Gandhāra

Entries have been selected based on their interpreted Hellenistic connections with or influences on excavated examples from the Gandhāra region. Note that this is neither a comprehensive list nor a series of agreed interpretations or chronological phases. Items in **bold and highlighted** indicate a ware, form, or other grouping followed by individual examples listed below. Rough stratigraphic ascription (based on original reference) is given in ***“site, periodisation, and form notes”***. For further detail on the location and dimensions of items in the specific site, see given reference. ‘No. *x*’ where given indicates the form number allocated in the original reference.

Ware/form grouping and typology (as originally recorded, see reference); general pottery tradition or feature	Site, periodisation, and form notes	Reference
	Barikot / Bīr-koṭ-ghwaṇḍai	
Hellenistic/Mediterranean/Graeco-Bactrian pottery tradition (HPT) *(Tradition)*	“… rarer or unique forms subjected to a special finish (such as the very rare Black Metallic Ware) or forms of Hellenistic style such as the *plats-à-poisson* … or with specific characteristics (such as the ring-foot bases) or embossed or appliqued decorations. Key sites for HPT are Ai Khanum, Termez, Kuganzol, Uzundara etc.” (Olivieri 2020b, p. 105)	(Olivieri 2020b, p. 105)
Fine fabric G *(Feature)*	Indo-Greek Period, Periods IIIA2-4, Barikot “…very depurated grey fabric with only small infrequent organic inclusions characterised by a glossy thick black slip with directly recall the Hellenistic black glazed ware. This is attested only in Indo-Greek assemblage, occurring on quite thick walled luxury vessel mostly decorated with ribs and probably imitating metal prototype” (Iori 2018, p. 213)	(Iori 2018, p. 213)
Wet brushed or washed surface treated pottery *(Feature)*	Hellenistic / Graeco-Bactrian Period, Period IIIA2, Barikot “Wet brushing... has a shining effect due to the suspended mica… The practice is known since Period IIA2 when it is used a more dilute solution rather than that applied on dishes and bowls in Hellenistic period” (Iori 2018, p. 217)	(Iori 2018, p. 217)

Black-on-red decorated pottery *(Feature)*	Hellenistic / Graeco-Bactrian Period, Period IIIA2, Barikot "…Black-on-red painted decorations occur since Period IIA2 on both restricted and unrestricted vessels with geometrical and vegetal patterns, and in the Hellenistic periods it mostly decorates, but it is not limited to, the upper surface of horizontal projecting rims of hemispheric/sub-hemispheric bowls." (Iori 2018, p. 218) "In general, the decorative repertoire of the Black-on-red painted Ware, firstly attested at Barikot in Macrophase 2a.2, remains constant and does not reflect any Hellenistic taste" (Iori 2018, p. 311)	(Iori 2018, p. 218)
Group AA - dishes[46] **AA 3.1 - with everted rim (*plats-à-poisson*)** **Class OA - dishes** **Sub-class OA-f - dishes with everted sides and *plats-à-poisson***	Trench BKG K105, Barikot "…*plats-à-poisson* are the most frequent table ware in trench BKG K105… this is a table vessel of the Hellenistic Mediterranean tradition… quite diffused in the Hellenistic East… the forms at Barikot, which find their most direct comparison with materials from Charsadda IV and Barama Period 3, feature close parallels with Graeco-Bactrian assemblages especially with the sites of Ai-Khanoum, Termez and Balkh and with Hellenistic assemblage from Kandahar." (Iori 2018, Series OA-f) "The Hellenistic tradition in Macrophase 3a marks the introduction of the so-called *plats-à-poisson* (OA-f), which more direct comparanda comes from the Graeco-Bactrian assemblages from Ai-Khanoum, Termez and Bactria and from Hellenistic Margiana" (Iori 2018, 4.41)	(Olivieri 2020b, p. 93) (Iori 2018, Series OA-f)
OA-f2 - straight everted wall, with two lines incised inside OA-f2.1 - with vertical lip OA-f2.2 - with two incised lines below rim	(Iori 2018, Table 4.1, Unrestricted Forms)	
OA-f3 - with simple rim and vertical lip OA-f3.1 - rim sloping-in OA-f3.2 - flared wall OA-f3.3 - slightly convex wall	(Iori 2018, Table 4.1, Unrestricted Forms)	
OA-f4 - with triangular rim OA-f4.1 – elongated	(Iori 2018, Table 4.1, Unrestricted Forms)	

[46] During the course of this project, Olivieri (2020b) and Callieri (2020) published a comprehensive 'final' ceramic taxonomy building on, but replacing that of Iori (2018). While it has been attempted to corroborate the two systems, it is likely that there are overlaps and potential for error in delineating the various groups, classes, etc.

OA-f5 - with rolled rim	(Iori 2018, Table 4.1, Unrestricted Forms)	
OA-f6 - with tri-split rim	(Iori 2018, Table 4.1, Unrestricted Forms)	
OA-f7 - with pointed rim/lip internally projecting OA-f7.1 - slightly convex wall OA-f7.2 - bi-everted rim	(Iori 2018, Table 4.1, Unrestricted Forms)	
Class OB - bowls - *assiettes-à-poisson* **Sub-class OB-b - fine bowl with everted wall, flat base**	"Macrophase 3a attests the introduction of a new formal repertoire connected both to the Hellenistic tradition - indicated by the appearance of *assiettes-à-poisson*" (Iori 2018, No. Group OB-b) "A*ssiettes-à-poisson* are very close in terms of morphology to the *plats-à-poisson* from Macrophase 3a mentioned above, of which it represents its deeper version. It is usually difficult, except when the profile is well preserved, to distinguish between *plats* and *assiettes*. The main difference lays in the major inclination of the wall."	(Iori 2018, No. Series OB-b)
OB-b1 - with simple flat topped rim, inclined outside OB-b1.1 - rounded rim		(Iori 2018, Table 4.1, Unrestricted Forms)
OB-b2 - with triangular rim OB-b2.1 - rim roughly outlined OB-b2.2 - thick walled OB-b2.3 - vertical lip OB-b2.4 - slightly convex OB-b2.5 - slightly convex wall, rim roughly outlined		(Iori 2018, Table 4.1, Unrestricted Forms)
OB-b3 - with rolled rim		(Iori 2018, Table 4.1, Unrestricted Forms)
Class OB - bowls - fine bowls with round/hemispheric wall **OB-d - hemispheric bowls with horizontal projecting rim**	"Macrophase 3a attests the introduction of a new formal repertoire connected both to the Hellenistic tradition - indicated by the appearance of *assiettes-à-poisson* (OB-b), hemispheric bowls with horizontal projecting (OB-d) or sharp pointed rim (OB-e2) - and to a local pottery tradition (e.g. OB-g1 and sOB-h1)." (Iori 2018, Group OB)	(Iori 2018, Sereis OB-d)
OB-d1 - with horizontal strongly projecting rim OB-d1.1 - shallow body OB-d1.1.1 - rib on top of rim OB-d1.2 - thick walled OB-d1.3 - with slightly inclined rim OB-d1.4 - painted, carinated wall	(Iori 2018, Table 4.1, Unrestricted Forms)	(Iori 2018, Table 4.1, Unrestricted Forms)
OB-d2 - with flat bi-everted rim painted on top OB-d2.1 - shallow OB-d2.2 - rim slightly inclined outside	(Iori 2018, Table 4.1, Unrestricted Forms)	(Iori 2018, Table 4.1, Unrestricted Forms)
OB-d3 - with slightly horizontal projecting rim OB-d3.1 – flared	(Iori 2018, Table 4.1, Unrestricted Forms)	(Iori 2018, Table 4.1, Unrestricted Forms)

OB-d4 - with horizontal slightly projecting rim OB-d4.1 - flat topped rim OB-d4.2 - with groove below rim OB-d4.2.1 - carinated wall	(Iori 2018, Table 4.1, Unrestricted Forms)	(Iori 2018, Table 4.1, Unrestricted Forms)
Class OB - bowls **OB-e - fine hemispheric bowls**	"Macrophase 3a attests the introduction of a new formal repertoire connected both to the Hellenistic tradition - indicated by the appearance of *assiettes-à-poisson* (OB-b), hemispheric bowls with horizontal projecting (OB-d) or sharp pointed rim (OB-e2) - and to a local pottery tradition (e.g. OB-g1 and sOB-h1)." (Iori 2018, Group OB)	(Iori 2018, Series OB-e2)
OB-e2 - with pointed rim OB-e2.1 - sloping-in with incised line below rim OB-e2.2 - rounded rim	(Iori 2018, Table 4.1, Unrestricted Forms)	(Iori 2018, Table 4.1, Unrestricted Forms)
Class CD - Urns/*krater*-like forms **CD-a - S-shaped profile**		
CD-a3 - on stand	BKG L, Layer 8, Macrophase 3a-4, Barikot "an unicum at Barikot…This is the lower part of a *krater*-like vessel in grey ware internally and externally covered by a black slip. Unlike *kraters* from Ai-Khanoum, all wheel-turned in red ware, usually with red slip, the specimen from Barikot consists of a high wheel-turned foot and of a lower part mould-made then attached to an upper part by wheel throwing… the 'relaxed' profile of the foot suggests a 2nd century BCE chronology (Rotroff 1997, figs 607–608). Formal parallels can be made with Taxila and Ai Khanoum… Although no direct parallels can be found in Gandhāra or in the neighbouring areas, the Hellenistic origin of this vessel is quite evident." (Iori 2018, Class CD - urns/kraters; Pl. 77)	(Iori 2018, Class CD - urns/kraters; Pl. 77)
Group DP 4 - decorated potsherds, embossed DP 4.2 - Hellenistic		
Group V3 - pot-stands (*lásana*) **Group V8 - pot stands**		(Olivieri 2020b, pp. 128–129) (Iori 2018, Group V8)
V8.1 - Cylindrical stand	"Hollow cylindrical pot-stand, of the types known as 'amphora stands' or 'ring-stands', which appear at Barikot (BKG K-105 and BKG L)… This form seems to be introduced in Swat only in the Hellenistic period… (see earliest examples in Roger Edwards 1975: pl 25.644-645)" (Iori 2018, Series. V8.1)	(Iori 2018, Series V8.1)

Group V3 pot-stands (*lásana*) V8.2 - cooking stand (λάσανα (*lásana*)) or portable cooking tripod / *lásana* type	"…attested at Barikot in Saka-Parthian period… fabric of this object is medium to coarse with quartz particles. It is made of coils fashioned on a potter's wheel. Morris (1981, p. 394) described it as a 'standard' and long-lived element of the Greek domestic pottery repertoire. Its contexts stretch in date from early Iron Age to Hellenistic." (Iori 2018, Group V8)	(Olivieri 2020b, pp. 128–129) (Iori 2018, Series V8.2)
	Taxila	
Group A - plain ware **Class II - oil and wine vessels** **Type D - large amphorae of Mesopotamian or Graeco-Roman from**	"…few specimens imported from Western Asia, where the Graeco-Roman amphora was in common use" (Marshall 1951, p. 406)	(Marshall 1951, pp. 406–408)
Two-handled amphora of buff-coloured clay covered with a buff slip and thin glaze both inside and outside	Stratum II, Block F, Sirkap, Taxila "Parthian date" (Marshall 1951, p. 406)	(Marshall 1951, No. 14)
Handle and neck only of reddish coarse clay with heavy admixture of sand, cream coloured slip	Stratum II, Block C, Sirkap, Taxila	(Marshall 1951, No. 15)
Group A - plain ware **Class III - narrow-necked flasks for oil** **Type D - pear-shaped with flat bottom** **Type C - ovoid with drooping shoulder and flat base, like the Greek alabastra**	Greek shape (Marshall 1951, p. 401)	(Marshall 1951, pp. 408–409)
Pear-shaped flask with flat, ring base and loop-handle, set vertically on belly	Stratum IV, Block A', Sirkap, Taxila	(Marshall 1951, No. 19)
Of fine grey clay, with polished surface	Stratum III, Block E', Sirkap, Taxila	(Marshall 1951, No. 20)
Group A - plain ware **Class VIII - water bottles for transport**	"First introduced by the Greeks" (Marshall 1951, pp. 411–412) No explicit examples tied to this claim	(Marshall 1951, pp. 411–412)
Group A - plain ware **Class XIII - handled jugs** **Type C - jugs with two handles**	Greek shape (Marshall 1951, p. 401) "These small amphorae appear for the first time at Taxila in the Greek strata at Sirkap and are found fairly frequently in the Saka-Parthian strata. They are however of local manufacture. The larger wine amphorae did not make their appearance until Parthian times and were a foreign import." (Marshall 1951, p. 416)	(Marshall 1951, pp. 415–416)
Two-handled amphora with ovoid body and ring base	Stratum II, Block F, Sirkap, Taxila	(Marshall 1951, No. 81)

Two-handled amphora (?) with elliptical body and flat base	Stratum II, Block G, Sirkap, Taxila “Grooved bands at base of neck and shoulder. Light red clay mixed with sand and lime” (Marshall 1951, p. 416)	(Marshall 1951, No. 82)
Group A - plain ware **Class XIV - drinking cups, beakers and goblets** **Type B - beakers with deep-flared mouth, often constricted at neck, and flat base** **Type C - similar to type B, but with ring or standard base**	Greek shape (Marshall 1951, p. 401) “Beakers with deep-flared mouths frequently constricted at the neck were introduced by the Greeks and became popular under the Śakas and Parthians. Some of them are furnished with flat bases (Type B); others with ring and standard bases (Type C). Those with horizontal ribbing copied from metal prototypes (No. 91) appear to be characteristically Parthian.” (Marshall 1951, p. 416)	(Marshall 1951, pp. 416–417)
Tall beaker with deep flared mouth	Stratum II, Block E’, Sirkap, Taxila “Three grooved bands around neck. Flat base. Buff-red clay mixed with lime; dark red wash” (Marshall 1951, p. 416)	(Marshall 1951, No. 86)
Squat beaker with deep flared mouth and slightly constricted neck. Slightly inverted lip.	Stratum II, Block E, Sirkap, Taxila “Two grooved bands around neck. Fine red clay with dark red wash.” (Marshall 1951, p. 416)	(Marshall 1951, No. 87)
Squat beaker (?) with deep flared mouth and ring base	Stratum II, Trench A68I, Sirkap, Taxila “Grooved bands around neck. Slightly everted lip. Brittle red clay mixed with fine *bajrī* and lime; deeper red wash” (Marshall 1951, p. 416)	(Marshall 1951, No. 88)
Beaker with deep flared mouth	Stratum III, Block I, Sirkap, Taxila “Short standard foo. Thin walls of brittle red clay, well levigated. Deeper red wash… a very favourite type of standard beaker in the Greek and Śaka-Parthian period occurring in all the Sirkap strata down to an including the sixth.” (Marshall 1951, p. 416)	(Marshall 1951, No. 89)
Beaker with deep flared mouth and constricted neck	Stratum III, Block I, Sirkap, Taxila “… neck adorned with single grooved band. Standard foot… good red clay with darker wash” (Marshall 1951, p. 417)	(Marshall 1951, No. 90)

Beaker with deep flared mouth and constricted neck	Stratum II, Block C, Sirkap, Taxila "…horizontal ribbing round body, copied from metal prototype. Good red clay with dark red wash. Only one specimen of this particular type has been found." (Marshall 1951, p. 417)	(Marshall 1951, No. 91)
Group A - plain ware **Class XVI - pans, dishes and frying-pans** **Type B - circular flat dishes with concave sides and small everted lip and raised boss in centre, similar to Greek *phiale mesomphalos* = Roman '*patera clipeata*'** **Type C - frying-pans with one handle**	Greek shape (Marshall 1951, p. 401)	(Marshall 1951, pp. 418–419)
Of fine red clay with darker red wash. Thin bottom, evidently not meant to take any pressure. In centre, a raised boss or *omphalos,* such as is frequently found in Greek vessels of this class	Stratum II, Block D', Sirkap, Taxila "*Mesomphalos* dish of Greek pattern" (Marshall 1951, p. 190) "Broken specimens of the same kind have been found on the Bhir Mound as well as in Sirkap. Several specimens from the former site are made of grey clay finished with a darker grey wash (Pl. 124, no. 109)" (Marshall 1951, p. 418)	(Marshall 1951, No. 109)
Of red clay with same coloured wash. Decoration in imitation of metal wirework. The handle is hollow	Below surface, The Dharmarājikā, Taxila "Compare the copper and bronze frying-pans … (nos. 298-300) … including earthenware facsimiles from Eturia of third century B.C. The handles are provided with a projecting foot beneath." (Marshall 1951, p. 418)	(Marshall 1951, No. 110)
Handle only with small fragment of pan. Red clay with pinkish wash, sprinkled with mica. Hollow handle, decorated with bands and pellets in imitation of metal-work.	Below surface, The Dharmarājikā, Taxila "Note what appears to have been the handle of a vessel of this class is in the form of a phallus" (Marshall 1951, p. 419)	(Marshall 1951, No. 111)
Group A - plain ware **Class XXI - lamps** **Type D - rectangular or tortoise-shaped lamps with ornamental spouts**	Greek shape (Marshall 1951, p. 401)	(Marshall 1951, pp. 421–422)
Of grey clay with brick red wash. Hollow loop beneath spout	Stratum II, Block E, Sirkap, Taxila	(Marshall 1951, No. 139)

Tortoise-shaped lamp of buff-brown clay with darker wash.	Stratum II, Block E', Sirkap, Taxila "Atlant-like figure beneath the wick spout; second hole on top for filling. Two pierced lugs on each side (suggestive of the tortoise's feet) for suspension. The little Atlant is well modelled." (Marshall 1951, p. 422)	(Marshall 1951, No. 140)
Group A - plain ware **Class XXII - inkpots** **Type A - inkpots in the form of small vases with wide, partly covered-in mouths and usually with two lug-ears** **Type B - inkpots in the form of a small vase with contracted, well-defined neck and two lug-ears** **Type C - square-based inkpot, with square open reservoir at side**	Greek shape (Marshall 1951, p. 401) "… probable…they were introduced at Taxila by the Sákas in imitation of Greek metal ones" (Marshall 1951, p. 422) "A more developed but rare type of the Saka period (type c) is square-based" (Marshall 1951, p. 422)	(Marshall 1951, pp. 422–423)
Of red clay with traces of darker red wash. Flat, slightly depressed top, surrounded by low rim. Two lug ears	Stratum IV, Block F', Sirkap, Taxila	(Marshall 1951, No. 142)
Of fine red sandy clay; no wash. Convex top without lug-ears. Two small holes for fixing disk-cover over pen-hole	Stratum III, Block C' Sirkap, Taxila	(Marshall 1951, No. 143)
Of dark red sandy clay sprinkled with mica. No wash. Carinated shoulder with cable band. Lug-ears broken; flat base	Stratum II, Block A, Sirkap, Taxila	(Marshall 1951, No. 144)
Of pale red clay. Additional rim round pen-hole	Stratum II, Trench H19, Sirkap Taxila	(Marshall 1951, No. 145)
Red clay with darker red wash. Flat standard base	Stratum I, Block B, Sirkap, Taxila	(Marshall 1951, No. 146)
Of buff-red clay with thin wash, roughly made. Relatively narrow neck without over. Two loop-shaped lugs.	Below surface, Cell 3, Jauliān, Taxila	(Marshall 1951, No. 147)
Of fine red clay. The three outer sides of the inkpot are relieved with half-lotus patterns	Stratum III, Block D', Sirkap, Taxila	(Marshall 1951, No. 148)
Another small bath-shaped vessel of terracotta may also have served as an inkpot. It has a handle projecting from the flat end, and a circular disk attached to the rim above the handle	Stratum II, Block F', Sirkap, Taxila	(Marshall 1951, No. 149)
Group A - plain ware **Class XXIV - miscellaneous vessels and other objects** **Type C - rhytons**	Greek shape (Marshall 1951, p. 401) "Probably used as incense burners" (Marshall 1951, p. 424) "Of Parthian period" (Marshall 1951, p. 424)	(Marshall 1951, p. 424)

Of coarse sandy, grey clay mixed with much *bajrī.*	Stratum III, Block 1, Sirkap, Taxila "In another specimen … the rhyton is solid except for a shallow bowl-shaped depression on the top. A third … has a small loop-handle on each side instead of one side only and is straight instead of bent. All are of Parthian period." (Marshall 1951, p. 424)	(Marshall 1951, No. 157)
Group B - painted and glazed ware **Class XXX - local red-and-black painted ware**		(Marshall 1951, pp. 430–432)
Two handled amphora of Greek shape	Below surface, Mahal, Sirkap, Taxila "One handle missing. Fine light red sandy clay; dark red slip. Three bands of painted decoration: one of hatched chevrons on shoulder below neck; the others, below the shoulder, of network and double loops or swags." (Marshall 1951, p. 431)	(Marshall 1951, No. 221)
Group B - painted and glazed ware **Class XXXII - Greek black ware**	Foreign ware (Marshall 1951, p. 401) "The ware is pure Greek. Whether it was imported or made at Taxila is uncertain." (Marshall 1951, p. 432) "… other fragments from the Bhir Mound are all plain but highly polished." (Marshall 1951, p. 433)	(Marshall 1951, pp. 432–433)
Two fragments of a large mixing bowl (*krater*).	Stratum I, Bhir Mound, Taxila " One piece belongs to the body of the bowl and is decorated in relief with a conventional fluted leaf pattern or lotus and a bead-and-reel border. The other is the lower half of one of the handles. It is composed of three stems in one, and is adorned at the base with a head of Heracles, or, perhaps of Alexander the Great in the guise of Heracles, wearing the lion's skin. The clay is blackish grey and mixed freely with sand, the slip brownish red; the paint grey-black without varnish. Pls. 130, e, f; 204 a" (Marshall 1951, p. 433)	(Marshall 1951, No. 226)
Fragment perhaps from the neck of the vase [No. 226].	Stratum II, Bhir Mound, Taxila "The paste and techniques are in all respects similar [to No. 226]. Decorated with a stamped rosette in relief." (Marshall 1951, p. 433)	(Marshall 1951, No. 227)

Fragment of bowl with flared rim decorated with lotus pattern in Greek black ware	Stratum IV, Bhir Mound, Taxila “Thin black paste well burnt; black paint, highly varnished. The design is convex on the outer side, concave on the inner. Evidently a ‘stray’ from one of the later strata”	(Marshall 1951, No. 228)
Group C - incised, embossed, applique and rustic wares **Class XXXV - embossed and stamped ware** **Type A - Hellenistic** **Type B - Local embossed ware with figural designs, in imitation of Hellenistic moulded ware**	Foreign ware (Marshall 1951, p. 401) “…earliest embossed ware found at Taxila comes from the Bhir Mound and is definitely Hellenistic in character.” (Marshall 1951, p. 434) “The examples of Hellenistic moulded ware… may have been either imported or made, possibly with the help of imported dies or moulds, at Taxila itself” (Marshall 1951, p. 435)	(Marshall 1951, pp. 434–435)
Fragmentary water-bottle of pale pink clay	Stratum III, Bhir Mound, Taxila “Both sides are decorated with a moulded design consisting of a central medallion surrounded by a vine-scroll with a roulette boarder on the outside” (Marshall 1951, p. 434)	(Marshall 1951, No. 234)
Fragment(?)	Stratum III, Bhir Mound, Taxila “… of light red clay finished with a darkish red slip on the outside and decorated with roulette bordering, running spirals and floral scrolls” (Marshall 1951, p. 434)	(Marshall 1951, No. 235)
Fragment(?)	Stratum III, Bhir Mound, Taxila “… coarser fragment [compared to No. 235] … is of sandy red paste sprinkled with mica, with a pinkish red wash on the outside. Its decoration consists of a repeat of simple almond-shaped bosses in three or more rows round the shoulder of the vase, possibly in imitation of lotus-buds and evidently copied from encrusted or embossed metal-ware” (Marshall 1951, p. 434)	(Marshall 1951, No. 236)

Little shallow bowl with flared mouth	Stratum I, Bhir Mound, Taxila "… decorated on the outside only below the neck cordon with an ivy scroll centred with a medallion on the bottom. The paste of this bowl is fine red, moderately well burnt. The walls are thin. For shape, cf. the gold bowl in Dalton's *The Treasure of the Oxus, p 82 no. 18,* which is embossed with designs underneath, and the plain silver bowl in the same work, *p. 120 no. 180."* (Marshall 1951, p. 434)	(Marshall 1951, No. 237)
Small jar / small vase	Stratum II, Bhir Mound, Taxila "… the pattern, though equally Greek, is more formal, being constructed of parallel bands, each of a single motif repeated between the shoulder and neck… the clay of this small vase is light red with many impurities… Hellenistic embossed ware of the same character as that found in the Bhir Mound is also found in the lowest strata of Sirkap." (Marshall 1951, p. 434)	(Marshall 1951, No. 238)
Fragment of bowl, fine red paste with light red wash	Stratum V, Block A, Sirkap, Taxila "… decorated with vine and other floral patterns in moulded relief" (Marshall 1951, p. 435)	(Marshall 1951, No. 239)
Fragment of fine red clay with red wash	Stratum VI or V, Block I, Sirkap, Taxila "… part of a horse in low relief" (Marshall 1951, p. 435)	(Marshall 1951, No. 240)
Fragment of vase that which is evidently a local imitation of Hellenistic ware	Stratum V, Block A, Sirkap, Taxila "It is of good grey clay burnt to red on both faces with a palish red wash on the outside. On the convex outer face, which formed the shoulder of the vase, are two bands of figures in low relief with a chevron border above and debased egg-and-leaf pattern below. In the upper band are two warriors on horseback with lances in hand, while a third is standing in front of them holding a club or sword, and two others are leading their horses" (Marshall 1951, p. 435)	(Marshall 1951, No. 241)
Base of bowl	Dharmarājikā, Taxila "… the design is characteristically Indian … stamped with a medallion of a lion and elephant in relief…to be assigned to the first century B.C." (Marshall 1951, p. 435)	(Marshall 1951, No. 242)

Charsada		
Group B - Grey ware **Greek Period** **Type 2 - bowl**	Shaikhān Dherī, Charsada "Truncate-conical or rounded bowl/dish on ring or flat base resembling Hellenistic *plat-a-poisson"* (Iori 2018, p. 109)	(Dani 1966, p. 184)
Bowl, out-turned rim, hollow pedestal base and internally grooved circle	D1 (12), Shaikhān Dherī, Charsada	(Dani 1966, Fig. 12, No. 1.)
Bowl having out-turned bent rim with almost tapering rough sies, internally grooved and flat base	D1, (12), Shaikhān Dherī, Charsada "It is a new variety of Ghosh, Fig. 4 No, 4A." (Dani 1966, p. 184)	(Dani 1966, Fig. 12, No. 5.)
Group B - Grey ware **Scytho-Parthian Period** **Type 2 - bowl**	Shaikhān Dherī, Charsada	
Bowl with out-curved rim and rough flat base	A7' (8), Shaikhān Dherī, Charsada "Greek." (Dani 1966, p. 191)	(Dani 1966, Fig. 24, No. 5.)
Group B - Grey ware **Greek Period** **Type 2 - bowl**	Shaikhān Dherī, Charsada "Deep goblet with almost ovoid shape and upright sides" (Iori 2018, p. 109)	
Bowl, flat topped and club rimmed, externally grooved and with almost vertical neck	D1 (13), Shaikhān Dherī, Charsada	(Dani 1966, Fig. 11, No. 3.)
Group C - Red or reddish buff ware **Greek Period** **Type 2 - bowl**	Shaikhān Dherī, Charsada "Deep goblet with almost ovoid shape and upright sides… simple deep rounded bowls with upright rim and grooves on the upper body and flat base… akin to those from well E and Ch. I at Charsadda" (Iori 2018, p. 109)	
Bowl externally grooved at the neck, simple incurved rim, tapering sides and sagger base	A 10' (9), Shaikhān Dherī, Charsada "See Ghosh No. 10f and Wheeler Nos. 77 and 85" (Dani 1966, p. 185)	(Dani 1966, Fig. 14, No. 1.)
Grooved bowl with incurved rim	K9' (8), Shaikhān Dherī, Charsada "See Wheeler No. 248" (Dani 1966, p. 185)	(Dani 1966, Fig. 14, No. 3.)

Bowl with incurved rim and internally and externally grooved lower down at the body and flat base	K9' (8), Shaikhān Dherī, Charsada "See Wheeler No. 251" (Dani 1966, p. 185)	(Dani 1966, Fig. 14, No. 4.)
Bowl with incurved rim, eternally grooved at the neck and flat base	K9' (7), Shaikhān Dherī, Charsada "Compare Wheeler No. 249" (Dani 1966, p. 185)	(Dani 1966, Fig. 14, No. 5.)
Bowl with straight neck and simple rim and externally grooved, fabric (a)	K9' (8), Shaikhān Dherī, Charsada "See Wheeler No. 489" (Dani 1966, p. 185)	(Dani 1966, Fig. 14, No. 12.)
Tall thin bowl, straightened from shoulder upward, with hammer-headed rim, grooves at the rim and shoulder, fabric (a)	K9', (7), Shaikhān Dherī, Charsada	(Dani 1966, Fig. 15, No. 2.)
Group C - Red or reddish buff ware **Greek Period** **Type 2 - bowl**	Shaikhān Dherī, Charsada "Truncate-conical or rounded bowl/dish on ring or flat base resembling Hellenistic *plat-a-poisson"* (Iori 2018, p. 109)	
Simple bowl, tapering sides and flat base	B1 (12), Shaikhān Dherī, Charsada "See Ghosh No. 4C" (Dani 1966, p. 186)	(Dani 1966, Fig. 15, No. 8.)
Bowl, flanged rim, tapering sides and flat base	A11' (9), Shaikhān Dherī, Charsada "See Ghosh type 5" (Dani 1966, p. 186)	(Dani 1966, Fig. 15, No. 9.)
Variety A - Female figures **Type VII - "emblemeta" figurines on bowls**	Shaikhān Dherī, Charsada "Figurines embossed on the inside of the bowls by a mould" (Dani 1966, p. 65)	(Dani 1966, p. 65)
Fragment of a flat-based bowl, thin in section, with the embossed figurine of a lady	Trench A7' (5), Shaikhān Dherī, Charsada "Fired red" (Dani 1966, p. 65) "…embossed *emblema* on the bottom of bowls bearing female images in Hellenistic 'taste' were discovered at Shaikhān Dherī" (Iori 2018, p. 109)	(Dani 1966, p. 65, No. 166) (Dani 1966, Pl. XXXI)
plat-à-poisson	Bala Hisar, Charsada	
Small bowl of reddish ware with vertical flanged rim	"From Ch IV, Well E… Depth of 12 ft" (Wheeler 1962, No. 475)	(Wheeler 1962, No. 475)

Small bowl of reddish buff ware	"From Ch IV, Well E… Depth of 12 ft, similar to 475" (Wheeler 1962, No. 476)	(Wheeler 1962, No. 476)
Bowl of reddish ware with vertical flange-rim	"From Ch IV, Well E… Depth of 2-4 ft" (Wheeler 1962, No. 500)	(Wheeler 1962, No. 500)
Polished black amphora	Bala Hisar, Charsada	
Polished black amphora imitating metalwork	"From Ch IV, Well E… Depth of 2-4 ft… Note the imitations rivet-studs at the handle" (Wheeler 1962, No. 496)	(Wheeler 1962, No. 496)
Bowl with flat everted and painted rim	Bala Hisar, Charsada "…characteristic of the Indo-Greek phase at Shaikhān Dherī and Barikot" (Iori 2018, p. 87)	
Small bowl of red ware	"Ch. 1, layer 22 …horizontal rim painted in black with cross-hatched triangles" (Wheeler 1962, No. 206)	(Wheeler 1962, No. 206)
Small bowl of red ware	" Ch. 1, layer 22" (Wheeler 1962, No. 206)	(Wheeler 1962, No. 207)
Small bowl of red ware	"Ch. 1, layer 20… with hatched triangles in black paint on the flat rim" (Wheeler 1962, No. 237)	(Wheeler 1962, No. 237)
Gor-Khutree		
Hellenistic embossed red ware	Layers 14-18, Gor-Khuttree Hellenistic embossed red ware with floral motifs	(Durrani et al. 1997)

Appendix 2. Select secondary references to distillation and proto-distillation applications from early to historical periods

Date range	Application	Description	Reference(s)
4th mill. BCE	Perfume	Sumerian perfume references from cuneiform tablets	(Blass et al. 1997, p. 432)
3rd mill. BCE	Zinc	Brass reported from China in the 3rd mill. BCE	(Agrawal 2000, p. 204) (Kharakwal and Gurjar 2006, p. 140)
c. 3500 BCE	Perfume(?), Medical(?)	Mesopotamian apparatus able to enable herbal condensation, but largely is an assumption, considered 'fantastical' by some	(Blass et al. 1997, p. 432)
c. 2100 BCE	Perfume(?), Medical(?)	Mesopotamian clay tablet detailing method and recipe for elixir created through extraction methods	(Blass et al. 1997, pp. 432–433)
c. 2500 BCE	Perfume, Medical	Intensification of contact between Anatolia and Syria/Mesopotamia in last quarter of 3rd mill. BC causing the 'Syrian bottle' to emerge; bottles produced to transport perfumes, valuable oils, 'potions' for rituals	(Zimmermann 2005) (Alp 2018)
c. 2000 BCE	Zinc	Copper artefacts from Cyprus (c. 2000 BC) contain 3-5 % zinc (some registering 9 %) and bronze bowls from Nimrud with several percent of zinc indicate that zinc was clearly present in copper before deliberate tin alloying	(Agrawal 2000, pp. 204–206)
c. 1800 BCE	Perfume	Perfumery of King Zimrilim reputed to have employed distillation methods every month to produce hundreds of litres of balms, essences, and incense from cedar, cypress, ginger, and myrth(?). Possibly employed for embalming, medicinal purposes, and as cosmetics	(Reinarz 2014)
c. 15th c, BCE	Perfume	Minoan palace at Zakros, Crete: dry distillation and essences; middle-late 15th c. BC (LM IB); complex of eight workrooms and storage areas making up an 'industrial quarter' of sorts. Room XLVII – braziers on perforated stands, incense-burners, wide mouthed jars, special vessels interpreted as 'censers', but suggested by some as equipment for dry distillation or as a means to volatise aromatic essences over water, prior to be adding to oil; vessel type concentrated in Zakros also alongside other 'appropriate' vessels	(Shelmerdine 1985, pp. 57–58)
C. 1200 BCE	Perfume	Assyrian extraction processes for perfume making using oil and fats during the reign of Tukultininurta I – used for salves and creams	(Blass et al. 1997, p. 433)
c. 14th c. BCE	Perfume	Hebrew olive oil-based perfumes from 14th c. BCE with myrrh and cinnamon for religious ceremonies	(Brun 2000, p. 279)
8th – 7th c. BCE	Zinc	Brass produced in Asia Minor from 8-7th c. BC at Gordion, though by today's definitions, these are gilding metal rather than brass as they only have around 2% zinc	(Agrawal 2000, p. 204)
6th – 7th c. BCE	Perfume	Perfume trade spread from Corinth, Hellenisation saw 'democratisation' of perfume, extensive trade from Corinth from 7th c. BC represented by alabastron, aryballos, and lecythus perfume vases	(Brun 2000, pp. 277, 281) (Biers et al. 1994, pp. 31–32)
c. 800 – 600 BCE	Medicine	Apparatus for treating ontological problems is described in the *Samhita* by Sushruta utilising herb-extract steam delivered to the ear by a grass tube	(Manglik and Jog 2009, pp. 121001–8)
630-582 BCE	Perfume	Tel Goren furnaces, jars, metal and bone objects (630-582 BC) linked to perfume production	(Brun 2000, p. 279)
5th c. BCE	Perfume	Oil-based perfume shops common in Athens towards end of 5th c. BCE	(Brun 2000, p. 281)
c. 500 BCE	Medicine	*Rasarnavam Rastantram* medical text describe material and medical chemistry	(Manglik and Jog 2009, pp. 121001–6)
3rd – 4th c. BCE	Zinc	Zinc ore mining in Zawarmala 3rd – 4th c. BCE	(Kharakwal and Gurjar 2006, p. 144)

1st c. BCE	Mercury	Cinnabar retorted by distillation to produce mercury for gilding and amalgamation	(Brooks et al. 2017, p. 44) (Henderson 2000, p. 240)
1st c. BCE – 4th c. CE	Zinc	Literary accounts on zinc and zinc distillation – smelting of zinc detailed in Sanskrit texts on medicinal chemistry and alchemy	(Agrawal 2000, p. 210)
600 BCE – 700 CE	Zinc	Brass was apparently extensively produced in the Ayurvedic Period in India	(Joshi 1970, p. 30)
1st c. CE	Zinc	Cementation used to make brass by the Romans in the 1st c. CE	(Agrawal 2000, p. 205)
1st – 2nd CE	Alcohol	Distilled spirts may have dated to at least the 1st-2nd c. CE made during the Eastern Han Dynasty using an inefficient distillation apparatus	(Haw 2006, pp. 147–148)
3rd c. CE	Zinc	Galen describes how zinc was prepared by throwing a sulphidic zinc ore into a fire and collecting the vapour from above	(Henderson 2000, p. 234)
4th c. CE	Zinc	Indian scientist Nagarjuna (text written in 8th c. CE) record (the Rasaratnākara) of process of producing zinc	(Henderson 2000, p. 234) (Kharakwal and Gurjar 2006, pp. 153–154)
6th c. CE	Alcohol	Use of freezing of 'grape liquid' in Gaochang area of China spread throughout China after the Dynastic Conquests	(Gwei-Djen et al. 1972; Haw 2006, p. 148).
6th c. CE	Alcohol	Literary references to a frozen-wine presented to the imperial court in the 6th c. CE	(Gwei-Djen et al. 1972, p. 97)
7th c. CE	Zinc	Indian copper alloy analysis and Tibetan material analysis shows that brass was used widely from 7th c. CE onwards, and high-zinc brass was relatively common from 15th c. CE	(Craddock et al. 1983, p. 211) (Kharakwal and Gurjar 2006, p. 151)
7th c. CE	Alcohol	Jesuits in China (in 1780 AD) note the existence of an earlier 7th c. CE poem on brandy	(Gwei-Djen et al. 1972, p. 95)
7th – 10th c. CE	Alcohol(?), Mercury(?), Alchemical(?)	Tang Dynasty stone(?) medicine or distillate bottles found in Hejia, Xi'an in the 1970s have been proffered to be simple distillation units for alcohol, and formed in part early ideas on the production of shōchū by Dezhen (1988). Dezhen's interpretation on this however has been contested from a number of perspectives suggesting instead that the units were employed in mercury and alchemy rather than used for alcohol distillation.	(Dezhen 1988) (Jian 2016, p. 438)
640 CE	Alcohol	Presence of frozen-wine in the Chinese region of Turfan	(Gwei-Djen et al. 1972, p. 100)
c. 670 CE	Alcohol	Pen Tshao Kany Mu passages mention different sorts of grape wine; one from fermentation, another that is 'heated in a still head', and a 'frozen-out wine', particularly describing the preferred quality of the frozen-out wine.	(Gwei-Djen et al. 1972, p. 83)
700 CE	Zinc	An indication of zinc found in the Hellenistic phases of the Athenian Agora represented by a small rolled sheet of zinc has been confirmed by chemical and archaeological evaluation, dating the sheet to roughly c. 700 CE.	(Craddock 1998, p. 3) (Agrawal 2000, p. 206)
8th c. CE	Alcohol	Tang Dynasty literature is considered to reference shōchū (conceptualised as a distilled alcohol) in the 8th c. CE.	(Jian 2016, p. 438)
8th c. CE	Alcohol	Chinese and Mongols are considered in some regard to have distilled fermented horse milk to produce *karakumyss*. Further to this, later fermentations of rice, millet seed, and barley were also known to have been distilled.	(Kockmann 2014, p. 5)
820 CE	Alcohol	Chinese references that mention an understanding of certain aspects of the distillation process are limited an understanding of evaporation in conjunction with the storage of burnt wines or spirits that must be kept in sealed pots and pipetted out to not loose said product	(Gwei-Djen et al. 1972, pp. 89–90).
9th – 10th c. CE	Zinc	Records of Iranian imports of Indian *tutiya* - the 'vapour of tin' - has been interpreted as an indication of zinc, and thus an indication that zinc was imported into the region	(Kharakwal and Gurjar 2006, p. 154)

10th c. CE	Zinc	Fully-fledged zinc smelting probably occurred about the 10th c. AD in northwest India. Probably undertaken on a much smaller scale prior to this, though any zinc buried will have probably corroded because of the chemical reactivity of the metal and supposed surviving pieces have often been misidentified as lead or tin.	(Craddock 1998)
1036 – 1101 CE	Alcohol	Production of a wine from oranges made in China through condensing vapour.	(Gwei-Djen et al. 1972, p. 92)
11th c. CE	Zinc	Al-Birūni describes how zinc oxide was prepared by placing zinc ore on a fire in a furnace and the 'condensed' oxide was collected from bars made of clay suspended from above amongst other Iranian authors that describe the use of clay bars coated with zinc ores or made of zinc ore.	(Henderson 2000, p. 234)
12th c. CE	Alcohol	Ciphered manuscript the *Clef de la peniture* has been deemed to describe distilled liquors	(Berthelot 1883, p. 92)
12th c. CE	Alchemical	Specific structures- the alchemical oven- sat in a sacred house or cave with specific conditions (detailed in 12th c. CE works)	(Barnes 1934, pp. 656–657)
13th c. CE	Alcohol	References by Marcus Graecus to distilled wines	(Gwei-Djen et al. 1972, pp. 70–71)
13th c. CE	Zinc	Distillation processes mentioned in medieval alchemical works in the 13th c. CE - the *Ratnasmuchchaya* – describes *tirakpatnayantra*: "distillations by descending"	(Agrawal 2000, p. 205)
13th – 14th c. CE	Alcohol	Arnaud de Villeneuve's *Discourse on Eau-de-vie* noted the use of *aqua vitae* within medical contexts.	(Berthelot 1883, p. 93)
1235-1315 CE	Alcohol	Followers of Raymond Lull are noted to have perpetuated how quintessence derived from a wine-ethyl-alcohol is spiritual. However, in order to produce a spirit that could ignite, a high enough alcohol content must have been met which would have only been achievable through an adequately efficient still leading to the creation of aquavits.	(Gwei-Djen et al. 1972, pp. 69–70)
1235-1315 CE	Alcohol, Metallurgy(?)	Raymond Lull's descriptions of products from alcohol distillation were noted to be called 'vegetable mercury', implying to an extent that conceptually the products of distillation (alcohol and metallurgical contexts) were unified and similar compositionally.	(Berthelot 1883, p. 93)
1280 -1367 CE	Alcohol	Explicit shōchū / burnt wine references are noted to be recorded from texts produced between 1280 and 1367 AD, which also make reference to utilising yeast-starter cultures in brewing and the mixing of supposed distilled wines with aromatic substances stored in casks.	(Gwei-Djen et al. 1972, p. 82)
1280 CE	Alcohol	Alderotti's Consilia *Medicinalia* describing what appears to be alcohol at least 90% ABV	(Gwei-Djen et al. 1972, pp. 70–71)
1368 – 1644 CE	Zinc	Chinese zinc extraction linked at least to Ming (1368 - 1644) in texts through heating calamine in sealed clay jar	(Alam 2020, p. 28)
1378 CE	Alcohol	Italian distillers are recorded to have supplied to the public *aqua vitae* - the "water of life" - considered as the first conclusive alcoholic spirit created for medicinal purposes	
14th c. CE	Alcohol	Ascribed distillation of wine by apothecaries at Salerno has and specifically considered to be an invention that was consolidated shortly before widespread use of Latin due to the level of detail in which it is described. The Salerno texts make little mention of apparatus or methods of cooling methods, but specifically how the distillate ignited when lit	(Berthelot 1883, p. 92) (Forbes 1970) (Gwei-Djen et al. 1972, p. 71) (Wilson 2006, p. 17)
14th c. CE	Alcohol	Spirits that provided a "feeling of warmth and well-being" common were prescribed to treat enteric diseases with symptoms linked to feeling cold and debilitated, and as such, monasteries (where the sick were treated) and the production of spirits were commonly linked, such as with Benedictine and Chartreuse	(Moorhouse 1972, p. 84).
14th c. CE	Alcohol	John of Rupescissa for instance is recorded to have used either alcohol or distilled alcohol in medicine and the preservation of organic substances.	(Gwei-Djen et al. 1972, p. 70

14th c. CE	Alcohol, Mineral acids	Medieval Arabic literature uses 'spirit' as a term reserved for the production for volatiles such as mercury, sulphur, and arsenic sulphurets	(Berthelot 1883, p. 85)
14th c. CE	Mineral acids	As documented by Geber as 'accepted knowledge', the preparation of mineral acids through distillation of inorganic materials developed rapidly in the 14th c. CE linked to the production of mineral substances and concentration of sulphuric and nitric acids	(Moorhouse 1972, p. 84).
14th – 15th c. CE	Zinc	Remains of furnaces and retorts used for zinc distillation found at 14th and 15th c. AD Indian mines from Zawar, Rajastan; literary references suggest that metallic zinc was known before date of Zawar commercial zinc distillation evidence. Archaeological zinc distillation remains consist of retorts, spend charges from them, clay furnace fragments vitrified on one side, clay condenser heads, perforated plates and rough discs of unknown function	(Henderson 2000, p. 235) (Agrawal 2000, pp. 209–210) (Kharakwal and Gurjar 2006, p. 154) (Craddock et al. 1983, p. 213)
1477 – 1512 CE	Alcohol, medicine	Publication *of Liber de arte destillandi* by Hieronymus Braunschweig in 1477 and its expanded version in 1512 provided the first solely dedicated book on distillation including detail on the distillation of alcohol as a medical treatment.	
1494 CE	Alcohol	Scottish Exchequer cited explicit amounts of malt to be used by friars in producing aqua vitae and made a distinction between simple aqua vitae (not redistilled over botanicals for medicinal waters) and aqua vitae	
Pre-15th c. CE	Alcohol	Marcus Graecus' *"Treatise on Fires"* derived from Arabic and Grecian sources included recipes on 'burning water' or 'inflammable water' through a distilled mixture of powdered sulphur, tartar, white wine, and salt was deemed to demonstrate a close connection between alcohol distillation and the noting of flammability.	(Berthelot 1883, pp. 92–93)
15th c. CE	Zinc	Retorts from Miaobeihou (15th-17th c. CE / Ming Dynasty) Fengdu County, China	(Zhou et al. 2012, p. 910)
c. 1500 CE	Alcohol	One key description of distillation considered as an explicit connection between the process and the distillation of alcohol is attributed to Brunschwig, though it is noted that alcohol distillation was practiced much earlier outside of Europe.	(Moorhouse et al. 1972, p. 81)
1596 CE	Alcohol	Passages by Chinese naturalists mention steam', 'steamer', and 'burnt wine', which when combined are seen as a reference to alcohol distillation wine'	(Gwei-Djen et al. 1972, p. 78).
16th c. CE	Alcohol	Coherent written discussion on the origins of wine in China occurs at the end of the 16th c. CE and states a clear differentiation between fermented and distilled wines.	(Forbes 1970, pp. 9–10).
16th c. CE	Zinc	Zinc in China (at some stage, at least 16th c. CE) produced through using an aqueous distillation with an internal condenser through using the 'Mongolian still' configuration	(Henderson 2000, p. 235)
1644 CE	Zinc	Retorts from Dafengmen, Shizhu County, China	(Zhou et al. 2014, p. 280)
1651 CE	Alcohol	John French published *The Art of Distillation* as the first major distillation-centric volume in English, which derived a significant proportion of its information from Braunschweig's work but with a greater emphasis on industrial operations and applications	

Appendix 3. Select textual references from ancient sources interpreted as inferring early distillation

Date range	Text and line/passage	Description/feature/passage	Interpretation and select secondary references*
5th – 4th c. BCE	Euripides, *The Bacchae* 755-8	"… the things set upon their shoulders remained there without bonds to hold them, and did not fall to the black earth, neither the bronze nor the iron; they carried fire blazing upon their curls, and it did not burn them."	Translations of (5th – 4th c. BCE) interpreted to describe how the maenads (female followers of Dionysus) carried bronze still heads during biennial rituals and those liquids were ignited over the heads of initiates to demonstrate the presence of Dionysus (see Wilson 2006, pp. 47–48)
4th c. BCE	Theophrastus	"…wine poured upon the fire, as for libations, throws out a light"	Translation used as evidence of alcohol distillates noted as flammable (Berthelot 1883, pp. 85–86). No text or passage is provided by Berthelot as to where this quote derives from.
4th c. BCE	Aristotle, *Meteorologica* II.3	"Seawater when it turns in vapour becomes sweet and the saltwater does not form saltwater again when it condenses… I know this by experiment. The same thing is true in every case of this kind: wine of all fluids that evaporate and condense into a liquid state become water. They are all water modified by a certain admixture, the nature of which determines the flavour… If one plunges a water-tight vessel of wax into the ocean, it will hold, after 24 hours, a certain quantity of water, that filtered into it through the walls, and this water will be found to be portable, because the earthy and salty components have been sieved off."	Noted by Forbes (1970, p. 14) Is this an experiment into reverse osmosis? Based on seeing description as a semi-permeable membrane; analysis used to support ideas on an Aristotelian origin for experiments on separation (Yfantis and Yfantis 2020, pp. 169–171)
4th c. BCE	Aristotle, *Historia Animalium,* IX.2	Repeat of what is stated in *Meteorologica* II.3	Noted by Forbes (1970, p. 14)
4th c. BCE	Aristotle, *Phusike akroasis* I.4	"…some say the opposites are separated out (*ekkrinesthai*) from the One, being present in it, as Anaximander says… for the other things separate out from the mixture"	Aristotle's use of '*ekkrinesthai'* is considered to suggest a distillation process in describing and conceptualising the constituent parts of matter and the universe and seen as clear understanding by Greek theorists that water in certain cases must be purified through boiling and collected; description used to rationalise a foundation for later distillation emergence (Hankinson 2001, pp. 18, 62)

* Many passages and textual references are synthesised in larger chartings of early distillation (e.g., Forbes 1948, 1970; Liebmann 1956; Needham et al. 1980; Kockmann 2014; Rasmussen 2014). Those listed here are given to demonstrate the range of literature and bodies of research that cite textual references from ancient sources interpreted as inferring early distillation.

4th c. BCE	Aristotle, *Meteorologica* IV.9	"exhalation of wine is inflammable" / "ordinary wine possesses a kind of exhalation, and this is why it gives out a flame"	Translation used as evidence of alcohol distillates noted as flammable. Noted by Berthelot (1883, p. 85), Diels (1913, 1965), Gwei-Djen et al. (1972, p. 72)
c. 28 BCE / 1st c. BC	Anaxilaus of Thessaly	Unidentified.	Anaxilaus of Thessaly (neo-Pythagorean expelled from Rome) produces instructions for 'magic' fires and lamps as created by Persian Zoroastrian magi, and used by Gnostic sect of Basilides; considered similar to what is mentioned in The Bacchae? (Wilson 2006, p. 18). Recipe by Greek physician and Pythagorean philosopher Anaxilaus is deemed to describe wine distilling, but was brought into Western Europe by Cathar missionaries (Berthelot 1883, pp. 92–93). No text or passage is provided by Berthelot as to where quote derives from, or what it specifically is.
c. 1st c. BCE - 1st. c. CE	The 'Hippolytus text' / *Philosophoumena* / *Refutatio omnium haeresium,* IV.31	Hippolytus translates supposed Persian Zorastrian recipe (listed by Anaxilaus) as "…sea-foam [salt] that has been heated in an earthenware wine-jar with new wine. When this has been 'boiled', if you apply a burning lamp to it, seizing the fire it sets itself alight…" Describes the Gnostic baptism "the fire obtained from distilled wine".	Instructions written by Hippolytus on distilling wine in Greek identified by Diels (1913, 1965) attempting to identify ancient Greek philosophical teachings tied to Gnostic sects (copied from Anaxilaus of Thessaly?) No reference to a still head, heating wine in this way would simply evaporate the alcohol without adequate collection means; it is however very similar to the 'formula' for the earliest Latin-recorded operational instructions for wine distilling (Wilson 2006, pp. 18–19).
c. 200 BCE and prior(?) 1st c. CE	Democritus(?),*Phuisika kai mustika*	Unidentified, possible source of illustrations	1st c. CE and prior - Greek texts – predominately *the Phuisika kai mustika* - copied around 1000 CE include material on philosopher-chemists of Egypt and their recipes apparently dated to 1st c. CE. In margin of text there are drawings of distillation apparatus (Berthelot 1888, p. 88). Philosopher-chemists in Egypt practicing distilling and other chemical techniques at least from this point - the *Phuisika kai mustika* (possibly by Democritus) could be comfortably dated to this according to some scholars is recognised to specially mention distilling and mercury sublimation at the end of the treaty. First version of the *Phuisika kai mustika* possibly compiled by Bolos of Mendes considering that Democritus had died about two centuries prior (Wilson 2006, p. 33).
c. 200 CE	Alexander of Aphrodisias *Commentaria in Aristotelem Graeca: Meteorologica,* I.20	"... sailors at sea boil sea water and suspend large sponges from the mouth of a bronzen vessel to imbibe what is evaporated. In drawing this off the sponges, they find it to be sweet water"	Methods conducted by sailors and described by Alexander of Aphrodisias (a commentator of Aristotle) for boiling seawater in brass kettles and condensing freshwater vapours to be collected in sponges is seen to reflect this practice. Noted by Berthelot (1883, p. 86), Von Lippmann (1912, p. 2061), Sherwood Taylor (1945, p. 186), Forbes (1970, p. 15), Gwei-Djen et al. (1972, p. 72), and Yfantis and Yfantis (2020, p. 168).

1st c. CE	Pliny the Elder, *Naturalis Historia,* XXXI.70	"As persons out at sea often suffer great inconvenience from the want of fresh water, we will here describe some methods of obviating it. Fleeces are spread round the ship, and on becoming moistened with the exhalations arising from the sea, the water is wrung from them, and found to be quite fresh."	Pliny notes fleeces would become moist with evaporated water and from this, fresh water could be wrung out suitable for drinking. Noted by Liebmann (1956, p. 167) and Needham et al. (1980, p. 60).
1st c. CE	Pliny the Elder	States Falernian wine (product of Faustian field) is only wine that can be ignited "on contact with flame"	Quote attributed to Pliny (Berthelot 1883, p. 86), though no text or passage is provided by Berthelot as to where this quote derives from. Pliny also noted by Berthelot to mention essential oil extraction (the distillation of pine resins (turpentines)) by heating mixtures in vessels with wool over the top, then pressed; description used to indicate early distillation processes, though again no text or passage is provided by Berthelot as to where this quote specifically derives from. (Berthelot 1883, p. 87)
1st c. CE	Dioscorides, *De Materia Medica*, I.42-63	"And ye servant that is under with all doth do ye same, and casteth on more coals, until all ye Cadmia that was laid on be consumed, so that by the burning, the thin and light part is carried into the upper room, and sticks to the walls and to ye roof thereof"	Dioscorides describing the sublimation of mercury and calamine (Liebmann 1956, p. 167).Dioscorides describes mercury distillation in *Materia Medica* - Insertion of cinnabar in an iron spoon (crucible), heating it, and collecting the condensed vapour from the underside of the vessel covering it Iron crucible would have been used instead of ceramic as mercury penetrates into clays very easily (Henderson 2000, p. 240).
1st c. CE	Dioscorides, *De Materia Medica* (unknown passage number)	Unidentified, possible description of illustrations	Mentions essential oil extraction (the distillation of pine resins (turpentines)) by heating mixtures in vessels with wool over the top, then pressed; description used to indicate early distillation processes (Berthelot 1883, p. 87) Discusses ingredients and medicinal value of various perfumes - Adding weakly-scented astringents (stypsis) to oil – makes it more receptive to stronger fragrances to be added and thicken the oil (see also Theophrastus). Indirect heat used ("double-boiler" bain-marie) with oil jars in containers of heated water (Shelmerdine 1985, p. 12)
1st c. CE	Dioscorides (unidentified text and passage number)	Unidentified, noted as stated by Egloff and Lowry (1930, p. 2063)	Hung fleeces in the vapour of boiling liquids and wrung the collected distillates; description used to indicate early distillation processes. Unidentified text and passage (stated by Egloff and Lowry 1930, p. 2063)
1st c. CE	Dioscorides, *De Materia Medica*, V.110	"For, putting on an earthenware pan (*lopas*) an iron saucer containing cinnabar; they fit on it an *ambix*,	Description of apparatus for sublimation (Sherwood Taylor 1945, pp. 186–187).

		luting it round with clay, and then heat it on the coals. For the vapour adhering to the *ambix*, when scraped off and cooled, becomes mercury.”	
1st c. CE	Archelaos, *Upon the Sacred Art* I.11-12	“Archelaos states (Id. 348, 11, 12) that the bath of mercury reveals the actual essence of the new metal which was formerly ocean-coloured. He probably refers here to the greenish corrosion or *ios* of tarnished copper which does not exist in the new copper-silver alloy.” (Browne 1948, pp. 20–21)	Archelaos translated to describe mercury distillation with an alembic through allegorical expressions (Browne 1948, pp. 20–21)
c. 300 CE 1st c. CE	Zosimos of Panopolis, *Mémoires Authentiques,* VII.2	“I shall describe to you the *tribikos*. For so is named the apparatus constructed from copper and described by Mary, the transmitter of the art. For she says as follows: Make three tubes of ductile copper a little thicker than that of a pastry-cook’s copper frying-pan: their length should be about a cubit and a half. Make three such tubes and also make a wide tube of a handsbreadth width and an opening proportioned to that of the stillhead. The three tubes should have their openings adapted like a nail to the neck of a light receiver, so that they have the thumb-tube and the two finger-tubes joined laterally on either hand. Towards the bottom of the still-head are three holes adjusted to the tubes, and when these are fitted they are soldered in place, the one above receiving the vapour in a different fashion. Then setting the still-head upon the earthenware pan containing the sulphur, and luting the joints with flour paste, place at the ends of the tubes glass flasks, large and strong so that they may not break with the heat coming from the water in the middle.”	Distillation apparatus from Middle East is considered as different to the Asian-type still - detailed drawings by Egyptian alchemist Zosimos of Panopolis are believed to be accurate and sophisticated representations known to become the ‘Arab still’ Describes the technical treatises of chemists ‘Cleopatra’ and ‘Mary’ (Berthelot 1883, p. 88). Maria the Jewess seen to describe distillation apparatus in late 1st c. CE, description only survives as attributed quotes by Zosimos. Noted by Sherwood Taylor (1945, 1952), Holmyard (1957), Forbes (1948, 1970), Rasmussen (2014), and Yfantis (2019).

Appendix 4. Notices, law, and legislation on alcoholic spirits production in the UK (as of May 2022)

Title	Type	Summary	Reference/Link
Exercise Notice 39: Spirits Production in the UK	HMCR alcohol duty guidance and notice	Explains licensing of distillers, rectifiers, and compounders, explains procedure of approving distiller's plant and production process, explains warehousing of spirits	https://www.gov.uk/government/publications/excise-notice-39-spirits-production-in-the-uk/excise-notice-39-spirits-production-in-the-uk
Exercise Notice 196:	HMCR alcohol duty guidance and notice	Legal requirements for exercise goods in duty suspension (storage)	https://www.gov.uk/guidance/registration-and-approval-of-excise-goods-held-in-duty-suspension-excise-notice-196
Exercise Notice 197a:	HMCR alcohol duty guidance and notice	Holding and movement of exercise goods (duty paid and suspended)	https://www.gov.uk/government/publications/excise-notice-197a-excise-goods-holding-and-movement
Exercise Notice DS5:	HMCR alcohol duty guidance and notice	License for procurement and application of duty stamps for spirits for consumption	https://www.gov.uk/government/publications/excise-notice-ds5-uk-duty-stamps-scheme
Exercise Notice 206:	HMCR alcohol duty guidance and notice	Records to be kept for traders in goods and services that require Exercise Duty to be paid	https://www.gov.uk/government/publications/excise-notice-206-revenue-traders-records
Spirits duty guidance	HMRC alcohol duty guidance	Explains process to become licensed as spirits producer, submit production returns, and make spirits duty payments	https://www.gov.uk/guidance/spirits-duty
Application for distiller's licence (DLA1)	HMRC alcohol license application	Application for distiller's license and approval of distillery plant and process	https://www.gov.uk/government/publications/alcohol-duties-application-for-a-distillers-licence-and-approval-of-distillery-plant-and-process-dla1
Application for rectifier's licence (L5/EX103/EX103A)	HMRC alcohol license application	Application for distiller's license and approval of distillery plant and process for redistilling spirits or compound spirits by using a still	https://www.gov.uk/government/publications/excise-application-for-an-excise-trade-licence-l5

Appendix 5. Instrumentation trials in preparation for experimentation

1. Introduction

In advance of experimental studies (and considering their exploratory nature), an appropriate measurement methodology was developed for temperature and observation recording. Instrumentation to record and monitor distillation apparatus was evaluated using a ceramic vertical distillation apparatus configuration reported in historical documents, archaeological studies, and ethnographic accounts (e.g., Lumholtz 1898; Barnes 1934; Bruman 1944; Mahdihassan 1972, 1979; Needham et al. 1980) (Figure 60). This acted as a control and context to determine an appropriate measuring method and suitable length of distillation run prior to undertaking exploratory distillation trials that would compare the ability of different apparatus configurations.

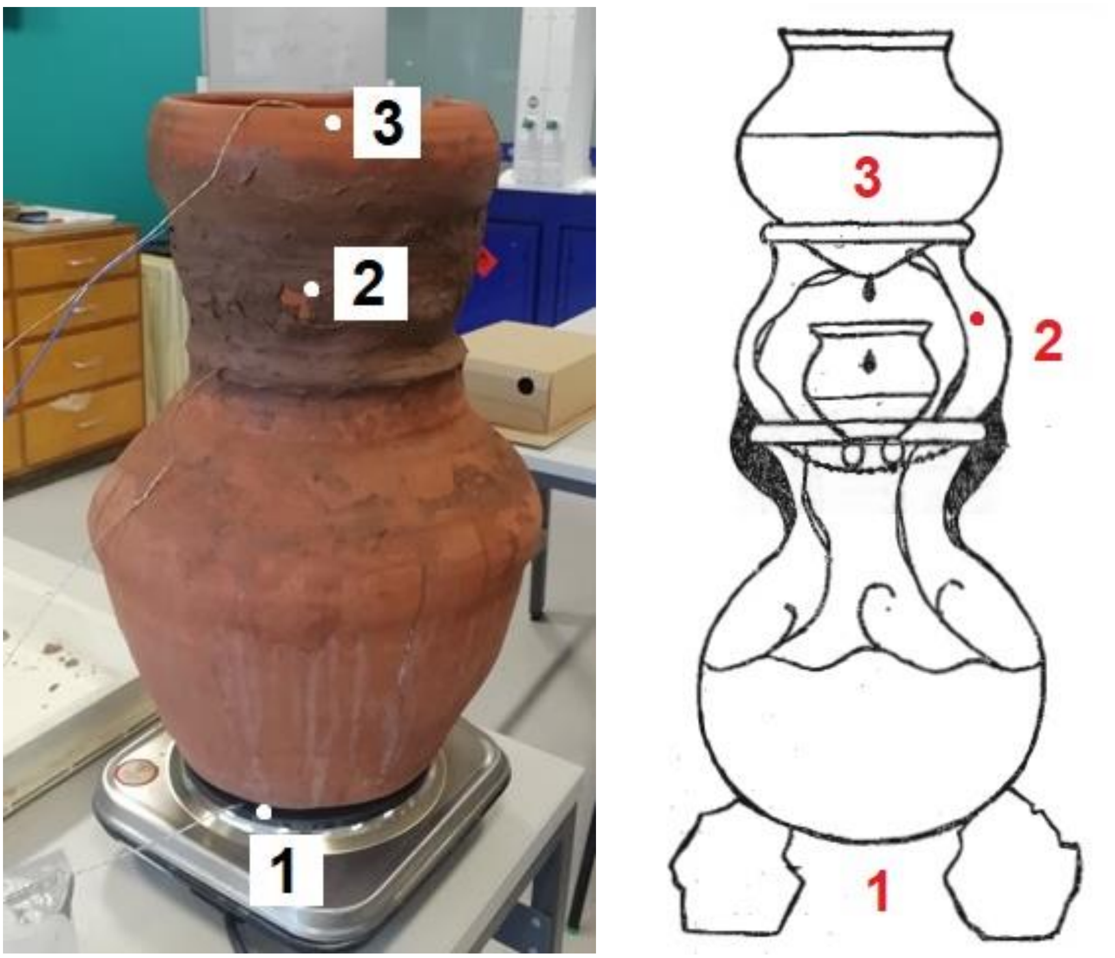


Figure 60. *Assembled reconstructed vertical configuration distillation apparatus (left) used for instrumentation trials in comparison to Mahdihassan's (1972, 1979) apparatus reconstruction. Location of thermocouples used in the trial and corresponding to the reconstruction: 1.) heat source; 2.) internal condensing area 3.) condenser (in water).*

2. Methodology

Experiments were undertaken in the Department of Archaeology's Material Science Laboratory between August 2020 and September 2020. It was originally hoped that experiments would begin soon after completing the apparatus, though implications of the COVID-19 pandemic meant that they could only begin in August 2020, significantly changing the timeframe for the project and abandoning additional experimental repetitions to ensure more accurate results.

Using 2000, 4000, and 6000 ml of water distilland to provide a range of starting distilland volumes that could affect heating rates, trials produced initial insights on distilling operation and the performance of apparatus. Temperatures of the condenser, heat source, and atmospheric temperature within the still body were measured using K- (for condenser and heat source) and N-type (for still body) thermocouples by taking manual readings at 15-minute intervals with a thermocouple reader. Prior to use, distillation apparatus was soaked in water for 20 minutes so that the ceramic fabric was saturated to help contain liquids. The still body was then filled with the relevant distilland volume (maximum capacity to rim of 13200 ml) and sealed using clay and clay slip. Apparatus heating was maintained by a Lloytron E831SS hotplate (maximum temperature of 250 °C when under load). For each run, the hotplate started from its 'off' position and was increased to its maximum temperature immediately. Distillation then ran for 240 minutes (4 hours). Seals were periodically repaired to maintain consistent distilling conditions when temperature readings were taken at 15-minute intervals, and seals showed signs of breakage. Once the run was complete, apparatus was immediately deconstructed, and distillate and distilland measured. Initial impressions on how the apparatus functioned were noted to identify possible points within runs when interventions would be required to maintain distillation.

3. Results

Three trials were carried out using the vertical configuration with differing distilland volumes. 2000 ml of water distilland was first measured and decanted into the still body after soaking. Once the apparatus was assembled and sealed, the hotplate was switched on and temperatures were recorded manually at required 15-minute intervals. The still body atmosphere temperature gradually rose from 17 °C to 62 °C by the end of the 4-hour period, whilst the condenser temperature increased from 19 °C to 28 °C by the end of the run. It became apparent that heat source temperatures would not be adequately mapped through 15-minute readings, considering that hotplate power would fluctuate to maintain its highest temperature (i.e., it would switch off once maximum temperature was reached and then switch on again to return to maximum temperature). This produced an unrepresentative dataset through manual recording rather than regulated data logging. At the end of the run, 50 ml of distillate was collected once the apparatus was deconstructed, with 700 ml of distilland remaining in the still body.

In tandem to temperature readings, some immediate observations were recorded. Indications of the water reaching temperature was noted by external spalling on the exterior of the body base (at 15 minutes) indicating that the still body was heating up, caused by excess water evaporating that had collected in ceramic fabric exterior during soaking. Water was added to the condenser at 90 minutes into the run to refill it once some loss was noted (possibly through being absorbed into the vessel fabric) with the condenser reaching capacity at 165 minutes and no further water added. This coincides with the condenser temperature rising more drastically. Seals between each join of individual component were not repaired frequently, only needing maintenance at 120 minutes, when all seals were repaired.

4000 ml of water distilland was then measured and decanted into the still body after soaking. Once the apparatus was assembled and sealed, the hotplate was switched on and temperatures were read at required 15-minute intervals. The body atmospheric temperature gradually rose from 18 °C to 54 °C by the end of the 4-hour period, while the condenser temperature increased, albeit more gradually than the previous run, from 18 °C to 22 °C by the end of the run. As in the previous distillation, heat source temperatures were not adequately mapped through 15-minute readings. At the end of the run, 23 ml of distillate was collected with 2450 ml of distilland remaining in the still body. Several sensory indications were noted throughout the process. External spalling was already noted on the exterior base of the still body at 15 minutes as it began to heat up and water was evaporating from the pores of the ceramic. Repairs to seals began at 90 minutes into the run, first with the body, and then at the condenser from 120 minutes in the run. Seals were maintained at every interval after this, until 225 minutes into the run. At 105 minutes, external 'sweating' was noted on the condenser exterior (Figure 61), when the body temperature was increasing to 46 °C and the condenser maintaining 18 °C. External sweating had stopped by 180 minutes, 75 minutes later, when the body temperature had reached 51 °C while the condenser temperature had increased slightly to 21 °C.

Figure 61. External 'sweating' noted on the condenser exterior.

6000 ml of water distilland was then measured and decanted into the still body after soaking. Once the apparatus was assembled and sealed, the hotplate was switched on to its highest temperature. Temperatures were read at the required 15-minute intervals. Body atmospheric temperature gradually rose from 18 °C to 58 °C by the end of the 4-hour distillation run, while the condenser temperature increased less drastically from 19 °C to 26 °C. Heat source temperatures were not adequately mapped through 15-minute readings, again due to the influence of temperature fluctuations from the hotplate whilst maintaining its maximum temperature. At the end of the run and the apparatus deconstructed, 41 ml of distillate was collected with 4860 ml of distilland remaining in the still body. External spalling was observed near the start of the run (15 minutes) and continued for 30 minutes, as was seen in the 2000 and 4000 ml distilland runs. Water was first added to the condenser at 105 minutes, however the condenser stayed at capacity for the remainder of the run, only being briefly topped up at 165 minutes into the run.

4. Evaluation and discussion

Instrument trials broadly demonstrated the need for more accurate and frequent temperature readings. Evidently, temperature readings of the heat source were not accurately mapped and therefore this line of data could not be corroborated with the still body and condenser temperature readings (Figure 62). As such, for future trials, shorter intervals between readings (in a period of seconds rather than minutes) would provide a higher resolution of data recording, coupled to a thermocouple data logger to guarantee that readings were being accurately taken. Despite this issue, relationships between still body and condenser temperatures could be noted irrespective of the heat source (Figure 63). Still body temperature expectedly increased faster with 2000 ml of water distilland in comparison to the other volumes, however all runs appeared to reach a point of equilibrium around 75 minutes into the run. This would need to be confirmed with higher resolution data recording. Equally, for more complete trials, increased repetitions of distillation runs would be needed to create an adequate and accurate understanding of distillation ability of each apparatus. This would need to be established by also noting the rate of temperature change of the distilland (the liquid being distilled) so that more accurate insights on distillation capacity of the apparatus configurations regarding their heat retention and transfer properties could be noted. Despite these issues, distillation appeared to be successful using the hotplate (though produced a low yield), hence the current testing environment could be used for the comprehensive preliminary trials going forward.

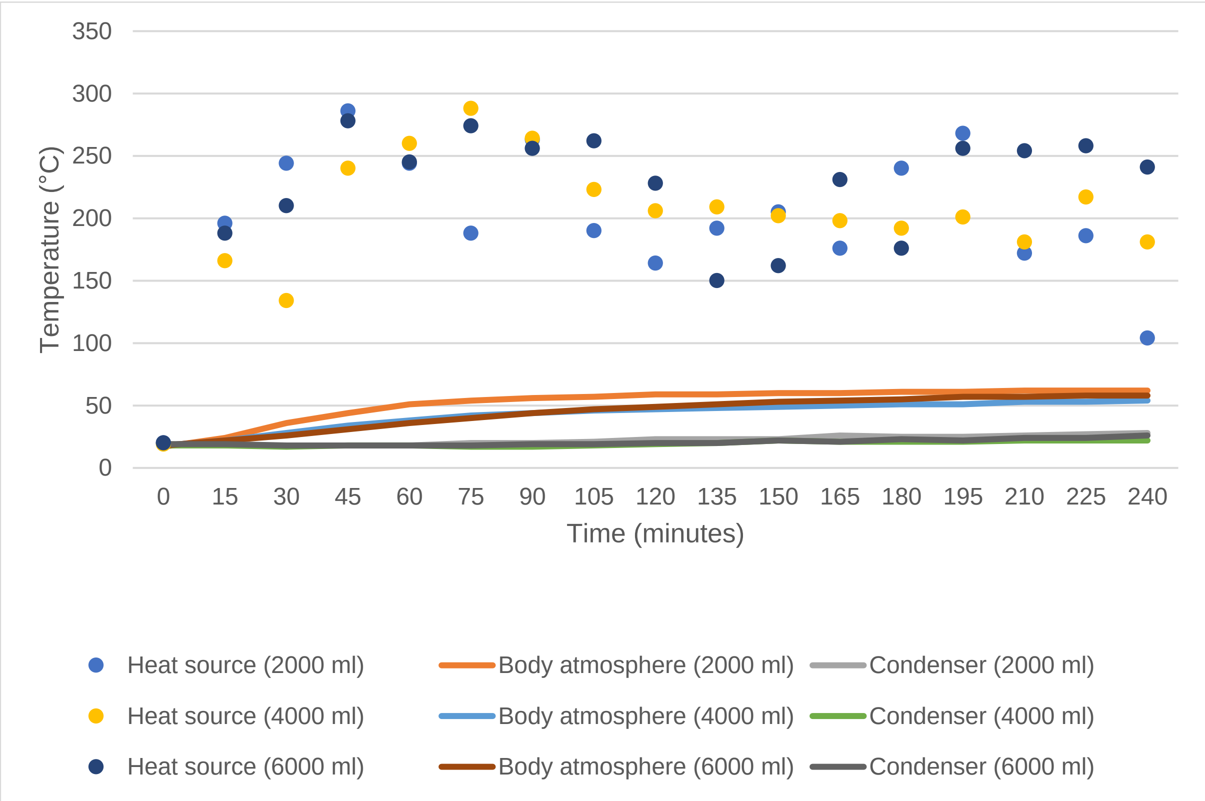


Figure 62. *Temperature readings of specific components from the vertical apparatus configuration to evaluate method of temperature reading.*

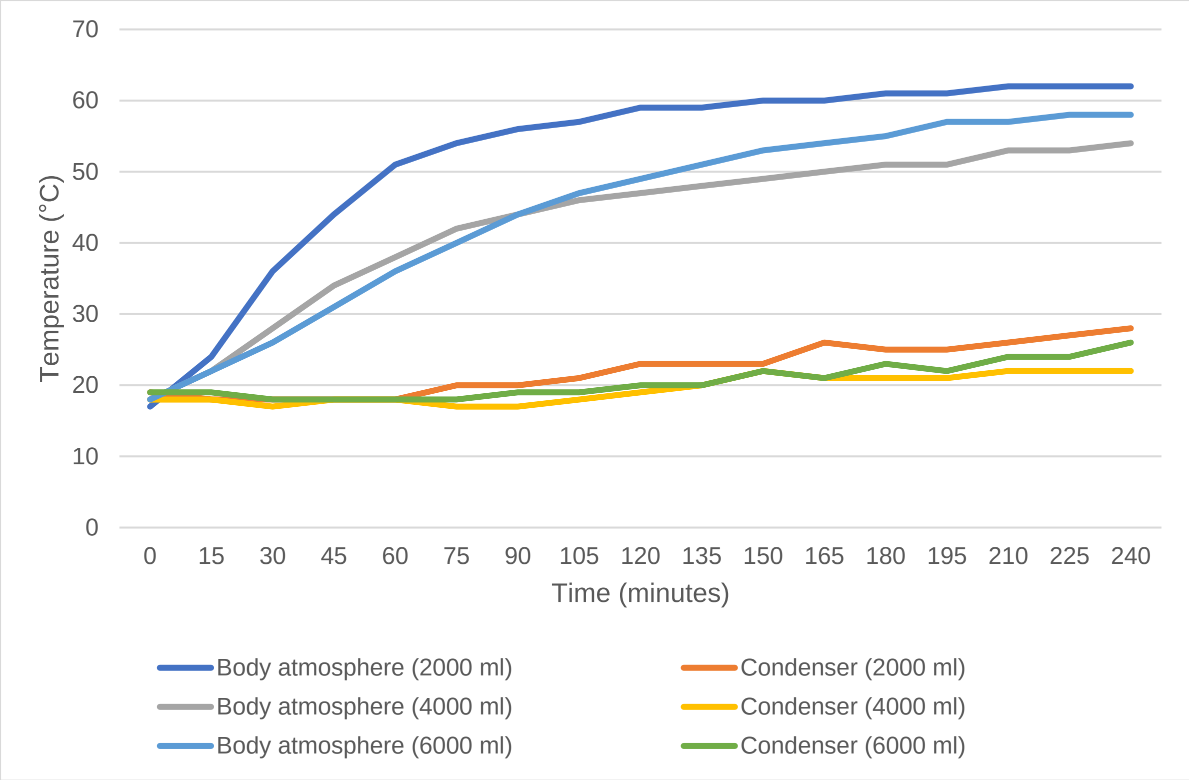


Figure 63. *Temperature readings of specific components from the vertical apparatus configuration to evaluate method of temperature reading, irrespective of heat source readings.*

5. Conclusion

The brief study demonstrated the need within subsequent experimentation for a higher resolution and more accurate method of temperature data recording. Moreover, while the current placement of thermocouples would guarantee that insights on distillation capacity could be noted, the changing temperatures of the distilland during distillation would also need to be recorded. Distillations with the apparatus configuration were ultimately a success, hence the use of a hotplate as a suitable controlled heat source for the next stage of experiments would be adequate.

Appendix 6. Experiential and sensory insights relating to craft practice recorded during preliminary distillation trials (Chapter 5)

Vertical configuration

2000 ml distilland run

Time (mins)	**Time**	**Notes**
0	10:45	Start run slightly before 10:45 (see logger times)
15	11:00	No intervention
30	11:15	Bubbling, simmering?
45	11:30	No intervention
60	11:45	No intervention
75	12:00	Body seal repaired
90	12:15	Vapour escaping, body seal repaired
105	12:30	No intervention
120	12:45	No intervention
135	13:00	No intervention
150	13:15	Condenser topped up to capacity, seals holding
165	13:30	No intervention
180	13:45	No intervention
195	14:00	No intervention
210	14:15	No intervention
225	14:30	No intervention
240	14:45	Run end, cool down begins
End		Cool down
300	15:45	Cool down, thermocouple reading end, apparatus disassembled and distilland measured

4000 ml distilland run

Time (mins)	**Time**	**Notes**
0	10:17	Run started
15	10:32	No intervention
30	10:47	Seals repaired
45	11:02	No intervention
60	11:17	No intervention
75	11:32	Condenser topped up
90	11:47	No intervention
105	12:02	No intervention
120	12:17	Condenser topped up
135	12:32	No intervention
150	12:47	No intervention
165	13:02	No intervention
180	13:17	No intervention
195	13:32	No intervention

210	13:47	No intervention
225	14:02	Vapour escaping it seems, potentially from seal, but cannot identify breakages
240	14:17	Run end, cool down begins
End		Cool down
300	15:17	Cool down, thermocouple reading end, apparatus disassembled and distilland measured

6000 ml distilland run

Time (mins)	Time	Notes
0	09:57	Run start
15	10:12	No intervention
30	10:27	Condenser topped up to capacity
45	10:42	No intervention
60	10:57	No intervention
75	11:12	Seals repaired between body and condenser
90	11:27	No intervention
105	11:42	No intervention
120	11:57	No intervention
135	12:12	No intervention
150	12:27	Condenser topped up to capacity
165	12:42	No intervention
180	12:57	No intervention
195	13:12	No intervention
210	13:27	Seal repaired at body, superficial slip layer dried
225	13:42	Steam escaping from somewhere, slip layer added to body seal
240	13:57	End of distillation run
End		Cool down
300	14:57	Cool down, thermocouple reading end, apparatus disassembled and distilland measured

Gandhāra configuration

2000 ml distilland run

Time (mins)	Time	Notes
0	09:56	Start recording
15	10:11	No intervention
30	10:26	External spalling noted, possibly bubbling?
45	10:41	Body seal repaired, cloth changed
60	10:56	Body and tube seals repaired, cloth changed
75	11:11	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals
90	11:26	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals
105	11:41	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals

120	11:56	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals
135	12:11	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals
150	12:26	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals
165	12:41	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals - seems to be coming out from the back clearly
180	12:56	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals - seems to be coming out of breaks in sealant
195	13:11	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals - seems to be coming out of breaks in sealant, major breaks appearing
210	13:26	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals - seems to be coming out of breaks in sealant, major breaks appearing
225	13:41	Body and tube seals repaired, cloth changed, distillate gathering around body rim and leaking through seals - seems to be coming out of breaks in sealant, major breaks appearing
240	13:56	Run complete, receiver and tube removed, distillate measured
End	13:56	Cool down
300	14:56	Cool down, thermocouple reading end, apparatus disassembled and distilland measured

4000 ml distilland run

Time (mins)	Time	Notes
0	10:04	Run started - no still head cooling
15	10:19	No intervention
30	10:34	No intervention
45	10:49	Seals repaired body and still head
60	11:04	No intervention
75	11:19	No intervention
90	11:34	No intervention
105	11:49	No intervention
120	12:04	Seals repaired body and still head
135	12:19	Seals repaired body and still head, distillate escaping through body seal
150	12:34	No intervention
165	12:49	Seals repaired body and still head, distillate escaping through body seal?
180	13:04	No intervention
195	13:19	Seals repaired body and still head
210	13:34	Seals repaired body and still head
225	13:49	No intervention
240	14:04	Run complete, cool down begins
End		Cool down

300	15:04	Cool down, thermocouple reading end, apparatus disassembled and distilland measured

6000 ml distilland run

Time (mins)	Time	Notes
0	10:10	Run started - no still head cooling
15	10:25	No intervention
30	10:40	No intervention
45	10:55	No intervention
60	11:10	Seals seemed 'dry' so wetted and repaired
75	11:25	No intervention
90	11:40	No intervention
105	11:55	No intervention
120	12:10	No intervention
135	12:25	Repaired body seal
150	12:40	No intervention
165	12:55	Seals repaired body and still head, distillate escaping through body seal
180	13:10	No intervention
195	13:25	No intervention
210	13:40	Seals repaired body and still head, distillate escaping through body seal
225	13:55	Seals repaired body and still head, distillate escaping through body seal
240	14:10	Run complete, cool down begins
End		Cool down
300	15:10	Cool down, thermocouple reading end, apparatus disassembled and distilland measured

Appendix 7. Experiential and sensory insights relating to craft practice recorded during the exploratory experimental campaign (Chapter 6)

Impressions presented here were established throughout the campaign as a whole and not limited to an individual trial.

Aspect of production sequence	Observations and impressions of note
Heating distilland	• Adequate supply of fuel • Maintaining heated environment (more control with hearth as opposed to open fire) • Ability to know correct temperature / if distilland is "hot enough"
Determining if system is distilling	• Visible point at which distilland begins to collect • Visible vapour loss • Leakages in system; vapour is condensing, but not channelling in the correct areas • Temperature difference between distilland and condenser
Judging temperatures	• Interaction with configurations and components - sensory levels of heating • Levels of "touch"; sensory signals and indicators of hot and cold components • Appearance of vapour and gathering distillate
Maintaining cooling environment	• Cloth changes and the regularity of changes • Adequate supply of cold water to cool cloths quickly • Refilling basins with cold water • Needing to find a way to replace water in basin without disturbing rest of the apparatus

Maintaining pressurised and distilling environment	• Repairing seals and the regularity of repairs • Visible distillate or vapour loss • Covering seals with slip layer • Maximising distilling area; need to provide large enough area so that interior has wide enough temperature differentiation between heated distilland and condenser
Monitoring vapour and distillate movement	• Point of condensing; unable to physically see where its occurring within the system so all based on sensory aspects
Adaptions during distillation	• Re-adjusting angles of condensing tube • Repairing hearth • Applying clay slip layer around still body and head joins • Level and flush joins between apparatus components to promote pressurised and sealed environment

Appendix 8. Photographic record of use-alteration changes to reconstructed Gandhāra apparatus after exploratory experimental campaign (Chapter 6)

1. Still body

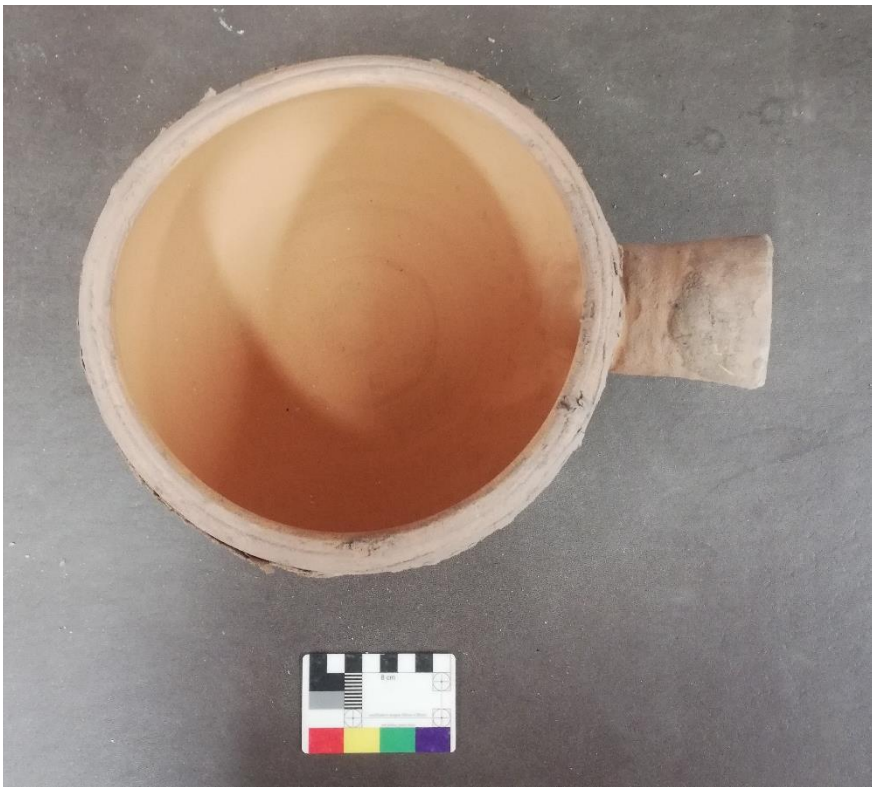
a.) Representative external (angled down) displaying shoulder and external sooting.

b.) Representative external (face on) displaying profile and sooting.

2. Condensing tube

a.) Representative external showing build-up of clay at both ends of tapered tube.

3. Still head



a.) Representative internal view of still head showing underside of join (rim) and underside of spout with clay remains from seals.

b.) Representative external view of still head

4. Scaled receiver

a.) Representative external view (from top) showing spout and clay accumulation on spout from sealing joins.

b.) Representative front external view.

c.) Representative side view.

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Map and Aerial Image Data

Esri Carto Light Mapping. 2022. *Topographic Mapping.* Sources: Esri, DeLorme, HERE, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, and the QGIS User Community 2022. Last accessed 21 October 2022.

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