Classification and Analysis of Regular Geometric Patterns with Particular Reference To Textiles.

By

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The candidate confirms that the work submitted is his own and that the appropriate credit has been given where reference has been made to the work of others.

ABSTRACT

Attention is focused on the range of literature which has contributed to the developing awareness of the theoretical principles governing the geometry of pattern. A means by which textile and other surface patterns can be classified by reference to the symmetry characteristics of their underlying structures is developed, and shown to be an objective, systematic and reproducible means of providing meaningful, standardised descriptions of regular geometric patterns. The potential of the classification system as a worthwhile analytical tool is explored through its application to groups of textile patterns from four distinct cultural settings: traditional Javanese batiks; traditional Sindhi ajraks; Jacquard woven French Silks (Autumn, 1893); Japanese textiles produced during the Edo period (1604-1867) using a variety of patterning techniques. Data are tested to establish firstly, if the patterns from different cultural settings show different symmetry preferences; secondly, if the symmetry preferences associated with a given culture are maintained over the passage of time, in the absence of external pressures for change; thirdly, if techniques of manufacture have any bearing on the symmetry preferences associated with a given culture.

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1. INTRODUCTION.

In general, textile designers have been aware of the importance of geometry in the construction of repeating patterns. However, explanatory literature on the subject has not been readily accessible, due to the inevitable barrier erected by unfamiliar symbols and obscure terminology. In an attempt to remedy this state of affairs a series of papers by H. J. Woods [1-4] was published in the *Journal of the Textile Institute* in the mid-1930's. Through these publications, Woods, a physicist working in the Textile Department of the University of Leeds, attempted to de-mystify the mathematical rules governing the geometrical structure of two-dimensional repeating patterns. His objective was to encourage an awareness among textile designers of the potential for application of the principles of geometrical symmetry to pattern construction; these theoretical principles had been developed by crystallographers in their quest to understand certain three-dimensional phenomena.

For much of the twentieth century archaeologists, anthropologists and design historians have, in the main, restricted their study of patterns on decorated objects to broad ranging subjective commentary and superficial analysis; cross-cultural considerations and comparisons have generally been hindered by the apparent lack of awareness of a procedure to systematically classify two-dimensional designs in a way which is both meaningful and reproducible. A framework for the objective classification of two-dimensional designs does however exist. In 1948 Anna Shepard [5], an eminent archaeologist, who was seemingly unaware of Woods' work, gave descriptions of the principles of geometrical symmetry and, in particular, explained how these principles could be applied to the classification of decoration on archaeological artifacts.

The work of both Woods and Shepard apparently remained unnoticed until the 1970's when, due largely to the individual and combined efforts of Crowe [6-12] and Washburn [13-19], these and similar studies were gradually brought to the attention of those practitioners and analysts who were receptive to the perspectives offered.

With the above considerations in mind, this thesis presents a rationalisation of a large quantity of information, including terminology and nomenclature, presented in literature from a wide range of interested disciplines. Appropriate concepts and ideas are introduced and employed in the development of a systematic means of objectively classifying all known regular repeating patterns. Further to this an exploration is made of the classification system, as an analytical tool, through its application to groups of textile patterns from a selection of cultures and periods.

2. PRINCIPLES AND PERSPECTIVES.

2.1. Preliminary Notions.

Regular geometric patterns can be conveniently defined as designs in the plane (categorised as either *border patterns* or *all-over patterns* by the designer) which exhibit the repetition of a motif, or motifs, at regular intervals. It should be noted that the term *geometric* is not used in a sense which excludes figurative and floral patterns, but rather to underline the fact that all regular repeating patterns have an underlying geometric structure which facilitates the regular repetition of motifs. Motifs (which may be geometrical, floral or figurative in nature) are either symmetrical or asymmetrical. A *symmetrical motif* is a figure which is comprised of two or more parts of identical size, shape and content; each identical part is known as a *fundamental unit* and the area enclosing it as a *fundamental region*, terms also employed when referring to the minimum repeating unit and area of a border or an all-over pattern. In the synthesis of patterns, *repetition* can be defined as the process which permits the reproduction of a motif by transferring it through a given distance, from one position in the plane to another while at the same time allowing its retention in its original position. Where repetition of a motif or motifs is continuous in one direction only, between two imaginary (or real) parallel lines, the pattern thus produced is referred to as a border pattern. Synonymous terms include *strip patterns* (Grunbaum and Shephard [20]), *one-dimensional designs* (Washburn and Crowe [21]) and *frieze groups* (Grunbaum and Shephard [22]). Where repetition of a motif, or motifs, is continuous in two independent directions and thus covers the plane, the pattern is referred to as an *all-over pattern*. Synonymous terms include *wallpaper groups* (Buerger and Lukesh [23]), *wallpaper designs* (Schattschneider [24]), *periodic patterns* (Grunbaum and Shephard [25]) and *crystallographic patterns* (Mamedov [26]). Investigators have, in the past, determined a means of classifying both motifs and patterns by reference to their symmetry characteristics (i.e. the geometry of their underlying structures), a system of classification which, as indicated in the Introduction , had its origins in the discipline of crystallography. This thesis presents a further adaptation of this system of classification in order that its potential for application to the synthesis and analysis of textile patterns can be more widely recognised.

2.2. The Study of Pattern: Historical Precedents.

Probably the most influential study of pattern to be published in Europe during the nineteenth century was Owen Jones' [27] *The Grammar of Ornament*, which covered subject matter from a number of periods and styles and was concerned with the classification of decoration across a wide range of architecture and the applied arts. Although not based on the consideration of the geometrical characteristics of pattern structure, Jones' work is none the less worthy of mention, for it stands out as the first serious attempt to categorise patterns by reference to their cultures and periods of origin. Crowe [28] commented,

> "...it has been the reference par excellence for mathematicians interested in the cultural aspects of patterned ornament. It is organised entirely on cultural and historical principles, not at all on stylistic or mathematical principles."

Subsequent to its publication in French and German, *The Grammar of Ornament*, as pointed out by Durant [29], seemingly acted as a stimulus for similar publications, and compendia illustrating patterns from various sources have continued to be published up to the present day. Works such as Racinet's [30] *L'Ornement Polychrome* were extensively illustrated in folio format. Others were wide ranging with reference to medium, culture and period: Franz Sales Meyer's [31] *Handbook of Ornament*, which illustrated a vast range of decorative elements, from across a wide spectrum of the applied arts, is one example; Speltz's [32-34] three volume work, ambitiously entitled *The Coloured Ornament of All Historical Styles*, is another example. Further compendia were presented by Bourgoin [35], Audsley and Audsley [36], Kelley and Mowll [37], Lewis [38], Fenn [39], Edwards [40], Christie [41], Bossert [42], Dye [43], Bain [44], Bodrogi [45], Proctor [46], Ernst [47], Hornung [48], Albarn et al. [49], Menten [50], and Hann and Thomson [51]. A comprehensive review of such treatises was recently provided by Durant [52].

Although it has long been recognised that geometry plays an important role in the underlying structure of pattern, this recognition has generally manifested itself in practice rather than theory. On the few occasions where an identification of the geometrical principles governing patterns was evident in the design literature of the late 1800's and early 1900's, this was often from the perspective of pattern synthesis (i.e. the construction of patterns) rather than from the perspective of patterns analysis (i.e. the determination of a pattern's geometrical structure). The majority of design publications were thus aimed at the design practitioner and not the design analyst. Meyer [53a], for example, in 1894, stated his intentions when he declared that his handbook was,

> "...based on a system which is synthetic rather than analytic and intended more to construct and develop...than to dissect and deduce."

It is none the less interesting to note that Meyer [53b] grouped designs according to their spatial characteristics into *ribbon-like bands*, *enclosed spaces* or *unlimited flat patterns* corresponding to *border patterns*, *motifs* and *all-over patterns* respectively. In addition, Meyer [53b] recognised that the foundation of every form of all-over pattern was a,

> "...certain division, a subsidiary construction or a network."

He thus anticipated the use of the term *nets* (used for example by Woods [54]) to refer to the skeletal grids (*or lattices*) underlying the structure of all-over patterns, a phenomenon explained later in chapter 5 of this thesis.

Whilst not adopting the terminology and theoretical perspectives being developed by crystallographers at that time, certain late nineteenth and early twentieth century observers none the less exhibited an astute awareness of the underlying geometrical principles fundamental to the construction of all-over patterns. In 1897, Stephenson and Suddards [55], for example, in their appraisal of the geometry of pattern design (particularly Jacquard woven patterns) illustrated patterns with constructions based on rectangular, rhombic, hexagonal and square lattices. In a similar vein, Day [56], in 1903, placed an emphasis on the geometrical basis of all design and illustrated the construction of all-over patterns on square, parallelogram, rhombic and hexagonal type lattices. In 1910, Christie

[57] rationalised all-over patterns, including many textile patterns, into two main types: those which were comprised of *isolated units* (spot-like effects, where the background totally surrounds each individual motif) and those which were comprised of *continuous units* (where motifs are repeated to form a continuous mass). Through further sub-division, Christie [57a] gave numerous examples of how all-over patterns could be developed by the practitioner. Christie's work is of importance for it represents a first stage in the categorisation of patterns, for the purpose of both analysis and synthesis, by reference to their geometrical structures. Interestingly, Christie [57b] claimed that his categorisation of patterns,

> "...followed broadly the lines laid down by the zoologist, who separates into well defined categories all living and extinct creatures."

During the early twentieth century another perspective of pattern analysis and classification was evolving: the consideration of patterns by reference to their symmetries, a perspective which, as mentioned previously, had its origins in the scientific investigation of crystals. Attention is focused below on the range of literature which has contributed to the development of the theoretical principles governing symmetry in pattern.

2.3. Symmetry: The Development of Concepts and Perspectives.

Both scientific and mathematical observers (such as Shubnikov and Koptsik [58], Coxeter [59], Jeger [60], Guggenheimer [61], Yale [62], Gans [63], Ewald [64], Dodge [65], Schattschneider [66], Hargittai [67] and Martin [68]) have recognised that symmetry in motifs and patterns is characterised by the use of one or more of the following geometrical actions:

(i) *Translation*, by which a figure undergoes repetition vertically, horizontally or diagonally at regular intervals while retaining the same orientation.

(ii) *Rotation*, by which a figure undergoes repetition at regular intervals round an imaginary fixed point (variously known as a *roto-centre*, a *rotational centre* or a *centre of rotation*).

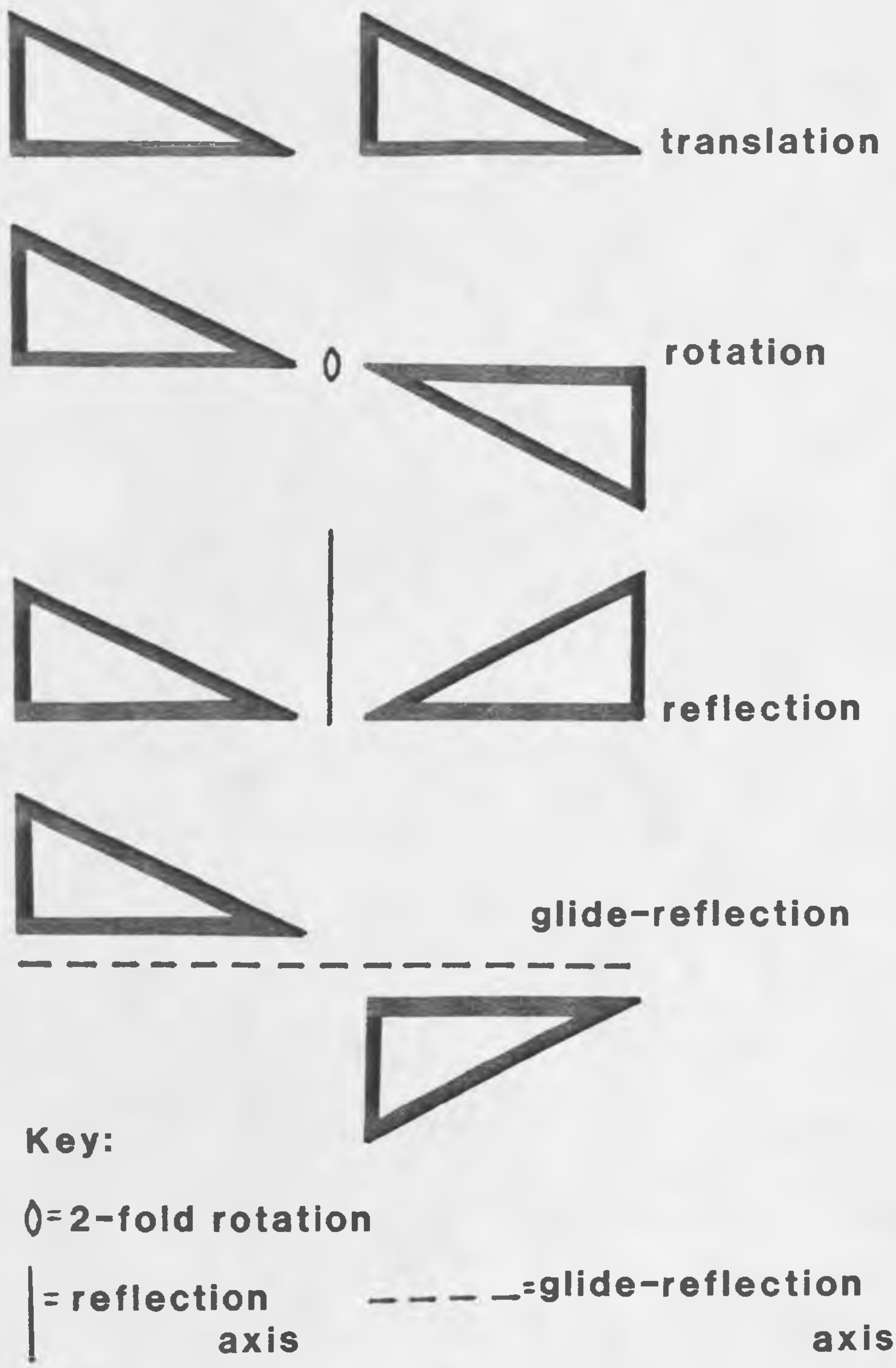
(iii) *Reflection*, by which a figure undergoes repetition across an imaginary straight line, known as a *reflection axis*, producing a mirror image. This is characteristic of so-called *bilateral symmetry*.

(iv) *Glide-reflection*, by which a figure is repeated in one action through a combination of translation and reflection, in association with a *glide-reflection axis*. This particular geometrical action is often illustrated by the pattern produced by a person's footprints.

These four basic geometrical actions are generally termed *symmetry operations*. Synonymous terms include *symmetries* (Grunbaum and Shephard [69]), *congruence transformations* (Campbell [70]) or *isometries* (Schattschneider [71a]). Relevant schematic illustrations are provided by Figure 1.

Translation is the underlying geometric feature of both border patterns and all-over patterns. In the former case translation is in one direction only and in the

Figure 1. The Four Symmetry Operations.



latter case translation is in two distinct directions across the plane. Schattschneider [71a] commented,

> "A translation of points in the plane shifts all points the same distance in the same direction."

Rotation may be present in certain varieties of motifs, border patterns and all-over patterns. Schattschneider [71b] commented,

> "A rotation of points in the plane moves points by turning the plane about a fixed point (called a centre of rotation)."

Reflection may be present in certain varieties of motifs, border patterns and all-over patterns, and reflection axes may be horizontal or vertical. Schattschneider [71c] commented,

> "A reflection of points in the plane is determined by a fixed line, called the mirror line or reflection axis; every point not on the line is sent to its mirror image with respect to the line and every point on the line is left fixed."

Glide-reflection may be present in certain varieties of border patterns and all-over patterns. Schattschneider [71d] commented,

> "A glide-reflection, as its name suggests, is a transformation of points in the plane which combines a translation (glide) and a reflection. It may be obtained by a reflection followed nonstop by a translation which is parallel to the mirror line or by a translation followed by a reflection in a mirror line parallel to the translation vector."

The combination of symmetry operations that characterise a given motif or pattern is called its *symmetry group*. As pointed out by Stevens [72],

> "A symmetry group is a collection of symmetry operations that together share three characteristics: (1) each operation can be followed by a second operation to produce a third operation that itself is a member of the group, (2) each operation can be undone by another operation, that is to say, for each operation there exists an inverse operation, and (3) the position of the pattern after an operation can be the same as before the operation, that is, there exists an identical operation which leaves the figure unchanged."

In a similar vein, Schattschneider [73] commented that a symmetry group,

> "...is a collection of all isometries (or symmetry operations) which, when applied to the design...create an image which is superimposed exactly on the original so that, to the eye, it seems that no transformation has taken place."

Where motifs or patterns possess the same symmetry group they are said to be of the same *symmetry class* and are therefore classified accordingly, based on the nomenclature explained in subsequent chapters of this thesis. All symmetrical motifs (of which there are an infinite number of classes) exhibit reflectional and/or rotational symmetry characteristics; border patterns (of which there are only seven distinct classes) and all-over patterns (of which there are only seventeen distinct classes) exhibit translation and may also exhibit combinations of one or more of the remaining three symmetry operations. Where problems in classification arise due to the availability of only a limited area of a border pattern or an all-over pattern, a common problem with archaeological textiles, the criteria suggested by Washburn and Crowe [74] seem worthy of adoption. They stated that a single translation of a motif in one direction is the minimal property of a border pattern and that translation of at least two identical motifs in more than one direction is the minimal property of an all-over pattern.

As pointed out by Grunbaum and Shephard [75] it is a surprising fact that the complex classification of the three dimensional crystallographic classes (of which there are two hundred and thirty) was accomplished by Fedorov [76], in 1885, in advance of the enumeration of the seemingly much more straight forward seventeen classes of all-over patterns which was also accomplished by Fedorov [77], six years later in 1891. Remarking on further developments, Grunbaum and Shephard [78] commented,

> "After many years of efforts it has been established that there are precisely 4,783 classes of crystallographic space groups in 4-dimensional Euclidian space... The number of classes in 5 dimensions is not known."

Since the primary focus of crystallographers was towards three-dimensional (and higher dimensional) phenomena, it was not until the 1920's that an interest in the application of the two-dimensional enumeration became aroused through the works of Polya [79] and Niggli [80] in 1924. It is a further surprise to realise that it was seemingly not until 1926 that the seven classes of border patterns were first enumerated by Niggli [81].

In a second edition of a work by Speiser [82], published in 1927, the notation used by Niggli was adopted but two of Niggli's symbols were unfortunately interchanged and, as pointed out by Washburn and Crowe [83], the mathematical literature of the next fifty years replicated this error until its correction by Schattschneider [84] in 1978. The crystallographic literature had, however, continued on its own path and was not similarly affected.

In 1933 Birkhoff [85], in his classic work *Aesthetic Measure*, defined and illustrated the four symmetry operations, and discussed their presence in motifs and patterns. In the context of textiles, the most notable attempt to classify regular repeating patterns according to geometrical principles was, as indicated in the Introduction, made in the mid-1930's by Woods [1-4]. In addition to classifying motifs, border patterns and all-over patterns according to their symmetry characteristics, Woods focused attention on border and all-over patterns with counterchange characteristics (that is, two-colour patterns which interchanged colour in association with successive symmetry operations). As recognised by Crowe [86], Woods' publications, which appeared under the general title of *The Geometrical Basis of Pattern Design*, anticipated work that would not be done by crystallographers or mathematicians for another twenty years. The wider significance of Woods' work was recognised by Washburn and Crowe [87], in 1988, when they commented that his published papers,

> "...were landmarks because he made available to the non-scientist a new way of understanding the formation of repeating patterns."

In 1937, Buerger and Lukesh [88] also produced a worthwhile account of symmetry in pattern and presented a series of symbols to denote lattice types and rotational orders (e.g. two-fold, three-fold etc..), and the presence of reflection and glide-reflection axes. An important attempt to explain the principles of symmetry and in particular to assess the application of these principles to the field of pattern analysis of archaeological artifacts was, as indicated previously, provided by Anna Shepard [89] in 1948. In 1952, Weyl [90] presented a description of symmetry in art as well as botany and other pure sciences. New perspectives were also provided by the Russian crystallographers Shubnikov and Koptsik [91]. From the viewpoint of designers the works of Walker and Padwick [92], Schattschneider [93,94] and Stevens [95] are probably the most useful and accessible accounts of symmetry in pattern. In 1980, Crowe [96] presented a flowchart (based on Schattschneider's work) to aid in the identification of all-over pattern classes; this was developed further and published in collaboration with Washburn [97] to take into account two colour counterchange patterns (which are briefly discussed later in Chapter 6 of this thesis). In 1981, Rose and Stafford [98] provided an outline of an elementary instruction course in mathematical symmetry. Grunbaum and Shephard's [99] monumental treatise on the mathematics of patterns, published in 1987, will surely prove to be a twentieth century landmark to mathematical investigators in the field of pattern analysis. Likewise, Washburn and Crowe's [100] wide ranging and perceptive treatment of the theory and practice of pattern analysis, published in 1988, should, for decades to come, prove to be of great value to archaeologists, anthropologists and design historians. The diverse presence and application of symmetry is exhibited by two recently published compendia [101,102] which together include over one hundred papers from the pure sciences, the arts and humanities.

2.4 The Application of the Principles of Symmetry to Pattern Analysis.

In order that the study of surface decoration can be conducted systematically, the classification of explicitly defined, replicable units would appear to be a necessary pre-requisite. Precise classificatory tools enable hypothesis formation and theory testing. Symmetry classification would appear to be such a tool. However, with only a small number of exceptions, archaeologists, anthropologists and design historians had, until the 1970's, generally used the concept of symmetry in design in one of two ways: one treatment inferred the presence of symmetry by employing such terms as harmony and balance, and the other treatment used the term symmetry to refer to bilateral reflection symmetry. The latter usage of the term was evident in Boas' [103] classic anthropological treatise *Primitive Art.* Citing a wide range of examples from Peruvian textiles, Pueblo pottery, Australian aboriginal wooden shields and Andaman Island body painting, Boas [103a] maintained that symmetry was a universal property in '...the art of all times and all peoples'. Observing that '...symmetrical arrangements to the right and left of a vertical axis' were widespread in use, Boas [103b] maintained that this was due to the orientation of most natural phenomena including the human body. Using the term in a similarly restricted sense to that employed by Boas, other anthropological investigators focused attention on the decoration of objects from specific cultural settings. Examples include Holm's [104] study of the bilaterally symmetrical figures of North American West Coast Indian art, Levi-Strauss' [105] consideration of symmetries of Caduveo body art, Critchlow's [106] comparison of symmetries in Islamic architecture with the Islamic perception of the cosmos, and Glassie's [107] study of the structure of traditional folk architecture in Virginia. In all cases, relationships between decoration and wider aspects of cultural organisation were inferred.

Brainerd [108] was seemingly the first archaeological investigator to adopt a wider perspective of symmetry to that employed by Boas. Using the concept of symmetry in the fuller geometrical sense developed by crystallographers, Brainerd's work was pivotal in providing a penetrating insight of how symmetry classification might provide a systematic route to the cross-cultural comparison of decorated objects. Using prehistoric pottery as a source of data on motifs and border patterns , Brainerd [108] conducted an analysis of the symmetry characteristics exhibited by fragments from two distinct archaeological sites (the Monument Valley area of Arizona and the Mayan site of Chichen Itza in the Yucatan, Mexico). Two principal observations resulted from the study. These are briefly summarised below.

Firstly, Brainerd found that different types of symmetry predominated in each of the two groups of pottery, and that the symmetry exhibited by one group of designs was more diverse than that exhibited by the other group of designs. In retrospect these findings may not seem to be startling, but the method of obtaining data (i.e. through recording the symmetry characteristics of defined groups of designs) demonstrated that an objective comparison could be made between designs originating in two widely different cultural settings.

Secondly, Brainerd implied that within a given cultural setting there will be a preferred symmetry or symmetries used to decorate objects and whilst such symmetry arrangements may not necessarily be named or even recognised consciously by the people using them, they will none the less be followed exactingly.

Although Brainerd's work was published in 1942, in one of the most popular North American archaeological journals, a more widespread acceptance of symmetry analysis, and its further development as an aid to the classification of pattern, was not readily forthcoming for some decades to come, a situation deplored by Stewart [109] as recently as 1980. There are however three notable early exceptions, published in 1944, 1948 and 1965; these are briefly reviewed below.

Muller [110] analysed the symmetries of tiling patterns in the Alhambra Palace, Granada, Spain, and found that eleven of the seventeen possible all-over pattern classes were represented. Although subsequent research, such as that conducted by Grunbaum, Grunbaum and Shephard [111] has indicated minor flaws in Muller's findings, her work none the less stands as the first systematic attempt to apply the principles of symmetry to the analysis of all-over patterns from a defined period and a specific cultural context.

As indicated previously, the work of Shepard [112] is of great importance. In 1948 she explored in some detail the potential of symmetry analysis as an analytical tool to the archaeologist and illustrated different classes of motifs and border patterns with pottery examples from the American Southwest. She outlined the nature of a variety of problems (e.g. faulty draftsmanship or the combination of different symmetries in complex designs) which may be encountered by the analyst and highlighted the tendency for certain symmetries to predominate within a given cultural context. In addition she remarked on how cultural change (brought about particularly by the adoption of cultural traits from another culture) may be pinpointed by symmetry analysis, subject to the availability of a representative time series of data. In a subsequent work, published in 1956, Shepard [113] included a summarised version of her 1948 study.

In 1965, MacGillavry [114] illustrated the seventeen classes of all-over patterns with examples taken from the work of Dutch artist M. C. Escher (1898-1971). As shown by Locher [115] Escher's inspiration for his tessellating figures, which are characteristic of many of his works, resulted in part from a visit to the Alhambra in the mid-1930's, prior, therefore, to the study conducted by Muller [110] in 1944. As pointed out by Washburn and Crowe [116], by 1942 Escher had compiled a notebook in which he had illustrated patterns with both rotational and glide-reflection characteristics, using two, three, four and six colours.
Subsequent to the four pioneering studies mentioned above, a number of investigators have set out to classify and compare patterns on decorated objects from specific cultural settings. Using symmetry classification as an analytical tool, it has been possible, as pointed out by Washburn [117], to,

> "...study more systematically consistencies and changes in temporal and spatial aspects of design styles and to relate these shifts to other patterns of activity in a given culture."

A selection of relevant publications, in which patterns have been classified by reference to their symmetry characteristics, are briefly reviewed below.

Crowe [118-120] in a series of studies of African decorative art, analysed the symmetries of Kuba decorated artifacts (from Zaire), Benin bronzes (from Nigeria) and Begho clay smoking pipes (from Ghana); in each case different symmetry classes were found to predominate. Focusing on the incidence of temporal changes in the use of certain symmetry classes, Crowe [120] found evidence to suggest the early absence, but subsequent presence, of three of the seven classes of border patterns and implied that parallel changes in society accounted for these changes.

Zaslow and Dittert [121] employed symmetry analysis in the study of Hohokam ceramics (largely from the site at Snaketown, Arizona), and presented a chronology of change in the dominant symmetry classes. Their analysis suggested,

> "...a connection between social factors and the pattern class selected for ceramic decoration."

The Aschers [122], in their study of Inca culture, analysed 300 border patterns and 120 all-over patterns on pottery fragments. All seven classes of border patterns were represented to varying degrees, but forty per cent were from one border class only, twenty per cent were from a second border class and eleven per cent were from a third border class. Seventy per cent of all-over patterns were from four all-over pattern classes and the remaining thirty per cent were from eight all-over pattern classes. The Aschers noted that other aspects of Inca culture (e.g. the structural layout of the residential compound) exhibited similar repetitive characteristics to the dominant pattern types.

Van Esterik [123] in her analysis of pottery designs from the site of Ban Chiang, Thailand, found that two of the seven classes of border patterns were the most consistently used for body and pedestal bands; two further classes of border patterns were most consistently used on the bodies of vessels.

In one of the few studies concerned with textiles, Kent [124] employed symmetry classification in the study of temporal changes and continuities in the patterning of prehistoric textiles from the American Southwest. She presented an interesting correlation of the shifts in design structure with other major events in the chronology of the area.

Washburn [125-128] presented a range of studies which employed symmetry classification as an analytical tool to: Anasazi ceramics, to make comparisons between different archaeological sites; Greek Neolithic ceramics, to aid the study of trade networks; Indian basketry designs from California, to facilitate the correlation of design characteristics with aspects of language, marriage practices and trade networks. Her results generally indicated that design structures within each cultural setting were homogeneous and non-random.

Campbell [129] presented a detailed commentary and symmetry analysis of specimens of Pueblo pottery from Starkweather Ruin in New Mexico. He observed a strong preference for two-fold symmetry and vertical reflection, and an almost total absence of horizontal reflection and glide-reflection. Campbell's major conclusion was that pattern analysis, based on symmetry classification, provided an easy comparison of artifacts from different archaeological sites. He commented that his findings offered support to Washburn's [130] assertion that,

> "...the use of symmetry classes to measure similarities in design structure is a very consistent, objective procedure that can yield accurate, reproducible and comparable results."

By way of summary, it appears from the relevant archaeological and anthropological literature that groups of artisans, working within a given cultural setting (i.e. a context, within which interacting individuals share a set of learned beliefs, values, attitudes, habits and forms of behaviour that are transmitted from generation to generation), will show preferential arrangements of design elements. Rather than randomly using many of the infinite number of motif classes, all of the seven border pattern classes and all of the seventeen all-over pattern classes, a preference for specific symmetry classes will be evident. This non-randomness of design structure is of fundamental significance, for it demonstrates that symmetry classification may be a culturally sensitive analytical tool. In the case studies presented in Chapter 7, non-randomness of design structure is tested in the context of groups of textiles from a selection of cultural settings. Data are also tested to establish if the symmetry preferences associated with a given culture have a tendency to be maintained over the passage of time, in the absence of external pressures for change (such as trade and other forms of inter-cultural communication). Further to this, data are tested to establish if technique of manufacture has any bearing on the symmetry characteristics of groups of patterns produced in the same cultural context.

The symmetry characteristics of motifs, border patterns and all-over patterns are further discussed in the following pages in association with an appropriate notation which facilitates the systematic classification of each of the three design categories.

3. THE CLASSIFICATION OF MOTIFS.

Dependent upon the symmetry operations used in its production, a motif is classified using the notation cn or dn, where n is some integer. Motifs from family cn (c for cyclic) exhibit n-fold rotational symmetry but no other symmetry. Motifs from family dn (d for dihedral) have n distinct reflection axes as well as n-fold rotational symmetry. Motifs therefore allow no translations or glide-reflections and are limited in terms of symmetry operations to rotations about a fixed point and/or reflection across an axis or axes. A further explanation of the geometrical principles governing the structure of motifs is provided below. In order to refer unambiguously to the area occupied by motifs, each is considered inscribed within a circle.

An asymmetrical motif, when considered as an independent entity, can only repeat (or coincide with itself) after a full rotation of 360 degrees. This being the case, asymmetrical motifs have no rotational (or any other) symmetry characteristics and are thus classified as c1 motifs. Examples of typical asymmetrical motifs are shown in Figure 2.

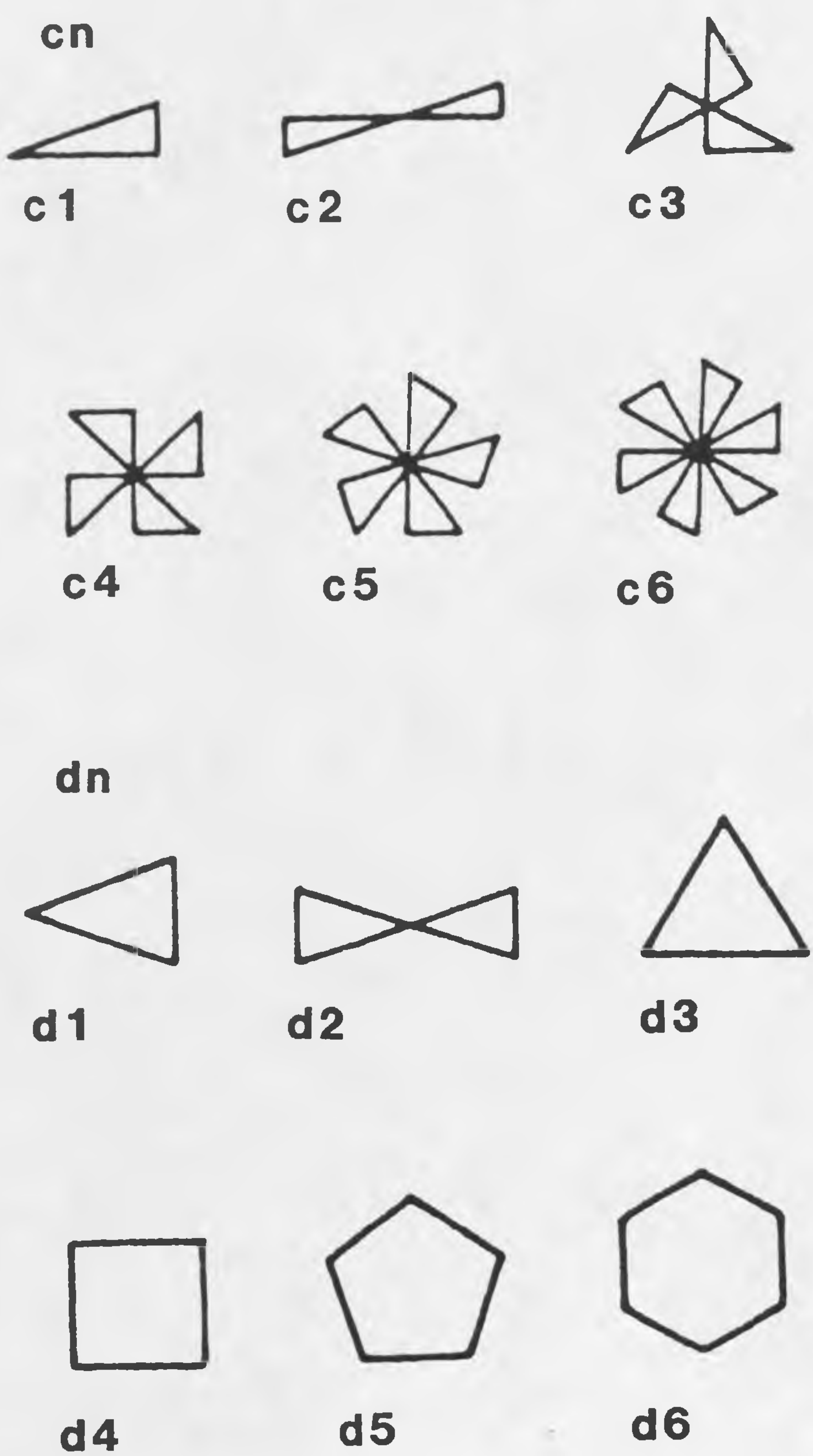
Symmetrical motifs, which are characterised by reflectional and/or rotational symmetry, are classified as follows:

d1, c2, d2, c3, d3, c4, d4, c5, d5, c6, d6...dn, cn + 1

Figure 2. Asymmetrical Motifs (c1).

Using simple geometrical figures, Figure 3 illustrates the basic principles underlying the above notation.

Figure 3. Class cn and Class dn Motifs.
(schematic illustrations)



The addition of a reflection axis to an asymmetrical unit will yield a motif with bilateral symmetry which can be classified as d1. Examples are shown in Figure 4. Each motif within this class contains two fundamental units, each a mirror reflection of the other.

Figure 4. Class d1 Motifs.

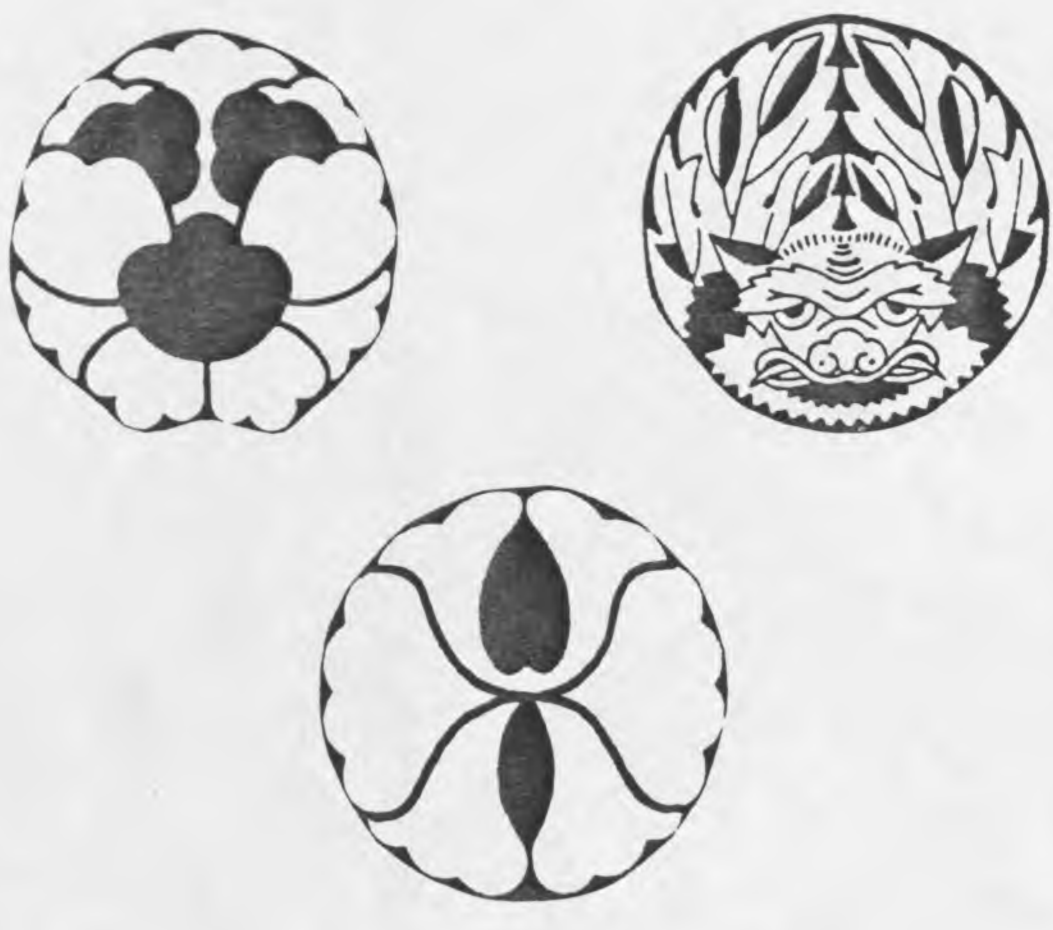
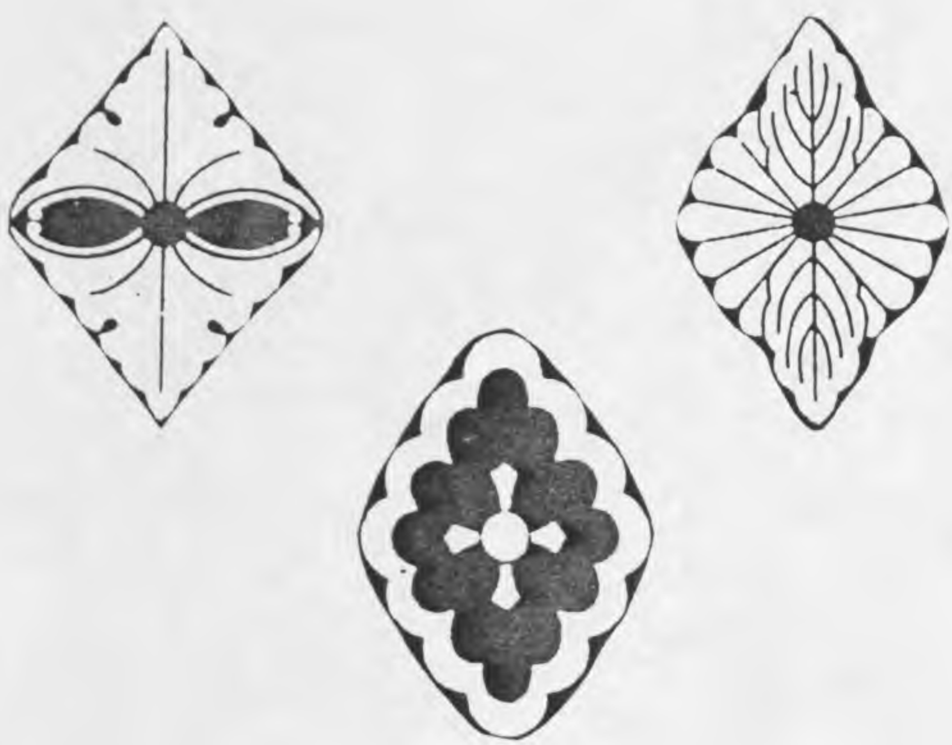


Figure 5 shows class c2 motifs. Each of these is comprised of two fundamental units, has two-fold rotational symmetry (i.e. rotation through 180 degrees allows one fundamental unit to coincide with its partner) and is of identical appearance if viewed right-side-up or up-side-down.

Figure 5. Class c2 Motifs.

Motifs from the dihedral family, of classes higher than d1, exhibit both reflectional and rotational symmetry in that they may be produced through reflection of a fundamental unit in a series of reflectional axes intersecting at a central fixed point, or alternatively, may be produced by rotation of a bilaterally symmetrical unit about a centre of rotation. Motifs from class d2, examples of which are shown in Figure 6, therefore have bilateral symmetry around both their horizontal and their vertical axes. Each motif has two reflection axes, intersecting at 90 degrees. The fundamental region is one quarter of a circle. The motif may also be produced by rotations of a bilaterally symmetrical unit through 180 degrees and 360 degrees.

Figure 6. Class d2 Motifs.



As shown by examples in Figure 7, three rotations (of 120 degrees, 240 degrees and 360 degrees) bring a class c3 motif into coincidence with itself.

Figure 7. Class c3 Motifs.

Class d3 motifs, examples of which are shown in Figure 8, have three intersecting reflection axes which produce bilaterally symmetrical units spaced at 120 degrees. The fundamental region is therefore one-sixth of a circle. This class of motifs may also be produced by rotations of a bilaterally symmetrical unit through 120 degrees, 240 degrees and 360 degrees.

Figure 8. Class d3 Motifs.

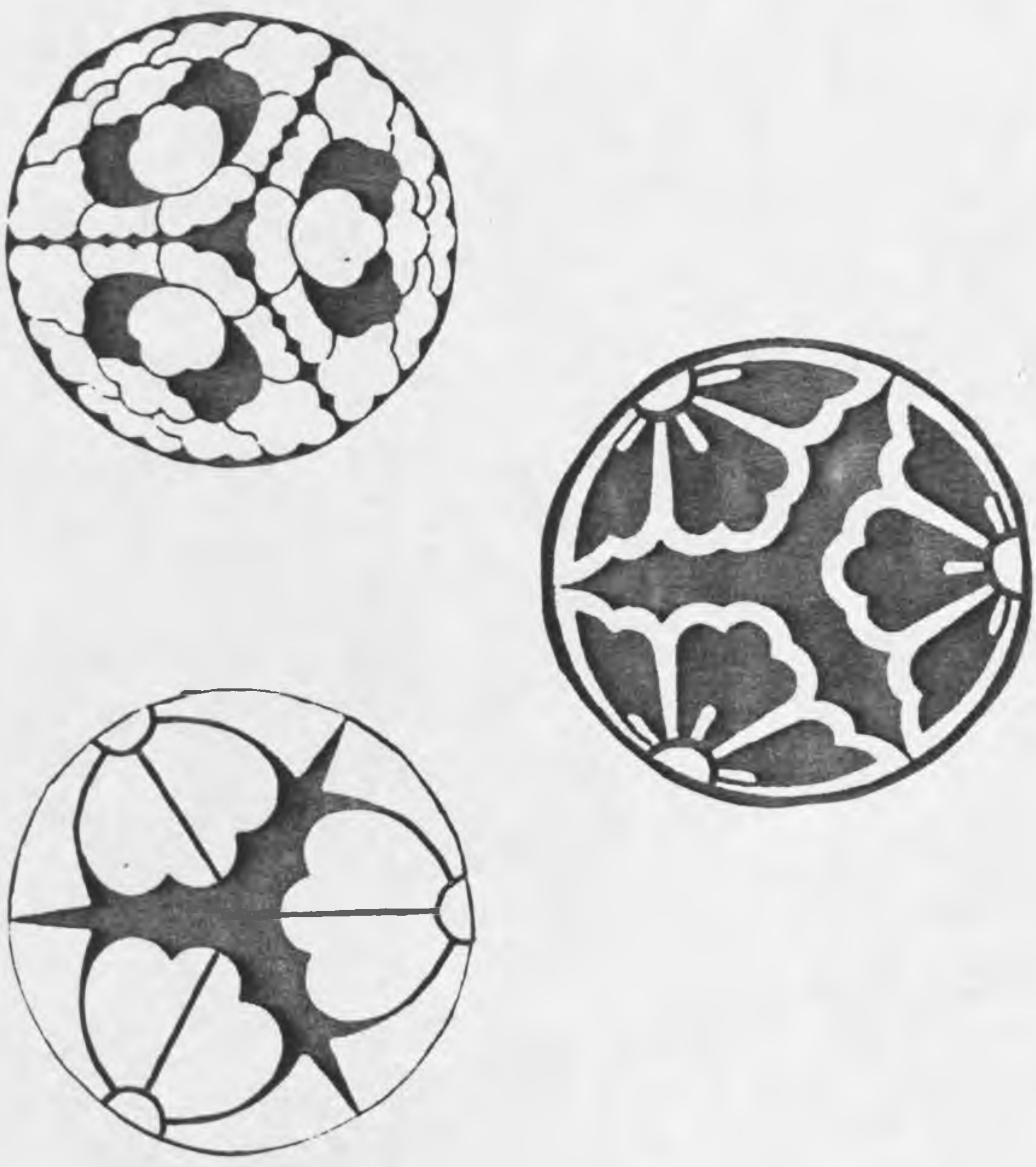
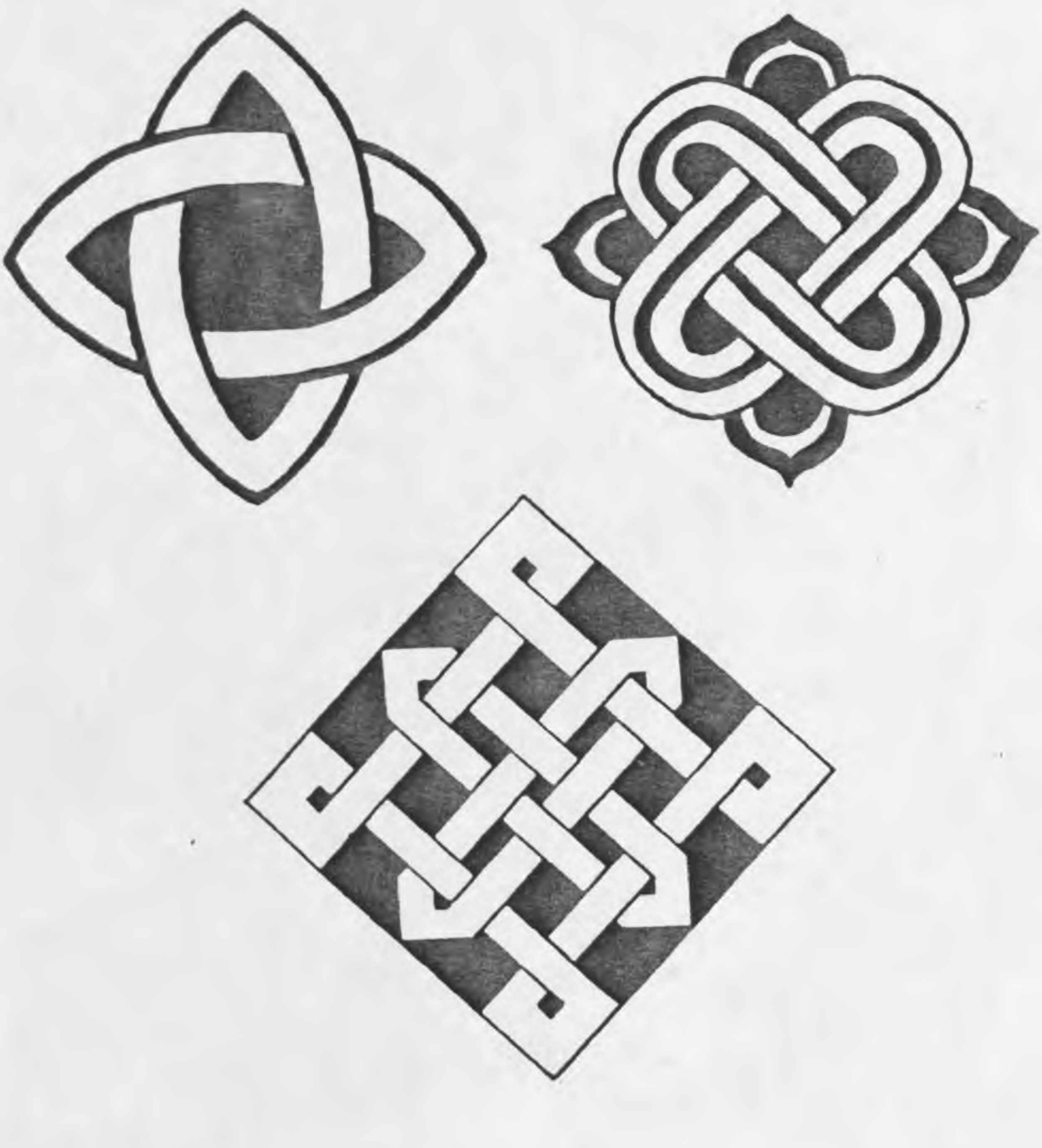


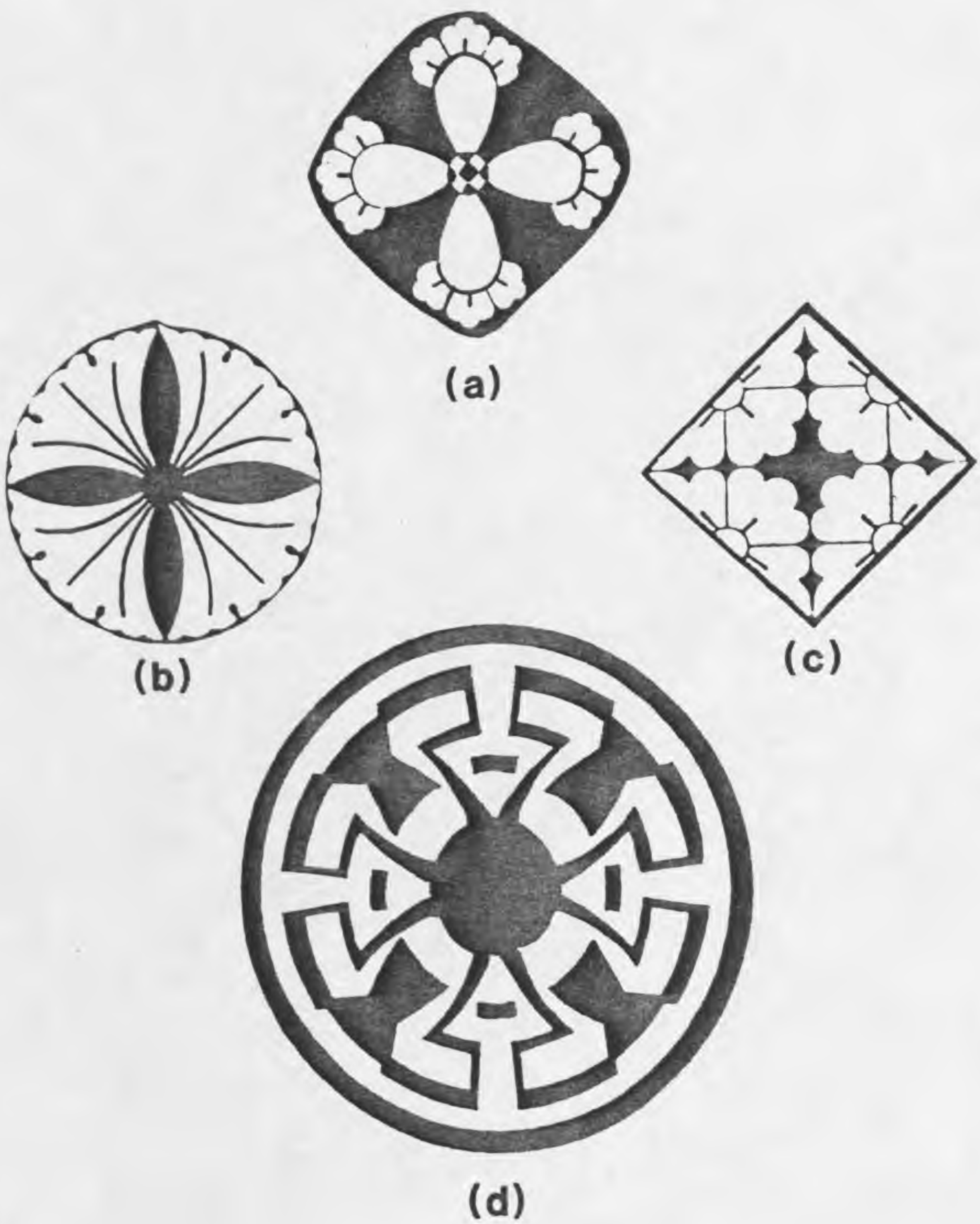
Figure 9 shows examples of motifs from class c4. These are characterised by the presence of rotations through 90 degrees, 180 degrees, 270 degrees and 360 degrees.

Figure 9. Class c4 Motifs.



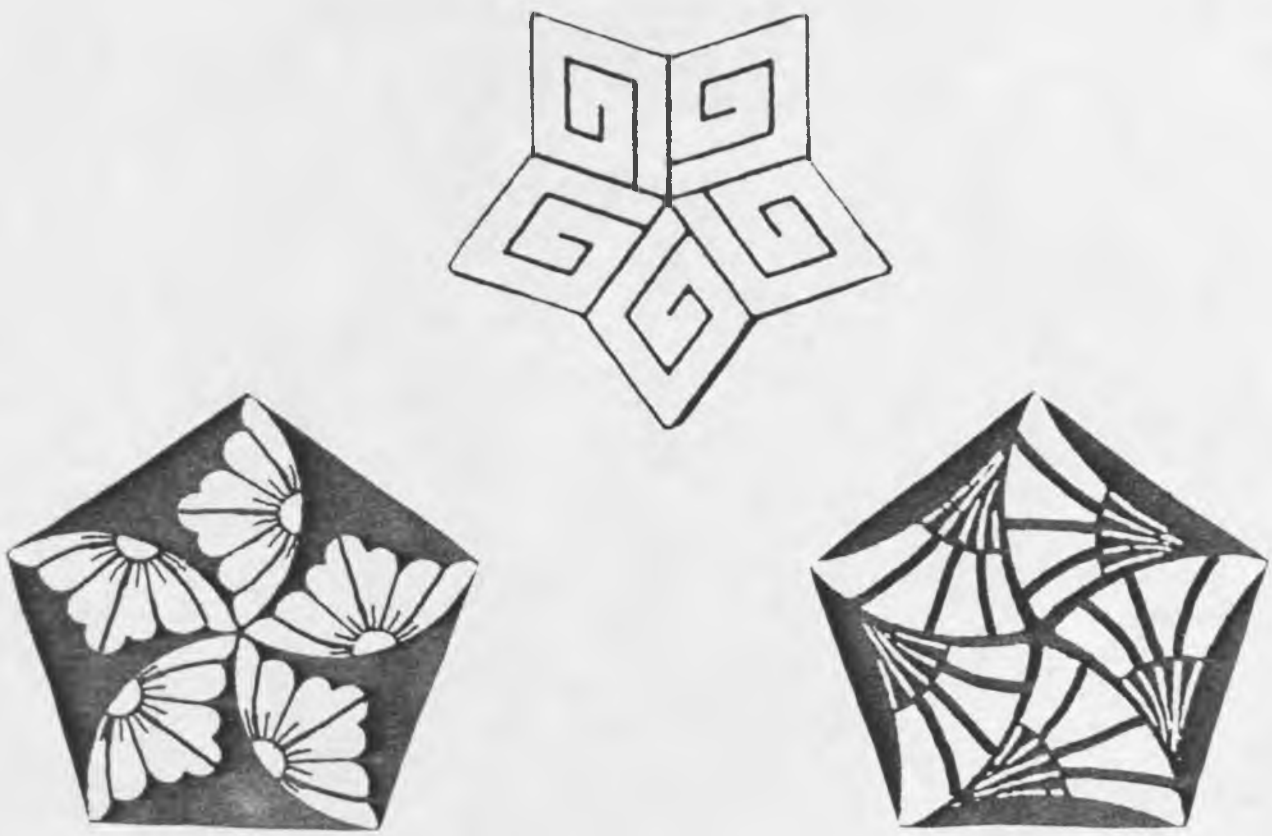
Four intersecting reflection axes produce class d4 motifs. Typical examples are shown in Figure 10. The fundamental region is one-eighth of a circle. Class d4 motifs may also be produced by rotation of a bilaterally symmetrical unit through 90 degrees, 180 degrees, 270 degrees and 360 degrees.

Figure 10. Class d4 Motifs.



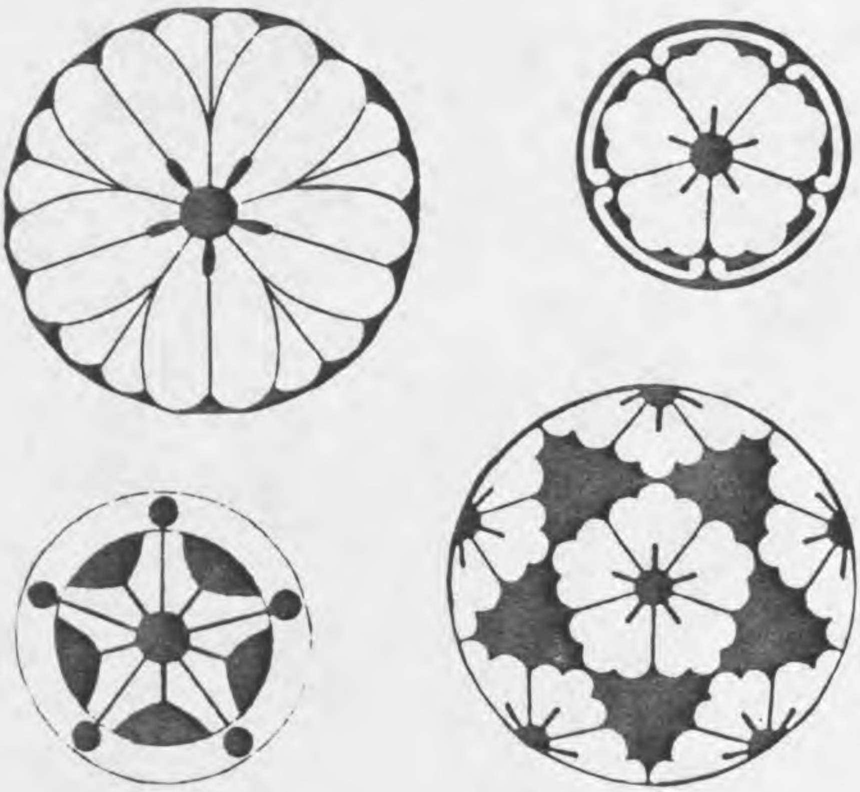
Five-fold rotation characterises motifs from class c5, examples of which are shown in Figure 11.

Figure 11. Class c5 Motifs.



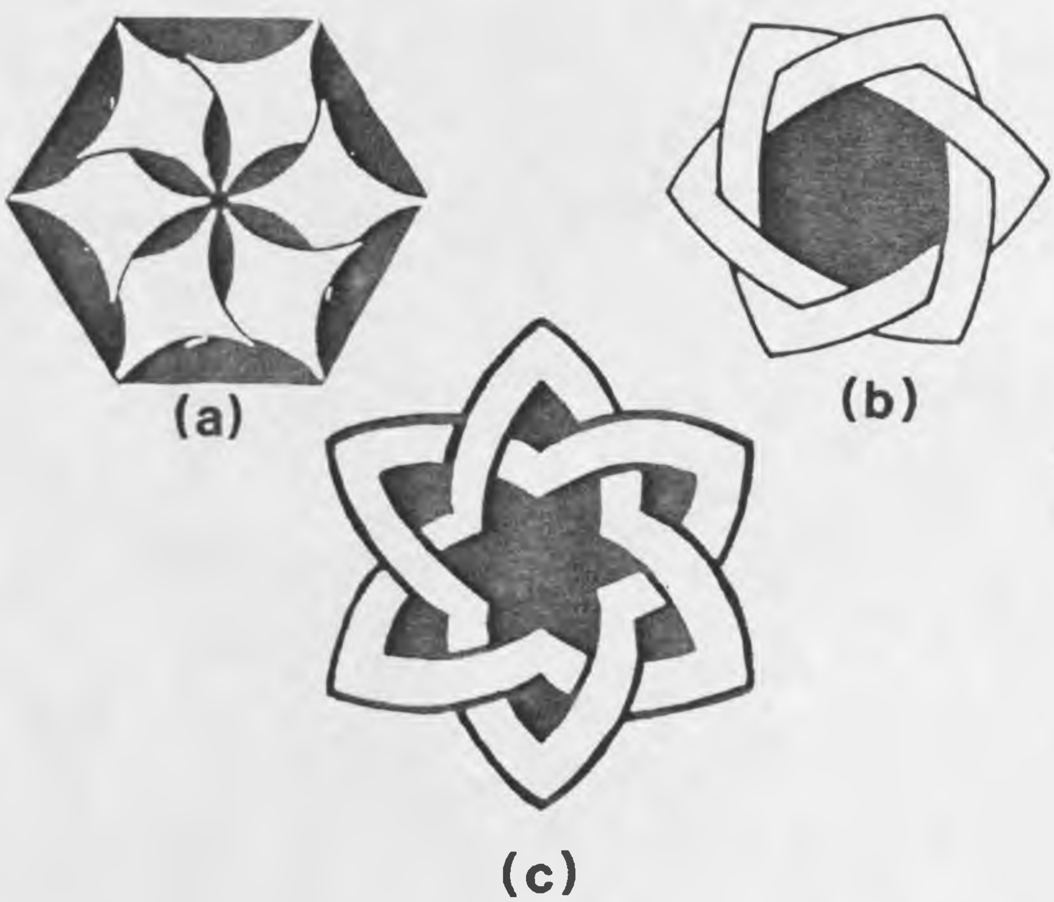
Five intersecting reflection axes produce class d5 motifs, examples of which are shown in Figure 12. In the case of motifs from this class the fundamental region is one-tenth of a circle (i.e. a 36 degree sector bounded by reflection axes). Class d5 motifs may also be produced by rotations of a bilaterally symmetrical unit through 72 degrees, 144 degrees, 216 degrees, 288 degrees and 360 degrees.

Figure 12. Class d5 Motifs.



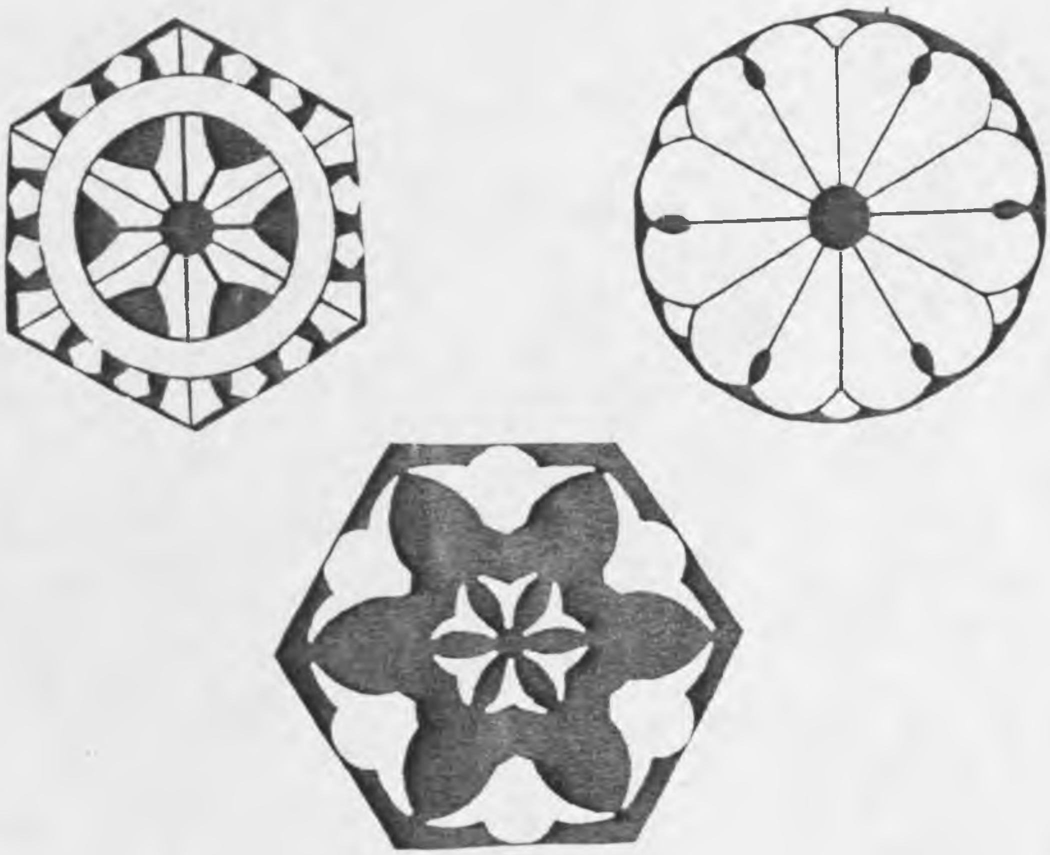
Six-fold rotation characterises class c6 motifs, examples of which are shown in Figure 13. The fundamental region is comprised of one-sixth of a circle.

Figure 13. Class c6 Motifs.



Six intersecting reflection axes produce class d6 motifs. Examples from this class are shown in Figure 14. The fundamental region is one-twelfth of a circle. Motifs from this class may also be produced by rotations of a bilaterally symmetrical unit through 60 degrees, 120 degrees, 180 degrees, 240 degrees, 300 degrees and 360 degrees.

Figure 14. Class d6 Motifs.



Figures 15 and 16 show examples of motifs from higher order c and d classes respectively, together with their relevant notation. The limiting case of both cn and dn is a circle, which has a rotational centre of infinite order and an infinite number of intersecting reflection axes.

Figure 15. High Order Class c Motifs.

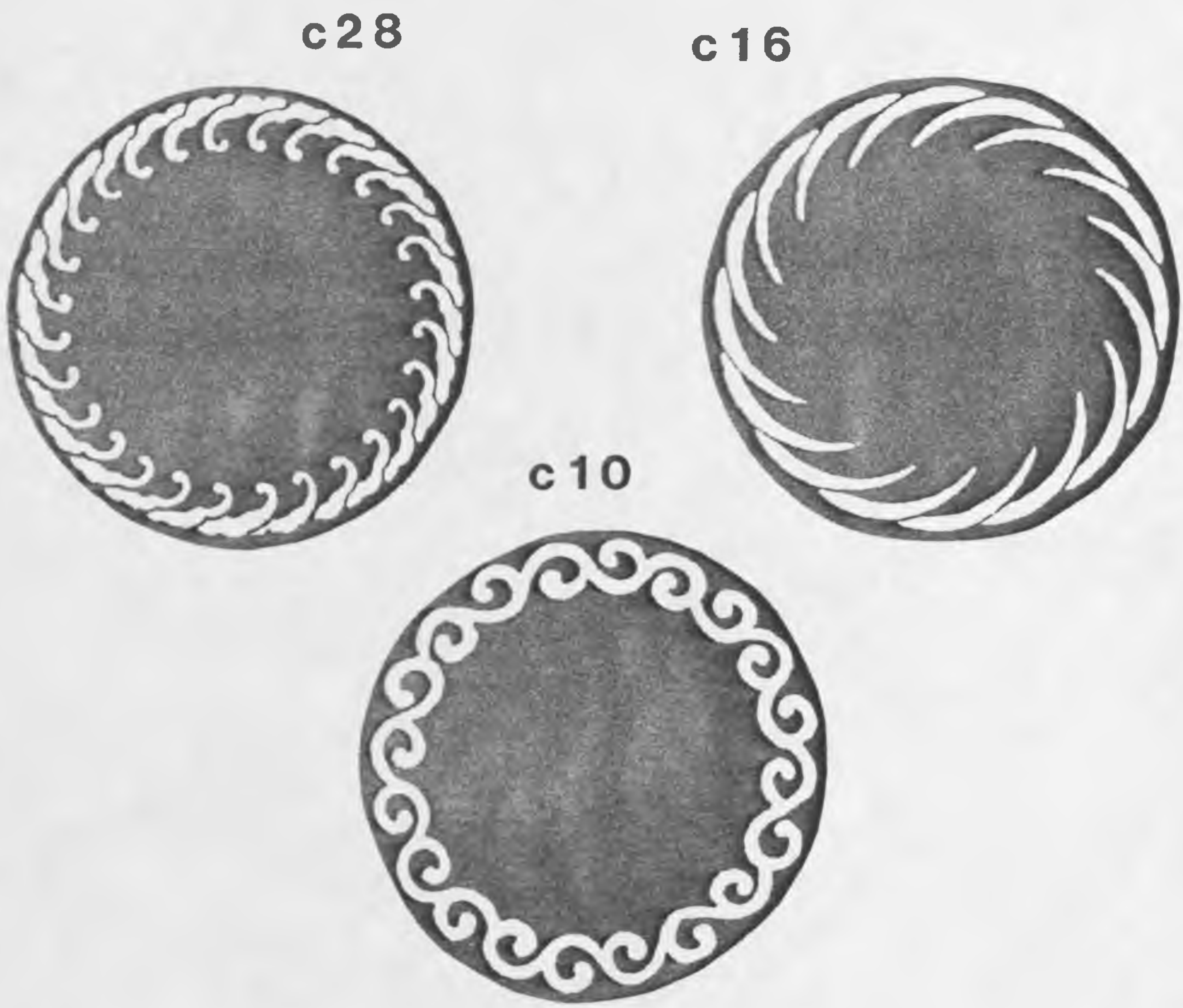
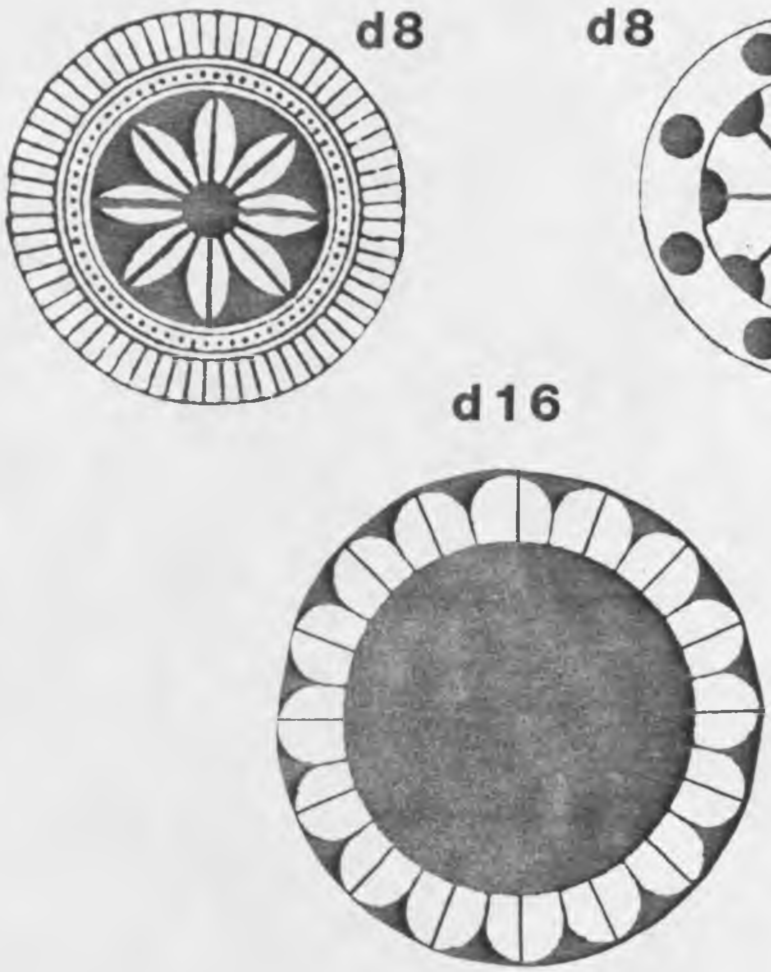


Figure 16. High Order Class d Motifs.



As will become evident when attention is focused on the symmetry characteristics of patterns, some of the rotational and reflectional properties exhibited by motifs may also be exhibited by regular repeating patterns.

4. THE CLASSIFICATION OF BORDER PATTERNS.

4.1. An Explanation of the Relevant Notation.

In the construction of border patterns, translation occurs along an imaginary horizontal axis which is parallel to the sides of the border and is known as a *translation axis*. Where reflection is present in a border pattern it may be across a reflection axis parallel to the sides of the border and/or across a reflection axis perpendicular to the sides of the border. To ensure that the sides of the border remain correctly orientated, rotation, where it is feature of border patterns, may only be of the two-fold (i.e. 180 degree) variety. Where glide-reflection is present, this occurs in association with an imaginary horizontal glide-reflection axis parallel to the sides of the border.

As indicated previously, a total of seven (and only seven) distinct possibilities, from the viewpoint of symmetry and ignoring interchange of colour, can be identified. Proofs for the existence of only seven classes of border patterns can be found in Washburn and Crowe [131a]. A generally accepted four-symbol notation of the form pxyz may be used to enable systematic classification. Further explanation is provided below.

As shown by Washburn and Crowe [131b] the first symbol p, of the four symbol notation, prefaces the notation for each of the seven distinct border classes. The symbols in the second, third and fourth positions denote the presence of vertical reflections, horizontal reflections or glide-reflections, and half turns respectively. Where a vertical reflection is present, x is m (for mirror); otherwise x is 1. Where a horizontal reflection is present, y is m and where a glide-reflection is present y is a; otherwise y is 1. Where two-fold rotation is present z is 2; otherwise z is 1.

Using a simple asymmetrical figure (of class c1), the seven distinct possibilities, employing combinations of the four symmetry operations are illustrated in Figure 17, together with the relevant notation:

p111, p1a1, pm11, p1m1, p112, pma2, pmm2

It should be noted (from Figure 17) that through the use of reflection and/or rotation, the asymmetrical figure appears to develop into a constituent part of a larger symmetrical figure which is subsequently translated along the axis. Each class of border pattern is further described and illustrated below.

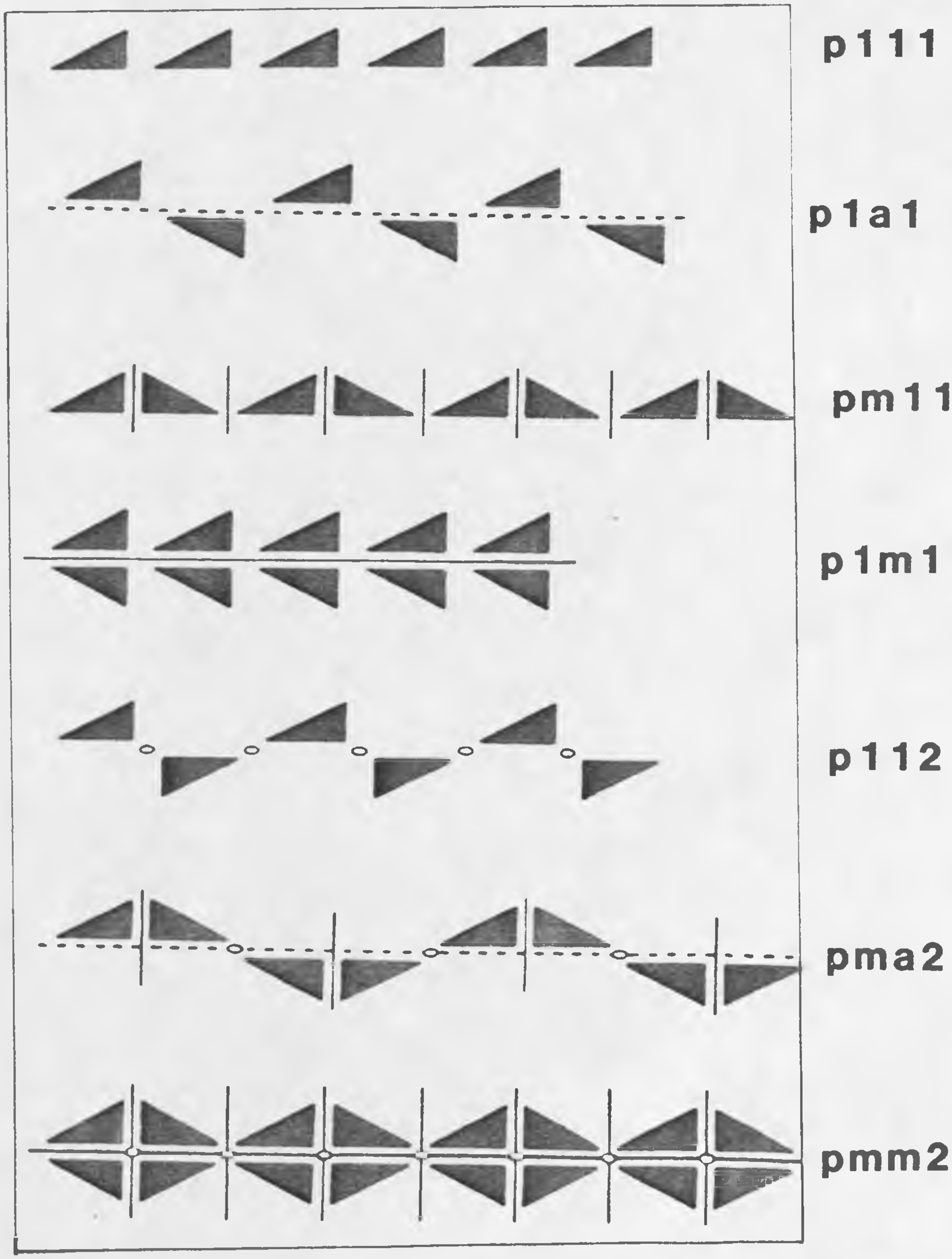
4.2. Class p111 Border Patterns.

The most elementary border class is translation class p111 which is generated by translation of an asymmetrical (class c1) motif by a specified distance along an imaginary line known as the translation axis. Examples are shown in Figure 18.

The fundamental region, which is the smallest area of the pattern that repeats itself with the absence of gaps or overlaps, is bounded by the edges of the border and by two imaginary lines (which are of parallel orientation and are of equal length) separated by a distance of one translation.

Figure 17. Schematic Illustrations of the

Seven Classes of Border Patterns.



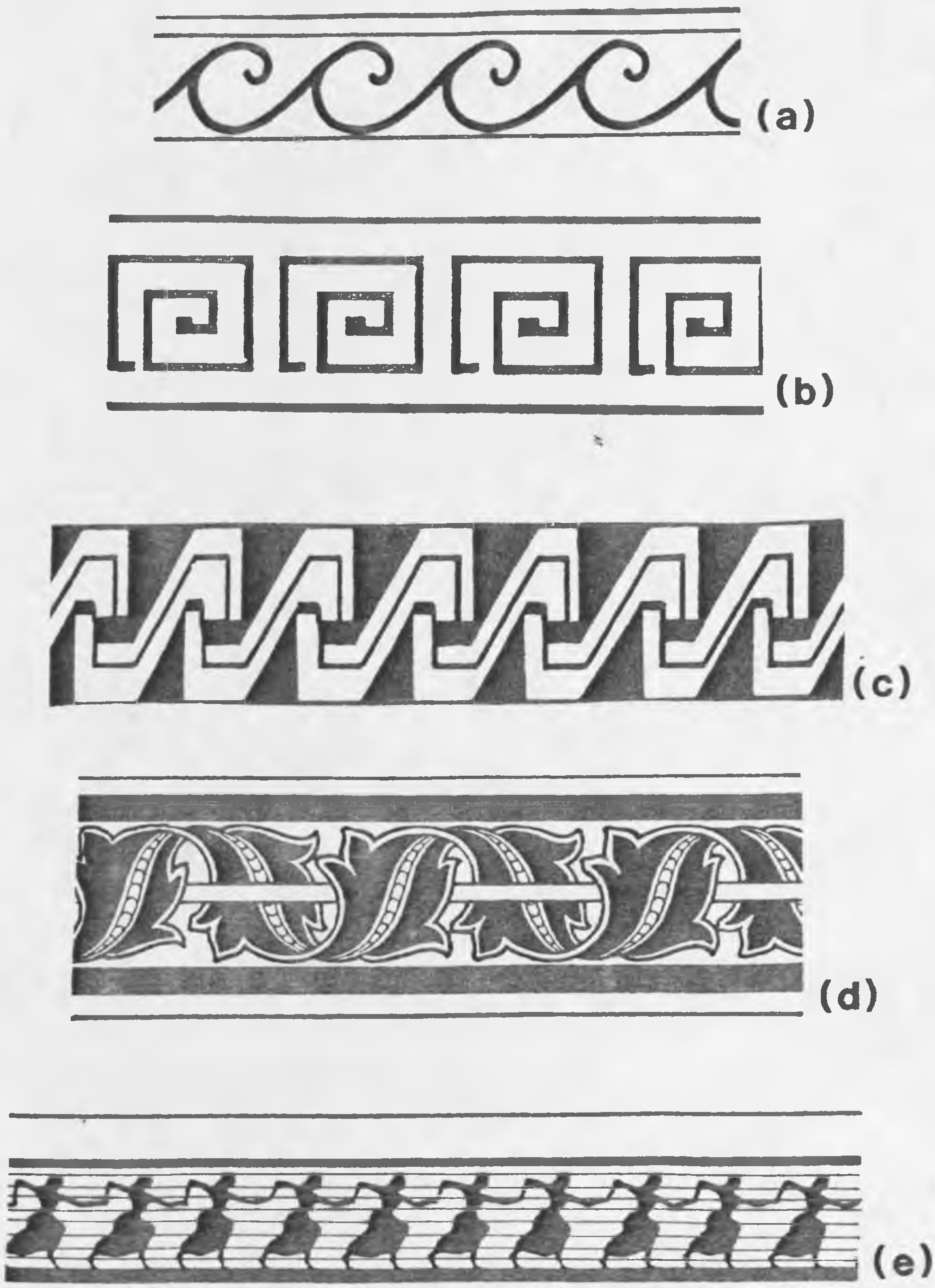
Key: ○ 2-fold rotation

— horizontal reflection axis

----- glide-reflection axis

| vertical reflection axis

Figure 18. Class p111 Border Patterns.



4.3. Class p1a1 Border Patterns.

Class p1a1 border patterns are generated by the glide-reflection of a class c1 motif. Examples from this pattern class are shown in Figure 19.

4.4. Class pm11 Border Patterns.

Class pm11 border patterns are generated by alternating reflection axes perpendicular to the axis of translation. Examples of class pm11 border patterns are shown in Figure 20.

4.5. Class p1m1 Border Patterns.

Class p1m1 border patterns have a single reflection axis that runs along the direction of translation. Examples of class p1m1 border patterns are shown in Figure 21. By way of differentiation between class p1m1 patterns and pm11 patterns, Stevens [132a] observed that class p1m1 reflects translations whereas class pm11 translates reflections.

4.6. Class p112 Border Patterns.

Class p112 border patterns exhibit two-fold rotational symmetry (indicated by the fourth position in the notation). These patterns are characterised by successive translations of motifs with two-fold centres of rotation (c2 motifs). In this way, a second two-fold centre is generated which alternates with the first two-fold centre. Examples of class p112 patterns are shown in Figure 22.

Figure 19. Class plal Border Patterns.

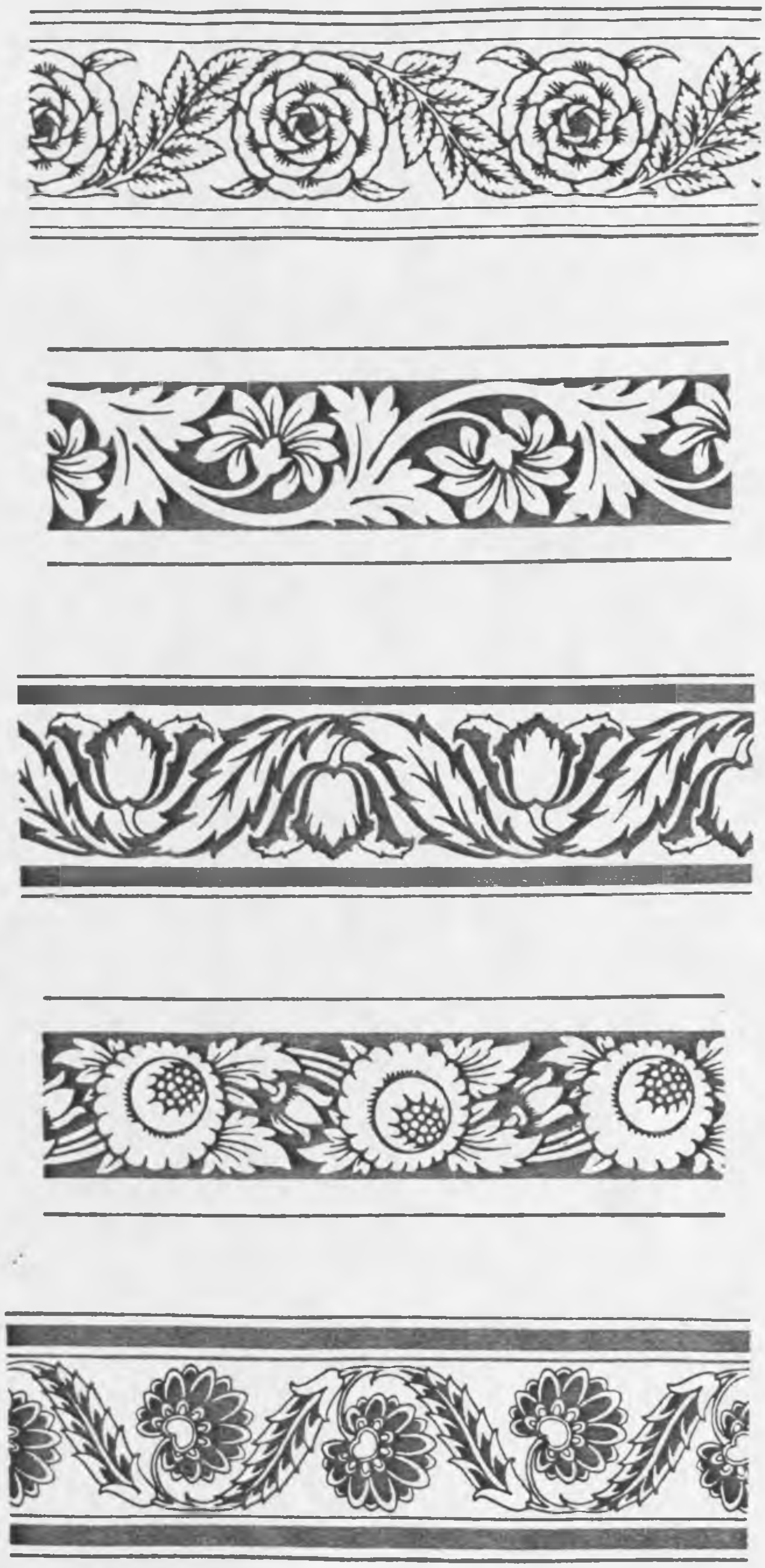
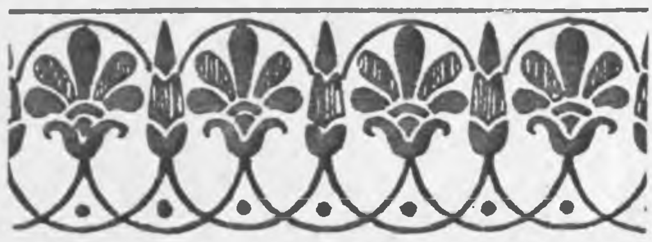


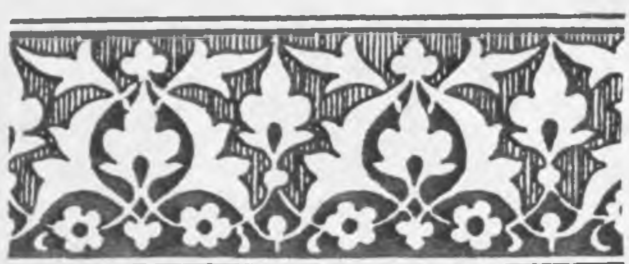
Figure 20. Class pm11 Border Patterns.

(a)

(b)



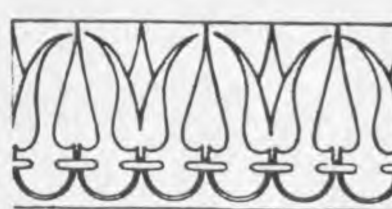
(c)



(d)

(e)

(f)



(g)

Figure 21. Class p1m1 Border Patterns.

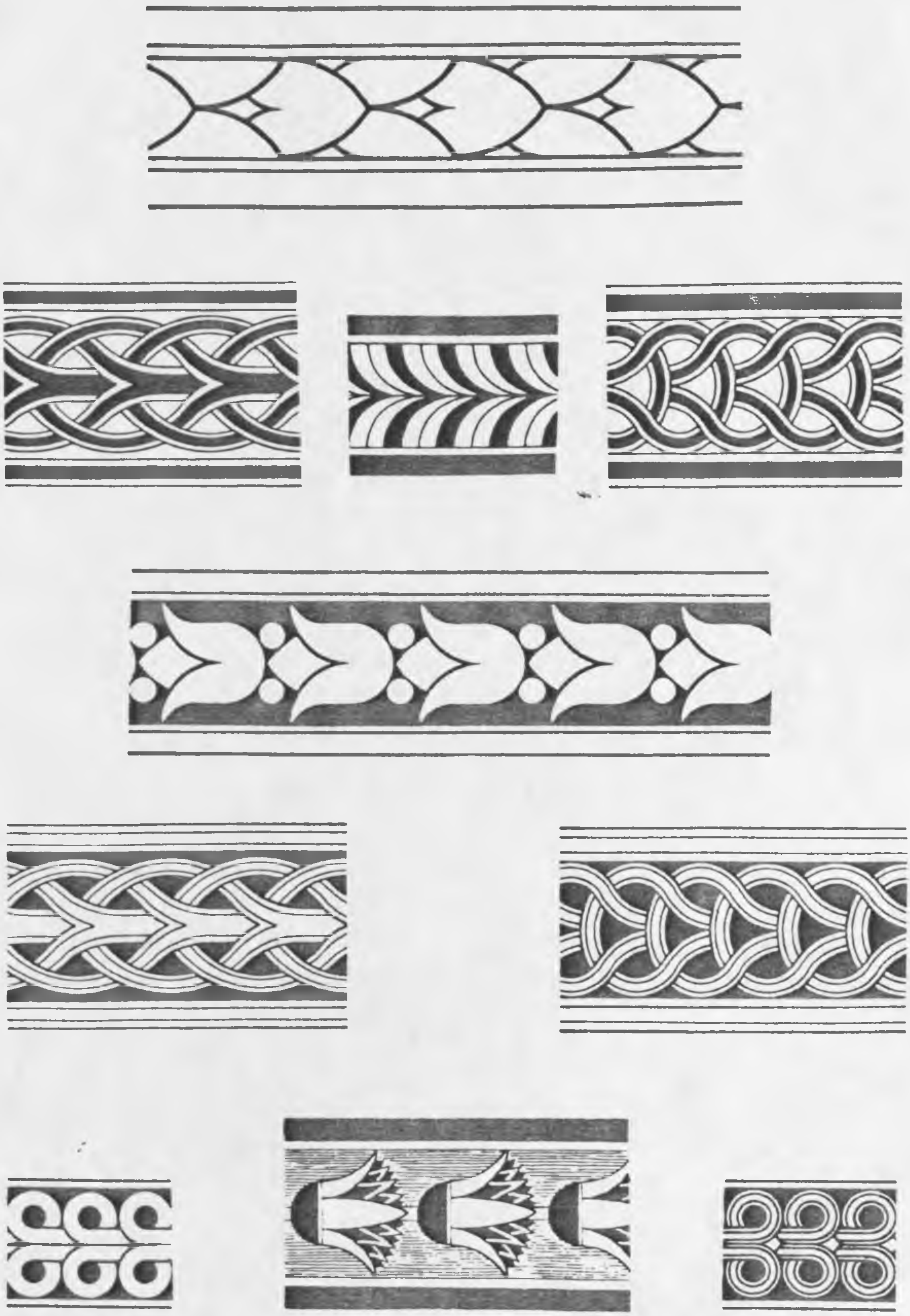
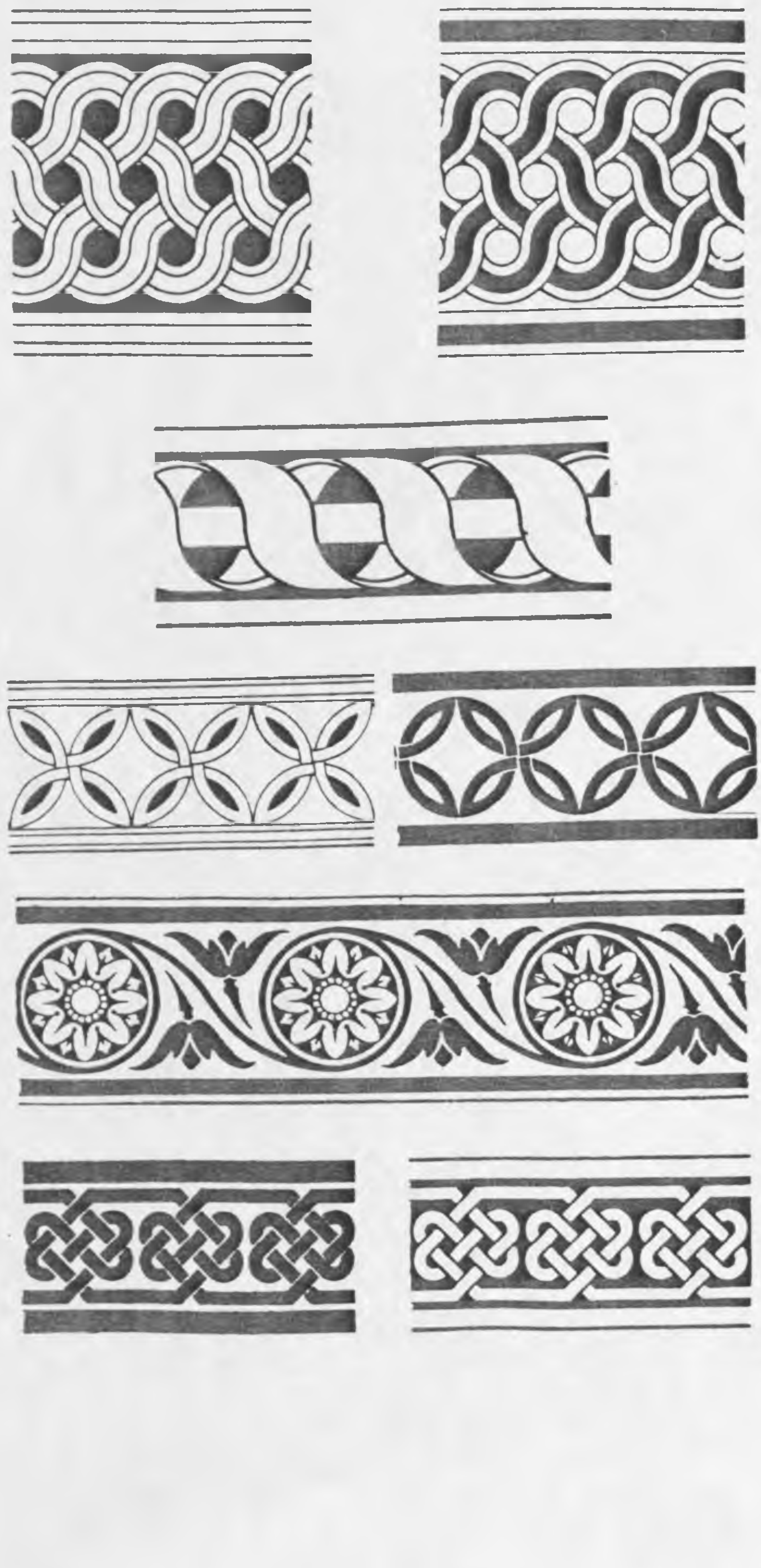


Figure 22. Class p112 Border Patterns.



4.7. Class pma2 Border Patterns.

As observed by Stevens [132b] border patterns from this class may be generated using one of four procedures: by successive reflection of a class c2 motif; by successive translation of two alternate class c2 motifs; by successive two-fold rotation of a class d1 motif; by successive glide-reflection of a class d1 motif. Examples of class pma2 border patterns are shown in Figure 23.

4.8. Class pmm2 Border Patterns.

The remaining class of border patterns, pmm2, has a continuous horizontal reflection axis intersected at regular points by two alternating perpendicular reflection axes. One of two class d2 motifs, each having a fundamental region of the same area, may be visualised within the pattern. In the diagrammatic example shown in Figure 17, the smallest angle of the scalene triangle orientates towards one of the two intersections of the horizontal and vertical reflection axes to produce one d2 motif; the other d2 motif is produced when the 90 degree angles of the scalene triangles are orientated towards the other intersection. Figure 24 shows examples of pmm2 border patterns.

It is worth commenting that any of the latter three classes of border patterns described above (i.e. classes p112, pma2 and pmm2) may be distinguished from the first four classes of border patterns by turning the pattern up-side down; if the pattern appears the same and is orientated in the same direction, then it is classed as p112 or pma2 or pmm2.

Figure 23. Class pma2 Border Patterns.

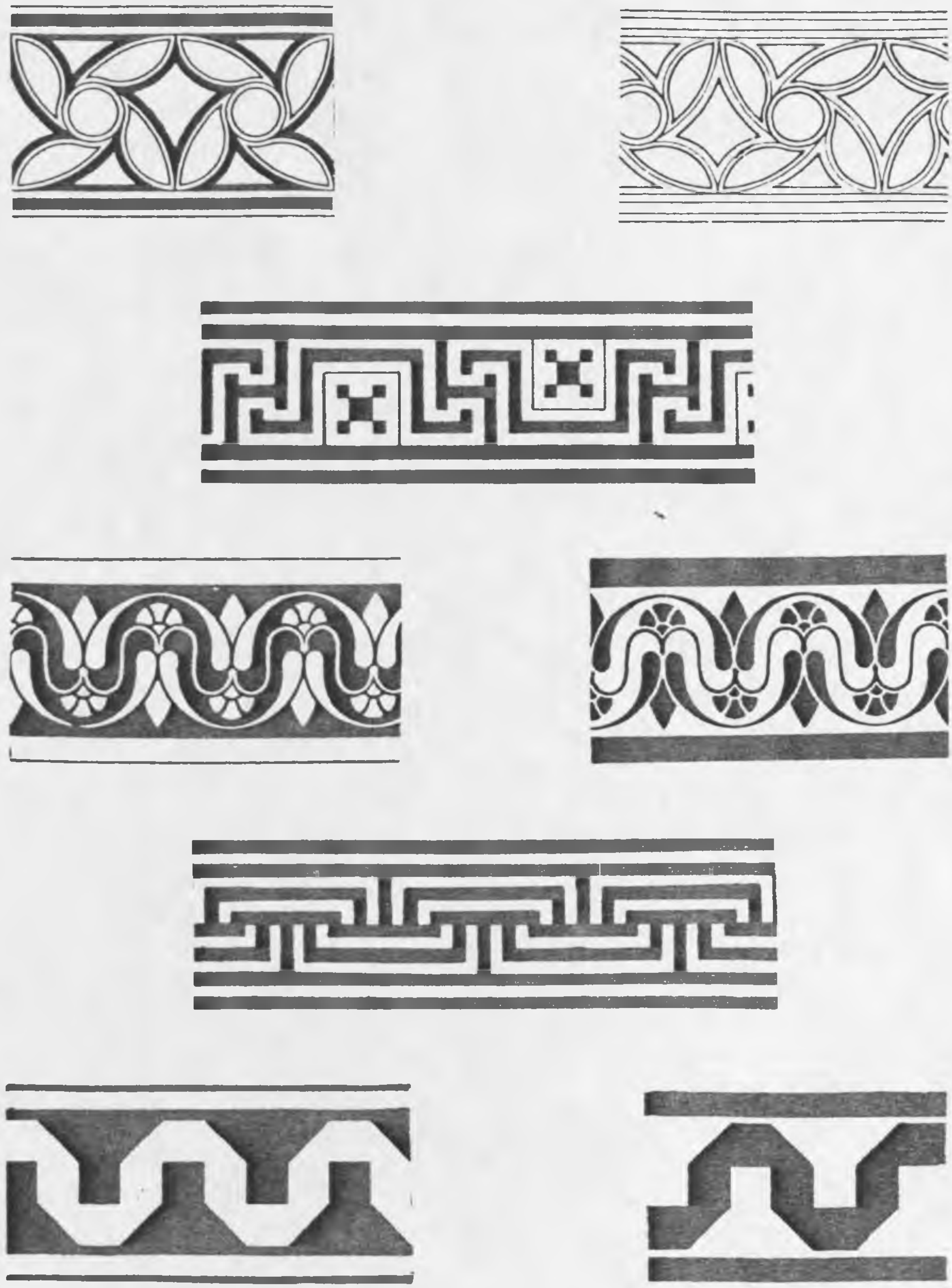
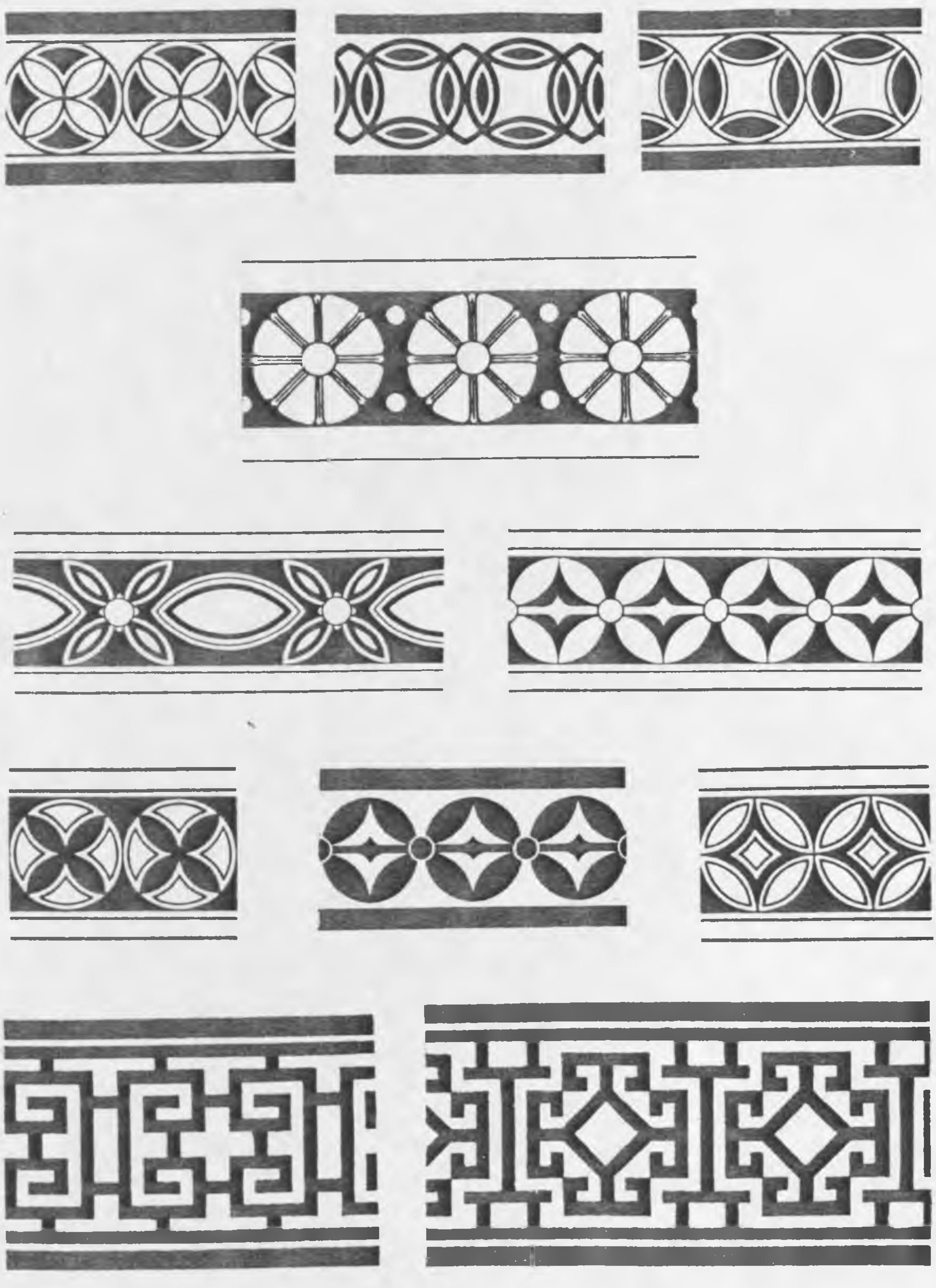


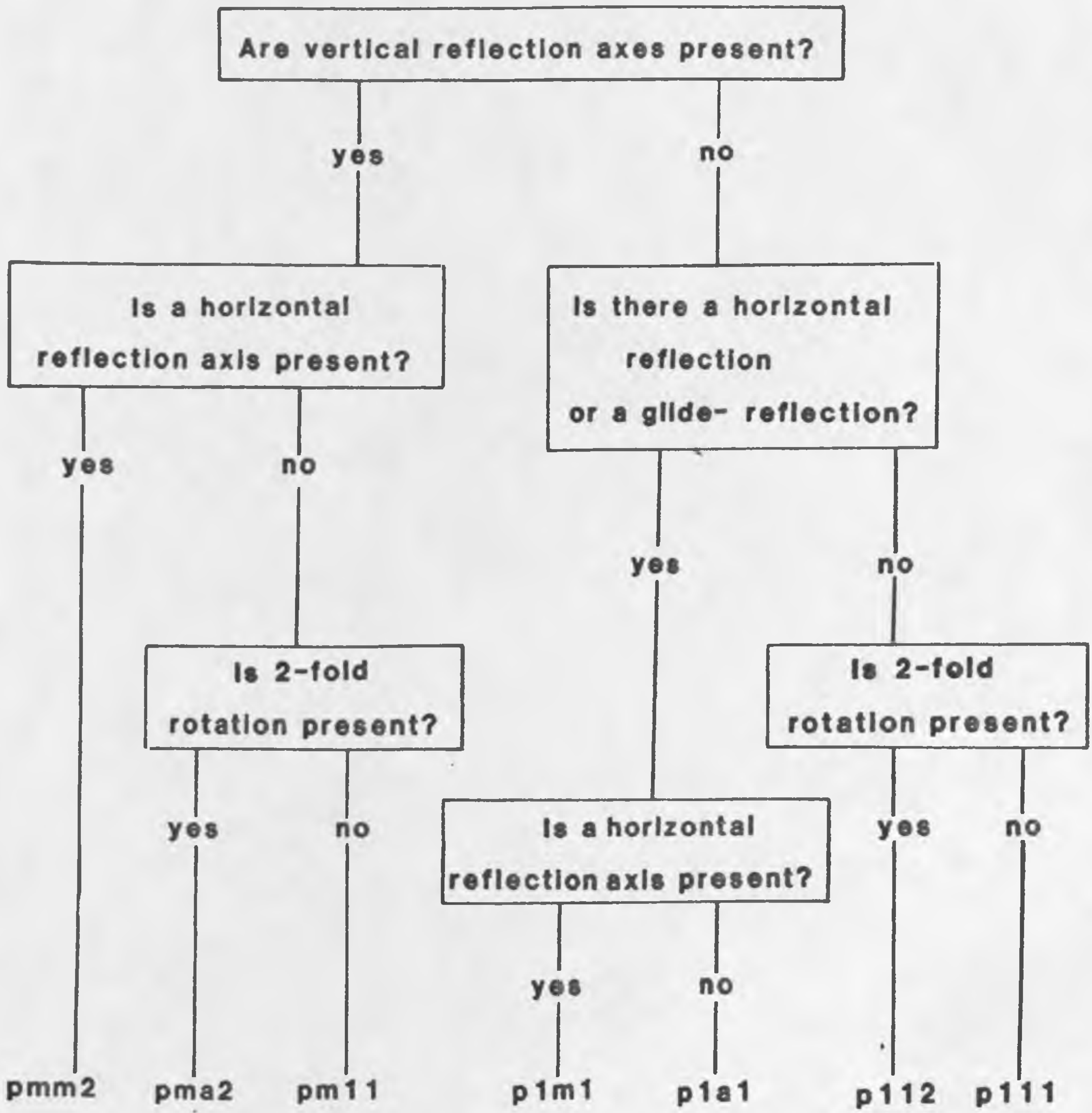
Figure 24. Class pmm2 Border Patterns.



Further accounts of the seven classes of border patterns were given by Woods [133], Crowe [134], Budden [135], Cadwell [136], Coxeter [137] and Stevens [138].

The flow-diagram in Figure 25, which is adapted from Crowe and Washburn [139] and Rose and Stafford [140], is designed to aid the identification of a border pattern's symmetry class, through presenting the user with a series of questions relating to the presence or absence of certain symmetry operations.

Figure 25. Flow Diagram to Aid Identification of a Border Patterns Symmetry Class.



5. THE CLASSIFICATION OF ALL-OVER PATTERNS.

5.1. An Explanation of the Relevant Notation.

As indicated previously all-over patterns are those patterns in which a motif (or motifs) is translated in two independent directions across the plane. When combined with one or more of the other three symmetry operations, a total of seventeen (and only seventeen) distinct classes of all-over patterns may be generated. Proof for the existence of only seventeen all-over pattern classes was provided by Martin [141] and Schwarzenberger [142].

In addition to combinations of the four symmetry operations, a further structural element is always present in all-over patterns: a framework of corresponding points which form a regular lattice. The corresponding points of an all-over pattern may be connected to produce lattice units (generally referred to as *unit cells*) of the same shape, size and content. When translated in two independent directions, across the plane, a lattice unit generates the full all-over pattern. Schattschneider [143] commented that every all-over pattern,

> "...must have in its symmetry group two 'shortest' independent translations (these correspond to the periodic nature of the design): a lattice unit for such a design is a parallelogram having as its sides the vectors of these two translations."

There are five distinct lattice types: parallelogram, rectangular, rhombic, square and hexagonal (the unit cell associated with this latter lattice type is a rhombus consisting of two equilateral triangles). The frameworks, which are known as

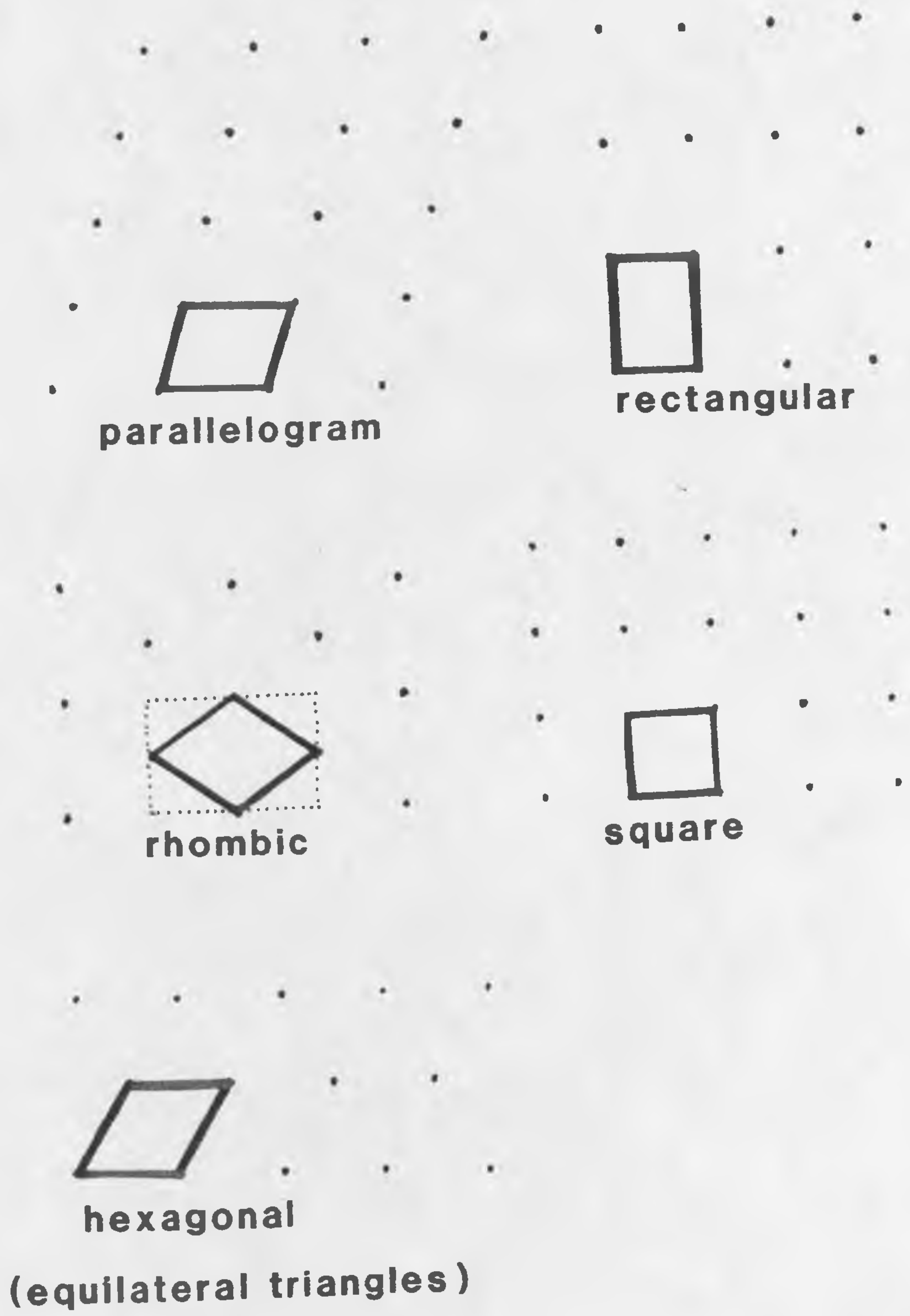
Bravais lattices (after Bravais who, as pointed out by Grunbaum and Shephard [144] proved that lattices could be classified into five general types) may be used in the generation of all-over patterns. The five Bravais lattice types, together with their corresponding unit cells are shown in Figure 26. Table 1 lists all seventeen pattern classes, together with the appropriate lattice type for each.

Table 1. Lattice Types for the Seventeen Classes of All-Over Patterns.

Full International Notation	**Lattice Type**
p1	parallelogram
p1m1	rectangular
p1g1	rectangular
c1m1	rhombic
p211	parallelogram
p2mm	rectangular
p2mg	rectangular
p2gg	rectangular
c2mm	rhombic
p3	hexagonal
p3m1	hexagonal
p31m	hexagonal
p4	square
p4mm	square
p4gm	square
p6	hexagonal
p6mm	hexagonal

Nowacki [145], Coxeter and Moser [146] and Schattschneider [147] presented tables which compared the various notations used in the classification of all-over patterns. The most widely acceptable notation, which has been adopted for use in the sub-sections below, consists of four symbols which identify the conventionally

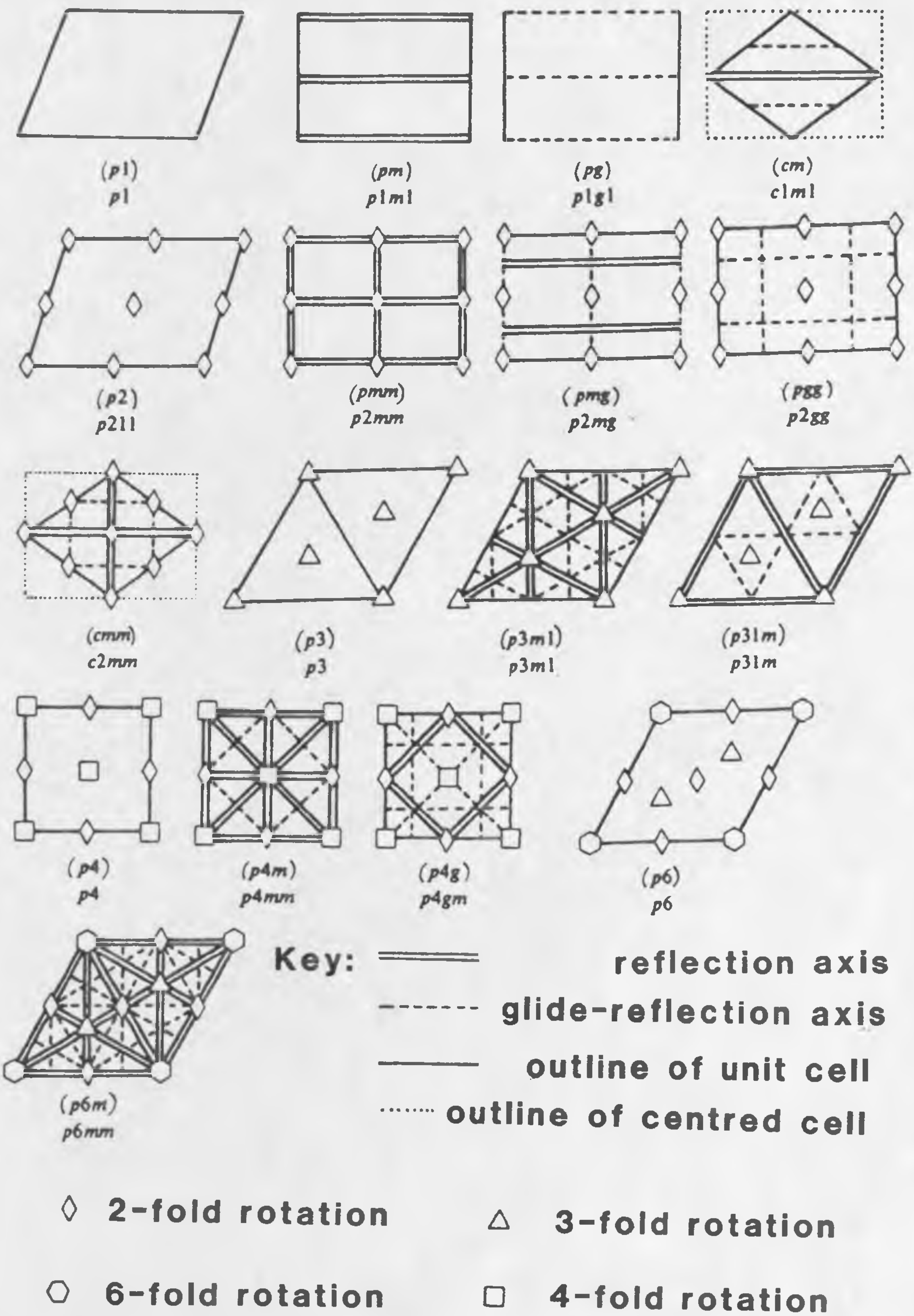
Figure 26. The Five Bravais Lattices.



chosen unit cell, the highest order of rotation and the symmetry axes present in two directions. The first symbol of the four symbol notation, either a letter p or a letter c, denotes whether the lattice cell associated with the pattern is primitive or centred. Primitive cells, which are present in fifteen of the seventeen all-over pattern classes, contain the minimum area of the pattern which may generate the full pattern by translation only. In the cases of the remaining two all-over pattern classes, the lattice cell is of the rhombic variety and is centred, i.e. a diamond shaped cell is held within a rectangle (shown by dashed lines in Figure 26) so that reflection axes can be positioned at right angles to the sides of the enlarged cell, which holds one full repeating unit (within the diamond cell) and a quarter of a repeating unit at each of the enlarged cell corners. As pointed out by Washburn and Crowe [148] the identification of the appropriate lattice of a pattern is not always easy. However, it is generally the case that an identification of the combination of symmetry operations used in the generation of the pattern is sufficient for purposes of classification. By way of further clarification, however, and to aid the discussion which follows, Figure 27 shows the relevant symmetry operations which characterise each class of all-over pattern, together with the appropriate unit cell and the relevant four symbol notation. The widely accepted shortened form of the notation is also provided (in brackets).

The second symbol, n, of the four symbol notation, denotes the highest order of rotation in the pattern. As pointed out by Schattschneider [147], only rotations of orders 2 (180 degrees), 3 (120 degrees), 4 (90 degrees) or 6 (60 degrees) may generate all-over patterns. This restriction, which is often referred to as the

Figure 27. The Unit Cells For Each of the Seventeen Classes of All-Over Patterns.



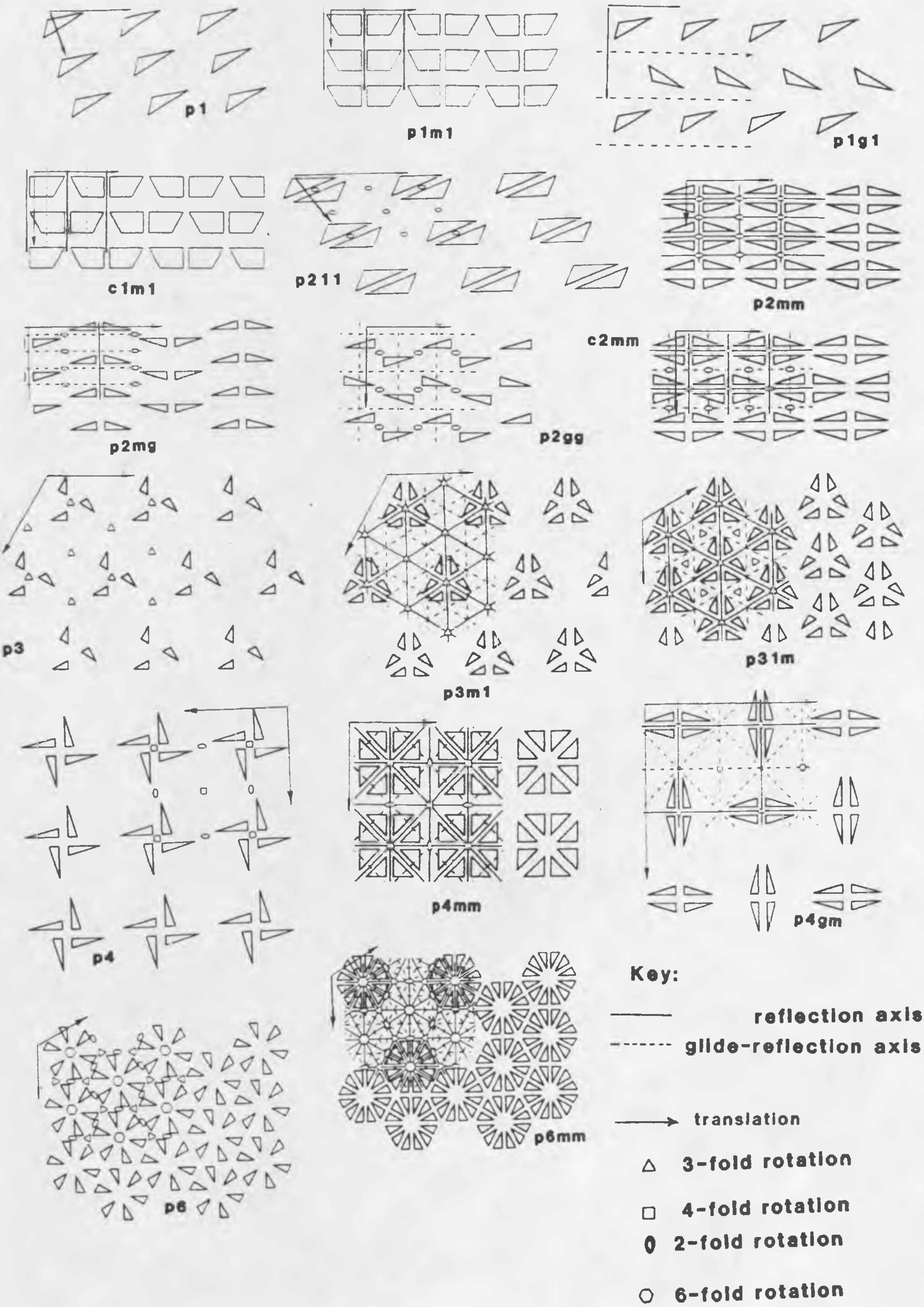
crystallographic restriction, is discussed by Stevens [149]. Where no rotation is present in an all-over pattern, n equals 1.

The third symbol denotes a symmetry axis normal to the x-axis of the cell (i.e. a symmetry axis at right angles to the left side of the cell). The letter m (for mirror) indicates an axis of reflection. The letter g (for glide) indicates the presence of a glide-reflection axis and 1 indicates no reflections or glide reflections normal to the x-axis.

The fourth symbol denotes a symmetry axis at angle α to the x-axis, with α dependent on n, the highest order of rotation (shown by the second symbol). The angle α equals 60 degrees for n equals 3 or 6: α equals 45 degrees for n equals 4; α equals 180 degrees for n equals 1 or 2. The letter m indicates that the relevant symmetry axis is an axis of reflection, g indicates a glide-reflection axis and 1 indicates that no symmetry axes are present at angle α to the x-axis. Where no symbols are placed in the third and fourth positions, this indicates that the pattern admits no reflections or glide-reflections.

All seventeen classes of all-over patterns are illustrated schematically in Figure 28, and are further described below under general headings which relate to the highest order of rotation present in each. Whilst illustrations for each pattern class are provided, reference to Figure 28 should act as a further aid to the understanding of the descriptions which follow each sub-heading below.

Figure 28. Schematic Illustrations of the Seventeen Classes of All-Over Patterns.



5.2 Patterns Without Rotational Properties.

5.2.1 Class p1 All-Over Patterns.

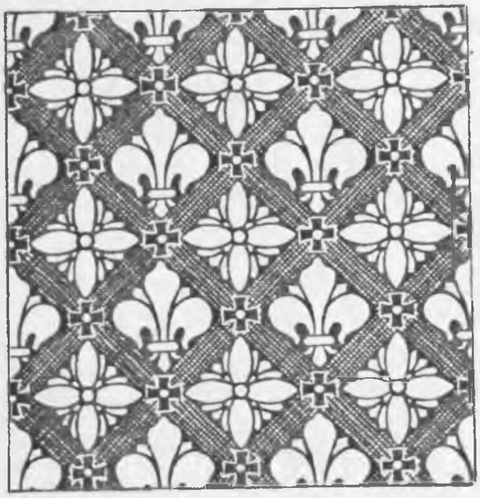
From the viewpoint of symmetry, class p1 all-over patterns are the most straightforward in terms of both construction and analysis. The conventionally chosen unit cell is of the parallelogram lattice type. No reflections or glide-reflections are present, and in view of the fact that the highest order of rotation is 1 (i.e. 360 degrees) the pattern is considered to have no rotational properties. The fundamental region and the unit cell are of the same area, and the pattern is generated by translations of a c1 motif in two independent directions. Examples from this pattern class are shown in Figure 29.

5.2.2 Class p1m1 (pm) All-Over Patterns.

Class p1m1 all-over patterns have rectangular lattice units with two alternating and parallel reflection axes and a highest order of rotation of 1. The corners of the unit cell fall on reflection axes and the pattern is thus generated by two parallel reflections and a translation along the direction of the reflection axes. The fundamental region is half the area of the unit cell and is bounded on opposite sides by reflection axes. Examples from this pattern class are shown in Figure 30.

Figure 29. Class p1 All-Over Patterns.

Figure 30. Class p1m1 All-Over Patterns.



5.2.3 Class p1g1 (pg) All-Over Patterns.

Class p1g1 all-over patterns are generated by two parallel glide-reflections of a c1 motif. The corners of the unit cell (which is a unit from a rectangular type lattice) fall on glide-reflection axes. The highest order of rotation is 1 and the fundamental region is half the area of the unit cell. Examples from this pattern class are shown in Figure 31.

5.2.4 Class c1m1 (cm) All-Over Patterns.

Class c1m1 all-over patterns have a unit cell of the rhombic lattice type. In this case, as mentioned previously, a diamond shaped cell is held within a larger rectangle. The pattern is generated by a reflection, at right angles to the enlarged cell, and by a parallel glide-reflection. Reflection axes therefore alternate with glide-reflection axes. The enlarged cell contains two repeating units, one full repeating unit within the diamond shape and quarter units at each of the enlarged cell corners. The fundamental region is one half of the diamond shaped unit cell area. Examples from this class of pattern are shown in Figure 32.

5.3 Patterns Exhibiting Two-Fold Rotation.

5.3.1 Class p211 (p2) All-Over Patterns.

Class p211 is one of the five classes of all-over patterns in which the highest order of rotation is of the two-fold variety. Classes p2mm, p2mg, p2gg and c2mm also exhibit two-fold rotation and, like class p211, appear the same when viewed up-side-down. Each class p211 pattern contains repetitions of four different two-fold centres of rotation; every similar two-fold centre has the same orientation. A parallelogram lattice type forms the unit cell which has corners on similar two-fold rotational centres and is twice the area of the fundamental region. Further two-fold rotational centres are located in the centre of the unit cell and on each of its sides. Examples from this pattern class are shown in Figure 33.

5.3.2 Class p2mm (pmm) All-Over Patterns.

Each class p2mm all-over pattern has a rectangular lattice type unit cell. The fundamental region is one quarter of the unit cell. The highest order of rotation is 2 and the pattern is generated by reflection in four sides of a rectangle. Two types of horizontal reflection axes alternate with each other, as do two types of vertical reflection axes. A different type of d2 rotational centre is present at each of the reflection axes intersections. The unit cell is constructed by joining four rotational centres of the same orientation. The fundamental region is one quarter of the unit cell area. Figure 34 shows examples from this pattern class.

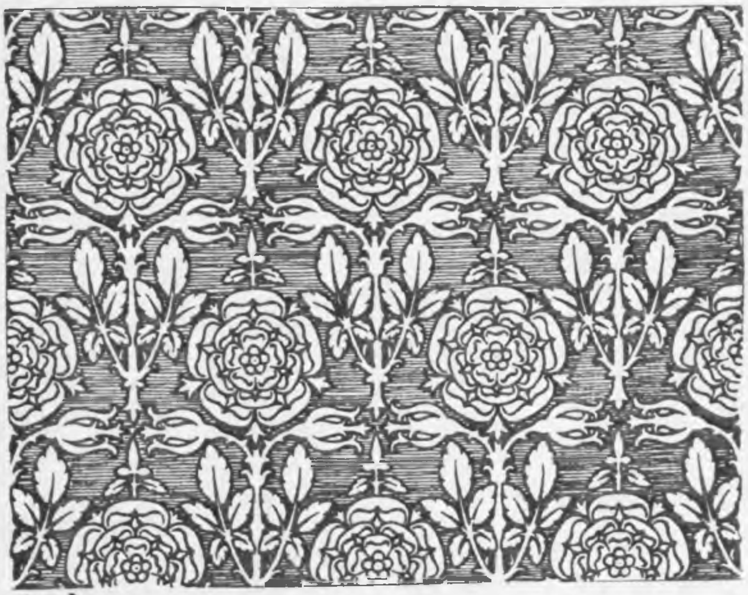
5.3.3 Class p2mg (pmg) All-Over Patterns.

In class p2mg all-over patterns two types of parallel reflection axes alternate with each other and intersect, at right angles, with two types of parallel glide-reflection axes. The highest order of rotation is 2 and all rotational centres are on glide-reflection axes. Reflection axes pass between rotational centres. Four types of d2 rotational centres are present. The fundamental region is one quarter of the unit cell area. Figure 35 shows examples from this pattern class.

Figure 31. Class p1g1 All-Over Patterns.

Figure 32. Class c1m1 All-Over Patterns.

(a)

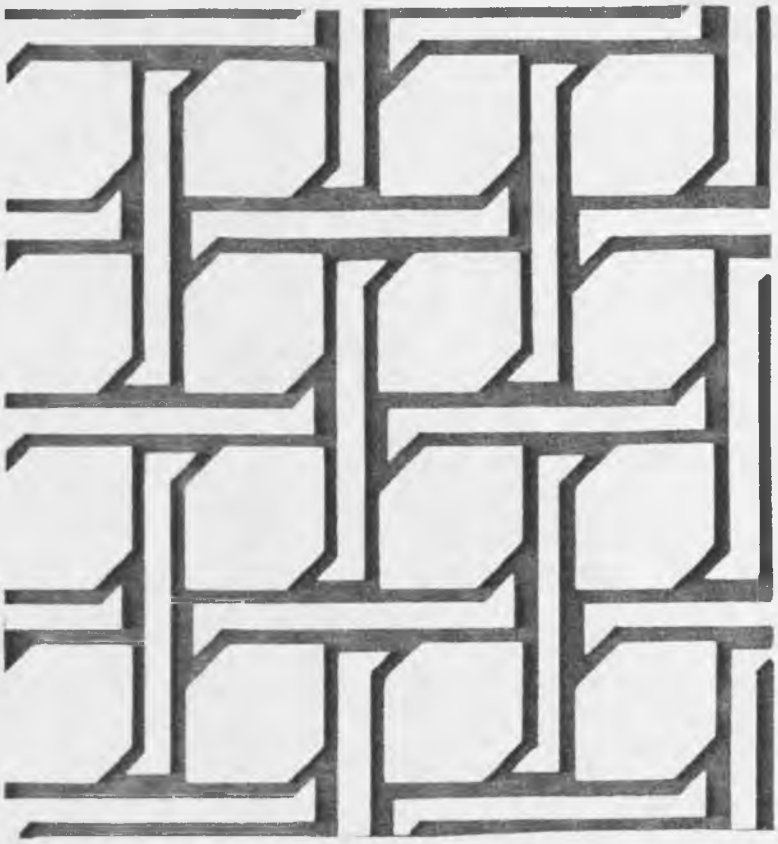


(b)

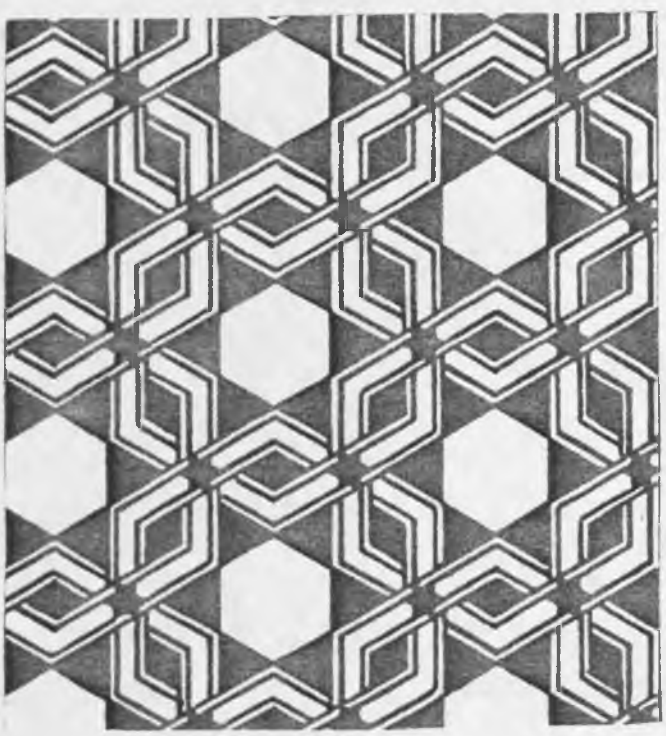
(c)

(d)

Figure 33. Class p211 All-Over Patterns.



(a)



(b)

Figure 34. Class p2mm All-Over Patterns.

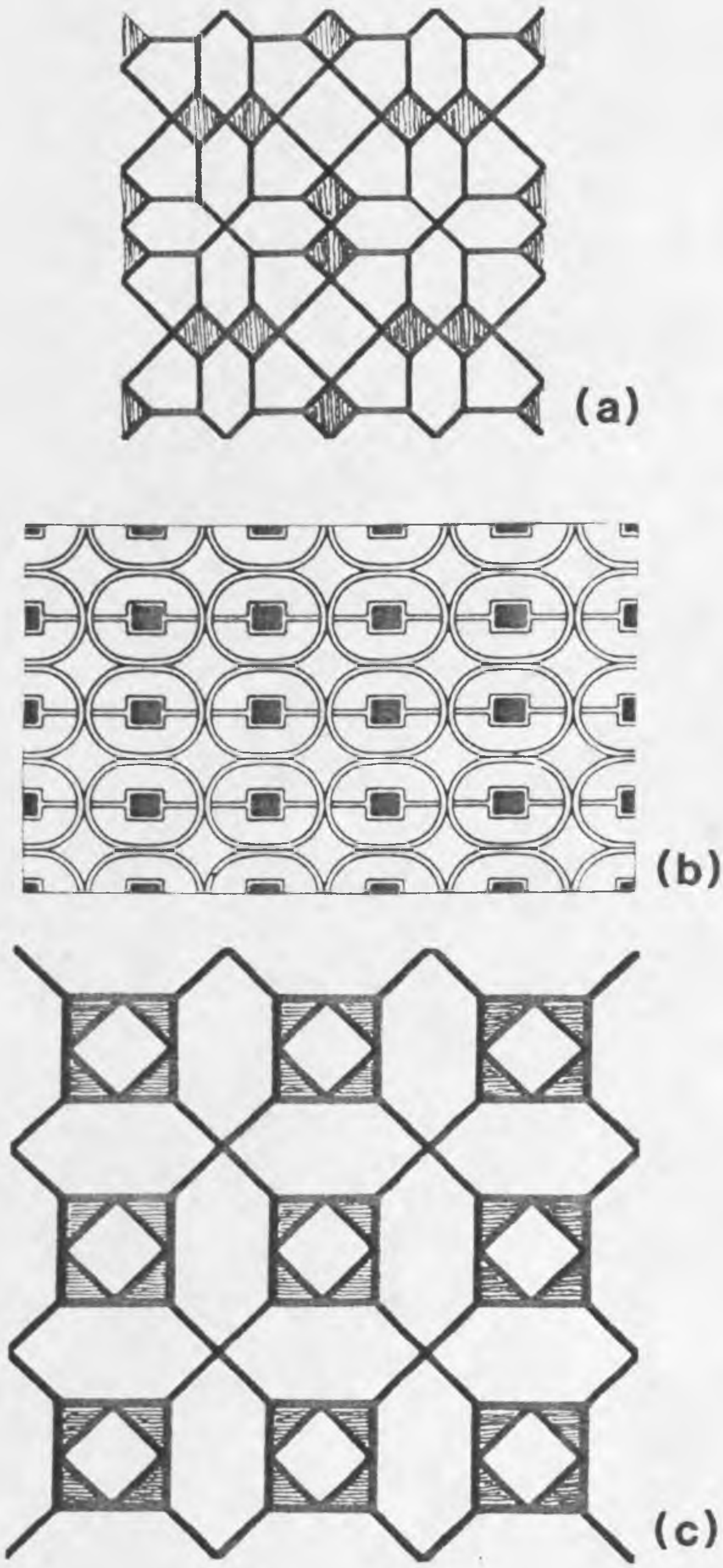
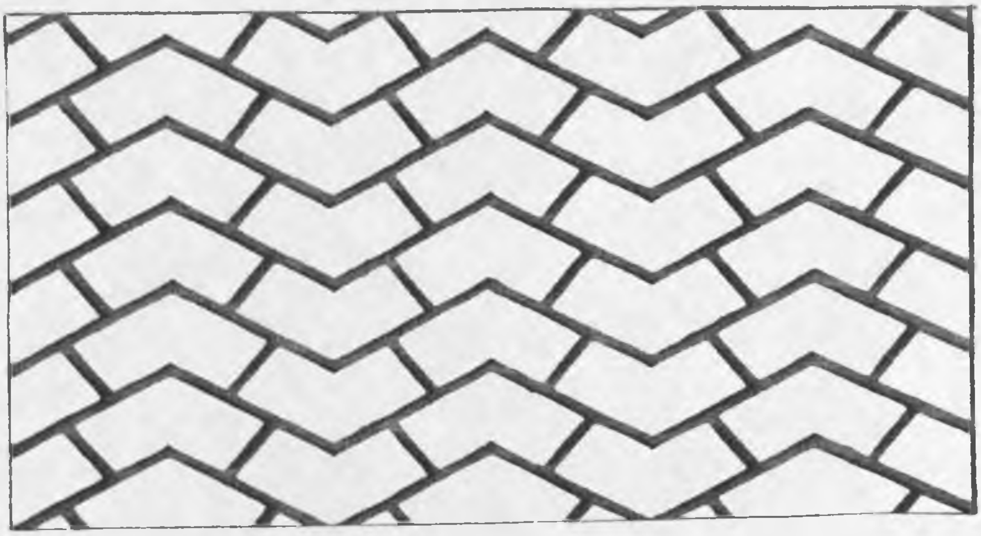
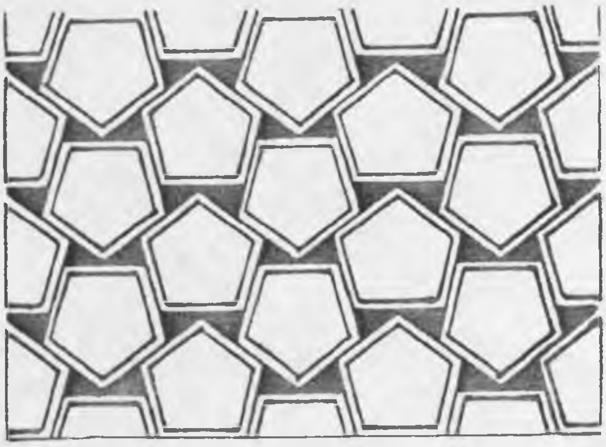
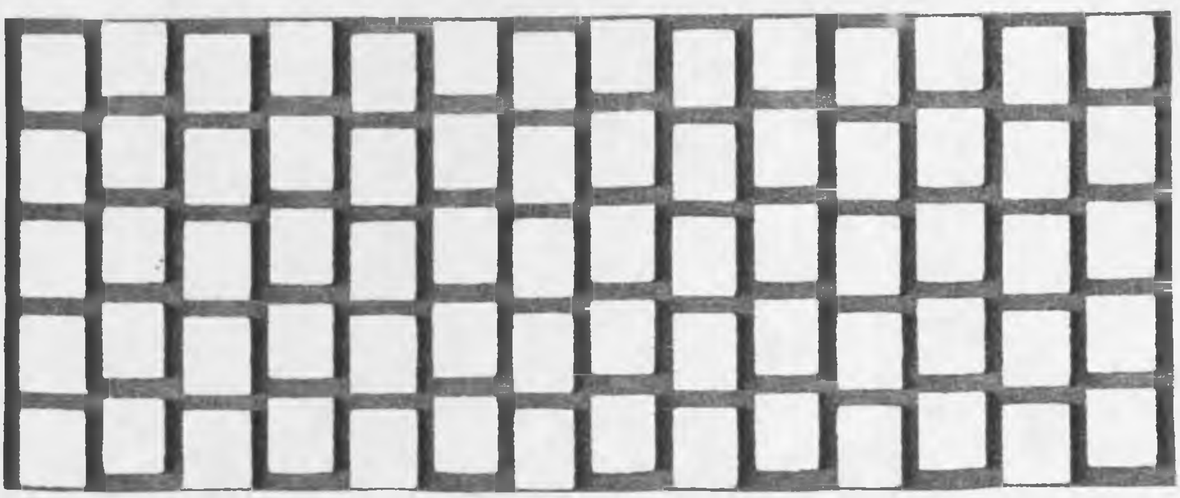


Figure 35. Class p2mg All-Over Patterns.







5.3.4 Class p2gg (pgg) All-Over Patterns.

Class p2gg patterns contain glide-reflection axes which intersect at right angles within a rectangular lattice unit cell. The fundamental region is one quarter of the area of the unit cell and the highest order of rotation is 2. Examples from this pattern class are shown in Figure 36.

5.3.5 Class c2mm (cmm) All-Over Patterns.

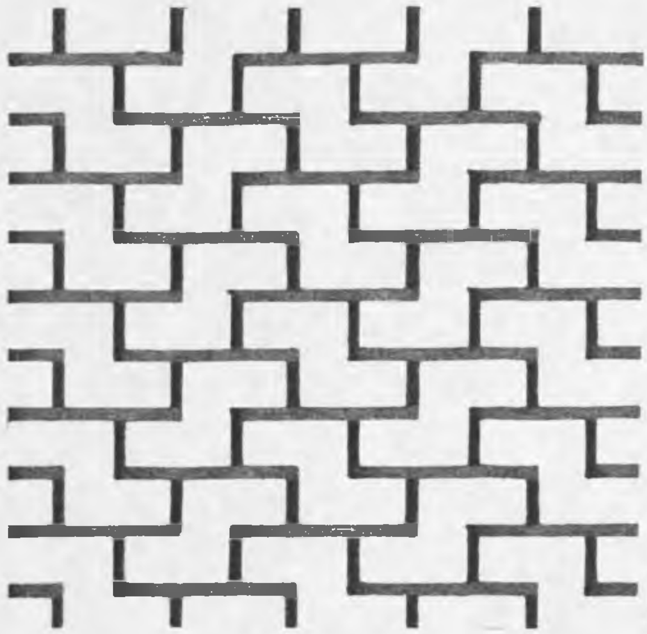
Class c2mm all-over patterns contain a large number of symmetry operations. These patterns are generated by a centred cell (c) whose corners and centre fall on two-fold rotational centres. Parallel reflection and glide-reflection axes alternate with each other in both vertical and horizontal directions. Two-fold rotational centres are present at both glide-reflection axes intersections and reflection axes intersections. Although the diamond shaped unit cell can generate the pattern by translation (as is the case with c1m1 patterns), convention dictates a larger rectangular shaped generating area. The corners and centre of the larger generating unit fall on similar two-fold rotational centres. The fundamental region is one quarter of the area of the diamond shaped unit cell. Examples from this pattern class are shown in Figure 37.

5.4 Patterns Exhibiting Three-Fold Rotation.

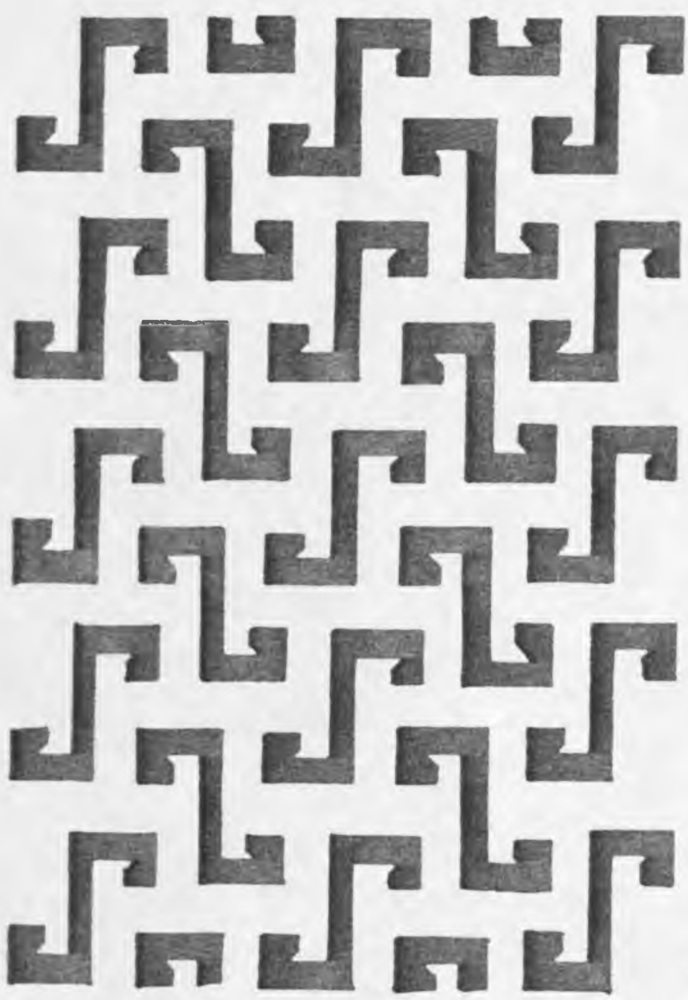
5.4.1 Class p3 All-Over Patterns.

Class p3 all-over patterns have an hexagonal lattice type unit cell and a highest order of rotation of 3. Three distinct three-fold rotational centres are present. The area of the fundamental region is one third of the unit cell area. Examples from this class are shown in Figure 38.

Figure 36. Class p2gg All-Over Patterns.



(a)



(b)

Figure 37. Class c2mm All-Over Patterns.

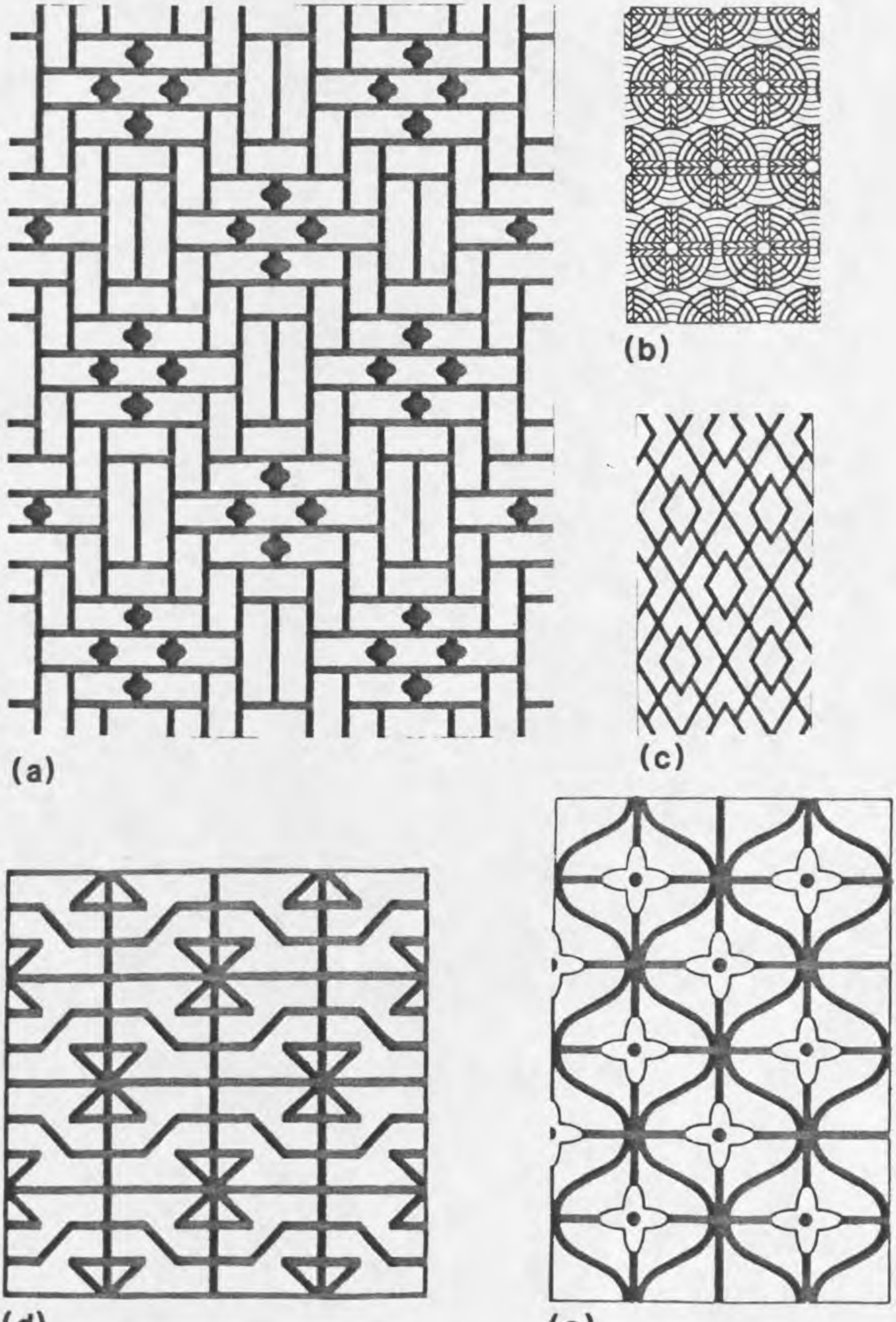
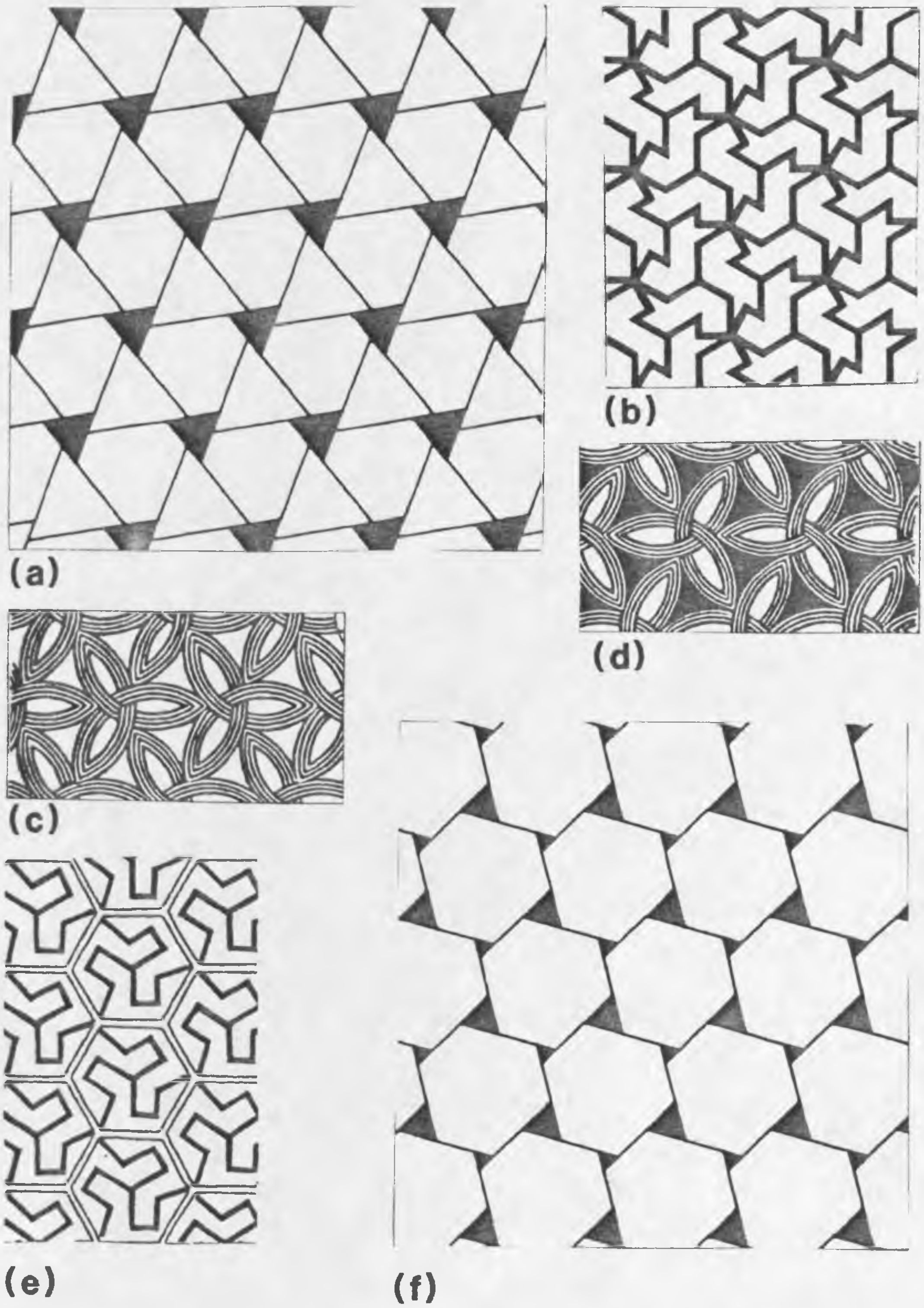


Figure 38. Class p3 All-Over Patterns.



5.4.2 Class p3m1 All-Over Patterns.

Class p3m1 all-over patterns have an hexagonal lattice type unit cell and a highest order of rotation of 3. These patterns combine three-fold rotational centres with reflection axes. Each three-fold rotation centre is positioned at an intersection of reflection axes. A reflection axis is positioned along the longest diagonal of the unit cell. The fundamental region for this pattern class is one sixth the area of the unit cell. Examples from this pattern class are shown in Figure 39.

5.4.3 Class p31m All-Over Patterns.

Class p31m, all-over patterns have an hexagonal lattice type unit cell and a highest order of rotation of 3. A reflection axis is positioned along the shortest diagonal of the unit cell and on each side of the unit cell. Not all three-fold rotational centres are on reflection axes. The fundamental region is one sixth of the unit cell area. Examples from this pattern class are shown in Figure 40.

5.5 Patterns Exhibiting Four-Fold Rotation.

5.5.1 Class p4 All-Over Patterns.

Class p4 all-over patterns have a square lattice type unit cell, no reflection axes and a highest order of rotation of 4. Two-fold and four-fold rotational centres alternate in both horizontal and vertical directions. Four-fold rotational centres are positioned at the centre and at each corner of the unit cell. A two-fold rotational centre is positioned on each side of the unit cell. The fundamental region is one quarter of the unit cell area. Examples from this pattern class are shown in Figure 41.

Figure 39. Class p3m1 All-Over Patterns.

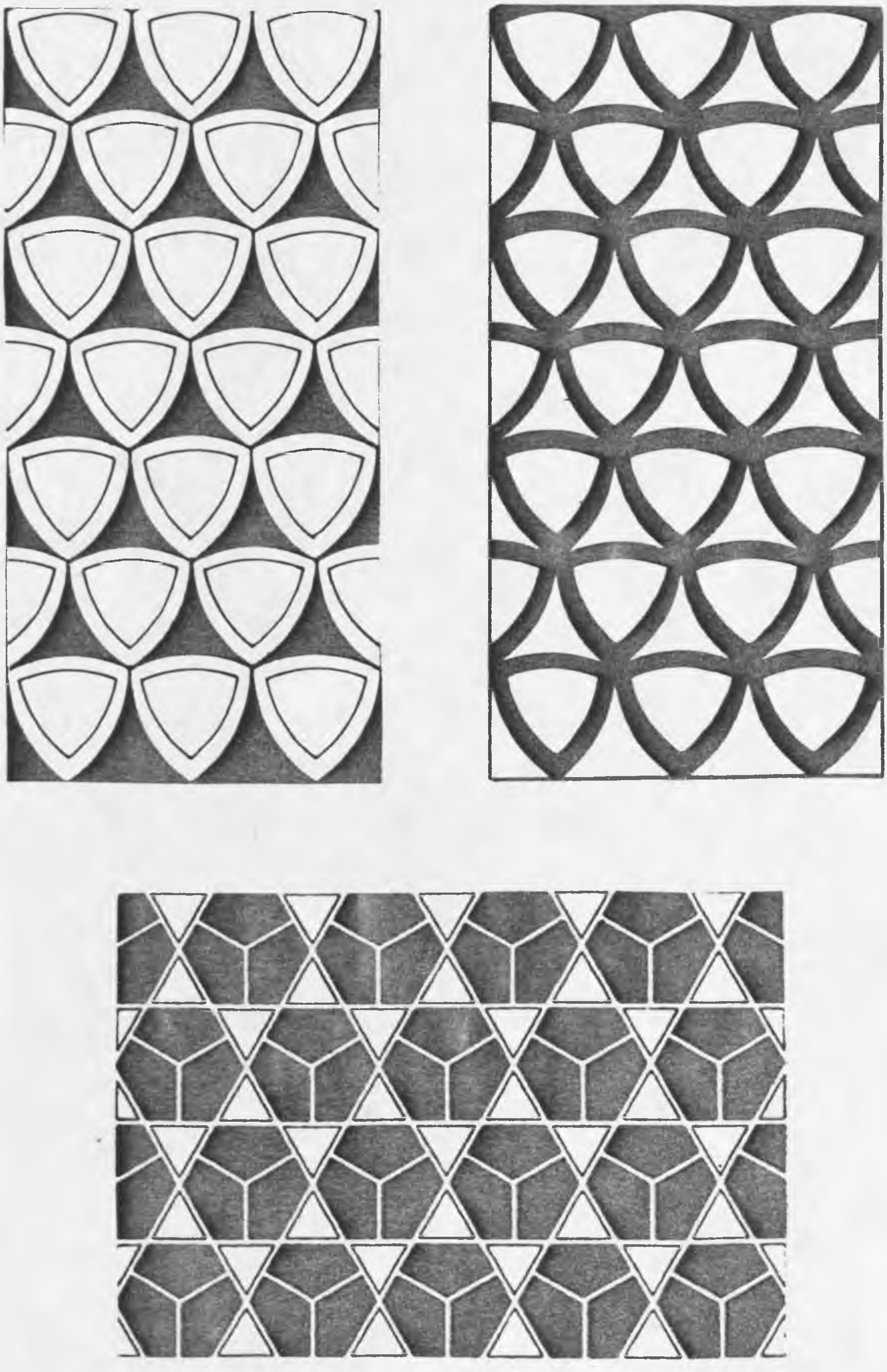
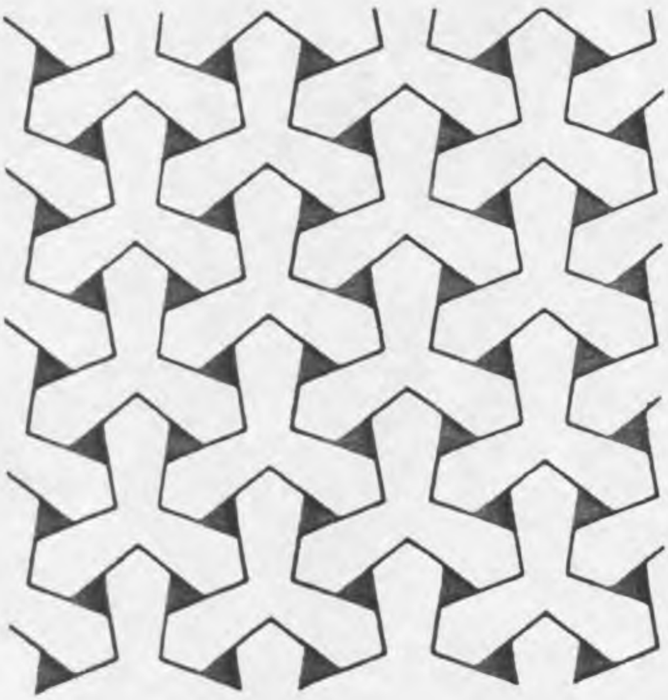
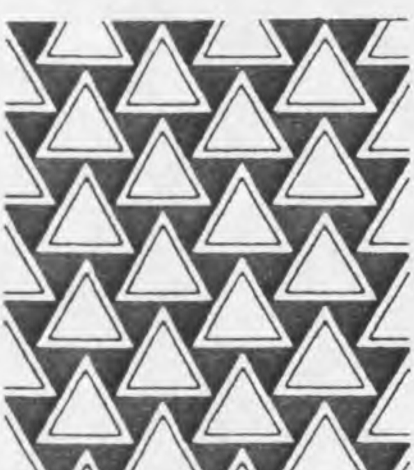


Figure 40. Class p31m All-Over Patterns.

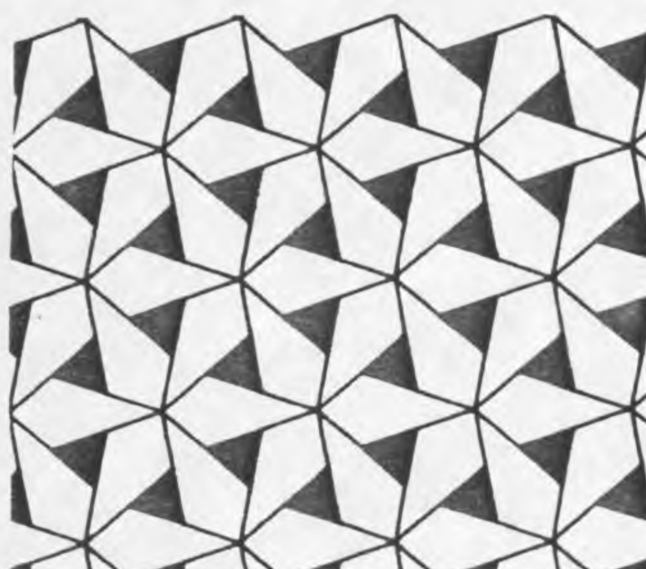


(a)

(b)

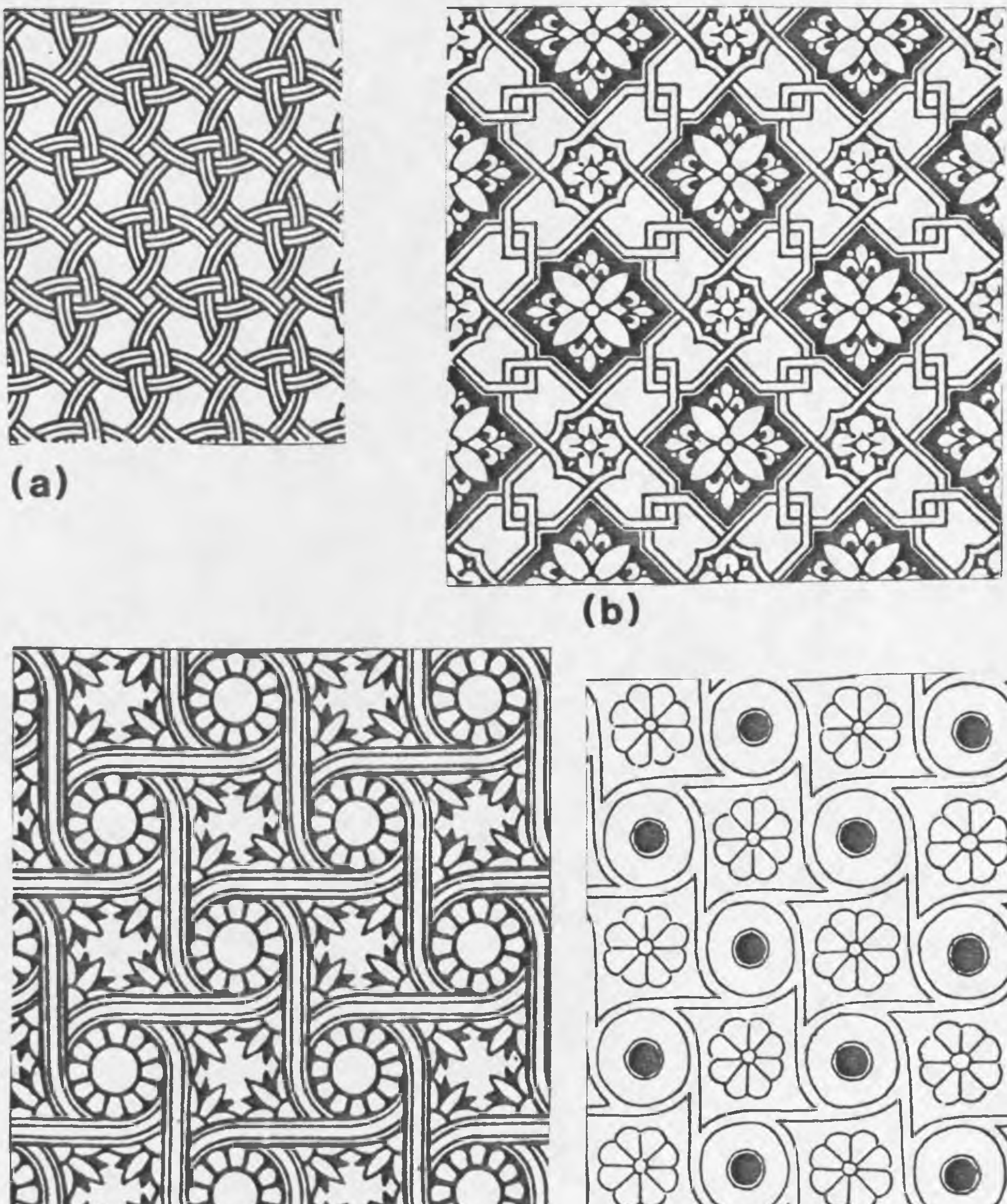


(c)



(d)

Figure 41. Class p4 All-Over Patterns.



(a) (b) (c) (d)

5.5.2 Class p4mm (p4m) All-Over Patterns.

Class p4mm all-over patterns have a square lattice type unit cell, a highest order of rotation of 4 and are generated by reflection in the sides of an isosceles triangle. The unit cell is divided into eight parts by reflection axes. A four-fold rotational centre is positioned at the centre and at each corner of the unit cell. A two-fold rotational centre is positioned on each side of the unit cell. The fundamental region is one eighth the area of the unit cell. Examples from this pattern class are shown in Figure 42.

5.5.3 Class p4gm (p4g) All-Over Patterns.

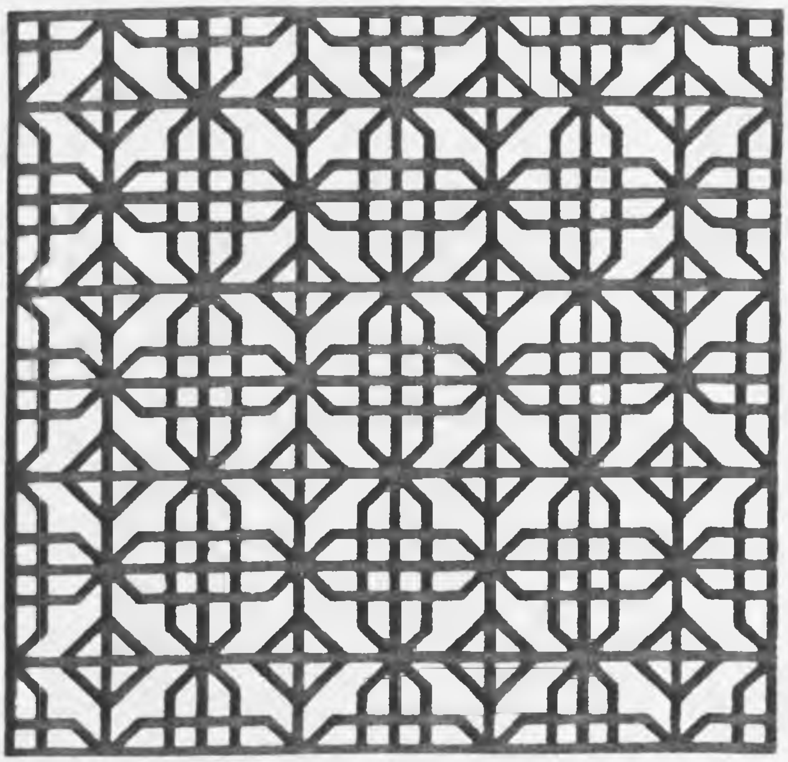
Class p4gm patterns have a square lattice type unit cell and a highest order of rotation of 4. Each corner of the unit cell is on a four-fold rotational centre. Reflection axes intersect at right angles on two-fold rotational centres positioned at the centre of each side of the unit cell. The fundamental region is one eighth the area of the unit cell. Examples from this pattern class are shown in Figure 43.

5.6 Patterns exhibiting Six-Fold Rotation.

5.6.1 Class p6 All-Over Patterns.

Class p6 all-over patterns have an hexagonal lattice type unit cell, with corners falling on six-fold rotational centres. Three-fold rotational centres and two-fold rotational centres are also present within this pattern class. All the six-fold rotational centres have the same orientation; the three-fold rotational centres have two different orientations; the two-fold rotational centres have three different orientations. The fundamental region is one sixth of the unit cell area. Examples from this pattern class are shown in Figure 44.

Figure 42. Class p4mm All-Over Patterns.



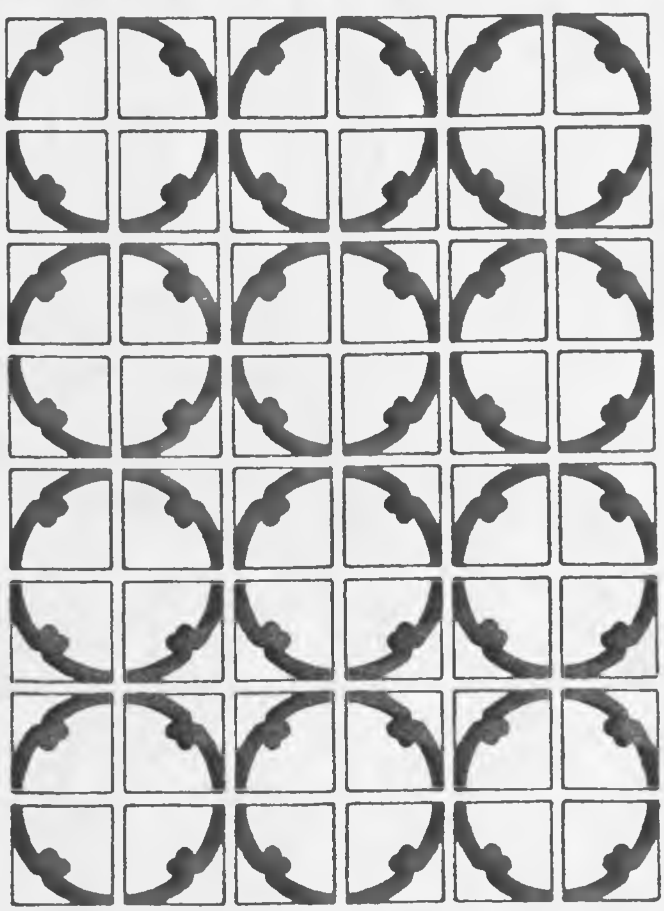


Figure 43. Class p4gm All-Over Patterns.

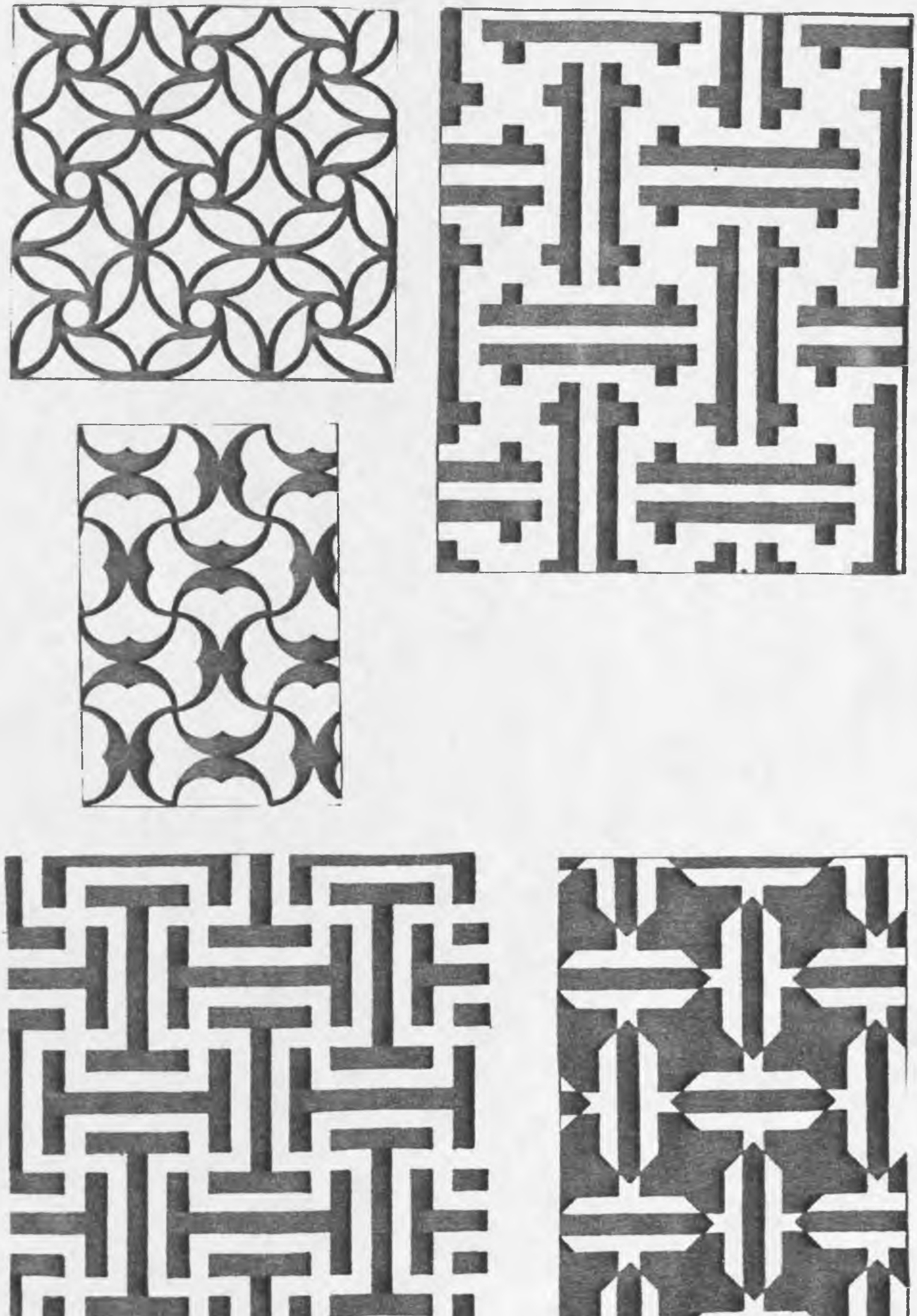
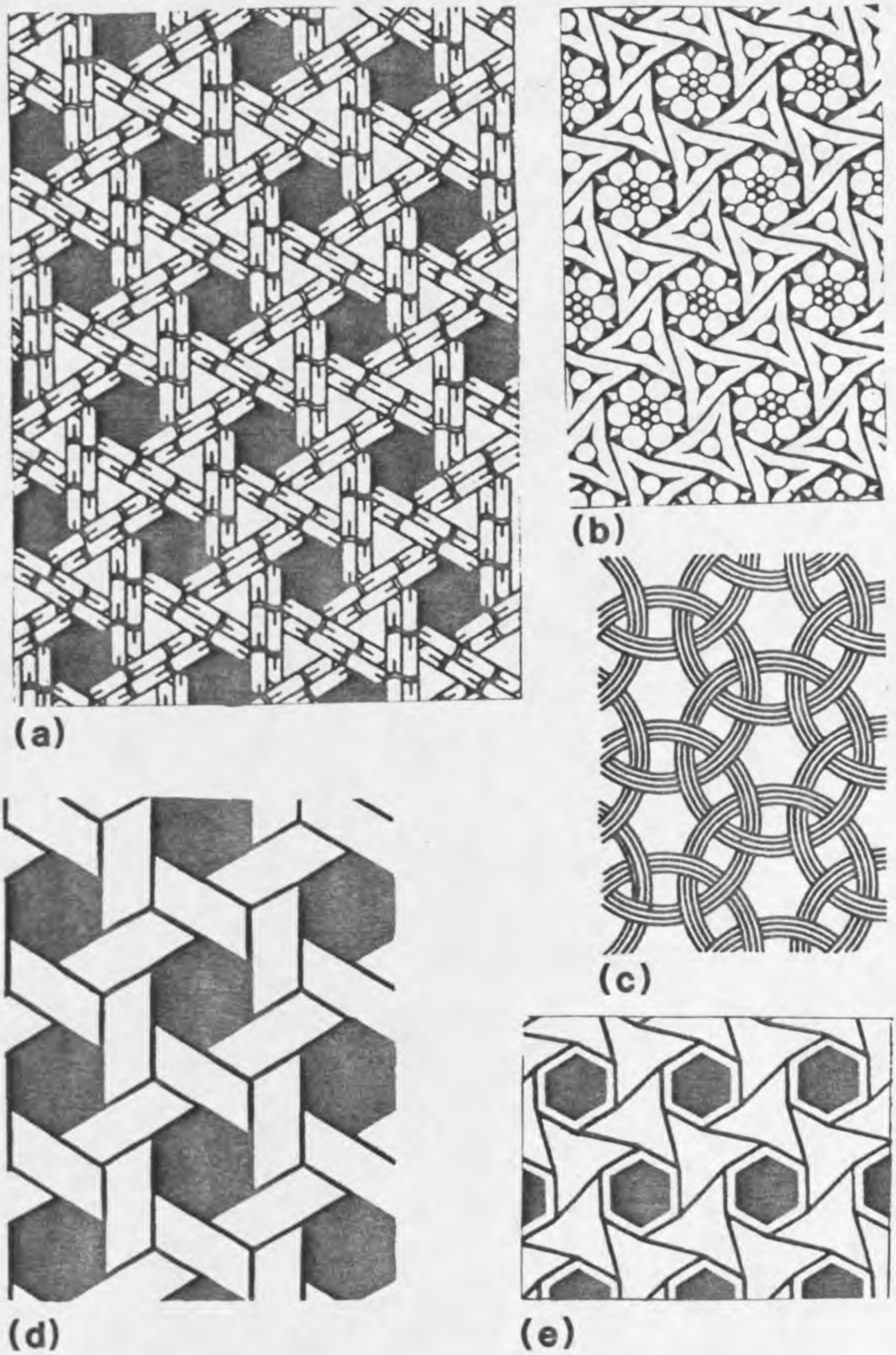


Figure 44. Class p6 All-Over Patterns.



5.6.2 Class p6mm (p6m) All-Over Patterns.

Class p6mm all-over patterns are generated by a combination of reflections and rotations. Six-fold rotational centres are present at each corner of the unit cell, which is of the hexagonal lattice type. Reflection axes connect each corner with the other three corners and in addition each side is bisected by a reflection axis. Three-fold and two-fold rotational centres are also present and located on intersections of reflection axes. The area of the fundamental region is one twelfth of the unit cell area. Figure 45 shows examples from this pattern class.

Historically important explanations and further descriptions of the seventeen pattern classes described above are provided by Birkhoff [150], Bradley [151], Buerger [152]. MacGillavry [153], Burckhardt [154], Coxeter and Moser [155], Loeb [156], Shubnikov and Koptsik [157], Schwarzenberger [158], Schattschneider [159] and Stevens [160].

The flow-diagram in Figure 46, which has been adapted from Schattschneider [159] and Crowe and Washburn [161], is designed to aid the identification of an all-over pattern's symmetry class, through presenting the user with a series of questions relating to the presence or absence of certain symmetry operations.

Figure 45. Class p6mm All-Over Patterns.

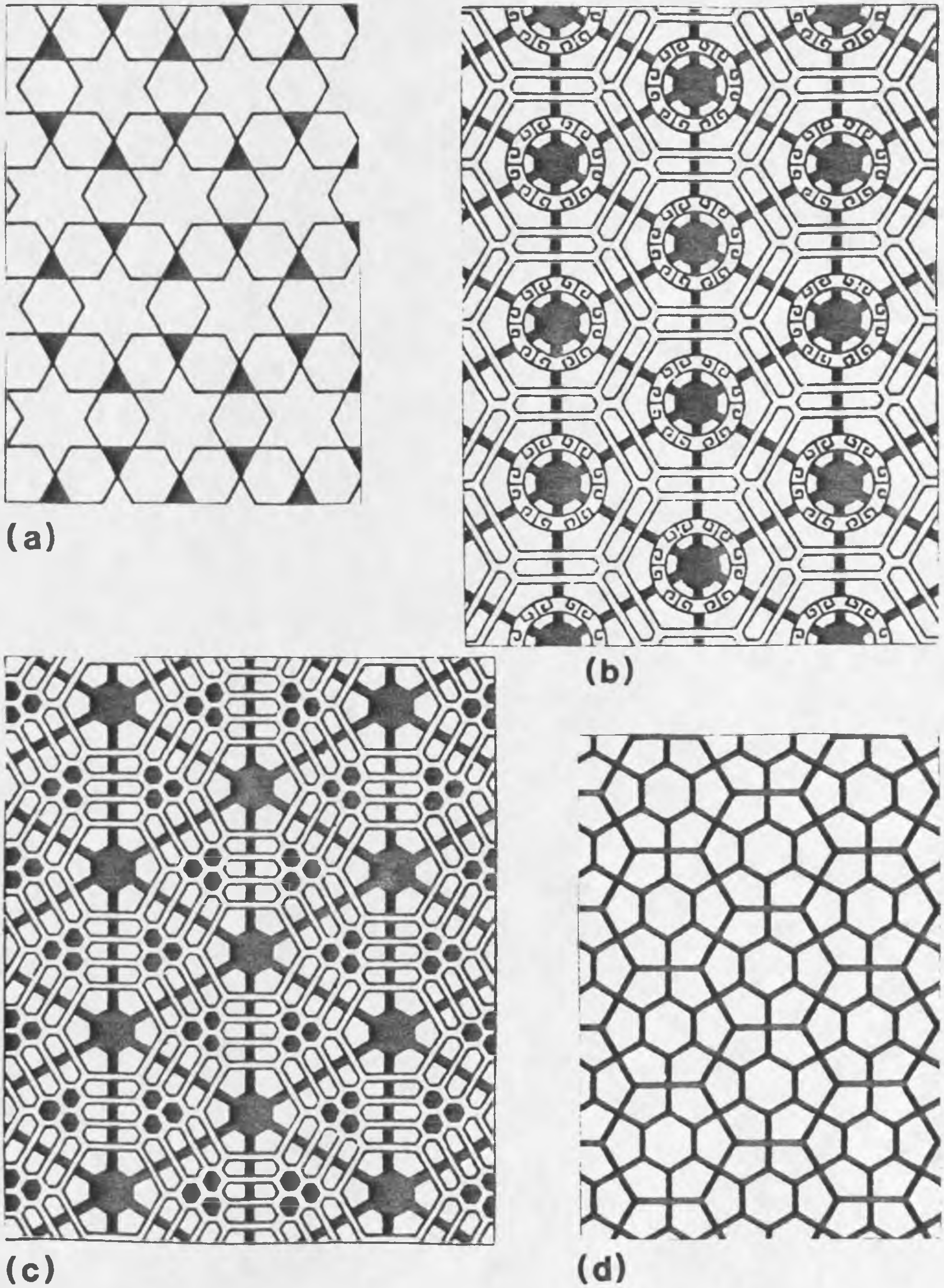
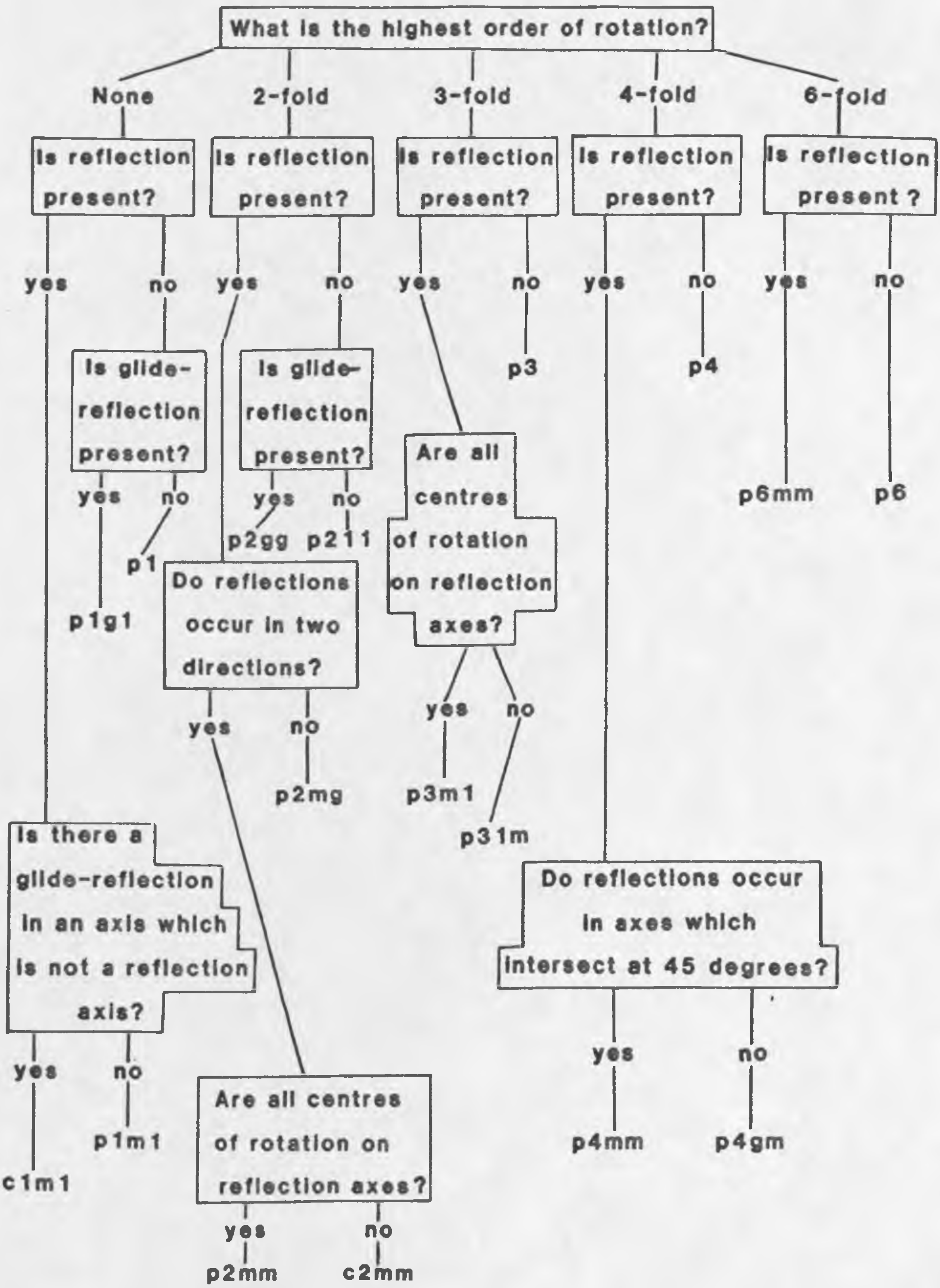


Figure 46. Flow Diagram to Aid the Identification of the Seventeen Classes of All-Over Patterns.



6. COUNTERCHANGE DESIGNS AND THEIR CLASSIFICATION.

6.1 A Description of the Concept.

Explanation and discussion, so far, have concentrated on symmetry operations which do not involve colour change, i.e. colour has been preserved following each symmetry operation. It may however be the case with certain two-colour designs that certain symmetry operations interchange colours in a systematic and continuous way. Such designs have been termed *counterchange designs* (Christie [162], Woods [163] and Gombrich [164]). A comprehensive appraisal of two-colour counterchange motifs, border patterns and all-over patterns (also known as *two-colour finite designs, two-colour one-dimensional patterns* and *two-colour two-dimensional patterns* respectively) was recently provided by Washburn and Crowe [165a]. The counterchange possibilities for motifs are briefly described below and subsequent attention is focused on the relevant internationally accepted notation used in the classification of counterchange border and all-over patterns.

6.2 Counterchange Motifs

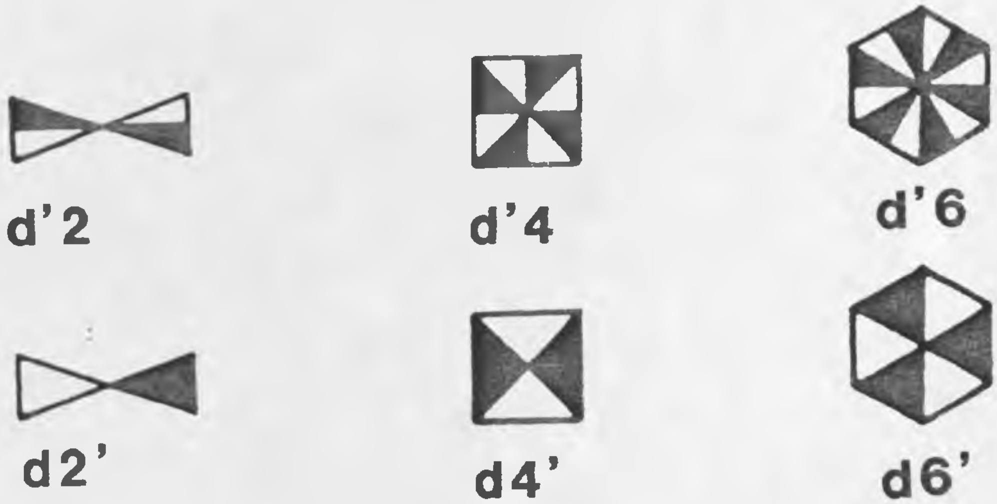
As pointed out by Washburn and Crowe [165b], there is only one way to systematically colour a cn motif with two colours and that is to alternate the colours around the design. Such a colouring is only possible where n is an even number. Schematic examples of counterchange cn motifs are shown in Figure 47. It can be seen that a prime (') has been introduced into the standard notation.

In the case of dn motifs, which admit reflections, there are, as recognised by Washburn and Crowe [165b], two possible approaches to systematically introduce

Figure 47. Counterchange cn' Motifs

Figure 48. Counterchange d'n Motifs (n=odd numbers).

Figure 49. Counterchange d'n and dn' motifs (n=even numbers).



colour interchange. Where n is an odd number, only one type of colouring is possible; where n is an even number alternative colourings are possible. In the former case, which is illustrated schematically in Figure 48, all reflections reverse the colours and all rotations preserve the colours. In the latter case, where n is an even number, half the reflections reverse colours and half preserve colours, and rotations by one nth of 360 degrees reverse colours; such possibilities are illustrated schematically in Figure 49.

6.3 Counterchange Border Patterns

As illustrated previously, when colour interchange between symmetry operations is ignored, only seven distinct classes of border patterns can be created using combinations of the four symmetry operations. For the sake of clarity, these seven classes may be referred to as the *seven primary border pattern classes*. By introducing colour interchange on these primary structures, a total of seventeen classes of two-colour counterchange border patterns are possible. The notation used in the classification of such designs is a modification of the pxyz notation used in the classification of the seven primary border pattern classes. This is the internationally accepted notation proposed by Belov [166]. A prime (') is generally associated with one of the symbols, if the corresponding symmetry operation interchanges colours. Washburn and Crowe [167a] described the determination of the notation as follows,

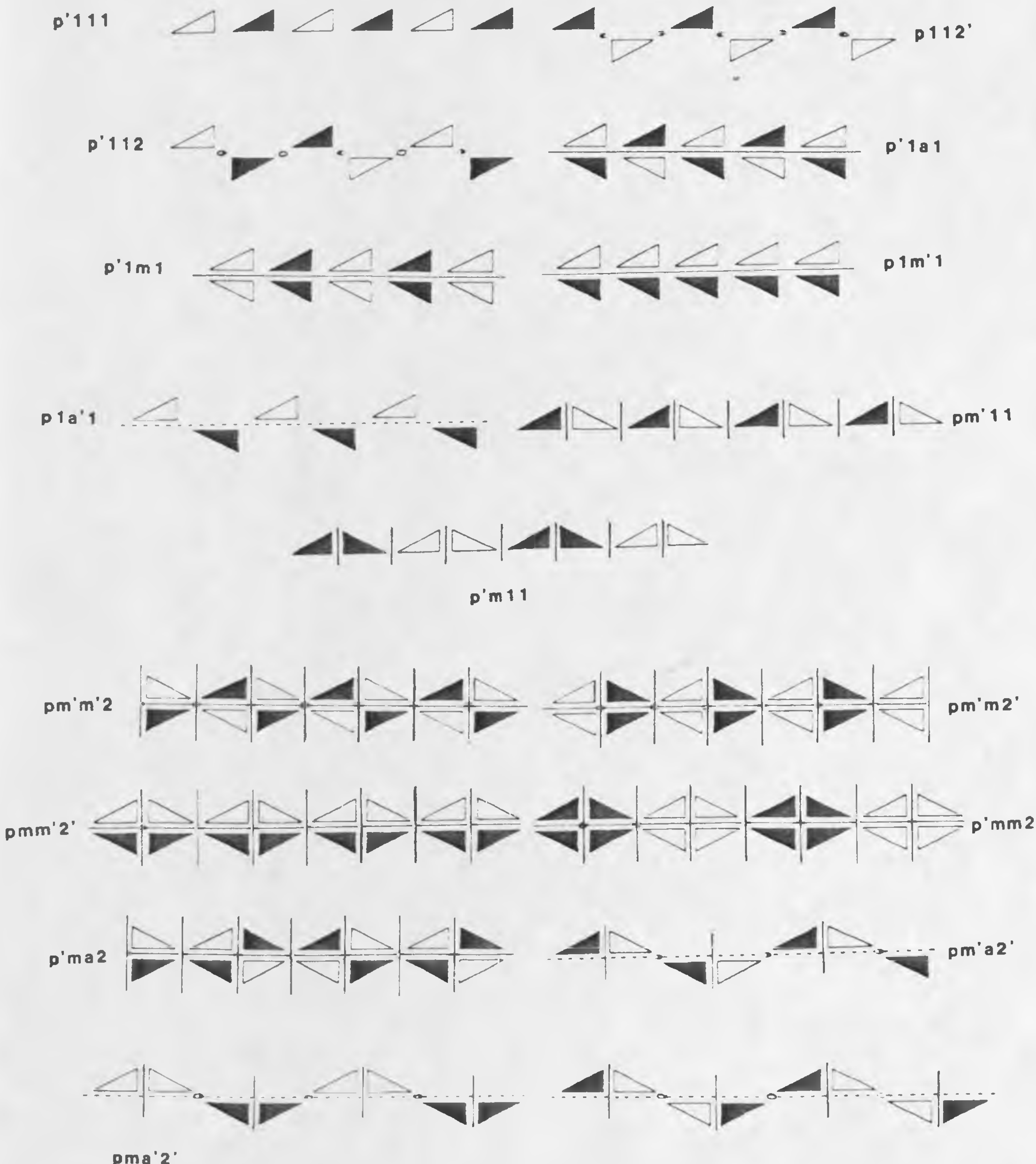
> "The first symbol is p if no translation reverses the two colours; it is p' if some translation does reverse the colours. The second symbol, x, is 1 if there is no vertical reflection consistent with colour [symmetry operations consistent with colour are those which preserve colour]; m if there is a vertical reflection which preserves colour; m' otherwise (i.e. if all vertical reflections reverse the colours). The third symbol, y, is 1 if there is no horizontal reflection; m if there is a horizontal reflection which preserves colour; m' if there is a horizontal reflection which reverses colours (except in two cases beginning with p', in which two cases y is a); a' if there is no horizontal reflection, but the shortest glide-reflection reverses colours; and is a otherwise. The fourth symbol, z, is 1 if there is no half-turn consistent with colour; 2 if there are half-turns which preserve colour; 2' otherwise (i.e. if all half-turns reverse colours)."

Schematic illustrations of each of the seventeen counterchange border patterns are shown in Figure 50, and the patterns previously published by Woods are reproduced in Figure 51 together with the relevant internationally accepted notation.

6.4 Counterchange All-Over Patterns

As stated previously, only seventeen distinct classes of all-over pattern may be produced using combinations of the four symmetry operations. For the sake of clarity these seventeen classes may be referred to as the *seventeen primary all-over pattern classes*. However, by introducing colour interchange on these primary structures, a total of forty-six classes of two-colour counterchange all-over patterns are possible. As pointed out by Washburn and Crowe [167b], although there is no universally accepted international notation for the forty-six counterchange all-over patterns, the notation proposed by Belov and Tarkhova [168] appears to be the most widely used. The notation is an adaptation of that

Figure 50. Schematic Illustrations of the Seventeen Classes of Counterchange Border Patterns.



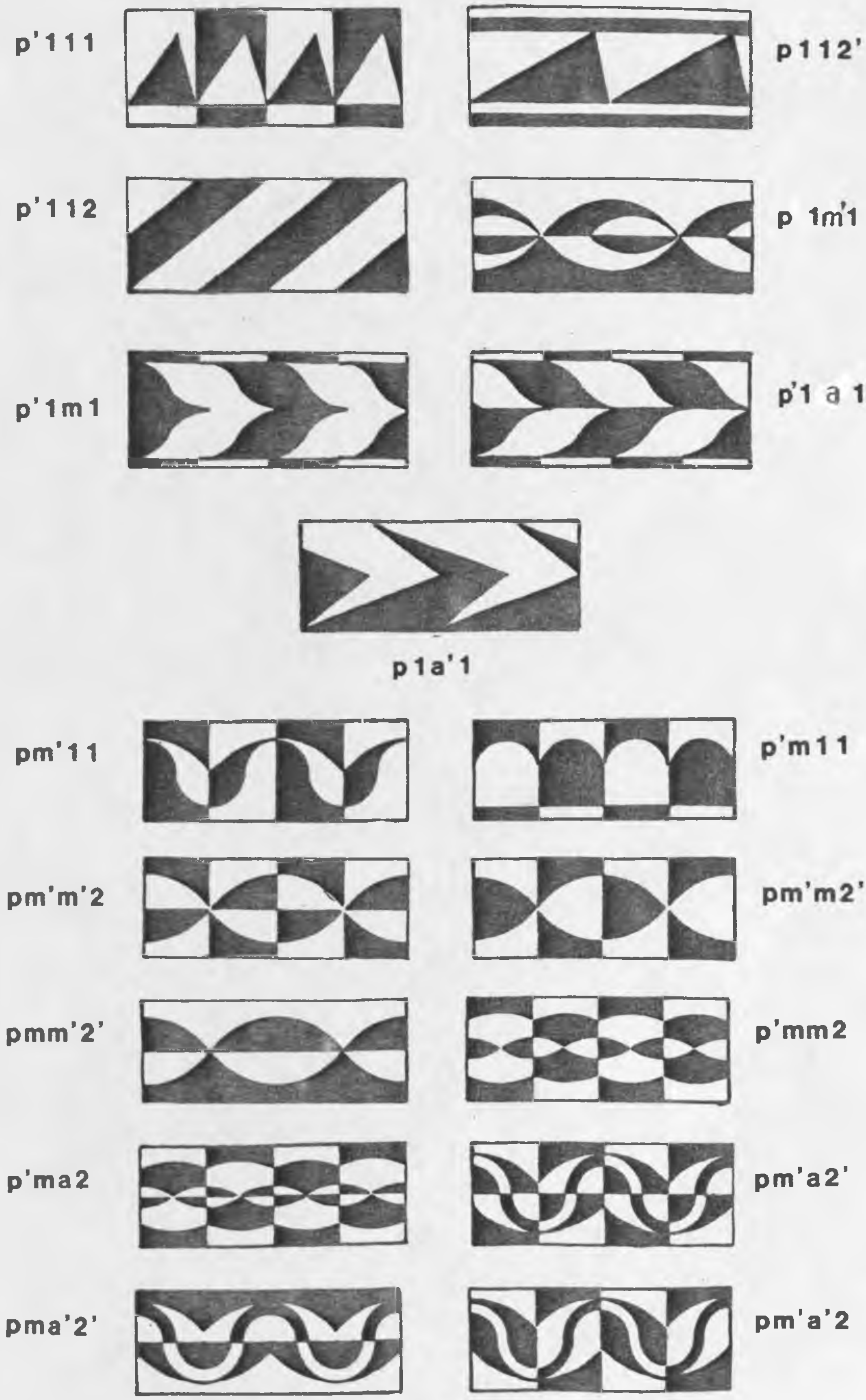
Key: ⬬, ○ 2-fold rotation

— horizontal reflection axis

----- glide-reflection axis

| vertical reflection axis

Figure 51. Woods' Counterchange Border Patterns.



used to classify primary all-over patterns, but is slightly more complex. Washburn and Crowe [169a] offered the following explanation,

> "As a general rule (not without several exceptions!) a prime (') attached to a symbol indicates a colour change when the corresponding operation is performed. If a translation makes the colour change, the p of the symbol is changed to p'_b when the translation is along the edge of the primitive cell, or to p'_c when the translation is along a diagonal of the primitive cell. (However, when p is changed to p'_b or p'_c in this way, no other symbol has a prime attached.) When all the mirror reflections in one direction reverse the colours then the corresponding m becomes m'; when all the glide-reflections in one direction reverse the colours then the corresponding g becomes g'."

Schematic illustrations of the forty-six counterchange all-over patterns are shown in Figure 52, and the patterns previously published by Woods [170] are reproduced in Figure 53 together with the relevant internationally accepted notation described above.

Further discussions of the two-colour counterchange all-over pattern classes, together with a well-developed series of flow-diagrams to aid the classification of such designs, were, as indicated previously, provided by Washburn and Crowe [171].

Figure 52. Schematic Illustrations of the Forty-Six Classes of Counterchange All-Over Patterns.

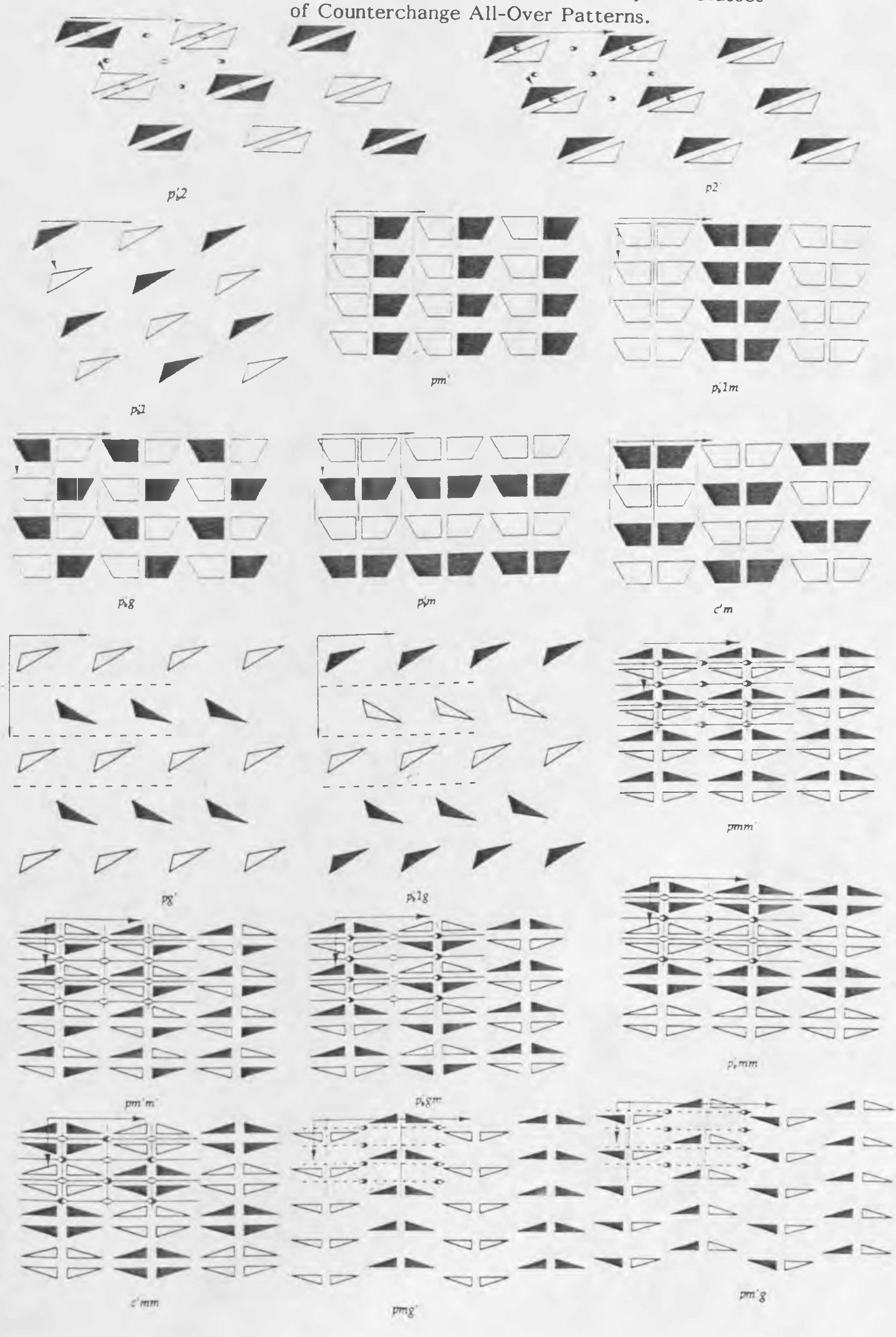


Figure 52 (cont). Schematic Illustrations of the Forty-Six Classes of Counterchange All-Over Patterns.

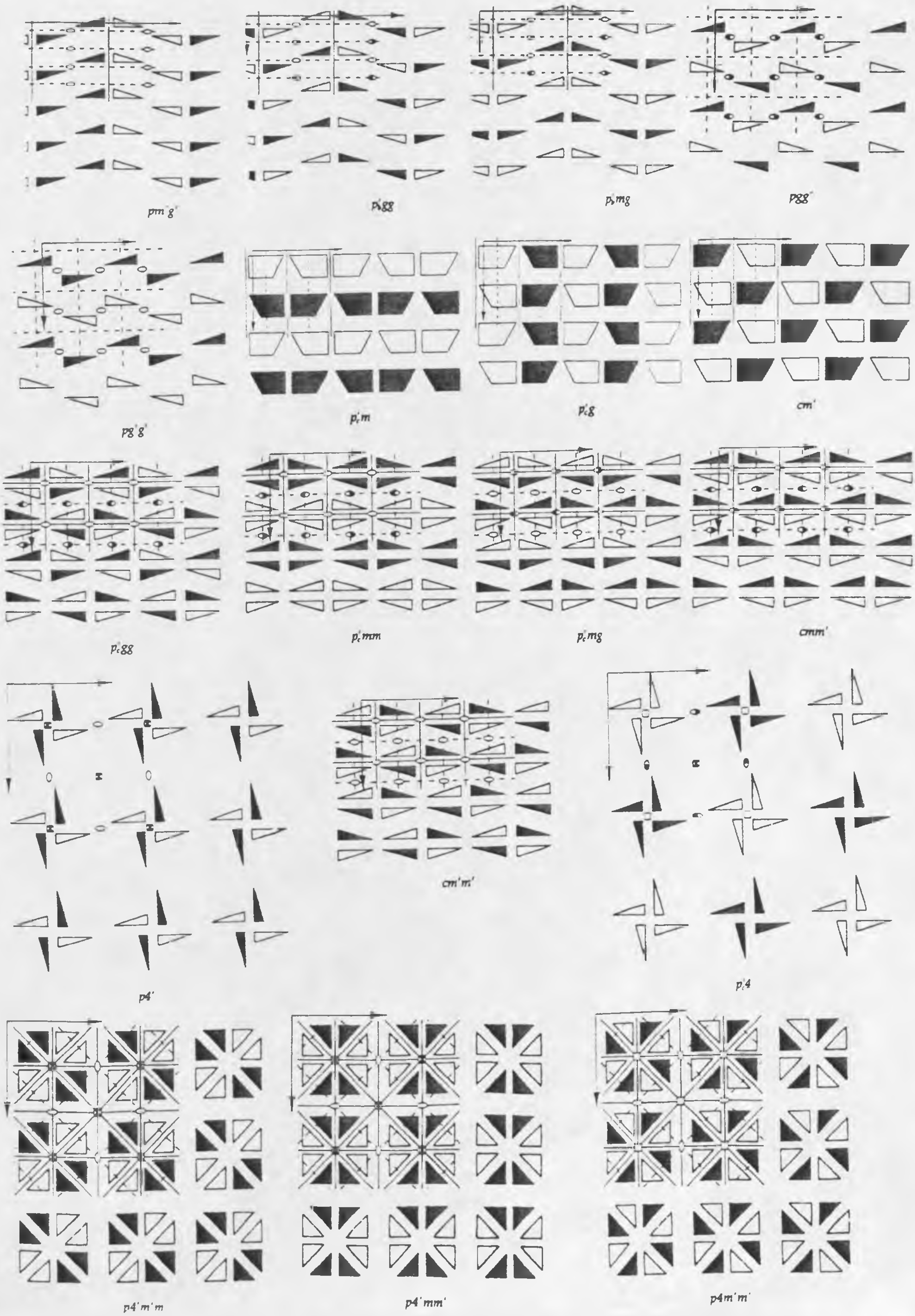


Figure 52 (cont). Schematic Illustrations of the Forty-Six Classes of Counterchange All-Over Patterns.

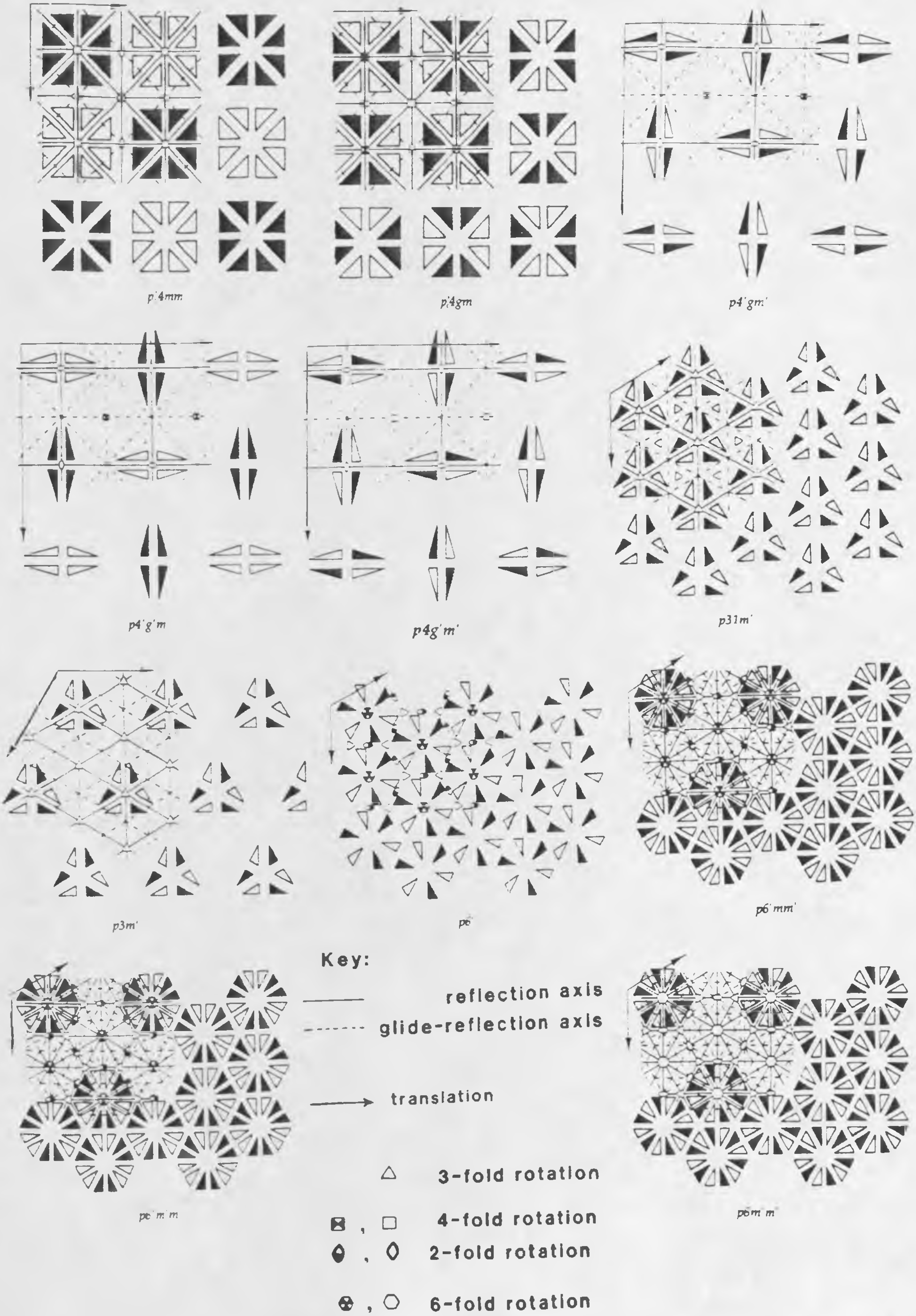


Figure 53. Woods' Counterchange All-Over Patterns.

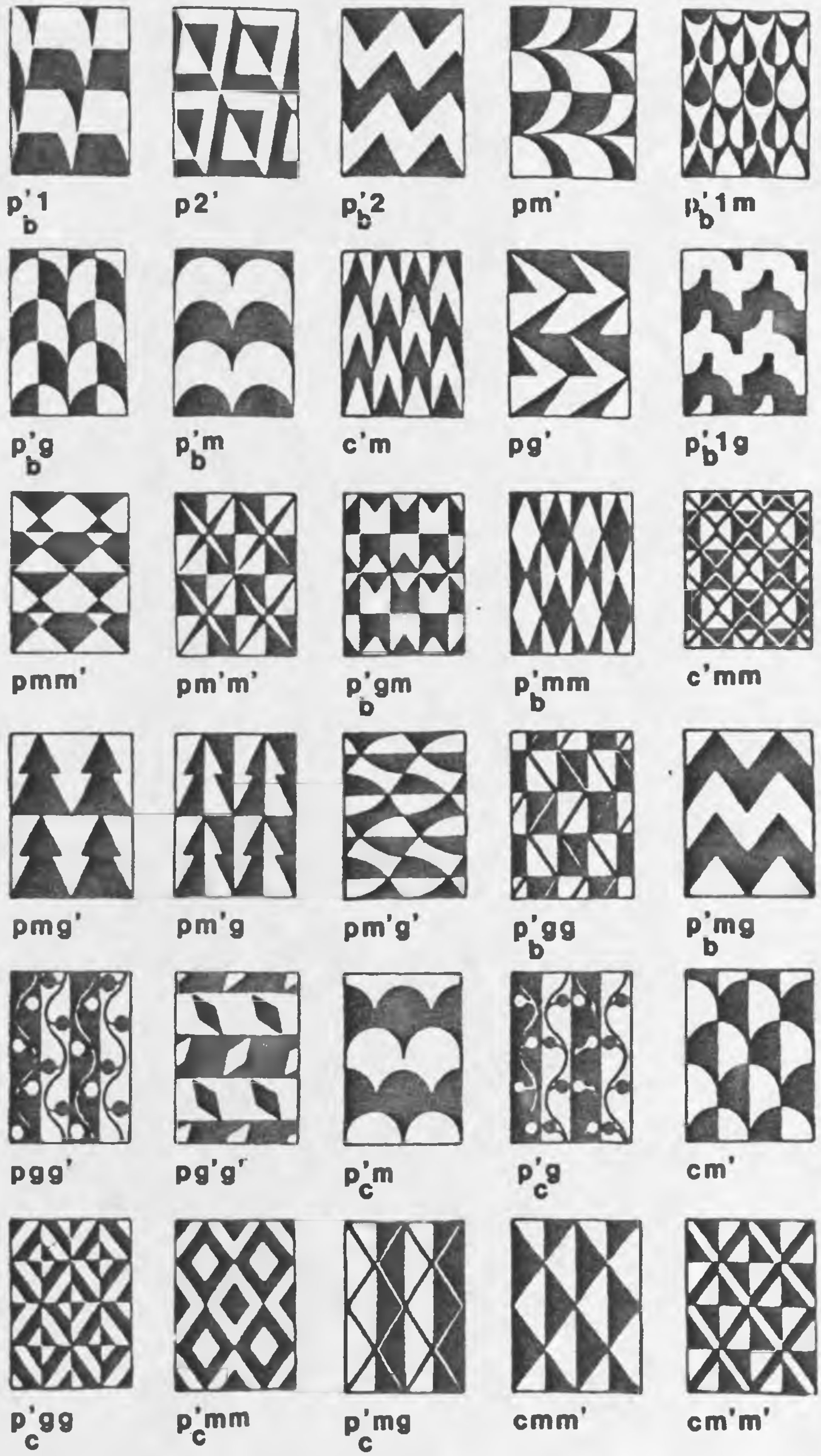
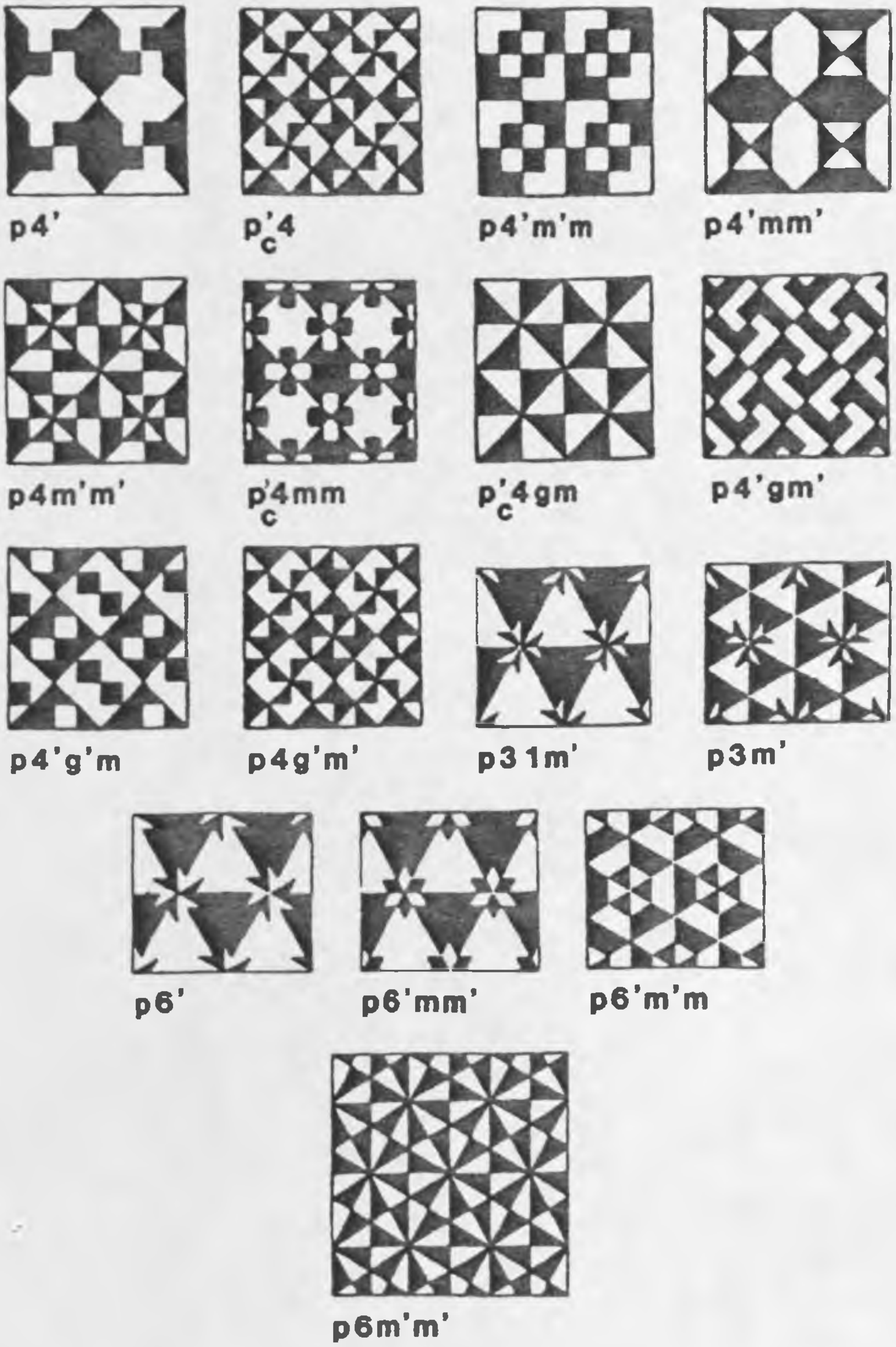


Figure 53 (cont). Woods' Counterchange All-Over Patterns.



Designs can of course be created by the systematic interchange of more than two colours. The theory accompanying such possibilities has only developed over the past two decades. Jarratt and Schwarzenberger [172] established the number of border pattern classes possible through interchanging n colours, for all values of n. Wieting [173] explored possible colourings of all-over patterns for values of n up to sixty. Extensive bibliographies of relevant literature were provided by Schwarzenberger [174] and Grunbaum and Shephard [175].

7. SYMMETRY IN REGULAR GEOMETRIC PATTERNS: CASE STUDIES FROM VARIOUS CULTURAL SETTINGS.

7.1 Introduction.

Having established a means by which regular geometric patterns can be classified by reference to their symmetry characteristics, the objective of this chapter is to apply these classification principles to groups of textile patterns from a small number of cultural settings, and, by so doing, test the validity of the following hypotheses:

i) When a representative group of all-over textile patterns from a given cultural setting are classified according to their symmetry characteristics, a non-random distribution of all-over pattern classes, and thus a unique range of symmetry preferences will result.

ii) The symmetry preference of a given culture will be maintained over time, provided that external forces for change are largely absent.

iii) When all-over textile patterns from a given cultural setting are differentiated by reference to technique of manufacture, the symmetry preferences associated with each technique will be broadly similar.

Case studies of patterns from four distinct cultural settings are presented below: traditional Javanese batik patterns; traditional Sindhi ajrak patterns; Jacquard woven French silk patterns (Autumn, 1893); Japanese textile patterns, produced during the Edo period (1604-1867) using a variety of patterning techniques. Data from each of the first three case studies were used to test the validity of hypothesis (i) above, and data from the fourth case study were used to test the validity of hypotheses (ii) and (iii) above.

It should be stressed at this stage of the enquiry that the objective is not to present an all-encompassing explanation and analysis of textile designs within each cultural setting. The emphasis in this thesis is on the way in which design elements have been repeated and not on the thematic or symbolic role of the elements themselves. The primary concern in the case studies is not therefore with broader issues of aesthetic development. Rather, the intention is simply to explore the viability of employing symmetry classification as an analytical tool within the context of textiles. Prior to the presentation of the case studies, a number of limitations relating to the nature of the data analysed are briefly considered below.

7.2 Data Considerations

Periods of fieldwork in Indonesia and Pakistan provided access to traditional Javanese batik patterns (sample size = 110) and traditional Sindhi ajrak patterns (sample size = 71) respectively. In the context of this thesis, *traditional patterns* are defined as those which, although manufactured in modern times, are considered by indigenous informants to have been produced, using similar techniques, for several generations without undergoing significant change. By adopting this definition, the following question may be posed: Are 'traditional' patterns a reflection of some aspect of past culture and/or some aspect of present culture? Both Javanese and Sindhi societies have certainly undergone change (particularly of an economic nature) during the course of 'several generations'. Equally, many aspects of culture have been retained (e.g. language, music, cooking practices and religion). Many textile patterns may well have fallen into disuse with the passage of time. Equally, many textile patterns (e.g. those classified as 'traditional') have been retained. Assuming that symmetry in pattern is in some way related to culture (as has been suggested by the bulk of the archaeological and anthropological literature cited previously), it may be suggested that the symmetry characteristics manifested by 'traditional' designs would seem to be in some way related to aspects of indigenous culture which have been retained despite the presence of pressures for change (particularly evident in contemporary times, due to the advent of mass production, mass communication and mass distribution).

It is often the case in the analysis of data relating to a given category of manufactured objects that random sampling techniques are employed with the intention of making inference relating to the total population as opposed to a small section of it. Random sampling of total populations of traditional Javanese or Sindhi textiles was not possible. However, attempts were made to ensure that the pattern samples were as representative as could be expected under the conditions prevailing during each field visit. In each case the testimony of indigenous informants/practitioners was sought to ensure firstly, that all the patterns included for analysis were typical of their region of origin and secondly that no commonly used pattern type had been excluded.

A pattern book of Jacquard woven French silks (dated Autumn, 1893), held in the Clothworkers' Collection at the University of Leeds, provided a readily available single source of a large number of historic patterns (sample size = 483) produced in a dated European cultural context. An illustrated compendium, published in 1960 by the Japan Textile Colour Design Centre [176] was used as a source for Japanese textile patterns (sample size = 290) produced during the Edo period (1604-1867), a time span of seemingly uninterrupted cultural stability. Whilst the representative nature of the two historical data sources stated above and the resultant sample sizes yielded by them may well appear to be more favourable than is invariably the case in comparable studies of groups of historical objects, it should none the less be recognised that the quality of data cannot be totally assured. This is a common problem, particularly associated with historic textiles; they are not only limited in number, but their distribution in time and space has a variation which is regulated both by the intensity of past production as well as by the physical conditions to which they have been subjected with the passage of time. For this reason, in the absence of supporting evidence, it is always difficult to determine the extent to which available data are a reflection of an historical and cultural reality. None the less, in order to encourage clarity of analysis and interpretation in the case studies which follow, all data series are assumed to be representative. All conclusions reached, however, should be seen within the context of the considerations outlined above.

It should be noted that the percentage figures given in all four case studies have been rounded to the nearest whole numbers.

7.3 Case Study 1 - the Symmetry Preferences Exhibited by Javanese Batik Patterns[1].

During a visit to Indonesia in September 1989, a survey was made of traditional Javanese batik designs [177]. Examples were examined from the island's principal batik producing regions, including the areas in and around the Central Javanese sultanates of Surakarta (Solo) and Yogyakarta (Yogya), the coastal areas of Cirebon, Indramayu, Pekalongan and Lasem, and the area in and around Garut in West Java. In addition, several practitioners were consulted, a small number of local collections were assessed and sketches were taken from authoritative Indonesian and other published sources [178-181]. In total, 505 traditional designs were examined and from these it was found that 110 exhibited regular all-over pattern characteristics. The remaining 395 designs were non-repeating varieties which, however, it should be noted in passing, often depicted figures with bilateral reflectional properties. The 110 regular all-over patterns were classified by reference to their symmetry characteristics with the aid of the flow diagram

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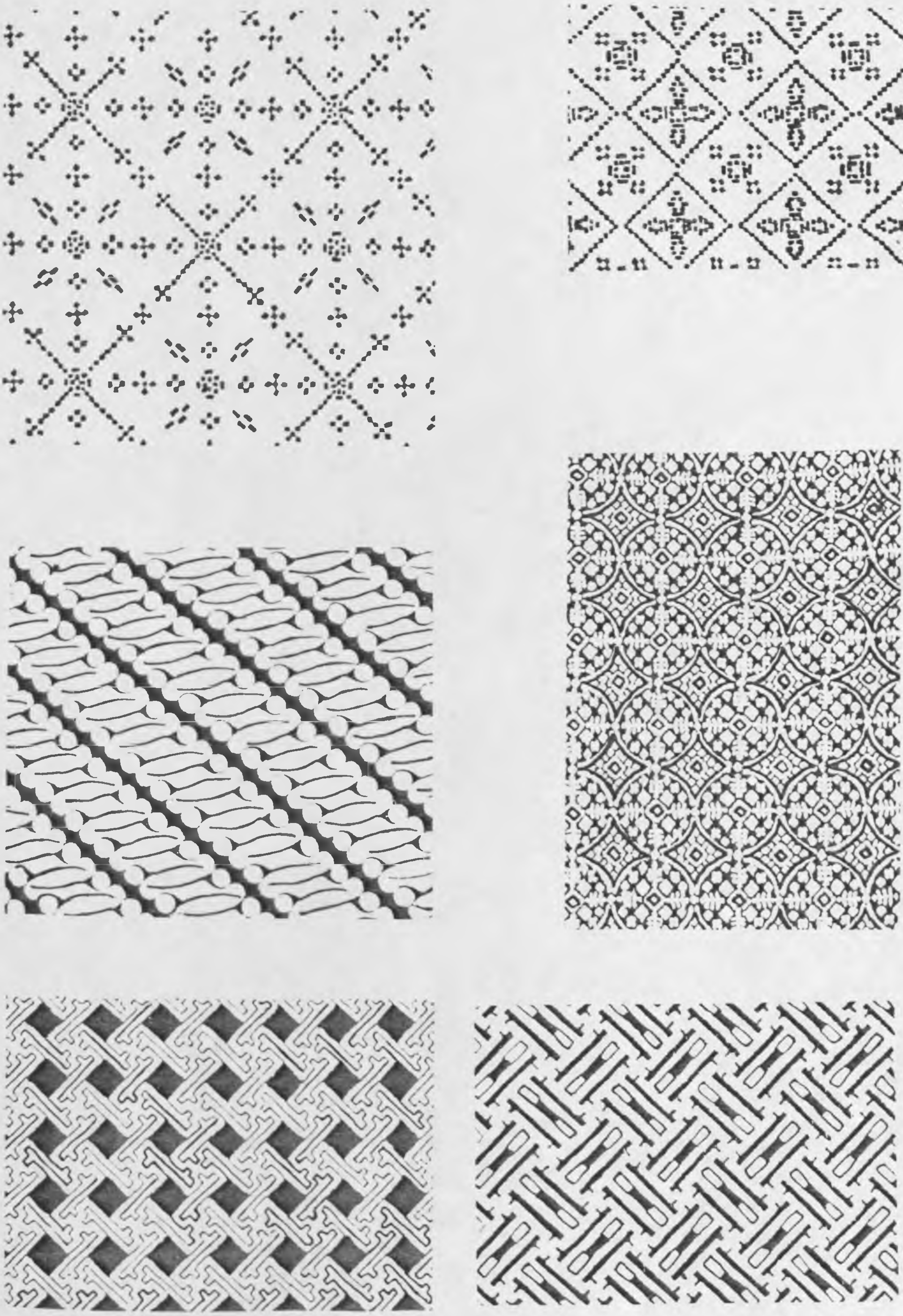
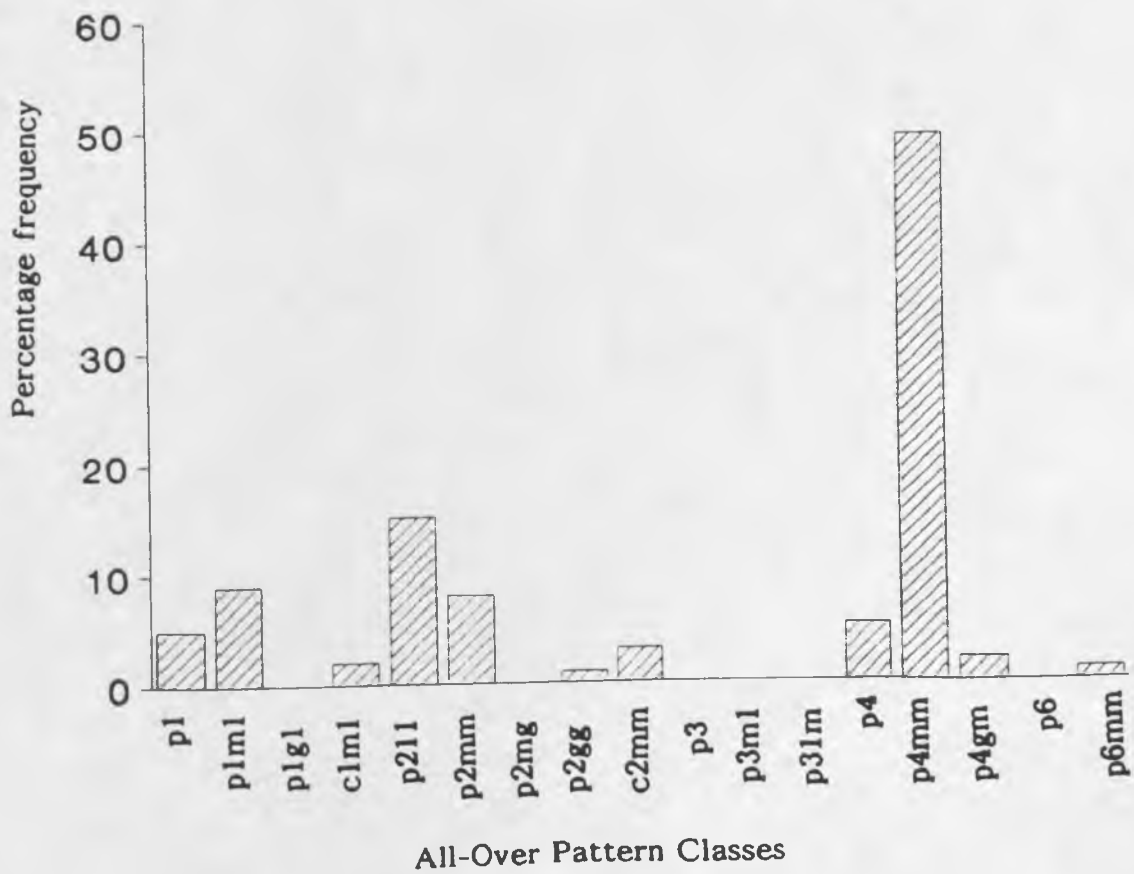
1. The word 'batik' is used to refer to wax (or sometimes paste) resist patterning techniques and their relevant products. The process, as practised in Java, involves the application of hot molten wax to areas of a fabric's surface. On solidification of the wax, the fabric is immersed in a dye bath. Waxed areas of the fabric remain impervious to the dyestuff which is taken-up only by the uncovered areas of the fabric. In Java, distinction is made between 'tulis' batik and 'cap' (pronounced 'tjap') batik. The former term designates the type of Javanese batik drawn by hand employing a hand-held drawing pen known as a canting (pronounced 'tjanting'), an implement consisting of thin copper with one or more capillary spouts and a handle shaped from reed or bamboo. The term cap is used to refer to the hand-held copper printing blocks which may be used as an alternative and speedier means of wax application. Regular all-over patterns may be produced using either method of wax application. The traditional use of batik is as a garment for festive or ceremonial dress. A wide ranging survey of batik motifs and patterns indigenous to Java is provided by Hann, M.A., 'Unity in Diversity: The Batiks of Java', submitted for publication in the *Journal of the Textile Institute*.

Figure 54. A Selection of Javanese Batik Patterns.



previously presented in Figure 46. Two-colour counterchange patterns were absent. A selection of all-over patterns typically found on Javanese batiks is presented in Figure 54. The numerical outcome of the classification exercise is included in Appendix 1 and the percentage frequency of each pattern class recorded is presented in histogram form in Figure 55.

Figure 55. Percentage Frequency of All-Over Pattern Classes (Javanese Batiks).



From the pattern sample of 110, eleven of the seventeen all-over pattern classes were represented to varying degrees. By far the most dominant symmetry class was four-fold reflectional symmetry (p4mm) which was evident in 49 per cent of the total sample. Rotational symmetry, in the form of class p211 patterns, which was evident in 15 per cent of the total sample, was the next most common symmetry feature. Four-fold rotational symmetry, in the form of class p4 patterns accounted for 5 per cent of the total sample, but three-fold (p3) and six-fold (p6) rotational symmetry were totally absent. Bilateral symmetry, which as mentioned previously was frequently evident in figures depicted on batiks with non-repeating compositions, accounted for 9 per cent of the total sample in the form of class p1m1 patterns and 2 per cent of the total sample in the form of the centred class c1m1 patterns. Classes p1, p2mm, c2mm and p6mm accounted for 5, 8, 3 and 1 per cent respectively. Classes p4gm and p2gg accounted for less than 2 per cent and less than 1 per cent of the total sample respectively. Classes p2mg and p1g1 were totally absent, as were classes p3m1 and p31m.

In order to confirm that the resultant distribution of symmetry classes was non-random, a chi-square test was performed on the data, comparing the frequency observed to the frequency expected (under conditions of randomness). The chi-square value of 426 with 16 degrees of freedom confirmed beyond reasonable doubt that the distribution was non-random and that a definite preference was expressed towards a small number of symmetry classes. This result lends support to hypothesis (i).

Assuming that the data are representative of Javanese batik patterns in general, the classification indicates a consensus among Javanese batik producers (as a whole) in the predominant use of a few symmetry classes, as well as an additional awareness of a wide range of symmetry possibilities. Reflectional, rotational and glide-reflectional classes were present to varying degrees. The extent to which this general consensus and awareness are typical of individual local conditions in each of the principal producing centres cannot however be assessed from the current data, due to the restrictions imposed by the sample size acquired during the field study. It certainly appears to be the case that motif types, judged in terms of thematic and symbolic content, differ from region to region within Java, and each particular centre of production is noted for its own speciality batik types. For example, it has been noted elsewhere [177] that the batiks from central Java show a predominance of design types associated with ancient Javanese Hindu culture (centred in and around the sultanates of Surakarta and Yogyakarta), whereas batik designs from northern coastal areas (e.g. in and around Cirebon) show motifs of Chinese origin (due to the intensity of past trade). It would seem worthwhile to conduct a wider ranging survey which would firstly encompass the symmetry classification of batik designs differentiated by reference to their source of production, and secondly, would include a symmetry classification of the full range of motifs used in the numerous non-repeating compositions. The extent to which symmetry class choice shows a consensus from centre to centre may act as an indication of the extent of intra-cultural interaction between producers.

7.4 Case Study 2 - the Symmetry Preferences Exhibited by Sindhi Ajrak Patterns[2].

During July 1987 and April 1988 a survey was made of traditional Sindhi textiles produced using the ajrak process. Two principal sources of data were used. Firstly, Threadlines Gallery, an organisation responsible for the marketing of the full range of Pakistani craft textiles. Associated with the various government sponsored regionally organised Small Industries Development Boards, Threadlines Gallery co-ordinates the retail distribution of the country's crafts through a series of outlets in the principal urban centres (Karachi, Islamabad and Peshawar). One example of each ajrak design in stock in each Threadlines Gallery outlet was purchased and this provided a total of 41 all-over patterns. The second source of data was Lok Virsa, the country's principal cultural museum based in Islamabad and considered to hold the nation's premier craft textile collection. Access to Lok Virsa's textile store was permitted. A total of 30 ajraks (purchased by Lok Virsa during the late 1970's and early 1980's) were located and recorded

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[2]. Typical ajrak textiles are used for turbans and shawls and are generally comprised of a series of borders surrounding a central all-over patterned area. Ajraks preserve one of the most ancient techniques of block printing associated with the Indus valley and are now exclusively produced in Sind province (Pakistan). Ajrak printing is a combination of mordant and resist block printing/dyeing. Prior to colouring, the process involves three stages of printing using hand-held wooden printing blocks. Firstly a resist mixture of chalk and gum is applied, secondly a mordant paste containing iron sulphate is applied and thirdly a mordant paste containing alum is applied. The first dyeing stage is when the cloth is dipped into a cold bath of indigo to pick-up a blue colour in the exposed areas. After drying, the cloth is dyed in a simmering madder bath with the result that the chalk and gum areas resist dye pick-up and thus remain white, the iron sulphate mordant areas are dyed black and the alum mordant areas are dyed red. The historic evolution of Sindhi ajraks and the precise details of the process remains largely undocumented. A brief. though highly ambiguous, outline is provided by Yacopino, F., '*Threadlines Pakistan*', the Ministry of Industry and Elite Publishers, Karachi, 1987, pp.84-89.

photographically or sketched. The all-over pattern sample from both sources was therefore 71. Each all-over pattern was classified according to its symmetry characteristics. Two-colour counterchange patterns were absent. A selection of typical Sindhi ajrak patterns is shown in Figure 56. The numerical outcome of the classification exercise is included in Appendix 2 and the percentage frequency of each pattern class recorded is presented in histogram form in Figure 57.

From the pattern sample of 71, only five of the seventeen all-over pattern classes were represented to varying degrees. By far the most dominant pattern class was the four-fold reflectional symmetry class p4mm, which was evident in 60 per cent of the total sample. The next most dominant symmetry class was the purely translational class p1, which accounted for 14 per cent of the sample. Reflectional symmetry in the forms of p2mm, p1m1 and c2mm patterns, accounted for 13, 7 and 6 per cent respectively. The four purely rotational classes p211, p3, p4 and p6, were totally absent from the sample, as were all forms of glide-reflection.

In order to confirm that the resultant distribution of symmetry classes was non-random, a chi-square test was performed on the data, comparing the frequency observed to the frequency expected (under conditions of randomness). The chi-square value of 425 with 16 degrees of freedom confirmed beyond reasonable doubt that the distribution was non-random and that a definite preference was expressed towards a small number of symmetry classes, thus lending further support to hypothesis (i).

Figure 56. A Selection of Sindhi Ajrak Patterns.

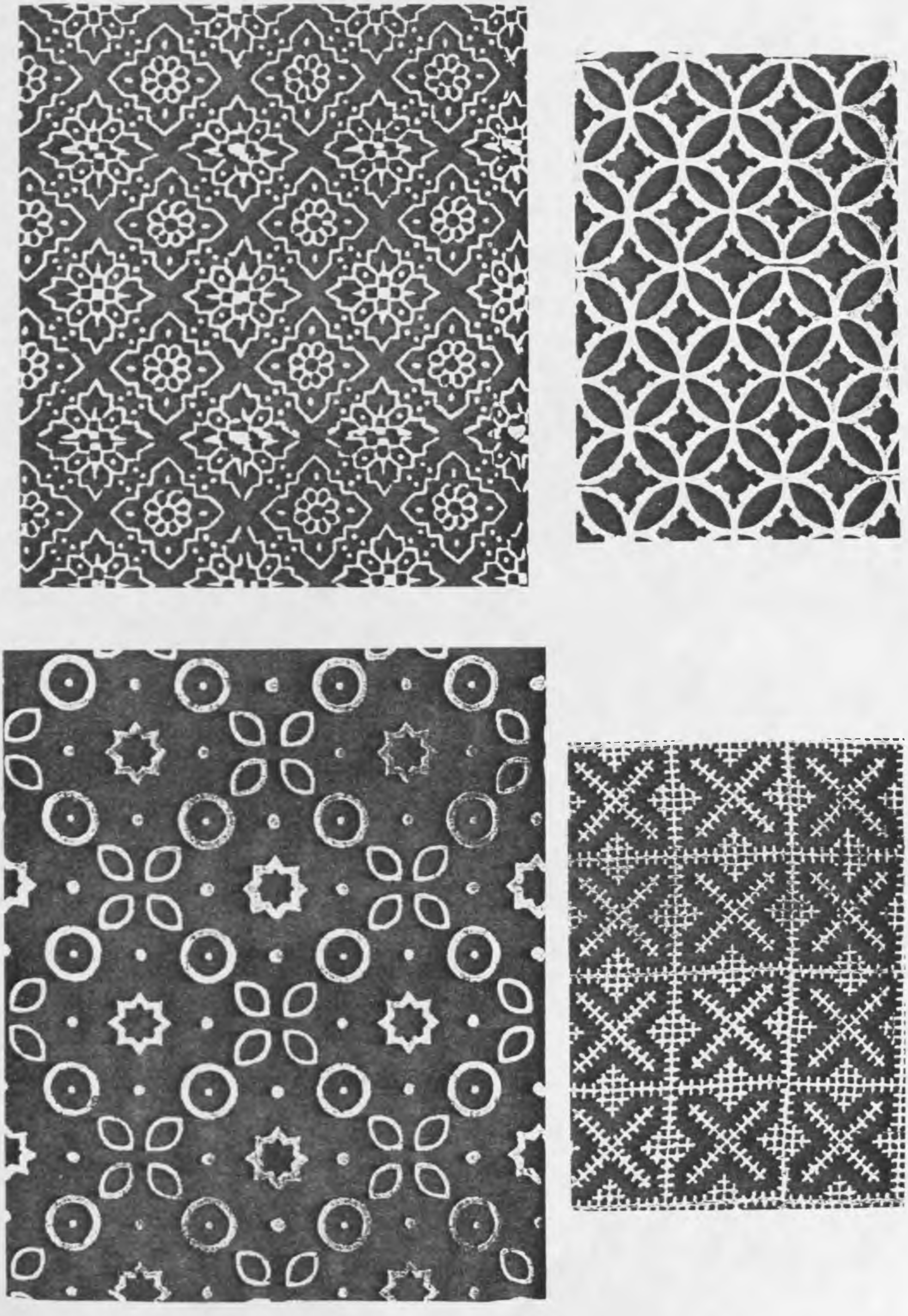
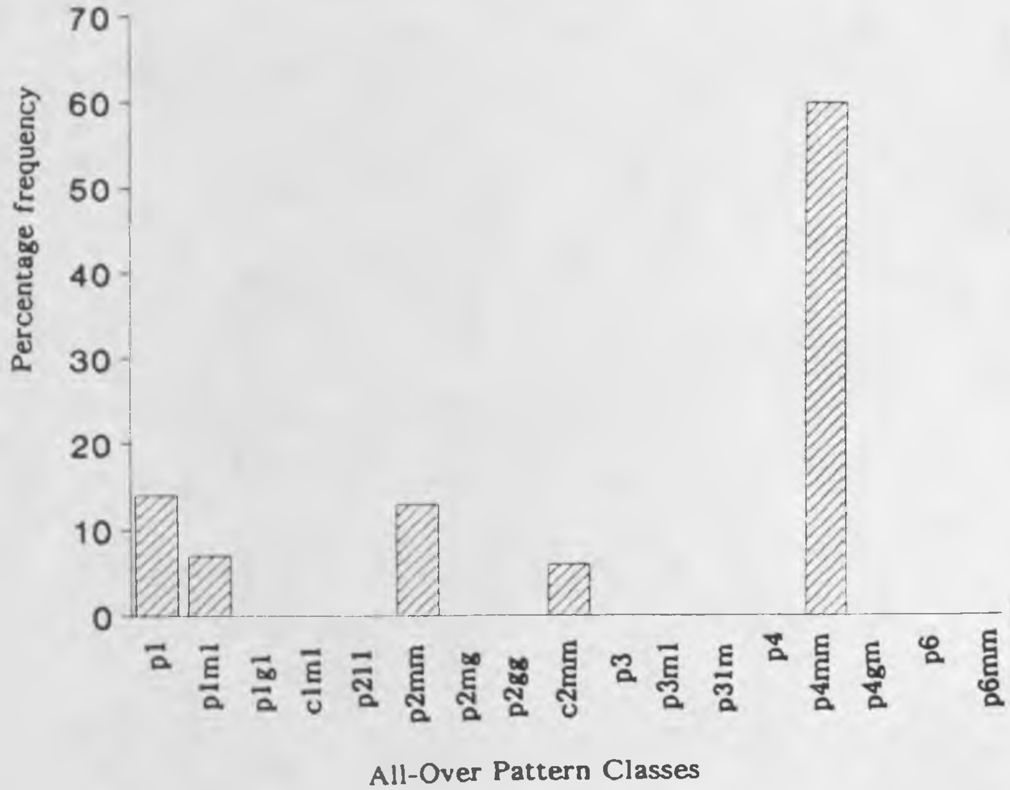


Figure 57. Percentage Frequency of All-Over Pattern Classes (Sindhi Ajraks).



Assuming that the data are representative of Sindhi ajrak patterns in general, the classification indicates a general consensus among ajrak producers in the predominant use of purely reflectional symmetry. An awareness of purely rotational and glide-reflectional symmetry classes is not however evident.

Sind province (which largely consists of the alluvial plain and delta of the River Indus) has been associated with block printing, and in particular the use of mordants, for the better part of three and a half thousand years (dating, seemingly, to the latter stages of the Indus Valley Civilisation, C.2300-1750 B.C., located at Mohenjo-daro). The ajrak process certainly seems to be of ancient origin, but whether 'traditional' ajrak patterns are of similarly remote origin is not known.

Sind province is also renowned for the production of decorative tiles (seemingly also produced in very remote times). During the course of the field study, the impression gained, based (it must be stressed) on a passing intuitive assessment, was that ajrak patterns and decorative tiling patterns were very similar in terms of structural characteristics (as well as colour). A rigorous comparative survey of the symmetry characteristics of patterns from both technique sources may give some indication of the extent to which artisans, working in different media, are governed by similar cultural rules (manifested by pattern symmetry).

7.5 Case Study 3- the Symmetry Preferences Exhibited by Jacquard Woven French Silks (Autumn, 1893)[3].

A readily available source of textiles produced in a European cultural setting was provided by the Clothworker's Collection [4] at the University of Leeds. A pattern book containing Jacquard woven silks, dated Autumn 1893, was selected because it provided a large dated sample of patterned textiles. A catalogue entry from the 1950's identified the samples as 'silk dress fabrics of French origin'. It was not, however, known where in France the silks were woven, nor if they represented the collective efforts of more than one production enterprise. Attempts to locate other Jacquard woven French silks of precisely the same date were unsuccessful. The total all-over pattern sample was 483. Each pattern was classified according to its symmetry characteristics. Although a very small proportion of two-colour counterchange patterns (< 2 per cent) was present, in these cases the pattern

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[3]. Silk production in France had become well established by the early 18th century with the principal centres of production located in Lyons and Tours. In 1805, Joseph Marie Jacquard (1752-1834) presented a mechanism which was to revolutionise the production of figured silk fabrics. Jacquard's mechanism, when attached to a conventional raised horizontal loom, introduced the possibility of automatic selective shedding. By the late 1800's looms with Jacquard attachments had largely replaced the drawloom in the vast bulk of French woven silk production (much of which was used for fashionable dress fabrics, with fresh collections of woven silks being presented on a seasonal basis to interested customers).

[4]. An appraisal of the collection's contents, together with a description of ongoing research projects is provided by Hann, M.A., 'The Clothworkers' Collection, the University of Leeds - An Archive Source for use by Scholars and Industrialists', *Ars Textrina*, vol.12, 1989, pp.157-174.

outline only was classified; this was to ensure that the analysis remained within the scope of the seventeen primary all-over pattern classes. A selection of patterns from the pattern book are shown in Figure 58. The numerical outcome of the classification exercise is shown in Appendix 3 and the percentage frequency of each pattern class recorded is presented in histogram form in Figure 59.

From the pattern sample of 483, twelve of the seventeen all-over pattern classes were represented to varying degrees. By far the most dominant pattern class was p1g1, produced by the glide-reflection of an asymmetrical motif. This class accounted for 76 per cent of the total sample analysed. The next most common pattern class was the purely translational class p1 which accounted for 14 per cent of the total sample. All other symmetry classes recorded, when taken together, accounted for around 10 per cent of the total sample, with no single class accounting for more than 2 per cent. All three-fold patterns of both the purely rotational variety (p3) and the reflectional varieties (p3m1 and p31m) were totally absent, as were class p4 and class p6mm patterns.

In order to confirm that the distribution was non-random, a chi-square test was performed on the data, comparing the frequency observed to the frequency expected (under conditions of randomness). The chi-square value of 4,504 with 16 degrees of freedom, confirmed beyond reasonable doubt that the distribution was non-random, and that a definite preference was expressed towards a small number of symmetry classes. This result lent further support to hypothesis (i).

Figure 58. A Selection of Jacquard Woven French Silk Patterns (Autumn, 1893).

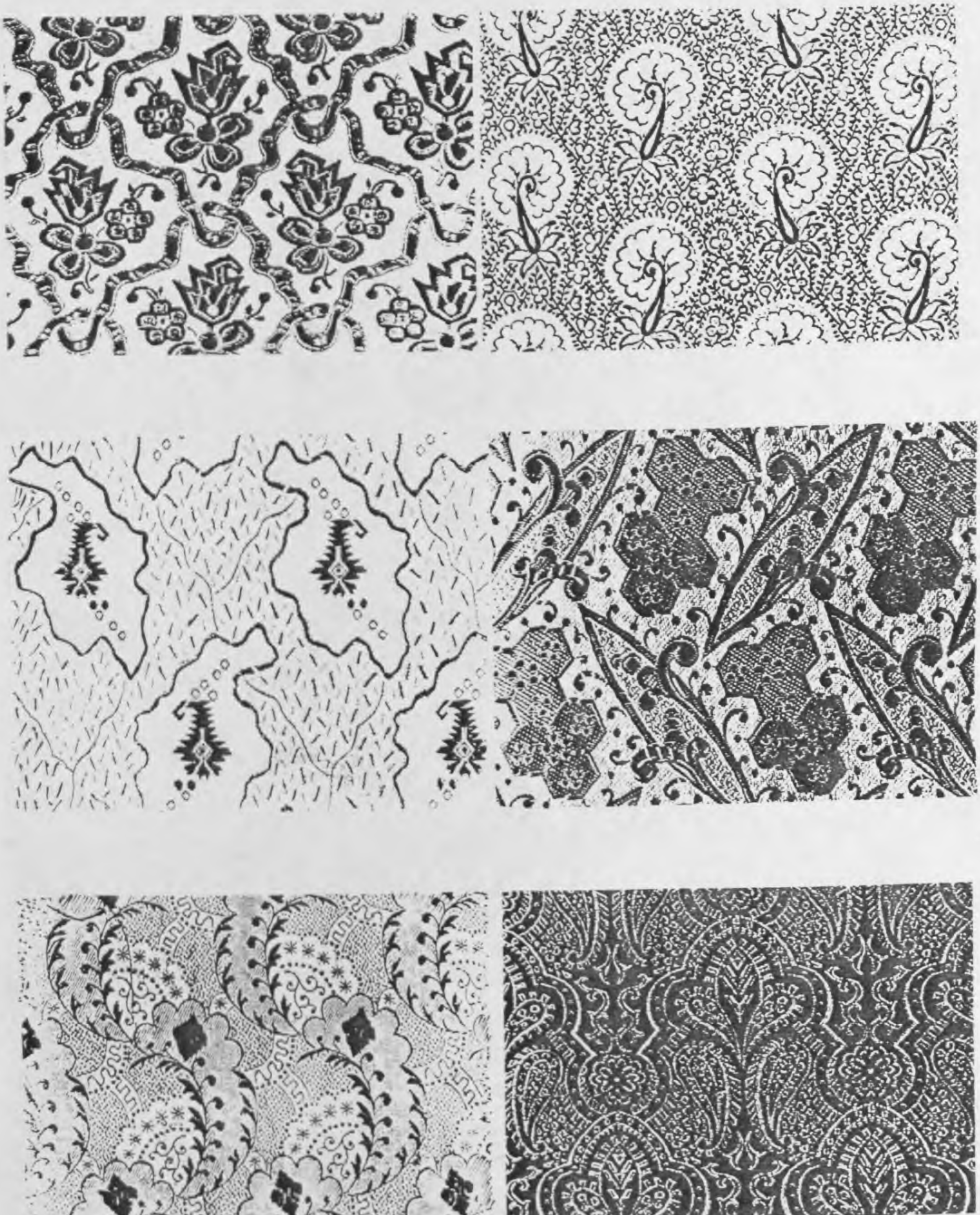
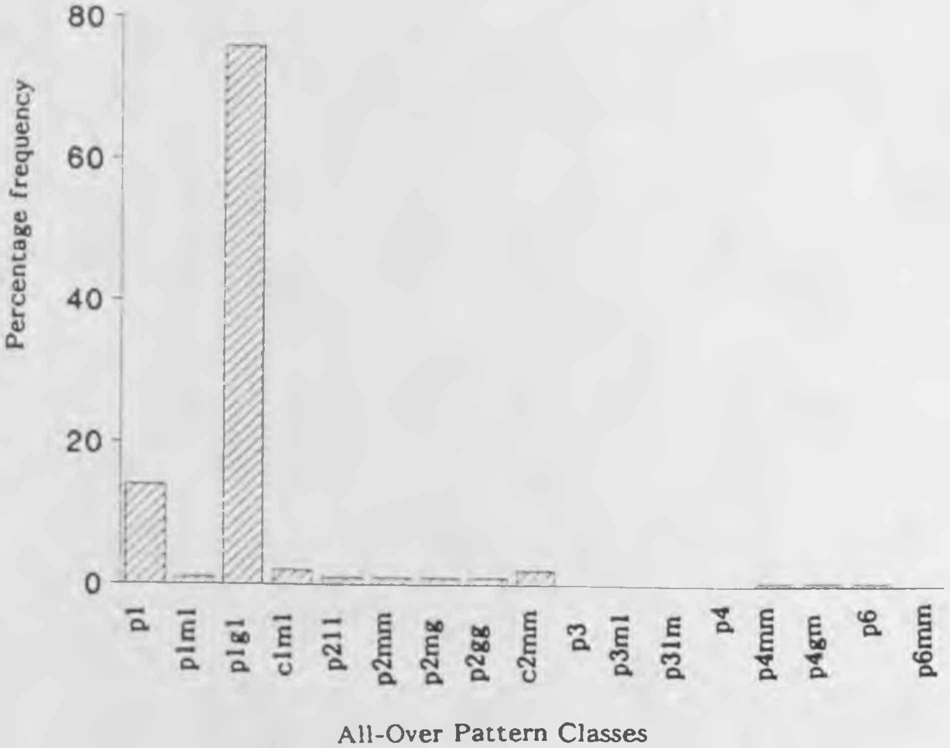


Figure 59. Percentage Frequency of All-Over Pattern Classes (Jacquard Woven French Silks, Autumn, 1893).



To what extent p1g1 patterns are typical of 1890's French figured silk designs is not yet known and further enquiry using compatible data sources would be necessary to establish the extent of the popularity at the time. It could of course be the case that the data is grossly misleading; all the patterns may have been produced in one single design studio where a definite house-style had emerged. As a consequence, the distribution described above may not be representative of 1890's Jacquard woven French silks in general, but rather an expression of the eccentricities of a particular design studio or even a single designer.

7.6 Case study 4 - the Symmetry Preferences Exhibited by Japanese Textile Patterns Produced During the Edo Period (1604 - 1867)[5].

The objectives of this case study of Japanese patterns from the Edo period are firstly to test the hypothesis that the symmetry preferences of a given culture will be maintained over time provided that external forces for change are largely absent and secondly, to establish whether the patterns produced using two distinct categories of patterning techniques will exhibit broadly similar symmetry characteristics.

The Japanese Edo period certainly seems to have been a time span when outside pressures for change were largely absent. A policy of national isolation had been enacted by the ruling feudal government, and communications (including trade)

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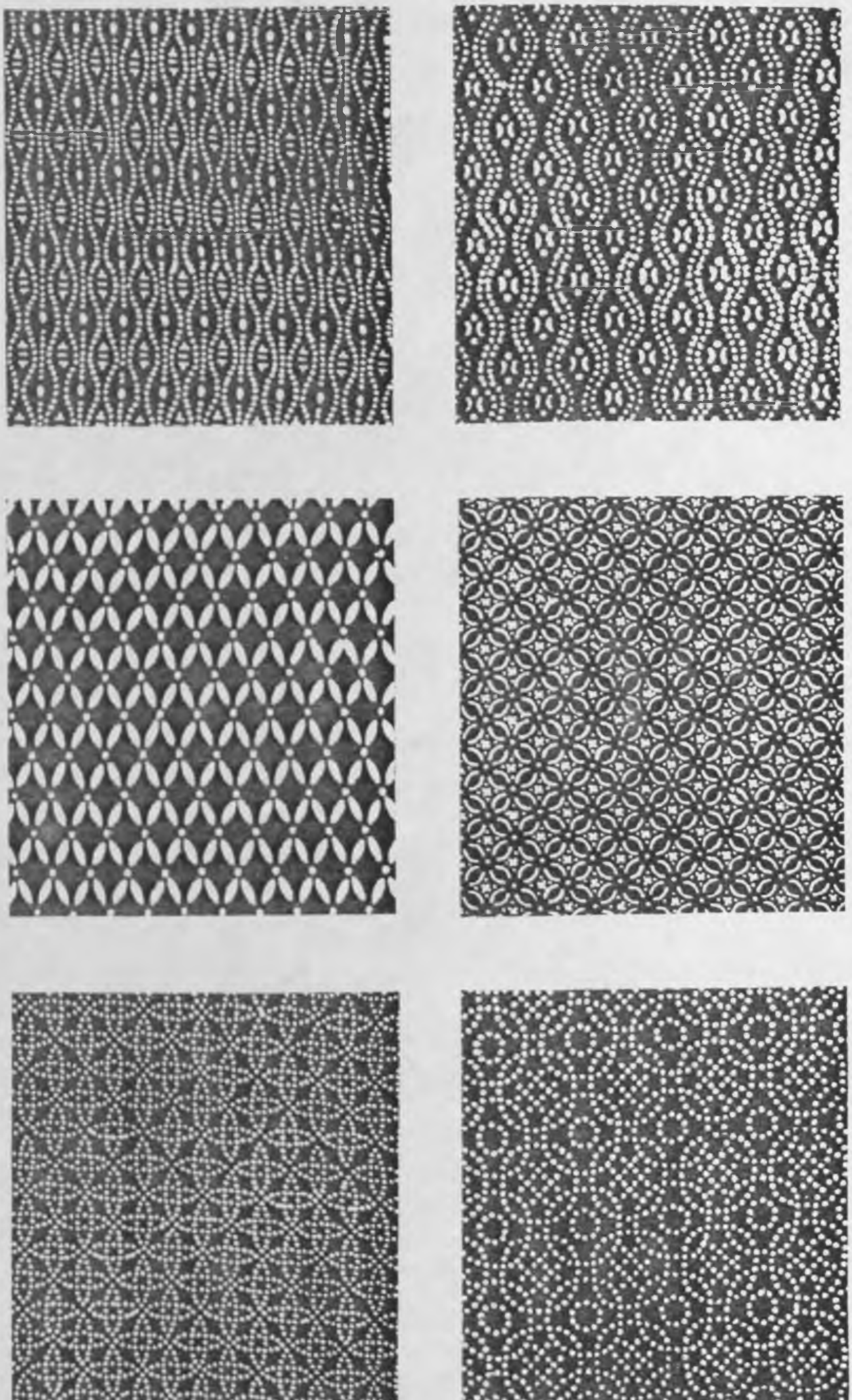
[5]. A wide range of patterning techniques were employed during the Edo period. Figured fabrics of cotton or silk were woven on the takahata (or high loom), a raised horizontal loom of a type which was seemingly introduced from China some centuries previously. Non-figured fabrics were produced on various forms of backstrap loom. Various embroidery techniques and gold-leaf imprinting were also in use. The Edo period is particularly noted for the range of resist dyeing techniques in use. These were of three general types: (i) 'Kasuri', the name given to the process of resist dyeing of yarns prior to weaving (known as 'ikat' in the West). After the precise form of the pattern has been decided, the parts of the yarn to remain undyed are bound with a material impervious to the dye. After dyeing, the yarns are woven so that the dyed and undyed sections are woven at previously determined points. Kasuri is generally categorised as warp, weft or double depending on whether the warp, the weft or both sets of yarns are resist dyed. (ii) 'Shibori', the name given to the technique more commonly known in the West as 'tie-and-dye' or 'plangi'. Portions of lightweight fabric are wrapped with dye resistant string and placed in a dyebath or alternatively the points of the fabric to remain undyed are picked out with a needle and a length of strong thread on which the fabric is drawn to form a series of tightly packed folds. (iii) Resist paste techniques, by which dye resist pastes are applied to the fabric in one of two ways: either by freehand drawing of the paste onto the fabric using a tube (held rather like a crayon) or else by a spatula through a pre-cut stencil. When the paste is dry the fabric is immersed in a dye bath and the dye takes to those areas not covered by the paste.

with other parts of the world were forbidden (with the exception of very limited contacts with China and the Netherlands at the port of Nagasaki) [182]. Until the restoration of trade with the West, in 1867, Japanese society remained largely undisturbed [183]. Significant innovations in patterning techniques none the less took place, but it seems that these innovations were not of the type aimed at the mechanisation of processes as was the norm in Western Europe at the time, but rather were aimed at improving the patterning potential of familiar craft techniques. In fact it has been suggested [184] that the textile designs produced during the Edo period were the '...richest in variety of techniques, styles and motifs in the history of Japanese textiles'. In addition to figured weaving, embroidery and gold-leaf imprinting (by which gold-leaf figures were gummed to the fabric surface), a full range of resist dyeing techniques (e.g. ikat, plangi and stencil resist techniques) were also in use. Stencil resist techniques, in particular, were the focus of much development during the period [185]. Further attention is focused on this development later in the case study, when a comparison is made between the symmetry characteristics of patterns produced by two distinct categories of patterning techniques (i.e. figured weaving and resist dyeing).

A three volume series entitled '*Textile Designs of Japan*' appeared to be the most authoritative illustrated source of Japanese textile designs published to date, and as such offered potential as a source of illustrations for pattern classification [186-188]. The second volume, in the series, which was subtitled 'Designs Composed Mainly in Geometric Arrangement' offered a rich compendium of all-over patterns, each identified by reference to its patterning technique and period of manufacture. Designs illustrated in the other two volumes in the series were unsuitable for inclusion in the study; volume 1 presented 'free style graphic designs', which were comprised mainly of non-repeating compositions, and volume 3 presented designs which were produced by remote island peoples, distant from the mainstream of Japanese culture at the time. From volume 2 of the series, a total of 299 Edo period Designs proved suitable for symmetry classification. A small selection of designs from the stated source are reproduced in Figure 60.

Figure 60. A Selection of Japanese Textile Patterns From the Edo Period.



7.6.1 A Comparison of the Symmetry Preferences Exhibited During Consecutive Time Periods.

In order to assess whether the symmetry preferences exhibited by Edo period patterns were maintained with the passage of time, the data were further categorised into four consecutive sub-periods dependant upon the time of manufacture: the Early Edo (1604-1673), the Middle Edo (1673-1750), the Late Edo (1751-1800) and the End of Edo (1801-1867)[6], yielding sample sizes of 9, 34, 94 and 162 respectively. The sample size of data from the Early Edo was obviously too small to be of much use in the subsequent analysis and as such was excluded from the study. The numerical outcome of the classification of patterns from the three remaining sub-periods is provided in Appendix 4 and the percentage frequency of each pattern class recorded is presented in histogram form in Figures 61 (a), (b) and (c).

From the data for the Middle Edo, twelve of the seventeen all-over pattern classes were represented to varying degrees. The most dominant pattern classes were as follows: class c2mm which accounted for 24 per cent of the relevant pattern sample, class p2mm which accounted for 18 per cent, and classes p1m1 and p1 which accounted for 15 per cent and 12 per cent respectively. Classes p1g1, p2mg, p2gg, p4 and p6 were absent from the sample. The eight remaining

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[6]. Although this chronology does not appear to be in widespread use, and the time span of each sub-period appears to be rather arbitrary, it is none the less the chronology presented in the data source in association with the patterns analysed and as such would appear to be acceptable in the context of this case study.

Figure 61(a). Percentage Frequency of All-Over Pattern Classes (Japanese Textiles, Middle Edo, All Patterning Techniques).

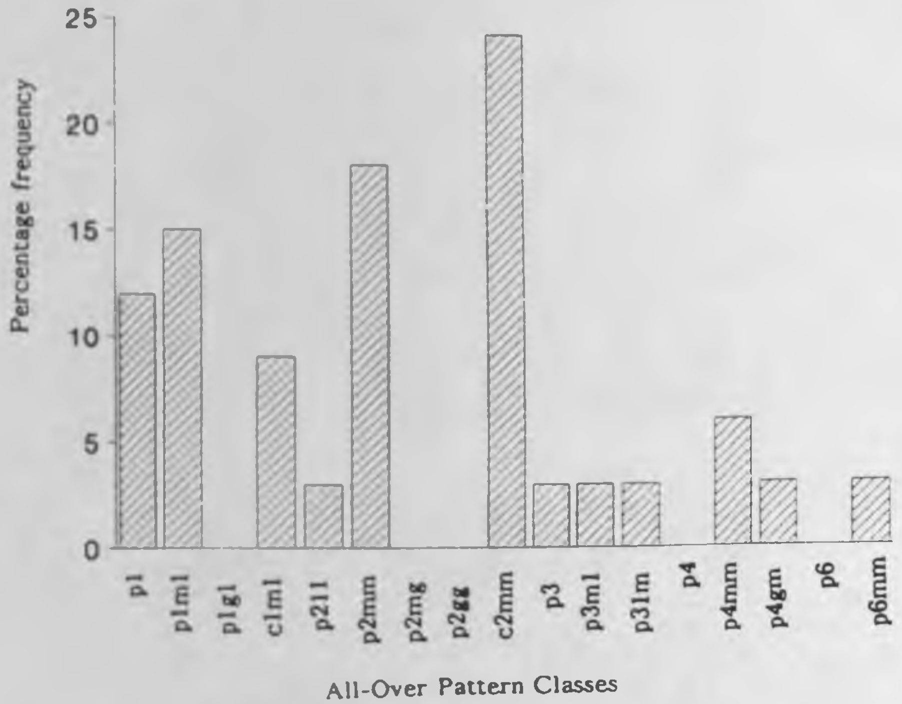


Figure 61(b). Percentage Frequency of All-Over Pattern Classes (Japanese Textiles, Late Edo, All Patterning Techniques).

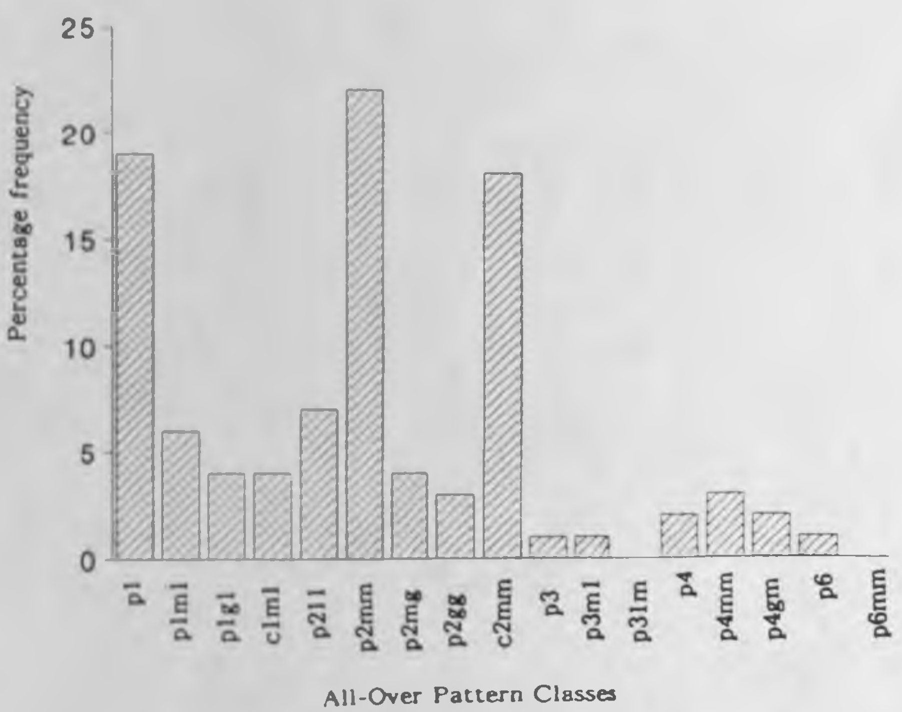
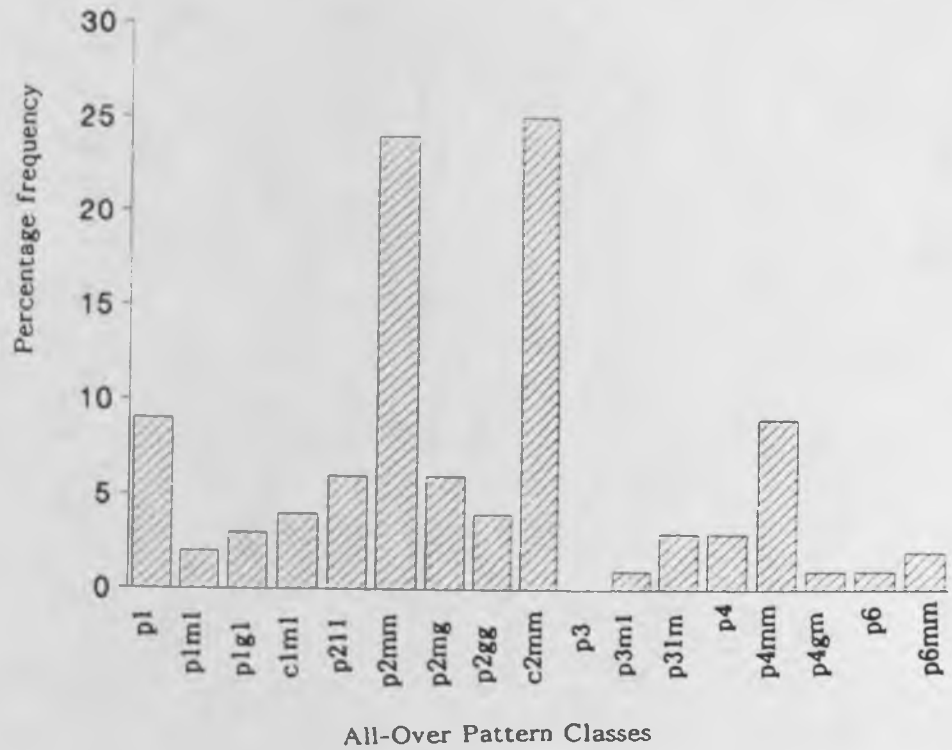


Figure 61(c). Percentage Frequency of All-Over Pattern Classes (Japanese Textiles, End of Edo, All Patterning Techniques).



all-over pattern classes, taken together, accounted for just over 30 per cent of the total sample with classes c1m1 and p4mm accounting for 9 per cent and 6 per cent respectively, and classes p211, p3, p3m1, p31m, p4gm and p6mm each accounting for slightly less than 3 per cent of the sample.

From the data for the Late Edo, fifteen of the seventeen all-over pattern classes were represented to varying degrees. The most dominant pattern classes were as follows: class p2mm which accounted for 22 per cent of the relevant pattern sample, class p1 which accounted for 19 per cent and class c2mm which accounted for 18 per cent. Classes p31m and p6mm were totally absent. The remaining pattern classes, taken together, accounted for around 38 per cent of the total sample, with classes p211 and p1m1 accounting for 7 per cent and 6 per cent respectively, and the remaining ten classes accounting for between 1 per cent and 4 per cent of the total sample.

From the data for the End of Edo, sixteen of the seventeen all-over pattern classes were represented to varying degrees. The most dominant pattern classes were as follows: class c2mm which accounted for 25 per cent of the relevant pattern sample, class p2mm which accounted for 24 per cent, and classes p1 and p4mm, each of which accounted for 9 per cent. Class p3 was totally absent. The twelve remaining classes, taken together, accounted for around 35 per cent of the total sample, with classes p211 and p2mg each accounting for 6 per cent, and the remaining ten classes each accounting for between just under 1 per cent and around 4 per cent of the total sample.

From the data available it seems to be the case that c2mm patterns, p2mm patterns and p1 patterns were dominant throughout the three time spans, together accounting for 54 per cent, 59 per cent and 58 per cent of the total samples in the Middle Edo, Late Edo and End of Edo respectively. Whilst these figures appear on first inspection to support hypothesis (ii), further attention to the data reveals two inconsistencies: patterns from class p1m1 accounted for around 15 per cent of the Middle Edo pattern sample and class p4mm accounted for 9 per cent of the End of Edo pattern sample.

The relatively high percentage frequency of p1m1 patterns during the Middle Edo may be a weakness resulting from the small sample size, and as a consequence may not be fully representative of an historical reality. It could however be the case that p1m1 patterns were indeed popular in the Middle Edo and subsequently underwent a decline in popularity over the three time spans, but further enquiry using a larger sample size would be a necessary pre-requisite to establish whether this was indeed the case.

As regards the relatively high percentage frequency of End of Edo class p4mm patterns, further examination of the data source revealed that the vast majority of these patterns had been produced using stencil resist patterning techniques, a category of patterning techniques which underwent development and showed an increased popularity during the End of Edo [189]. Further attention is focused on this development in the next sub-section. On the basis of the increased percentage frequency of p4mm patterns it seems to be the case that an important change in the symmetry preferences manifested by Edo period textile patterns did indeed occur, despite the absence of outside forces of cultural change.

From relevant past literature [190-192], it seems that temporal changes in the symmetry preferences expressed by a given culture are generally explained by reference to outside agents of change only. In addition there appears to be the underlying suggestion that symmetry preferences will be maintained indefinitely providing agents of diffusion (e.g. missionaries, trade delegations or military conquests) are excluded. On closer inspection, however, this underlying assumption does not appear to be well founded. Whilst the importance of diffusion of innovations in the development of all societies should not be underestimated, to suggest that cultures remain static when outside forces for change are absent, appears to be distant from reality. Indeed it would seem to be more feasible to suggest that all isolated societies undergo certain occasional incremental changes (e.g. of an economic, religious or technological nature) which, taken cumulatively, may help to perpetuate the society or alternatively lead to its breakdown. Such incremental changes may also manifest themselves through subtle changes in the decorative arts, changes which may in turn be revealed through symmetry classification.

It appears therefore that although classes c2mm, p2mm and p1 all-over patterns remained dominant throughout the three time spans of the analysis, an extension of the symmetry preferences also occurred, firstly in terms of the number of symmetry classes used (which increased from 12 to 15 to 16) and secondly in terms of the increased popularity of class p4mm patterns.

7.6.2 A Comparison of the Symmetry Preferences Exhibited by Patterns Produced Using Two Distinct Categories of Patterning Techniques.

There appears to be the underlying assumption in much of the archaeological and anthropological literature concerned with symmetry in pattern, that the patterns produced in a given cultural context using different techniques of manufacture will show the same symmetry preferences [193]. However, this outlook does not seem to have been satisfactorily tested by reference to two or more concurrent series of data, which although of the same time period and cultural source, were each derived from patterns produced using a distinctly different category of production technique. The objective of the analysis presented below is to ascertain if the patterns produced by two different categories of patterning techniques (i.e. either weaving or resist dyeing) exhibit the same symmetry preferences. Data obtained from designs woven during the Late Edo and End of Edo were combined, as were data from designs produced by resist dyeing, with resultant sample sizes of 115 and 116 respectively. The numerical outcome of the symmetry classification of each series is included in Appendix 5 and the percentage frequency of the all-over pattern classes recorded for each category of technique is presented in histogram form in Figures 62 (a) and (b).

From the data available, the most dominant symmetry class exhibited by woven patterns was class p2mm which accounted for 30 per cent of the total sample. The next most dominant classes were p1 and c2mm, each of which accounted for 17 per cent of the total sample. The most dominant symmetry classes exhibited by resist dyed patterns were classes p2mm and c2mm, each of which accounted for 18 per cent of the total sample, and classes p1 and p4mm, each of which accounted for 11 per cent of the total sample. Classes p1, p2mm and c2mm therefore showed a dominance in the patterns produced by each category of technique, and as such some support seems to be lent to hypothesis (iii) (in that the symmetry preferences of each category of patterning technique are 'broadly similar'). However, taken together, these three classes accounted for 64 per cent of woven patterns but only 47 per cent of resist dyed patterns. In addition the relatively high percentage incidence of p4mm resist dyed patterns should not be ignored. Further examination of the data source revealed that all p4mm resist dyed patterns were produced by stencil resist techniques. During the course of further enquiry into the circumstances which led to the development and increased popularity of stencil resist techniques during the Late Edo and End of Edo, it was realised that the principal end-use of such patterns was as clothing products and

Figure 62(a). Percentage frequency of All-Over Pattern Classes (Japanese Textiles, Late Edo and End of Edo, Woven Patterns Only).

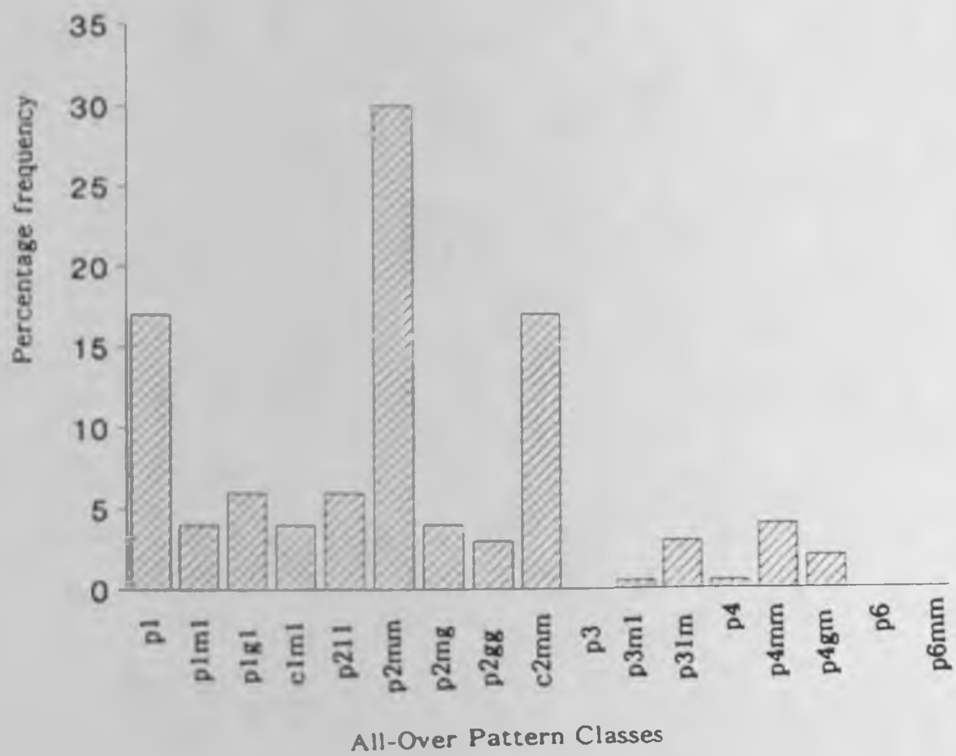
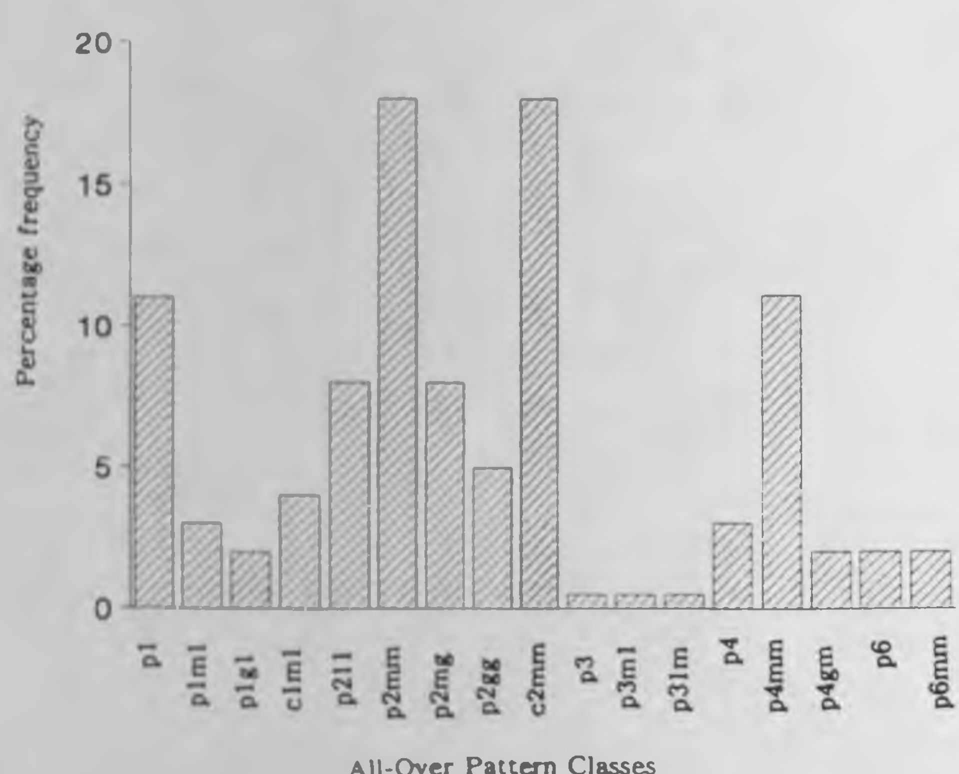
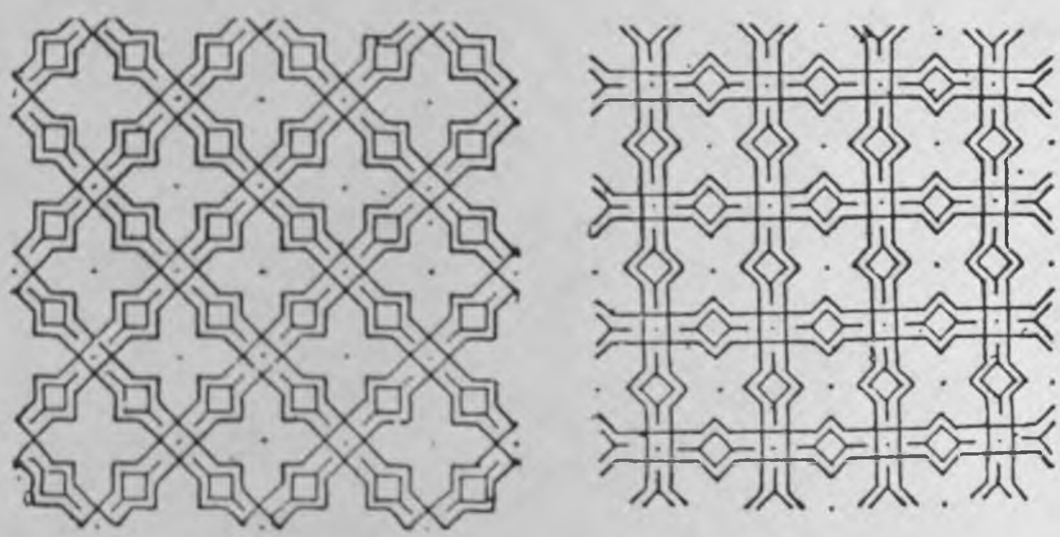


Figure 62(b). Percentage frequency of All-Over Pattern Classes (Japanese Textiles, Late Edo and End of Edo, Resist Dyed Patterns Only).



that the use of p4mm patterns was particularly suited to the nature of Japanese clothing construction. Further explanation is presented below. Japanese clothing construction during the Edo period had developed from the simple method of doubling a length of cloth and then simply slashing a hole in the middle of the fold, through which the head of the weaver ultimately passed [194]. Unlike Western clothing, Edo period clothing had no seam at the shoulders, but instead continued in one piece from the front to the back. It appears that a large proportion of designs on clothing fabric, during much of the Edo period, were of a 'graphic' variety, comprising large scale non-repeating compositions with figures of an asymmetrical nature [195]. With such designs it was necessary to ensure that the orientation of figures remained the same on both the front and the back of the garment. Using freehand painting or embroidery, this was facilitated by reversing the orientation of the design elements at the mid-way shoulder line. The problem of design orientation imposed by clothing construction was easily resolved with the increased use of stencil resist techniques: after applying paste to one half of the cloth with the stencil continuously orientated in one direction, the stencil was simply rotated through 180 degrees and the paste thus applied to the other half of the cloth. By the End of Edo, stencil resist techniques were increasingly used in the patterning of clothing products. A parallel development was the introduction of small-scale stencil resist all-over repeating patterns (known as 'Komon' or 'small patterns'). With the increased application of stencil resist techniques, it appears that the necessity of turning stencils through 180 degrees became redundant through the increased use of p4mm patterns (which appear the same if viewed either right-side-up or up-side-down). It seems that p4mm patterns offer potential for usage in a range of garment forms; not only can

Figure 63. A p4mm Pattern Tilted by 45 Degrees.



they be rotated through 90 degrees, 180 degrees, 270 degrees and 360 degrees to produce the same visual effect, but, as shown in Figure 63, they can also be tilted by 45 degrees to produce a second visual effect (which in turn can be viewed in one of four directions). Recalling the dominance of p4mm patterns in both Javanese batiks and Sindhi ajraks, it would seem that the visual flexibility of p4mm patterns may well contribute, at least in part, to their usage in a wide range of apparel products.

Whilst the Late Edo and End of Edo data showed that the dominant symmetry preferences exhibited by each category of patterning technique were broadly similar, it has none the less been shown that an increase in one particular symmetry class (i.e. p4mm) came about in the absence of outside pressures for change, firstly through developments in stencil resist techniques and secondly through the restrictions imposed by garment construction techniques. However, it should be noted that the increased acceptance of p4mm patterns, during the later years of the Edo period, may indicate that other concurrent cultural changes also took place.

7.7 Summary of Results

On classifying textile patterns from different cultural settings, it has been shown that a non-random distribution of symmetry classes and thus a unique range of symmetry preferences results in each case. This non-randomness is of fundamental significance to anthropologists, archaeologists and design historians for it demonstrates that design structure, assessed in terms of symmetry characteristics, is in some way culturally sensitive and as such may prove of use as an indicator of cultural adherence, continuity and change.

On assessing the extent to which the symmetry preferences of a given culture were maintained with the passage of time, in the absence of outside forces for change, it was found that a small number of symmetry classes remained in predominant use throughout the chosen time period. In addition, it was observed that an extension of symmetry preferences came about firstly, through an increase in the total number of symmetry classes used and secondly, through the increased popularity of one particular symmetry class.

When the patterns produced by two different categories of patterning techniques were classified by reference to their symmetry characteristics, it was found that the dominant symmetry preferences exhibited by each category were broadly similar. In addition an increase in the use of one particular symmetry class was noted; this increase may have come about due, at least in part, to the restrictions imposed by the garment construction techniques in use at the time.

8. IN CONCLUSION

For many years now anthropologists have focused upon understanding culture as a series of inter-related subsystems bound together by a series of organisational rules (e.g. laws, values, attitudes and habits), developed by participants in order that their society can be maintained and perpetuated. Typical examples of subsystems include the economy, religious practices, language and music. Observers have maintained that the conception, execution and function of the decorative arts of any culture can be considered to be a subsystem equally as integral to the growth and maintenance of a culture as any other subsystem [196]. Following from this, it appears that much of the relevant anthropological literature assumes firstly, that the same organisational rules permeate through the many subsystems of a given culture; secondly, that these organisational rules are somehow manifested in the structural characteristics of the culture's decorative arts; thirdly, that continuities and/or changes in any one subsystem are reflected in all other subsystems (including in the decorative arts), due to changes in the organisational rules applicable to the culture in general. Based on these assumptions a number of investigators have attempted to relate the structural characteristics (but not the full spectrum of symmetry characteristics) of the decorative arts with other aspects of culture. Adams [197] attempted to relate the organisational principles of Sumba textile design to certain other activities such as marriage exchange, ritualistic practices, and structure of ceremonial language. A study by El-Said and Parman [198] attempted to relate the geometry of Islamic tiling patterns to aspects of Islamic cosmology. Kaeppler [199] found structural relationships between Tongan music and bark cloth design and maintained that these were manifestations of wider societal characteristics. Arnold [200], in a study conducted among the residents of Quinua (Peru), found a relationship between decoration on textiles and the principles governing the spatial organisation expressed in ritual and religion. Whilst these studies may well be worthwhile in their own right, in that they have contributed to advances in the understanding of specific cultures, it should be stressed, however, that clearly defined rules of universally applicable methodology have failed to emerge. In addition, the relationship between the decorative arts and other subsystems never seems to be specified in a way which can lend itself to general application in cultures other than that which was the focus of attention in the relevant study.

The apparent importance of the decorative arts as an integral component of all cultures should not, however, be underestimated. This was recognised by Alland [201], for example, when he stated that the art of any society is,

> "an emotionally charged and culturally centred storage device for complex sets of conscious and unconscious information."

In order to gain access to the information contained therein, Washburn [202] argues that the,

> "...regularised formal aspects of its structure must be delineated. In order to achieve this, however, it is first necessary to define some parameter which can be used to measure the systematic nature of the structure. The parameter chosen must be fundamental to all [decorative] art forms in order to enable the study and comparison of [decorative] art produced by all societies throughout the world. In this sense the parameter must be a cultural

universal."

It does indeed seem to be the case that symmetry classification is a systematic and reproducible analytical procedure which relies on the use of standardised units of measurement of a parameter which is fundamental to all decorative art form. As such, it would appear to offer the facility for advancing the understanding of the decorative arts, either in general or else with specific reference to a given culture, medium or time period.

Why different cultural settings show different symmetry preferences is not as yet fully understood. However the fact that they do, indicates that symmetry classification is capable of isolating and classifying an attribute which is culturally sensitive, and as such would appear to offer the key to discovering firstly, the precise relationship between the decorative arts and other subsystems and secondly, the nature of the process of cultural change itself.

In addition to the potential offered to researchers concerned with the analysis of patterns in order to determine their cultural significance, symmetry classification should also prove to be of value to textile designers concerned with construction of patterns. The system of classification developed in this thesis could act as a framework for the teaching of the principles of pattern construction to undergraduate textile design students and in addition would seem to be worthy of further application in the realms of computer aided design.

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APPENDIX 1.

Numerical outcome of the Classification of Traditional Javanese Batik Patterns (Sample Size = 110 All-Over Patterns)

Symmetry Class	Frequency
p1	6
p1m1	10
p1g1	0
c1m1	2
p211	17
p2mm	9
p2mg	0
p2gg	1
c2mm	3
p3	0
p3m1	0
p31m	0
p4	5
p4mm	54
p4gm	2
p6	0
p6mm	1
Total	**110**

APPENDIX 2.

Numerical outcome of the Classification of Traditional Sindhi Ajrak Patterns (Sample Size = 71 All-Over Patterns)

Symmetry Class	Frequency
p1	10
p1m1	5
p1g1	0
c1m1	0
p211	0
p2mm	9
p2mg	0
p2gg	0
c2mm	4
p3	0
p3m1	0
p31m	0
p4	0
p4mm	43
p4gm	0
p6	0
p6mm	0
Total	**71**

APPENDIX 3.

Numerical outcome of the Classification of Jacquard Woven French Silk Patterns, Autumn 1893 (Sample Size = 483 All-Over Patterns)

Symmetry Class	Frequency
p1	67
p1m1	3
p1g1	370
c1m1	10
p211	7
p2mm	3
p2mg	6
p2gg	4
c2mm	9
p3	0
p3m1	0
p31m	0
p4	0
p4mm	2
p4gm	1
p6	1
p6mm	0
Total	**483**

APPENDIX 4.

Numerical outcome of the Classification of Japanese Textile Patterns, (All Patterning Techniques) Produced During the Middle Edo, the Late Edo and End of Edo
(Sample Sizes = 34; 94; 162 respectively)

Symmetry Class	Middle Edo Frequency	Late Edo Frequency	End of Edo Frequency
p1	4	18	14
p1m1	5	6	3
p1g1	0	4	5
c1m1	3	4	7
p211	1	7	9
p2mm	6	21	38
p2mg	0	4	9
p2gg	0	3	6
c2mm	8	17	40
p3	1	1	0
p3m1	1	1	1
p31m	1	0	5
p4	0	2	4
p4mm	2	3	14
p4gm	1	2	2
p6	0	1	2
p6mm	1	0	3
Total	**34**	**94**	**162**

Note: All patterning techniques include: stencil resist techniques; warp, weft and double ikat, free-hand painted resist; gold-leaf imprints; tie-dyed and other bound resists; embroidery and other stitch work; various forms of figured weaving.

APPENDIX 5.

Numerical outcome of the Classification of Japanese Textile Patterns, Produced Using Two Distinct Categories of Patterning Techniques, During the Late Edo and End of Edo (combined)
(Sample Sizes = 115 woven patterns; 116 resist dyed patterns)

Symmetry Class	Woven Patterns Frequency	Resist Dyed Patterns Frequency
p1	19	13
p1m1	5	4
p1g1	7	2
c1m1	5	5
p211	7	9
p2mm	34	21
p2mg	4	9
p2gg	3	6
c2mm	20	21
p3	0	1
p3m1	1	1
p31m	3	1
p4	1	4
p4mm	4	13
p4gm	2	2
p6	0	2
p6mm	0	2
Total	**115**	**116**

Note: Woven patterns are of the figured variety, of the type produced on drawlooms or their equivalent. Resist dyed patterns are produced by stencil resist techniques; warp, weft and double ikat; free-hand painted resist; tie-dyed and other bound resists.