WHITBY JET AND ITS RELATION TO UPPER LIAS SEDIMENTATION IN THE YORKSHIRE BASIN.

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ABSTRACT.

The Upper Lias of Yorkshire as represented to the north and west of the Peak Fault, is a phase of deposition of argillaceous sediments under varying physical conditions. The Grey Shales are shallow water deposits which pass gradually but rapidly into the finely laminated, bituminous shales of the Jet Rock, which were laid down under 'Black Sea conditions', but in water much s shallower than the Black Sea. As the basin was gradually filled up during Bituminous Shale and Hard Shale times, its floor rose into the zone of aerated water, when the poorly bedded Alum Shales were deposited. Thes sedimentational conditions were interrupted by the deposition of an argillaceous limestone at the end of Jet Rock times and by several beds and rows of masses of siderite mudstone, at varying horizons during subsequent zone-moments.

The best 'hard' jet is found only in the Jet Rock, and is entirely composed of collapsed and compressed wood structures, soaked in humic substances resulting from the decomposition of the original wood. Annual rings, medullary rays, tracheids, bordered pits, stem bases and bark are all recognised in the jet. Some specimens of jet are silicified along a central zone, and here the wood structure is well preserved in an uncrushed state. Within the jet are frequent rows of included quartz grains and other minerals, which had become wedged into cracks in the wood before sedimentation.

Whitby jet is the altered ermains of coniferous wood washed from the Liassic land surface into the Yorkshire Basin, where it became waterlogged and sank. The dominating factors in the subsequent jetonisation were the conditions of reduction and stagnation in the deeper parts of the basin during Jet Rock times. These conditions caused the formation of a fine, black viscous mud which, together with the absence of oxygen due to the same reason, controlled the decomposition of the wood and

limited it to a unique and prolonged breakdown of organic constituents. As a result the wood which was in the form of stems and trunks, was reduced to a pulpy condition. The constant slow deposition of muds caused the stems to be much flattened and to assume theform in which they are now found.

The inferior varieties of jet are due to formation in more oxygenated conditions of sedimentation, and probably to a greater degree of aerobic decomposition before incorporation in the argillaceous sediments. The increased amount of oxygen would cause decomposition to follow a more normal course.

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I. GENERAL.

INTRODUCTION.

Jet has two inseparable associations in the mind of the layman. The first is with the town of Whitby, where as a raw material for a now decadent industry, jet assumed considerable economic importance during the latter half of last century. The second is with "jet-black", a word which is to be found in all types of literature,denoting a depth of colour and richness of tone that is surpassed by no other black material.

Jet must rank amongst the oldest of materials of economic importance in the British Isles. It was held in high esteem by Neolithic Man, who carved it into ornaments which were later buried with their owners. Rings, toggles, rough jet, and more particularly, beads and necklaces, have been found in such numbers in the tumuli of Cleveland and the Wolds as to show that a jet industry of sorts was an established fact in Neolithic times. It has been said with some justification, that the carving of jet should be ranked with the making of pottery as one of the earliest of British industries.

With the coming of the Romans, jet played a part in the domestic life of the conquerors. In the Roman Museum at York are examples of ornaments found in that city. The finding of pieces of rough jet suggests that it was brought from the coast in this stateand carved in York itself into numerous articles, especially pins of distinctive workmanship and design.

In later times, the manufacture of rosary beads, crosses and crucifixes of jet appears to have been quite common down to the time of Queen Elizabeth. There is an entry in the Rolls of Whitby Abbeyof 1394, "For seven rings to Robert Car of jet 7d" The name of John Carlill, "jet-worker", occurs in a deed dated 1598. Still later, in the North Riding Records, the occurrence of the names of Whitby men described as "jeators" or jet workers, proves that the trade was still carried on to some extent.

It was not, however, until the first half of last century that the jet trade began to assume any commercial importance. Its growth was at first gradual, but by 1850 we find, in a guide book, that "Whitby has become that head of the trade in jet ornaments, which are manufactured and sent throughout the country in considerable lnts." In the following year, 1851, a number of jet exhibits were sent to the Great Exhibition held in London. This brought jet to the notice of a larger public and gave a decided fillip to the trade, with a result that from 1850 to 1870 the jet trade developed to a remarkable degree. Drawing classes were set up "with a view to introducing a larger and more correct knowledge of the true principles of taste into the jet manufacture." Exhibitions were held, competions promoted, prize money donated by local gentlemen, and "jet-shops", (i.e. workshops) sprang up with great rapidity. In the seventeen years following 1856, Bower has estimated that the trade more than quadrupled itself. In 1873 the jet industry was at its prime. It employed from1500 to 1800 men in Whitby, and the trade realized £90,000. The manufactured articles were known, not only throughout the country, but were also exported to Europe and the United States. The amount of jet worked must have been enormous. The basic designs for the articles were chiefly natural objects, fruit, foliage, flowers, executed with great skill. Massive brooches, necklaces, pendants, bangles, chains and trinkets of every sort were produced by the thousand. But the reaction was soon to set in, and since 1873 the jet trade has gradually declined to its present position. The workers sought employment in other branches of industry. By 1883 the number of men employed in the trade was 600, but in the following yearit is said to be scarcely300. By 1901 the numbers had fallen to 174, and by 1921 not more than 40 men were engaged. At the present time only twelve menare employed in the carving of jet.

The causes for the decline of the jet trade are many. During prosperous times inferior jet was used, which was brittle and difficult to work. Ornaments made of this material chipped easily, causing dis~~s~~appointment and dissatisfaction, and doing infinite harm to the trade. The imported French jet was especially liable to chipping, and was worked in a bed of sawdust and paraffin in order to minimise this danger before the article left the worker's hands.

The fact that the manufacture was largely in the hands of men, several of them sharing a workshop and requiring few and inexpensive tools, each working on his own account, buying the raw material as he needed it, and selling his output at the end of the week to a dealer, prevented any aggreement as to quality, or the enforcement of any regulations protecting the industry.

Probably the main reason contributing to the decling was the change in fashion from the large articles of jewel~~l~~ery to those of smaller dimensions, and the failure of the local manufacturers to adopt styles and patterns that would meet with the altered demands of the market.

The trade has also suffered from imitations made from glass, vulcanite cannel coal, and other materials, which were sold under the name of jet. Articles made of these materials, although not so light or beautiful in appearance, were cheaper and less likely to suffer damage.

The outlook for the future of the jet trade is very depressi ing. No young men are entering the trade, and the demand for the manufactured articles is only that created by the visitors to the town in summer. Like other Whitby industries, the glory of the jet trade is only in its past.

THE MINING OF JET.

There is little doubt that the greater part of the jet carved into ornaments was, until well into last century, picked up on the sea shore , where it had washed from the cliff exposures, or from the submarine outcrops. It is considered, however, that the Jet Rock was systematically worked in a series of bell-pits round the base of Roseberyy Topping in Neolithic times. Except for this, no mining for jet is thought to have taken place until the third or fourth decade of the nineteenth century.

That the jet industry depended for its raw material, in the first instance, upon jet collected from the shore, is undoubted. As late as 1876, Tate and Blake write,[47] "...it has only of late years ceased to be worth while to walk along the shore to look for it (jet)". With the exhaustion of this as a source of supply, attention was turned to the Jet Rock. Bower states[7] that "It (jet) was formerly obtained in the largest quantity by working in the cliffs, by a process called 'dessing' (very dangerous work), that is by clearing away and hewing down the cliff sides till jet-ends protruded; the seams were then followed until exhausted." This mode of working did not persist, and was eventually replaced by a more conventional method. Parkin describes it as follows;[35] "This drift six feet high and three or four feet wide is driven in from the outcrop; when these drifts are advanced a few yards, side excavations are made, and the systematic search for jet commenced. The shale over the roof of the side excavations is hewn or wedged down, serving as a platform to work on, and the whole thickness of the shale is then explored in a fashion somewhat resembling a combination of longwall in coal, and of stoping in lead and other metalliferous mines. While the preparatory drifts are being driven, the shale has to be conveyed outside, but in the

1.

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3.

Photos: J.E.H.

Jet Rock shale tips along the Cleveland escarpment and in the inland dales.

1. Carlton Alum Works and shale tips.
2. Upper Raisdale.
3. Tripsdale, near Bilsdale.

regular course of working most of it tossed back, and as little taken out of the mines as possible, horses and lads hardly ever being required. When a discovery is made, the deposit is carefully followed up and excavated in as large pieces as possible; sometimes weeks will elapse and no jet be found, while occasionally exceptional luck is met with, and a great quanitiy got in a few days."

By the use of this method of mining, the Jet Rock was exploited in many of the dales of Cleveland. The entrances to the workings are now usually closed by the collapse of the walls or roof, but the greyish-white heaps of weathered shale mark the positions of the old drifts, and of the horizon of the Jet Rock. They are to be found in Iburndale, Glaisdale, Westerdale, Rosedale, Farndale, Bransdale, Bilsdale, and its tributary dales, Tripsdale and Raisedale. For the greater part of the distance from Cod Hill, near Guisborough, to Osmotherly, about 20 miles, the Jet Rock may be accurately traced by means of the tips of shale along the western scarp of the Cleveland Hills.

Along the coast, the Jet Rock has been worked from Robin Hoods Bay to Saltburn, wherever it is accessible, but unless they are at sealevel the workings are collapsed or covered by debris from the cliffs above.

No minig for Whitby jet is carried on today. What little is used by the jet workers is obtained from the old source, the seashore, where it may still be found in small quantities amongst the sea-wrack. A little is also obtained by men who walk along the sea-level exposures of the Jet Rock, and remove any jet exposed by a recent fall of cliff. There is, however, no systematic working of the Jet Rock.

HISTORICAL REFERENCES TO JET.

References to jet in the literature of the past are not wanting. Pliny the Elder, in his "Natural History"[37] refers to a material 'Gagates', which is usually considered to be jet, in the following way. "Gagates is a stone, so called from Gages, the name of a town and river in Lycia.... It is black, smooth, light and porous, and differs but little from wood in appearance; is of a brittle texture and emits a disagreeable odour when rubbed." Gagates, as described here is not the same material as Whitby jet, which is neither brittle nor porous. This discrepancy, together with the fact that 'gagates differs but little from wood in appearance', suggests that the material that Pliny described was a lignite, probably partly jetonised, but not comparable with Whitby jet. It should be remembered, however, that some poor jets occurring near Whitby are very brittle, as well as is some Spanish jet. Tate and Blake write,[47] "Whether or not this (gagates) was the same substance that is found at Whitby is difficult to say; several shining black substances may have been confused under the same name." In all probability the gagates of Pliny was either jet of inferior quality or a partially jetonised lignite.

Vegetius Vetutus refers to jet in his works, and Caius Julius Solinus (fl. 3rd. century) alludes to jet as being found in Britain.

The first reference to jet in English literature is to be found in Bede's "Ecclesiastical History of the English Nation",[5] where he states "It (England) produces a great deal of excellent jet, which is black and sparkling, and burns when put in the fire...."

Apparently Bede and Pliny remained the only authorities on jet for a considerable period of time. Until about 1600 all references to jet, as for example, in the "Chronicles" of Henry of Huntingdon (c.1100) or the "Lapidarium" of Marbodus may be traced to either Bede or Pliny, the later historians using not only the few facts but also the phrases of the earlier recorders.

In an old book on Yorkshire, written in 1610, is to be found one of the earliest, if not the first reference to Whitby jet. "....near Moulgrafe Castle... is found black amber or jette; some take it to be Gagates, of old times a Gemme and a precious stone of great estimation." Mulgrave Castle is at Sandsend, three miles from Whitby.

Early in the seventeenth century, Camden, translated the Lapidarium of Marbodus, which was written in Latin verse, and some five lines of this translation are the most often quoted of the early references to jet.

"Jeat stone almost a gemm the Libyans find;
But fruitful Britain sends us wondrous kind;
'Tis black and shining, smooth and ever light;
'Twill draw up straws if rubbed till hot and bright;
Oyl makes it cold and water gives it heat."

Fox-Strangways erroneously states in the Survey Memoir[15] that the Saxon poet, Caedmon, who lived and died in Whitby Abbey, wrote these lines, and this has been repeated in several works. No works of Caedmon are extant, and the error is doubtless due to the similarity between the names Caedmon and Camden.

Drayton, in his Poly-Olbion, a long poetic topography of England, published in 1613, writes;-

"The rocks by Moulgrave too my glories forth to set,
Out of their crannied cleeves can give you perfect jet."

There is among the Harleian manuscripts an account of the voyage of Don Manoel Gonzales, a Portuguese merchant, to Great Britain in 1730, who speaks of jet, geat or black amber as being found in various places in Yorkshire "in the chinks and clefts of the rocks," "It is," he adds, "of a ~~shining~~ reddish or rusty colour, but when polished, a shining black."

REVIEW OF EARLIER WORK.

With the opening of the nineteenth century, the records and references to jet take on a more descriptive character, the authors at the same time putting forward some suggestion as to the origin of the material. Three differing opinions were held by the various schools of observers, as to the origin of jet, and the contesting views were maintained with great conviction.

The first of these theories was simply that jet was wood that had been incorporated in the shales during sedimentation, and which had eventually decomposed and changed in character so as to become jet.

The second group of observers appears to have been impressed by the strong bituminous odour of the Jet Rock shales when they are broken, and by the apparent homogeneity of jet when fractured. It was thought that pieces of jet represented segregations of bitumen in the shale, which had collected in various places, and later hardened in the shale to form jet, "a process which may undoubtedly be now going on."

The third theory was an attempt to bring the two contesting views together, and as a result, was something of a compromise between them. It was considered that bitumen, flowing through the shales, had replaced the wood which occurred in the shale, bitumen being substituted for the decayed matter in the wood.

It will be seen that the opinions put forward as to the origin of jet all fall into one or other of these three groups, usually into one of the first two.

One of the earliest opinions as to the origin of jet was that of the Rev. E.Blomfield,[6] who in 1807 stated that "Jet seems nearly allied to coal, and particularly to that species called canal (i.e.cannel) coal. From which, however it is easily distinguished by its lightness, its electrical properties, and its being composed of fibres parallel to each other, like those of wood. In fact, it seems to be wood..." It was exactly one hundred years later that this observation regarding the relation between jet and cannel coal was proved to be true, by German investigators.

In 1817, Young in his "History of Whitby"[50] cited a considerabl amount of field evidence, which he considered sufficient to prove the 'ligneous' origin of jet. These observations were also recorded in 1822 in "A Geological Survey of the Yorkshire Coast" by Young and Bird,[51] and had they been better regarded the controversy of the 'bitumen theory' as opposed tothe 'ligneous theory' which lasted during the whole of last century would have been averted. These authors observed that jet "oc "occurred in the form of flattened branchesor trunks of trees," with "often branches diverging from the principle mass". They were the first to note that "the transverse fracture...displays the annual growths in elliptical zones", and also that jet sometimes occurs "with a core of siliceous wood." The relation between jet and cannel coal was also commented upon.

Sectioning of jet was carried out by W.Nicol, who published his results in 1834.[34] He sectioned a specimen which was partly silicified and partly jetonised, and found that the silicified material "displayed distinctly the coniferous reticulated structure, while the jet showed "the same blackish zig-zag lines which occur in every transverse section of that bitumen." Nicol had no doubt as to the derivation of jet from coniferous wood.

In the third edition of John Phillp's "Illustrations of the Geology of Yorkshire", published in 1875,[36] the author shows no doubt, in his opinion as to the material from which jet is derived. "it (jet) is simply coniferous wood, and in thin se sections shows clearly the characteristic structure".

The work of Young , Phillip's, and Nicol, based essentially on careful observation both in the field and in the laboratory, firmly established the 'ligneous theory' of the origin of jet for twenty or thirty years following the publication of Young's work. With the extensive mining, however, during the second half of the nineteenth century, the bituminous content of the shales of the Jet Rock was observed, and the 'bituminous theory' gained considerable hold.

Thus Martin Simpson, in 1868says,[44] "It has been very generally concluded that jet is of ligneous origin, but this opinion is supported neither by chemical analysis, nor microscopic observation.... It is not unlikely that vegetable matter may have become jet, for we find wood and the scales of fishes converted into something like it; but it is far more probable that the best jet is an aggregation of bituminous matter, which abounds in the Jet Rock of the Lias."

Tate and Blake in "The Yorkshire Lias" (1876)[47] adhere to this view, stating that "It (jet) is the result of the segregation of bitumen in the shales, which allowing to a certain extent the access of air, has hardened it into jet".

A.G.Lebour, Professor of Geology at Newcastle-on Tyne, commenting upon a paper on "Jet Mining" in1882,[27] showed that he strongly favoured the bitumen theory, while Fox-Strangways , in "The Jürassic Rocks of Yorkshire" (1892)[15] considered that forest trees incorporated in the Jet Rock shales during sedimentation "were subsequently convertrd into bitumen, which became diffused through the neighbouring shales, or occupied cavities in them; where it is now found as jet , often occurring as pseudomorphs of organic remains."

The opening of the twentieth century saw a reversion to the ligneous theory. Following the method used by Nicol, Seward[40] sectioned specimens consisting partly of silicified wood and partly of jet and concluded that jet originated from the alteration of coniferous wood, and in part, at least, of wood of Araucarian type.

In 1906, Speilman, in a paper "on the Origin of Jet",[45] concluded from the evidence of Seward and Gothan that jet was formed from coniferous wood, and suggested some ways in which the alteration may have been brought about. Two years later he brought forward evidence from chemical investigations conducted at Zurich, for the classification of jet with cannel coal.

E.H.Cunningham Craig, in "Jet and Jetonised Material" (1927), a paper dealing primarily with the value of jet as retortable material from which oil could be obtained, showed that vegetable structures were not obliterated entirely in jet, and in thin sections identified the medullary rays of the original wood.

Von Hans Klaehn, of Rostock, in a paper "On Animal Incrustations on Wood From the Swabian Posidonomya Sea",[26] ~~He~~ describes pieces of wood, generally jetonised, always rather compressed, "the woody character of which is not to be doubted." Some smaller specimens are however, considered by Hauff to be, not altered wood, but concretions of foul mud, "Konkretionen von Faulschlamm".

The vagueness and inaccuracy which surrounds the topic of jet may be shown by a quotation from a recent publication. Dr.W.J.Arkell, in "The Jurassic System in Great Britain",[3] (April 1933) writes, "Jet/occurs in lumps and lenticles....It is believed to be a product of waterlogged wood, so thoroughly altered that all traces of structure have been obliterated".

This piece of work has been undertaken to investigate into the true nature of Whitby jet, as far as is possible by petrological and chemical methods, and to determine under what conditions of sedimentation the material which was to be changed to jet was laid down. A petrological investigation into the Jet Rock has been conducted with a view to determining sedimentational conditions during the time of its deposition.

Since jet of a poorer quality is also found in other parts of the Upper Lias of Yorkshire, as well as the Jet Rock, a petrological investigation, though to a less detailed degree, was carried out upon the remaining beds of the Upper Lias, in order to determine what changes in deposition occurred during later Whitbian times which resulted in a different q quality of jet being preserved,

Jet from other localities and horizons, both in Great Britain Europe and North America, has been examined, and comparisons made with the type material, 'hard' Whitby jet.

II. THE UPPER LIAS OF YORKSHIRE.

(1) RANGE AND EXTENT.

The Upper Lias of Yorkshire consists of about 200 feet of shales overlain nonsequencially by the Dogger, or the lowest bed of the Inferior Oolite, which has in places cut through the Dogger and into the Alum Shale below.

The most south-easterly exposure in Yorkshire is at Peak, Ravenscar, where on the downthrow (east) side of the Peak fault the uppermost Whitbian and Yeovilian beds are fully developed. To the west of the fault the upper Whitbian and Yeovilian are missing, and this paper deals with the remainder of the Whitbian as developed over the rest of Yokkshire. The fault throws the top of the Alum shale to about 750 feet above sea-level, from which height it gradually dips northwards, being wełl exposed on the coast between Hawsker Bottoms and Whitby.

The Whitby fault throws the Upper Lias shales below sea-level, but at Sandsend they rise above sea-level again and occupy the greater part of the shore and cliffs for the next 5 miles, as far as Port Mulgrave, below Hinderwell. Here the shales finally leave the shore, and rise into Boulby cliffs, the top of the Upper Lias being here almost 600 feet above sea-level.

At Huntcliff, near Saltburn, the shales swing inland, and the outcrop follows a south westerly direction for about 9 miles to Roseberry Topping, where it turns southwards, and occupies a part of the great scarp which bounds the Cleveland block to the west. Near Ingleby Greenhow the scarp turns sharply to the west, influenced by the elongated Cleveland dome, and after continuing in this direction for about ten miles, again turns south. The beds are here dipping southwards, and south of Osmotherley to Market Weighton, the Upper Lias is seen only in small isolated sections.

The Cleveland dales, cut by streams flowing off the Cleveland dome, provide another series of exposures of the Upper

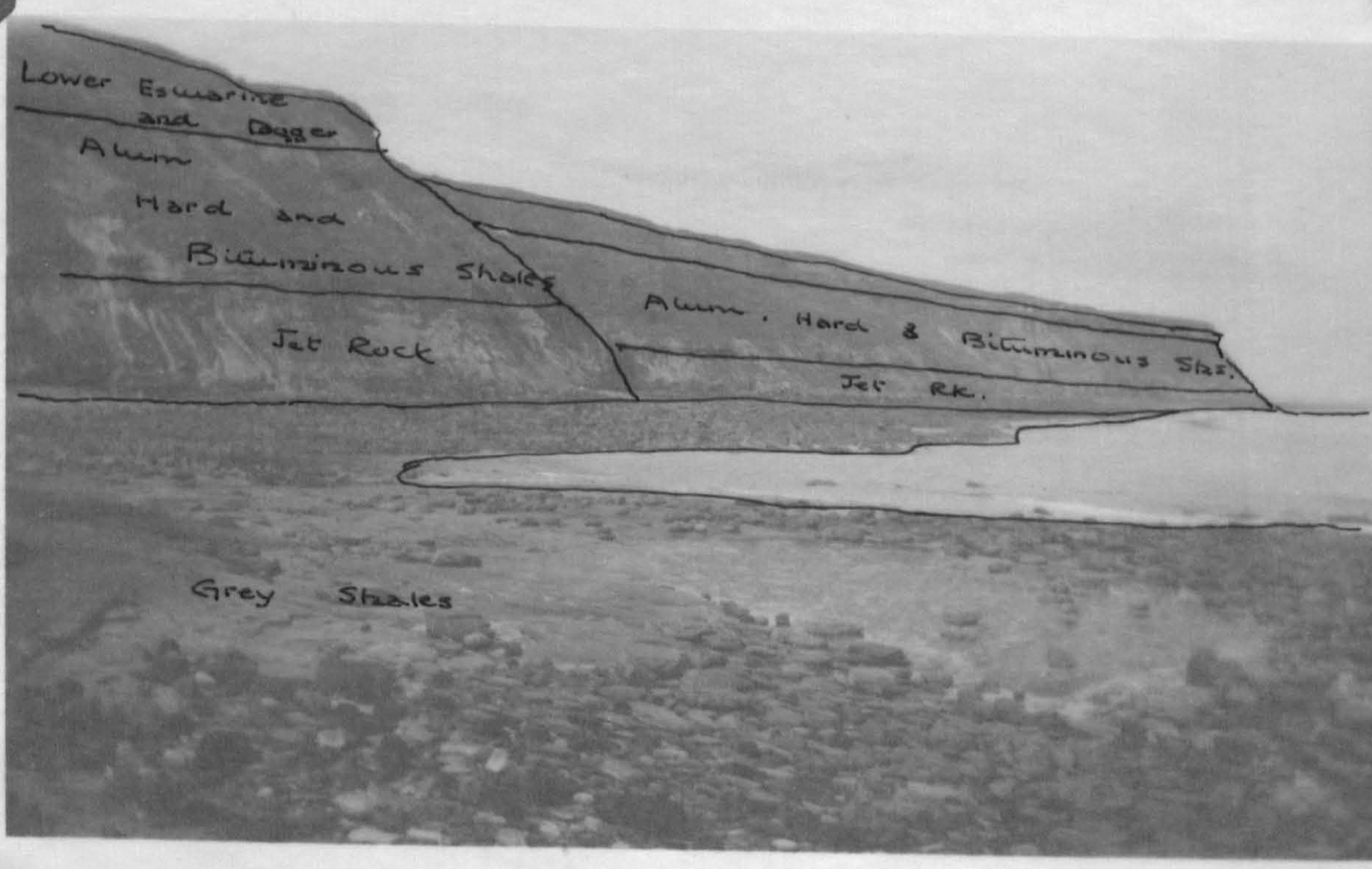


Photo: J.E.H.

Cliffs and shore at Loop Wyke.

1.

2.

Photos: J.E.H.

Greater Fryup, a typical Cleveland dale.

1. Looking downstream.

2. Fryup Head and 'the Hills', due to slumping.

Lias. Six dales drain northwards to the River Esk in Eskdale. From west to east thede are Baysdale, Westerdale, Danbydale, Great and Little Fryup, and Glaisdale and Iburndale. Four larger dales drain southwards:- Bilsdale, Bransdale, Farndale, and Rosedale. These valleys cut through the Inferior Oolites of the moorlands, through the Middle and Upper Lias into the Lower Lias, which usually floors the dales.

The beds of the Upper Lias being comparitively soft, form few natural exposures. On the coast they are well exposed between low and high water mark, but above high water level they weather quickly and are covered by shale screes and vegetation. In the inland dales, the beds are only naturally-exposed in stream sections, frequently in steep-walled shale gorges at the heads of the dales.

The Alum Works, which are found along the coast from Peak to Saltburn, and along the inland escarpment from Guisborough to Osmotherley, doubtless provided excellent exposures of the lower Whitbian shales in times past, but today they are largely covered by vegetation and talus.

Similarly the jet workings provided exposures of a part of the Jet Rock, during the last century, but today they are covered, the excavations being flooded or collapsed. Although the position of the tips from the old jet workings enables the Jet Rock to be accurately mapped along the Cleveland escarpment and in the dales, nevertheless, actual exposures are few, and difficult of access.

Fig. 1.

Distribution of the Upper Lias in Yorkshire.

LITHOLOGICAL DIVISIONS.

The Upper Lias of the Yorkshire basin in a thick series of shales totalling about215 feet at Whitby. It has been estimated, however, that there are nearly another 120 feet of superior shale deposits belonging to the Upper Lias, which are only found to the south and east of the Peak fault, as well as almost 90 feet of sandy beds also belonging to the same formation.

The deposits are divided into two stages on palaeontological evidence - the lower one, Whitbian, in which planulate ammonites of the communis type are very abundant, and an upper one, the Yeovilian, in which these planulates are not found. It is only intended to deal with the lower of these two divisions, the Whitbian, excluding from it also, the two upper zones of variabilis and lilli, fond only south of Peak, where they comprise the Peak Shales. The shales discussed here will be only those of the Upper Lias occurring to the North and West of the Peak fault, the highest zone being braunianum, the Cement Shales of the Geological Survey.

The old lithological division of the Upper Lias was threefold :- Alum Shales, Jet Rock, and Grey Shales, with sometimes a fourth division, the Hard Shales. The use of these terms,was, however, extremely loose. In some cases the Alum Shales included all the strata down to the Jet Rock, (Martin Simpson), but in other cases the Bituminous Shales were placed with the Jet Rock, and not with the Alum Shales (Tate and Blake).According to some authors the term Jet Shales includes all the strata from the base of the Jet Rock to above the Ovatus band. The term Hard Shales was sometimes used , and applied to the bed of shale immediately above the Ovatus band, sometimes to the Bituminous Shales, and Sometimes to both. In 1915. however, Fox-Strangways and Barrow, in "The Geology of the Country between Whitby and Scarborough"[14], divided the Whitbian (excluding the zones of variabilis and lilli) , into the Cement Shales, Main Alum Shales, Hard Shales, Bituminous Shales, Jet Rock and Grey Shales, and did much to simplify the then confused nomenclature. These lithological divisions and terms, will, on the whole, be maintained here, although some slight modifications will be suggested.

In his recent work,[3] Dr.Arkell has reverted to the threefold lithological division, including the Main Alum Shales and Hard Shales of Fox-Strangways and Barrow in the Alum Shale Series; the Bituminous Shales and Jet Rock are grouped together as the Jet Rock Series, and the Grey Shale Series is the same as the Grey Shales of Fox-Strangways. This was the same classification as was used by the Geological Survey in 1892, and there seems little justification to revert to it, especially as the author himself has discarded it.

CORRELATION OF PREVIOUS SECTIONS.

The easy accessibility and clear definition of the various beds of the Upper Lias, by virtue of the 'indurated bands', on the Scaur, or shore, between Whitby and Saltwick, a mile to the south-east, led to their being measured at an early date by Martin Simpson, the Curator of Whitby Museum. "Being convinced by observation,"he wrotein 1868,[43] "that a few species of Lias fossils had existed during the deposition of any great thickness of strata, I carefully measured, with a two-foot rule, all the beds and seams of the Lias both to the south and north of Whitby, and at the same time collected fossils from each stratum."

In 1875 Phillips published a series of measurements of the Scaur section, as did Tate and Blake in the following year, and Fox-Strangways and Barrow in 1882.[13] These were followed by a revised section by Simpson in 1884.[44]

The differences in the sections of the four authors were so

CORRELATION OF UPPER LIAS SECTIONS MEASURED ON THE SCAUR, WHITBY.

J. PHILLIPS 1875

Grey Alum Shale with layers of small limestone nodules in upper part, worked for cement: Maximum thickness	34·0
A conspicuous irreg. bd.	
Dark Alum Shale with an irregular band of nodules	34·0
Thin bed of ironstone	
Dark Alum Shale	18·0
Double band of nodules	
Dark, firm shale	18·0
Dark, hard, reddened shale bed.	
Hard, dark shales	12·0
Line of flattened spheroidal balls.	
Hard, dark shales	20·0
Band of irreg. balls	
Grey, hard shales	20·0
Hard shale with calcareous concretions	10·0
Hard shale with nodules in upper part	20·0
Soft shale. 20-30	25·0

TATE AND BLAKE 1876.

ZONE OF AM. COMMUNIS.

1	Lias shale	6·6
2	Line of cement nodules	·4
3	Shale	1·8
4	Line of cement nodules	·4
5	Blue shale	1·10
6	Cement-stones	·5
7	Blue shale	2·10
8	Cement stone	·5
9	Blue shale with scattered irregular doggers	35·0
10	Strong, well marked dgr.	·6
11	Blue shale	16·8
12	Indurated band of sh.	·4
13	Shale	18·0
14	Dogger band	·6
15	Shale	17·0
16	Distinct line of doggers	·4
	Blue shale	10·0

ZONE OF AM. SERPENTINUS

1	Blue shale	10·0
2	Large lenticular dgrs.	·10
3	Blue, hard, semi-bituminous shale	16·0
4	Solid, continuous indurated band	1·0
5	Blue shale, hard very bituminous - the jet rock -	20·0

ZONE OF AM. ANNULATUS.

Micac. sandy shale.	30·0

SIMPSON 1884

ALUM.

1	Blue shale. Upper half contains an abundance of nodules of Lias limestone.	34·0
2	First indurated band	3
	Dark, blue shale	18·0
3	Band of uninterrupted sh.	2
	Shale.	18·0
4	Third indurated bd.	
	Shale	18·0
5a	Hardened ferrug. sh.	
	Shale	10·0
5b	Line of large, flat, nod. of Lias limestone.	
	Shale	12·0
6	Nodular bed.	
	Hard. bitumin. sh.	24·0

JET ROCK

7	Hard Lias limestone	4
	Very hard bituminous shale full of nodules of Lias limestone	20·0
8	Dark, grey shale.	40·0

FOX-STRANGWAYS AND BARROW. 1882.

Shale. Soft, grey and micaceous with cement-stone nodules in the first 18 feet	34·0
Hard, ferrugin. sh. bnd	4
Shale, soft, grey & mic.	19·0
Lumpy calcareous band	4
Shale, similar to above	20·0
Band of hard shales	3
Shale, harder & darker	20·0
Double band of pyritous doggers.	
Hard, blue black sh.	18·0
Hard, black shale.	10·0
Thin band of pyritous doggers.	
Hard, black sh., bitum.	24·0
Band of pyrit. doggers	
Hard, dark, bitum. shs	30·0
Jet Rock, hard platey rock, with thick dogger at top: source of all hard jet.	25·0
Soft shale, or grey sh.	30·0

FOX-STRANGWAYS 1892.

ZONE OF AM. COMMUNIS

1.	Shale. Soft, grey and micaceous, with cement-stone nodules in the upper 15 feet	34·0
2	Lumpy calcar. band	–
3	Soft, grey micac. sh.	15·0
4	Hard nodular band	–
5	Shales, similar to above	20·0
6	Indurated sandy band	6
7	Shales, harder & darker	18·0

ZONE OF AM. SERPENTINUS

1	Double line of pyritous doggers.	10
2	Hard, blue black shs.	15·0
3	Red, indurated band	6
4	Hard, dark shale.	13·6
5	Line of scattered doggs	–
6	Hard, dark shales	19·0
7	Line of pyrit. doggs	20·0
8	Hard dark shales	20·0

JET ROCK.

9	Solid band of hard sh.	1·0
10	Hard dark shales	5·3
11	Line of large irreg. doggers	–
12	Sh. with several rows of small doggers.	9·0
13	Hard, dk. lamin. shale.	8·0

ZONE OF AM. ANNULATUS

Soft, grey shales.	30·0

FOX-STRANGWAYS AND BARROW. 1915.

1. PEAK SHALES

2. CEMENT SHALES

Soft micaceous shale with cement nodules	16·0

MAIN ALUM SHALES.

3	Soft micaceous shale.	15·0
4	Lumpy calcareous band	–
5	Soft, grey micac. shale.	20·0
6	Hard nod. band, irreg.	–
7	Soft, grey micac. shale	18·0

HARD SHALES

8	Indurated, sandy band.	–
9	Shales, somewhat harder	18·0
10	THE OVATUS BAND.	·10

BITUMINOUS SHALES.

11.	Hard. blue-black sh.	15·0
12	Red, indurated band	·6
13	Hard, dark shale.	15·0
14	Line of scattered doggers	–
15	Hard, dark shales	20·0
16	Line of pyritous doggers	–
17	Hard, dark shales	20·0

JET ROCK.

18.	Solid band of hard sh.	1·0
19.	Hard, dark shales	6·0
20.	Sh. with several rows of small doggers	–
21.	Sh. with several rows of small doggers.	9·0
22.	Hard, dk, laminated sh.	8·0

GREY SHALES.

Soft, grey shales	30·0

HEMINGWAY. 1933.

ALUM SHALES.

2 & 3.	Soft, grey micaceous shales with cement stones in upper part	31·0
4	Row of masses of siderite mudstone.	
5	Soft grey shales	17·0
6	Row of sid.-mudst. masses	
7	Soft, grey shales.	17·0

HARD SHALES

8	Siderite mudstone	5
9	Shales, harder & darker	20·0
10	THE OVATUS BAND.	10

BITUMINOUS SHALES.

11	Hard, blue black sh.	17·0
12	Siderite mudstone.	·3
13	Hard, dark shale.	11·6
14	Line of pyritous nodules	–
15	Hard, dark shales	19·9
16	Line of pyritous nods.	–
17	Hard dark shale.	17·0

JET ROCK.

18	Argillaceous limest.	4
19	Hard dark shales	9·6
20	Line of large nodules	
21	Shales with pyrit. nod.	7·9
22	Hard dark shales	10·6

GREY SHALES.

Soft, grey shales.	30·0

greatthat in 1892, Fox-Strangways states "It is generally impossible to compare the measured sections of different authors". He suggested that it was due to "the fact that the beds do not preserve a uniform thickness and that the different authors did not measure their sections in the same place". It can be shown, however, that the variation of thickness of the beds in such a limited locality is only small, and since the individual beds are accessible only in a few places, it is suggested that the discrepancies are due not so much to the reasons given above, as to estimations being made in some cases, instead of actual measurements. It has been found that the sections of the earlier authors are, on the whole, more accurate than the more recent Geological Survey measurements.

In 1892, Fox-Strangways, dissatisfied with the existing measurements of sections, published anotherwhich formed the basis for the section in the 1915 Survey Memoir. The writer has measured with a ten- foot rod all accessible sections of the Upper Lias in the vicinity of the Scaur, Whitby, and Saltwick Bay, and the results differ, in some cases condiderably, from the more recently published sections.

A correlation of the previous sections has also been attempted and from it some of the difficulties stated by Fox-Strangways can be explained. Undoubtedly Simpson missed out one 17 foot bed from hid section, the lowest bed of the Main Alum Shales, probably because of a small syncline which crosses the scars, and confused his measurements.

The section of Tate and Blake is difficult to correlate, since the authors have measured the upper beds of their Ammonites serpentinus zone, (lower Bituminous Shales), on the south-east side of the Peak fault, probably because those beds only occur on the flat Scaur at Saltwick, where they cannot be measured. The lower part of the Bituminous Shales , on the downthrow side of the Peak fault, is, however, not typical of the remainder of the Yorkshire coast, and the inclusion of these measurements therefore renders their section incorrect.

(2) THE GREY SHALES.

The Grey Shales or Zone of Dactylioceras tenuicostatum, are exposed at Hawsker Bottoms, Keldhowe Steel near Sandsend, and Rosedale Wyke, and they vary little lithologically from the Middle Lias shales below them. They are soft,grey,micaceous shales, coarser than the Alum Shales, and usually about 30 feet thick. Only two features are worthy of note.

Thin sandstones are recorded in the lower part of these beds by Tate and Blake, occurring in the banks of the Murk Esk, near Grosmont. In the field these do not form a conspicuous feature, appearing as rather coarser beds of micaceous shale 4 to 6 inches thick. Microscopically the arenaceous nature of the rock is readily discernible. Some sections of this coarse bed show marked rhythmic deposition, each indivual band being about 0·2 inches thick. The base of each rhythmic deposit is made up almost entirely of comparitively coarse quartz grains, with abundant large flakes of muscovite, some iron pyrites, argillaceous material and organic matter.Towards the middle of the rhythm the rock becomes darker in colour, until at the top it is a dark brown, due to a large percentage of organic matter. False bedding is easily discernible to the naked eye when the rock is sectioned, and in one case, the coarse grained deposit at the base of one rhythm cuts down into the organic layers which mark the end of the preceeding rhythm.

The second feature is the presence of the rows of "ferrugineo-argillaceous limestone nodules" occurring in the lower half of the zone. These concretions, which yield the zone fossil as well as belemnites, are remarkable in that the distribution of the pyrites in them is unusual. In typical pyritous nodules this skin is confined to the outer quarter inch of the concretion, but in these 'doggers' it forms a band or sphere rarely more than a quarter inch thick, but always about an inch from the outside of the concretion.

Micsoscopically the only other difference between the nodules of the Grey Shales and typical pyritous nodules of the rest of the Upper Lias is the presence of an increased amount of pyrite throughout the main body of each nodule of the former group.

Variations in thickness of the Grey Shales is recorded by Tate and Blake, but no regular variation in any direction can be determined. The maximum thickness is 40 feet at Staithes, witha minimum of 25 feet at Glaisdale and at Whorlton Hill, a faulted outlier to the west of the Cleveland scarp. The thickness recorded at Hawsker Bottoms is 36 feet.

(3) THE JET ROCK.

Zone of Harpoceras exaratum.

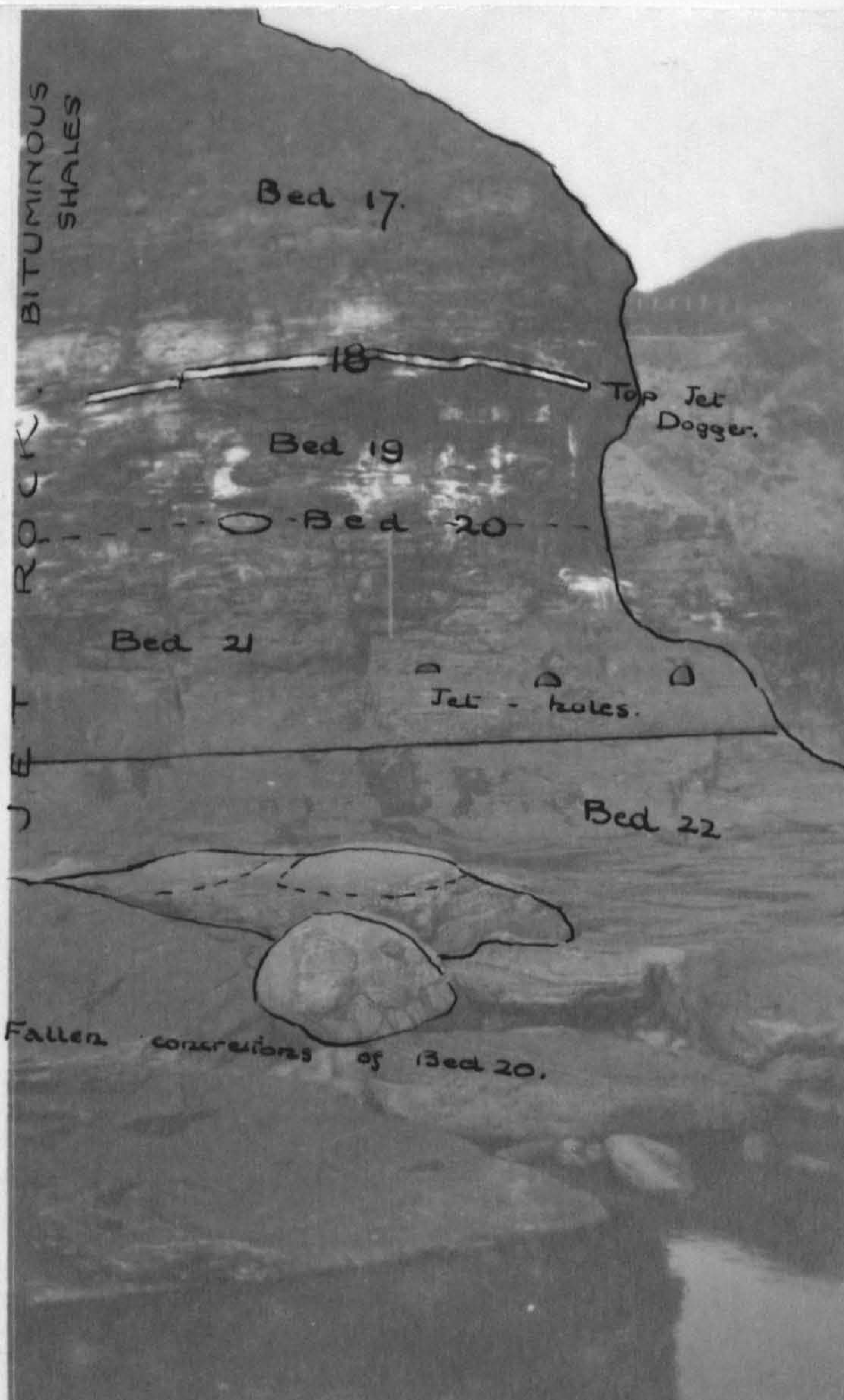
The Jet Rock, which was first named as such by Martin Simpson, was subdivided by the Geological Survey into five beds. These subdivisions have been maintained here, though modifications have been made in the description of the beds and in the measurements. The measurements of the Geological Survey "were taken from an exposure at Hawsker (Bottoms) and to the north of Sandsend, since the greater part of the Jet Rock is always below sea-level at Whitby". These two localities are, however, separated by a distance of over 6 miles, and since variations in thickness do occur, it scarcely seems justified to make up a section at Whitby from the averages of the Hawsker and Sandsend measurements. At Hawsker Bottoms the Jet Rock rises rapidly into the cliff and is not easy to measure. On the north side of Sandsend Ness, in a small bay known as Overdale Wyke, the Jet Rock is excellently exposed. By reason of the gradual dip to south-east, each of the beds may be e examined and measured accurately, and because of this it is proposed to take this Overdale Wyke section as the type section of the Jet Rock, and refer to it as the Overdale section. The exposure here is also the only one where measurement of all the beds of the Jet Rock can be made satisfactorily.

The section of the Jet Rock as measured at Overdale is as follows:-

		ft	ins
18.	Top Jet Dogger		4
19.	Hard dark shales	9	6
20.	Line of large ellipsoidal nodules some distance apart	.	.
21.	Shales with several rows of small pyritous doggers, i.e. nodules. .	7	9
22.	Hard dark laminated shales . .	10	6
		28	1

PLATE 4.

1.



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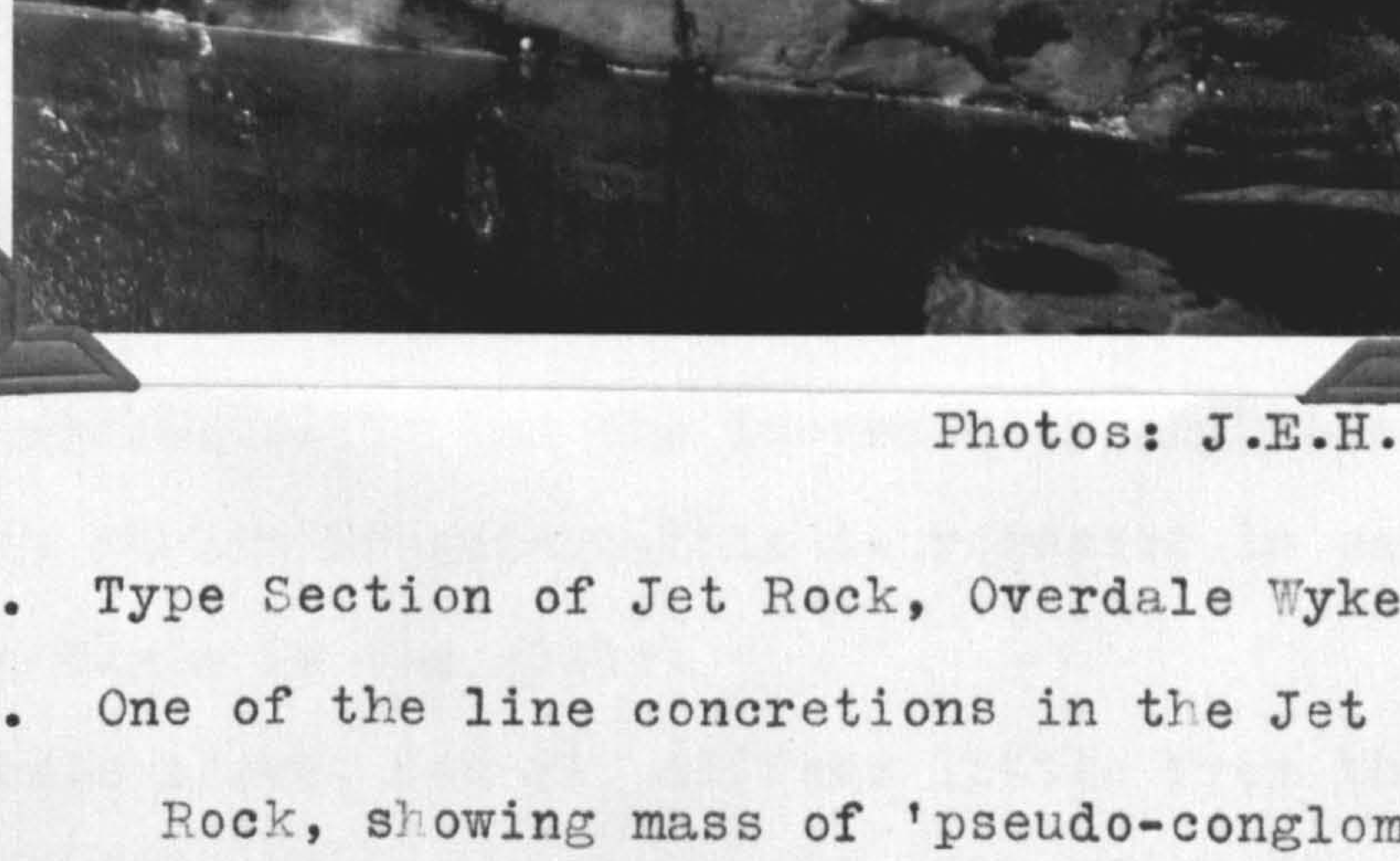

Photos: J.E.H.

1. Type Section of Jet Rock, Overdale Wyke.
2. One of the line concretions in the Jet Rock, showing mass of 'pseudo-conglomerate' (white), in centre of nodule. This concretion is one foot thick. Sandsend Ness.

The numbers given to each bed are those used by the the Geological Survey in the 1915 Memoir in the "Section of the Whitbian."

Lithology of the Jet Rock.

The Shales.

In the field, the lowest bed of the Jet Rock is a hard, dark, well-laminated shale splitting easily and with and appreciable amount of mica on the bedding planes. Microscopically it is a fairly coarse shale, with occasional gritty bands made up almost entirely of quartz grains. Muscovite is present in small flakes. Pyrite is common, occurring always as small rounded masses. A conspicuous constituent is an indeterminable brown material, presumably organic, which occurs in small lenses and short irregular lines, and which gives the thin section much of its colour. The larger minerals and the organic matter are embedded in a background of indeterminable argillaceous material.

In the specimen from Overdale Wyke, the thin section shows a marked rhythmic arrangement in the size of quartz grains in the shale. The slide may be divided into three separate beds, the centre one being 0.4 inches thick, each bed exhibiting the same phenomenon. The lowest part of each indivual bed is a very coarse shale or finegrained argillaceous grit, made up almost entirely of quartz grains, with some pyrites and a small amount of shaly material. The shale becomes progressively finer in texture higher up the thin band, and with the introduction of brown organic matterand the increase of argillaceous material, is markedly darker in colour. This is repeated in each of the other thin bands in the slide.

The shale above, Bed 21, differs little from that below it, except that it contains a number of rows of small pyritous nodules, up to 4 and 5 inches long. This shale is slightly coarser than the bed below it.

The upper shale of the Jet Rock is dark, dense, and very well laminated, breaking across the bedding planes with a sub-conchoidal fracture. The fine lamination is well brought out under the microscope. The shale is coarse in texture,small quartz grains being abundant and arranged in lines and bands as well as occurring as isolated grains in the body of the shale itself. The thin section of the rock is dark in colour due to a large amount of organic matterand an increased amount of pyrites, which usually occurs in small rounded masses, but occasionally in larger rounded aggregates of many of these masses.

Another feature of this bed is the occurrence of small, microscopic lenses of calcite distributed sporadically throughout the shale, and also in one thin section, concentrated into one small band. These calcareous masses are similar to the dsecriptions and illustrations of 'drewite', as recorded by Archangelski from the black, saprnpelic muds of the Black Sea. Writing of the "thin alternation of light and dark coloured stripes" in the mud, he states, "Under the microscope it may be seen in thin sections that the white stripes consist of powdery ~~calcite~~ $CaCO_3$ for which the term 'drewite' has been recently proposed...The grains of drewite lying in close contact with each othercommonly form elliptical lumps which are elongated parallel to the stratification planes.". The similarity between these masses and those occurring in the upper bed of the Jet Rock is striking.

A few broken and distorted spore cases occur in this shale, and when not entirely compressed are infilled with chalcedonic silica.

A heavy mineral separation of this rock was made, using Thoulet's Solution. Pyrite was extremely abundant, forming the greater part of the minerals brought down.Pyrrhotite was also present. Other minerals identified were zircon, one preserving good crystal shape; yellow, brown and colourless garnets; rutile and barytes.

The Top Jet Dogger.

Bed 19, the upper shale of the Jet Rock, passes gradually into the bed above it, the Top Jet Dogger. The name is the miners' term for the bed that was used as the roof of the jet-workings. It was described as a hard Lias limestone by Simpson, and as an 'indurated band' Tate and Blake, and Fox-Strangways and Barrow. Fox-Strangways described it as "a nodular band of impure limestone" , in a section on Economic Geology in the 1915 Survey Memoir, although in the Whitbian section on another page it is described as " a solid band of hard i indurated shale".

In the field it forms the most conspicuous feature in the Upper Lias. It is well exposed at Saltwick at low tide where it forms a reef which can be traced below sea-level by a line of breakers that mark its position. It is a platey impure limestone, from 4 to 6 inches thick, splitting into large plates up to a quarter-inch thick.The bedding planes are frequently crowded with crushed Inoceramus and ammonites of exaratum form.

Under the microscope, little evidence of bedding can be recognised. 60% of the field is made up of calcite, which has recrystallised into lenses and irregular masses, roughly parallel with the bedding. Between the calcite masses are irregular whisps of shaly material, making up the greater part of the rest of the rock, together with pyrites in small rounded masses crushed spore-cases and organic matter. From the petrological as well as the field examination, it is obvious that the Top Jet Dogger is an argillaceous limestone, and not an indurated shale, as it has frequently been described.

1.

2.

Photos: J.E.H.

1. Sandsend Ness (foreground) and Keldhowe Steel (background). Jet Rock and Bituminous Shales.

2. Large limey bosses in Top Jet Dogger. Sandsend Ness.

On the upper surface are large bosses of the same limestone, which are striking structures usually round in plan, attaining a diameter of 15 feet in some cases, and elliptical in section up to 18 inches thick. These bosses are not usually separate from the Top Jet Dogger, but are part of the limestone itself, which swells out and thickens to form them. In some few cases the bosses are separate from the Top Jet Dogger, a few inches of shale intervening. These however, are exceptional. The 'bosses' and the limestone cannot be distinguished, either in the hand specimen or under the microscope. They are composed of the same platey limestone, in which occurs, under the microscope, the irregular masses of recrystallised calcite parallel with the bedding, separated from each other by shaly material. Pyrite is common, occurring in rounded masses.

That these elliptical bosses may be concretionary in origin has not been lost sight of . Certain features in the field occurrence do, indeed suggest this origin, particularly the presence ofa row of these discoidal limestone masses about 24 feet above the top of the Jet Rock, on the south-east side of the Peak fault. The lithological similarity between the limestone ' and the 'bosses' does not favour this. That the Top Jet Dogger is not itself concretionary in origin is discounted because of its great extent, the presence of flattened fossils on the indivual plates of limestone, the gradual transition in the field from the Jet Rock shale to the limestone, and the general microscopic features, the presence of shaly material, spore cases and pyrites, not found within other c concretions of the Upper Lias.

In all probability, the Top Jet Dogger was deposited as a finely laminated, calcareous mud, which underwent crystallisationto form the large , irregular masses of calcite seen under the microscope. The bosses on the surface result from a segregation of calcareous matter within the mud, which drew together into elliptical areas, probably as the result of a pause in sedimentation, and crystallised to form these dome-like bosses. There is at many places in the field, a definite break at the top of the Top Jet Dogger, indicating a pause in deposition.

The suggestion regarding the origin of the 'bosses' of the Top Jet Dogger is put forward tentatively. It is felt that more conclusive evidence may yet be found in the field in favour of either concretionary origin or original deposition of the bosses.

The Concretions.

The concretions of the Jet Rock may be divided into two groups :-

1. Pyritous concretions.
2. The large calcareous concretions of Bed 20.

They will be dealt with in this order.

1. Lines of pyritous concretions are found throughout the shales of the Jet Rock, but occur in greatest number in Bed 20, where twelve to fifteen individual rows may be recognised. Some of these rows, by virtue of an individual characteristic, are recognisable in widely separated localities. Such a line of nodules is that occurring midway in Bed 19, the concretions being here rather larger than usual, about 2 feet long, 1 foot broad and 10 inches wide. Another row is in Bed 22where the nodules are almost completely spherical, and because of which it is known to ammonite collectors as the "cannon ball bed".

The pyritous nodules of the Jet Rock do not differ in any way from the pyritous nodules previously described by many authors, from other formations. They are found in many shapes, some almost spherical, others discoidal and ellipsoidal, while a very large number take an irregular and fantastic forms. The pyrites is confined to an outer skin or coat up to a quarter inch thick. The inner part is a fine-grained impure limestone, and frequantly contains well-preserved uncrushed ammonites. The laminations of the shale in which the concretions are found appear to bend above and below the nodules, which are in some cases slickensided.

The bending of the shale around the nodules may be examined in the many vertical shale faces between tide levels, which include nodules that have been broken in two. The action of sea-water etches the broken face as well as the shale, removing the more calcareous lines from them. Under such conditions it is apparent that while some laminations bend up and over, or down and under the nodule, others bend up or down and appear to end atthe pyritous face of the concretion. Unfortunately this critical zone suffers the most from the action of sea-water, for immediately round the pyrites is deeply etched. Attempts to remove specimens of nodule and shale together were frustrated because of this deeply etched zone . However, in a Jet Rock shale tip at Hole Gate, Westerdale, such a specimen was found. A face which included both the shale and the nodule was ground flat and lightly etched with weak hydrochloric acid. The more calcareous lines were more readily attacked, and after etching could be easily traced. It was found that in the shale the limey laminations bend up towards the concretion, and on touching the face pass through the pyritous zone into the nodule where they are again perfectly horizontal, parallel to the laminations of the shale. A comparison of the distances between any two of the calcareous laminations in the concretion and in the shale some few inches away from it, showed that the shale had been compressed relative to the concretion in the ratio of from 5 to 6 : 1.

2. Bed 20 of the Whitbian section is "a line of large ellipsoidal nodules some distance apart". This row of concretions is easily recognised and is of striking appearance. Separated from each

other by varying distances up to about 15 feet, some of these large concretions attain a length of four feet, being 3 feet broad and up to 2 feet thick. They differ from the smaller nodules of the Jet Rock in that they have no pyritous 'skin', and are throughout calcareous concretions. Broken nodules show the development of septarian cracks, filled with calcite, within the concretion, but these rarely reach the surface. Other material is also revealed within the concretions, which is more unusual and has not been previously recorded. It is brown in colour, occurring in irregular masses in the centre of the nodules, with veins running in all directions from the main 'reservoir', sometimes reaching the surface of the nodule. In the hand specimen it shows a brecciated appearance, the individual 'pebbles', usually of a darker colour, being cemented with calcite showing a flow structure. Microscopically the rock is seen to be made up entirely of calcite of varying degrees of purity, the calcite rhombs being of varying sizes.. The darker 'pebbles', which are usually composed of more coarsely crystallised calcite are cemented together by finer calcite, and in many the individual 'pebbles' themselves are composed of smaller masses 'cemented' together. Winding through the rock are 'flow lines' of finely crystallised calcite. (Fig.6)

In an attempt to explain this structure, sections were cut where this material was found in contact with the surrounding concretion. Veins of this substance, passing out through the nodule from the main 'reservoir' were frequently fringed with pyrites and invariably exhibited flow structure along their length. The larger veins, as well as showing flow structure along the surfaces in contact with the concretion, also showed the individual 'pebbles' typical of the main mass , in the central zone of the vein. In some rare cases, sections have been cut showing veins of a different type cutting through the mass of 'pseudo-conglomerate'. These veins are made up

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J.E.H.

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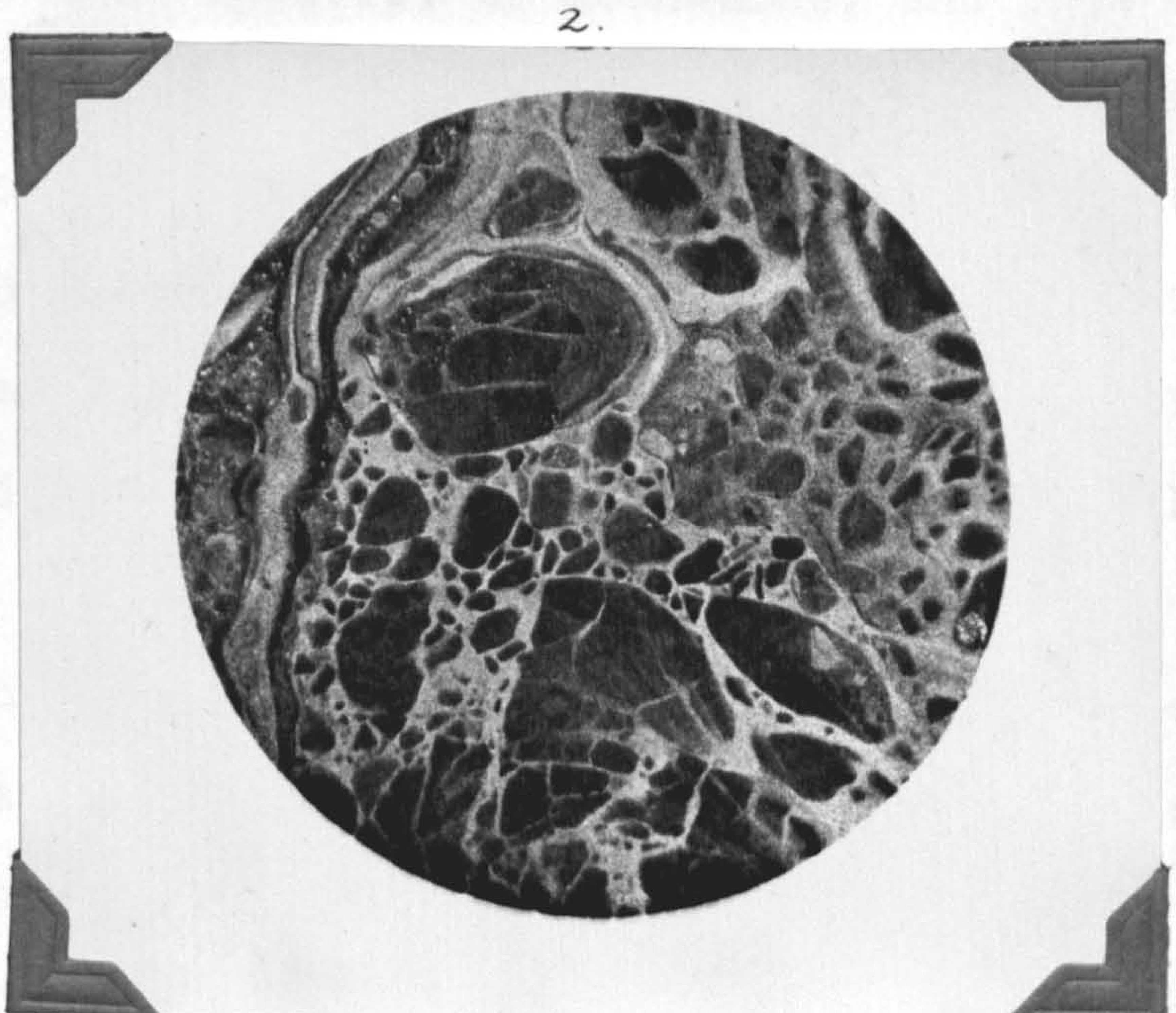

W.P.

'Pseudo-Conglomerate' from the centre of the large concretions of the Jet Rock.

1. Magnification 45.

2. Magnification 20.

of the impure calcareous material of the concretion itself, and must have been formed at a very early stage in the origin of the nodule. Many examples were found of the septarian cracks of the nodule cutting through the 'pseudo- conglomerate', proving it to be crystallised before the "chemical dessication" of the concretion set in.

In some of these large concretions the passage of the laminations of the shale into the noduleis shown to an even more striking degree than in the pyritous concretions already described. One such specimen, cut in two but remaining in the cliffs, occurs on the west side of Sandsend Ness. As in the case of the pyritous nodule, the more calcareous laminae in the shales here bend upwards, or downwards, and pass directly into the concretion, being immediately horizontal, parallel to the original lamination. It was possible in this case to measure, in the field, the distances between the individual calcareous laminae, in the shales and in the concretion, and as before to determine the relative compression of the shale, compared with the concretion.Two well marked bands were 2.4 inches apart in the undisturbed shale while in the concretion they were separated by a distance of 10.1 inches. The ratio of compression of the shale with that of the nodule is 4.2 : 1. This does not however, represent the full compression of the shale, since undoubtedly the concretion itself has undergone some compression since its formation as an unconsolidated mass.

Variations in Lithology of the Jet Rock.

Unlike some of the higher beds of the Upper Lias, the Jet Rock was found to vary little in all other exposures, whether on the coast or in the inland dales.The individual shales were examined wherever possible, usually in stream sections, and although some variation in thickness did occur, few lithological variants were noted in the field.

The shales of the Jet Rock, as a whole appear to be rather harder and denser in the inland dales, and this was brought out more strongly in thin section, under the microscope. Although the texture and mineral composition is essentially the same, the organic content is markedly increased. Sections of shale from Rosedale and Bilsdale are of a dark brown colour to the naked eye, compared with the pale grey-brown thin sections from Sandsend. Microscopically the increase in the indeterminable brown, organic material is striking. In a specimen from Rosedale the decrease in laminationunder the microscope is marked, there being very little evidence of bedding. The row of large concretions (Bed 20) was found over the whole area wherever the upper Jet Rock was exposed, along the coast, in Eskdale, Iburndale, Greater Fryup, Westerdale, Baysdale, Rosedale, Bransdale and Bilsdale. In all places it exhibited the same characters as are shown at Overdale. The 'pseudo-conglomerate' within the nodules was found at localities as far distant from Whitby as Tripsdale, a tributary dale to Bilsdale, and at the southern end of Bransdale.

From an examination of other sections of Jet Rock, it is evident that this calcitic 'pseudo-conglomerate' is not confined to the large concretions of Bed 20. In Howedale, Robin Hood's Bay, and in Rosedale as well as other localities, it was found in association with large pyritous nodules both above and below Bed 20. On no occasion was it found in association with nodules of less than one foot in length, with corresponding thickness.

The argillaceous limestone of the Top Jet Dogger does show a marked lithological variation when traced southwards from Whitby. It maintains its calcareous character up to the Peak fault, where it may be examined in a flooded jet-working near Tan Beck, about one hundred yards from the fault. On the south-east side of the fault its lithological character is considerably changed, appearing in the field as a dense laminated mudstone to which the ~~name~~ term of "indurated shale band" could be more correctly applied than to the typical Top Jet Dogger, Microscopically the lamination is less well shown. Calcite is common with argillaceous and organic material. The rock may be described as a ~~an~~ calcareous mudstone, and it differs from typical Top Jet Dogger in being much less limey, the calcite being much finer grained, and there being a corresponding increase in shaly and brown, organic material.

Another similar variation is found at the heads of four of the dales flowing northward from the Cleveland dome. In becksections in West ArnecliffWoods and near High Hardhill Farm in Glaisdale, at the head of Little Fryup and atGate Holm Beck and Esklets in Westerdale, the Top Jet Dogger is represented by a two to three inch band of black, dense mudstone differing little from that at Peak. In thin section this mudstone shows fine lamination to the naked eye, but these are not striking under the microscope. The calcite occurs in much less quantity than in typical Top Jet Dogger, and brown organic matter with some argillaceous material and pyrites makes up the rest of the rock. As at Peak, it may be described as a calcareous mudstone with organic matter, but with much less calcite than the Top Jet Dogger at Overdale.

It is unfortunate that the lack of exposures to the north of the Cleveland dome, as well as in other directions, prohibits

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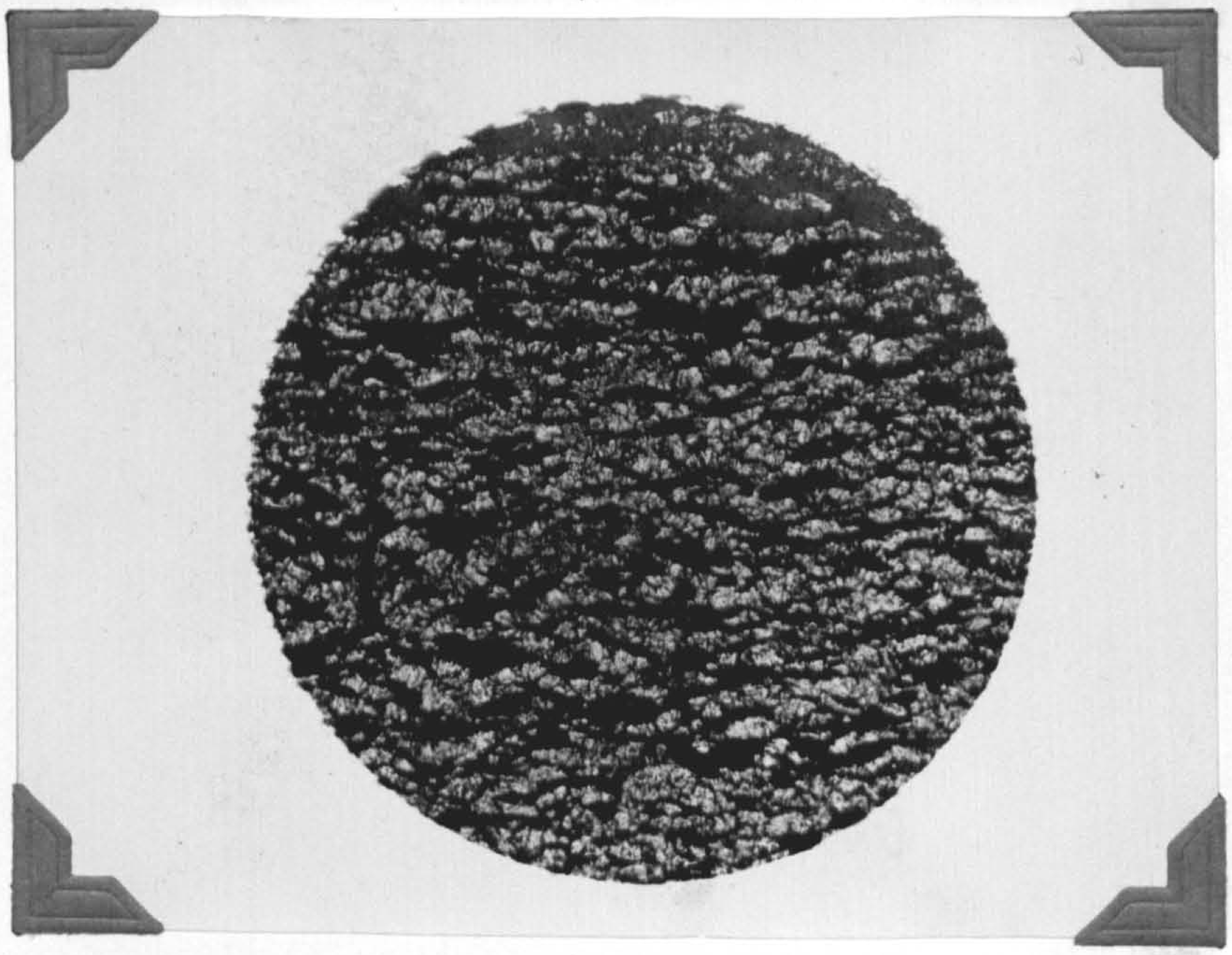

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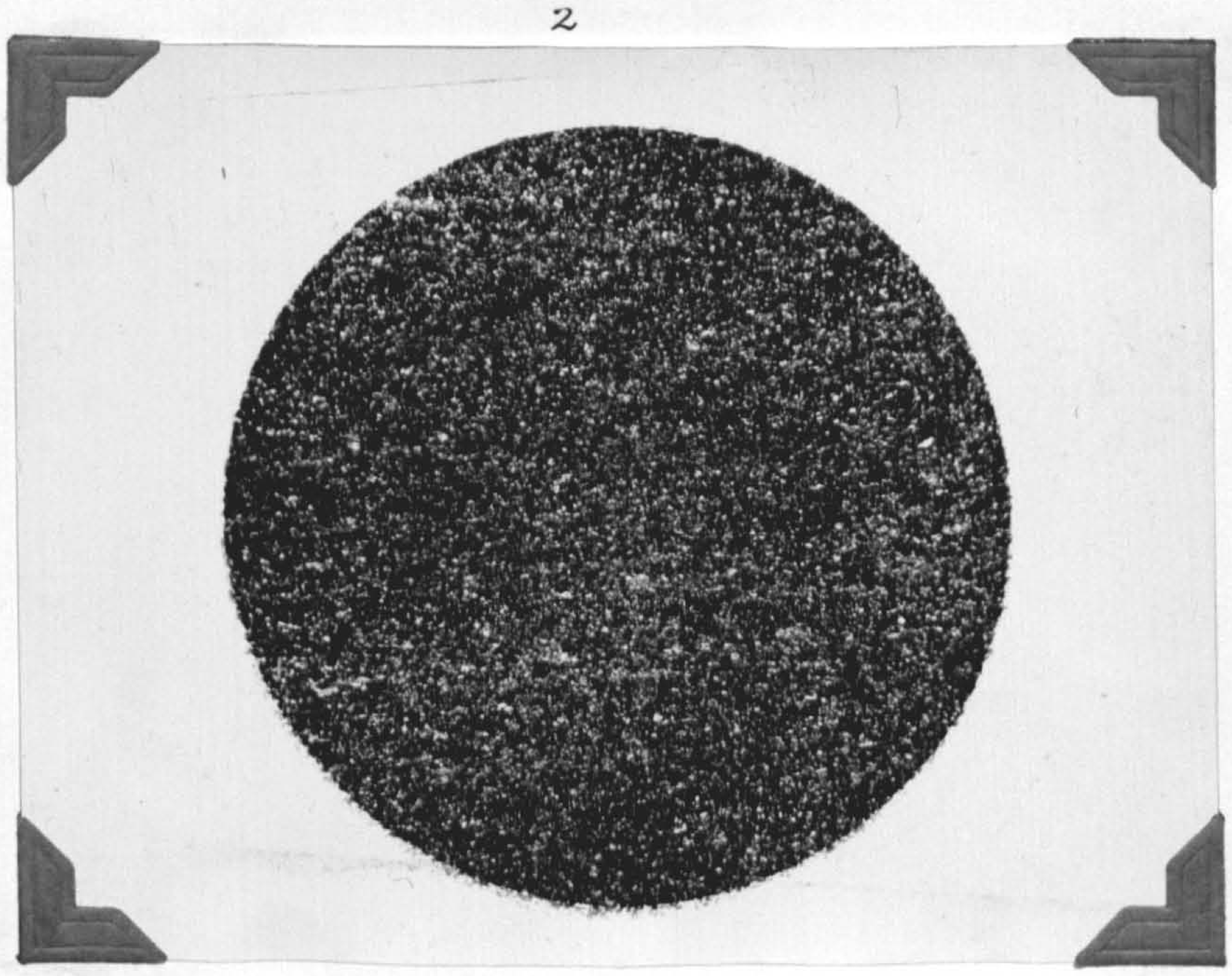


Photos: W.P.

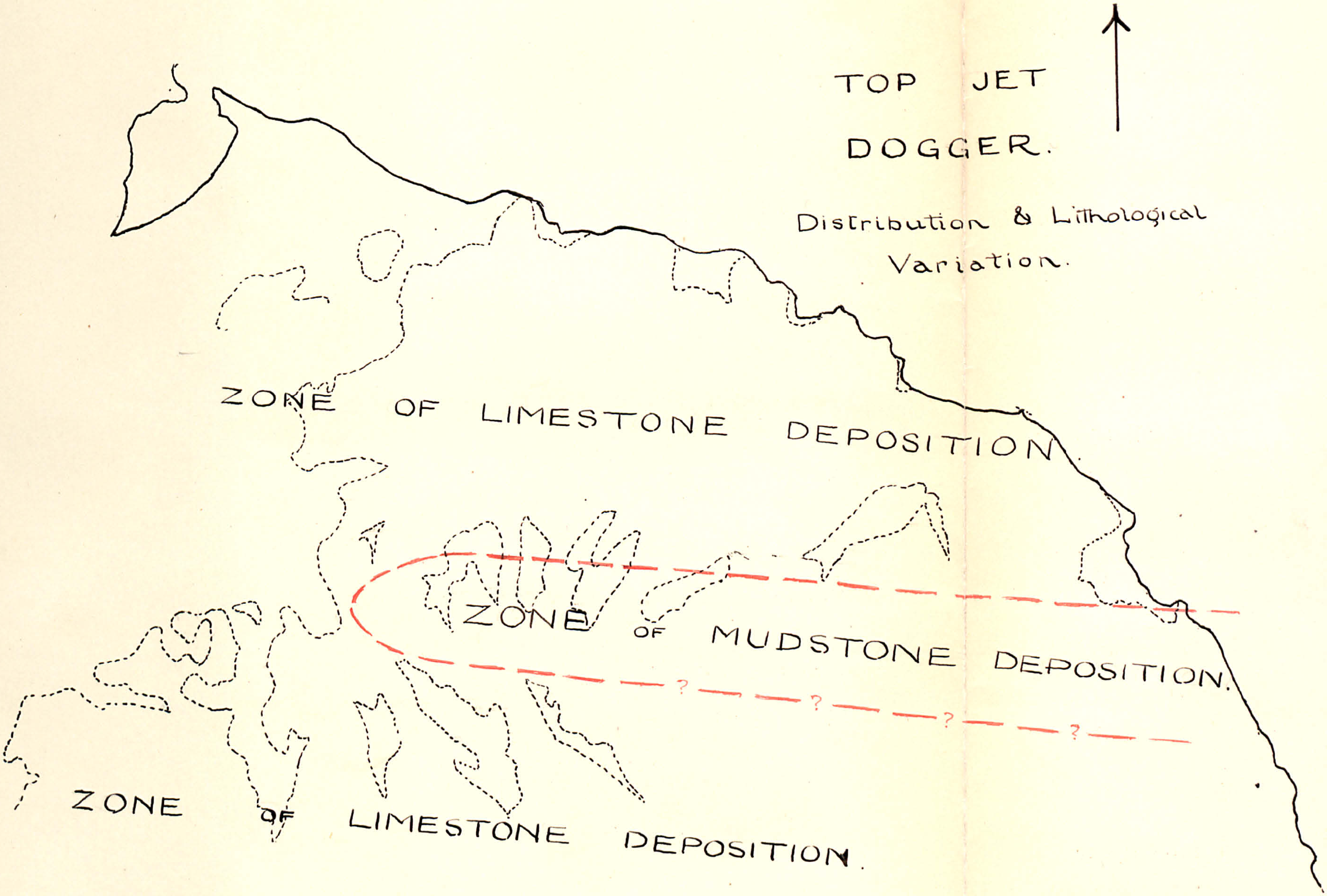
The Top Jet Dogger.

Mag. 22.

1. Typical specimen from Sandsend Ness. Calcite is white; argillaceous material, black.

2. Fine grained calcareous mudstone from Glaisdale.

Fig 2.



TOP JET DOGGER.

Distribution & Lithological Variation.

accurate delineation of the boundaries of this zone. In Baysdale the rock is the typical limestone. In Bloworth Beck, to the north-east of Bransdale, although it is still an argillaceous limestone, the shaly material shows a marked increase, indicating proximity to "the mudstone zone". In Farndale, to the south, exposures are poor, but at the head of Rosedale it is a typical limestone. To the north, the Top Jet Dogger is a limestone in East Arnecliff Woods and a mudstone in West Arnecliff Woods, a mile and a quarter to the south.

It is apparent that the zonewithin which the Top Jet Dogger is represented by a thin mudstone is in all probability roughly ellipticalin shape, the main axis being in an East-West direction. The northern boundary is parallel to and about one mile southof Upper Eskdale; the southern is coincident with the main axis of the elongated Cleveland dome. The east and west boundaries of the zone are less easy to define. The presence of the Top Jet Doggeras a limestone all along Baysdale indicates that the northern boundary of the 'mudstone zone' is turning south between Baysdale and Westerdale. Although in the Ingleby re-entrant exposures are much obscured, no limestone was found in the tips from the old jet-workings, as is usual when the Top Jet Dogger is represented by a limestone, and it is probable that the mudstone zone extended as far as, and slightly beyond this lodality.

To the east of Glaisdale exposures are lacking until the coast is reached. Extrapolation of the northern boundary zone of the mudstone zone, drawn as accurately as it has been possible to define it , cuts the coast almost exactly at Peak. This aggees with the field evidence, the Top Jet Dogger being a limestone at Tan Beck and thewest side of the fault, and a mudstone on the east, downthrow side, on the shore. If the Top Jet Dogger on both sides of the fault were again brought into juxtaposition , these two localities would be little more than a mile apart and it may be argued that such a distance is unsufficient for the marked lithological change to take place and that the difference in lithology is due to contemporaneous faulting during deposition known to cause striking stratigraphical and lithological varitions in the higher Whitbian. Against this it may be stated that the fault did not move before the deposition of the pseudovatus zone (the Hard Shales), since the measurements of the shale between the double line of nodules of this zone and the Top Jet Dogger, on both sides of the fault, show no differences in thickness. Again, in the two localities near Glaisdale, in West and East Arnecliff Woods, the Top Jet Dogger is represented by the two lithological variants, limestone and mudstone, the two exposures being only one and a quarter miles apart. From this it is concluded that the variations at Peak are not due to contemporaneous faulting, and that the fault is merely fortuitously coincident, at this point, with the boundary of the 'mudstone zone'.

The final conclusion is that within an elliptical area approximately 4 to 5 miles broad, extending from the Ingleby re-entrant in the west, along a line almost coincident with the long axis of the Cleveland dome, to and beyond the coast at Peak in the east, the Top Jet Dogger, elsewhere an argillaceous limestone, is here represented by a fine-grained calcareous mudstone of marked lithological dissimilarity. The long axis of this zone is W.N.W. by E.S.E., and may be defined as Armoricanoid in direction (E.N.E.- W.S.W. through E.W. to W.N.W.-E.S.E., according to Dr.A.Morley Davies.[52]).

Variations in thickness of the Jet Rock.

Variations in thickness of the indivual beds of shale in the Jet Rock do occur, but usually exposures are not sufficiently good for measurements of the full section to be made. Almost invariably the lower part of the Jet Rock is hidden, only the Top Jet Dogger and a few feet of shale below it being visible.

One distinctive bed of p~~t~~yritous nodules occurs in the Overdale section at 3 feet 8inches below the Top Jet Dogger, and the shale interval betweenthis dogger line and the Top Jet Dogger can frequently be measured. The thickness varies from 3'6" at Runswick Bay, to a maximum of 5'3" in Rosedale Wyke,near Hinderwell. This distance is varied all over Cleveland and no regular variation in any direction ~~in any direction~~ could be determined.

It is not suggested that these pyritous concretions define the base of an individual bed of shale. Nowhere in the Jet Rock sequence is a bed defined in the field by rows of nodules. These bands are merely convenient horizons used for the subdivision of the Jet Rock. Indeed there appears to be little justification of the division of the upper part of the Jet Rock into three individual beds(Beds19, 20, and 21), by means of the row of large concretions. A break in sedimentation does appear to have taken place at the base of Bed 21, but none is visible in the field at the base of Bed 19, which is defined by the Survey as coincident with the row of large concretions. On field and microscopic evidence the Jet Rock may equally well be subdivided in three beds:-

A. The Top Jet Dogger (Bed 18 of the Survey)

B. The Upper Jet Rock, with a row of large concretions along the middle of the bed. (Beds 19, 20, and 21.)

C. The Lower Jet Rock. (Bed 22 of the Survey.)

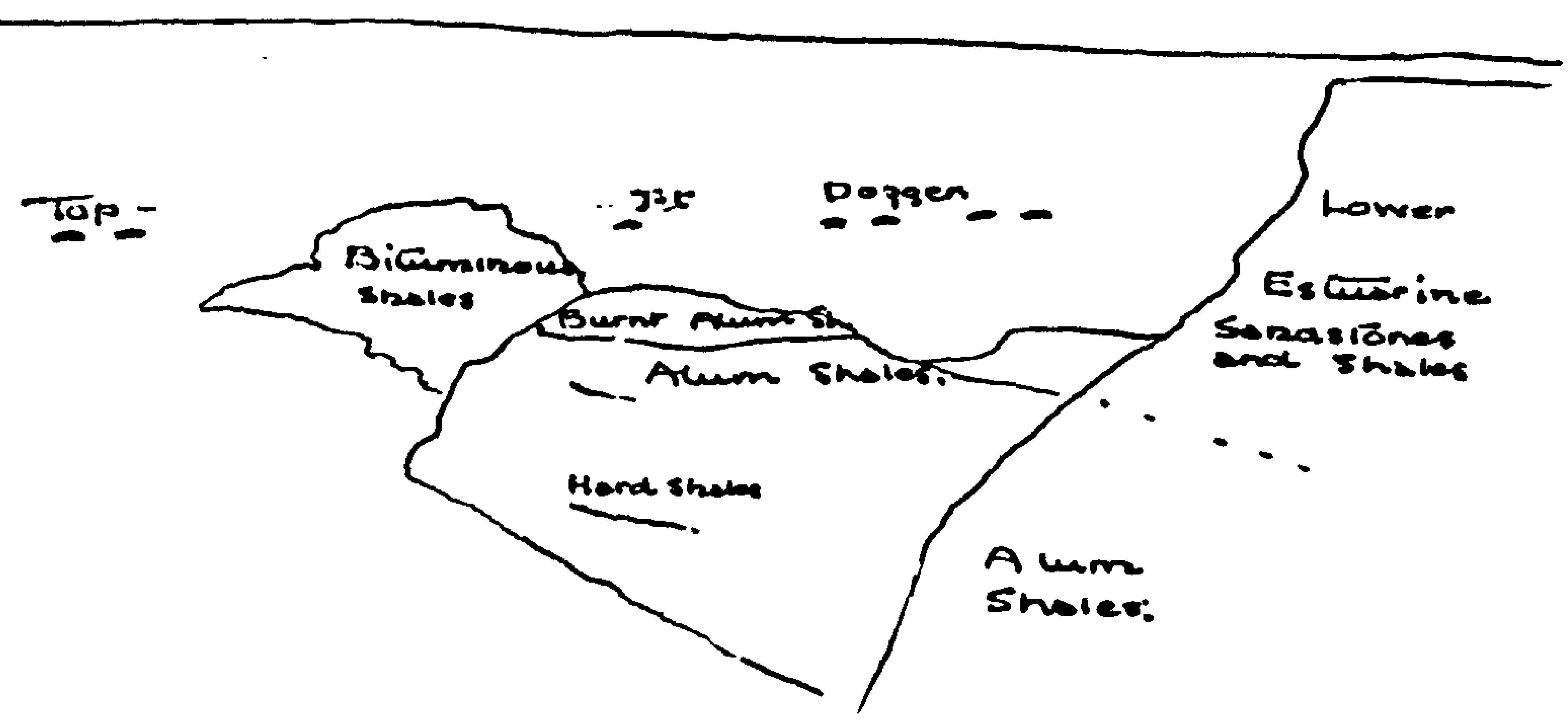
(4) THE BITUMINOUS SHALES.

Zone of Harpoceras falcifer.

The Bituminous Shales are subdivided by the Survey into four individual beds of shale, by means of one 'indurated band' and two lines of pyritous nodules. They are well exposed at Saltwick Nab, the lowest bed formingthe shore on the seaward end of the Nab. Here the following section was measured, excepting the lowest bed, in which case the mean is taken of two measurements, 16 feet and 18 feet, at Hawsker Bottoms and at Sandsend respectively. The numbers denoting each bed are the same as are used by the Geological Survey for the Whitbian section.

		Feet	Inches
11.	Hard blue-black shales. . . .	17	0
12.	Siderite mudstone.		3
13.	Hard dark shale.	11	6
14.	Line of pyritous nodules . . .		-
15.	Hard dark shale with great numbers of fossils. Harpoceras of the mulgravium type, Phylloceras, belemnites, Inoceramus. . .	19	9
16.	Line of pyritous nodules . . .		-
17.	Hard dark shales.	17	0
		66	6

Specimens were taken from about the middle of each of the beds of shale and submitted to petrological examination. Heavy mineral separations were made of the specimens of the Bituminous Shales as well as those from higher horizons, but in no case were the results worthy of record. As was expected pyrite occurred in great abundance, but the other minerals were very few and frequently so small as to prevent accurate determination.


Top
Jet
Dogger
Lower
Estuarine
Sandstones
and Shales
Bituminous
Shales
Burnt Alum Sh
Alum Shales.
Hard Shales
Alum
Shales.

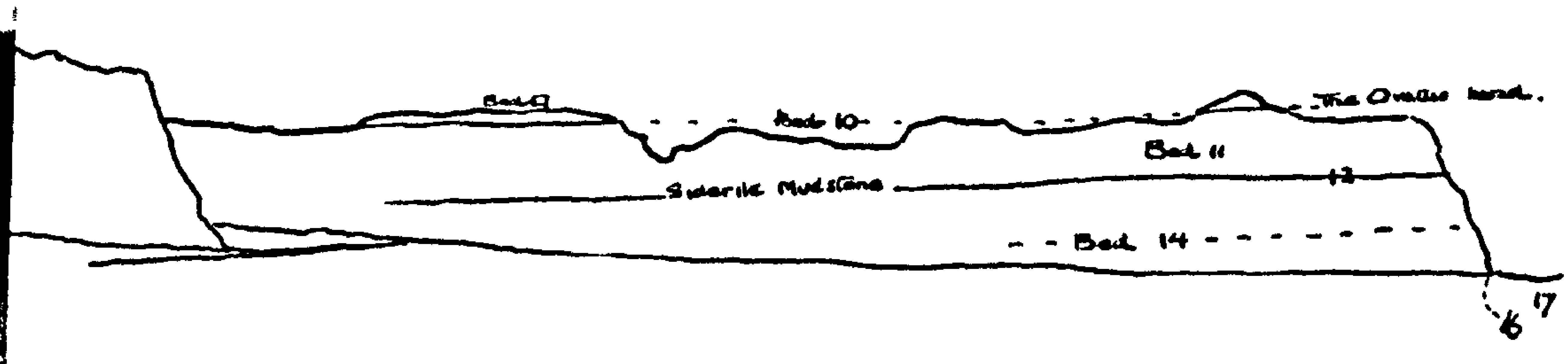
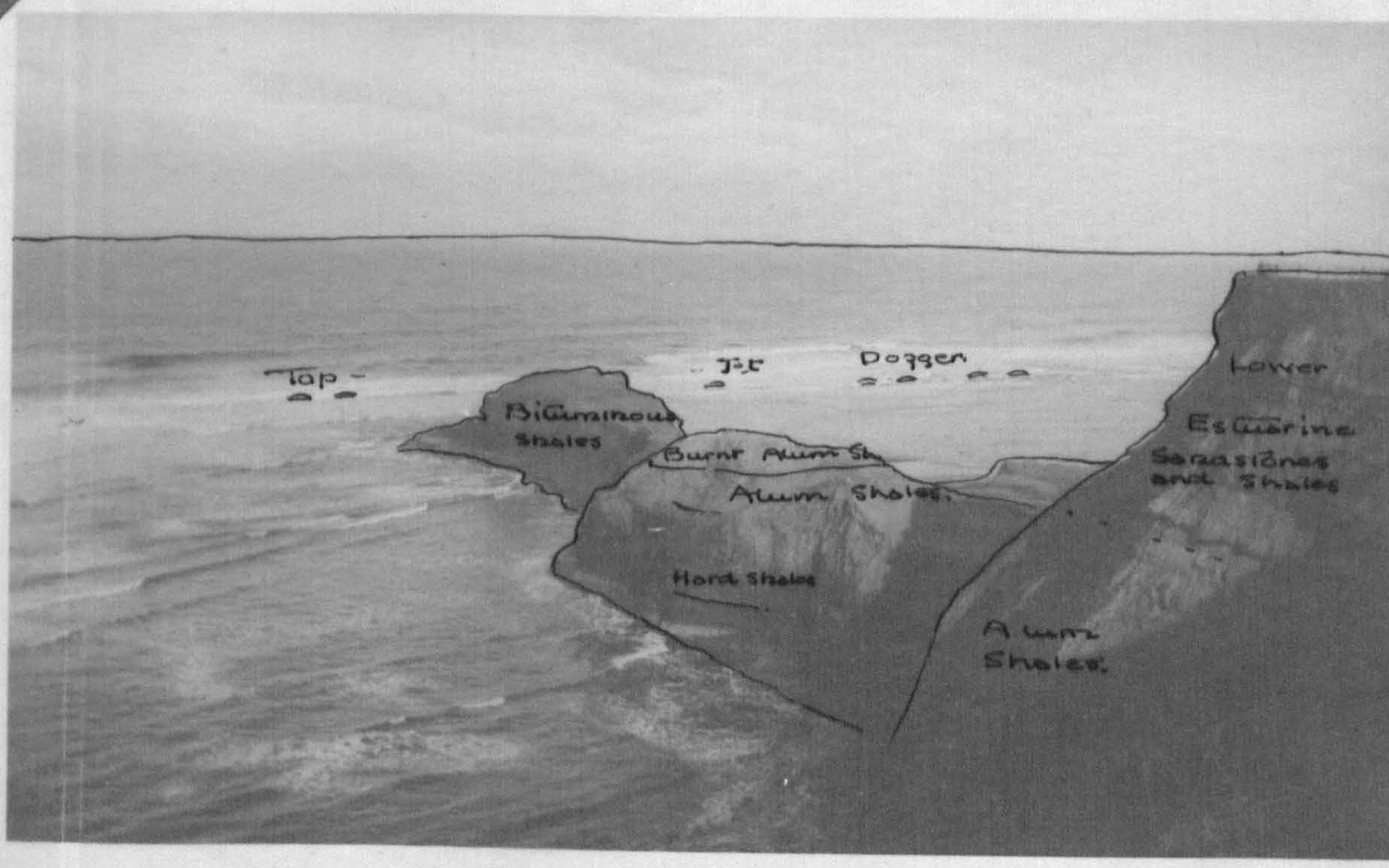

Bed 9
Bed 10
The Ovalis band.
Bed 11
Siderite Mudstone
13
Bed 14
16
17

PLATE 8.

Saltwick Nab. General View.

Photos: J.E.H.

Saltwick Nab. View from South-East
showing siderite mudstone bands.



Saltwick Nab. General View.

Photos: J.E.H.

Saltwick Nab. View from South-East
showing siderite mudstone bands.

Lithology of the Bituminous Shales.

The Shales.

The lowest bed (17) is a hard, blue-black shale smelling strongly of bitumen when freshly broken, and very little different from the shale of the Jet Rock, in the hand specimen. It contains a fair amount of mica and splits easily along well defined laminations.

Under the microscope the shale is dark fawn in colour. Quartz occurs in abundance, in the mass of the shale itself as wellas in gritty lines or bands which run for only a short distance and which are made up almost entirely of quartz grains. Flakes of muscovite are common and pyrites is extremely plentiful occurring in small rounded masses. The laminations are marked principally by the short dark brown lines or elongated masses of a dark brown, indeterminable material which occur in very considerable numbers. As in the Jet Rock, theircolour is darker than that ofspores or jet fragments, and it is assumes that they are of vegetable origin. Not only are they distributed sporadically throughout the whole section, but they also occur concentrated into one band one eighth inches wide, composed almost entirely of them and inter-stratified shaly malerial. With these are also found short lenses of black opaque carbonaceous material.

In striking contrast with this dark organic bed, another band, much thinner is made up of argillaceous material alone, with no coarser quartz grains or organic material. The main portion of the section is however, made up of a shale intermediate between these two variations.

Shells presumably Inoceramus, preserved in calcite, as well as isolated calcite rhombs from broken shells are common, together with small fragments of jet and spores. Both macro- and micro-spores may be distinguished, the former usually broken and badly crushed, the latter frequently well preserved.

Three microspores were found in the slide and six macrospores.

Bed 15 is the thickest individual bed of the Bituminous Shales. In the field it differs little from the shale below it, save that here occur large numbers of fossils, pyritised Inoceramus being present in very great abundance.

Microscopically the difference is more marked. The shale is lighter in colour in thin section, finer in texture, and contains fewer 'dark brown lines' of organic material, than does the bed below . Quartz is present both in the shale and in gritty lines and bands, but the latter as well as the isolated quartz grains are fewer than in the lower shale. Microspores are extremely abundant, 36 being counted in the slide, together with three macrespores, one of exceptional size. The most striking feature in the slide is the presence of small, broad lenticular masses of chalcedonic silica, which displace the laminations of the shale between which they have developed. Chalcedony also occurs as an infilling material in such macro- and microspores that are not completely compressed.

Bed 13 is again finer in texture that the bed below it. The brown organic lenses and black carbonaceous masses are still fewer in number, as are the quartz grains and gritty lines of microscopic quartz pebbles. Pyrite is a conspicuous constituent. A few macrospores occur and microspores are fewer in number, 21 being counted. Chalcedony is found as an infilling amterial in some of the spores, and as broad isolated lenticles.

The uppermost bed of the is little different, both in the field and under the microscope from that immediately below it. The shales no longer small of bitumen and microscopically are seen to be slightly finer grained, the quartz grains being smaller and no gritty bands being found. Black carbonaceous masses still occur but the brown organic lenses are no longer present. Lamination, both macro- and microscopically, is much less well defined. The microspores in this section number 16.

The Siderite Mudstone.

Bed 12 is described by Phillips and Simpson as "a hardened ferruginous shale", and by Fox-Strangways as "a red indurated band". It is rarely more than two to three inches thick and forms a conspicuous band in the cliffs of Saltwick Nab. The rock is a grey-brown earthy mudstone which weathers red on the outer surface. Microscopically it appears to be a finely crystallised mudstone, with small amounts of pyrite and carbonaceous matter, and showing no sign of bedding. The rock was tested for siderite in the manner suggested by Hallimond. The polished surface of a chip of rock, before mounting in the usual way, was immersed for 5 to 10 minutes in a hot concentrated solution of caustic potash, to which a little hydrogen peroxide was added at intervals. The surface was finally washed and dried in air. In this way the siderite was atained brown, the calcite being roughened but not destroyed. Under the microscope the siderite was seen to occur in small irregular masses, sometimes grouped together to form larger aggregations. Calcite was common , comprising much of the remainder of the rock, with a small amount of argillaceous material. This rock may therefore be considered as an iron ore, and may be described as a siderite mudstone.

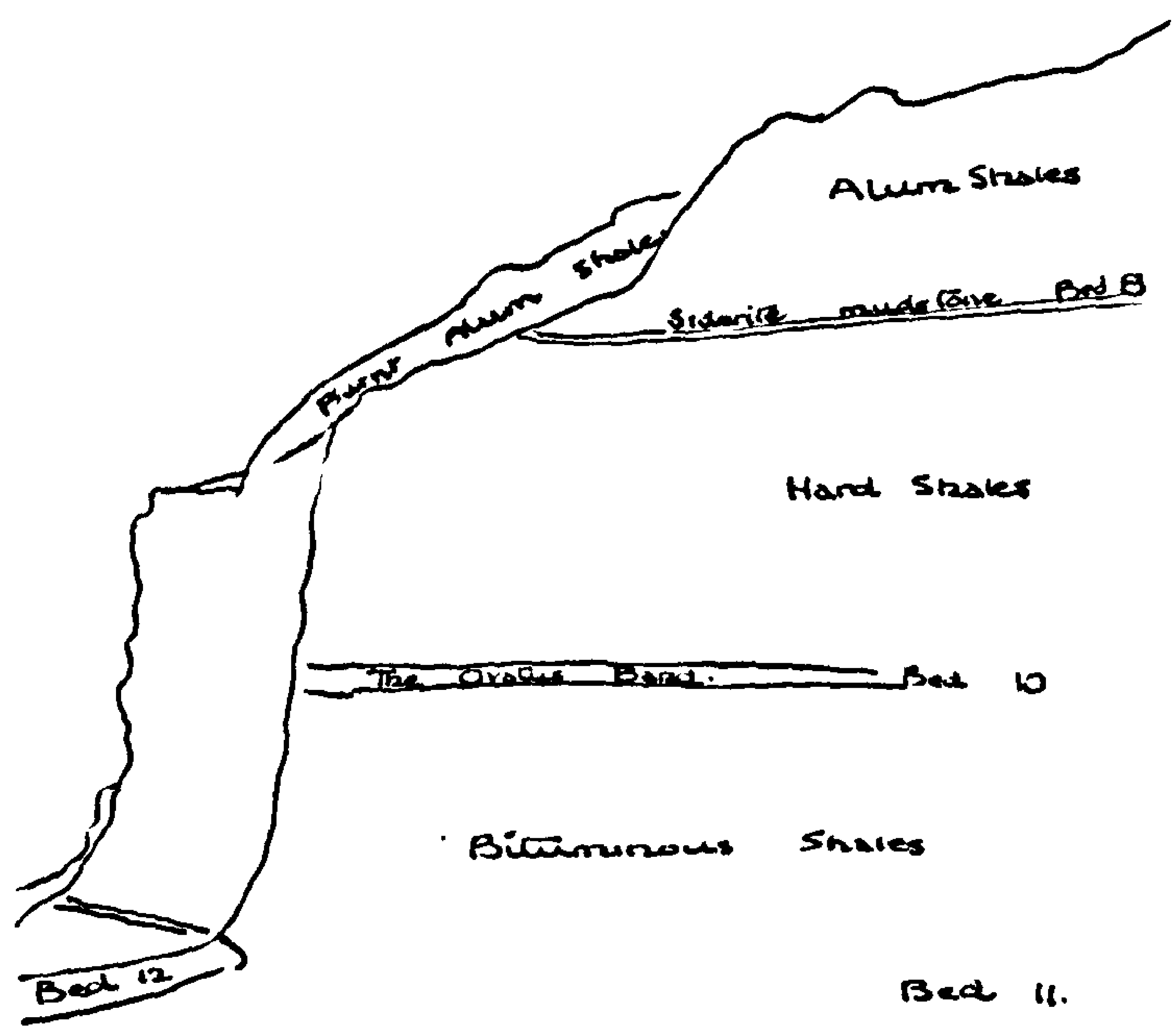
(5) THE HARD SHALES.

Zone of Pseudolioceras Pseudovatum.

The Hard Shales receive their zonal name from an ammonite occurring an a double band of pyritous nodules at the base of thezone, and which is not known in the South-West of Midlands of England, although something like it is found in the North-West of Germany". The shales of this zone are well exposed on the Whitby side of Saltwick Nab, between the cliffs and the path across the Nab. A section measured here is as follows:-

		Feet	Inches
18.	Siderite mudstone containing a very few pyritous nodules. . .		5
9.	Shales lighter in colour and softer than those below . .	20	0
10.	The Ovatus Band. A double line of pyritous and calcareous nodules containing Pseudolioceras pseudovatum, with siderite mudstones and masses of belemnites.		10
		21	3

The so-called Ovatus Band is of considerable lithological interest, and is exposed at the base of the cliff at North Batts, ~~North~~ Saltwick Bay. Here, as wellas on the west side of the Nab, it leaves the cliff and forms a reef running across the scars and is thus easily examined. The main features of the band are two lines of pyritous concretions separated by 10 inches of hard shale. This is the typical development of the band as found on the west side of the Nab, but at North Batts local variations are found. As well as the pyritous concretions, calcareous nodules of similar size and discoidal shape occur, together with large masses of siderite mudstones in which the



Alum Shales
Burnt Alum Shale
Siderite mudstone Bed 8
Hard Shales
The Ovatus Band. Bed 10
Bituminous Shales
Bed 11.
Bed 12

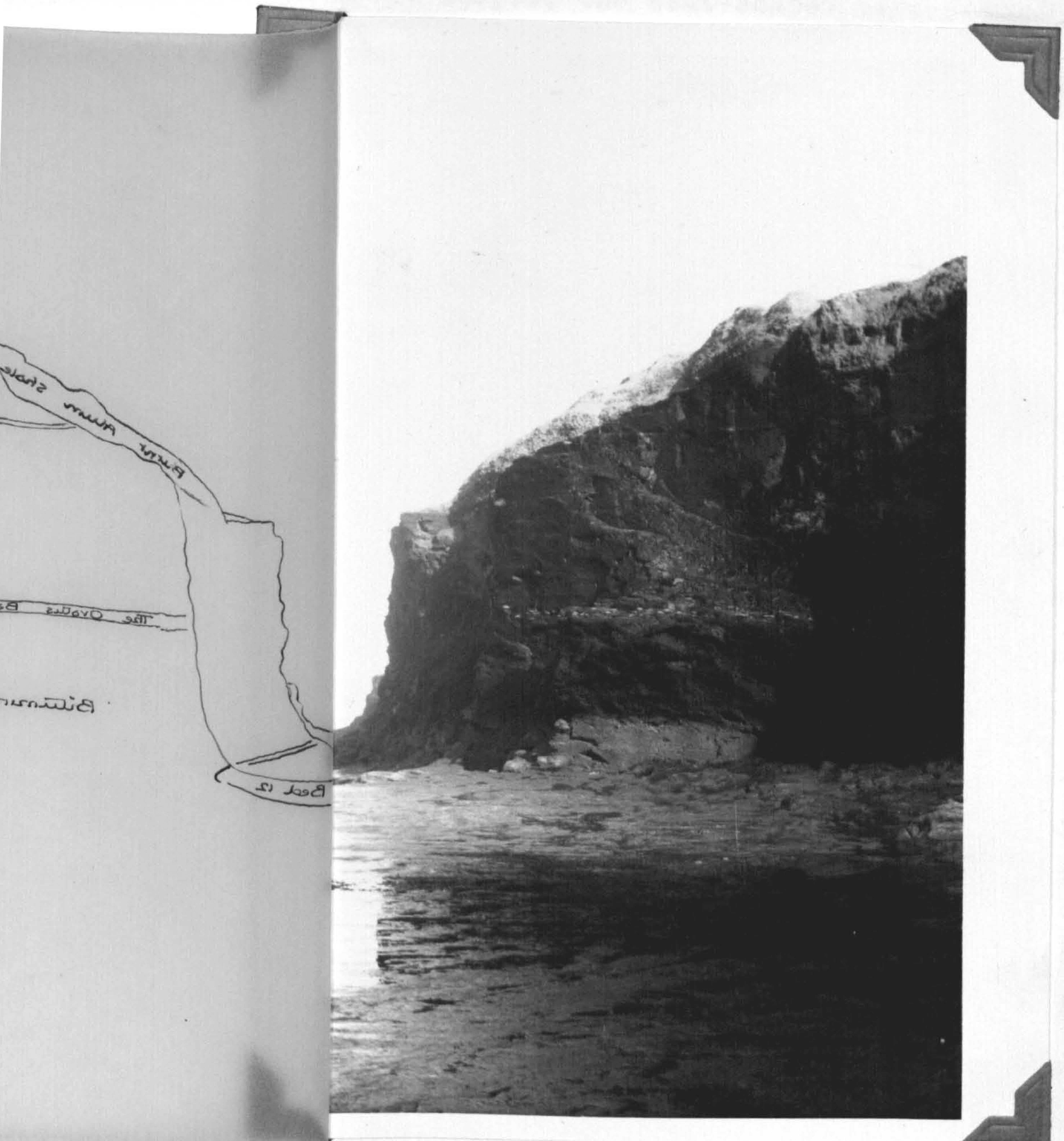


Photo: J.E.H.

The Hard Shales and Bituminous Shales.

North side of Saltwick Nab.

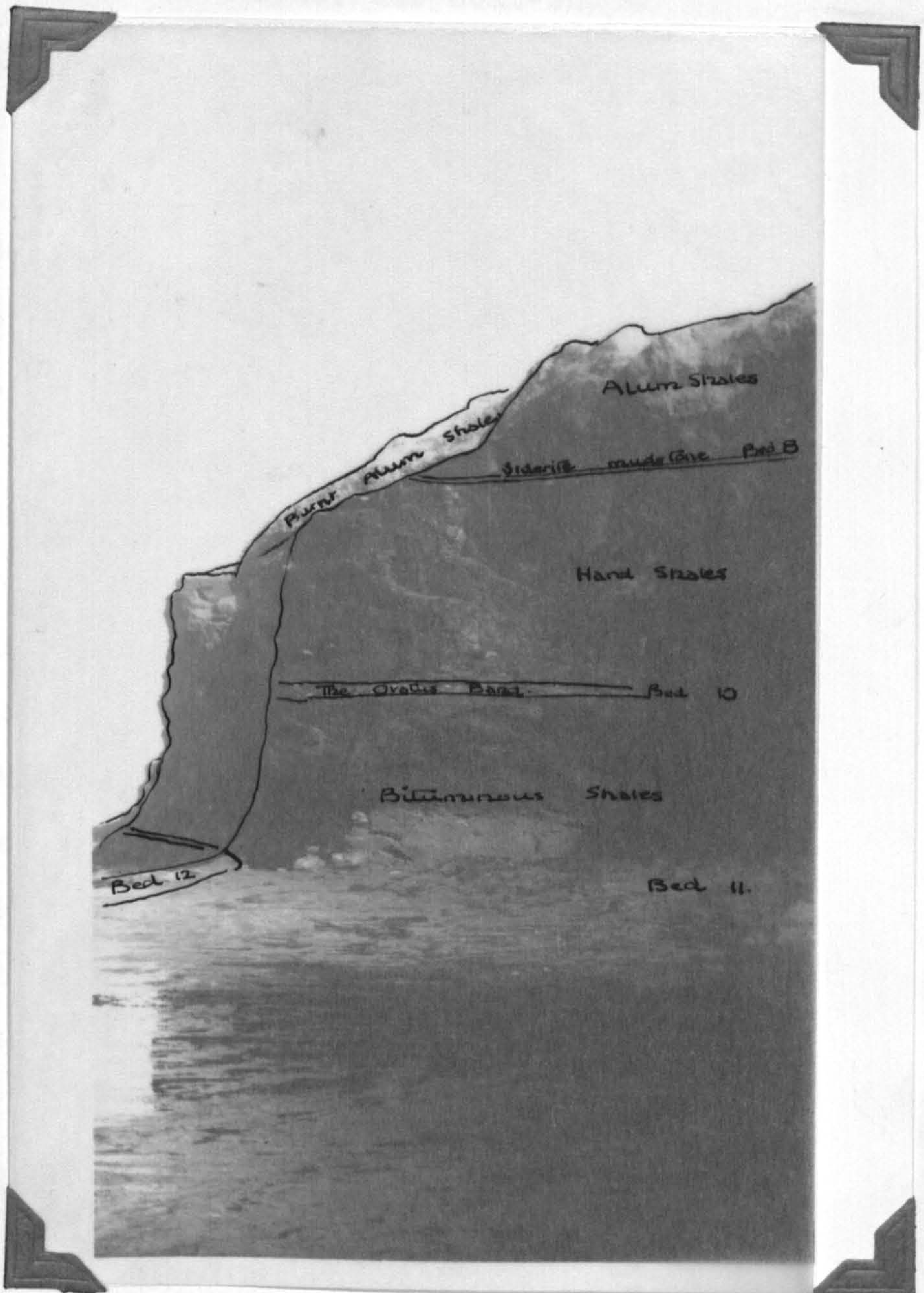


Photo: J.E.H.

The Hard Shales and Bituminous Shales.

North side of Saltwick Nab.

concretions frequently are embedded. These mudstones develop into curious shapes, one boat-shaped mass being 20 feet in length, with cone-incone structure on the upper surface. The most remarkable feature of the Ovatus Band is the occurrence of masses of belemnites cemented together to form a limestone. Until recently the area of one such mass was several square feet, while a large specimen in the Whitby Museum from this locality indicates that it had a much greater extent. The development of pyritous concretions on its under sidehas considerably disturbed the original horizontal surface of the bed, which now swings up and over the nodules below. Such beds of belemnite guards are called by the German writers "belemnite battlefields", (belemnitenschlachtfelder), although this term usually refers to beds of greater areal extent than that at North Batts. Under the microscope the spaces between the belemnites are seen to be filled with shell fragments, some of which are preserved in opaline silica, and by large masses of pyrites. The whole mass is cemented together by calcite.

In the field the Hard Shales are intermediate in texture between the soft grey Alum Shales above and the hard blue-black Bituminous Shales below. These shales have, in the past, yielded a small quantity of alum, but that yield was, in all probability insufficient for economic working.

Microscopically this shale is again finer in texture than the bed immediately below it. The quartz are fewer and smaller. The muscovite increases in quantity and in size of flakes. Pyrite also is much more common, occurring in small ronnded masses and in larger irregular masses, which under greater magnification prove to be an aggregate of the smaller rounded mas masses. Carbonaceous matter has decreased much in quantity as has the number of microspores in the section, which is 10. Chalcedony occurs as before in small irregular masses.

T The uppermost bed of the Hard Shales, the five inch siderite mudstone, was referred to by Phillips as "a thin bed of ironstone" and by Fox-Strangways, in 1892 and in 1915 as "an indurated sandy band, becoming a distinct line of ironstone towards Whitby". There is no evidence, field or microscopic, of this rock being arenaceous in character, but treatment with caustic potash and hydrogen peroxide stains the siderite and proves it to be an ironstone. Doubtless Hallimond had this bed in mind when, writing of the non-chamositic siderite mudstones, he stated "Probably some doggers of the Lias also belong to this class."[19]

Bed 8 however, although known to be an ironstone, is much less rich in siderite than are the isolated masses of mudstone in the Ovatus Band. The latter were found to be the richest of the siderite mudstones in the Upper Lias section.

In both beds calcite occupied much of the remainder of the rock, the amount of shaly material being only small. Occasional shell fragments occurred, preserved in the original calcite.

(6) THE ALUM SHALES.

Zones of Peronoceras braunianum, P. fibulatum and Frechiella subcarinata.

The Cement Shales and the Main Alum Shales of the Geological Survey 'Section of the Whitbian',[14] will here be classed together since they cannot be separated satisfactorily either on lithological or on palaeontological grounds. The Cement Shales differ from the Alum Shales only in the presence of nodules, in the former, from which hydraulic cement was made. No satisfactory boundary can be drawn in the field. Nuculana ovum although a characteristic fossil in the Cement Shales, also occurs in the upper beds of the Alum Shales. The Cement and Main Alum Shales together comprise the three zones Peronoceras braunianum, P. fibulatum and Frechiella subcarinatam, but, according to Fox-Strangways, how these shales are divided between the three zones is not known.

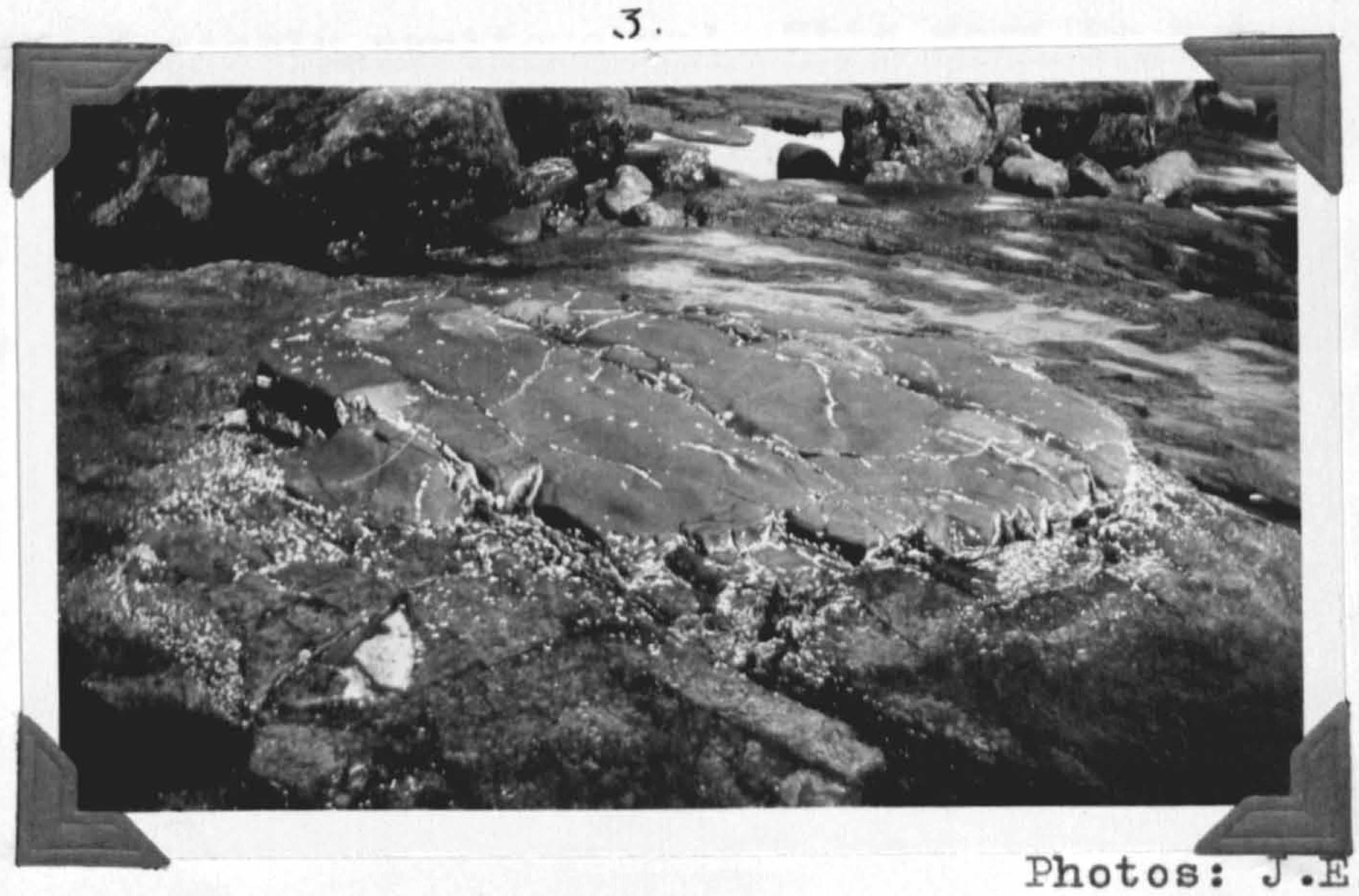
Thus at present, there seems little justification for the division of the uppermost bed of soft grey shales into two lithological divisions. The writer therefore proposes, for the reasons stated, to group together theCement Shales and Main Alum Shales of the Survey under the term Alum Shales. After more detailed zonal work has been done, when the limits of the three zones are accurately defined, the term Cement Shales may again be used as a lithological term in all probability equivalent to the braunianum zone

The Alum Shales were measured in the cliffs of the Scaur, Whitby, between Rail Hole Bight and Saltwick Nab, a distance of 300 yards. The section here is as follows:-

1.

2.

3.



Photos: J.E.H.

1. Sandsend Alum Works, showing the Dogger resting non-sequencially on the upper Alum Shales.
2. Boulby Alum Works.
3. Isolated mass of siderite mudstone of Bed 6.

		Feet	Inches
2 & 3.	Soft grey micaceous shales. .	31	0
4.	Line of isolated masses of siderite mudstone. . .		-
5.	Soft grey micaceous shales. .	17	0
6.	Row of isolated masses of siderite mudstone. .		-
7.	Soft grey micaceous shales. .	17	0
		65	0

Lithology.

The Alum Shales differ considerably from the Hard Shales and still more markedly from the Bituminous Shales and the Jet Rock. They are soft, grey and micaceous, and weather easily into crisp fragments easily distinguishable when walking over them from shales of the lower horizons. Small logs and stems of wood, as well as a small amount of jet, are found throughout these shales. The former are invariably covered with a thick coat of richly pyritous mud. This wood is not compressed or contorted in any way, and the cells are infilled with calcite.

The lowest bed of the Alum Shales is a soft grey-black micaceous shale. Microscopically it is lighter in colour than the Hard Shales below, with quartz in the same abundance. Pyrites, however is much more common, as is biotite. On account of the decrease of quartz and organic material, the indeterminable argillaceous matter is much more abundant. Four microspores occur in the thin section of this bed.

Bed 5 is very similar to the bed below it, slightly lighter in colour but containing much more pyrites. The pyrite occurs in large irregular, as well as rounded forms, together with the smaller finer grains, as are found in the Bituminous Shales. Six spores were counted in this slide.

The upper bed of the Alum Shale is again a light coloured shale, but with still more pyrite. No spores were fonnd in this bed of shale.

The two rows of siderite mudstone differ very little from those of the Ovatus Band. They are both richer in siderite than the continuous beds of this rock found at lower horizons, Bed 6 being particularly rich. Much of the remainder of the rock is made up of fine grained calcite, with only a small amount of argillaceous material.

(7) Summary of the Lithological Variations in the Upper Lias Section at Saltwick.

The varied lithology in the Upper Lias section at Saltwick between the Grey Shales and the Alum Shales is very marked in the field and even more striking microscopically. The soft micaceous Grey Shales at the base of the Upper Lias pass gradually but fairly rapidly into the dark, dense bituminous shales of the Jet Rock, with the contrasting fine laminations and strong smell of bitumen. In the Bituminous Shales proper lamination is less well marked, while the Hard Shales are less dense, less well bedded, and do not smell of bitumen. The Alum Shales show little lamination, are grey in colour and much softer than the shales below. All these lithological variations take place gradually.

Microscopically quartz varies in quantity and size of grain being most common and most coarse in the upper bed of the Jet Rock. Above the Jet Rock it progressively decreases from bed to bed both in quantity and in grain size.

Pyrite occurs in all the shales as small rounded aggregates, as rounded spheres in the Jet Rock, as aggregates of spheres in the upper Bituminous Shales and in the Hard Shales, and as large irregular masses together with the smaller spheres , in the Alum Shales. The actual percentage of pyrite appears to increase from the Jet Rock to the Alum Shales, But it is impossible to state with accuracy that this is so, without chemical analysis.

Muscovite varies very little throughout the Upper Lias, in distribution or in size of flakes.

Organic matter occurs abundantly in the Jet Rock, especially in the upper bed. It decreases rapidly downwards into the Grey Shales, and more gradually upwards through the Bituminous Shales to the Alum Shales.

One of the most interesting variants are the spore cases, since they can be counted accurately in a unit area of thin sectionof each bed. A few microspores occur in the Jet Rock and the lower bed of the Bituminous Shales, as well as some macrospores. The ~~latter~~ former decrease upwards through the Upper Lias, but the latter show a sudden and marked increase in the sdcond bed of the Bituminous Shale (bed 15). Above this bed they decrease progressively upwards until in the upper bed of the Alum Shale no spores are present.

The siderite mudstones occurring in the upper part of the section vary in iron content. This is not related to their position in the section, but to their field occurrence as continuous thin bands or as rows of isolated, thicker masses. The latter are invariably richer in siderite than are the continuous beds.

Thus in all characters of lithology, the Upper Lias section at Saltwick shows a gradual transition from the soft light-coloured Grey Shales, through the dark dense Jet Rock and lower Bituminous Shales, to the soft grey Alum Shales, very similar to the Grey Shales.

(8) VARIATIONS IN THICKNESS AND LITHOLOGY OF THE BITUMINOUS, HARD AND ALUM SHALESIN CLEVELAND.

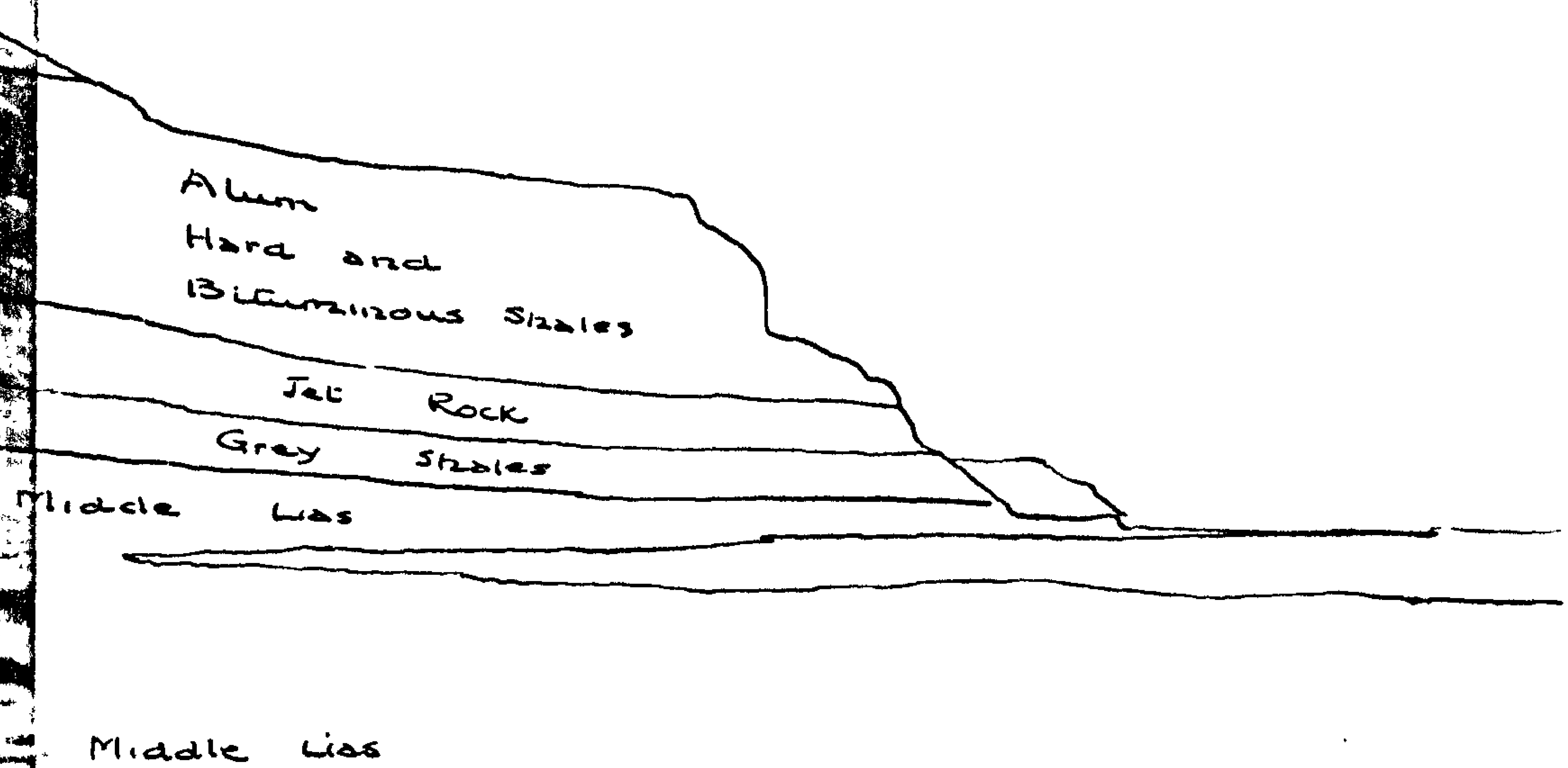
3½ miles to the south-east of Whitby, at Hawsker Bottoms, the beds of the Upper Lias may again be measured, though not examined, in the steep cliff exposures. Here no important change in thickness was noted. At Howedale, 6 miles to the South-south-east of Whitby, the beds are again accessible in a steep-sided shale gorge, and are thicker by 40 feetthanthe shales above the Jet Rock at Hawsker Bottoms. The Alum Shales and the Hard Shales are similar in thickness to the Whitby section, but the Bituminous Shales, 66 feet thick at Saltwick, are here 30 feet thicker.

To the north of Whitby, the Upper Lias may be measured in detail in only three localities, at Sandsend, Kettleness and Boulby. In no case are the measurements taken from one continuous section but within a distance of a quarter mile, wherever the indivual beds were accessible. The Sandsend section was measured in Deepgrove Alum Works; the Kettleness section in a number of separate embayments in the Kettleness Alum Works; at Boulby two sections were measured, one in Rock Hole Alum Works, to the east, and another in Boulby Alum Works, to the west.

The few measurements taken at Sandsend correspond fairly closely with the Whitby section, four miles to the east, The individual siderite bands, where inaccessible, can be recognised in the vertical cliffs of Sandsend Ness.

At Kettleness, however, the section changes considerably and differs much from that of the Scaur, six miles to the east-south-east. This is also true of the Boulby sections, abd although the latter pair are less than a mile apart, the siderite bands in the shale can only be correlated with difficulty.

A correlation has been attempted of the measured coast


Alum
Hard and
Bituminous Shales
Jet Rock
Grey Shales
Middle Lias
Middle Lias

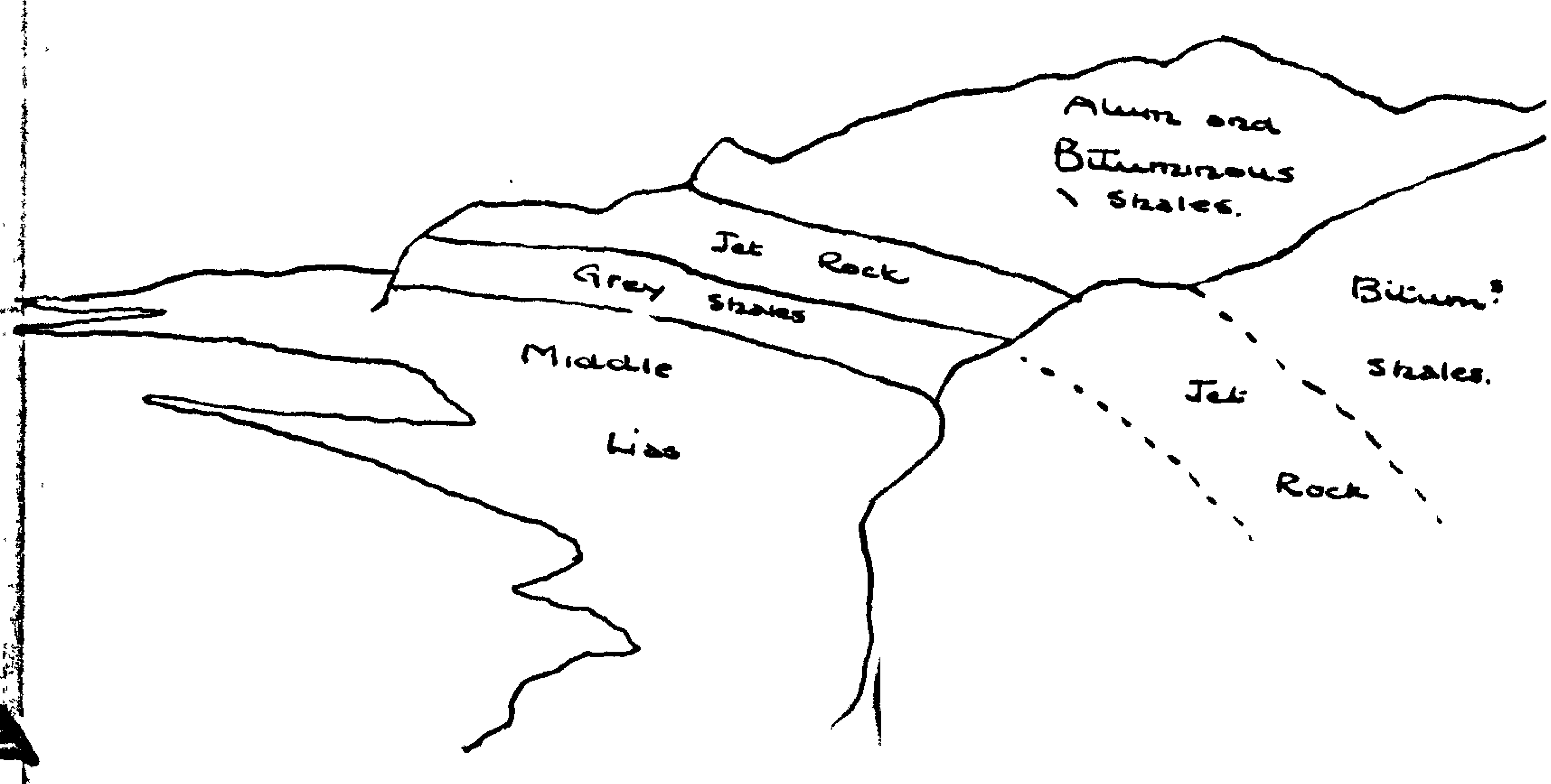

Alum and
Bituminous
Shales.
Jet Rock
Grey Shales
Middle
Lias
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PLATE 11.

1.

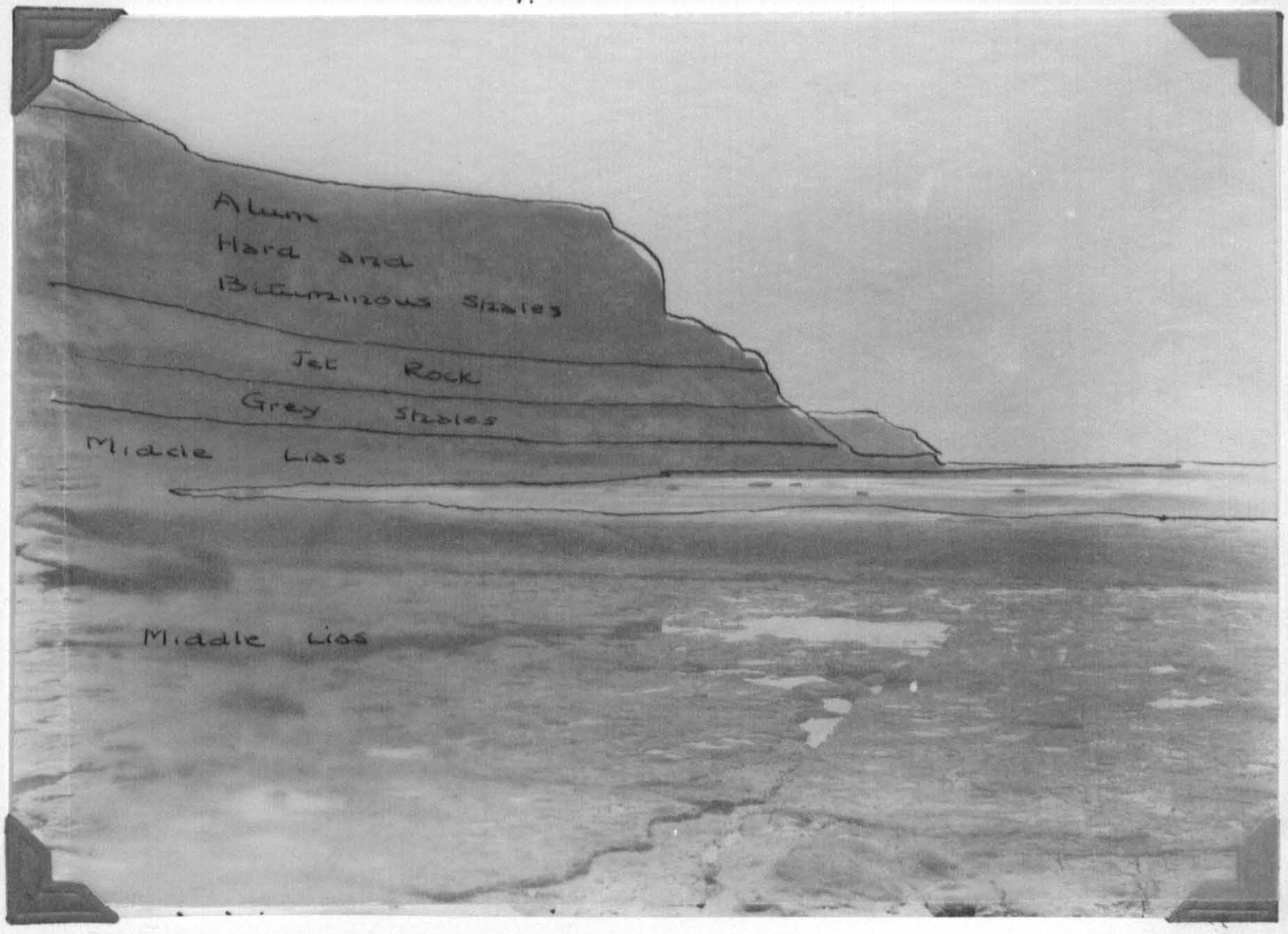
2

Photos: Godfrey Bingley.

1. Hawsker Bottoms.

2. Kettleness and Alum Works.

1.



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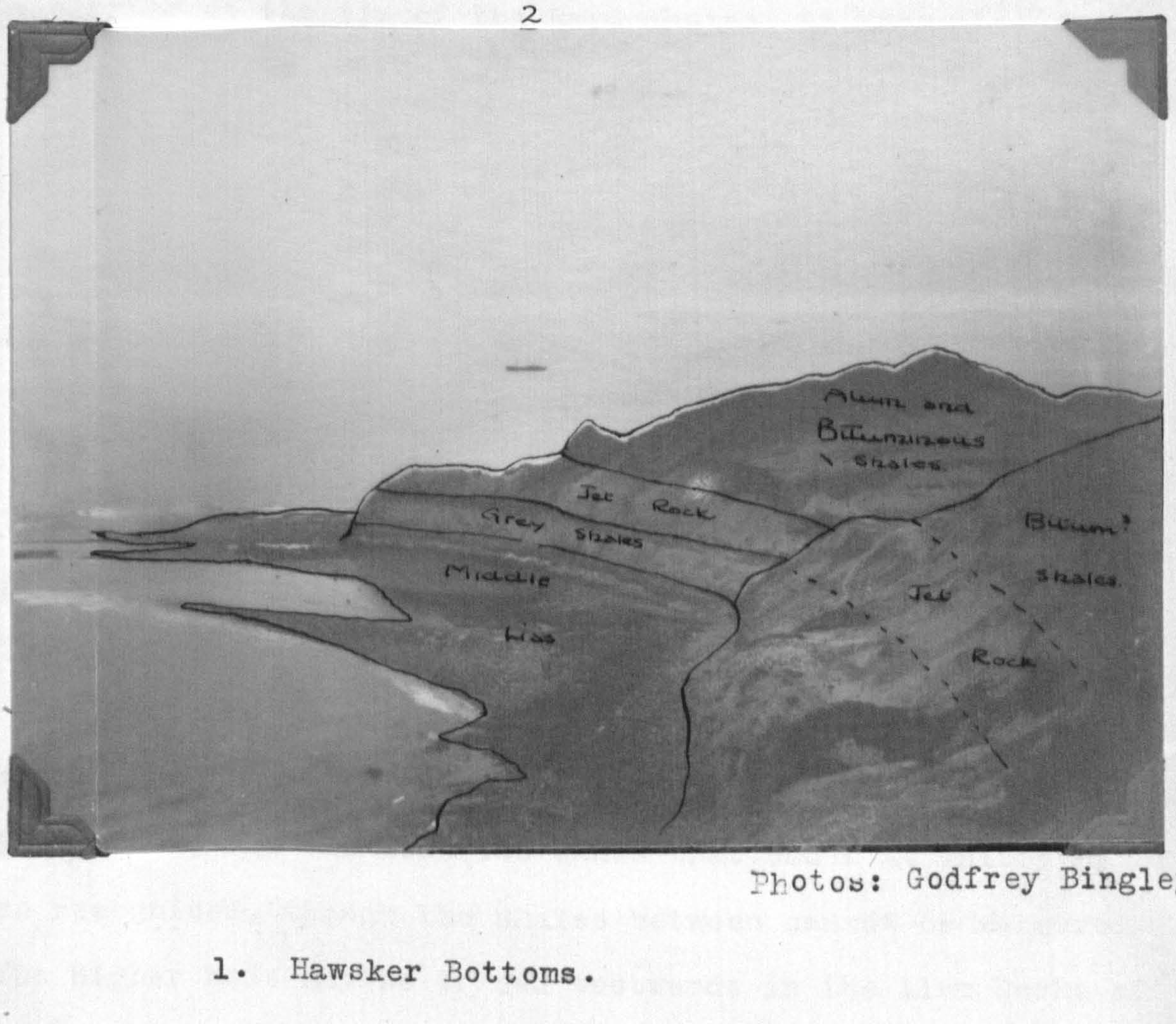


Photos: Godfrey Bingley.

1. Hawsker Bottoms.

2. Kettleness and Alum Works.

sections between Peak and Boulby cliffs. It is admittedly based on lithological grounds and as such is open to criticism. Accurate palaeontological work is, however impossible in the much weatered shales of the Alum Works, and it is only possible to measure the sections and not to examine them in detail.

One horizon, the Ovatus Band, may be recognised in all the sections to the north. At Sandsend large, septariate calcareous nodules occur in the band , and to the north these are increasingly developed, until at Boulby the Ovatus Band is represented by a row of septariate nodules of considerable size, some being 4 feet in diameter, and 10 inches thick.

Bed 8, the thicker bed of siderite mudstone at Whitby, occurring at the top of the Hard Shales, is recognisable in all the coast sections, thickening towards Boulby. At Boulby and at Kettleness however, beds of siderite mudstone, both continuous and broken into isolated masses, as well as rows of pyritous nodules occur which are not represented further south. These beds may be usually traced for a few miles before running out to the south.

The Upper Lias above the Jet Rock does thicken definitely in the direction of Boulby, being here about 175 feet as compared with 160 at Whitby.

The Inland Dales.

Iburndale runs parallel to the coast at a distance of four miles west of Hawsker Bottoms., and here, in a gorge above Littlebeck, all the siderite bands that occur at Whitby may be recognised, though the shales between cannot be measured. The Higher beds may be traced westwards in the Alum Works of Goathland Banks and Sleights, and some, though not all in a vertical exposure of Alum and Hard Shales in West Arnecliff Woods, near Glaisdale. This is also true of an exposure in East Arnecliff Woods. In the exposures in the other inland dales, opening both north and south isolated red 'doggers' may be seen, but no lines of such doggers, or continuous siderite bands such as occur on the coast. This is also true of the exposures along the Cleveland escarpment, from the Alum Works of Guisborough to that at Osmotherley.

This absence of siderite bands is not due to any lack of exposures. At Great Fryup Head rapid denudation maintains an exposure of Alum, Hard and upper Bituminous Shales which show no lithological differences themselves, but no siderite bands occur.

In Westerdale there are many Upper Lias exposures forty and fifty feet high, while in Baysdale Grain Beck runs through a gorge exposing the whole of the Upper Lias.

In Rosedale the shales are excellently exposed in gorges at the head of the dale. In Bransdale Upper Lias sections are found at both the north and south ends of the valley, while the many exposures near the village of Chop Gate in Bilsdale, and the section in its tributary valley Tripsdale, renders the Upper Lias clearly visible.

On the escarpment are the natural exposures at Blue Bell Trough and in the Ingleby re-entrant, where the moorland streams erode quickly when descending the scarp. The alum works at Guisborough, at Carlton and at Osmotherley, expose the Alum, and sometimes the Hard Shales.

In all these localities there is little or no suggestion of siderite mudstones or rows of pyritous mudstones as are found on the coast. Only isolated 'doggers' occur, and these cannot be correlated with beds on the coast. Detailed examination of the above sections renders it apparent that such marked lithological horizons as the siderite mudstones at Whitby, are confined to the coast, and to a belt, perhaps six miles wide, parallel to it.

Slight variation in total thickness of the Alum, Hard and Bituminous Shales may occur throughout Cleveland, but they are certainly are not of a greater order than those of the coast. At Carlton Alum Works the thickness of shale between the Dogger and the Top Jet Dogger is the same as that at Whitby.

To the south however , the thickness of the Upper Lias as a whole decreases. These thicknesses were recorded by Fox-Strangways, and it is not known to what extent each zone or lithological division is represented in these sections. The thickness of the Upper Lias is stated to be 160 feet at Swainby Mines, and 116 feet in a boring at Feliskirk. At Coxwold it is about 100 feet thick, and near here, at Kilburn, the Jet Rock is known to be represented, since Jet Rock shale tips are found although exposures are negligible. Near Crayke the Upper Lias is not more than than 80 feet thick. Much further south, at Sancton it is recorded as 40 feet in a well boring.

Fox-Strangways records a number of small and temporary exposures of Upper Lias between Osmotherley and Market Weighton and some of these have been visited. Opposite the weir at Kirkham Abbey dark shales are exposed which contain Inoceramus dubius. On the south side of the Derwent a section of dark dense shales occurs in Leavening Beck with Inoceramus dubius. Fox-Strangways records 'Ammonites serpentinus' from here. In Painsthorpedale blue-black shales with Inoceramus dubius and an ammonite of falciferum or exaratum form underlying an argillaceous limestone which probably represented the Scarborough Limestone. Blake recorded 'Jet Rock ammonites' from this exposure. It is evident that those shales of the Upper Lias extending far to the south, especially those south of the Derwent, are of exaratum or falciferum age.

(9) THE CONDITIONS OF SEDIMENTATION OF THE UPPER LIAS OF THE YORKSHIRE BASIN.

For the greater part of Jurassic time from the Lower Lias to the Kimeridge Clay, the sedimentation of the Yorkshire Basin was controlled by conditions confined to that basin, and not widespread over the whole of England and North-West Europe. In many ways the Yorkshire Basin developed along lines peculiarly its own, cut off as it was from the remainder of Britain by the submarine ridge of the Market Weighton axis in the south and in all probability, by land on the north and west.

Boundaries of the Basin.

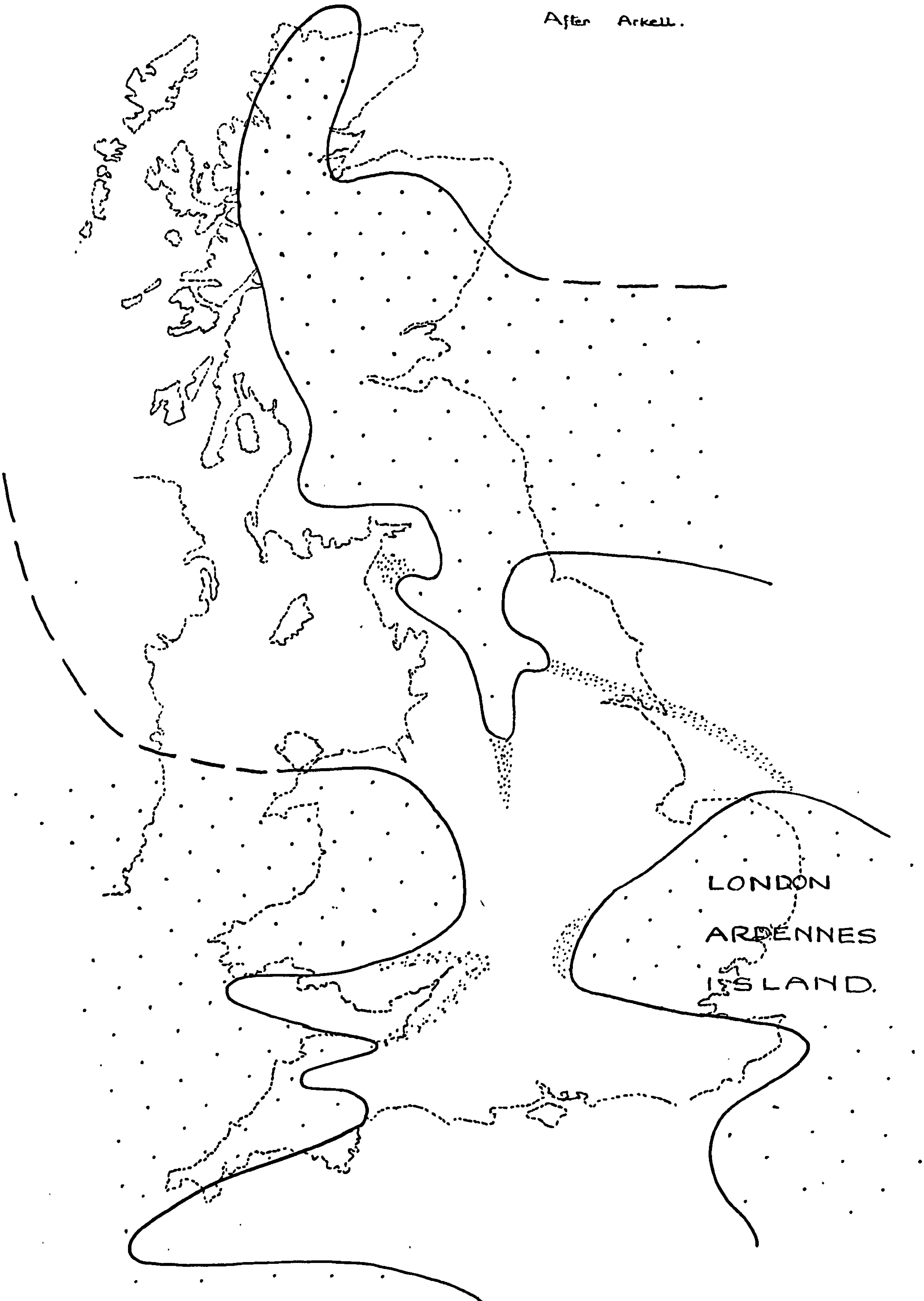
Before the conditions of sedimentation within the Yorkshire Basin during Whitbian times are investigated, it is necessary to consider the relation of the basin to the Liassic sedimentation of North--West Europe. To the west, over much of Ireland and the Irish Sea stood the great continent of North Atlantis, with promentaries of Central Wales, the Dartmoor Highlands and Brittany extending to the east. To the east Fenno-Scandia was a landmass, while to the south and south-east the London-Ardennes Island rose above the Liassic sea. The greater part of Scotland was similarly above sea-level, the Liassic deposits, later preserved by outpourings of basalt, forming round its edge. The south-eastern shore of that island, probably extending in an east-west direction, formed the northern boundary of the Yorkshire Basin.

Whether the Pennines were above sea-level during Jurassic times, so as to form a western boundary to the Yorkshire Basin, is open to doubt. Until recent years the consensus of opinion was that the Jurassic seas spread over the Pennines and the rocks of the Lias and even all the Jurassic, once overspread all northern England and were continuous with those in other parts of the kingdom".[18] Professor Marr came to same conclusion, as did Jukes Brown[33] and Kendall and Wroot.[25] Dr.Arkell in his recent work, summarises the arguments brought forward by these authors, and states "When we come to examine the arguments, we find each of them harbours a fallacy.". He discusses the recent work of Profs. Marr and Jones, Dr. Rastall, Mr. Turner and Messrs. Trotter and Hollingworth on the stratigraphy of the Northern Pennines. Arkell concludes that since some 8000 feet of strata have been removed from the Alston Block between Post-Permian and Early Tertiary times, as a result of its elevation by movement along the surrounding faults, "the amount of movement is so great that it seems likely that it was spread over a very long time - perhaps through the whole of the Jurassic and Lower Cretaceous periods - denudation perhaps keeping pace with elevation as movement continued along the faults.". In his sketch map showing the supposed distribution of land and sea during the deposition of the Lower Lias, Arkell places the Pennine axis above sea-level. If the Pennines were above sea-level in Jurassic times, forming a low promentary extending southwards from the Scottish Island, they would form a western boundary to the Yorkshire Basin, cutting it off from direct communication with that arm of the Jurassic sea which passed northwards along the Western Isles of Scotland.

To the south of the basin the Market Weighton axis formed a boundary against which the Jurassic sediments were banked. The general subsidence of the drowned areas did not everywhere proceed at the same rate. In England they were separated into a number of indivual basins by stable ridges or axes which crossed the submarine areas at intervals. On these ridges sedimentation was slow and interrupted, as on the margins of a land mass, since they had an upward tendency relative to the subsiding seabed. The English Jurassic area was crossed by a number of such axes, of which the Market Weighton Axis is the most regular and the most persistent. It ran W.N.W.-E.S.E.

FIG. 3.

Distribution of land and water in early Whitbian times.
After Arkell.



across South-East Yorkshire, separating the Yorkshire Basin from the remainder of the English trough of deposition throughout the whole of the Jurassic Period.

This ridge although possibly above sea-level for a part of Jurassic time, was probably more frequently below the water. Effective sedimentation along it was uncommon. It is likely that the maintenanceof shallow water conditions above the ridge would prevent the accumulation of any great amount of sediment. If again, the axis was undergoing oscillations of level, it may have been frequently elevated into very shallow water, into the zone of scouring by wave and current action, so that the previously deposited unlithified sediments may have been winnowed away.

The ridge proved an effective southern boundary to the Yorkshire Basin in Liassic timesas well as during the the deposition of succeeding Jurassic formations. The Lower Lias passes over the Market Weighton Axis, though in a much attenuated form. The Middle Lias is absent over the ridge, indicating that the oscillations were of sufficient amplitude to maintain it in very shallow water, or possibly as a low land surface. "The Upper Lias was continuously deposited over the ridge, but greatly reduced in thickness, so that we may safely regard the movement as continued in the same way as in Lower Lias times."[24] Evidence has been brought forward in a previous section which suggests that only the zones of exaratum and falciferum passed over the ridge, and not sediments of all the zones of the Upper Lias as found in Cleveland, even in an attenuated form.

Thus was the Yorkshire Basin, in Liassic times, separated from the rest of the trough of deposition in Britain. This permitted it to develop along its own lines, for conditions of sedimentation to obtain which were not common to the rest of England, and for sediments to be found here which are in many respects peculiar to the Yorkshire Basin.

Conditions of Sedimentation during Upper Lias Times.

The shales, ironstone seams and nodular bands of the Middle Lias were "tranquilly deposited", according to Fox-Strangways in a gulf or somewhat sheltered sea, shallow in the North-West of the Yorkshire Basin, indicating the presence of a shoreline and deeper water to the east, giving rise to the splitting of the ironstone seams and the deposition of a larger amount of argillaceous material. The Grey Shales at the base of the Upper Lias are very similar, both lithologically and palaeontologically to those of the Middle Lias, and were presumably laid down under similsr physical conditions. Liassic conditions are pictured by Wills as "well watered and gently undulating lands teeming with plants and animals, drained by rivers turbid with with mud and sand, and discharging their burden of sediment, organic debris and soluble salts into an open but not very deep sea in which life abounded.".[49] Such conditions obtained during the deposition of the Grey Shales. In certain localities, as at Grosmont, coarser beds were laid down, fine grained argillaceous silts, due to local variations in supply of sediment and in water sufficiently shallow to cause false-bedding on a small scale. This suggests that the seafloor as a whole was shallow and that only a slight variation in supply or position of shorelines would have caused sandstones to be deposited over the whole area.

Conditions of sedimentation changed gradually but fairly rapidly from the deposition of the shallow water Grey Shales to that of the black, sticky muds of the Jet Rock. It has been customary in the past to interpret such black shale deposits as having being laid down in deep enclosed basins of sedimentation under anaerobic conditions, far removed from land.

Large areas of such black muds occur at considerable depths in the Black Sea, as has been proved by the soundings recorded by Andrussov[1] and Archangelski[2], and the conditions at present obtaining in the Black Sea, and particularly the great depth are frequently invoked to explain the deposition of black, fissile, bituminous shale.

Although the Jet Rock and to a less extent the other shales of the Upper Lias show a striking similarity to the sediments of the Black Sea as described and figured by the Russian authors, it is not considered necessary to invoke 'Black Sea conditions' in the full sense of the term, as an explanations of the conditions under which these Upper Lias deposits were laid down. A modification of Black Sea conditions will however, be adopted.

The Black Sea is divided into a number of zones by Andrussov in each of which sediments of definite lithological character accumulate. To a depth of 20 fathoms is a littoral zone of fine sandy detritus. Andrussov also located a grey finegrained micaceoud sand at varying depths. These sands bear a strong resemblence to the silty beds occurring in the Grey Shales at Grosmont.

Andrussov's second zone extending to a depth of 100 fathoms is characterised by a grey-blue sticky mud "often replete with small fragile shells of Modiola." This is described by Archangelski as "almost black in a moist state, the dry mud being grey or light-grey in colour... Not unfrequently the clay shows no traces of stratification, presenting a homogeneous grey mass." Pyrite is present as globules usually about .01 mms. in diameter, either in moderate or in very large quantities. Irregular aggregates of globules also occur, as well as lamellar aggregates. These muds correspond lithologically with the Grey Alum Shales.

The third of the main varieties of Black Sea deep water

This description could be applied with equal truth to the Top Jet Dogger of Yorkshire, and the accompanying photograph in Andrussov's paper has the exact appearance of a thin section of the Top Jet Dogger, except that in the latter case the calcite has recrystallised from the powdery form to coarsely crystalline masses which further distort the argillaceous material. The $CaCO_3$ content of this Black Sea sediment varies from 56.34% to 72.47%, which agrees with the $CaCO_3$ determinations made upon the Top Jet Dogger, from 60% to 70% in three specimens from widely separated localities.

The striking similarity between the sediments of the Black Sea and those of the Upper Lias of Yorkshire, necessitates a brief examination of the physical and bionomic conditions of the Black Sea, before the sedimentational conditions in the Yorkshire Basin during Whitbian times may be postulated. Andrussov describes the Black Sea as follows: Beyond the shallow marginal waters of 100 fathoms depth, there is no bottom-living life (benthos), while in the surficial fresher water down to about 750 feet there is more or less great abundance of floating, usually microscopic open-sea forms (plankton), and the larger free-swimming life (nekton), collectively also spoken of as a pelagic biota. The upper layer of freshened water and its peculiar life conditions are brought about by the enclosed nature of the deep basin, the inflowing of immense quantities of less dense fresh water that remains at the surface or is there evaporated, and the deep-seated, partially compensating current of salt water from the Sea of Marmora through the Strait of Bosphorus.

Because of these differences between the lighter surface and the heavier bottom salt waters, there is no vertical streaming or convection currents beyond 750 feet in depth, and therefore no replenishing of the deeper marine waters with the oxygen that is so necessary for the maintenance of benthonic life. At a depth of 600 feet, hydrogen sulphide begins to form (33ccs. in 100 litres of water) and increases rapidly with the depth to 3,000 feet (570 ccs.) and then more slowly to the seafloor. The formation of H_2S is in the main due to sulphur bacteria. Hand in hand with the increase of H_2S goes the decrease of the sulphates in the seawater ahd the precipitation of the carbonates and iron sulphides.

Similar stagnant conditions described by Sir John Murray,[32] "prevail in several Norwegian 'threshold fjords', or on a smaller scale in the oyster-'polls'." . Here the bottom is thickly covered with organic matter. A slimy black mud is formed swarming with bacteria that produce sulphuretted hydrgen, and which spreads through the water, combining with the oxygen to form sulphates. This causes the oxygen to disappear, when the sulphuretted hydrogen is able to appear free in solution. This gradually spreads upwards, until water devoid of oxygen and rich in free hydrogen sulphide is found at a depth of only 2 metres, as compared with 100 fathoms in the Black Sea.

The Yorkshire Basin in Upper Lias times was much smaller than the present Black Sea. It is therefore to be expected that it was much shallower in depth. The common fossils are those of the nekton (saurians, fishes, Belemnites) and drifted land plants. Of the benthos only a few species of bivalves are common, particularly Inoceramus dubius and Posidonomya bronni, and while the ammonites are also bottom-dwellers and occur commonly as fossils, their empty shells were probably drifted into this sea, in the same manner as Pompeckj suggested the introduction of ammonites into the dark bituminous shales of the Posidonomya bronni zone in Swabia and Franconia.

The most essential requisite for the deposition of black shale is not great depthas has often been assumed, but tranquillity of water. The fine muds of the Black Sea occur at great depths because of the great size of the basin, the storm waves being able to penetrate and aerate the waters down to considerable depths. In the oyster polls the black muds form at depths of a few metres, because of the small area, which does not permit the development of large waves. The depth at which black shales form in all probability varies with the size of the basin in which they are deposited, occurring at greater depths in larger basins where the storm waves are able to penetrate to considerable depth, and in the shallower water in the smaller basins, where the storm waves do not penetrate so far. The Black Sea is an exceptional example of black shales deposition, and according to Schuchert may have no fossil analogue."Depth of water", he states,[39] "is not the first essential for the production of foul bottoms, but it does seem that large areas must have depths of greater than 300 f feet, for otherwise great waves generated by storms would set up vertical circulation and so at least periodically replenish the oxygen and take away the foul gases from the depths." Since the Yorkshire Basin was not a large area, the depth of 300 feet for penetrationof storm waves may be reduced, probably to 200 feet and possibly less. Below this the waters were foul and stagnant, reeking of hydrogen sulphide. The abundance of bivalves, particularly Inoceramus dubius and Posidonomya bronni appear analogous with the Modiola in the grey mud, occurring at depths in the Black Sea from 20 to 100 fathoms. From this therefore, it would appear that the Yorkshire Basin did not exceed a depth of 600 feet at any time during the deposition of the black bituminous shales of the Jet Rock and Bituminous Shales.

Thus from an analogy with the Black Sea, with due modifications because of the smaller size of the Yorkshire Basin, it may be said that the Jet Rock was deposited at a depth of more than 200 feet but not more than 600 feet. The conditions under which it was laid down were similar to those of the Black Sea of today except in depth. Along the shores, in the oxygenated water, there was probably was an abundance of seaweeds which on being broken up by storms, were dragged by currents and the undertow generated by waves and tides, into deeper water where they slowly rotted and were further altered by sulphur bacteria. Hydogen sulphide was formed from the decay of sulphur-bearing proteids, as well as from the decomposition of sulphur granules in the dead cells of the sulphur bacteria, Beggiatoa. As the result of the lack of aeration foul bottoms obtained, free from oxygen and reeking with carbonic acid and sulphuretted hydrogen. The reaction of the iron salts with the hydrogen sulphide caused the formation of iron pyrites, so common in the sediments.

One point however, must not be disregarded in the reconstruction of sedimentational conditions in the Jet Rock and lower Bituminous Shales times. This is the presence of detrital minerals in these shales, coarser in grain and more abundant in distribution than in the grey Alum Shales above or the Grey Shales below. This is not in keeping with the conception that black shales were formed in deeper water, and therefore presumably further from land, than were grey shales. Apparently the development of stagnant conditions in the Yorkshire Basin was with slight orogenic activity in the surrounding land masses, resulting in rejuvenation of the rivers flowing into the basin, and increasing, but only to a small but yet marked degree their carrying power. As a result slightly coarser material was carried by the rivers into the Yorkshire Basin, together with the finely divided mud, causing the foul sediments accumulating on the seafloor to be slightly coarser in texture. This slight rejuvenation of the rivers, bringing coarser silt is not opposed to the idea of the development of stagnant conditions in the sea. While it may have increased the depth of the upper aerated waters to a small degree, it would not materially effectthe waters in the depths of the basin, except to contribute to their sediments minerals of coarser grain.

The very coincidence in the development of stagnant conditions with the slight orogenic activity is itself suggestive. It is not inconceivable that the activity which resulted in slight elevation of the surrounding landmasses was also responsible for the formation of stagnant conditions, by cutting off in a more effective manner, the Yorkshire Basin from the remainder of the Liassic trough of deposition. Of the extension of the basin to the east nothing is knownand it is not impossible that slight earth movement along an unknown axis, in what is now the North Sea, cut off the Yorkshire Basin, limiting its area and permitting the development of anaerobic conditions within it, when such would have been impossible in a larger area of deposition.

On the other hand, it is known that in the zone of Posidonomya bronni in the Upper Lias of Swabia and Franconia, a zone which corresponds with exaratum and falciferum in Yorkshire, similar conditions obtained as have been postulated for Yorkshire. An alternative explanation for the development of black shale deposits in both areas at the same time, is that the orogenic movement which resulted in the coarser beds being deposited in Yorkshire, was also responsible for effectively separating the Swabian-Yorkshire trough from the remainder of the Liassic Sea of North-West Europe. This indeed, appears to be more likely than the former suggestion. This is ind aggeement with Fox-Strangways, who from palaeontological evidence, states that "There is reason to suppose that the

Yorkshire Liassic sea was connected with the North-West-German basin".[14]

About twentyfive feet of black shale were laid down in the Yorkshire Basin as foul black muds when sedimentation underwent a marked change, resulting in the deposition of the calcareous muds of the Top Jet Dogger. Gradual subsidence of the surrounding landmass relative to sealevel caused Cleveland to be further removed from the shoreline. A change in sedimentation took place, calcareous muds being laid down over North-East Yorkshire as the zones of shale deposition moved in the direction of the depressed coastlines. That the subsidence as slow is shown by the change from Jet Rock shale to Top Jet Dogger, which is gradual and never marked. The deepest part of the area was a zone of Armoricanoid trend stretching from Ingleby Greenhow to Peak and beyond. This was almost beyond the range of calcite deposition and the rock formed in this locality was much thinner and poorer in calcite. It is likely that during the deposition of the upper Jet Rock, the Top Jet Dogger and the lower Bituminous Shales, the Yorkshire Basin reached its maximum depth and the Upper Lias sea its maximum areal extent. The Market Weighton Axis was at this time under a greater depth of water than at any subsequent period in the Liassic. The top of the Top Jet Dogger marks a pause in the sedimentation during which time the calcite in the calcareous mud crystallised into the coarse masses in which it is now found.

With the deposition of the Bituminous Shales, sedimentational conditions over Cleveland alnost reverted to those of Jet Rock times. The surrounding coasts were re-elevated and North-East Yorkshire was again invaded by the zone of foul, black mud, the area of deposition of calcareous mud withdrawing to deeper water, probably to the east or south-east of Yorkshire. Clastic sediments were again distributed over the district, but in less abundance and of smaller size than during Jet Rock times.

During the deposition of the higher beds of the Upper Lias, the rivers draining into the Yorkshire Basin increased in sluggishness, with a corresponding decrease in carrying power. The coarser grained detrital material gradually lessened in abundance and in grain size as later beds were laid down. Stagnant conditions continued on the floor of the basin during the deposition of the Bituminous Shales, but as it was slowly filled with some hundreds of feet of soft, finely laminated mud, the floor rose into the zone of water aerated by currents and by storm agitation. The Hard Shales were laid down in water only just sufficiently deep for black shale deposition in this particular basin. By the time of the deposition of the Alum Shales the floor had been built up to a level insufficiently deep for the development of stagnant water and grey shales with no fine lamination were laid down in the shallow aerated sea.

From Bituminous Shale times onward the Yorkshire Basin is pictured as a sea being gradually filled up by fine sediment brought by rivers which were progressively decreasing in their carrying power with the passage of time. It is not suggested that the actual floor of the basin was stationary. The 150 feet of shales above the Jet Rock would represent as soft mud a greater thickness than the depth of the sea at any time during Whitbian times. Subsidence was gradually taking place, but at a slower rate than deposition. As a result the seafloor was gradually built up until in braunianum times the whole of the Yorkshire Basin was an area of shallow, aerated water fed by rivers of extreme sluggishness.

This deposition of muds under gradually changing conditions was interrupted by the laying down of siderite mudstones, both as regular beds and as rows of isolated masses. Five such interruptions occurred at Whitby, with a varying number at localities on the present coastline and a maximum of seven at Kettleness. Some of these beds thin out and disappear to the north-east and the south-west, with the development of other bands at other horizons. All the ironstone beds thin out to extinction to the south-west away from the present coastline.

Harder states[20] that "sedimentary iron carbonate beds are supposed to have been formed by chemical precipitation from iron-bearing waters where oxidation could not take place... The precipitation of iron carbonate probably occurs in shallow lagoons or marshes along the seacoast and is due to the absorption by plants of the excess of CO_2 held in solution." Hallimond also writes "Precipitation of siderite is favoured by rising FeO content and diminishing CO_2 content". He considered that the shallowest waters must contain an amount of CO_2 approximately in equilibriumwith that in the atmosphere, and suggests rather deeper water coupled with reducing conditions.

The distribution of these iron ores suggests a landmass to the North-east, since all these beds thin to extinction away from this direction. The impersistence of most of these beds to the north-west and south-eastmay be due to variation in FeO content in the waters, which depended upon the rivers bringing FeO to the sea in solution. These beds therefore die away in directions away from the mouths of the rivers flowing into the basin.

Genesis of the Concretions.

Rows of pyritous concretions, limey nodules nodules with a skin of iron pyrites, are found throughout the whole of the Upper Lias but are only common in the Bituminous Shales and Jet Rock, being particularly abundant in parts of the latter.

The field evidence already cited, points to penecontemporaneous origin of these concretions and is entirely in agreement with the theory put forward by Tomkieff regarding the genesis of kaolinite-bearing nodules in the Coal Measures, based on chemical evidence.[48] Briefly, Tomkieff's theory is as follows: clay is considered as a disperse system consisting mainly of microscopical and submicroscopical particles of minerals, with their weathering products, as hydrous alumino-silicates os ferro-silicates, mostly in colloidal form. Clay deposited in Coal Measure swamps usually contains a large amount of hydrosols and hydrogels of humic compounds. The pore space in the freshly deposited mud must be very great and was originally filled with solutions rich in organic and inorganic colloids. The presence of bacteria, together with their products of decay, tends to produce different inorganic colloidal solutions as well as colloidal precipitates. The organic colloidal products may exercise a protective action on the newly-formed unstable inorganic colloid. The formation of a globular colloidal state may be considered as two distinct processes going on side by side.

(1) Formation of individual spherites from the sol, and their individual growth.

(2) Aggregation of spherites into larger units.

The aggregative process observed in emulsoids is considered as an incipient stage in concretionary formation. In the first place a finely granular emulsoid is formed, then through aggregation of spherites, the next stage of higher units is reached, which through a still further process of aggregation under favourable conditions continue to grow in size. Certain nodules are known to contain one or more spheroidal nuclei, vestiges of their evolution. The fact that nodules contain so many fossils is regarded as indicatingthat decaying organic matter is a primary cayse of such an aggregation. Thus according to Tomkieff, in a freshly deposited mud, the hydrosols of oxides of calcium, iron, aluminium and silica were gradually segregated in the form of concretions under the protective action of humic acids derived from decaying vegetation. Such nodules were formed subsequent to the deposition of the sediments but prior to their compression and are truly penecontemporaneous.

This theory may be applied with equal truth to the concretions of the Upper Lias. On the stagnant seafloor was abundant vegetation, evidence of which still remains in thin sections, which was decaying and would act as a protective agent round the newly formed inorganic colloids. These large aggregates grew in roughly spherical form, when growing from one nucleus, and accumulated entirely irrespective of the laminations in the soft mud. The bedding planes of the mud passed through the aggregates without interruption. When compression subsequently took place, together with the crystallisation of the inorganic aggregate and lithification of the muds, the nodules were less compressed. The laminations passing through the major horizontal plane of the nodules were undisturbed, but those above and belowwere warped downwards and upwards respectively as traced away from the nodule, since they were compressed more than the nodule. As a result of this, it frequently appears on cursory examination in the field, that the laminations of the shale pass round the nodulesand not through them.

The skin of iron pyrites now occurring round the nodules is probably due to the organic colloidal products which exercised the protective action on the unstable inorganic colloid. Hydrogen sulphide may have been derived from this organic colloid, which in contact with solutions of iron salts would precipitate ferrous sulphide, which would crystallise into iron pyrites.

Some concretions continued to grow for much longer periods than others, attaining dimensions in each direction, of several feet, while some measure only a few inches. In the field the large nodules of the Jet Rock, Bed 20, continued to develop long after rows of nodules at slightly higher horizons had ceased to grow. This is shown in the field by the bending of lines of small concretions round the larger nodules, although they are over a foot apart in vertical section.

III. JET.

(1) J E T .

Jet occurs in all the beds of the Upper Lias from the Jet Rock to the highest Bituminous Shales, but it differs much in quality according to the horizon from which it is obtained. Good jet has been found in the Alum Shale, but the best 'hard' jet of commerce occurs only in the Jet Rock.

Properties of Jet.

Jet has a uniform black colour, the depth of which cannot be surpassed, and is hard,tough and homogeneous in texture, breaking with a conchoidal fracture. The specific gravity varies from 1.14 to 1.25 according to the quality of the jet and the horizon from which it is obtained. Because of its high volatile content, it burns readily and violently with a sooty flame, and was used as a fuel before the jet industry was established. The best jet, which is tough, and dull in fracture, withstanding rough usage without breaking, is termed 'hard' jet by the jet workers and is obtained exclusively from the Jet Rock. 'Soft' jet is most brittle,and bright when fractured, occurring in the Alum and Estuarine Shales.

Field Occurrence.

Hard jet occurs most plentifully in the upper 10 to 15 feet of the Jet Rock, the jet miners usually exploiting the two beds of shale (Beds 19 and 21). Jet always in the plane of the bedding. It is distributed sporadically throughout the shale, the individual masses having no relation to each other either in horizontal on in vertical distribution. No locality is known where the Jet Rock is richer in jet than in any other locality. The occurrence of many worked back fragments of jet in the Sandsend section (Overdale Wyke), is probably due to the better exposure of the Jet Rock here than elsewhere. As far as is known, the horizontal and vertical distribution of Jet in the Jet Rock is entirely fortuitous.

Jet may be divided in its field occurrence into two types, 'stem' or 'plank' jet, and 'cored' jet. These two groups are not mutually exclusive, one type sometimes passing into the other, but are adopted in order to facilitate description.

Stem Jet.

Stem jet occurs in plank-like form in theshales. The cross section is invariably lenticular, the upper surface being of greater curvature than the lower, which frequently approaches the horizontal. The upper surface is by no means regular, ridges and bosses in the jet being frequent in occurrence. The section along the length of the stem is more regular, preserving a uniform thickness along much of the 'plank', but thinning rapidly to the ends, which are usually semicircular in plan. The term 'plank' jet was used by jet miners over a hundred years ago, referring to jet occurring in this form , and it is suggested may be revived, as a suitable descriptive term for this type of jet. It may also be referred to as 'stem' jet, from its similarity to flattened 'stems' or branches of wood.

In some few specimensthe elliptical zones of the compressed annual rings of the wood are strikingly conspicuous in cross sections. These are especially distinctive in a fine specimen from Sleights, which appears to have been naturally etched by ground acids. (Fig.). Such specimens are however extremely rare, jet usually appearing homogeneous when fractured.

Dimensions of Stem Jet.

The sizes of planks of jet vary from small wisps, a mere film in thickness to large masses 10 or 12 feet long, 12 or 18 inches wide and 2 or 3 inches thick. According to Martin Simpson One famous mass was reported to be 20 feet by 6 feet wide and in places 3 inches thick; but masses approaching at all such dimensions are exceedingly rare." Fox-Strangways states "The largest piece of solid jet in one lump ever found is stated to have been 6feet 4 inches in length, 4½ to 5½ inches wide and one and a half thick, weighing eleven pounds and a half." This statement is open to doubt, since Simpson writes "In extracting the jet from the rock, it is generally broken into small pieces, but occasionally some are obtained 3 or 4 feet long by a foot wide",(I.E. broken pieces). Also in the Whitby Museum there is a specimen of jet (No. 674), for many years a show piece in a Whitby shop, which must by unique. It is a stem or plank of jet 39¾ inches long, split longitudinally. It measures 1¼ inches in its thickest part, thinning to the edge of the plank, and is from 2½ to 6 inches in ~~thickness~~ breadth, weighing 5 lbs. 14 ozs. In the original unbroken state it must have been almost as large as the supposed largest piece quoted by Fox-Strangways. In all probability a good average whole piece of jet would be 3 to 4 feet long, 8 to12 inches broad and 1 to 1½ inches thick.

Jet is rarely obtained in such dimensions today, not because of the exhaustion of the supply, but because of the cessation of systematic exploitation of the Jet Rock. The thickest piece of hard jet obtained by the writer was a half inch thick and 5 inches broad. Usually it is thinner, about a quarter inch thick, and 3 to 4 inches broad, and such a stem has been found which was over 6 feet long.

On the upper surface of planks of jet are frequently horizontal striations running along the length of the stem, together with occasional irregular bosses of jet. Impressions of ammonites and Inoceramids are common.

The 'Skin'of Jet.

The outer surface of jet, when removed from the Jet Rock, is contaminated by the contact with the shale and is removed by the jet-worker. Fox-Strangways, using the jet-workers' term, calls this the 'skin', and in so doing gives an erroneous impression, since it is a mere film in thickness and may be ignored except by the jet-worker. He also states that the skin "is blue in the cliffs and brown inland". No justification has been found for this, it being impossible to distinguish Whitby hard jet from any particular locality.

Only on one specimen, out of the many examined has anything been found which may be called a skin. One small stem of jet two inches broad, was found, on taking it from the shale, to have a thin layer of shale firmly adhered to its upper surface. This shale, which was inches thick along the middle of the stem and thinner towards the edge, appeared to form an integral part of the stem and could not be removed without injuring the surface of the jet beneath.

Cored Jet.

Cored jet is distinguished from stem jet by the presence of a silicified core running along the centre of the stem of jet. The core is dark brown in colour, the boundary between it and the skin of jet being sharply defined. The jet is rarely more than one inch thick in any specimen of cored jet, regardless of its size. As a result of the silicified core, the plank of jet is invariably thicker than an average piece of stem jet, and the cross section is more irregular, depending upon the distribution of the silica. Some cross sections are spindle-shaped, but many are lenticular, although much more irregular than corresponding sections of stem jet.

Unfortunately only one poor specimen of cored jet has been found in the field, and the writer has had to rely upon those in the Whitby Museum. These museum specimens are usually labelled "Jet Rock", with the locality, and old jet miners state that this type of jet is met with in the jet mines of the Jet Rock, but is less common than stem jet.

The largest known piece of cored jet is in Whitby Museum, and was again for many years, a show piece in a noted jet shop. The specimen is 28 inches long, 16 inches broad and 6 inches thick, and the skin of hard jet is never more than an inch thick. The outer appearance of this specimen is that of a trunk od wood compressed to one-third of its thickness, with a depression like a stem-base or knot hole from which a branch has forked from the main trunk. Another large specimen of cored jet is in the British Museum (mineralogical Department), and there are many other smaller specimens in the Whitby Museum.

No specimen is known where the siliceous core penetrates to the surface. In all cases the outer skin of jet covers the whole specimen.

(2) THE STRUCTURES OF JET.

Methods of Investigation.

The structures shown by jet have been examined by means of thin sections and etched surfaces. Stem jet and cored jet presented little difficulty in sectioning, being tough and compact, but some of the soft and bastard jets, by reason of the presence of many small cracks, were impregnated by Canada Balsam before sectioning. In the more recently prepared sections the method suggested by Prof. Hickling for the preparation of vitrain sections has been adopted. When a surface has been ground flat by the usual method, it is smoothed and then polished slightly on a cloth stretched over a glass plate. Similarly, when a section is nearing completion, and has been ground thin on a hone, final thinning is completed by polishing on a cloth. The polishing enables the section to be made much thinner than is possible by the use of the hone as a final abrasive, and at the same time produces a really smooth surface. Jet, like vitrain, is a highly refracting substance, so that a slight roughness scatters the transmitted light and obscures the exceedingly fine detail of its microscopic structure. Goddard's Plate Powder has been used as a polishing medium.

For etching plane polished surfaces of jet, Seyler's Solution has been used :- concentrated chromic acid 30 ccs.; concentrated sulphuric acid 10 ccs.; water 5 ccs.. The solution was used boiling and the surface to be etched was immersed in it from one half to two and a half minutes.

Microscopic examination of thin sections and etched surfaces of jet yields abundant evidence of its vegetable origin. Wood structures, invariably crushed and contorted are readily discernible, and no section of jet has been found to be structureless. In the following section these structures are described.

Hard Whitby Jet.

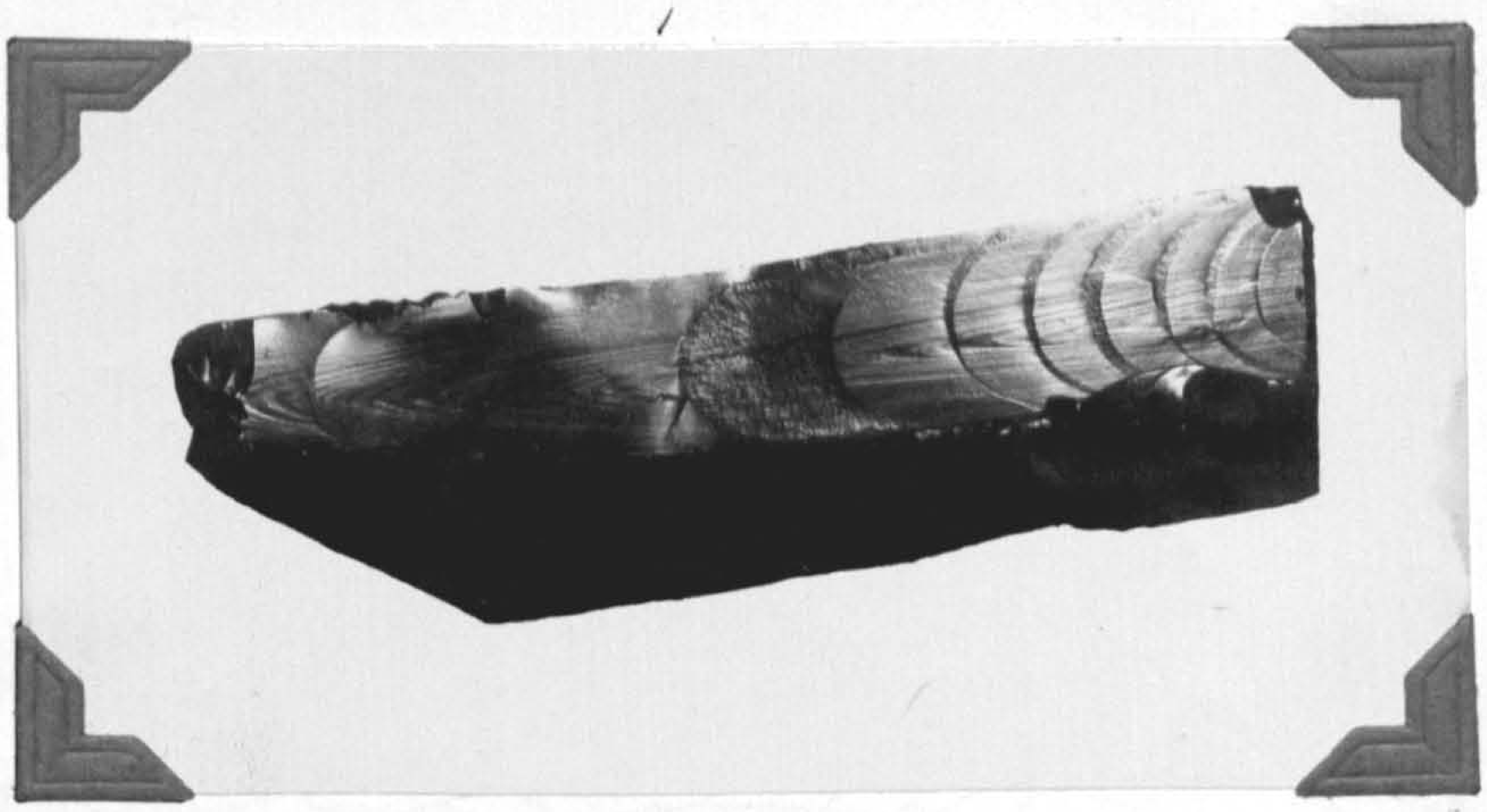
Stem Jet.

In transmitted light through thin sections hard jet is red-brown to golden-brown in colour, according to the thickness of the section. When very thin it is orange yellow, but for most purposes a thickness of jet giving a pale golden-brown colour is suitable.

Thin sections cut across a stem of jet frequently show the annual rings when examined by the naked eye. These are made up of alternate lighter and darker zones compressed into the form of ellipses. Under the microscope these are usually hardly discernible. In some few examples they are visible, particularly the apices of the ellipses. The individual rings stand out as lighter or darker bands of golden brown, but there is nothing to suggest, even under high power magnification that these zones are the annual rings of a tree stem.

Under low power medullary rays are discernible, preserved as short dark brown lines crossing the field in an irregular manner. In the living plant these rays acted as ducts along which the plant foods passed from the centre of the stem towards the outside, and in cross section they radiate from the centre outwards. In some fields the medullary rays are approximately straight, showing only a slight waviness. In other fieldsthey occur as zig-zag lines, buckling and twisting in a highly irregular manner. In such cases the rays are much less well preserved, being broken into shorter lengths which are thrust and folded one part over the other. Under the highest magnification the medullary rays show no evidence of internal structure.

This varying mode of occurrence of the medullary rays in different fields of the same section is the direct result of the compression that the original stem of wood has undergone. The stem, on incorporation in the shales, lay horizontally, 1



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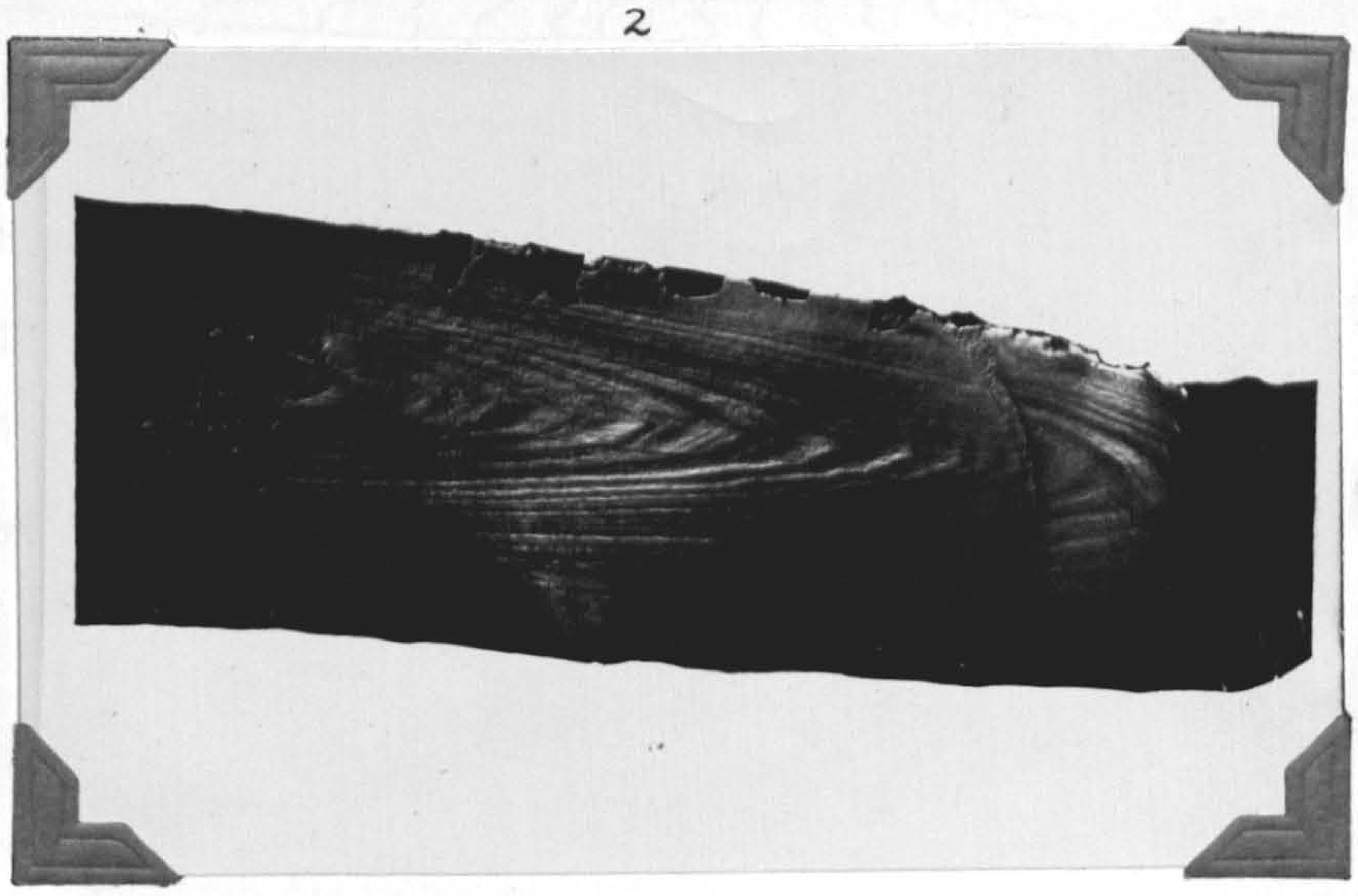

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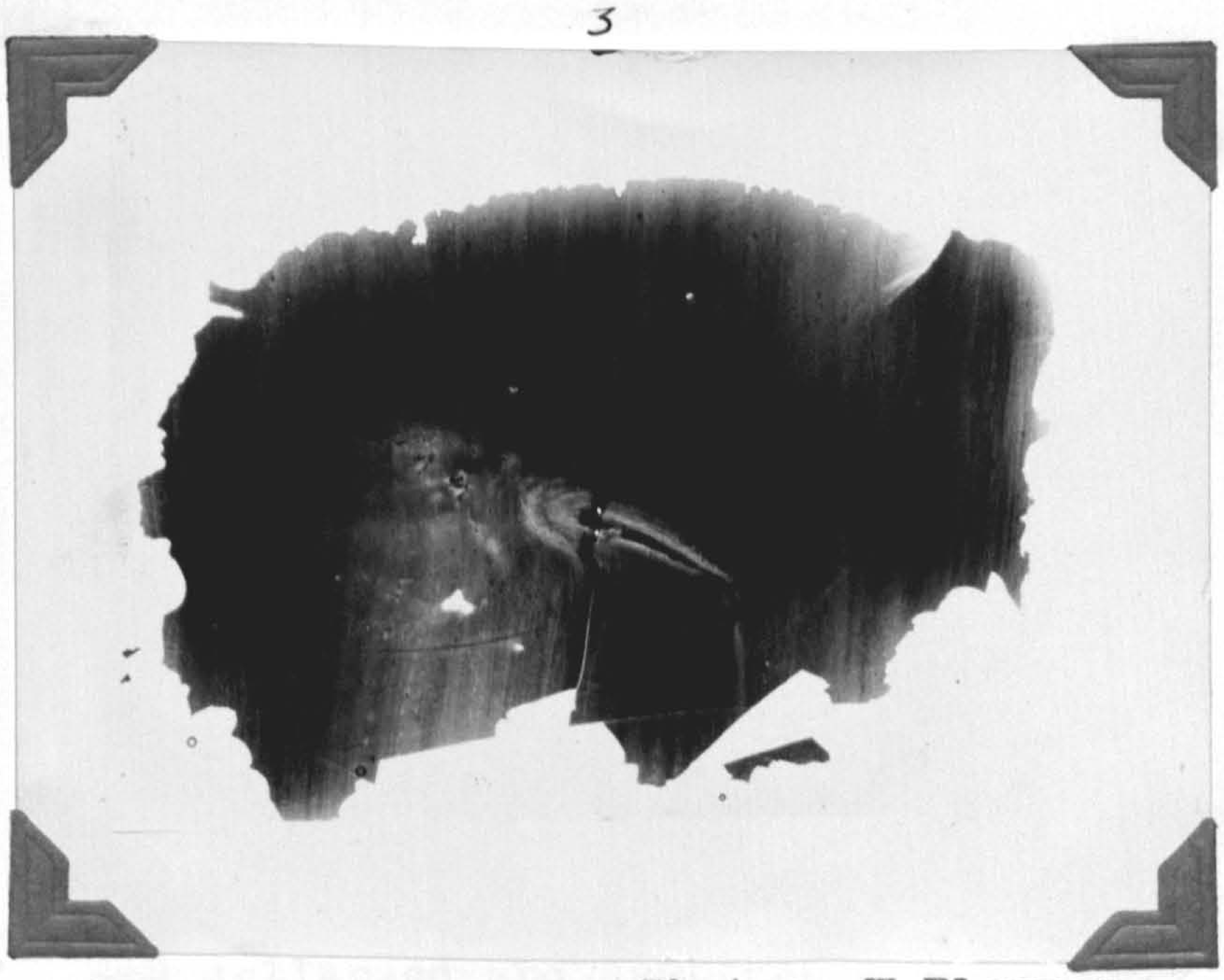


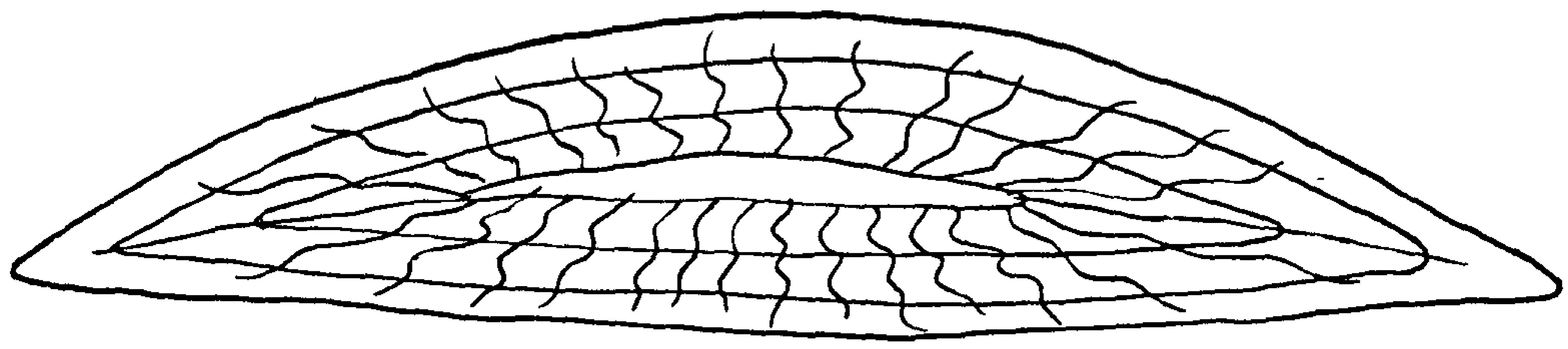
Photos: W.Plowman.

1. Cross-section of stem of jet. $\frac{3}{4}$ natural size.

2. The same. magnification $1\frac{1}{2}$.

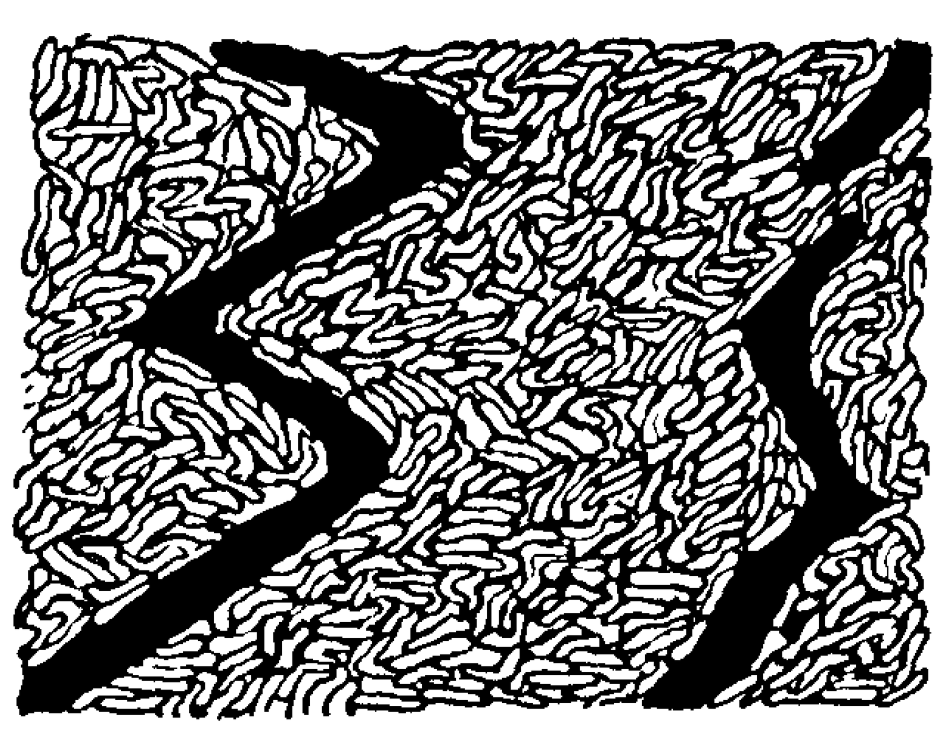
3. Thin section through stem-base or knot in jet. Magnification $2\frac{1}{2}$.

FIG. 4.



Diagrammatic cross section of stem of jet showing compression of annual rings and the varied degree of buckling of the medullary rays in different parts of the stem. Thickness of stem exaggerated.

Bogen-structure.



Arrangement of medullary rays (black) and collapsed and compressed tracheids as seen in cross section of jet.

its long axis in the plane of the bedding. Because of this, it will be seen that some of the medullary rays occupied a vertical position, while some were parallel and others oblique to the plane of lamination of the enclosing sediments. The compression which the stem underwent buckled the vertical rays into a zig-zag form, while those parallel to the bedding, because they were perpendicular to the direction of compression, were only flattened and not unduly disturbed. This is represented in diagrammatic form, showing the course of the rays in all parts of the prostrate stem.

Under low magnification the jet between the medullary rays exhibits no structure, appearing to be homogeneous. Higher magnification shows that this is not so. The zones between the medullary rays are entirely made up of contorted cells, arranged in a strikingly irregular manner. These are cross sections of compressed wood fibres or tracheids. The compressed cells do not form any pattern, but occur contorted and twisted into irregular forms, tightly packed together with no spaces between the individual cells. For a short distance along the middle of some of these cells, a fine dark line may frequently be traced, representing the inner wall of the original wood fibre now compressed to a thin line.

The examination of vitrain and fusain in thin section and by etched surfaces, has revealed a structure similar to this, which has been termed "bogen-structure" by Seyler.[41] In this case however, the cells are not only crushed but fractured. Prof. Hickling in a recent paper,[21] describes the examination of vitrain by etching and states that "the 'bogen-structure', supposed to represent broken cells, is incorrest in the case of vitrain, due to the inability of the etching fluid to bring out the exceedingly fine structure of the inrolled angles of the cells", although "in fusain proper, true 'bogen-structure' with broken cell walls is undoubtedly common". The 'bogen-structure in jet is as described by Hickling in vitrain. The individual cells are telescoped, compressed and much contorted, but the continuity of the cell walls is unbroken.

Owing to the compression of the jet, only two radial planes in each specimen of jet is preserved uncontorted (see diagram), and the cutting of a radial section presented some difficulty. Cross sections of a small piece of stem jet were ground flat and etched. Lines were scratched through the apices of the annual rings, and a section made as nearly as possible to the plane defined by the radial lines of the cross section. The thin sections so made were in no case perfect radial sections over the whole of the slide, but when successful. areas amounting to many microscopic fields in extent were found to be radial, the remainder of the stem being cut in a horizontal tangential direction.

A radial section cuts along the medullary rays of the wood which forms the jet, exposing large sections of the indivual ray along which it is cut. These rays in the jet are made up of rectangular brick-shaped cells, defined by thin orange-yellow lines, and arranged in rows, frequently extending from the centre of the stem almost to the edge and grouped in masses of from four to twenty rows.

It is possible to reconstruct the arrangement of medullary rays in the original wood. They were large walls of brick-shaped cells, one cell thick, up to twenty cells high, arranged radially from the centre of the stem towards the outside edge.

Sections cut haphazardly along the major plane of a plank of jet (i.e.lengthways along it), rarely cut the stem in a radial direction. The greater part, usually all of such sections are along a tangential longitudinal plane. The tracheids or wood fibres are cut along their length, and appear when so secti tioned as long, narrow elliptical cells. The medullary cells of the jet are, in tangential longitudinal section, poorly defined, occurring as rows of up to twenty cells, usually badly preserved and not clearly discernible, being sometimes merely a darker mass among the tracheids.

Since tangential longitudinal sections of jet are the easiest to prepare, it is likely that they were the first to be made by some of the earliest investigators. On cursory examination, such sections appear to have few or no structures which can be related to those of wood, the lines formed by the tracheids, and the darker, often vague areas of medullary rays being all that would be observed. It is therefore suggested that many such statements as "all traces of structure have been obliterated", and others, less sweeping, that jet "contains little or no structure", are due to examination of tangential longitudinal sections only, cross sections and radial sections not being prepared.

Perhaps the most striking evidence of the woody origin of jet is provided by one tangential longitudinal section, which cuts through the 'stem-base' of a twig branching off the main 'stem'. This stem-base, which is 0.3 inches in length, bears marked resemblance to a 'knot' in a section of modern wood. The wood fibres of the main stem swing round the stem-base, which is cut through in an oblique direction. From the centre of the incipient twig, which is unfortunately preserved almost entirely in pyrites, radiate medullary rays, they being the small but independent system of rays of the twig itself, and not related to the rays of the main stem. One field of the core not destroyed by pyrites shows the cells of the core of the twig cut in an oblique direction which is almost longitudinal. These cells are much contorted but appear to be much larger than those of the medullary rays or wood fibres, and are approximately brick-shaped.

Another interesting feature shown in this section is a small lenticular mass of bark, about inch long. Bark has never been recorded from the surface of a specimen of jet, it being stripped off by abrasion and bacterial action before the wood was incorporated in the shales. In this case however, it is probably that the twig either died or was broken off the main stem, while the latter was still living, and bark grew deeply into the knot hole in the manner frequently observed in modern trees. The bacterial decomposition and abrasion that the stem underwent after death and before incorporation in the muds of the Jet Rock, although sufficient to strip off the greater part of the bark, was nevertheless unable to remove the small mass which had grown far into the knot hole, and which was subsequently changed into jet. The bark is slightly darker in colour than the main body of the jet and is entirely structureless, being crossed by a few shrinkage cracks. There was no indication on the surface of the jet of either the stem base or the bark. The cutting of the section through this plane was entirely fortuitous.

Cored Jet.

Microscopic examination of thin sections of cored jet demonstrate even more strikingly than does stem jet, the vegetable origin of this material. In all cases the structures in the hard jet surrounding the silica core are better preserved than in the hard stem jet.

The core, which occupies the central zone for the greater part of the length of a specimen of this type of jet, is made up entirely of silicified wood, as has been noted by Seward. The cells here preserved are very little crushed or contorted while the outer skin of jet shows all the typical collapsed wood structures as has already been described for stem jet.

Cross sections of jet show, in the silicified areas, excellently preserved cells, usually rounded in shape, some being more square than others, arranged in rows apparently radiating from the centre of the branch or trunk of wood. These cells are cross sections of tracheids and the rows are grouped in long bands or zones from two to eight rows wide, each group of rows separated from the next by a medullary ray. In no case are these rays completely silicified. Usually along the central zone of the ray is a line of jet substance which has formed before silicification took place, and before the ray could be preserved in its entirety.

Annual rings, formed of two or three rows of tracheids with thickened walls, cross the medullary rays approximately at right angles.

The silica preserving these wood structures is in the form of quartz, groups of three and four cells, rarely more, being in optical continuity. The silica infilling the cells is colourless but that replacing the cell-walls is pale yellow in colour, due to staining by humic material in the original wood.

The cells of the silicified wood are frequently traversed by lines of jet substance which sometimes swell outinto larger masses, and which cross the rays and the rows of tracheids in an irregular manner. Surrounding each individual mass of jet, between it and the well preserved cells, is a zone of clear quartz in which no cell walls are discernible. It is evident from such examples, which are numerous, that the formation of these small jet patches preceded the silicification of the core. The cells, in the formation of the jet in these areas, collapsed to form a small mass of jet substance, leaving a space which the greater number of the cells had recently occupied. In the silicification of the core, quartz occupied a space between the contracted jet substance and the unattacked cells and crystallised out as clear quartz.

Other examples of the formation of jet which has been arrested by silicification, are in the cell walls themselves. The cell walls are usually preserved in quartz stained yellow by humic solutions, but in these cases they are represented by a brown line of jet substance much thinner than the original cell wall. In such examples it is evident that the wall has been converted into jet, but that it had not collapsed before silicification took place. The cell therefore retains its position in the row of fully silicified tracheids, maintaining approximately its original shape, because of the infilling of quartz, but withtthe cell wall converted into jet substance and shrivelled to a thin brown line.

The thin bands of jet substance to which reference has been made, and which cross the tracheids and rays irregularly, increase in number and thickness on approaching the skin of hard jet surrounding the core. They finally connect together one with another, completely surrounding groups of ten to twenty silicified cells. In such cases the band of clear quartz is no longer visible. The jet formed from more than a half of the cells in this particular zone, collapsed round the groups of unattacked cells which had not been converted into jet, thus leaving no empty space surrounding the jet in which the silica could subsequently crystallise out.

Nearer to the hard jet skin the groups of unattacked silicified cells decrease in number and size, until only one or two cells are in each group, which is surrounded by typical hard jet.

Thus the relation of jet formation to the silicification of the core and the manner in which jet formation proceeded, may be worked out from an examination of cored jet. This will be developed in a later section.

The wood structures shown in the hard jet surroundingthe core are the same as those of stem jet but are better defined. This is due in part to the medullary rays, which are preserved in a brown jet substance, much darker than the corresponding material in stem jet and which causes them to stand out clearly. The rays are also less crushed, being broader and more persistent than the rays in the stem jet.

The crumpled structure of the medullary rays, due to compression, is strikingly clear, the rays maintaining a rough parallelism between the individual contortions. The zones between the rays are again apparently homogeneous under low magnification, but show collapsed, compressed and contorted wood fibres with greater magnification.

The most remarkable feature of the cored jet is the passage of the wood structure from the well preserved silicified core into the jet with the typical crushed structures, proving incontravertibly the woody origin of jet. In favourable microscopic fields, where the 'transition zone' of partly silicified cells and partly jet is narrow, the wood can be traced with great exactitude from the 'core' to the jet. In cross section the medullary rays, preserved in brown jet substance pass through the transition zone into the jet , where they again are dark brown in colour. In the jet they are crumpled and broken, while in the 'core' they are almost straight, differing little from the form in which they grew.

The tracheids on passing across the transition zone lose their rounded form, due to the quartz infilling, and become collapsed, elliptical, arc-shaped masses, the space between the walls being compressed to a thin dark line .

The annual rings present greater difficulties. Although they are well defined in the silicified core and may be traced with ease across the transition zone, in hard jet they are extremely faint under the microscope. Slightly darker bands do cross the rays in the hard jet and may be seen under low magnification, but under higher power no effect id discernible. With the naked eye or with a hand lens however, the results are more conclusive. The annual rings in the core cross the transition zone and may be seen undoubtedly connected with the darker bands, which associated with lighter bands, have been described in stem jet. Because of compression, they are bend out of alignment with the silicified section as soon as the transition zone is crossed, but there is no doubt of the connection. This evidence shows also that the elliptical lighter and darker zones in the stem jet are due to original structural differences in the wood, (I.E.the annual rings), and not to compression, as may be suggested.

Sections of cored jet cut in radial and horizontal directions reveal the same transition from silicified cells to jet.

Radial sections of the silicified wood fibres show their elongated shape, the cell walls being replaced by stained yellow quartz, and infilled with clear quartz. The medullary rays are preserved in jet substance, and occur as rows of brick shaped cells in radial section, and as a row of dark brown cubes in horizontal tangential section.

Within the main mass of silicified core are other smaller areas of calcite. These also preserve small groups of cells but in less perfect detail than does the quartz. In all cases of calcite preservation the cell walls are defined only by lines of jet substance, signifying that the calcite solutions which passed through the wood were only able to follow the cracks where the jet substance had formed from the cell walls and not able to pass through the main body of the wood as did the silica at a subsequent stage.

From an examination of many thin sections of jet, one fact of importance should be noted. In comparitively few cases are the specimens of stem and cored jet formed from one whole trunk or branch of wood. In the majority of cases, particularly in the larger specimens, the jet is formed from part of a log split along the grain previous to its incorporation in the de sediments. This entirely conforms with observations carried out on the shore at Whitby after the heavy flooding of the Esk valley during the summers of 1930 and 1931. Large quantities of wood were brought down by the river Esk, were carried out to sea and by the currents in the bay, were cast upon the shore about a day later. In very many cases the individual pieces of wood, although round in cross section, did not show any whole annual rings. The heavy battering that the wood had undergone had split the logs along shrinkage cracks and the subsequent abrasion in the flood waters, as well as stripping off the bark, had rounded off each individual segment of wood, so that in section it was again round or slightly elliptical.

The ends of the logs of wood also bore remarkable similarity to the ends of stem jet. Although some of the larger logs had been derived from heaps of sawn wood, in no case were the ends angular. Abrasion in the flood had rounded the ends until they were roughly hemispherical. This entirely conforms with the shape of the ends of jet 'seams' which are always semicircular in plan.

Identification of Wood.

Although later investigators agree, in the main, to the vegetable origin of jet, there is no unanimity in the identification of the wood. Prof.Nicol, as early as 1834 considered that the wood may be referred to the genera of Pines and Araucaria.

Prof.Seward in 1901 definitely stated that jet is Araucarian wood, which identification is usually quoted in literature.

In the Whitby Museum are micro-photographs of thin sections of jet, cut by Dr Hallimond. These have been identified by Dr.Hamshaw Thomas as Cedroxylon sp. .

In some few cases, in the wood of the silicified core, bordered pits are visible in the walls of the wood fibres. These are arranged in one row along the tracheid, i.e. they are uniseriate. Bordered pits are also faintly discernible in some cases in the tracheids of the hard jet.

Miss Scott, of the Botanical Department of this University, states that the presence of uniseriate pitting indicates that the wood is not Araucarian, and although unable to identify the wood, suggests it is a high conifer.

It is not unlikely that more than one genus of tree contributed to the wood which was subsequently converted into jet. This branch of the study requires further investigation on the botanical side, when it is probable that several coniferous woods will be identified.

Compression of Jet.

By measuring the perimeter of a specimen of stem jet proved by thin section to be derived from a whole stem of wood, the amount of compression to which the jet has been subjected may be calculated. The thickness of a number of specimens was found to be from 24% to 29% of the original diameter of the uncompressed wood. The stem of wood therefore, in the formation of jet, is compressed to about one quarter of its thickness.

Other British Jets.

Jets occurring at horizons other than the Jet Rock differ in quality from hard jet. Jet has been found at many other horizons in the Upper Lias from the Bituminous Shales to the highest Alum Shales. It has been obtained from the ironstone mines of the Middle Lias of Yorkshire, and has been recorded by Kendall from the Lower Lias of Robin Hood's Bay. Extensive workings at High Normanby near Whitby, and at Cloughton in the shales ~~shhlls~~ of the Middle Estuarine Series testify to the amount of jet found in these beds. A specimen has been collected from the Middle Estuarine plant bed at Gristhorpe Bay, and Young and Bird record jet from the Oxford Clay ar Terrington and Malton.

Fox-Strangways[16] records jet approaching jet in character from Charmouth, Chipping Campden in Gloucester, Barrow-on-Soar and Melton Mowbray in Leicester, while Murchison states that jet occurs in the Lower Lias of Shropshire.[31] In the Upper Lias jet is said to occur near Northampton and Leicester. At Alexton near Leicester "large masses of wood converted into jet are found" which "are used by workmen for whetting razors". Attempts to obtain specimens of this material have failed.

In Scotland jet occurs in Skye at the horizon of Harpoceras aff. exaratum, the same zone as the Jet Rock of Yorkshire.[26] Jet is also recorded[17] from the Middle and Upper Oolite in the gorge of the river Brora, Sutherland, and from the Upper Oolite at Navidale, north of Helmsdale.

Terminology.

Jet from horizons other than the Jet Rock is usually termed 'soft' by the jet workers, being easier to carve but less durable and more liable to crack. Fox-Strangways uses 'bastard' jet as synonymous with 'soft' jet. 'Bastard' however is a term applied to jet which is shattered by small cracks and calcite veins and is absolutely useless for carving.

Most jets from horizons other than the Jet Rock are a bright shining black when freshly fractured in contrast with the dull, deep blackness of hard jet.

Lower Lias.

In the Lower Lias of Robin Hood's Bay no material has been observed which could be referred to as jet. Flattened carbonised logs shattered by calcite and pyrite veins and coated with a thick mass of pyritous mud have been examined, but it was found to be impossible to cut sections thin enough to transmit light satisfactorily. Such material could not be referred to as jet.

Middle Lias.

A specimen obtained from the Dorman Museum, Middlesborough, was found in the shale of the Middle Lias. It is a piece of stem jet $\frac{3}{4}$inches thick and bright in fresh fracture. Under low power magnification it shows no stnucture, being apparently a homogeneous golden brown mass with some iron pyrites. Only under higher magnification are structures visible when crushed tracheids similar to those in hard jet are readily discernible. No medullary rays are present, the entire mass being composed of tracheids compressed and contorted into innumerable forms.

Upper Lias

Exaratum Zone.

A specimen was obtained from the zone of Harpoceras aff. exaratum, the same zone as the Jet Rock of Yorkshire, from a locality in the island of Skye $5\frac{1}{2}$ miles north-north-east of Portree. It is typical stem jet and shows no difference in structure from the stem jet of Whitby. The compressed annual rings occur as lighter and darker zones, and in much of the section the medullary zays stand out clearly as dark brown crumpled lines. Towards the edge however, the rays change in character to ill-defined bands, lighter in colour than the main body of the jet, though crumpled and irregular as they were when dark brown in colour. Under highest magnification the tracheids are preserved exactly as are those in the hard jet. From the evidence provided by microscopic structure it is impossible to distinguish this jet from the hard jet of Whitby.

Falciferum zone.

The quality of jet from the Bituminous Shales is not uniform. One specimen from Peak occurring as stem jet, was bright and rather brittle in fracture. The most interesting feature of this jet was the medullary rays which were preserved as very fine dark lines. These could be traced only with difficulty, frequently fading out altogether for considerable distances, to reappear again as short crumpled lengths. The greater part of these rays had been destroyed and could not be distinguished as definite structures. The tracheids were normal occurring in arc-like irregular forms

Jet such as this differs from hard stem jet in its brighter lustre, its brittleness and the absence of well preserved medullary rays. This jet is found most commonly in the Bituminous Shales although a few specimens have been found in the Jet Rock. It is not true soft jet and may be termed 'bright' jet.

Soft jet also occurs in the Bituminous Shales. A specimen from Sandsend Ness shows the annual rings as dark and light zones, but the compression is markedly less.The ellipses of the rings do not terminate in sharp apices but in gently rounded curves. Under the microscope the differnece between this and hard jet is striking. Small cells preserved in light straw yellow jet substance and in shape rounded, oval and elongated into long irregular lenses occur in large numbers. They are arranged roughly in rows radiating from the centre ofthe stem. In some cases these bodies collect into long yellow lines, which, from their radiation from the centre of the stem , and from the occasional crumpled zig-zag form of the lines, are identified as rays. The distribution of the small yellow bodies is not uniform, but appears to a large extent to be controlled by the annual rings. In the lighter zones of the rings they occur in some abundance, while in the darker bands they are only few in number. The smaller yellow bodies are apparently tracheids which have resisted collapse and compression during the formation of jet and have been infilled with pale yellow jet substance.

Except for the annual rings and the yellow bodies representing medullary rays and tracheids, no other structures were discernible in this jet. The main body of the jet substance was practically structureless, there being only vague suggestions of crushed tracheids in the form of bogen structure.

Alum Shales.

The jets from the Alum Shales, although in the form of stem jet, differ from hard jet by the presence of broad cracks filled with calcite which break up the stem into rectangular blocks. Pyrite is frequently present in such jets, occurring along cracks as well as in the jet substance. Frequently the soft jet from the Alum Shales is enclosed in a mass of pyritous mud up to a half inch in thickness.

Middle Estuarine Series.

A specimen of soft jet was found in the shales of the Middle Estuarine Series, Cloughton Wyke. It occurred in the form of stem jet, being 1.6 inches thick, and was much less crushed than hard jet. Under the microscope only crushed tracheids were discernible and these with difficulty. In one small and isolated band however, uncrushed cells were present arranged in an irregular manner. They were preserved in a lighter coloured jet substance than the remainder of the jet, only the walls being the darker golden brown colour. Apparently this small zone escaped compression, the walls of the cells being converted into the golden brown material, while the cells themselves were infilled with the lighter golden yellow jet substance.

Oxford Clay.

In a specimen from the Whitby Museum labelled "Oxford Clay," Malton", the buckled medullary rays, preserved in a dark brown jet substance were in every way analogous with similar structures in hard jet. The areas between the rays did not show the bogen structure as clearly as the hard jet, some fields being apparently structureless.

Specimens of Yorkshire jet have been collected from the workshops of jet workers, from the beach and from the Whitby Museum, which show structures and preservations of the wood not found in jet obtained in the field. Although it is impossible th state accurately from what horizon these were obtained, nevertheless they merit description. In some cases it is possible from the quality of the jet to suggest the horizon from which it was obtained.

In one specimen of soft jet lenticles and bands of a soft brown woodlike material were found, distributed irregularly in the body of the jet. In thin section the annual rings were easily discernible, occurring as light and dark bands. The soft brown zones proved to be wood, but not preserved in any medium whatsoever. The wood structure was here excellently preserved being in the most part uncrushed and unaltered. In cross section the groups of rows of tracheids were divided from each other by medullary rays, long lenticular cells. The structure cannot be traced into the jet since here the rays are destroyed. The crushed tracheids are very indistinct, many parts of the jet appearing to be structureless.

A bastard jet with a silicified core, probably from the Bituminous or Alum Shales, showed certain differences from hard jet in thin section. Before silicification of the core the wood had been much crushed. As a result of this, a section cut across the specimen included in it areas cut in radial and horizontal tangential directions. All the features of cored hard jet were observed here. The jet surrounding the core was 'soft', and contained the small yellow bodies previously described. As before it is probable that these are isolated uncrushed tracheids or fragments of medullary rays preserved in the pale yellow jet substance.

One fine specimen of soft jet, probably from the Estuarine Series, shows only a very small compression. From it branches a small twig which stands out quite uncrushed. A cross section of the stem shows the core of the incipient twig within the main stem. The centre of the twig is a structureless mass of brown jet substance which is surrounded by a zone of large cells little compressed, but disturbed so that the relation to the surrounding structures is not clear. In the case of the main stem the same arrangement of cells is found, but is less well preserved.

Radiating from the cores of the main stem and of the twig are rows of yellow bodies which group themselves into two classes The larger are the medullary rays, chains of brick-shaped cells filled with the yellow jet substance. The smaller appear to be isolated tracheids which have resisted compression. These usually are found as single isolated cells, but some large areas do occur where both rays and tracheids are slightly crumpled from the original alignment but otherwise uncrushed. In such fields the annual rings are traceable across the rays and rows of cell fibres. Both rays and wood fibres are infilled with the straw yellow jet substance, the walls being preserved in the more typical golden brown material. The similarity between these areas in soft jet, with the uncrushed wodd structures preserved in yellow jet substance, and those in hard cored jet, where they are preserved in quartz, is striking. Except for the differing preserving medium it is impossible to distinguish one from the other.

In the greater part of the section the yellow bodies occur abundantly as small isolated masses within the golden brown jet, the larger bodies, the rays, showing some continuity in the typically zig-zag lines. In the golden brown jet the crushed tracheids are discernible, but only with some difficulty.

The outer zone of this specimen, forming a skin of varying thickness, is entirely free from yellow bodies, and is entirely made up of crushed tracheids, only faintly visible. The transition between the 'jet with yellow bodies' and that without such structures is abrupt and well marked. Apparently, in the outer zone, all the cells both of the rays and the wood fibres, collapsed completely and none were preserved uncompressed in the yellow jet substance.

One specimen of jet from the Whitby Museum is hollow along its core, though from examination of the sides of the space it appears that decayed wood which has resisted preservation in quartz, calcite or jet, has recently occupied it. The jet itself shows distinct 'eeny' structure, but microscopically it is not in any way distinctive. The rays are faintly preserved as dark brown bands, and the wood fibres are clearly discernible showing bogen structure.

Soft jet has been sectioned which shows penecontemporaneous calcite veining. These veins are overfolded and thrust as are the wood structures in the jet, which preserve a rough parallelism with them. Apparently while the jet was still soft, calcite veining took place. During compression these veins were crumpled with the wood structures, and took upon the form in which they ar are now found.

Foreign Jets.

Spanish Jet.

According to Bauer,[4] the localities in Spain where jet is found are confined to Aragon, Galicia and Asturias. In the British Museum a specimen of Spanish jet is labelled "Olés, Asturias". D.S.Calderon[8] mentions Villaverde and Arguero, both in the Villaviciosa districtof Asturias. In Chamber's Encyclopedia[9] jet is stated to occur "in irregular veins in the lower marls of the Cretaceous Series in Spain, corresponding with the Sussex Gault." Repeated attempts to verify these statements have not been successful. Apparently the localities and horizons of the present jet workings are closely guarded secrets.

Spanish jet differs little in the hand specimen from hard Whitby jet. It occurs as stem jet and when fractured is a more brilliant black than is hard jet, and is more brittle. A jet worker states that some Spanish jet is equal in quality to hard Whitby jet, but in general it is poorer, being more likely to fracture. Whether cored jet occurs in the Spanish deposits is unknown. Isolated silicified cells are found in this jet, which suggests that cored jet is found. There is no reasonto suppose that some of the varieties of jet found in Yorkshire, do not occur in Spain.

In thin section the similarity between hard and Spanish jet is striking. The colour of the sections in transmitted light is the same golden brown as in hard jet, the rays being a darker brown. The latter occur as brown lines as in hard jet, both crumpled and almost straight according to the position in the stem, and sometimes slightly thicker and more well defined than others.

The only microscopic difference between hard Whitby jet and Spanish jet is the presence of small brown bodies in the latter. These occur in the bands of crushed wood fibres between the medullary rays and only differ from some of the yellow bodies in soft jet in the colour of the jet substance, straw yellow in soft jet, and dark brown, the same colour as the rays, in Spanish jet. On analogy with soft jet, where it can be proved that the yellow bodies are uncrushed wood fibres, it is suggested that the 'brown bodies' of Spanish jet are also tracheids that have escaped compression and were subsequently infilled with the brown jet substance.

American Jet.

According to Bauer, material equal in quality to Whitby jet is found in the southern part of Colorado. In the British Museum a specimen of American jet is labelled "Vernal, Utah", and a specimen of Utah jet from Whitby Museum has been examined. Prof. Schneider of the University of Utah states in a letter, however , that neither he nor the members of his staff have any knowledge of jet in this State.

Microscopically 'Utah' jet differs little from hard jet. Rays and wood fibres occur inthe same manner as in hard jet, but in radial sectionthe individual brick shaped cells of the rays were shown to be preserved in both a light brown and a dark brown jet substance. Apart from this, no difference was observed.

German and French jets are also known, but it has not been possible to obtain specimens of these materials. The former occurs "in Wurtemberg....under the same conditions as at Whitby, in the Posidonia beds of the Upper Lias, for example at Schomberg, Balingen Boll and many other places in the Swabian Alps". French jet is said to occur in the "Greensand of the Cretaceous formation" as does the Spanish material. The chief locality is the department of Aude, in the province of Languedoc.

The presence of abundant wood structures in all specimens of jet examined demands some revision of a term previously used in literature. Cunningham Craig, writing of recognisable vegetable debris'in true coals and in cannels" states that "it is frequently in what has been called the 'jetonised' state, i.e. resembling jet. The term 'jetonised', so far as I have been able to ascertain, means that the vegetable shape is retained, though no doubt somewhat flattened by pressure, but not the vegetable structures".

Since jet alone can be regarded as the type material in the jetonised state, and since jet can be shown to be made up entirely of vegetable structures, the term jetonised must now refer to such vegetable debris as has retained its shape, though somewhat flattened by pressure, as well as the vegetable structures now collapsed and crumpled.

A term 'jetonisation' has been coined, indicating 'the formation of jet' and will be used for simplification in description in the following pages.

(3) Minerals in Jet.

Only in comparitively few cases are specimens of jet absolutely pure, i.e. made up of jet alone. In many cases lines of minerals, chiefly quartz, occur along cracks and lines of weakness in the jet. Although these have been known to jet workers for a considerable time, who refer to these lines of mineral grains as "spar", they have not been previously recorded except by Simpson in 1855, in "The Fossils of the Yorkshire Lias". In the second edition in 1884 this record was excluded. Simpson states "In a specimen in MR.Ripley's collection, two plates of jet enclose waterworn quartz pebbles and in another jet partially invests an angular fragment of quartz rock." These specimens are now in the Whitby Museum. In the former a number of quartz pebbles occur along the centre of a piece of jet, which now bends round them. In the latter a subangular pebble of quartzite 2 inches long has apparently been wedged in a crack or in the partly rotted core of the original wood and carried from the old land surface to the Upper Lias sea. A second smaller pebble of quartzite has been found incorporated in a stem of jet obtained from a jet-worker's shop. In all three cases the pebbles were embedded in good hard jet which in all probability was derived from the Jet Rock. These examples are, however outstanding. The quartz usually occurs as a fine sand and has frequently been found in what has been thought to be 'clean' hard jet.

The minerals occurring in the jet are almost entirely quartz. Only three other grains are known. In a specimen of hard jet from the Jet Rock was found a small zoned pyroxene, while in another from the base of the Bituminous Shales at Sandsend Ness was found a small zircon. In the jet from Skye was found a fine grain of microcline.

These minerals are always arranged in rows, either along cracks or lines of weakness in the jet. The latter are the cracks of the original wood as is indicated by the slight interruption and discontinuity of the wood structures crossing them, they being invariably 'thrown' slightly. The cracks in the jet are cracks that were closed during jetonisation and which opened again in the making of the slide. The tracheids bend round each individual mineral grain, being displaced from their general direction by them. The tracheids are wrapped round the grains in a manner similar to mica flakes round 'augen' in gneiss. There is no interruption nor dislocation of structure in the vicinity of the minerals, except at the cracks, already mentioned. They show a varying amount of bending but no structures are destroyed, nor has any silicification of the jet taken place.

The minerals vary in size from 0.4 inches in diameter, in the case of those mentioned by Simpson, to those only seen under high power magnification. Many, but not all of the quartzes show marked strain shadows and some contain lines of included minerals. Although these lines of inclusions are plainly discernible, the individual minerals are too small for identification.

The presence of included minerals within the grains proves incontrovertibly that the quartzes are of allogenic origin, and not masses of quartz introduced at the time of silicification of the core, which have crystallised into single grains without replacing any cells.

When not entirely isolated within the jet, the quartz grains are associated with pyrites and shaly material rich in organic matter. This is well shown in the specimen with the large quartzite pebble, the crack in which it was wedged also containing small quartz grains and organically rich shale.

(4) CHEMICAL ANALYSES OF JET.

Analyses of Whitby jet were made in 1908 ar Zurich under the direction of Prof.Constam and were recorded by Speilman.[46] Three analyses were made of the one sample of Whitby jet and compared with analyses of cannel coal from the Ruhr and from Wigan. The calorific value of jet and cannel coal were also compared, and from the results Speilman concluded that "jet must be classed with cannel coal rather than lignite" and that Jet is far removed from bitumen as compared with cannel coal."

A summary of these analyses is as follows:-

Proximate Analysis.	Jet.	Ruhr Cannel.
Volatile matter.	74.62	43.59
Moisture.	2.12	0.73
Ash.	0.47	5.50
Fixed carbon.	22.79	50.18

Ultimate Analysis.

Dry, ash-free sample.

	Jet.	Ruhr Cannel.	Wigan Cannel.
Carbon.	83.81	86.85	85.20
Hydogen.	7.57	6.69	6.07
Oxygen.	6.25	4.35	
Nitrogen.	1.06	1.28	8.58
Sulphur.	1.31	0.80	
Calorific value	9084	9194	

Speilman writes""The differance in the amount of fixed carbon is not surprising since jet and cannel coal have been formed ar different geological periods, probably from very different woods and certainly under different conditions".

The calorific value of lignite is 5500 calories and for +

Something missing here

Chemical analyses of jet have been carried out by the writer under the direction of the Coal Survey Department in this University, with a view to determing in what way the various qualities of jet differ from one another. The standard methods for the analysis of coal were employed. The result are appended below.

Best Whitby Hard Jet.

Proximate Analysis.	Airdried Jet.
Moisture.	1.9
Volatile matter (less moisture).	74.7
Fixed carbon.	22.8
Ash.	0.6

Volatile matter (dry, ash-free sample) 77.6

Ultimate Analysis.	Dry Jet.	Dry, ash-free jet.
Ash	0.6	--
Carbon	83.9	84.49
Hydrogen	7.5	7.5
Nitrogen	1.0	1.0
Difference (Oxygen, Sulphur and errors)	7.0	7.1

Specific Gravity 1.14

Hard Whitby Jet.

Proximate Analysis	Airdried Jet
Moisture	1.8
Volatile matter (less moisture)	73.7
"Fixed carbon"	23.4
Ash	1.1
Volatile matter (dry, ash-free sample)	75.9

Ultimate Analysis	Dry Jet.	Dry, Ash-free Jet.
Ash	1.1	---
Carbon	83.5	84.5
Hydrogen	7.4	7.4
Nitrogen	110	1.0
Difference (Oxygen, Sulphur and errors)	7.0	7.1

Specific Gravity 1.14

Bright Jet, Bituminous Shales, Sandsend Ness.

Proximate Analysis.	Airdried Jet.
Moisture	1.4
Volatile matter (less moisture)	69.4
"Fixed carbon"	26.6
Ash	2.6
Volatile matter (dry, ash-free sample)	72.3

Ultimate Analysis.	Dry Jet.	Dry, Ash-free Jet.
Ash	2.7	---
Carbon	80.7	82.8
Hydrogen	7.2	7.4
Nitrogen	1.1	1.2
Difference (Oxygen, Sulphur and errors)	8.3	8.6

Specific Gravity 1.16

Middle Lias Jet.

Proximate Analysis.	Airdried Jet.
Moisture	2.0
Volatile matter (less moisture)	60.6
"Fixed carbon"	34.4
Ash	3.0
Volatile matter (dry, ash-free sample	63.8

Ultimate Analysis	Dry Jet	Dry, ash-free jet.
Ash Ash	3.1	---
Carbon	81.6	84.2
Hydrogen	6.4	6.6
Nitrogen	1.1	1.2
Difference (Oxygen, Sulphur and errors)	7.8	8.0

Specific Gravity 1.20

Spanish Jet.

Proximate Analysis.	Airdried Jet.
Moisture	3.1
Volatile matter (less moisture)	56.4
"Fixed carbon"	39.2
Ash	1.3
Volatile matter (dry, ash-free sample)	59.0

Ultimate Analysis.	Dry Jet.	Dry, ash-free jet.
Ash	1.3	---
Carbon	82.7	83.8
Hydrogen	5.9	5.9
Nitrogen	0.8	0.8
Difference (Oxygen, Sulphur and errors)	9.3	9.5

Specific Gravity 1.23

Soft Jet, Middle Estuarine Shales, Cloghton Wyke.

Proximate Analysis.	Airdried Jet.
Moisture	6.1
Volatile matter (less moisture)	51.5
"Fixed carbon"	41.3
Ash	1.1
Volatile matter (dry, ash-free sample)	55.5

Ultimate Analysis.	Dry Jet.	Dry, Ash-free Jet.
Ash	1.1	---
Carbon	82.8	83.8
Hydrogen	5.9	6.0
Nitrogen	1.0	1.0
Difference (Oxygen, Sulphur and errors)	9.2	9.2

Specific Gravity 1.24

Bastard Jet.

Proximate Analysis.	Airdried Jet.
Moisture	2.1
Volatile Matter (less moisture)	61.8
"Fixed carbon"	32.4
Ash	3.7
Volatile matter (dry, ash-free sample)	65.6

Ultimate Analysis.	Dry Jet.	Dry, Ash-free Jet.
Ash	3.8	---
Carbon	79.5	82.7
Hydrogen	6.6	6.8
Nitrogen	1.1	1.2
Difference (Oxygen, Sulphur and errors)	9.0	9.3

Specific Gravity 1.23

In these analyses certain features are especially striking. The ash content is invariably low, being only 0.6% in the best hard jet. This is to be expected since jet is formed from indivual pieces of wood, and contains only the inherent ash of the wood. In the samples of high ash content, bastard jet and Middle Lias jet particularly, mineral matter could be seen by the naked eye on the faces of the innumerable small cracks, which would account for the relatively high ash content.

The volatile matter is very high, especially in the cases of the hard jets, and was always driven off very rapidly in the first 30 seconds of the heating. In all samples the resulting coke was black, lustrous, cellular and very friable. All cokes were highly swollen, the ratio of volumes of coke mass to jet mass before combustion was 9:1 in the hard jets; 8 : 1 in the case of bright jet, with lower ratios in the remaining samples.

The dry, ash-free analyses of jet bear some resemblence to those of vitrain, in that in both cases the ash content is low and the carbon content high. The hydrogen content of vitrain however, is lower than that of jet, the nitrogen is higher and the volatile matter much less.

Statistical Analysis.

Professor Hickling has examined many thousands of analyses of fossil fuels of all types including peats, lignites, bituminous coals and anthracites by plotting graphs of their composition[22] The method adopted is as follows: only three organic constituents of coal are considered to be of primary imptortance, carbon, oxygen and hydrogen. Graphs were prepared in which the composition of each coal (calculated free from ash, moisture and sulphur) is represented by a point, of which one co-ordinate represents the content of carbon and the other, oxygen. This point is in effect a nearly complete indication of the organic constitution of the coal., since the position of the coal shows by difference the amount of the remaining constituents.

From such an examination, Hickling concluded that "all types of fossil vegetation from peat to the highest grade of anthracite, forms a continuous series as regards their ultimate composition....The conclusion appears irresistible that all these substances (peat, lignites, bituminous coals and anthracites) have been derived from the same general type of material altered to varying degrees, but always in the same direction."

In a similar way to that adopted by Hickling, the seven jet analyses were plotted on graphs. Owing to laboratory difficulties it had been impossible to estimate the sulphur content of the jets, but and estimate of 1% was used, based on Speiman's analyses. The sulphur content is not likely to show marked variation in the various samples and does not materially affect the result.

Such graphs bring out certain definite relations in the jet. As is expected, the two hard jet analyses agree closely. Spanish jet and soft jet are closely related, as are bright and bastard jet. The latter agreement is also expected, the difference between them being only the presence of fine cracks in the bastard jet.

When included in Hickling's curves, all the jets fall between the analyses of bituminous coals and antracite, the hard jet being nearest to the anthracitic end of the 'coal Belt', bright and bastard nearest to the bituminous coal section, closely followed by Spanish and Estuarine jets, with Middle Lias jet midway between them and the anthracitic hard jet.

If Hickling's is made to apply to jet, and there seems to be no reason why it should not, hard jet has been most altered, while the other jets have been changed to a smaller degree. This however, is entirely in opposition to the microscopic evidence, which shows that hard jet contains the best preserved wood structures, those in the bright, soft, and bastard jets being less well preserved, and sometimes even unrecognisible. On these grounds it is impossible to accept a modification of Prof.Hickling's progressive change theory of coal formation, applied to the formation of jet.

(5) JETONISATION.

It is now possible to trace with some exactitude, the stages through which the wood has passed in the process of jetonisation. It grew in the form of trees, probably the higher conifers, which grew to an unknown but not inconsiderable size, and which lived on an old land surface. On death these trees fell to the ground where they dried and cracked and probably slight anaerobic decomposition took place. Into the cracks grains and pebbles of minerals and rocks occurring in the immediate vicinity, became wedged. Since these trees grew on dry land, and since they were jetonised before great aerobic decomposition had occurred, it is likely that they were carried to the Upper Lias sea by flood waters of nearby rivers, when much of the dead timber from the lowlying forests was cleared away. The trees so removed suffered considerably from the violent action of the flood waters; they were split along old shrinkage cracks, the bark was stripped off and the individual pieces of wood were rounded by abrasion and violent contact with other objects and with the banks of the river. The presence of mineral grains in the jet may also be explained by the trees lodging on a sandspit during an early part of their journey to the sea and so incorporating minerals from other places as well as the site where the trees grew. The wood eventually reached the open water of the Yorkshire Basin, where it floated until waterlogged, when it sank on to the sticky black muds of the floor of the Jet Rock sea.

Jetonisation now set in, the wood decomposing from the outer surface towards the centre of each individual log. During this process the wood fibres and rays were softened, the lignin being removed, and with continued accumulation of mud above the wood, collapse of the cells was an immediate consequence. Jetonisation did not procede regularly from the outside inwards.

The medullary rays, because of their radial arrangement in the wood were more readily attacked; isolated stringers' of jetonised material also passed into the unaltered wood in an irregular manner. Jetonisation therefore, gradually but not regularly proceeded from the outside inwards, until in most cases the wood was entirely converted into jet. The manner in which the wood was attacked is shown in the arrested jetonisation in the cored ejt. Such allogenic matter as was present in the original woodinterfered with the collapse of the wood structures, which were bent round the individual mineral grains.

In the case of cored jet however, jetonisation was incomplete when silicification took place. In the core the cellwalls were replaced by quartz which was stained yellow by humic matter while the cells themselves were infilled by pure, clear quartz. At the edge of the advancing zone of jetonisation, silica replaced those cells not converted into jet, with the formation of what has been called the 'transition zone'. Wherever jetonisation has only affected a group of a few cells, which has contracted to form a small mass of jet, the whole space was filled-in by quartz, now in optical continuity.

The replacing silica crystallised before any great thickness of mud was deposited above it, for apart from a slight waviness in the medullary rays and the rows of wood fibres in the silicified wood, no dislocation nor crumpling of structure occurs.

A considerable thickness of mud was laid down above the log, before the jetonised wood hardened, because the structures, prevously pulpy and collapsed due to jetonisation, were compressed to the maximum degree. Thus the process of jetonisation was penecontemporaneous with the deposition of the sediments around it. It started soon after the log settled to the seafloor and was protracted over a not inconsiderable period, during which some thickness of mud accumulated over the changing stem.

The replacing silica must have been derived from the water of the Jet Rock sea. According to Murray and Irving,[33] seawater contains from 1 part in 220,000 to 1part in 460,000 of silica. Such a source appears to be too small to account for the silicifation of the Upper Lias wood. Clarke however, states[10] that from a comparison of the analyses of river waters, "waters relatively high in organic matter are likely to be high in silica also. From this it has been inferred that the organic matter holds the silica in solution, although the connection between the two is not invariable. The humus acids, however, are almost insoluble in water alone, but readily soluble in alkaline solutions. It appears possible that the alleged relation between humus and silica is purely coincidental and that the alkalies are the really effective solvents. There is no proof that they dissolve silica when alkalies are absent. As colloids they are most likely to precipitate silica than to bring it into solution."

The floor of the Jet Rock sea, rich in decomposing vegetable matter, probably resulted in the deeper parts of thessea becoming relatively enriched in silica. The silica rich solutions passed through the masses of collapsed, jetonised cells surrounding the core of unattacked wood and replaced that core in silica, because of the surrouning colloidal jet substance. This also happened within spore cases in the shales, while in some examples silica was precipitated as chalcedonic masses, without any apparent influence of humic matter.

Of the actual process of jetonisation very little can be said. Apparently both the lignin and the cellulose of the original wood were destroyed, and the structures of the wood collapsed, forming a soft pulpy mass. Shells falling to the seafloor left their impressions on the softened wood, and in some cases guards of belemnites penetrated the wood undergoing or that put forward by Prof.Hickling appear to be applicable to jetonisation in its varied forms.

Whitby jet is a wood that has undergone a peculisr decomposition which has resulted in a unique product. Until further work has been done on the sedimentational conditions under which foreign deposits containing jet have been laid down, little more than suggestions can be put forward as to the reason why the Whitby material is unique. Beds of black shale are known in every geological formation and in many parts of the world and the Jet Rock appears to differ little from other black shales the wood from which jet is derived has a wide geological and geographical range. Limestones occur in many localities interbedded in black shales, so that the suggestion that the deposition of the Top Jet Dogger may have had a modifying influence on the decomposition of the wood in the shales below does not appear to be tenable. The only conclusion that can be made is that a combination of stagnant 'Black Sea' conditions abundant supply of waterlogged timber, and perhaps the deposition of a calcareous mud sealing the deposit and causing an unusual decomposition below, resulted in the formation of that unique material which is peculiar to the Yorkshire Basin, Whitby jet.

Microphotographs of Thin Sections of Jet.

Magnification 20.

Plate 13.

Spanish Jet.

1. Cross section showing crumpled medullary rays.
2. Cross section showing rays compressed but not crumpled.
3. Crumpling with greater compression.
4. Disturbed rays due to proximity of twig.

Soft Jet.

5. Twig base or knot within main stem. Structureless pith surrounded by large cells.
6. Medullary rays and tracheids infilled with straw yellow jet substance.

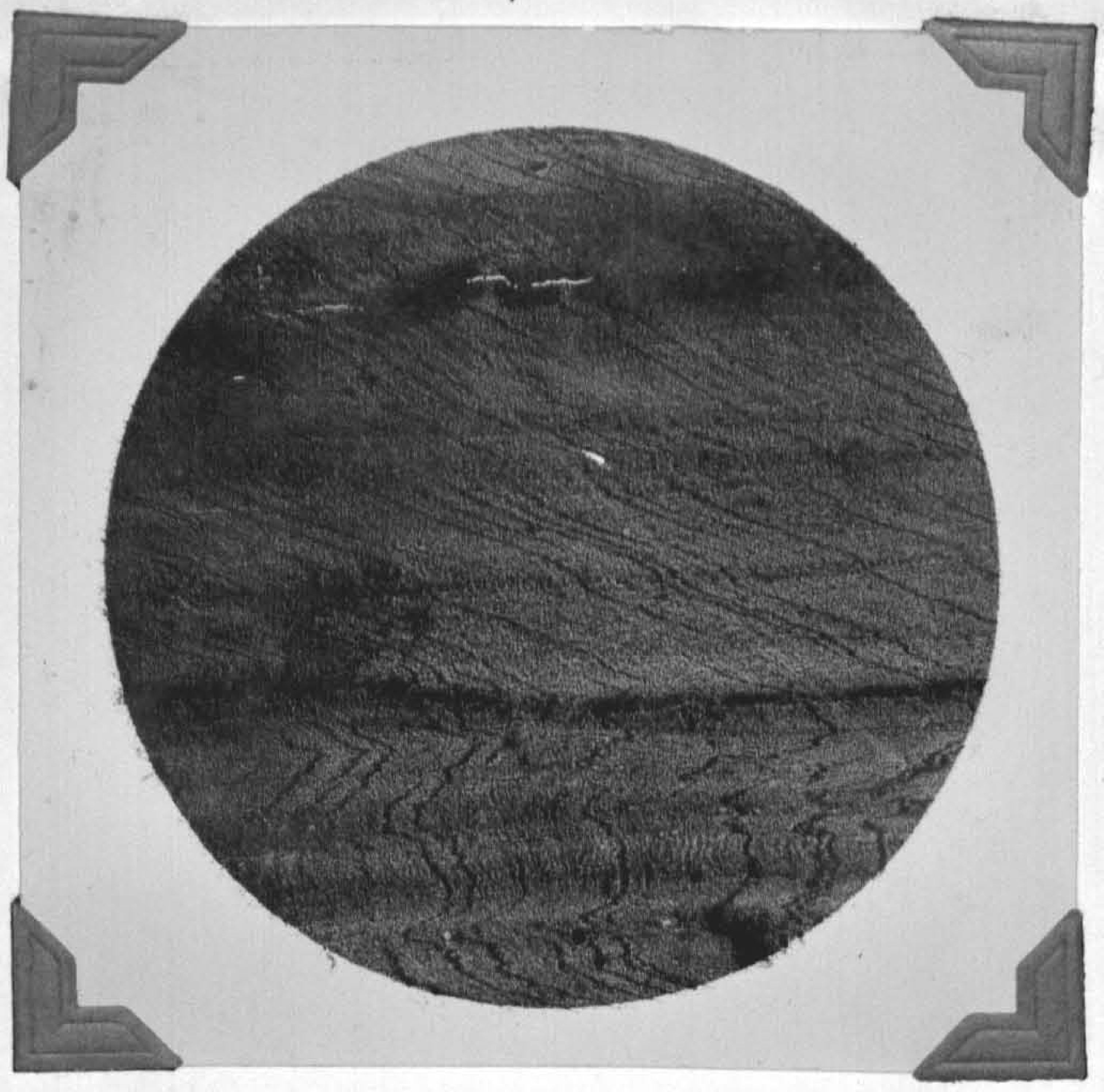
Plate 14.

Hard Jet.

7. Cross section showing crumpled rays with collapsed tracheids.
8. Cross section with compressed annular rings and rays.
9. Radial section. Chains of medullary rays, some of which have contracted into arc-like forms.
10. Cored jet, showing transition between the silicified wood (light-coloured), and jet (dark-coloured).
11. Cored jet, tangential longitudinal section. Hard jet in contact with part of the 'transition zone'.
12. Hard jet with quartz pebbles. Note bending of rays round individual grains.

PLATE 13.

1



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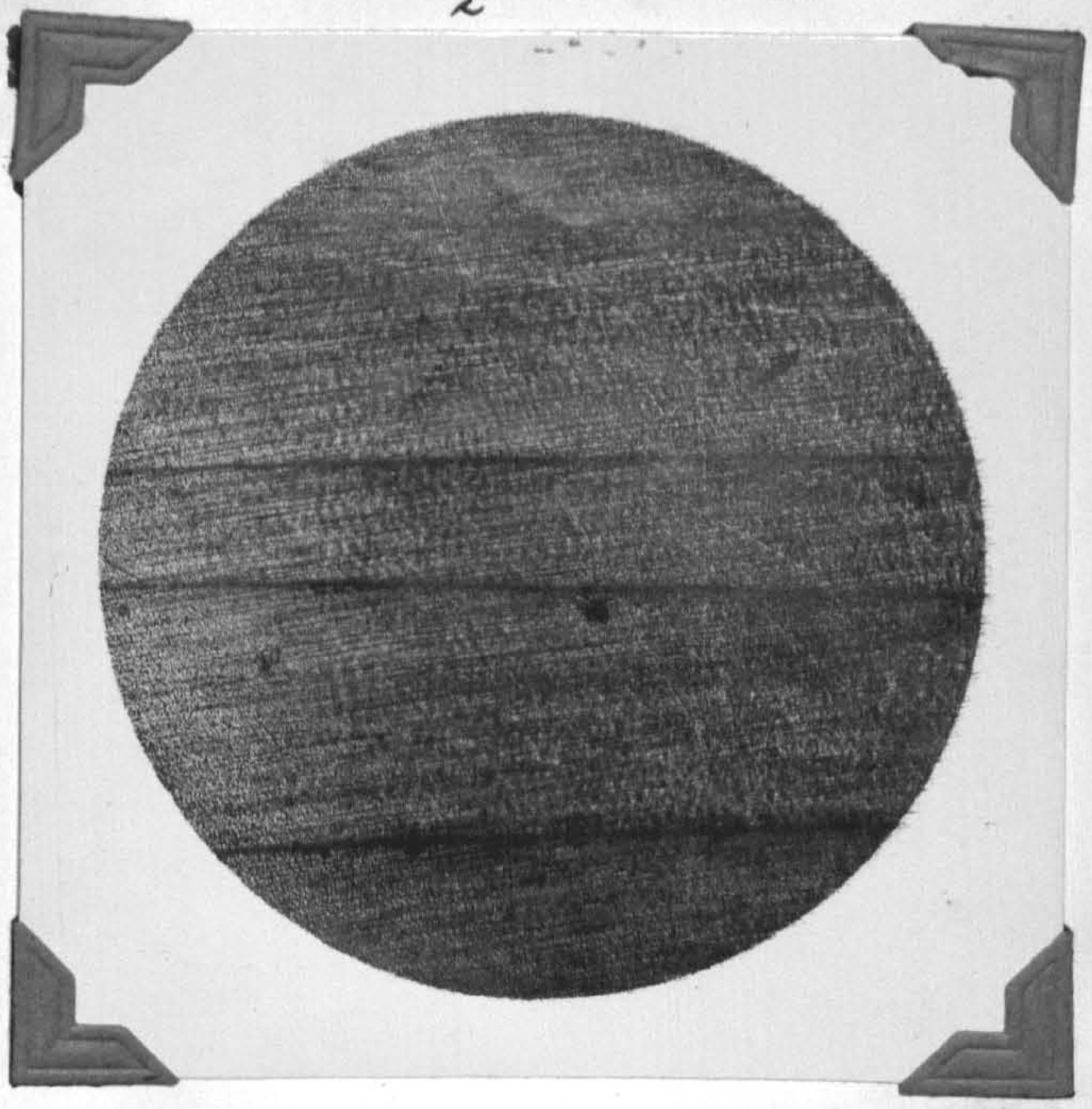

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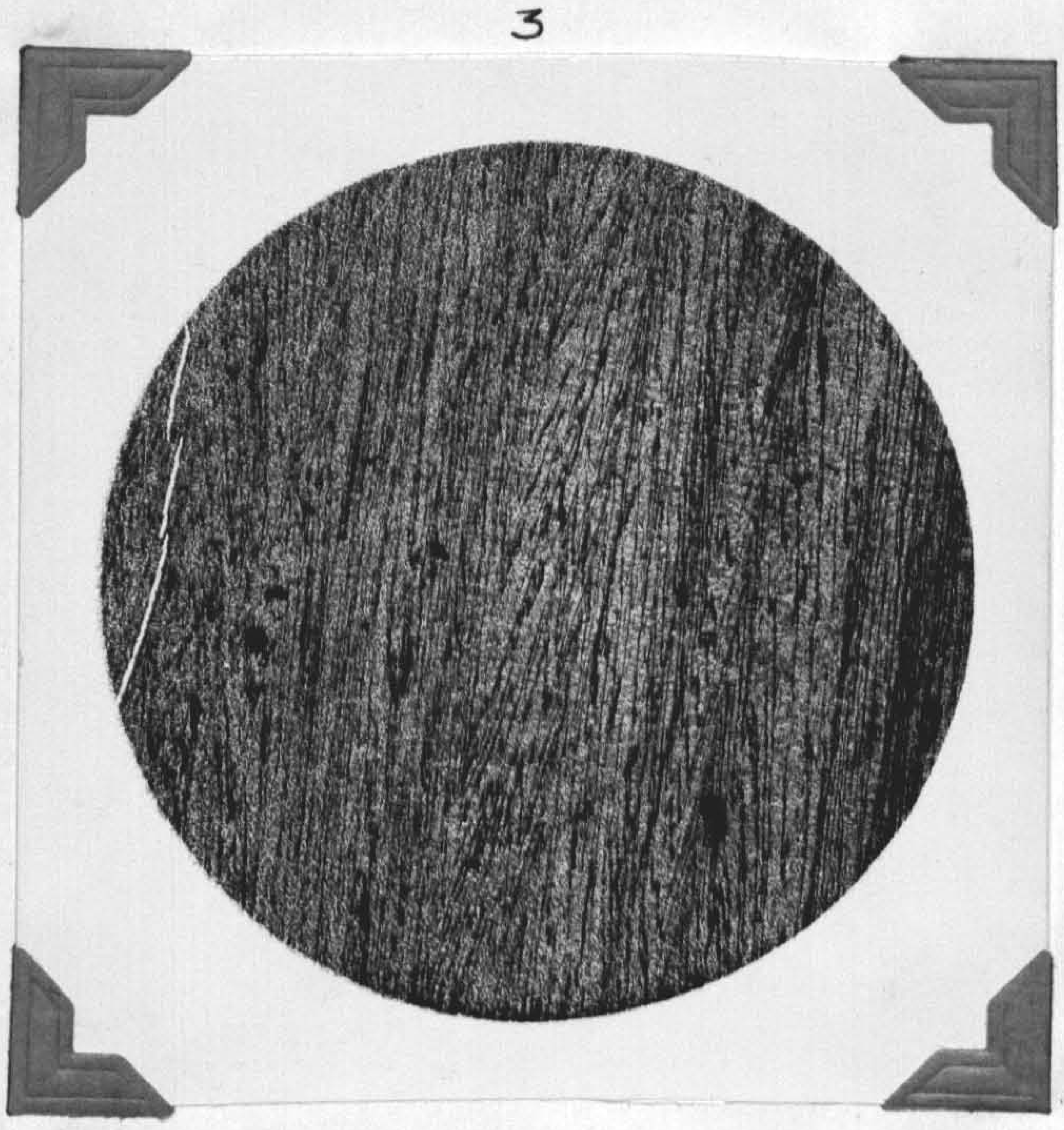

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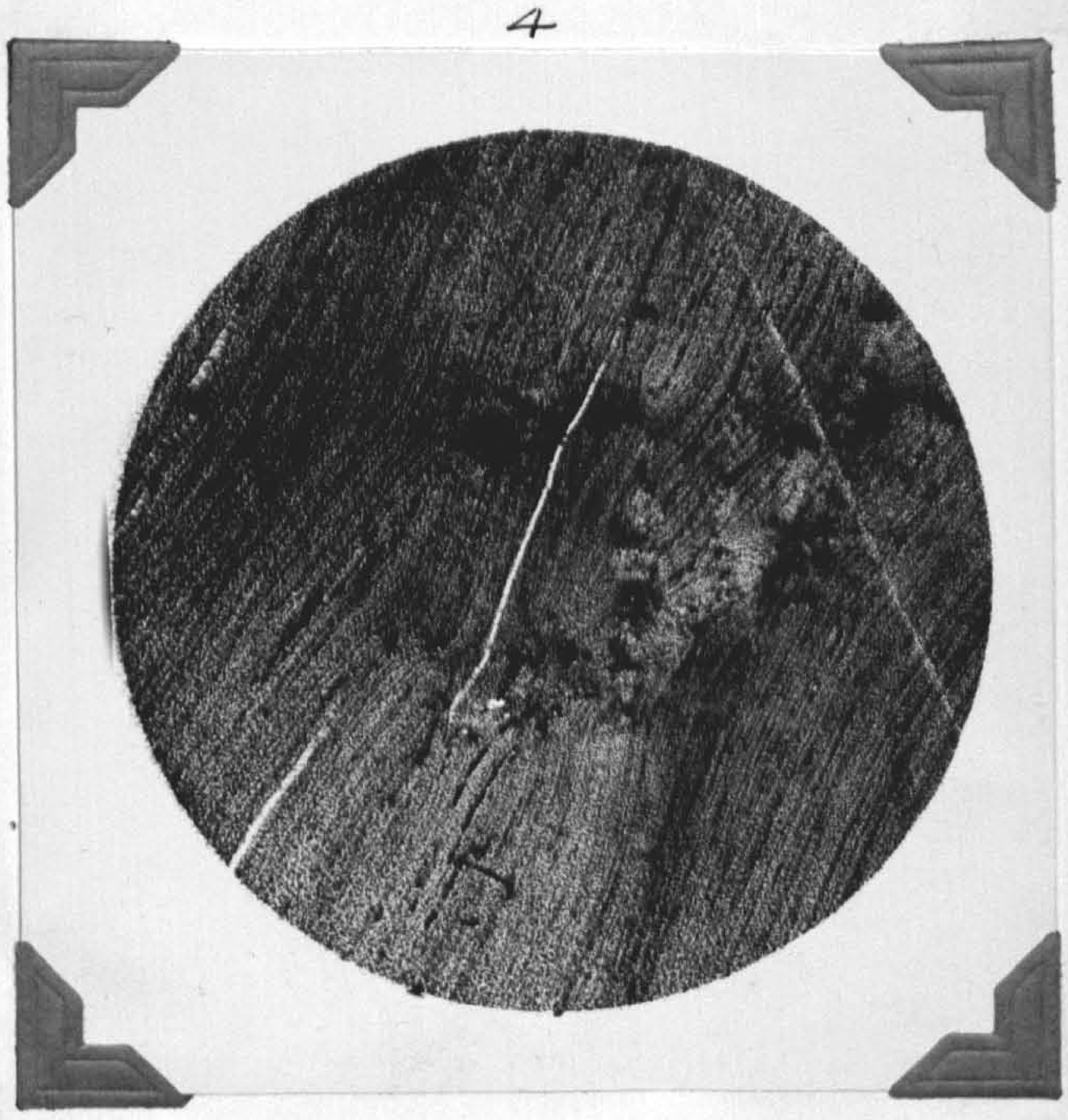

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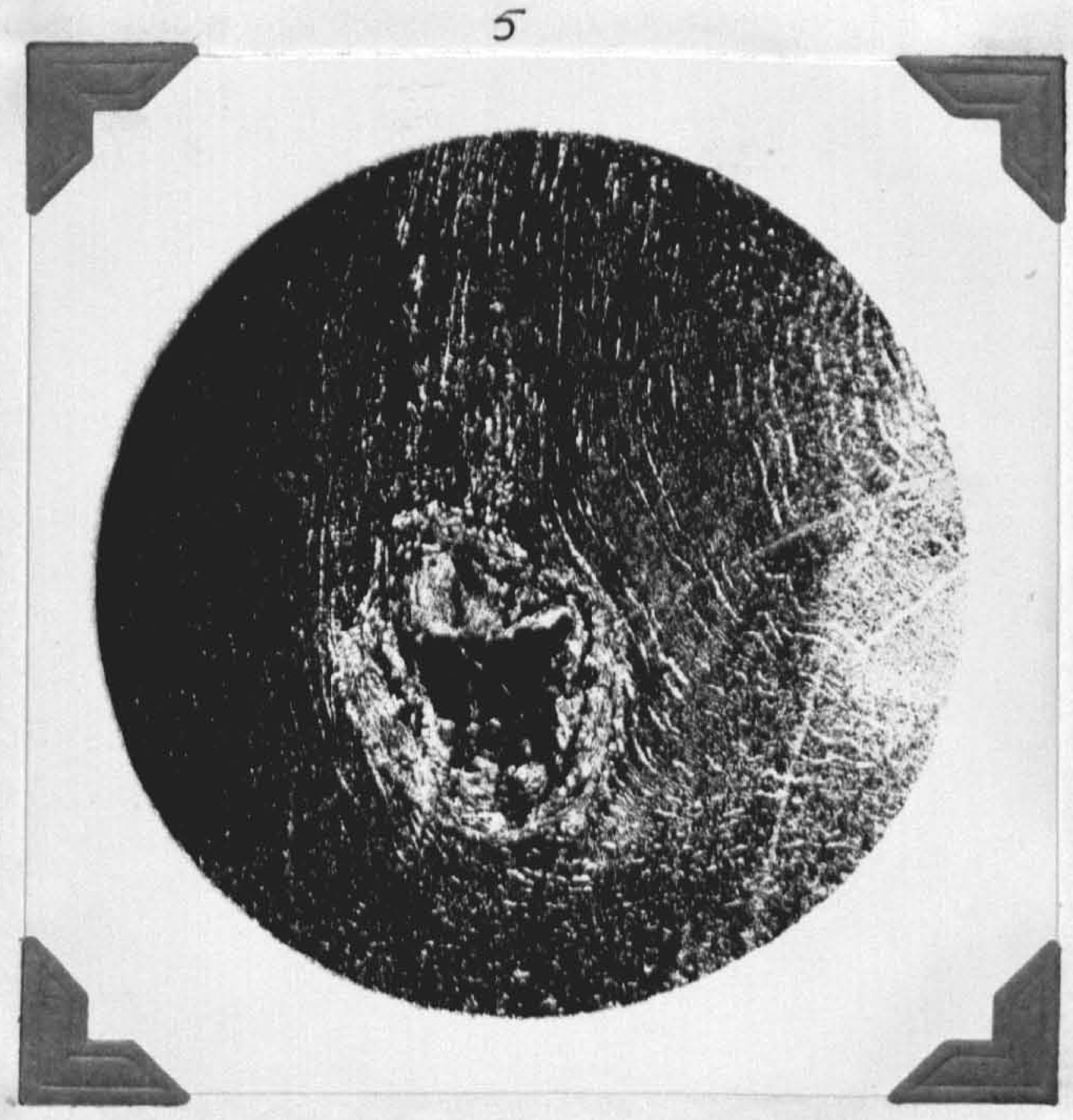

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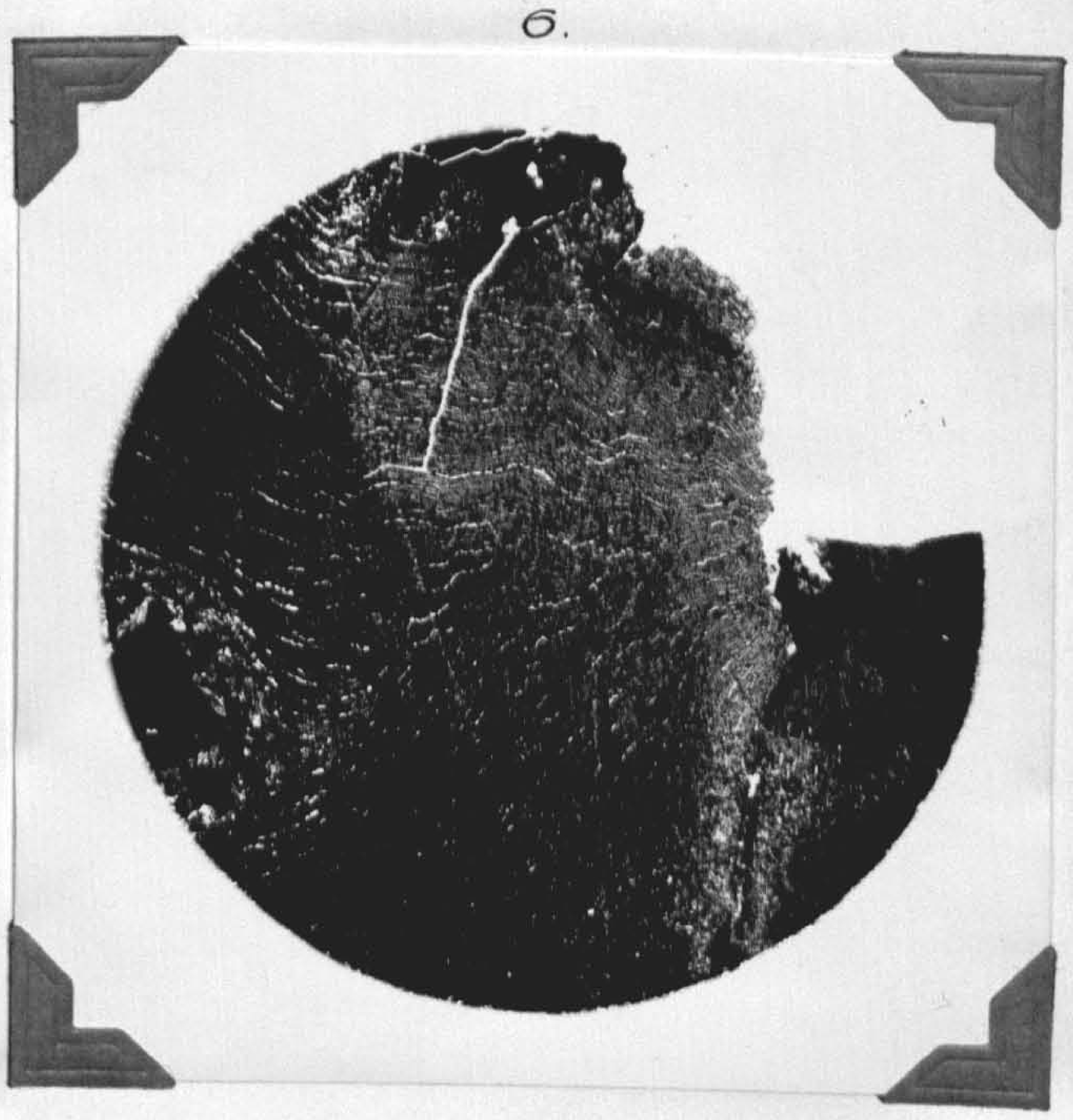

PLATE 14.

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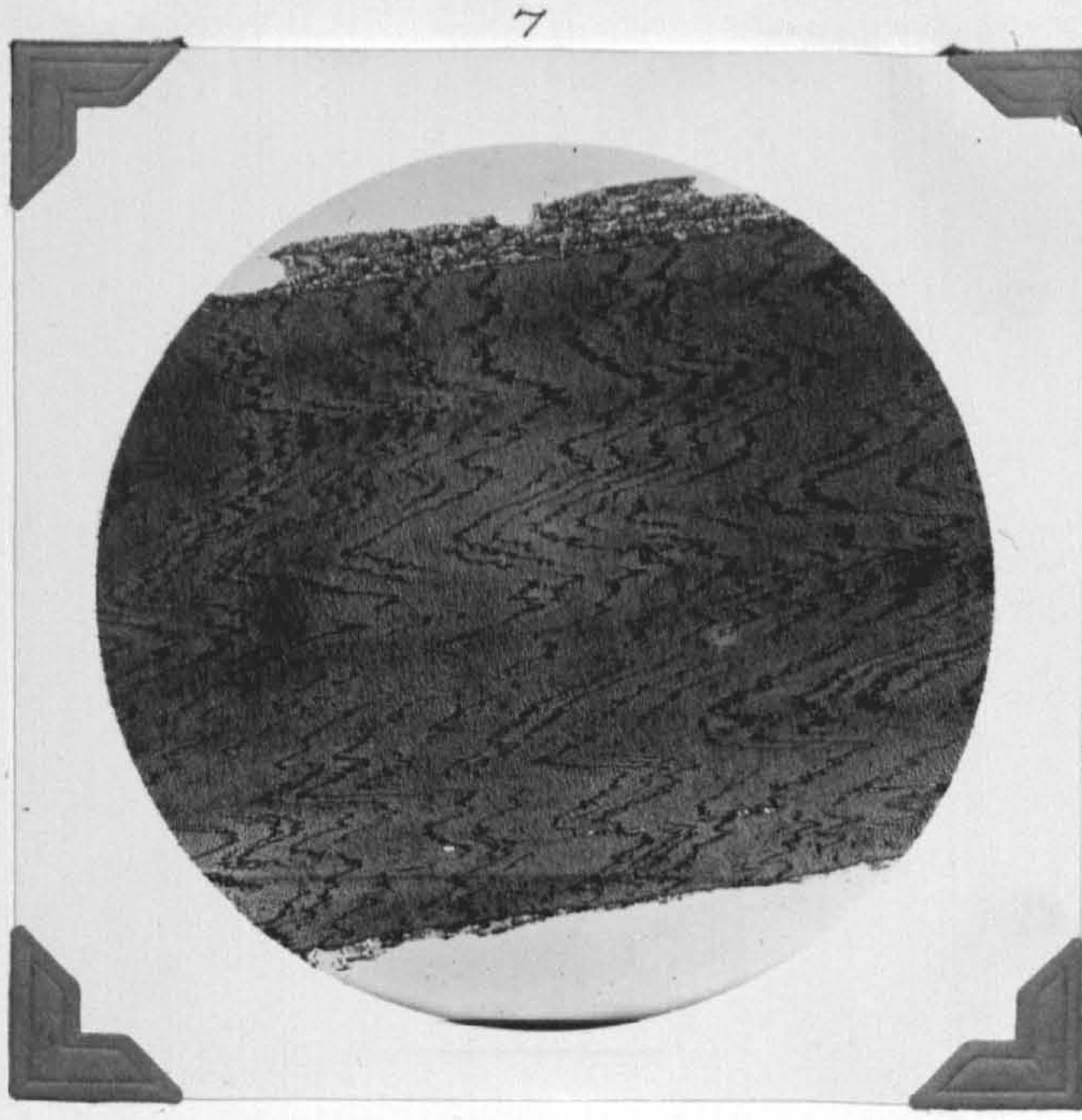

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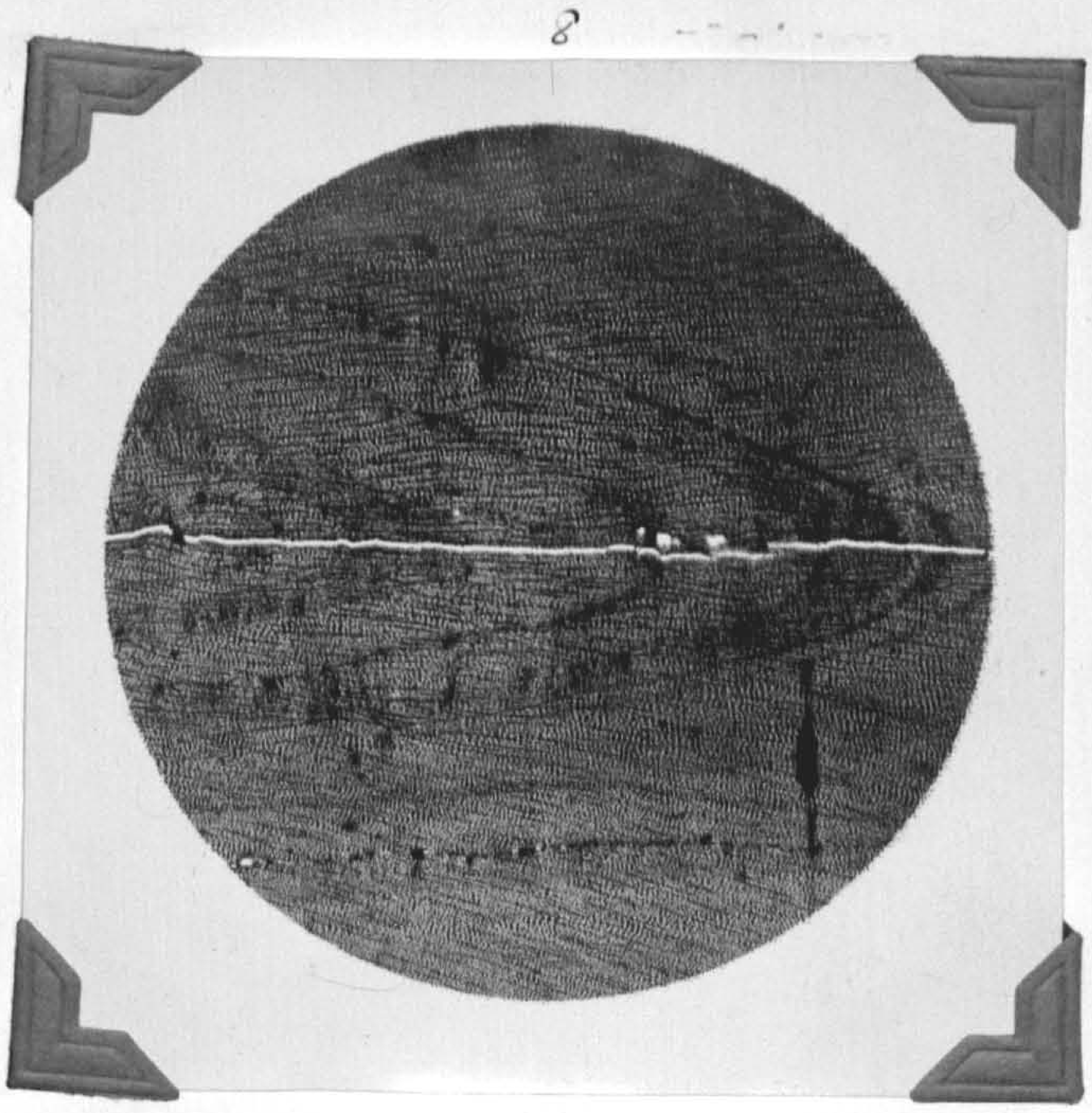

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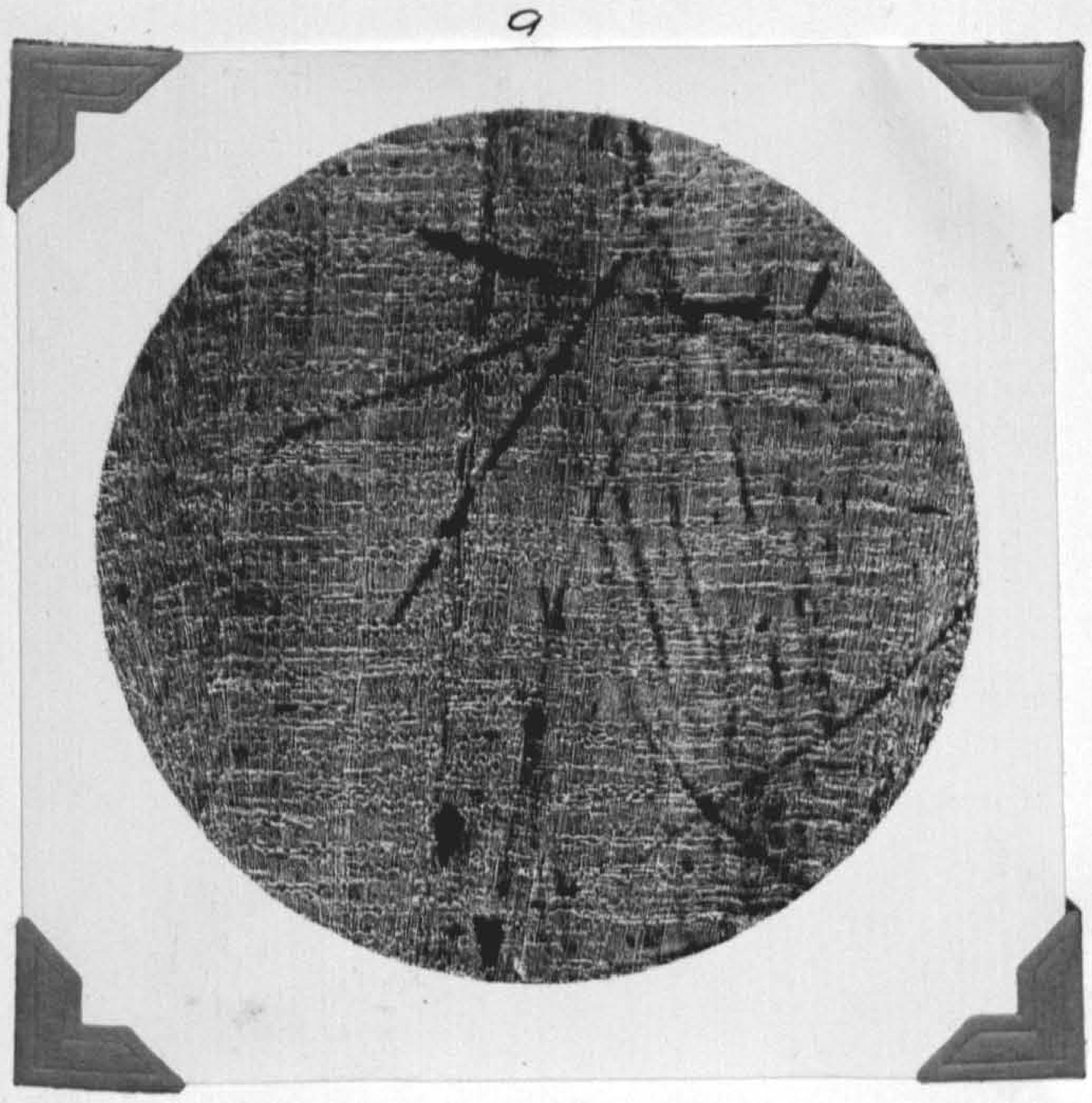

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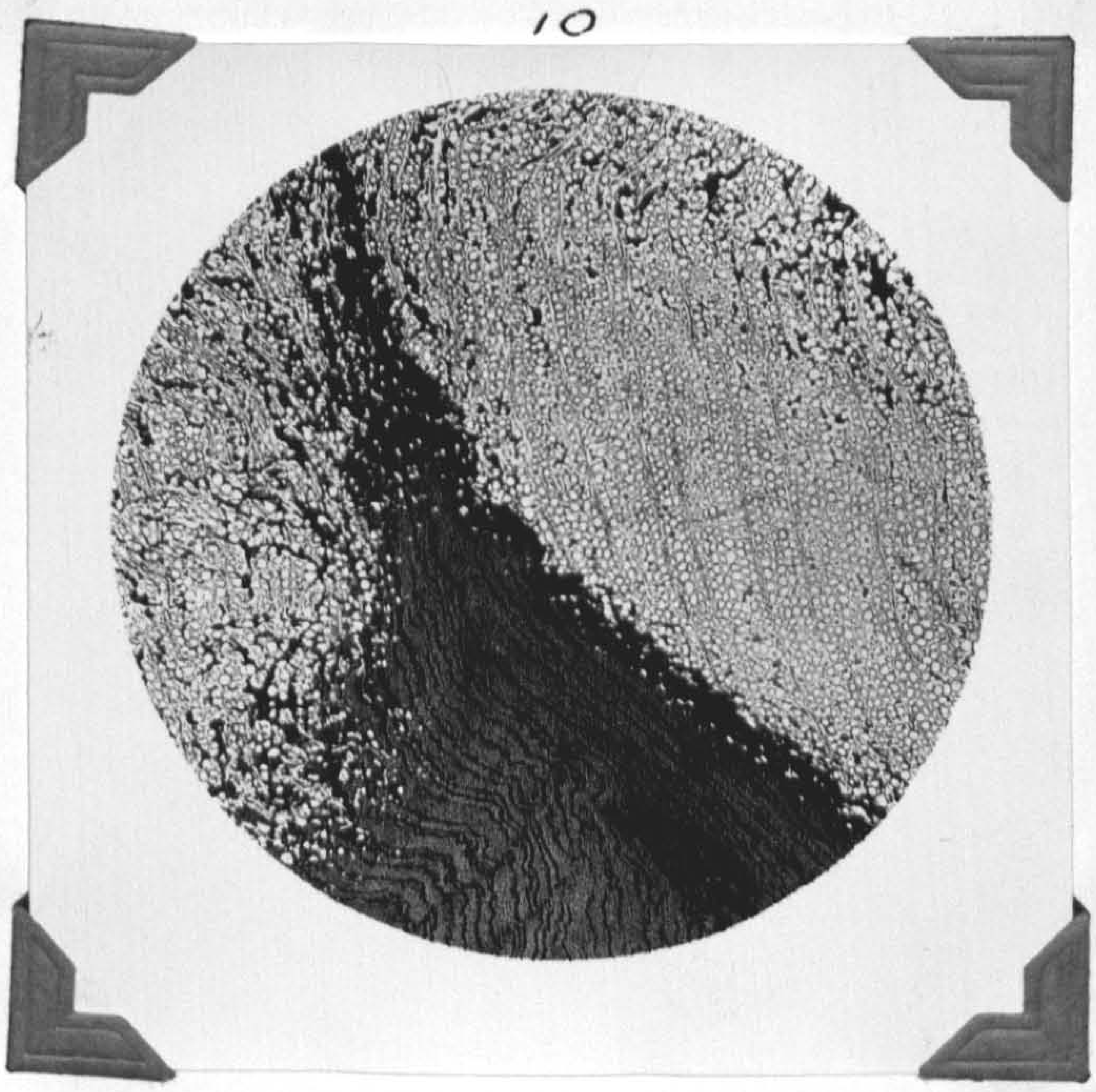

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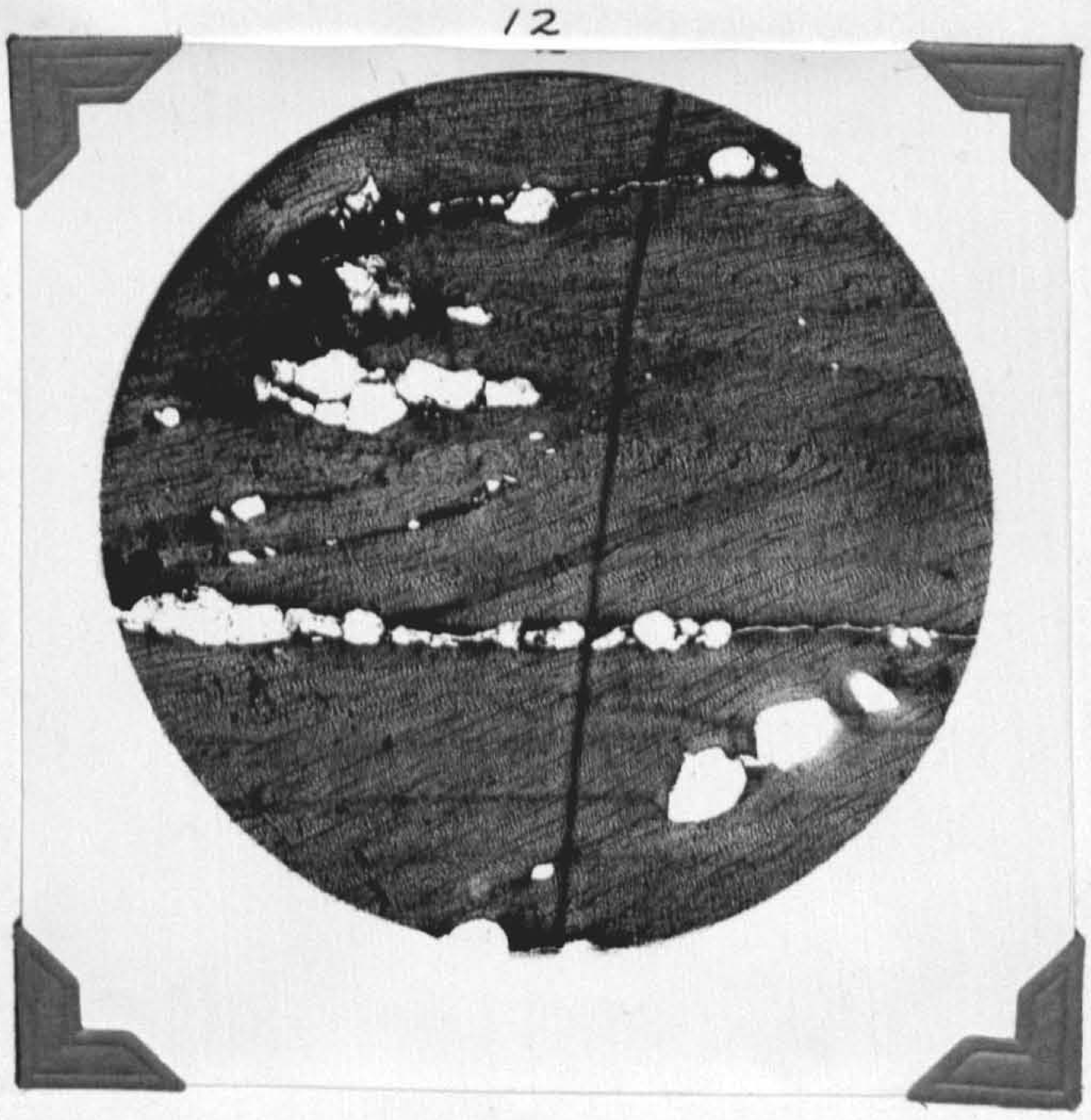


Plate 15.

13. Soft cored jet in radial section, showing silicified wood fibres and rays.

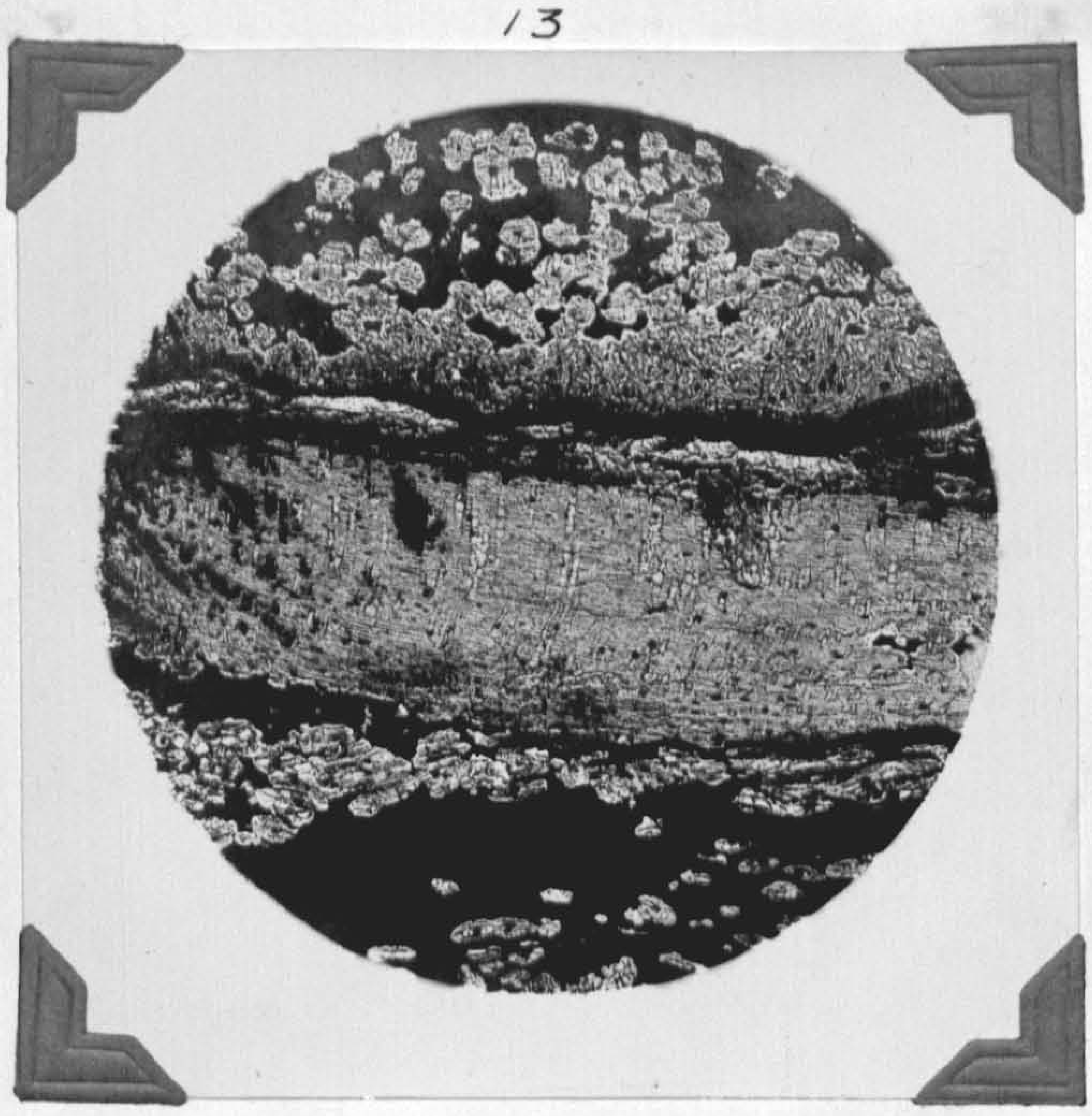
14. Hard jet with calaite vein injected contemporaneously with jetonisation. This was folded and thrust when the wood structures were crumpled.

15. Core of cored jet. Mag45. Note part of an annual ring, small jetonised areas surrounded by quartz in optical continuity, and partly jetonised (black) cell walls and rays.

16. Radial section of hard jet. Mag.35. See 6.

PLATE 15.

13



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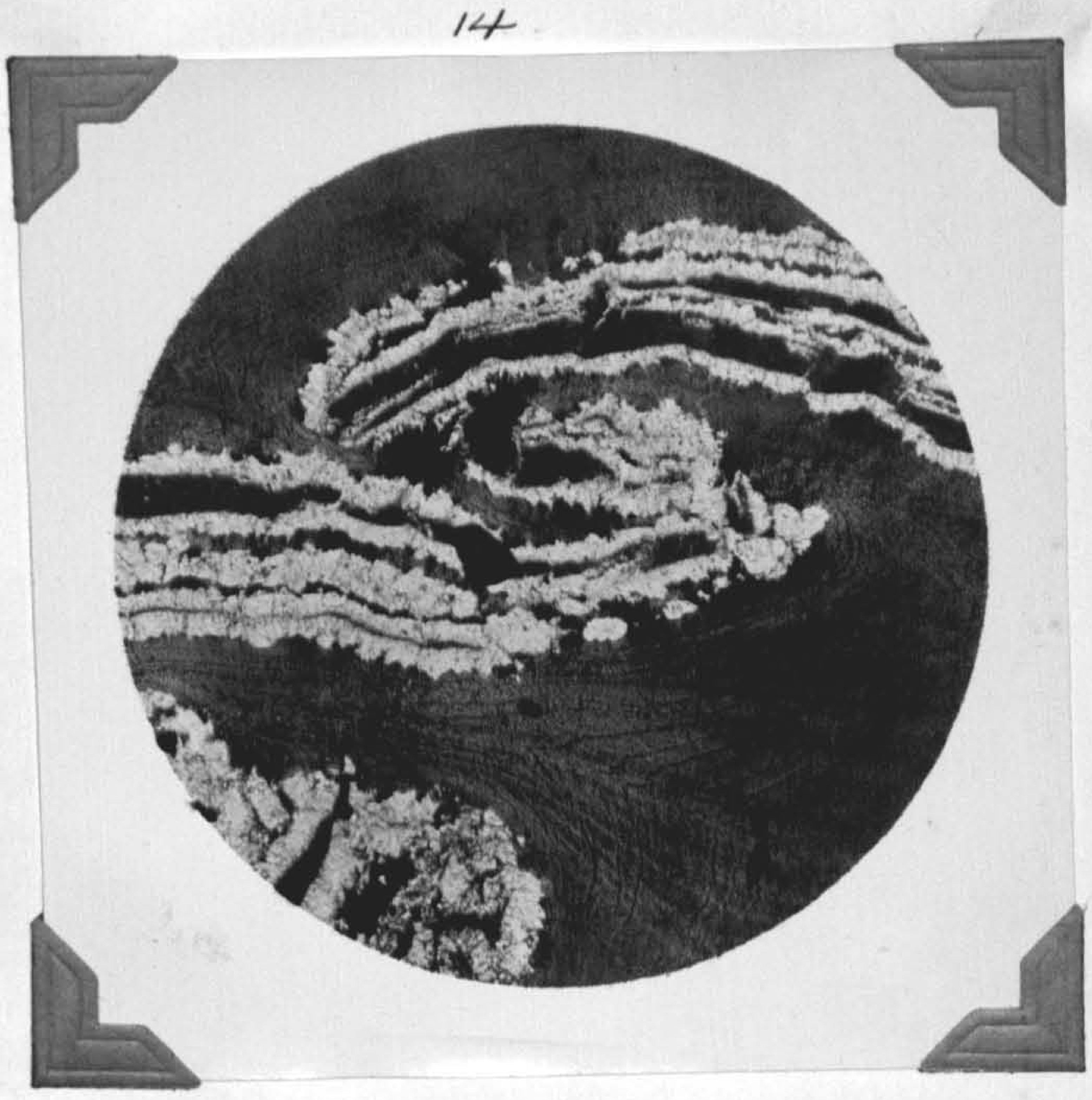

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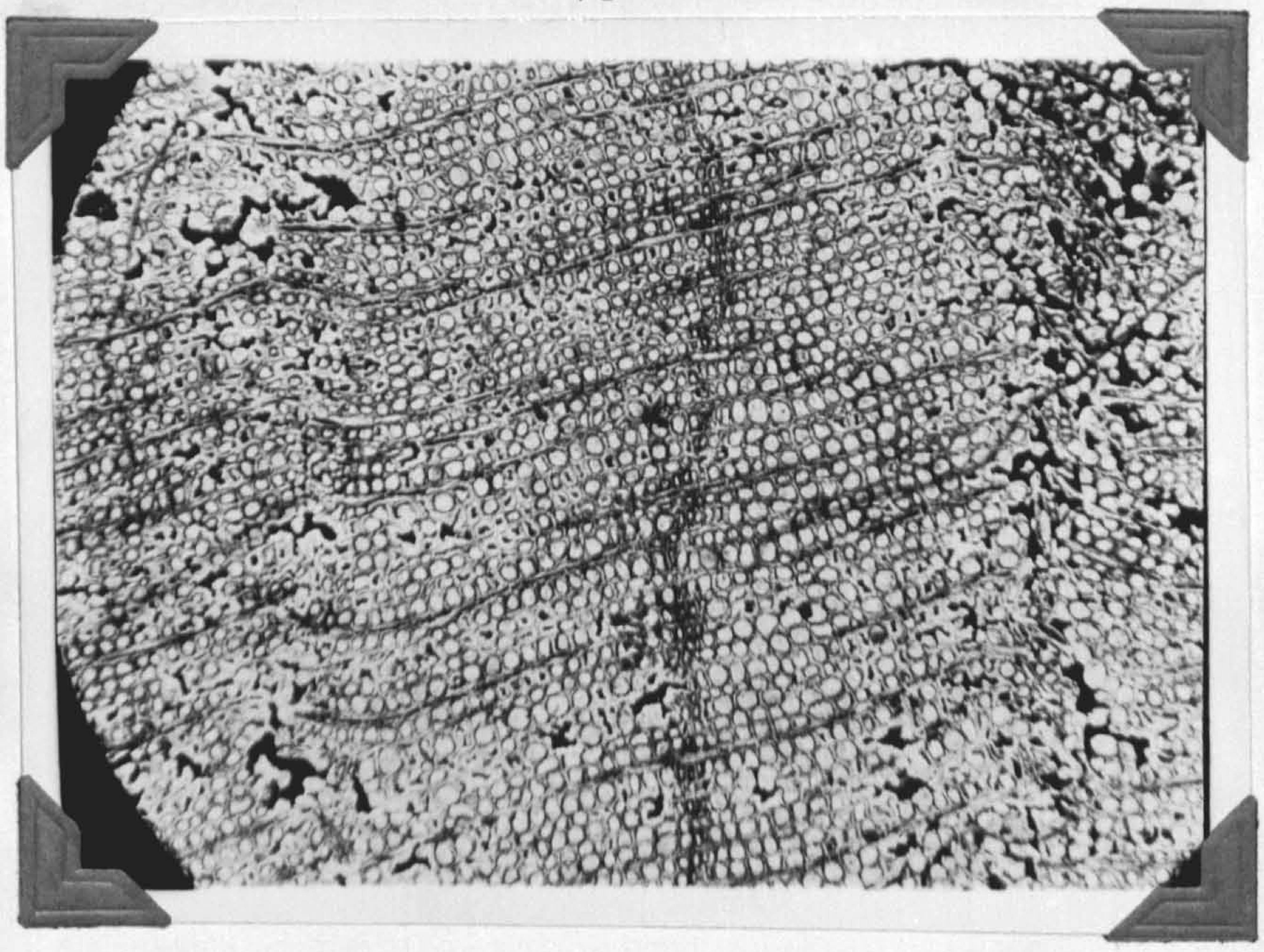
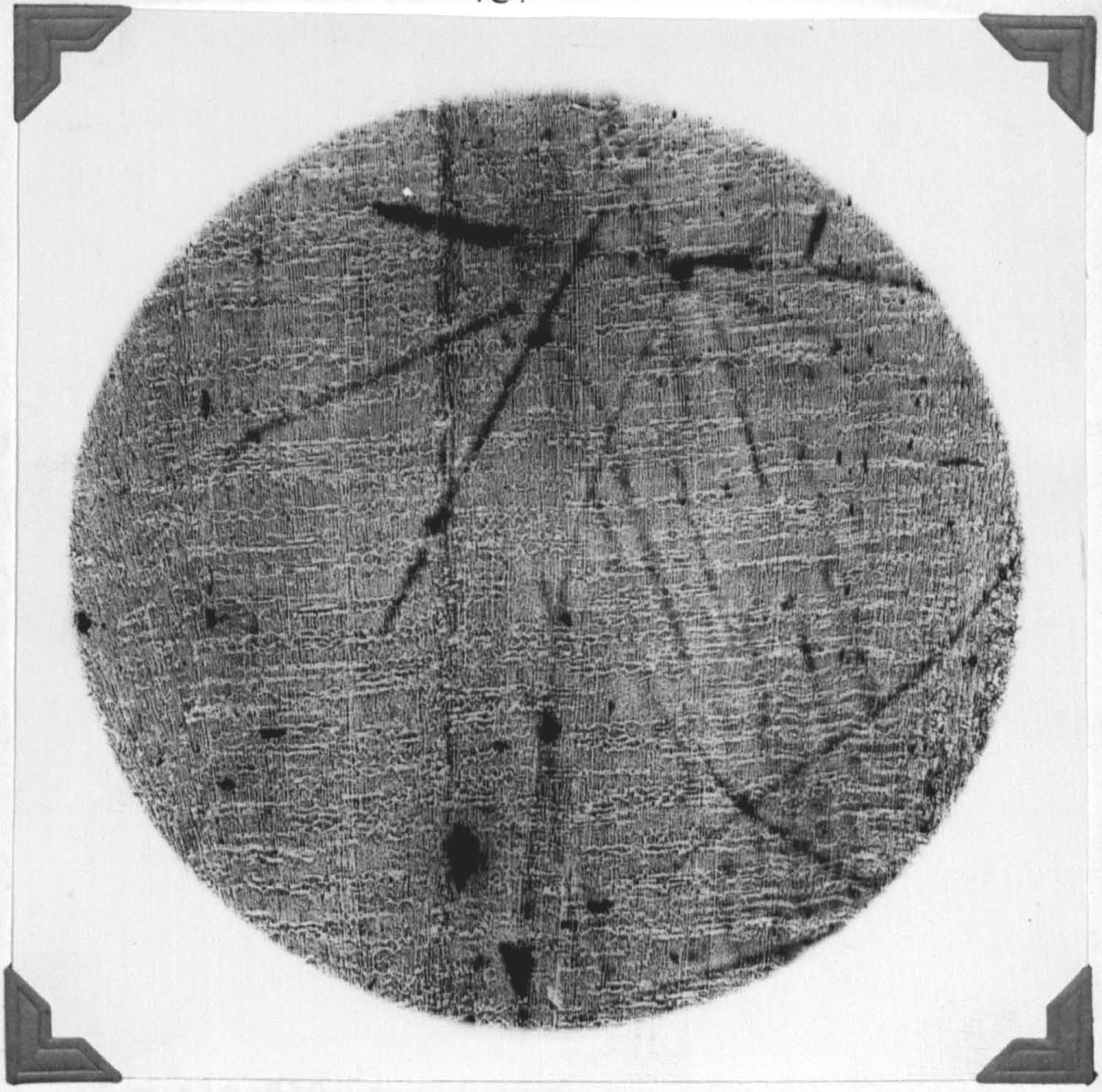


16 Overleaf

PLATE 16.

16.



May 35

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