THE STRATIGRAPHY AND SEDIMENTOLOGY OF THE 'POCKET-DEPOSITS' IN THE BEES NEST AND KIRKHAMS PITS, NEAR BRASSINGTON, DERBYSHIRE.

by

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ABSTRACT

The Brassington Formation, in south Derbyshire, comprises a succession of gravels, sands and clays, the youngest beds of which, on palaeobotanical evidence, are of Lower Pliocene age. It is now preserved in deep 'pockets' in the Carboniferous Limestone which were produced by solution subsidence mechanisms. A detailed sedimentological study of the Brassington Formation shows that there is no stratigraphical break in the succession; hence the sediments below the plant-bearing beds must also be of Neogene age. The subsidence outliers of the Brassington Formation are remnants of a once-continuous sheet of fluviatile sediments, laid down on the Carboniferous Limestone and Namurian shales of south Derbyshire during Neogene times. These sediments consist almost entirely of reworked Triassic and Carboniferous materials.

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1. INTRODUCTION

A- Summary of previous work

The Pocket-Deposits of Derbyshire (also known as Silica Sands) have attracted the attention of geologists for many years. They occur in large cavities in the Carboniferous Limestone, lying mainly at elevations of 270 - 315 m. (900 - 1050 feet) above O.D. The most comprehensive map of these deposits is that given by Ford and King (1969 Fig. 1). This map clearly shows that most of the pockets occur within a belt of country 18 km long and 9 km wide (12 x 6 miles) trending NW - SE. However, some large related deposits in Staffordshire e.g. Ribden (SK 078474) and Sallymoor (SK 085465) lie well outside this belt. Sand used in the manufacture of silica-bricks has been extracted from at least sixty pockets and some other unworked deposits are known from borehole data. The Pocket-Deposits consist essentially of sands, gravels and clays. There is a great variation in the relative proportion of these sediments in the various pockets, but sands are nearly always predominant.

Although the sediments in the pockets are generally highly disturbed by processes which are usually attributed to the effect of Karstic subsidence, some evidence of stratification can be seen in most of the larger pits. According to Ford and King (1969) the stratification is of three types:-

"(a) Undisturbed horizontal bedding, showing at the most a little sagging owing to compaction.

(b) Highly disturbed bedding due to repeated subsidence collapse, sometimes with inward dips from all sides giving a funnel-shaped appearance.

(c) Disturbance in the upper parts of the sand owing to downward glacial intrusion or to cryoturbation. Slickensided masses of red clay appear in many pits, and are similar to slickensided masses in the Golconda Mine where the pressure has obviously been due to roof subsidence. In the open pits the cause is thought to be the weight of overlying ice."

In the nineteenth century the Pocket-Deposits were thought to be of Carboniferous age but in 1906 Bemrose showed that the sand grains in them were rounded and, as such, he deduced that they were probably of Triassic origin. Scott as late as 1927, nevertheless, still favoured a Carboniferous origin. He examined the pebbles from the Kenslow Pit (SK 182616) and the Blakemoor Pit and failed to find any pebble showing the 'pitting' which is characteristic of those in the Bunter of the Midlands. He concluded that the source of the pocket materials in Derbyshire was probably 'Pendleside' and Millstone Grit deposits.

Boswell (1918) noted well rounded grains of heavy minerals in the sand from the Pocket-Deposits and the heavy minerals were also briefly described by Fearnsides (1932) who found them to be not uncharacteristic of a normal Triassic assemblage. He, therefore, postulated a wide spread Triassic cover, formerly resting on the Carboniferous Limestone and which was later removed except where small outliers had foundered into sinkholes.

In 1946,a large mass of Namurian shale was noted in direct association with the supposed Triassic deposits at Kenslow Top Pit (SK 182616). Kent (1957) therefore suggested that the subsidence at Kenslow took place at a former junction of the Carboniferous Limestone and an overlying cover of Namurian shale, the shale masses having collapsed into the sinkholes along with the supposed Triassic sediments. Furthermore, since the summits of numerous limestone hills rise 60 - 75 m. (200 - 250 feet) above the 300 m.(1000 feet) plateau, Kent suggested that the sediments were deposited on a surface which must have been at a level of 75 m.(250 feet) or more above the present 300 m.(1000 feet) plateau. He suggested that the 300 m.(1000 feet) plateau is of Mio-Pliocene date and that summits of limestone hills above this plateau are relics of a more ancient surface, possibly a plane of marine erosion produced by the Permian (Zechstein) sea. In support of this idea he suggested that the transgression of Permian sea was also responsible for the widespread dolomitisation of the Carboniferous Limestone in the area where Pocket-Deposits are present.

To explain the existence of pieces of wood of the supposed Tertiary tree 'Dadoxylon', which were recovered from the Harboro Farm Pit near Brassington (Howe 1897), Kent suggested the deposition of sediments in Tertiary swamps or lakes which developed on the site of the infilled sinkholes of supposed Triassic origin.

Yorke (1954-61) considered that Triassic sediments were widely spread over the Derbyshire Dome, the basal portions of which were trapped in pre-existing limestone hollows which were partly solution cavities and partly surface "water courses". He explained the occasional presence of stratification by suggesting that some of the Pocket-Deposits accumulated in very large cavities or valley like hollows. He realised, however, that the presence of highly inclined beds in some of the deposits could be a strong argument against the notion of the infilling of pre-existing cavities and to explain this feature and also the existence of the Namurian shale,which is found in association with the Triassic deposits at Kenslow Top Pit,Yorke attributed the disturbances to glacial effects.

Ford and King (1969) attributed the formation of the pockets to the collapse of solution caverns. They claim that the chief controlling factor in the distribution of the Pockets is the location of the base of dolomitised zone of the Carboniferous Limestone. Subsurface observations by these authors show that the contact between limestone and dolomite undulates considerably and that the dolomitisation in the area of the Golconda Mine (SK 249551) has reached to a depth of as low as 210 m.(700 feet) above O.D. Since dolomite has a much higher porosity than limestone,a preferred path for the underground water movement would be the contact between limestone and dolomite and so at this contact small solution caverns developed. The collapse of these caverns,at some localities,extended to the surface of the Carboniferous Limestone and let down overlying sediments,such as sands,into the pockets.

By about 1960, the plant bearing clays at both Bees Nest and Kenslow Top Pits became permanently exposed. But it was not until 1970 that it became generally known that the plant beds were datable as upper Miocene/Lower Pliocene (Boulter and Chaloner 1970 and Boulter 1971). At both localities the plant beds are immediately overlain by glacial sediments and overlie coloured clays, which are underlain by sands and gravel which are sought for refractory material. Ford and King (1969) and Boulter and Chaloner (1970) all took the view that since no unconformity can be detected in the (then) existing exposures of the Pocket-Deposits it follows,logically,that the preserved sediments could all be part of a single continuous sheet of sediments, the upper part of which being definitely of Neogene age, there is a strong possibility that the entire sequence is of this age.

Subsequently, in 1971, the author in collaboration with Boulter, Ford and Walsh proposed the term 'Brassington Formation' for the sediments which are preserved in the cavities in the Carboniferous Limestone of Derbyshire and which are demonstrably of pre-Glacial/post-Namurian age and which are conformable with the plant beds. On the basis of the age of the plant remains, preserved in the grey clays, the age of these older sediments is likely to be neither much older nor much younger than Upper Miocene (see paper in the pocket of this thesis).

According to the aforementioned authors the Brassington Formation is divisible into three easily recognised members.

3- Kenslow Member (Grey clays containing plant fossils).

2- Bees Nest Member (Coloured clays).

1- Kirkham Member (Basal sands and gravel).

The term 'Pocket-Deposits' should now be used only when referring to all the contents of the pocket fills i.e. those of post viséan age, including not only the Brassington Formation but also both Namurian and Pleistocene deposits. Whereas some might argue that its retention might cause some confusion, the author considers that it is a useful term when used in this context.

Although there has been no dispute concerning the age of the beds which contain the plant remains (Kenslow Member), the beds below have given rise to considerable controversy both as regard to their age and to their structural relationship with the Kenslow Member. The author will describe later in this thesis the experimental work which has led him to the conclusion that the sediments below the Kenslow Member are in fact conformable.

During the Geologists' Association excursion to the Neogene Pocket-Deposits of Derbyshire (11th-13th June 1971; Ford 1972[b]) a third mass of plant bearing Kenslow clays was somewhat unexpectedly discovered at Kirkhams Pit. This further supports the concept of a natural threefold division of the Brassington Formation. Again, no structural disconcordance with the underlying Bees Nest Member is discernable.

Recently, reasons have been given for postulating (Walsh et al, 1972) that the Brassington Formation was formed on a Miocene planation surface which if preserved would now lie at about 450 m (1500 feet) above O.D. If this proposal is correct then the amount of subsidence must have been much greater than previously thought, namely something of the order of 150 - 250 m.(500 - 830 feet).

B- Main objectives of author's research

Because of the contrasting conclusions of many of the authorities quoted above, it is obvious that there are still several fundamental problems regarding the Pocket-Deposits which remain to be resolved beyond doubt.

(i) The satisfactory correlation of strata at all of the various exposures. This would help to confirm or deny the use of the term 'Brassington Formation' on a regional scale.

(ii) The exact relationship of the Brassington Formation to the Namurian shale at the various localities.

(iii) The exact relationship between the Kenslow Member and the underlying sediments.

(iv) The detailed comparison of the detrital minerals in the Brassington Formation with those in the local Triassic and pre-Triassic rocks and the relative importance of the later as the source of the detrital minerals in the Brassington Formation.

(v) The depositional environment of the Brassington Formation, and the extent of the area of deposition.

In order to try to solve these problems a detailed field survey and a laboratory investigation was carried out on two of the few remaining actively worked sections - namely those at Kirkhams Pit and Bees Nest Pit. These two pits were selected for detailed study on account of their reasonably close proximity to each other and because the sections show clear evidence of stratification throughout. The section at Kenslow Top Pit, the only other actively worked section in the area, was also studied but not in comparable detail. Distortions of the strata, due to Karstic subsidence and/or glaciation, are less pronounced at Bees Nest Pit than at Kirkhams or Kenslow Top Pits. The sections in Bees Nest Pit are also somewhat cleaner than in the other pits. For this reason Bees Nest Pit has been adopted as the type locality for the Brassington Formation (Boulter et al 1971).

In order to determine whether these pockets are the remnants of a continuous sheet of sediment which once covered the southern Pennines, the sections at Bees Nest and Kirkhams Pits were very carefully measured. The most important result recorded in this thesis is that the sedimentological analysis has shown that there is strong evidence upon which to base a correlation between the two successions. The Kenslow Top section has not been sampled in detail, but there is considerable evidence for a broad sedimentological correlation between Kenslow Top and the other pits. Because Kirkhams Pit is only about 3 km. (2 miles) from Bees Nest Pit, whereas Kenslow Top Pit is about 9 km. (6 miles) from both Kirkhams and Bees Nest Pits, it would seem reasonable to suggest that the Brassington Formation is in fact remnant of a single sheet of sediment which during Mio-Pliocene time covered the southern Pennines.

In order to determine the relationship of the Brassington Formation to the Namurian shale the author has visited all localities where a contact is known to be exposed. On the basis of field evidence he is of the opinion that the Namurian shale formed a discontinuous pre-subsidence foundation for the Brassington Formation.

In order to determine the age of the sediments below the Kenslow Member it is necessary to establish initially the exact structural relationship between the Kenslow Member and underlying sediments and particularly to determine whether all the members of the Brassington Formation are conformable or whether there is a hidden unconformity in the sequence.

A method of determining whether a hidden unconformity exists appeared to be a series of one dimension consolidation tests on samples taken from clay beds at critical horizons in the Bees Nest Pit and Kenslow Top Pit sections. The preconsolidation tests broadly indicate that all the clay beds have undergone a similar consolidation history and it would seem that no significant pre-pleistocene break occurs in the successions at the two pits.

In order to determine the source rocks for the Pocket sediments, the local Triassic and Carboniferous rocks were investigated. Sedimentological analyses of these rocks suggest strongly that there is no reason to suppose that they did not contribute the bulk of the materials comprising the Brassington Formation and on the basis of sedimentological evidence the author believes that the Brassington Formation is of fluvial origin.

2. GENERAL FIELD OBSERVATIONS

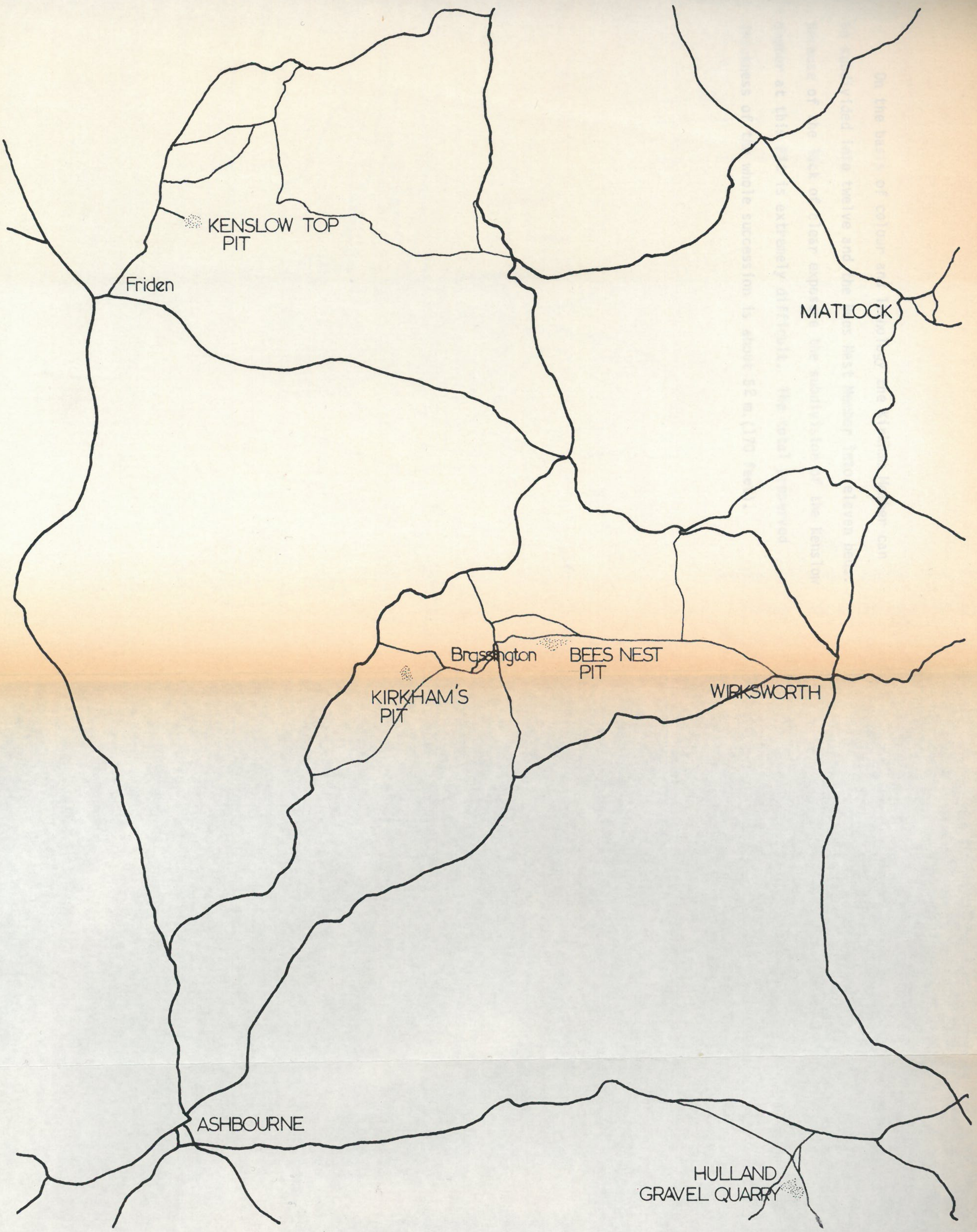
For the reasons outlined earlier, Bees Nest Pit and Kirkhams Pit were selected for detailed study and Kenslow Top Pit for general investigations. (Fig. 1).

A- The stratigraphy of Bees Nest, Kirkhams and Kenslow Top Pits

Bees Nest Pit (Fig. 2)

Bees Nest Pit, about 1 km. ($\frac{3}{4}$ mile) east of Brassington is owned by Hoben Quarries Ltd., and until recently has been actively worked for sand which has been used for the manufacture of silica bricks.

In outline, the succession is of Kenslow Member resting on the Bees Nest Member and this in turn on the Kirkham Member. The Kirkham Member rests unconformably on discontinuous masses of Namurian shale or otherwise on chert-clay sheets. The chert-clay sheets are visibly sandwiched between the Namurian shale and the dolomite wallrocks of Bees Nest Pocket, and since they have also been detected by boreholes on the floor of the pocket, underneath the Kirkham sand fill, they are interpreted as solution residues from the Carboniferous Limestone. D2 zone fossils have been identified in some of the chert fragments by Dr. J.E. Robinson of the Geology Department, University College, London, whereas the wallrocks of the cavity are shown as D1 age by Ineson and Ford (1971).



Scale : One Inch to One Mile

FIG. I MAP SHOWING RESEARCH AREAS

On the basis of colour and lithology the Kirkham Member can be subdivided into twelve and the Bees Nest Member into eleven beds. Because of the lack of clear exposure the subdivision of the Kenslow Member at this Pit is extremely difficult. The total preserved thickness of the whole succession is about 52 m. (170 feet).

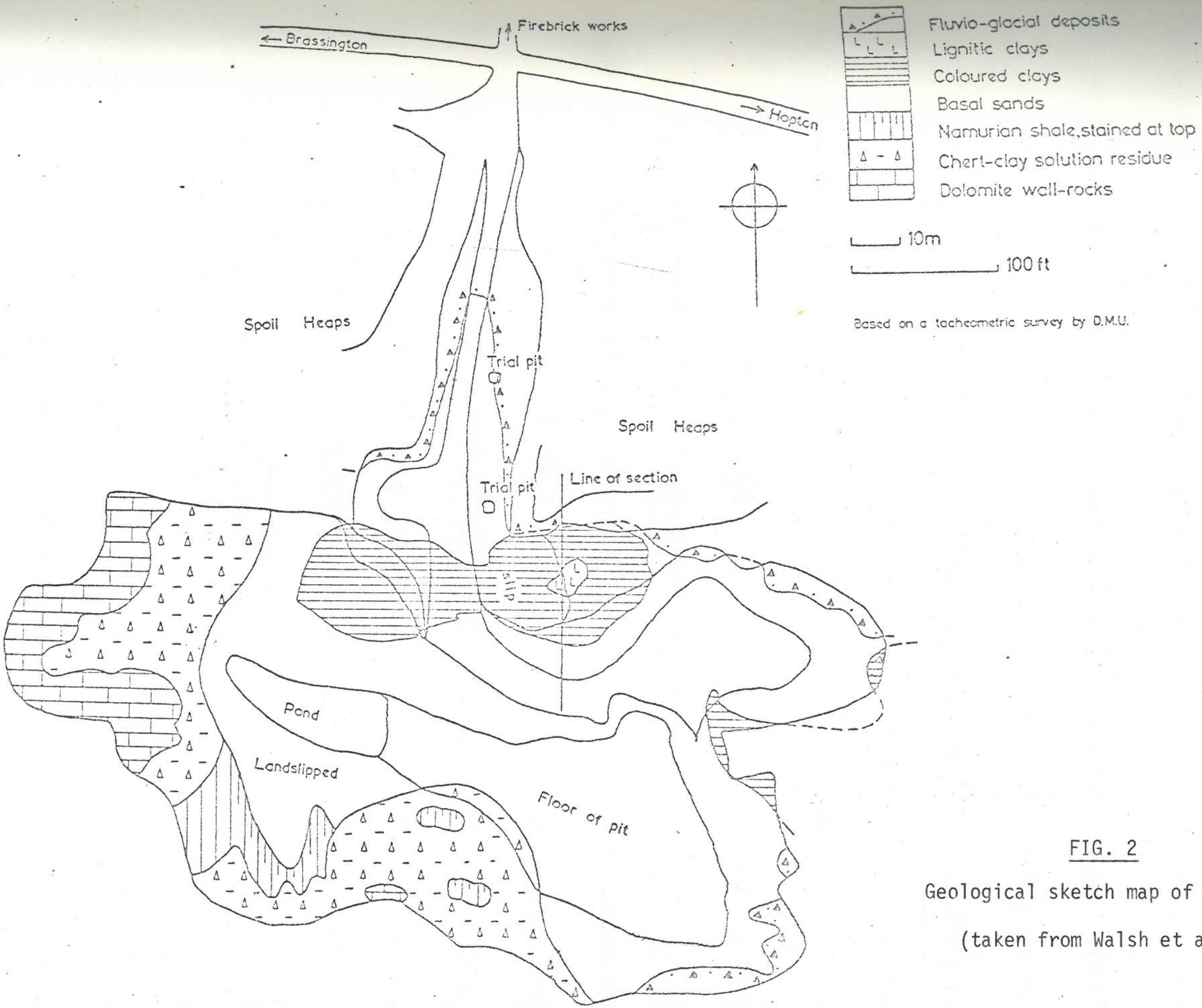


FIG. 2

Geological sketch map of Bees Nest Pit

(taken from Walsh et al 1972)

The Bees Nest Pit Succession (Fig. 3)

		Thickness (m)
	Fluvioglacial deposits	at least 4
24-	Grey clay with lignite	1.07 (3' - 7")
23-	Green clay	3.00 (10' - 0")
22-	Red clay	1.05 (3' - 6")
21-	Green silty clay with yellow bands	0.90 (3' - 0")
20-	Red clay	0.22 (0' - 9")
19-	Red, yellow and green silty clay	0.30 (1' - 0")
18-	Fine white sand	0.02 (0' - 1")
17-	Red and green silty clay	0.15 (0' - 6")
16-	Orange silty clay with pebbles	0.22 (0' - 9")
15-	Fine grained sand with pebbles	0.15 (0' - 6")
14-	Red clay with yellow bands	0.15 (0' - 6")
13-	Discontinuous ferruginous sandstone	0.01 (0' - ½")
12-	Buff sand with occasional pebbles	1.95 (6' - 6")
11-	Green clay	0.07 (0' - 3")
10-	Red clay	0.30 (1' - 0")
9-	Green silty clay with black stains	0.15 (0' - 6")
8-	Buff sand	0.15 (0' - 6")
7-	Pebbles with sand, some mud flakes present	3.30 (11' - 0")
6-	Green clay	0.07 (0' - 3")
5-	Greenish silty sand	1.12 (3' - 9")
4-	Buff and brown sand	0.90 (3' - 0")
3-	Sand with occasional pebbles and orange streaks	9.00 (30' - 0")
2-	Red clay	0.30 (1' - 0")
1-	Undifferentiated white sand with occasional pebbles and orange streaks	18.00 (60' - 0")
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	Namurian shale weathered at the top (not a normal contact - a subsidence effect)*	4.50 (15' - 0")
	Chert and clay residues (not a normal contact - a subsidence effect)*	4.50 (15' - 0")
	Dolomite wall rock	

* Note that in both cases considered by W.B. Evans (in the discussion of Walsh et al 1972) and Ford (1972(a)) to be a pre-Namurian feature.

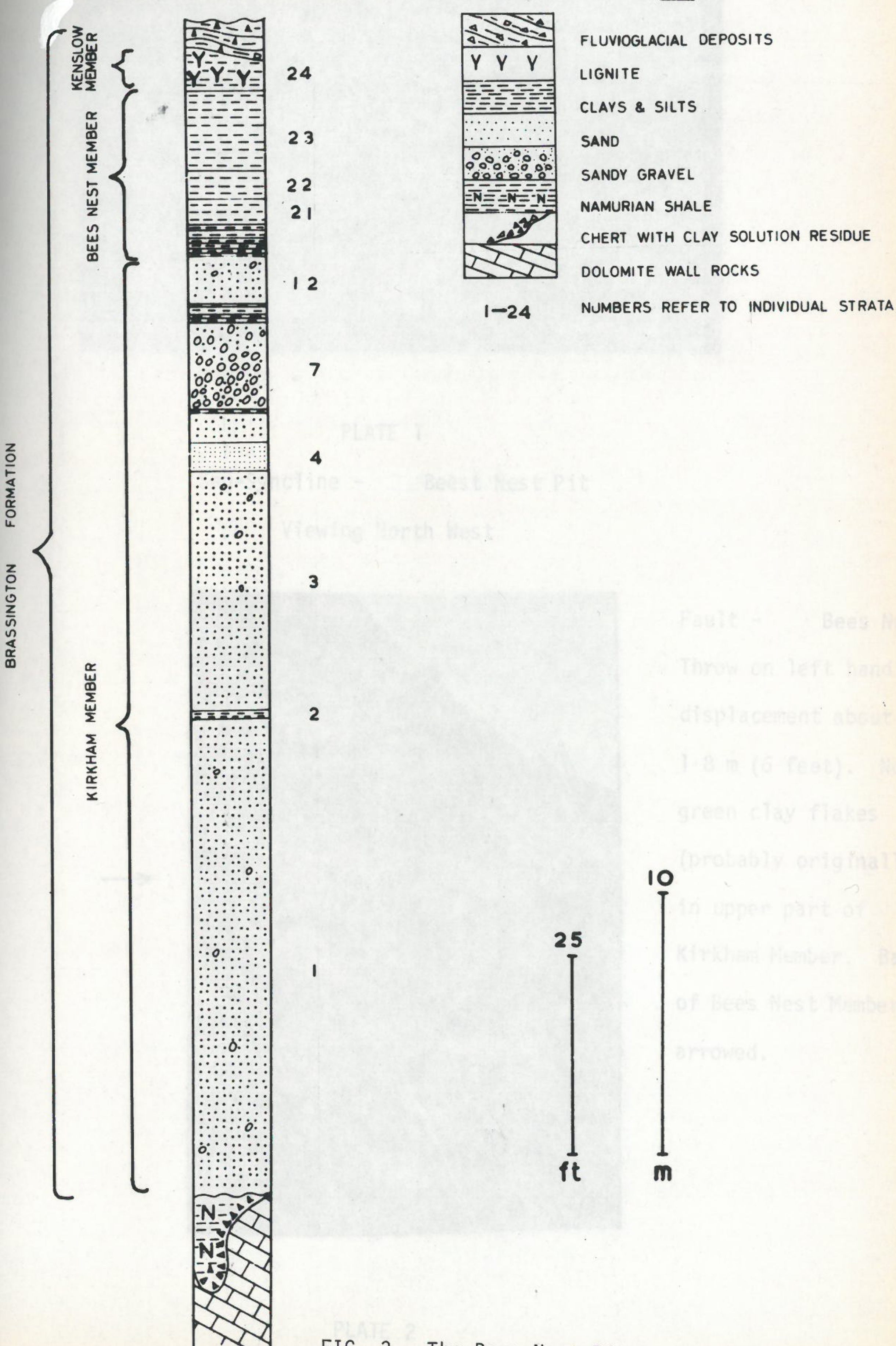


FIG. 3. The Bees Nest Pit Succession

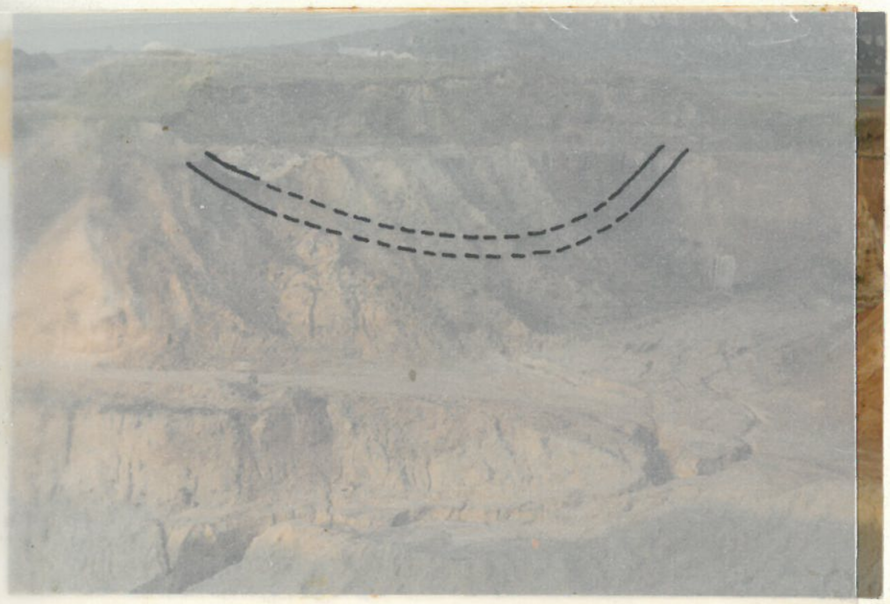
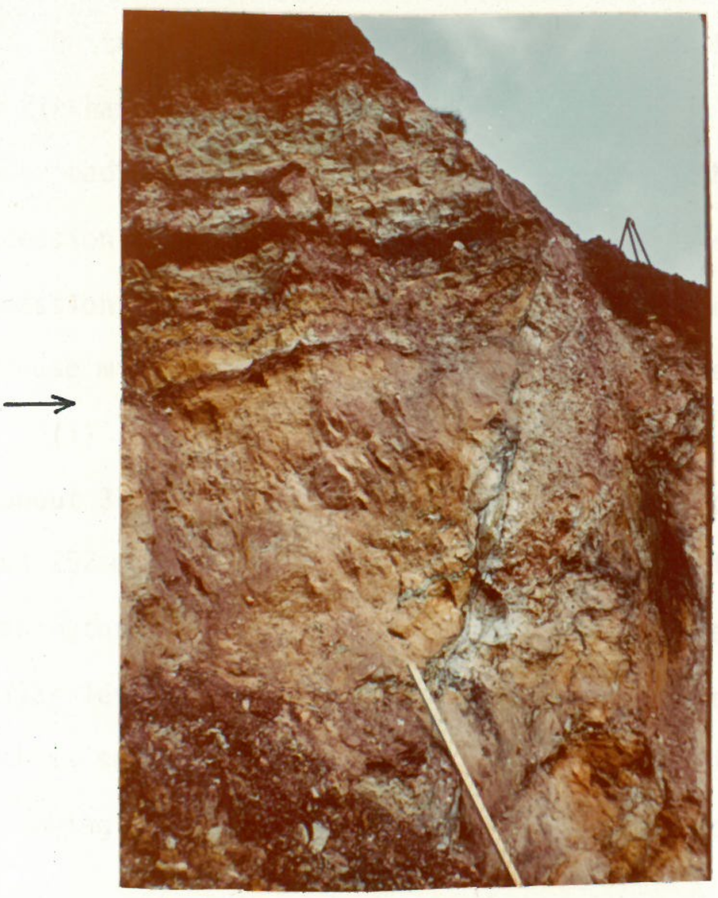


PLATE 1

Sag-Syncline - Beest Nest Pit

Viewing North West



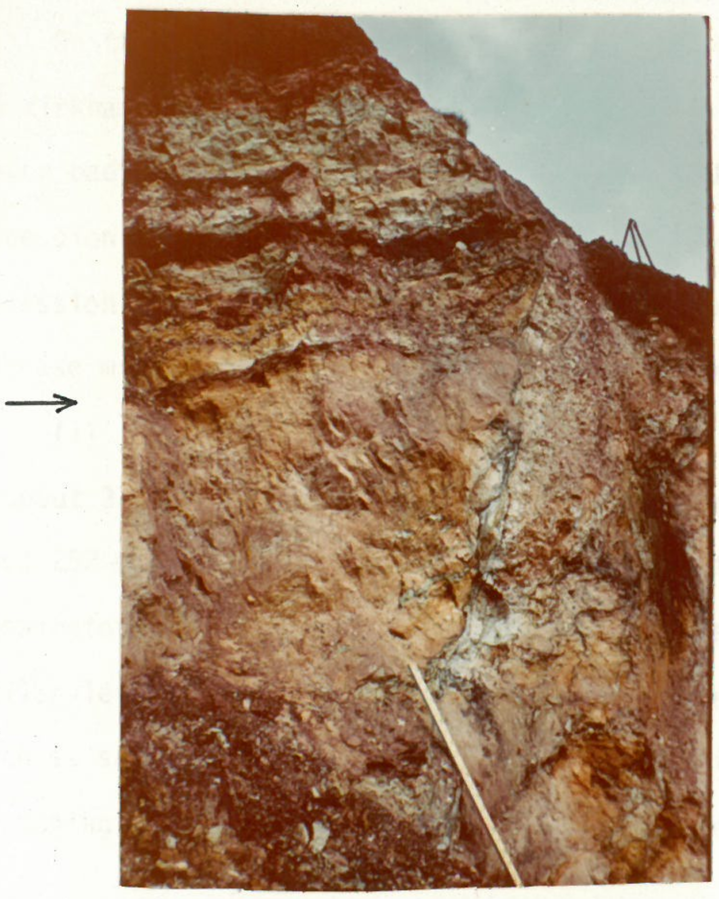
Fault - Bees Nest Pit
Throw on left hand side, displacement about 1·8 m (6 feet). Note green clay flakes (probably originally red) in upper part of Kirkham Member. Base of Bees Nest Member arrowed.

PLATE 2

PLATE 1

Sag-Syncline - Beest Nest Pit

Viewing North West



Fault - Bees Nest Pit

Throw on left hand side, displacement about 1·8 m (6 feet). Note green clay flakes (probably originally red) in upper part of Kirkham Member. Base of Bees Nest Member arrowed.

PLATE 2

Kirkhams Pit (Fig. 4)

Kirkhams Pit lies about 3 km (2 miles) west of Bees Nest Pit and is owned by Hoben Quarries Ltd. This pit is also being actively worked for sand and as with Bees Nest Pit, the succession is divisible into:

Kenslow Member

Bees Nest Member

Kirkham Member

Namurian shale mostly sheared

(not a normal contact)

Chert and clay residues, thin and very patchy

(not a normal contact)

Dolomite wall rock

On the basis of colour and lithology the Kenslow, Bees Nest and Kirkham Members can be subdivided here into twelve, ten and eleven beds respectively. In contrast to the thickness of the succession at Bees Nest Pit namely 52 m (170 feet) the Kirkham Pit succession is apparently only about 28 m (93 feet) thick. This decrease might be accounted for in at least three ways;

(i) The dolomitised rim at Bees Nest Pit lies at an elevation of about 315 m (1050 feet) above O.D. and that of Kirkhams Pit at about 252 m (840 feet) above O.D. Assuming that the members of the Brassington Formation were of similar thicknesses and originated at similar levels, then greater solution subsidence at Kirkhams Pit which is suggested by different levels of the rim rocks caused a stretching out or attenuation of the beds in the Brassington Formation.

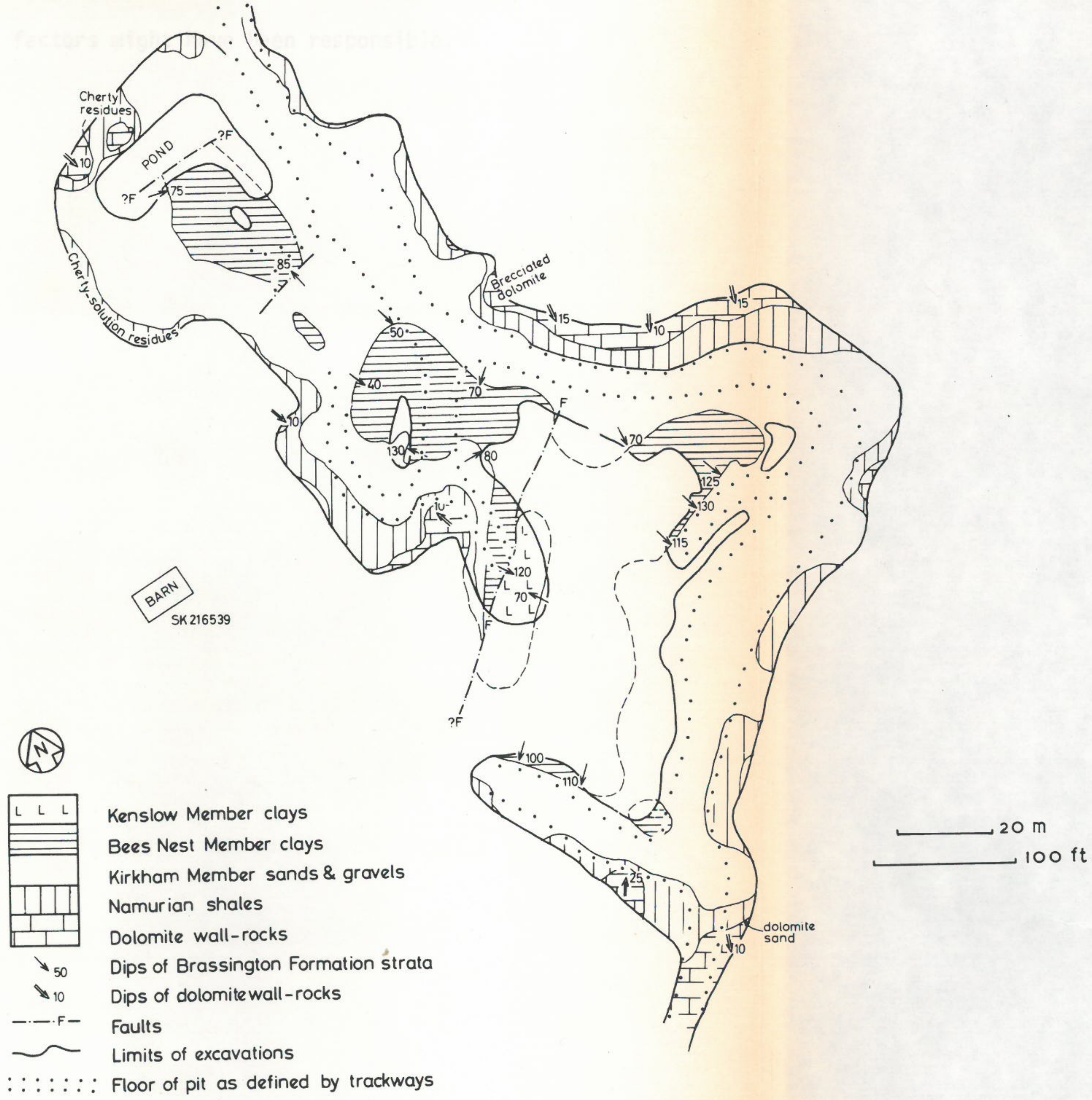


FIG. 4. Geological Map of Kirkhams Pit

(ii) The succession might originally have been thinner at the site of Kirkhams Pit.

(iii) Both factors might have been responsible.

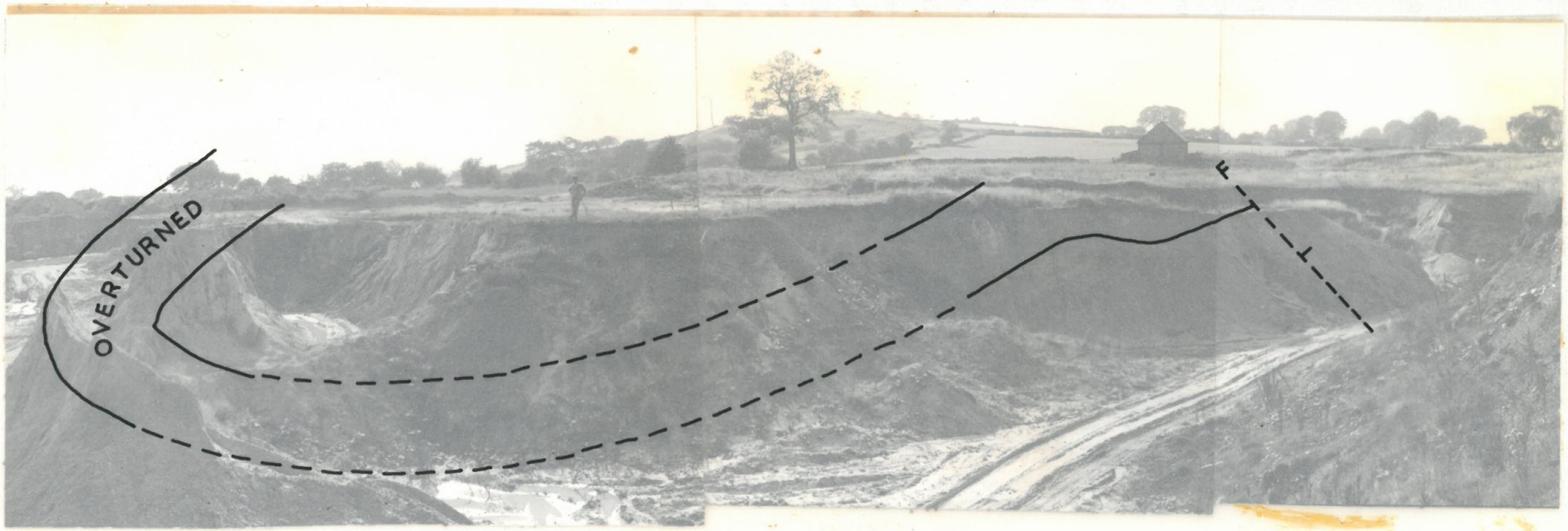


PLATE 3

Viewing S.E. Panoramic View of Kirkhams Pit Viewing S.W.

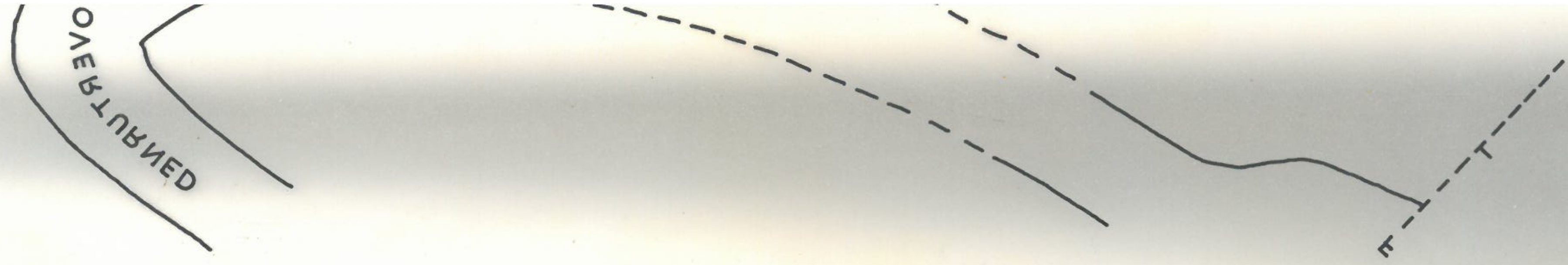


PLATE 3

Viewing S.E. — Panoramic View of Kirkhams Pit — Viewing S.W.

The Kirkhams Pit Succession (Fig. 5)

		Thickness (m)	
34-	Grey clay	0.30	(1' - 0")
33-	Grey clay with orange band mottled and yellow at top	0.30	(1' - 0")
32-	Discontinuous lens of silty sand	0.30 - nil	(1'- nil)
31-	Carbonaceous grey clay with blocks of lignite	0.30	(1' - 0")
30-	Pale yellowish grey clay	0.45	(1' - 6")
29-	Dark grey clay	0.30	(1' - 0")
28-	Lignitic clay	0.15	(0' - 6")
27-	Pale grey clay	0.07	(0' - 3")
26-	Lignitic clay	0.07	(0' - 3")
25-	Pale grey clay	0.60	(2' - 0")
24-	Lignitic clay	0.15	(0' - 6")
23-	Nondescript pale grey clay with occasional organic fragments	1.80	(9' - 0")
22-	Mottled red yellow silty clay	0.15	(0' - 6")
21-	Green clay	2.24	(8' - 0")
20-	Red clay	0.60	(2' - 0")
19-	Green silty clay with orange streaks	1.05	(3' - 6")
18-	Green and red clay	1.05	(3' - 6")
17-	Very fine buff and orange sand	0.02	(0' - 1")
16-	Green and red clay	0.02	(0' - 1")
15-	Sand with orange streaks	0.25	(0' - 10")
14-	Red clay	0.22	(0' - 9")
13-	Green silty clay with black streaks	0.25	(0' - 10")
12-	Very fine sand with yellow and orange streaks	1.15	(5' - 0")
11-	Wedge of gravel	0.30 - nil	(1'- nil)
10-	Green clay	0.10	(0' - 4")
9-	Buff sand with brownish streaks	0.60	(2' - 0")
8-	Green clay	0.10	(0' - 4")
7-	Gravel with sand	2.10	(7' - 0")
6-	Green clay (partly red)	0.15	(0' - 6")
5-	Lens of sand	1.20	(4' - nil)
4-	Orange pebbly sand	1.50	(5' - 0")
3-	Red, yellow and buff with streaks of red silty clay	4.50	(15' - 0")
2-	Red clay	0.22	(0' - 9")
1-	Buff sand with orange streak	6.00	(20' - 0")

	Thickness (m)
Namurian shale	1.50 (5' - 0")
(not a normal contact)	
Chert and clay residues	0.30 (1' - 0")
(not a normal contact)	
Dolomite wall rock	

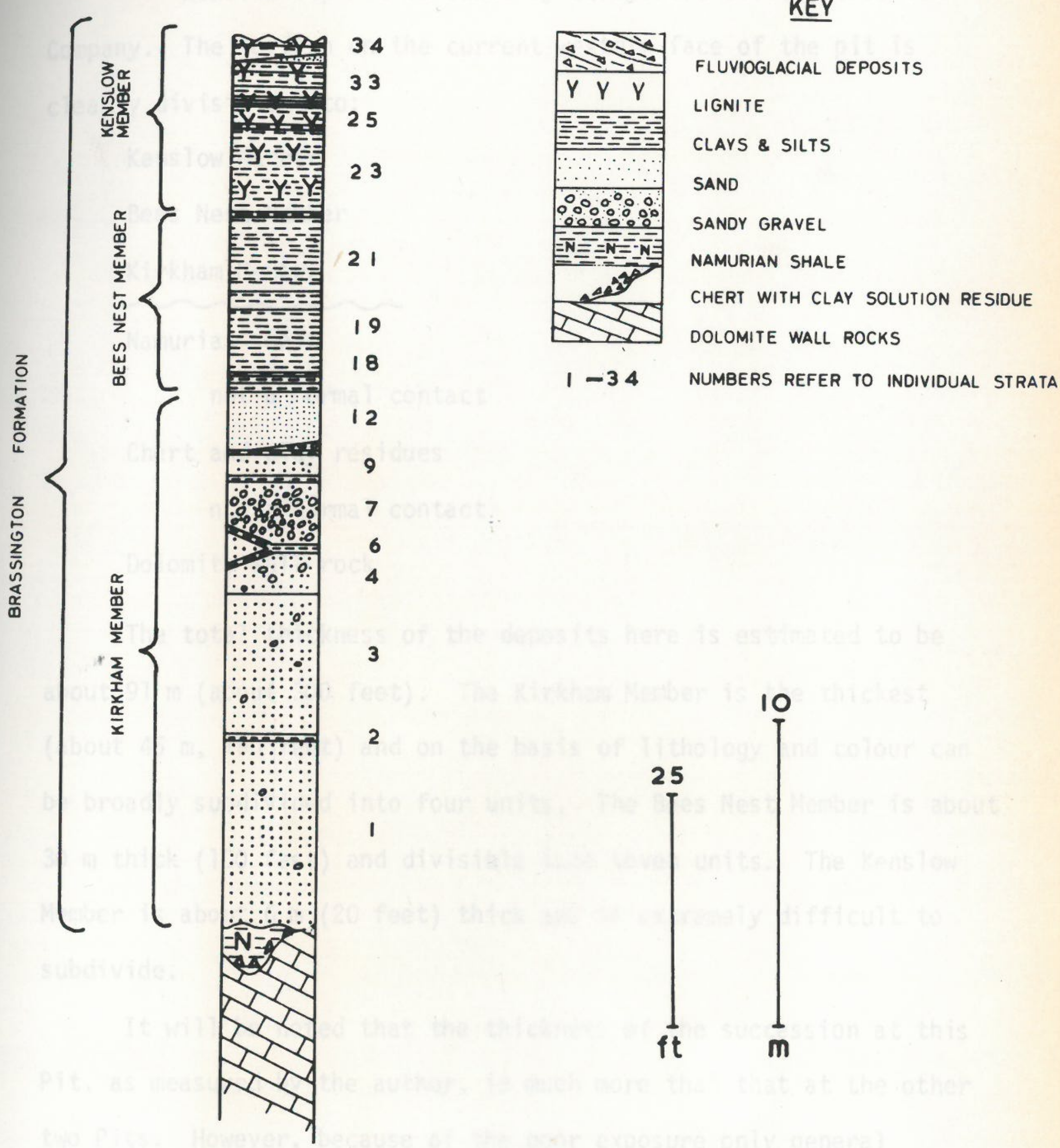


FIG.5. The Kirkams Pit Succession

Kenslow Top Pit (Fig. 6)

Kenslow Top Pit is owned by Derbyshire Silica Firebrick Company. The section on the current western face of the pit is clearly divisible into:

Kenslow Member

Bees Nest Member

Kirkham Member

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Namurian shale

not a normal contact

Chert and clay residues

not a normal contact

Dolomite wall rock

The total thickness of the deposits here is estimated to be about 91 m (about 300 feet). The Kirkham Member is the thickest (about 45 m, 150 feet) and on the basis of lithology and colour can be broadly subdivided into four units. The Bees Nest Member is about 30 m thick (100 feet) and divisible into seven units. The Kenslow Member is about 6 m (20 feet) thick and is extremely difficult to subdivide.

It will be noted that the thickness of the succession at this Pit, as measured by the author, is much more than that at the other two Pits. However, because of the poor exposure only general estimates could be made for some parts of the sections and the apparent great difference in thickness might conceivably be partly due to difficulties of measurement. Kent (1957) quoted a total thickness of 38 m (127 feet) for Kirkham and Bees Nest Members in Kenslow Top Pit. This was measured in 1946 when presumably a much smaller and
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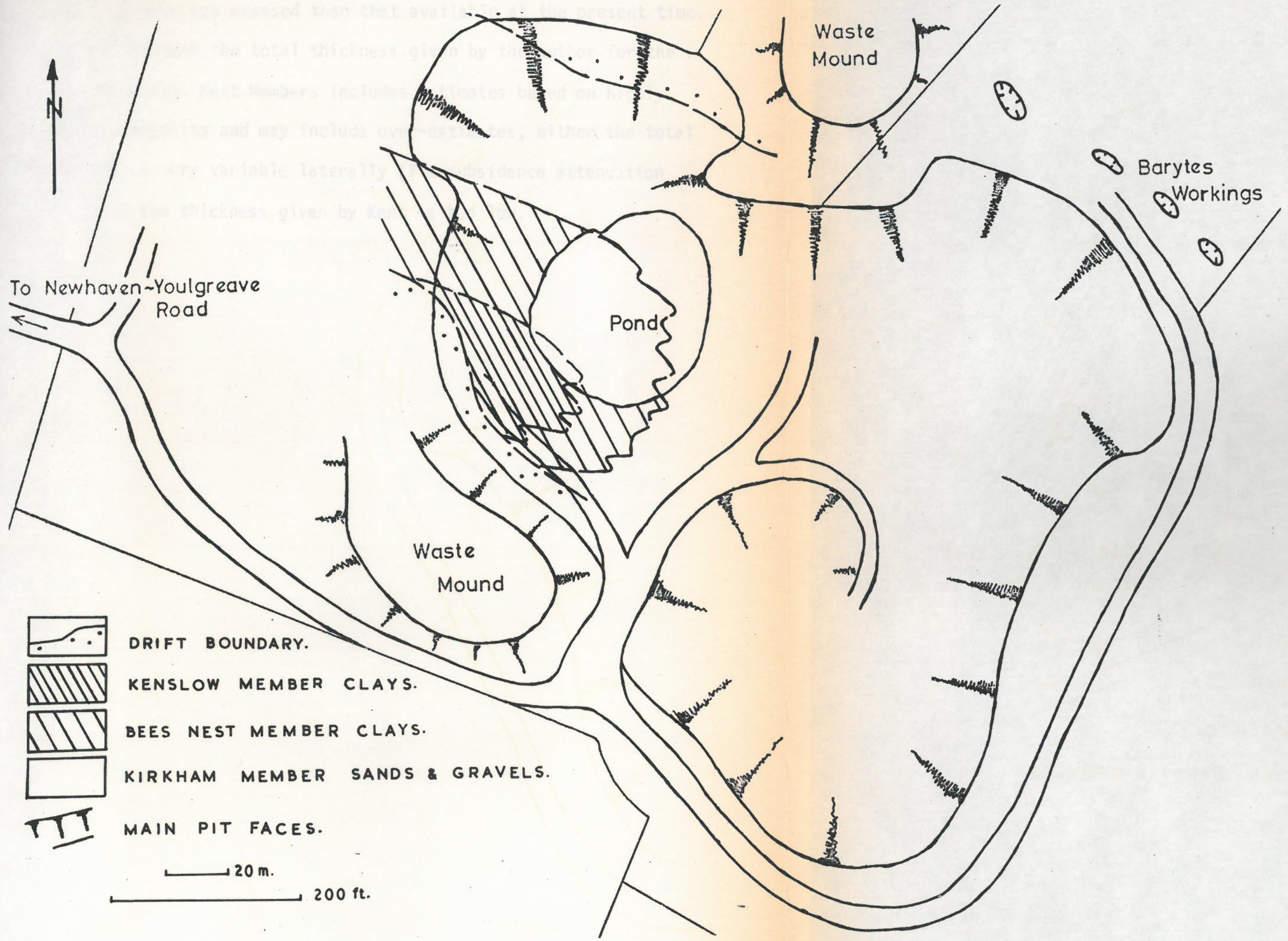


FIG. 6. Geological sketch map of Kenslow Top Pit (July 1970)

clearer section was exposed than that available at the present time. However, although the total thickness given by the author for the Kirkham and Bees Nest Members includes estimates based on highly disturbed deposits and may include over-estimates, either the total thickness is very variable laterally (? a subsidence attenuation effect) or the thickness given by Kent is too low.

PLATE 4

Kenslow Top Pit (South Western Corner)

B- Summary of the field characteristics of the three members comprising the Brassington Formation.

The Kirkham Member is composed of gravel, sands and clays. There has been no apparent break in deposition but there is considerable lateral variation in the thickness of individual beds. The general sequence is remarkably comparable at Bees Nest and Kirkhams Pits. Each bed corresponds to a change in the conditions of deposition and sometimes this change is very abrupt as represented by sharp contact of sand and clay.

The middle part of the Kirkham Member is a thick gravel bed. The pebbles in this bed range up to 18 cm (7 inches) in diameter are mostly composed of bleached quartzite. There are also occasional pebbles of rhyolite, granite, and slate etc. The upper and lower parts of the Kirkham Member consist essentially of medium-grained sand with interbedded clays.

The Kirkham Member is conformably overlain by the Bees Nest Member which consists of bright coloured silty clays.

The Bees Nest Member is overlain by the Kenslow Member. Although the boundary is not easy to define, the contrast in general character between the Kenslow Member and the Bees Nest Member is marked and unmistakable (the Bees Nest Member is more silty and does not contain organic material).

C- Correlation of the successions studied by the author

Despite the difference in thickness at the three localities described here,the stratigraphy is essentially similar at all three. All three sections are clearly divisible into three members.

Because of the stratigraphical similarity at all these three localities one might reasonably conclude from the field evidence that the sediments preserved at these localities are subsidence outliers of what was once a single continuous sedimentary sheet (Fig. 7).

D- The rocks upon which the Brassington Formation was probably deposited

The relationship of the Brassington Formation to the Namurian shale is somewhat controversial. In some pits large blocks of fresh, undisturbed Namurian shale are present but in others none has been detected. Some authors have stated a belief that the Brassington Formation sediments were laid down directly on the Carboniferous Limestone (Ford & King 1969, Yorke 1954-61) and have assumed that wherever Namurian shale is found, its presence is due to glacial transportation.

There are at least six localities where large shale blocks are known. These are Bees Nest Pit, Green Clay Pit (SK 241548), Kirkhams Pit, Low Moor Pit (SK 187566),the southern of the two Mininglow Pits (SK 202574) and Kenslow Top Pit. It is quite clear that, in each case, the Namurian shale is sandwiched between the Kirkham Member and either cherty residue or the dolomite wall rock. It would be a coincidence had the glacier conveyed the blocks to exactly the same stratigraphical position in each of the localities (though Dr. T.D. Ford informed the author that he has observed shale blocks which were unquestionably well away from the margins of certain pits and which have now been entirely quarried away). The author, therefore, considers that over at least the area

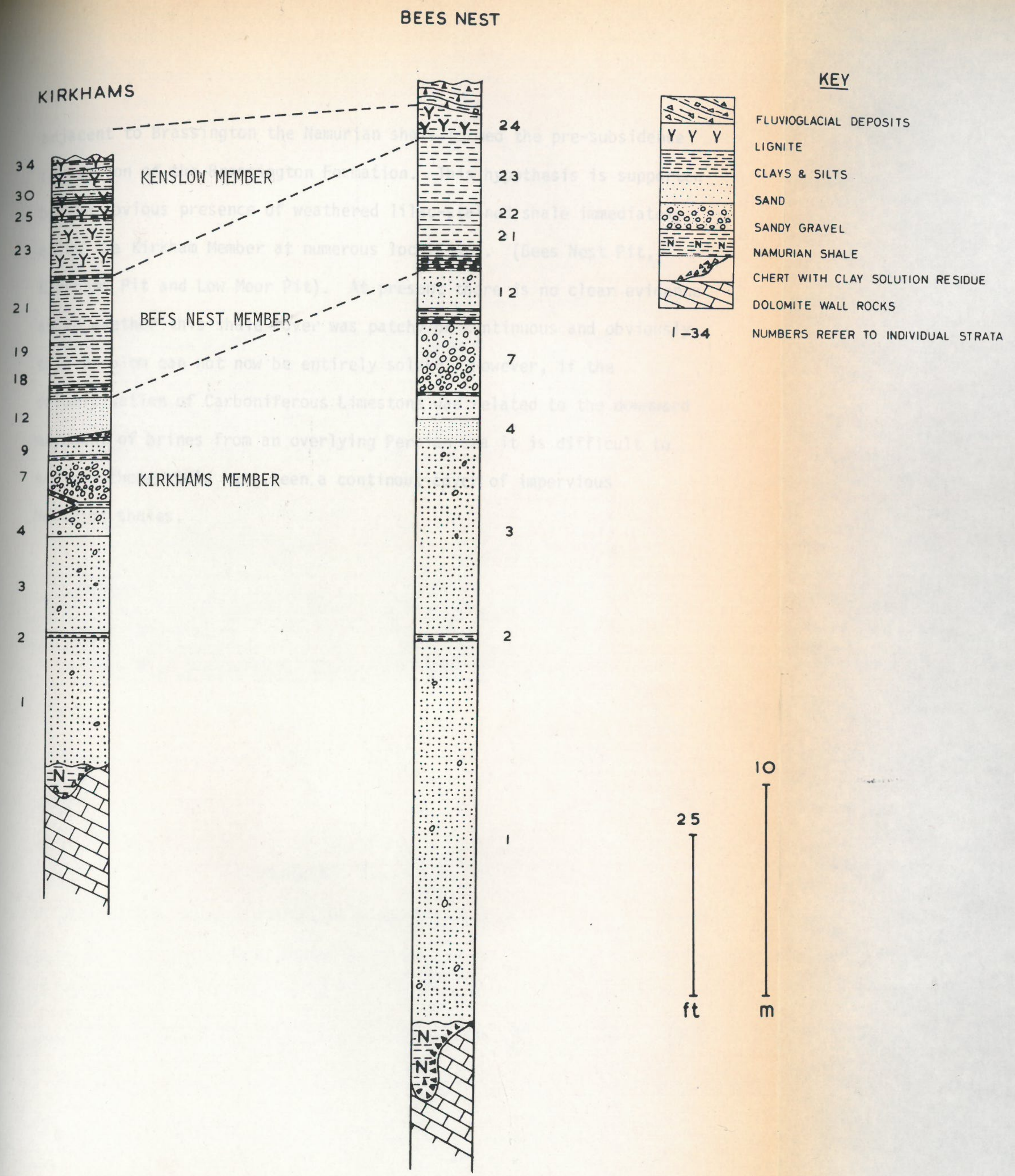


FIG.7. Correlation between the Kirkhams and Bees Nest Pits Successions

adjacent to Brassington the Namurian shale formed the pre-subsidence foundation of the Brassington Formation. This hypothesis is supported by the obvious presence of weathered lilac-stained shale immediately below the Kirkham Member at numerous localities. (Bees Nest Pit, Kirkhams Pit and Low Moor Pit). At present there is no clear evidence as to whether this shale cover was patchy or continuous and obviously this problem can not now be entirely solved. However, if the dolomitisation of Carboniferous Limestone was related to the downward movement of brines from an overlying Permian sea it is difficult to see how there could have been a continous cover of impervious Namurian shales.

PLATE 5

Contact of weathered Namurian shale and Kirkhams sand -

Bees Nest Pit

3. SEDIMENTOLOGICAL LABORATORY INVESTIGATIONS

Various laboratory techniques were used in the study of samples from Bees Nest Pit, Kirkhams Pit, the nearest exposure of the Bunter i.e. that in Hulland Quarry. This was undertaken in order to obtain sedimentological evidence additional to that provided by the field evidence and to try and establish:

(a) a bed by bed correlation between Bees Nest and Kirkham Pits;

(b) the depositional environment of the Brassington Formation;

(c) the provenance of the sediments.

A- Mechanical analyses

(i) Sampling

There are two methods of sampling - the channel sampling and the spot sampling (Folk 1965). As channel sampling yields composite data, made of several sets of individual data and furnishes no information whatever on the degree of sorting or mineralogical composition of individual beds,it is of no use for the determination of depositional environment or detailed correlation. For this reason, the second method was used and a series of spot samples were collected at reasonable intervals.

(ii) Procedure

Each sample was air dried and then crushed manually on a sheet of glazed paper. It was then examined with a hand lens to check whether or not all of the sample was crushed. In order to reduce the sample to a mass of individual grain, whenever a lump of sand was seen,a screen just larger than the size of the largest individual grain was selected and the whole sample was run through it. The lumps were then poured into a mortar and gently pounded with a rubber cork until they were disaggregated. The representative fraction was obtained from the disaggregated material, by quartering. The representative fraction was then carefully weighed. The sand fraction was separated from silt and clay by wet sieving through a 62 micron screen. The material retained on this screen (sand) was dried and run through a set of 0.5Ø interval sieves. The material which passed through a 4Ø (62 micron) sieve was first dispersed and then analysed by pipette. Several dispersants were tried. Ammonium hydroxide (NH_4OH) was found to be the best for most of the samples. For some samples, however, ammonium hydroxide was not found to be effective and sodium hexametaphosphate was used instead. The dispersed sediments were then poured in a one litre cylinder and more distilled water containing dispersant was then added to bring it to exactly 1000 ml. At a constant temperature of 20^{o}C, suspensions were sucked by pipette according to the time and depth given in Table 16 of Krumbien and Pettijohn (1938).

(iii) Tabular presentation of the representative data

The data thus obtained for the sand and silt fractions is given in Tables 1 - 13.

TABLE 1

BEES NEST PIT 24(TOP)		BEES NEST PIT 24(BOTTOM)		BEES NEST PIT 23			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
						1.405	-0.49
						1.003	-0.00
						0.699	0.52
						0.500	1.00
		.105	.105			0.353	1.50
.59	.59	.215	.320			0.251	1.99
.62	1.11	.412	.732	.066	.066	0.178	2.49
.98	2.09	.673	1.405	.299	.365	0.124	3.01
.92	3.01	1.595	3.00	1.092	1.457	0.089	3.49
6.51	9.52	15.82	18.82	6.017	7.474	0.066	3.91
9.21	18.73	11.680	30.50	3.662	11.136	0.44	4.50
12.17	30.90	17.28	47.783	10.301	21.446	0.031	5.00
12.82	43.72	4.850	58.893	12.650	34.096	0.022	5.50
9.86	53.58	3.950	67.929	9.986	44.082	0.015	6.00
14.14	67.72	6.650	83.159	18.310	62.392	0.007	7.00
25.00	92.72	4.200	92.777	18.310	80.702	0.003	8.00
7.23	99.95	3.150	99.991	19.280	99.982	0.002	9.00

TABLE 2

BEES NEST PIT 22		BEES NEST PIT 21		BEES NEST PIT 20			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
						1.405	-0.49
		.09	.09			1.003	-0.00
		.100	.19			0.699	0.52
		.24	.43	.192	.192	0.500	1.00
		.48	.91	.485	.677	0.353	1.50
		.71	1.62	.667	1.344	0.251	1.99
		1.24	2.86	1.436	2.780	0.178	2.49
		3.62	6.54	3.015	5.795	0.124	3.01
		6.48	13.02	4.355	10.150	0.089	3.49
4.97	4.97	24.36	37.38	10.420	20.572	0.066	3.91
16.39	21.36	13.31	50.69	1.518	22.080	0.44	4.50
6.17	27.53	10.30	60.99	8.095	30.175	0.031	5.00
6.17	33.70	2.74	63.73	1.012	31.187	0.022	5.50
6.17	39.87	7.41	71.14	9.105	40.292	0.015	6.00
16.57	57.44	9.33	80.47	17.200	57.492	0.007	7.00
23.80	80.24	10.30	90.77	20.740	78.232	0.003	8.00
19.74	99.98	9.19	99.96	21.750	99.982	0.002	9.00

TABLE 3

BEES NEST PIT 19		BEES NEST PIT 18		BEES NEST PIT 17			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
.29	.29			.10	.10	1.405	-0.49
.26	.55			.14	.24	1.003	-0.00
.20	.75	.20	.20	.21	.45	0.699	0.52
.53	1.28	.99	1.19	.90	1.35	0.500	1.00
1.69	2.97	.304	4.23	3.26	4.61	0.353	1.50
4.61	7.58	6.42	10.65	6.53	11.14	0.251	1.99
11.90	19.48	12.36	23.05	9.57	20.71	0.178	2.49
25.39	44.87	25.58	48.59	17.12	37.83	0.124	3.01
15.29	60.16	21.53	70.12	14.47	52.30	0.089	3.49
14.32	74.48	21.78	91.90	16.25	68.55	0.066	3.91
6.99	81.47	3.42	95.32	8.16	76.71	0.44	4.50
1.48	82.95	.996	96.28	.72	77.43	0.031	5.00
1.63	84.58	.67	96.95	1.63	79.06	0.022	5.50
.59	85.17	.37	97.32	.54	79.60	0.015	6.00
2.67	87.84	1.11	98.43	4.35	83.95	0.007	7.00
5.80	93.64	.96	99.39	6.89	90.84	0.003	8.00
6.25	99.89	.52	99.91	9.07	99.91	0.002	9.00

TABLE 4

BEES NEST PIT 15		BEES NEST PIT 14		BEES NEST PIT 12			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
.48	.48	.079	.079	.16	.16	1.405	-0.49
.73	1.21	.142	.221	.18	.34	1.003	-0.00
1.32	2.53	.232	.453	.61	.95	0.699	0.52
3.57	6.10	.451	.904	5.31	6.26	0.500	1.00
10.63	16.73	1.472	2.376	28.63	34.89	0.353	1.50
15.85	32.58	1.752	4.128	34.28	69.17	0.251	1.99
16.59	49.17	1.177	5.305	16.55	85.72	0.178	2.49
20.29	69.46	1.132	6.437	4.58	90.30	0.124	3.01
15.64	85.10	2.075	8.512	.55	90.85	0.089	3.49
8.19	93.29	2.987	11.499	2.90	93.75	0.066	3.91
1.83	95.12	19.00	30.499	.31	94.06	0.44	4.50
1.33	96.45	.258	30.757	.73	94.79	0.031	5.00
.33	96.78	8.170	38.936	.73	95.52	0.022	5.50
.50	97.28	10.290	49.226	.82	96.34	0.015	6.00
.66	97.94	18.33	67.556	1.32	97.66	0.007	7.00
.58	98.52	17.93	85.486	1.41	99.07	0.003	8.00
1.41	99.93	14.51	99.996	.86	99.93	0.002	9.00

TABLE 5

BEES NEST PIT 11		BEES NEST PIT 10		BEES NEST PIT 9			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
						1.405	-0.49
.01	.01					1.003	-0.00
-	-					0.699	0.52
.01	.02					0.500	1.00
.04	.06	.035	.035			0.353	1.50
.05	.11	.064	.099			0.251	1.99
.04	.15	.083	.182			0.178	2.49
.05	.20	.136	.318	.34	.34	0.124	3.01
.11	.31	.483	.801	1.30	1.60	0.089	3.49
2.43	2.74	1.631	2.432	5.95	7.59	0.066	3.91
64.17	66.91	3.86	6.292	19.13	26.72	0.044	4.50
10.00	76.91	14.79	21.08	14.77	41.49	0.031	5.00
2.08	78.99	5.84	26.922	12.47	53.96	0.022	5.50
4.29	83.28	6.73	33.652	8.96	62.92	0.015	6.00
5.91	89.19	20.08	53.732	13.44	76.36	0.007	7.00
5.66	94.85	24.95	78.682	13.33	89.69	0.003	8.00
5.08	99.93	21.30	99.982	10.29	99.98	0.002	9.00

TABLE 6

BEES NEST PIT 8		BEES NEST PIT 7		BEES NEST PIT 5			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
				.82	.82	2.057	-1.04
		.884	.884	.16	.98	1.405	-0.49
		1.995	2.879	.69	1.67	1.003	-0.00
.24	.24	3.867	6.746	2.3	3.97	0.699	0.52
2.05	2.29	14.860	21.606	8.73	12.70	0.500	1.00
14.24	16.53	40.760	62.366	38.73	51.43	0.353	1.50
37.40	53.93	16.590	78.956	33.63	85.06	0.251	1.99
24.28	78.21	5.126	84.082	6.75	91.81	0.178	2.49
8.92	87.13	4.592	88.676	1.43	93.24	0.124	3.01
3.38	90.51	2.844	91.520	1.31	94.55	0.089	3.49
2.58	93.09	1.590	93.110	.88	95.35	0.066	3.91
1.08	94.17	.720	93.830	.63	95.98	0.044	4.50
.68	94.85	.504	94.334	.31	96.29	0.031	5.00
.46	95.31	1.270	95.604	.509	96.799	0.022	5.50
.71	96.02	.648	96.252	.473	97.272	0.015	6.00
1.24	97.26	2.016	98.268	.982	98.254	0.007	7.00
1.52	98.78	1.224	99.492	1.05	99.309	0.003	8.00
1.15	99.93	.504	99.996	.509	99.818	0.002	9.00

TABLE 7

BEES NEST PIT 4		BEES NEST PIT 3		BEES NEST PIT 2			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
						1.405	-0.49
		.049	.049			1.003	-0.00
		.140	.189			0.699	0.52
		1.496	1.685			0.500	1.00
.55	.55	14.39	16.075			0.353	1.50
1.33	1.88	25.850	41.925	.042	.042	0.251	1.99
3.81	5.68	24.190	66.115	.075	.117	0.178	2.49
20.01	25.69	11.690	77.805	.084	.201	0.124	3.01
41.59	67.28	4.705	82.510	.632	.833	0.089	3.49
14.04	81.32	2.401	84.911	4.305	5.138	0.066	3.91
4.23	85.55	1.094	86.005	5.663	10.791	0.44	4.50
2.34	87.89	1.841	87.846	6.371	17.162	0.031	5.00
1.39	89.28	.788	88.634	7.314	24.476	0.022	5.50
1.99	90.27	1.314	89.948	8.258	32.734	0.015	6.00
3.64	93.91	3.331	93.279	19.13	51.860	0.007	7.00
3.51	97.42	2.980	96.259	23.830	75.690	0.003	8.00
2.52	99.94	3.725	99.984	24.310	100.00	0.002	9.00

TABLE 8

BEES NEST PIT 1			
Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
		2.057	-1.04
		1.405	-0.49
		1.003	-0.00
		0.699	0.52
		0.500	1.00
		0.353	1.50
16.93	16.93	0.251	1.99
44.20	61.13	0.178	2.49
13.30	74.43	0.124	3.01
5.09	79.52	0.089	3.49
2.76	82.28	0.066	3.91
1.77	84.05	0.44	4.50
1.87	85.92	0.031	5.00
1.38	87.30	0.022	5.50
3.03	90.33	0.015	6.00
4.15	94.48	0.007	7.00
2.37	96.85	0.003	8.00
2.5	99.35	0.002	9.00

TABLE 9

KIRKHAMS PIT 31		KIRKHAMS PIT 20		KIRKHAMS PIT 19			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2,057	-1.04
						1.405	-0.49
						1.003	-0.00
						0.699	0.52
						0.500	1.00
						0.353	1.50
.11	.11					0.251	1.99
.23	.34					0.178	2.49
.70	1.04					0.124	3.01
1.64	2.68	2.905	2.905	.263	.263	0.089	3.49
5.12	7.80	5.878	8.783	1.105	1.368	0.066	3.91
22.05	29.85	14.739	23.522	2.408	3.776	0.44	4.50
12.05	41.90	7.049	30.571	8.74	12.650	0.031	5.00
11.17	53.07	7.263	37.834	11.916	24.566	0.022	5.50
9.11	62.18	8.544	46.378	9.888	34.454	0.015	6.00
16.76	78.94	10.895	57.273	19.269	53.723	0.007	7.00
12.05	90.99	26.275	83.548	41.582	95.305	0.003	8.00
9.11	100.1	16.448	99.996	4.690	99.995	0.002	9.00

TABLE 10

KIRKHAMS PIT 18		KIRKHAMS PIT 14		KIRKHAMS PIT 13			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
		.171	.171			1.405	-0.49
		.143	.341			1.003	-0.00
		.217	.531			0.699	0.52
		.522	1.053			0.500	1.00
		1.203	2.250	.76	.76	0.353	1.50
		1.48	3.674	1.12	1.88	0.251	1.99
		1.325	4.99	1.58	3.46	0.178	2.49
.323	.323	2.660	7.659	3.67	7.13	0.124	3.01
.263	.586	8.989	16.608	14.02	21.15	0.089	3.4(
1.585	2.17	11.801	28.499	22.50	43.65	0.066	3.91
6.880	9.051	23.022	51.521	16.47	60.12	0.044	4.50
4.487	13.538	6.362	57.883	6.51	66.63	0.031	5.00
10.470	24.008	6.594	64.477	3.57	70.16	0.022	5.50
3.590	27.598	5.784	70.261	5.49	75.65	0.015	6.00
12.265	39.863	11.221	81.482	7.27	82.92	0.007	7.00
28.121	67.989	11.800	93.282	9.45	92.37	0.003	8.00
32.011	99.95	6.710	99.92	7.53	99.90	0.002	9.00

TABLE 11

KIRKHAMS PIT 9		KIRKHAMS PIT 8		KIRKHAMS PIT 6			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
						1.405	-0.49
						1.003	-0.00
						0.699	0.52
						0.500	1.00
.72	.72	.44	.44			0.353	1.50
3.93	4.65	.51	.95			0.251	1.99
17.41	22.06	.44	1.39			0.178	2.49
36.83	58.89	.44	1.83	.49	.49	0.124	3.01
20.88	79.77	.61	2.44	1.13	1.62	0.089	3.49
3.82	83.59	1.29	3.73	4.54	6.16	0.066	3.91
1.86	85.45	4.25	7.98	10.97	17.13	0.44	4.50
2.09	87.54	7.49	15.47	6.62	22.75	0.031	5.00
1.96	90.50	9.02	24.49	5.29	29.04	0.022	5.50
1.36	90.86	10.21	34.70	7.75	36.79	0.015	6.00
3.28	94.14	23.32	58.02	15.32	52.11	0.007	7.00
3.10	97.24	23.32	81.34	27.24	79.35	0.003	8.00
2.68	99.92	19.06	100.4	20.62	99.97	0.002	9.00

TABLE 12

KIRKHAMS PIT 4		KIRKHAMS PIT 3		KIRKHAMS PIT 2			
Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
						2.057	-1.04
.41	.41					1.405	-0.49
.52	.93					1.003	-0.00
1.30	2.23					0.699	0.52
8.18	10.41					0.500	1.00
31.03	48.44	11.92	11.92			0.353	1.50
24.33	72.77	44.52	56.44			0.251	1.99
90.74	82.51	22.1	78.54			0.178	2.49
4.27	86.72	6.78	85.32			0.124	3.01
3.50	90.28	4.42	89.74			0.089	3.49
1.27	91.55	2.15	91.81	.81	.81	0.066	3.91
.78	92.33	1.13	93.02	4.73	5.54	0.44	4.50
.72	93.05	.97	93.99	5.91	11.45	0.031	5.00
.72	93.77	.71	94.70	7.94	19.39	0.022	5.50
.70	94.47	.87	95.57	9.29	28.68	0.016	6.00
1.66	96.13	1.74	97.31	20.78	49.46	0.007	7.00
2.00	98.13	1.74	99.05	29.23	78.69	0.003	8.00
1.79	99.92	,87	99.92	21.29	99.98	0.002	9.00

TABLE 13

KIRKHAMS PIT 1			
Weight % Retained	Cumulative Percent	Aperture in mm	Phi Value
		2.057	-1.04
		1.405	-0.49
		1.003	-0.00
		0.699	0.52
		0.500	1.00
.79	.79	0.353	1.50
9.19	9.98	0.251	1.99
20.13	30.11	0.178	2.49
19.33	49.44	0.124	3.01
15.71	65.15	0.089	3.49
10.93	76.08	0.066	3.91
3.76	79.84	0.44	4.50
3.69	83.53	0.031	5.00
2.28	85.81	0.022	5.50
2.71	88.52	0.015	6.00
4.29	92.81	0.007	7.00
4.32	97.13	0.003	8.00
2.82	99.95	0.002	9.00

(iv) The types of sediments were differentiated by plotting the percentage of sand, silt and clay (Tables 14 & 15) in terms of the triangular diagram proposed by Folk (1954) Figs. 8 & 9 .

TABLE 14

Percentage of sand, silt and clay in individual beds - Bees Nest Pit

Bed Number	% Sand	% Silt	% Clay
24	6.11	58.01	35.86
23	4.69	58.10	37.20
22	2.94	56.31	40.74
21	24.78	41.56	33.64
20	8.12	31.35	60.52
19	46.85	15.99	37.14
18	90.46	7.91	2.63
17	41.18	18.84	39.96
15	82.33	5.43	12.22
14	6.93	53.45	39.69
*12	35.48	5.66	8.85
11	2.42	84.71	12.85
10	1.55	62.16	36.28
9	6.26	76.08	17.65
8	91.02	6.72	2.25
5	92.33	4.32	3.34
4	78.33	17.94	3.27
*3	79.10	13.56	7.3
2	2.89	53.25	43.85
*1	79.67	16.43	3.89

* also contains an insignificant amount of gravel.

TABLE 15

Percentage of sand, silt and clay in individual beds - Kirkhams Pit

Bed Number	% Sand	% Silt	% Clay
31	4.34	52.50	43.14
20	5.14	53.43	41.42
19	1.33	96.31	2.35
18	0.90	40.81	58.28
16	21.58	63.98	14.42
14	23.03	57.79	19.16
13	34.82	44.90	20.26
12	52.71	35.79	11.49
9	79.88	15.63	4.63
8	2.00	58.77	39.21
6	3.49	53.24	43.25
* 4	86.89	7.13	5.79
* 3	90.76	7.79	1.26
2	0.50	62.12	37.36
* 1	73.13	22.96	3.89

* Also contains an insignificant amount of gravel.

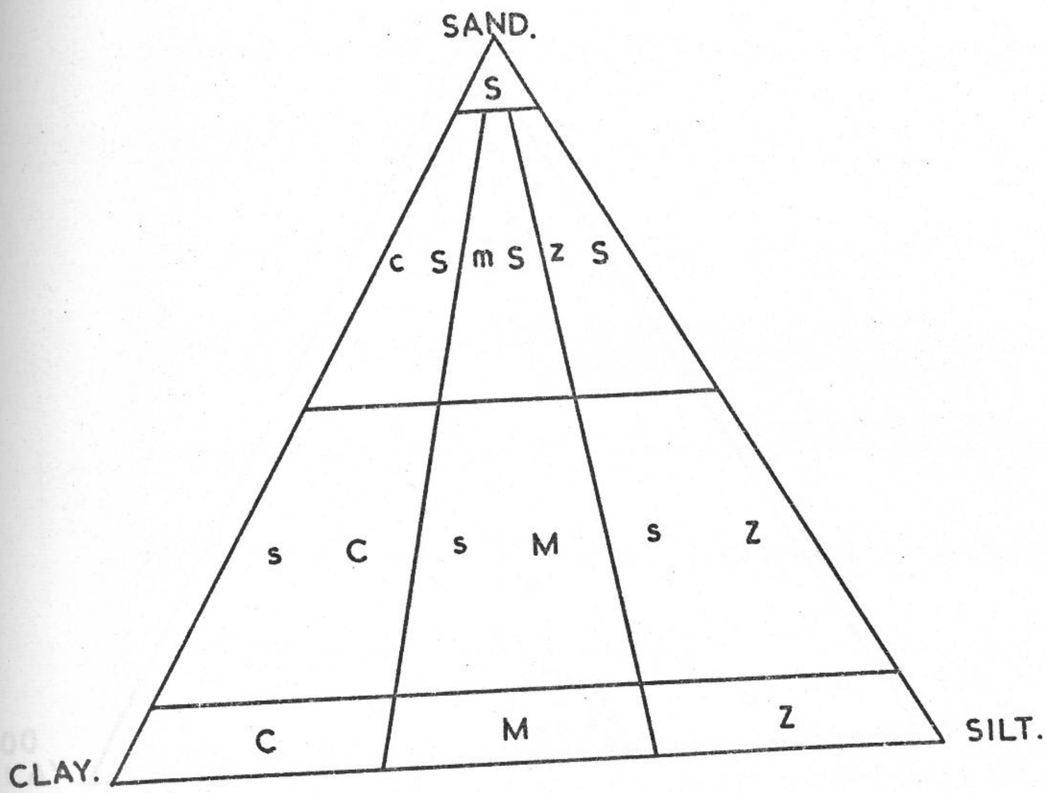


FIG.8. Ten major textural groups as defined by the relative percentages of sand, silt and clay (After R.L. Folk 1954). Letters refer to textural names shown below.

S = sand

s = sandy

Z = silt

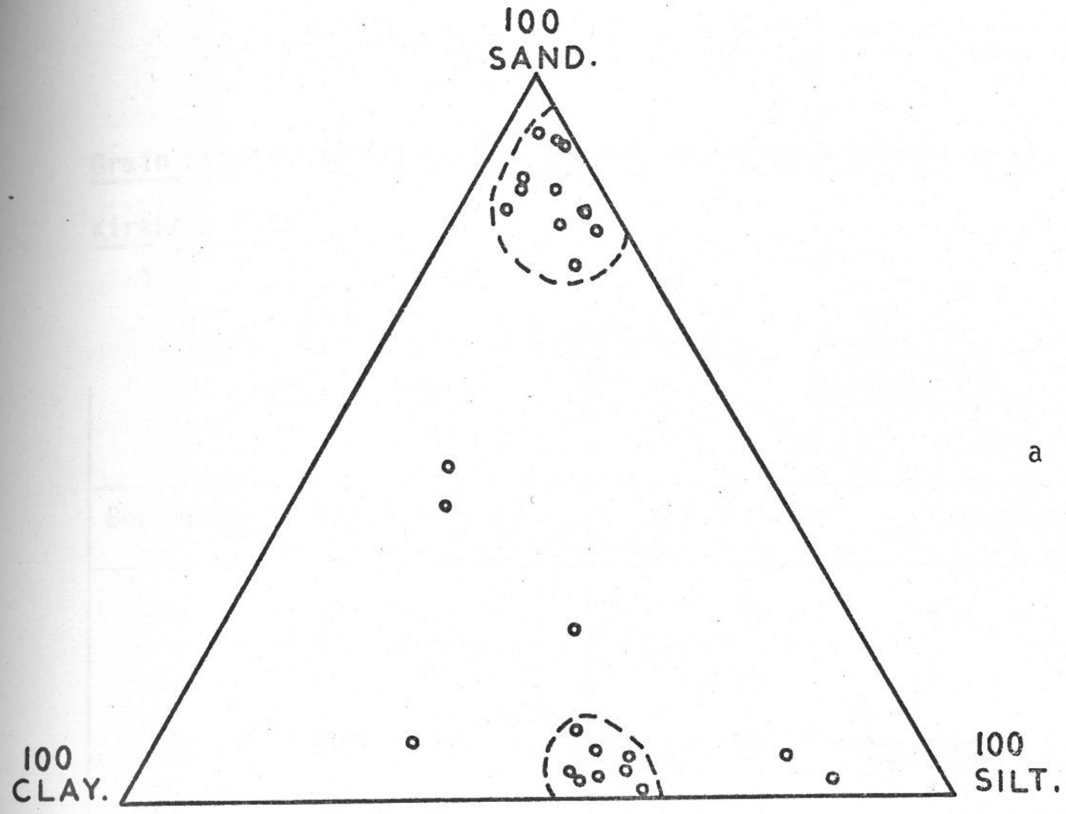
z = silty

M = mud

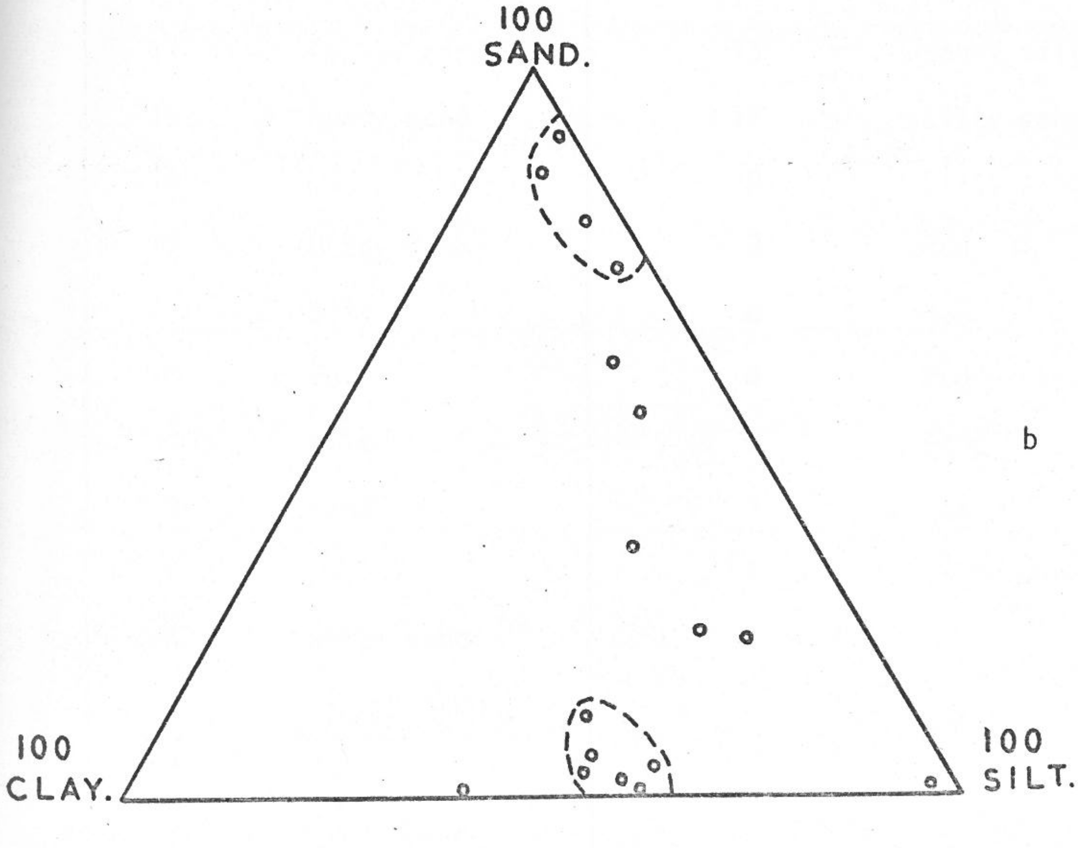
m = muddy

C = clay

c = clayey



a



b

FIG. 9. a - Bees Nest Pit sediments
b - Kirkhams Pit sediments

TABLE 16

Grain size nomenclature for the sediments from Bees Nest and Kirkhams Pits

Bees Nest Pit		Kirkhams Pit	
Bed Number	Nomenclature	Bed Number	Nomenclature
24	Mud	31	Mud
23	Mud	23	Mud
22	Mud	20	Mud
21	Sandy mud	19	Silt
20	Mud	18	Mud
19	Clayey sand	16	Sandy silt
18	Sand	14	Sandy silt
17	Clayey sand	13	Sandy silt
15	Muddy sand	12	Silty sand
14	Mud	9	Silty sand
12	Muddy sand	8	Mud
11	Silt	6	Mud
10	Mud	4	Muddy sand
9	Silt	3	Sand
8	Sand	2	Mud
5	Sand	1	Silty sand
4	Silty sand		
3	Silty sand		
2	Mud		
1	Silty sand		

(vi) Statistical parameters

In order to attempt to correlated the Bees Nest succession with the Kirkhams succession and to determine the sedimentary environment it was found necessary to determine precisely the average size, sorting, symmetry and peakedness of sediments. These measures or parameters may be determined either mathematically by method of moments or graphically by reading selected percentiles off the cumulative curves. Because the method of moment is far more complicated and probably of no greater value, the graphical method was used. For this, probability graphs were plotted on the phi scale from the data given in Tables 1 - 13. A few graphs are shown in Figs. 10, 11 & 12.

Different authors have suggested different criteria for obtaining these parameters. Because they were found to be sufficiently accurate for use in the author's research those formulae suggested by Folk (1965) were adopted. These formulae are as follows.

Graphic Mean (Mz)

$$Mz = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Inclusive Graphic Standard Deviation (OG)

$$OG \quad \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

Inclusive Graphic Skewness (SK I)

$$SKI = \frac{\phi 16 + \phi 84 - 2\,\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\,\phi 50}{2(\phi 95 - \phi 5)}$$

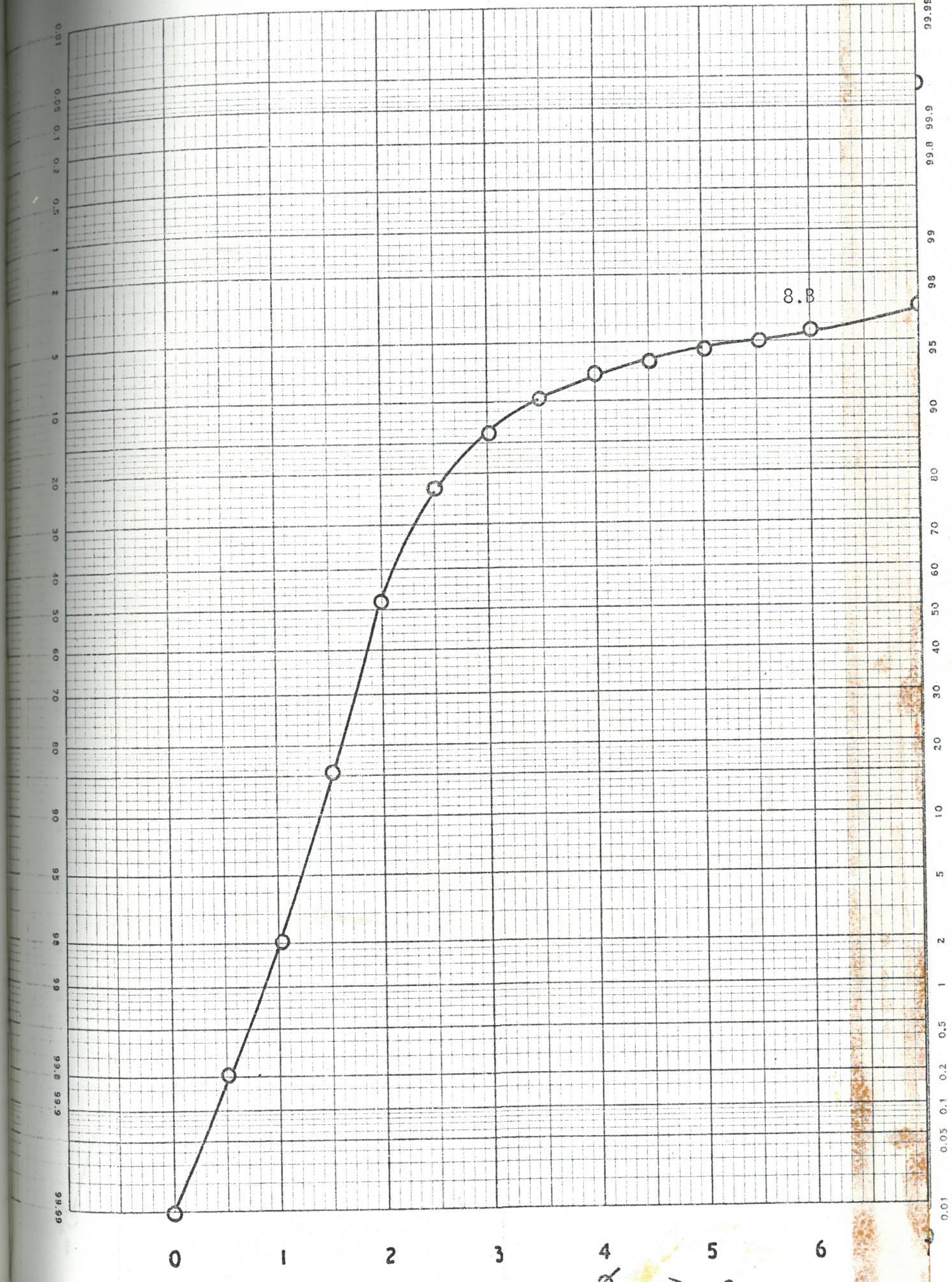


FIG.10. Particle size distribution of the sediment from Bed 8 - Bees Ne

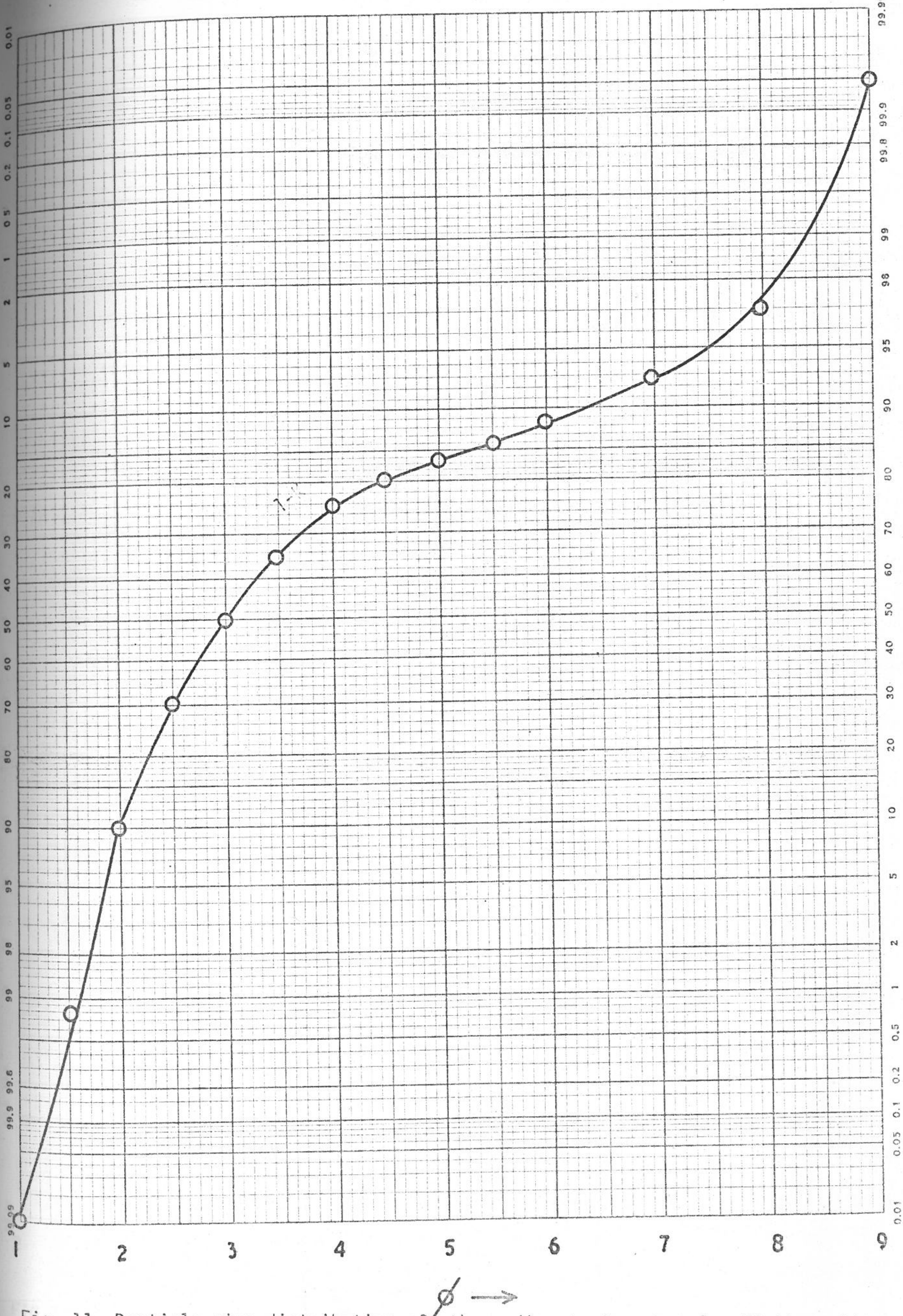


Fig. 11. Particle size distribution of the sediment from bed 1 - Kirkhams Pit

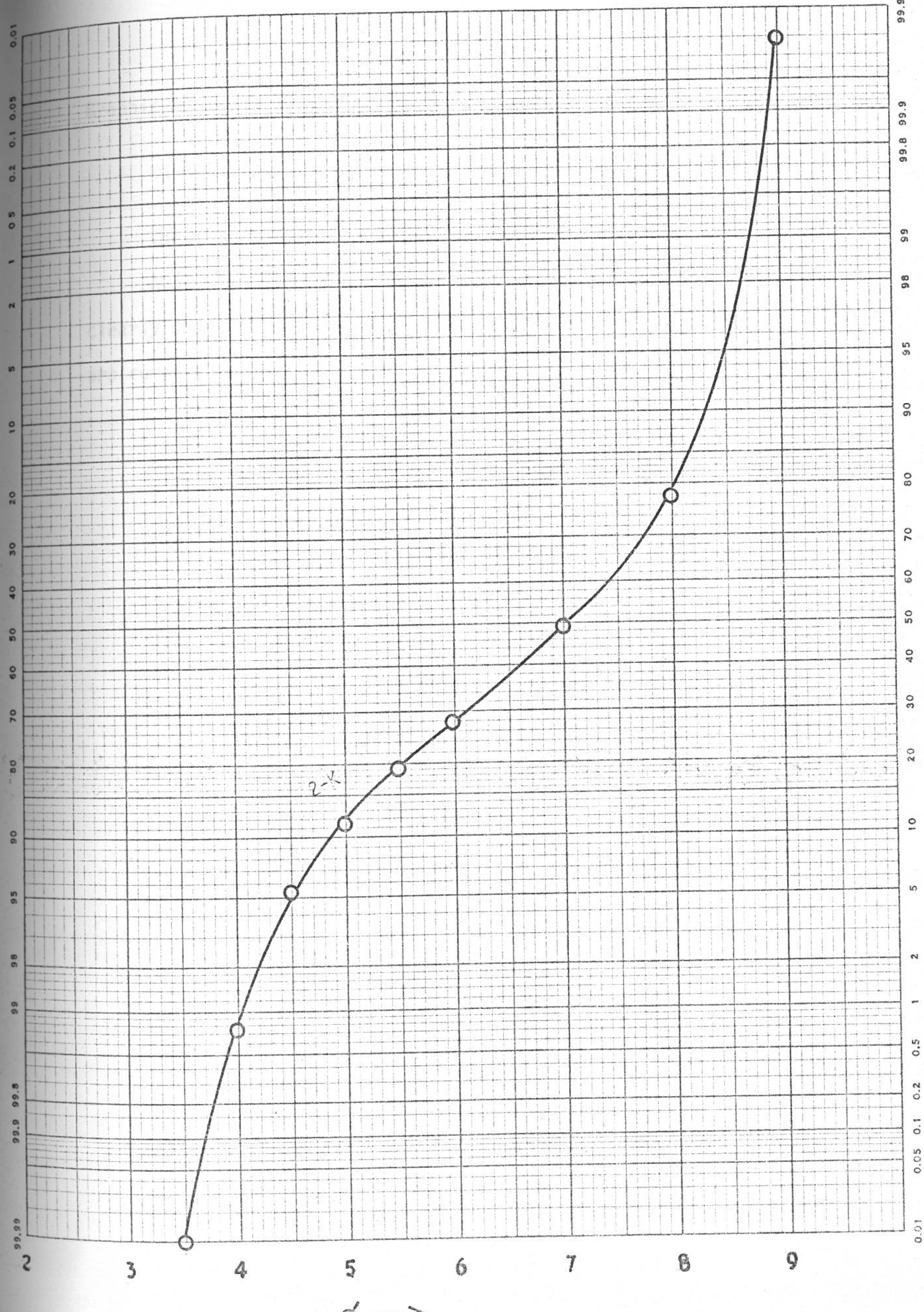


FIG.12. Particle size distribution of the sediment from bed 2 - Kirkhams Pit

Graphic Kurtosis (KG)

$$KG = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

The statistical parameters are given in Tables 17 & 18.

A plot of statistical parameters of grain size (Fig. 13) clearly shows that the Bees Nest and Kirkhams Pits successions are comparable.

TABLE 17

Statistical parameters of grain size, Bees Nest Pit

Bed Number	Mean Size	I.G.S. Deviation	I.G. Skewness	G. Kurtosis
24 (TOP)	6.1	1.67	+.39	.73
24 (BOTTOM)	5.3	1.45	+.18	.92
23	6.4	1.53	-.04	.74
22	6.7	1.56	-.29	.72
21	5.2	1.78	+.46	.80
20	6.16	1.90	-.26	.62
19	3.7	1.80	+.41	2.02
18	3.0	0.79	-.03	1.04
17	4.3	2.2	+.55	1.57
15	1.8	0.94	+.29	1.87
14	6.00	1.77	-.10	.84
12	1.8	1.12	+.32	2.42
11	4.9	1.06	+.81	2.67
10	6.6	1.42	-.17	.64
9	5.7	1.51	+.35	.75
8	2.13	1.00	+.45	3.11
7	1.53	1.20	+.48	2.37
5	3.4	1.15	+.39	3.11
4	3.4	1.26	+.44	3.46
3 (TOP)	2.3	1.22	+.56	3.41
3 (MIDDLE)	2.5	1.40	+.61	2.22
3 (BOTTOM)	2.76	1.82	+.71	2.08
2	6.73	1.48	-.26	.65
1 (TOP)	3.23	1.67	+.705	2.16
1 (MIDDLE)	2.86	1.51	+.35	1.64
1 (BOTTOM)	3.00	1.51	+.8	2.29

TABLE 18

Statistical parameters of grain size, Kirkhams Pit

Bed Number	Mean Size	I.G.S. Deviation	I.G. Skewness	G. Kurtosis
31	5.43	1.42	+.42	.76
23	5.9	1.49	-.06	.78
20	6.2	1.58	-.15	.90
18	6.96	1.46	-.50	.72
14	5.13	1.76	+.39	.88
13	4.9	1.83	-.49	.92
12	4.6	1.58	+.77	1.36
9	2.03	0.98	+.66	3.01
8	6.6	1.40	-.11	.80
6	5.9	1.45	-.09	.70
4	1.8	1.23	+.6	2.6
3(TOP)	2.56	1.87	+.29	1.22
3(MID)	2.56	1.87	+.39	1.19
3(BOTTOM)	3.1	1.3	+.6	2.6
2	6.8	1.32	-.25	.81
1(TOP)	2.76	1.05	+.27	1.26
1(MID)	3.16	1.88	+.58	1.69
1(BOTTOM)	3.4	1.63	+.49	1.48

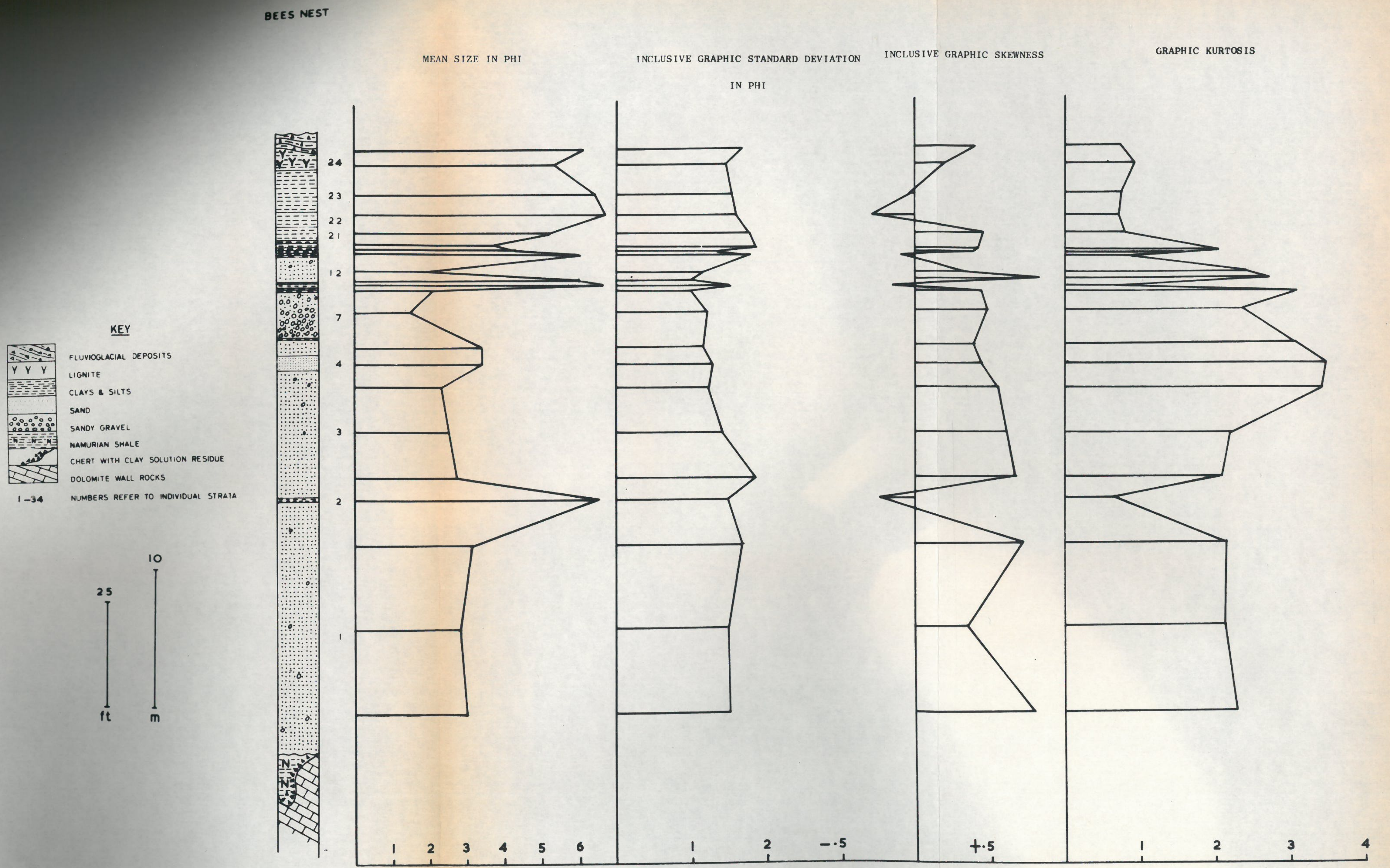
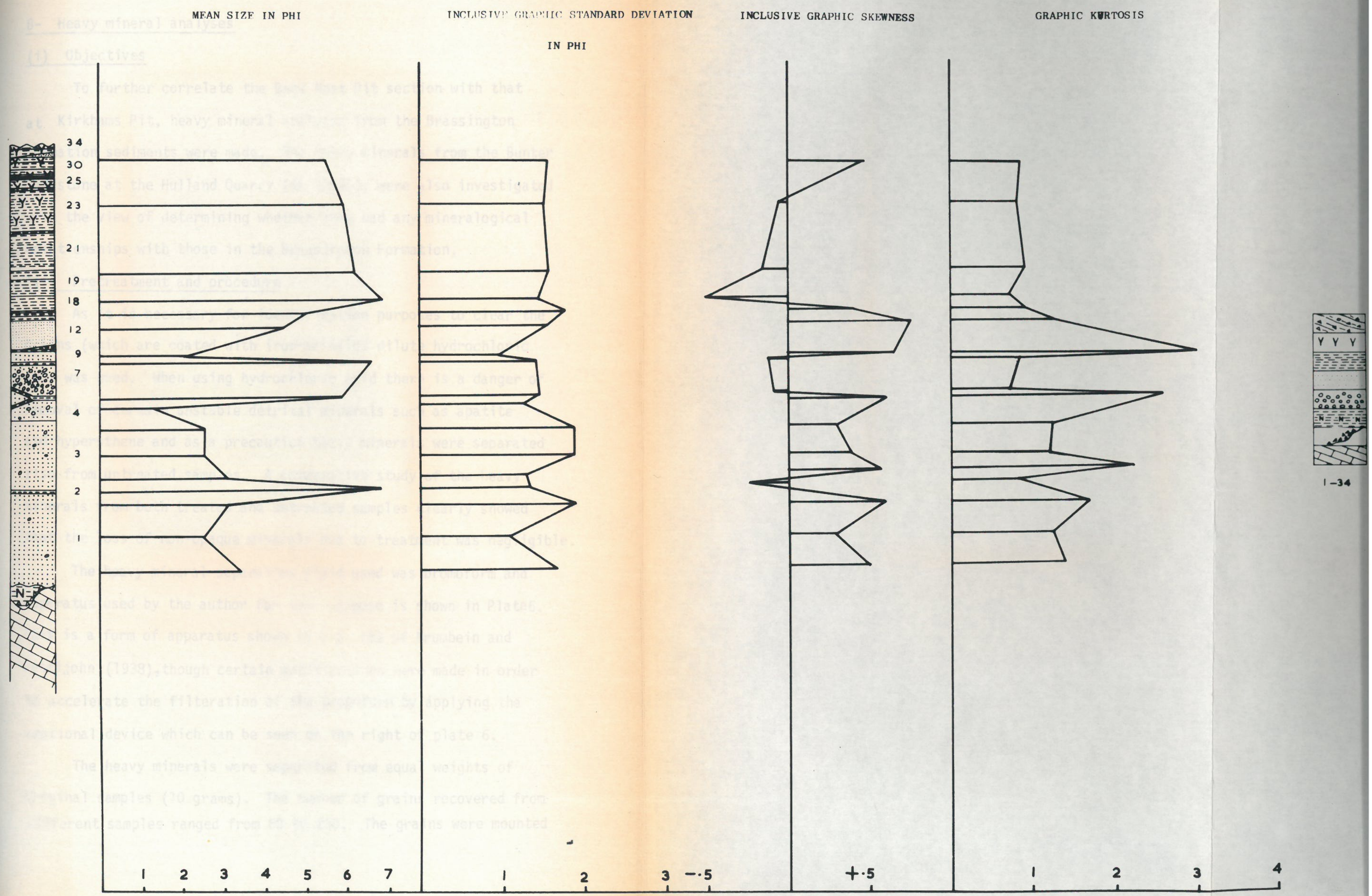


FIG.13. Plot of statistical parameters

KIRKHAMS



MEAN SIZE IN PHI
INCLUSIVE GRAPHIC STANDARD DEVIATION
IN PHI
INCLUSIVE GRAPHIC SKEWNESS
GRAPHIC KURTOSIS
34
30
25
23
21
19
18
12
9
4
3
2
1
1 2 3 4 5 6 7
1 2 3
-·5 +·5
1 2 3 4
1-34

B- Heavy mineral analyses

(i) Objectives

To further correlate the Bees Nest Pit section with that at Kirkhams Pit, heavy mineral analyses from the Brassington Formation sediments were made. The heavy minerals from the Bunter Sandstone at the Hulland Quarry (SK 278456) were also investigated with the view of determining whether they had any mineralogical relationships with those in the Brassington Formation.

(ii) Pretreatment and procedure

As it is necessary for identification purposes to clear the grains (which are coated with iron-oxide10% dilute hydrochloric acid was used. When using hydrochloric acid there is a danger of removal of certain unstable detrital minerals such as apatite and hypersthene and as a precaution heavy minerals were separated also from untreated samples. A comparative study of the heavy minerals from both treated and untreated samples clearly showed that the loss of non-opaque minerals due to treatment was negligible.

The heavy mineral separation fluid used was bromoform and apparatus used by the author for this purpose is shown in Plate6. This is a form of apparatus shown in Fig. 153 of Krumbein and Pettijohn (1938),though certain modifications were made in order to accelerate the filteration of the bromoform by applying the suctional device which can be seen on the right of plate 6.

The heavy minerals were separated from equal weights of original samples (10 grams). The number of grains recovered from different samples ranged from 50 to 250. The grains were mounted

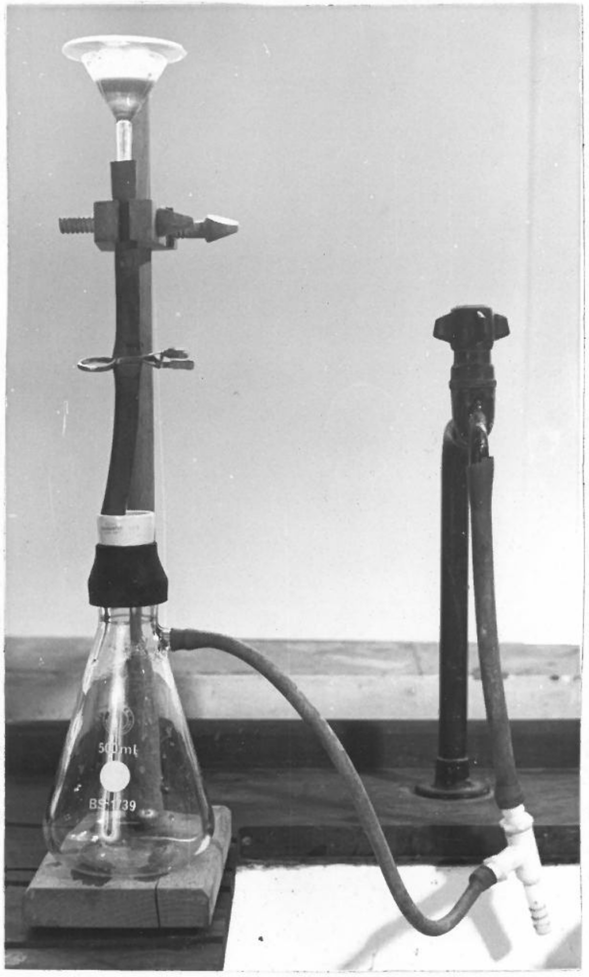


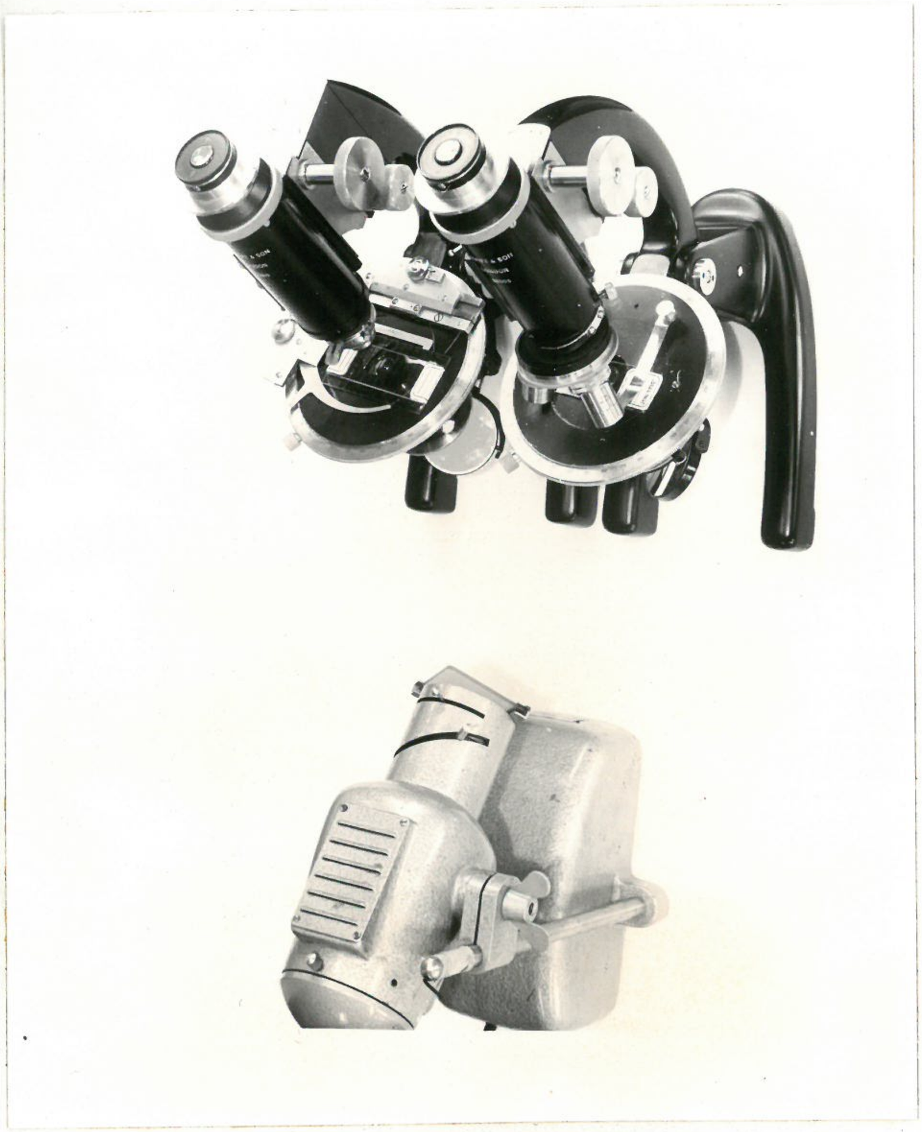
PLATE 6

Apparatus used for separation of heavy minerals on graduated slides and every grain identified and counted. The percentage distribution was then calculated for each mineral variety. The roundness and particle size of the heavy minerals were also studied. In order to determine the roundness of the grains, Powers roundness scale was used. Initially micrometers were used to determine the grain size but it soon became obvious that this technique was extremely time consuming. The author, therefore, attempted to separate the heavy minerals,in terms of their grain size by sieving the whole sample (both light and heavy fractions) and then separate the heavy minerals by using bromoform. This method is much easier but one has to separate heavy minerals and prepare slides for each grade so that the technique, while easier, is no less time consuming and also more expensive.

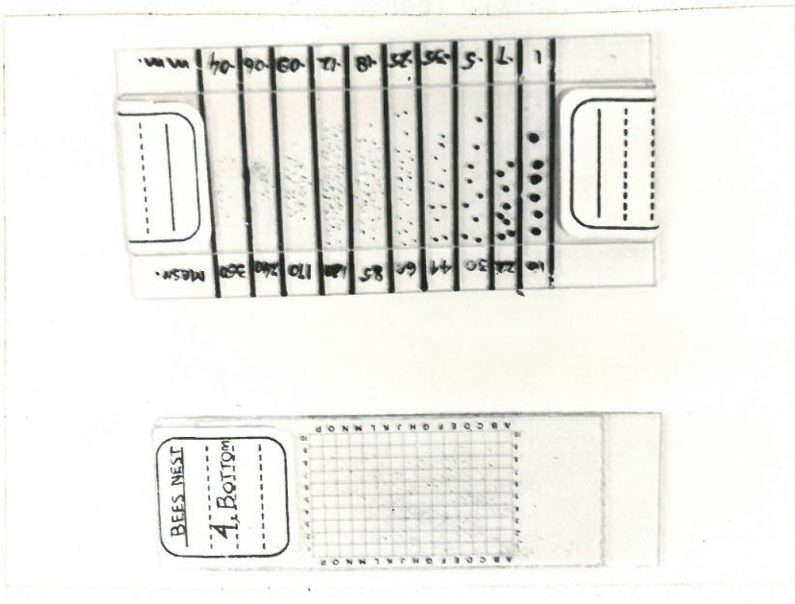
To accelerate this work the author devised a method in which two microscopes were used side by side. On the stage of microscope No.1 a heavy mineral slide was placed at a certain magnification. A special slide containing grains of known size in an ordered arrangement was placed on microscope No.2 (which had the same magni fication). Grain size of the test sample was then determined by making a visual comparison (Plates 7 a & b).

The light fractions were also examined under a binocular microscope, they were found to consist almost entirely of quartz but time did not permit a detailed investigation of them. However, there appeared to be a close resemblance between the roundness of grain of equivalent grade size in both the Bunter and the Kirkham Member.

Microscope No.1   Microscope No.2



(a)



Special slide

(b)

Heavy mineral slide

PLATE 7

(iii) Mineralogy

Nine species of non-opaque minerals were identified in the heavy fractions obtainedfrom the Brassington Formation sediments and the Bunter (Fig. 14).

Out of these nine non-opaque minerals only four were comparatively common and present in all samples. The other five namely anatase, monazite, brookite, titanite and garnet were very scarce or absent in many samples.

Zircon

Zircon is the most dominant mineral in the Brassington Formation sediments and the Bunter. The degree of roundness increases with increase of grain size. A few crystals with distinct terminal faces were observed. Many grains have dirty appearance because of numerous irregularly distributed inclusions,whilst a few displayed a faint dusty zoning parallel to the length of the crystal.

Tourmaline

Tourmaline is abundant in all samples. Brown, blue, green, yellow and particoloured varieties were recovered. The degree of roundness ranges from angular to very well rounded. In general larger grains are better rounded. Intensity of pleochroism is extremely variable.

Garnet

Fractured,colourless,isotropic grains are of infrequent occurrence in the Brassington Formation but are relatively common in the Bunter.

Rutile

Although rutile is present in all separations it is always a minor constituent. Both red and yellow varieties are found but it is only the red variety which is ubiquitous. All the grains show some degree of roundness ranging from subrounded to rounded. Transverse striations are present on some grains.

Staurolite

Staurolite is wide-spread but only as a minor constituent of the Brassington Formation sediments. It is straw yellow and shows marked pleochroism. Some grains have conchoidal surface.

Monazite

Rounded grains of monazite were observed in very small amounts in only two samples from the Brassington Formation and in the Bunter. The grains were distinguished from zircon by means of their light yellow colour and biaxial character.

Anatase

Yellowish, bluish and dusky tabular grains of anatase were observed in a few samples from the Brassington Formation, their euhedral character suggests that they are authigenic.

Brookite

Very few brownish and dusky ragged and tabular grains of brookite,which failed to extinguish when rotated between crossed polarisers,were observed in some of the samples from the Brassington Formation but not in the Bunter.

Titanite

Only two grains of brownish titanite were observed in all the samples examined, both were in a sample from Bees Nest Pit.

Opaque minerals in all residues consisted of hematite, ilmenite with a partial to complete coating of white leucoxene,and magnetite, some of which having a partial coating of hematite, it is possible that some, at least, of the hematite grains were originally magnetite.

A detailed study of the relative frequencies of these opaque minerals was not undertaken because the author is of the opinion that the data obtained would be unlikely to yield evidence of such significance to justify the work involved.

The author attempted to use the heavy minerals in making a bed by bed correlation of the Kirkham Member sediments at Bees Nest Pit with those at Kirkhams Pit but because of the general paucity and lack of significant variations in the mineralogical composition of the fractions it proved impracticable to make such detailed correlation. Nevertheless, the average composition of the heavy fractions from the Kirkham Member sediments at both localities were found to be broadly comparable. The provenance of the Kirkham Member sediments is discussed under the heading of "The Provenance of the Brassington Formation".

C- Clay mineral analyses

(i) Objectives

The primary purpose of this study was to obtain some knowledge of the clay mineral assemblage in the Brassington Formation sediments and then apply that knowledge to the problem of correlation and provenance.

The clay minerals were identified mainly by the X-ray techniques and differential thermal analyses. Wherever necessary electron micrographs were also obtained. The thermobalance was used to determine the percentage of gibbsite.

(ii) The preparation of X-ray powder photographs

The field samples were disaggregated in the laboratory and dispersed in distilled water. Ammonium hydroxide was added to suspensions to aid deflocculation. Particles whose diameters were less than two micron were separated by sedimentation. For this purpose the author designed and constructed the apparatus shown in Plat 8. It is in fact a sedimentation cylinder with a tap attached to it. The sediments were poured into this cylinder and more distilled water containing dispersant was added to the level of the markwhich is exactly 10 cm above the tap. The suspension was then thoroughly shaken so that the particles were uniformly distributed and was then set at rest. According to Folk (1965),at a constant temperature of 24^{o}C all the particles having diameter more than two micron would have settled below the level of the tap in 7 hours and 24 minutes. The only particles which remained above the level of the tap were those having a diameter less than 2 micron and were collected by simply opening the tap. The clay fractions thus separated were

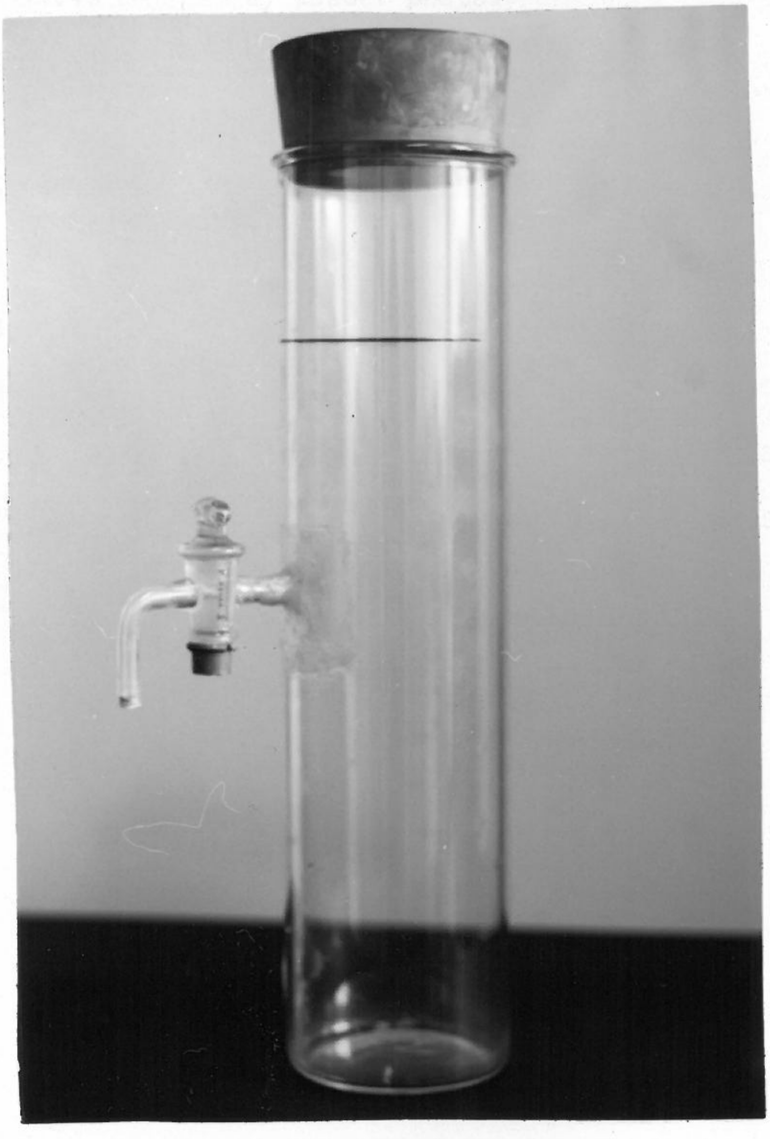


PLATE 8

Sedimentation apparatus

dried at a temperature of not higher than 60°C. Test samples then uniformly packed into Lindemann glass capillary tubes of 0.2mm. diameter. The capillary tube was then set in a Philips camera of diameter 11.46 cm. X-ray powder photographs were obtained with C o K α radiation at 6 KV and 8 mA, each sample being exposed for 24 hours.

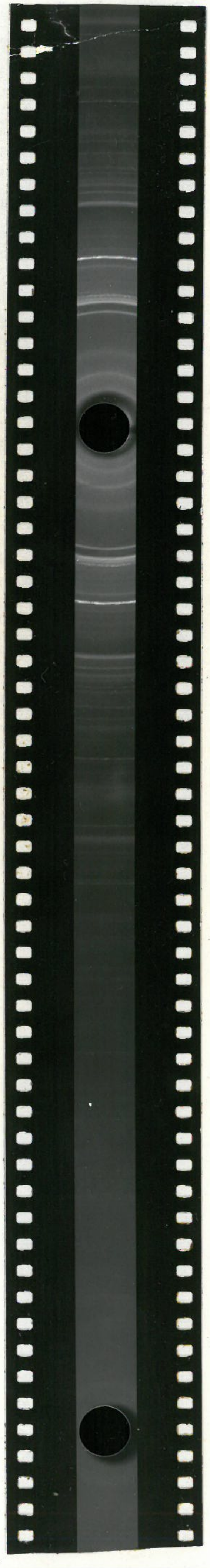
(iii) Interpretation

Spacing of the lines on the resulting photographs were measured with an Å C o K α ruler. Some of the spacings were calculated by using Bragg's Law $n \lambda = 2 d \sin \Theta$.

In order to determine the mineralogical composition of different samples, the spacings were compared with the spacings tabulated in Brown (1961) and Grim (1968) for different clay minerals.

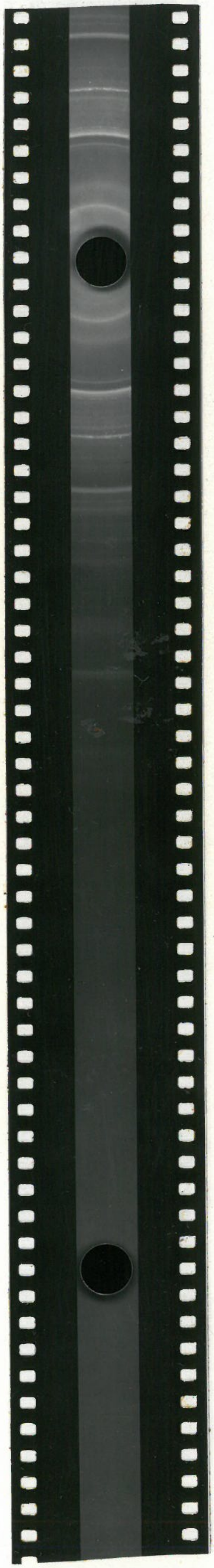
24 Top, Bees Nest Pit

SPACING (Å)	INTENSITY	MINERALS
10	S	I
7.2	S	K
6.27	M	L
4.85	S	G
4.5	S	I
4.26	S	Q
4.18	M	K
3.9	W	F
3.7	M	F
3.51	S	A
3.34	V.S	Q
3.2	M	M + F
3.0	W	F
2.86	M	M + F
2.78	M	M
2.57	M	I
2.45	W	G + Q
2.385	M	I + G.A
2.245	W	G
2.13	W	M
2.04	W	G
1.98	W	Q
1.826	W	Q
1.75	V.W	G
1.68	V.W	G
1.54	M	Q
1.50	M	I



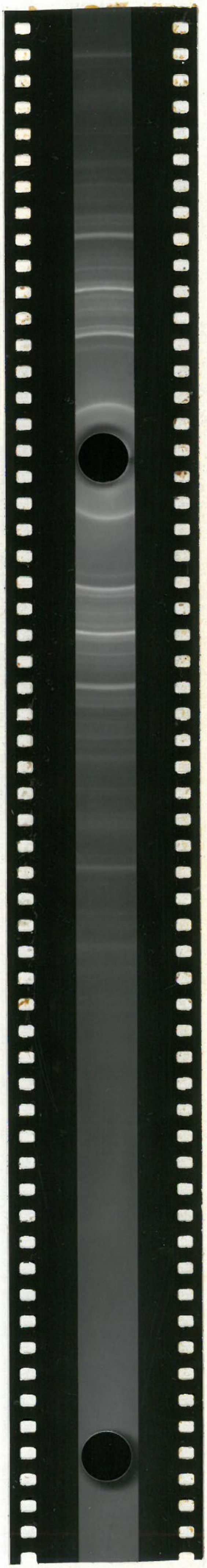
24 Bottom, Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
7.2	S	K
4.85	S	G
4.5	S	I
4.26	S	Q
4.18	M	K
3.9	W	F
3.7	M	F
3.51	S	A
3.34	V.S.	Q
3.2	M	M + F
3.0	W	F
2.86	M	M + F
2.78	M	M
2.57	M	I
2.45	W	G + Q
2.385	M	I+G+A
2.245	W	G
2.13	W	M
2.04	W	G
1.98	W	Q
1.826	W	Q
1.75	V.W.	G
1.68	V.W.	G
1.54	M	Q
1.50	M	I



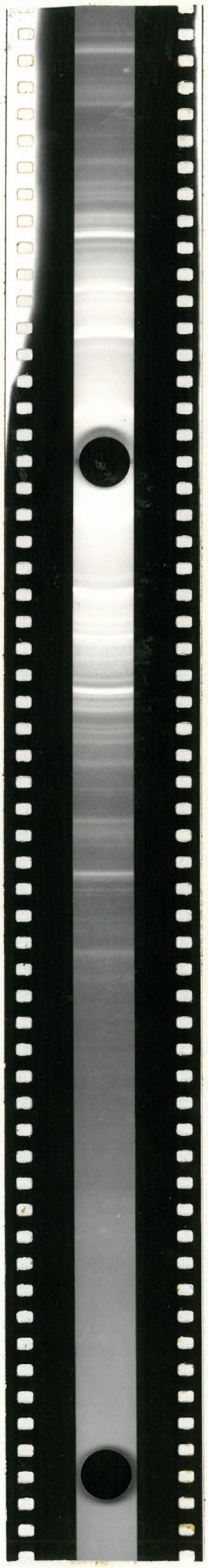
23 Middle, Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5	M	I
4.5	S	I
4.26	S	Q
3.34	V.S	Q
3.2	M	M
2.98	M	M
2.4	W	Q
2.38	M	I
2.25	M	I
2.12	W	Q
1.82	S	Q
1.54	M	Q.
1.50	M	I
1.37	W	Q



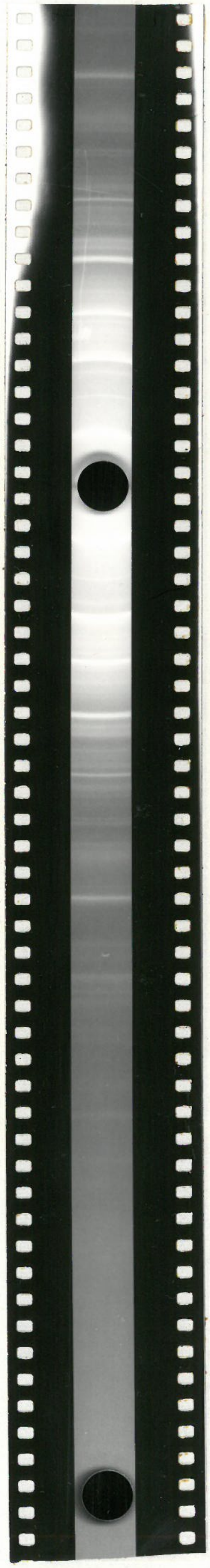
22 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5	M	I
4.5	S	I
4.26	S	Q
3.67	W	H
3.9	M	?
3.48	M	M
3.34	V.S	Q
2.98	S	M
2.69	S	H
2.57	M	I
2.515	S	H
2.45	W	Q
2.12	V.W	Q
1.98	W	Q
1.84	M	H
1.69	M	H
1.50	M	I
1.48	M	H



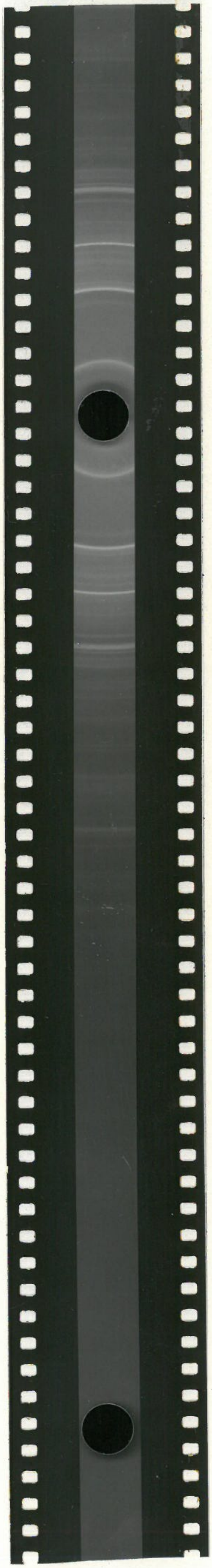
21 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
6.27	S	L
5	M	I
4.5	S	I
4.26	S	Q
3.51	S	A
3.34	V.S	Q
2.57	M	I
2.47	W	L
2.38	W	C
2.25	M	I
2.12	W	Q
2.08	S	C
1.82	W	Q
1.80	M	?
1.54	M	Q
1.50	M	I
1.37	M	Q + C



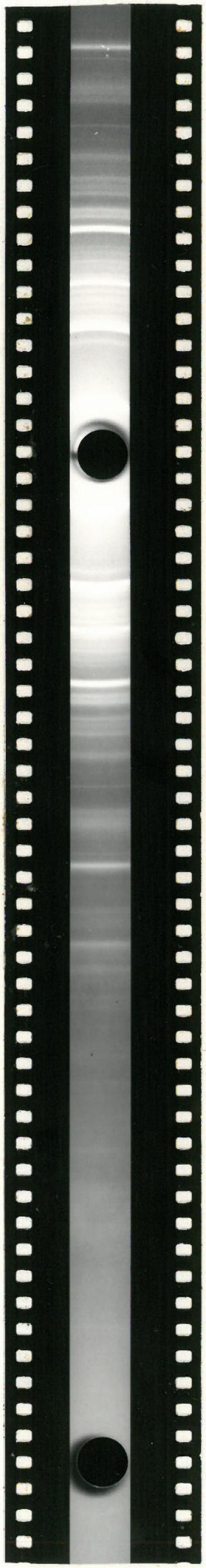
20 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5	M	I
4.5	S	I
4.26	S	Q
3.67	W	H
3.34	V.S	Q
2.69	S	H
2.57	M	I
2.51	S	H
1.82	S	Q
1.50	M	I



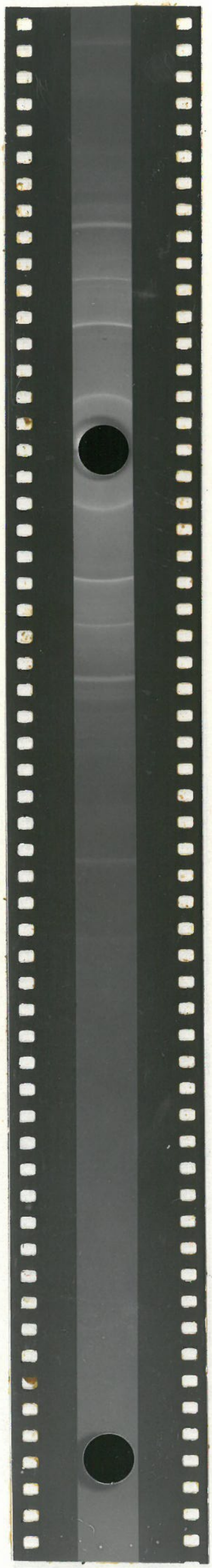
19 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5	M	I
4.5	S	I
4.26	S	Q
3.51	S	A
3.34	V.S	Q
2.98	M	M
2.78	W	M
2.45	W	Q
2.25	M	I
2.12	V.W	Q
1.82	S	Q
1.54	M	Q
1.50	M	I
1.38	W	Q
1.37	W	Q
1.3	W	?



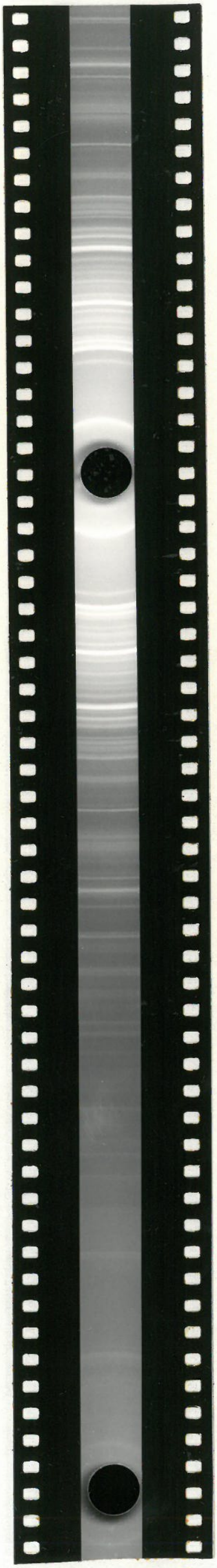
17 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5	V.W	I
4.5	S	I
3.34	V.S	Q
2.57	M	I
1.50	M	I



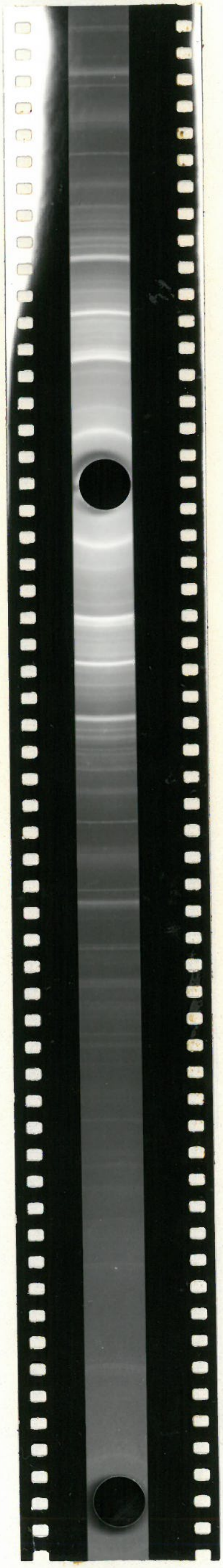
14 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5	M	I
4.5	S	I
4.26	S	Q
3.87	M	I
3.67	W	H
3.48	W	M
3.34	V.S	Q
3.2	M	M
2.98	S	M
2.86	W	M
2.78	M	M
2.69	S	H
2.57	M	I
2.515	S	H
2.45	W	Q
2.38	M	I
2.28	W	Q
2.23	W	Q
2.2	W	H
2.12	W	Q
1.98	V.W	Q
1.82	W	Q
1.67	W	Q
1.54	W	Q
1.50	M	I
1.45	M	H



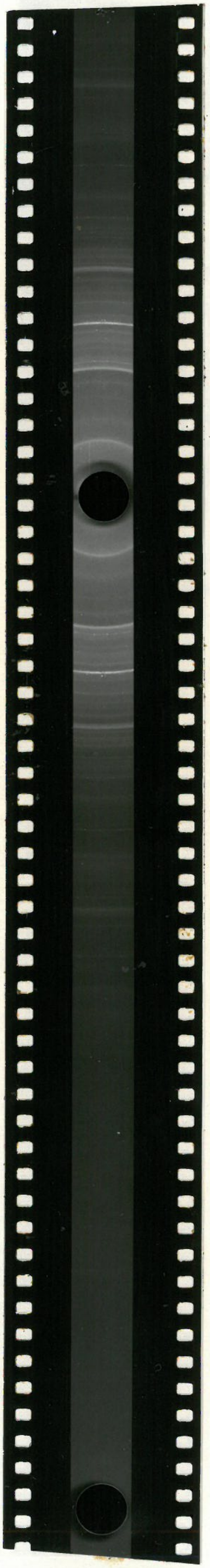
11 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
7.2	S	K
5.75	M	?
5	M	I
4.5	S	I
4.26	S	Q
4.18	W	K
3.87	M	I
3.57	M	K
3.48	W	M
3.34	V.S	Q
3.2	M	M
2.98	M	M
2.86	M	M
2.78	M	M
2.57	M	I
2.45	M	Q
2.28	W	Q
2.23	W	Q
2.12	V.W	Q
1.82	S	Q
1.67	W	Q
1.54	M	Q
1.50	M	I
1.38	W	Q
1.37	W	Q
1.29	W	Q
1.25	W	Q
1.2	W	Q
1.18	W	Q



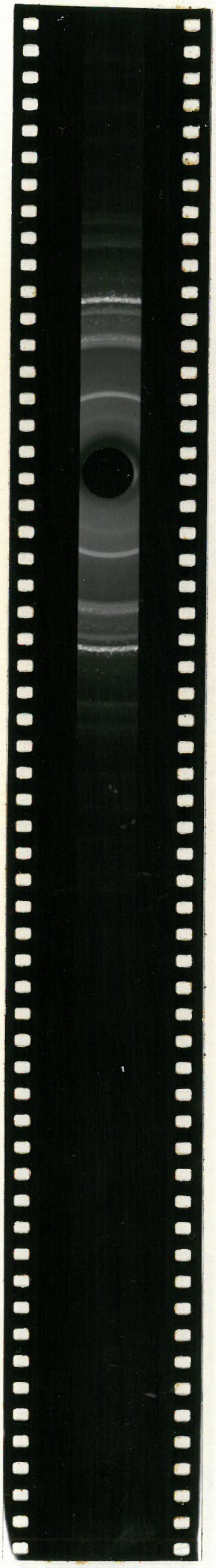
10 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
7.2	S	K
5.75	M	?
5	M	I
4.5	S	I
4.26	S	Q
4.18	W	K
3.87	M	I
3.69	W	H
3.57	S	K
3.48	W	M
3.34	V.S	Q
3.2	M	M
2.98	S	M
2.86	M	M
2.78	W	M
2.57	M	K
2.514	M	H
2.45	W	Q
2.28	W	Q
2.23	W	Q
2.2	W	H
2.12	V.W	Q
1.98	V.W	Q
1.84	M	H
1.82	M	Q
1.69	M	H
1.54	M	Q
1.50	M	I
1.45	M	H
1.38	W	Q
1.37	W	Q



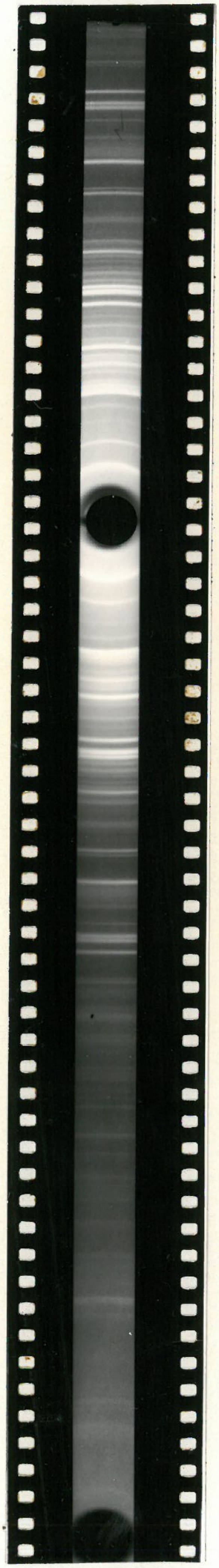
6 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	W	I
7.2	S	K
4.5	S	I
3.34	V.S	Q



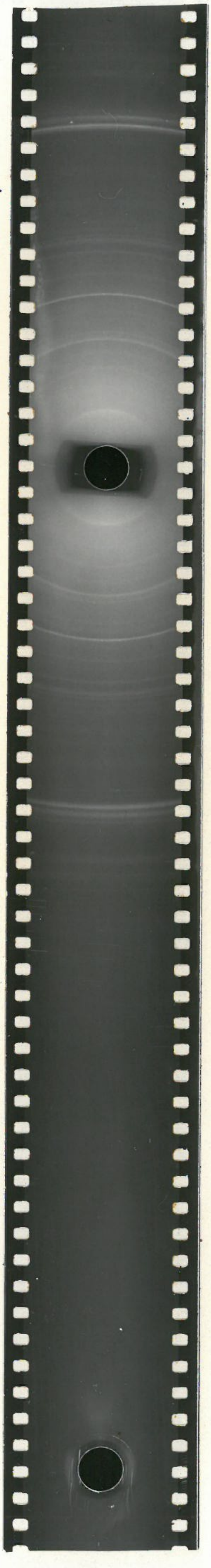
2 Bees Nest Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
7.2	S	K
5.75	M	?
5	M	I
4.5	S	I
4.26	S	Q
4.18	M	K
3.87	M	I
3.67	W	H
3.48	W	M
3.34	V.S	Q
3.2	M	M
2.98	S	M
2.86	W	M
2.69	S	H
2.57	M	I
2.515	S	H
2.45	W	Q
2.28	W	Q
2.23	W	Q
2.12	V.W	Q
1.84	M	H
1.82	S	Q
1.69	M	H
1.54	M	Q
1.50	M	I
1.48	W	H
1.45	W	H
1.38	W	Q
1.37	W	Q



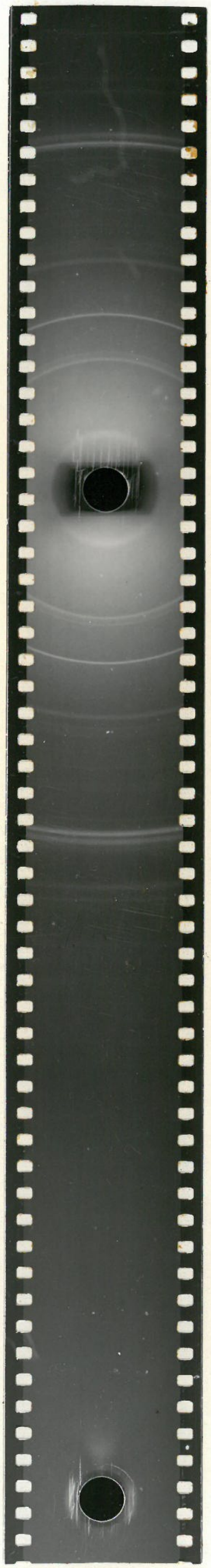
Hulland Quarry

SPACING (Å)	INTENSITY	MINERAL
10	S	I
7.2	S	K
5.75	M	?
5	M	I
4.5	S	I
4.26	S	Q
3.57	S	K
3.34	V.S	Q
2.69	S	H
2.57	M	I
2.51	S	H
1.50	M	I



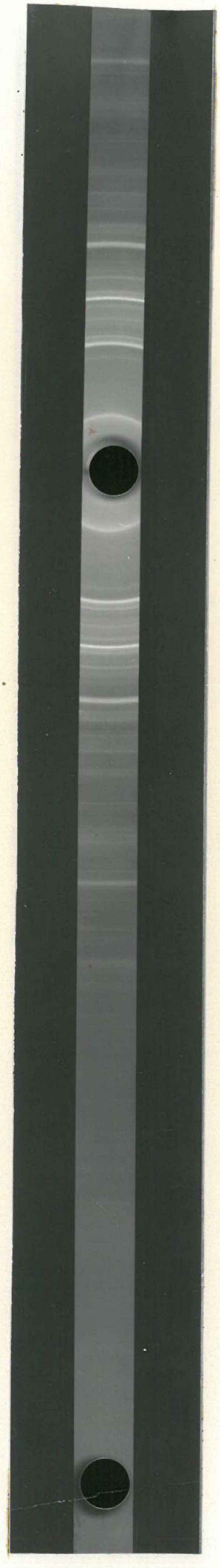
Namurian shale - Parwich

SPACING (Å)	INTENSITY	MINERAL
10	S	I
4.5	S	I
4.26	S	Q
3.34	V.S	Q
2.57	M	I
2.45	W	Q
2.12	V.W	Q
1.82	W	Q
1.54	M	Q
1.50	M	I



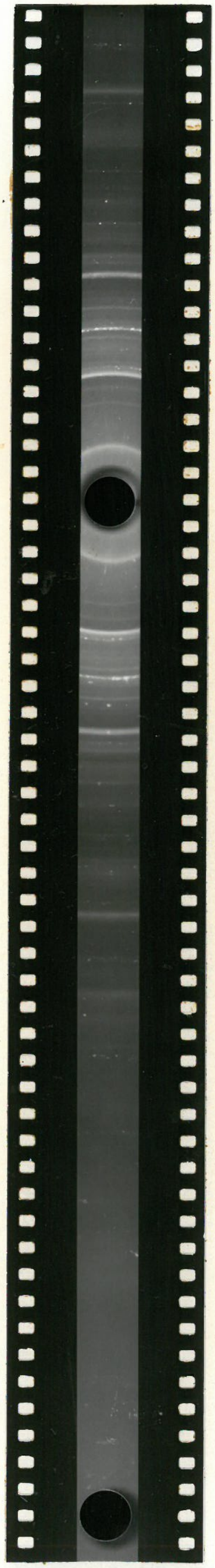
21 Kirkhams Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5	M	I
4.5	S	I
4.26	S	Q
3.48	W	M
3.34	V.S	Q
2.98	S	M
2.57	M	I
2.12	V.W	Q
1.50	S	I



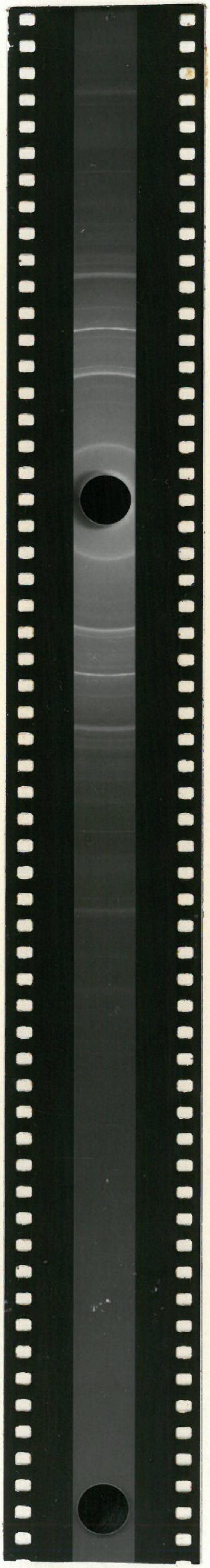
16 KIRKHAMS PIT

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5.75	M	?
5	M	I
4.5	S	I
4.26	S	Q
3.34	V.S	Q
2.98	S	M
2.57	M	I
2.45	W	Q
2.12	V.W	Q
1.82	S	Q
1.50	S	I



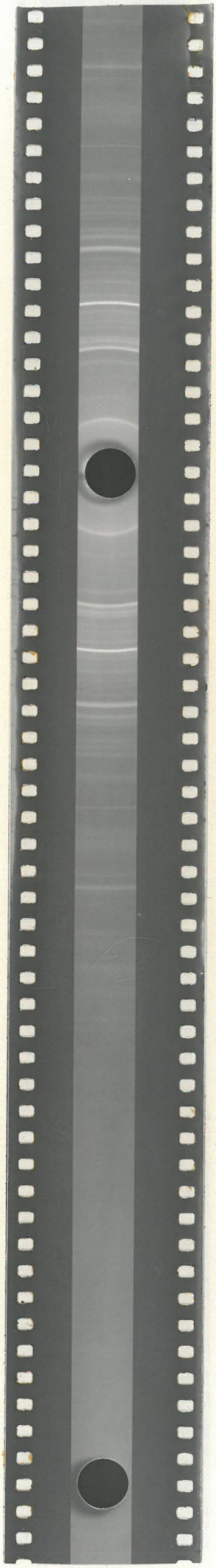
14 KIRKHAMS PIT

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5.75	W	?
4.5	S	I
4.26	S	Q
3.34	V.S	Q
2.98	S	M
2.57	M	I
2.45	W	Q
2.28	W	Q
1.82	S	Q
1.54	M	Q
1.50	S	I



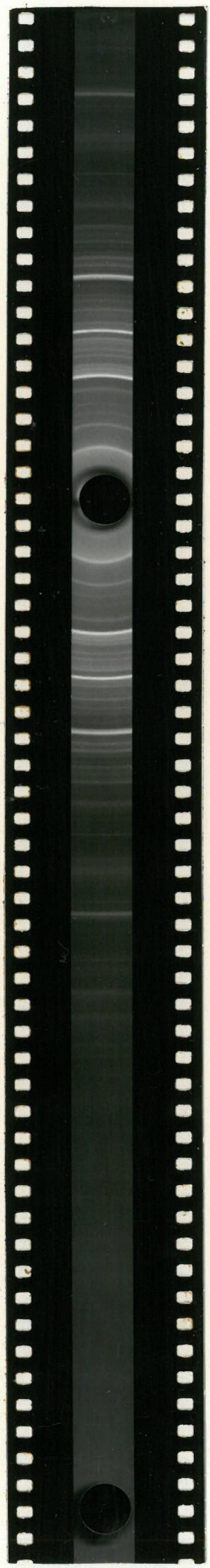
8 Kirkhams Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
7.2	S	K
5.75	V.W	?
5	M	I
4.5	S	I
4.26	S	Q
3.87	M	I
3.48	W	M
3.34	V.S	Q
2.98	S	M
2.57	M	I
1.82	S	Q
1.54	M	Q
1.50	M	I



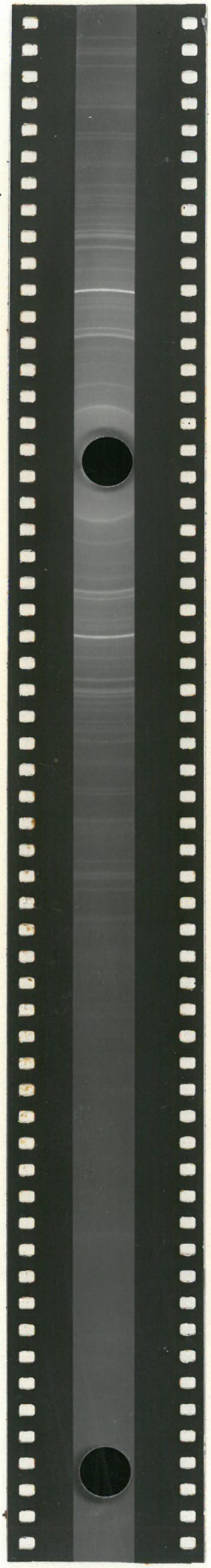
6 Kirkhams Pit

SPACING (Å)	INTENSITY	MINERAL
10	S	I
7.2	S	K
5.75	?	?
5	M	I
4.5	S	I
4.26	S	Q
3.57	S	K
3.34	V.S	Q
3.2	M	M
2.98	S	M
2.86	W	M
2.78	V.W	M
2.57	M	I
2.45	W	Q
2.38	W	K
2.34	W	K
2.3	W	K
2.28	W	Q
2.23	W	Q
2.12	V.W	Q
1.98	V.W	Q
1.82	S	Q
1.54	M	Q
1.50	S	I
1.38	W	Q
1.37	W	Q



2 Kirkhams Pit

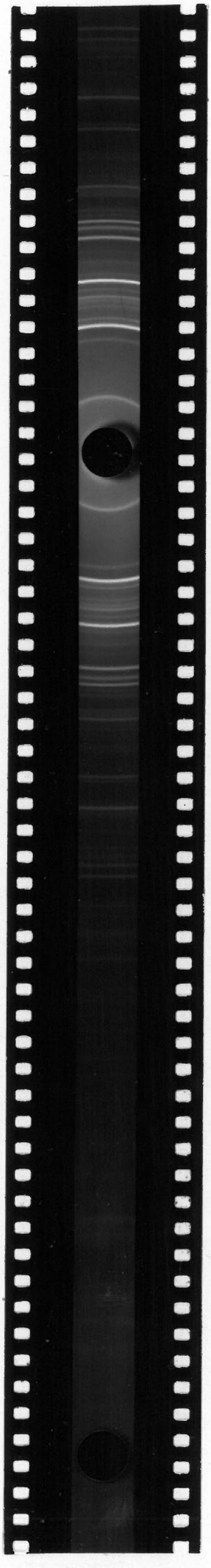
SPACING (Å)	INTENSITY	MINERAL
10	S	I
7.2	S	K
5.75	M	?
5	M	I
4.5	V.S	I
4.26	S	Q
3.87	M	I
3.67	W	H
3.57	S	K
3.48	W	M
3.34	V.S	Q
2.86	W	M
2.69	S	H
2.57	M	I
2.51	S	H
2.45	W	Q
2.28	W	Q
2.23	W	Q
2.2	W	K
2.12	V.W	Q
1.84	M	K
1.82	S	Q
1.69	M	H
1.54	M	Q
1.50	S	I
1.48	M	H
1.452	M	H
1.38	W	Q
1.37	W	Q



2 Kirkhams Pit

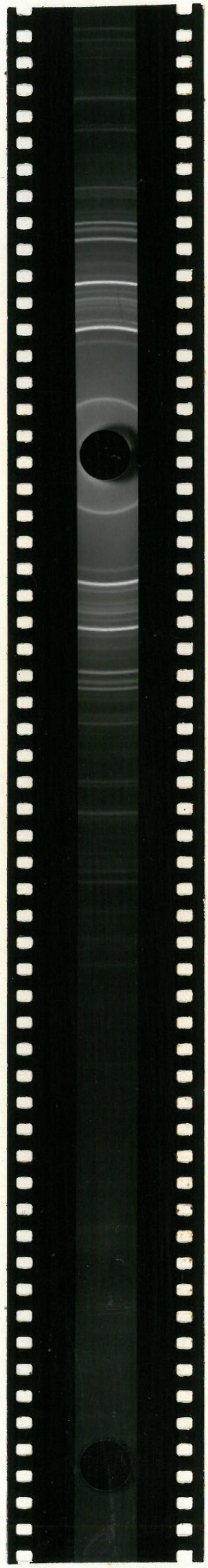
Heated for two hours at 600°C.

SPACING (Å)	INTENSITY	MINERAL
10	S	I
5	M	I
4.5	S	I
4.26	S	Q
3.87	M	I
3.67	W	H
3.48	W	M
3.34	V.S	Q
2.86	W	M
2.69	S	H
2.57	M	I
2.51	S	H
2.45	W	Q
2.28	W	Q
2.23	W	Q
2.12	V.W	Q
1.82	S	Q
1.69	M	H
1.54	M	Q
1.50	S	I
1.48	M	H
1.452	M	H
1.38	W	Q
1.37	W	Q



ıours at 600°C.

ːNTENSITY	MINERAL
S	I
M	I
S	I
S	Q
M	I
W	H
W	M
V.S	Q
W	M
S	H
M	I
S	H
W	Q
W	Q
W	Q
V.W	Q
S	Q
M	H
M	Q
S	I
M	H
M	H
W	Q
W	Q



INTENSITY

V.S. = Very strong

S = Strong

M = Medium

W = Weak

V.W. = Very weak

MINERALS

A = Anatase

C = Corundum

F = Felspar

G = Gibbsite

H = Hematite

I = Illite

K = Kaolin

L = Lepidocrocite

M = Muscovite

Q = Quartz

(iii) Differential thermal analyses

In the past three decades differential thermal analysis (D.T.A.) has developed into a very useful mineralogical technique and the application of this method for the investigation of clay minerals has been very successful.

In this method the material to be tested is heated together with a similar sample of inert material (e.g. calcined alumina). When no reaction occurs in the specimen, there is no difference between the temperature of the sample and that of the inert material but as soon as the reaction commences, the specimen becomes hotter or cooler than the inert material and a peak develops on the curve for the temperature difference against temperature $\Delta T/T$.

An endothermic peak is due to absorbtion of energy; in other words dehydration or loss of crystal structure. An exothermic peak is due to release of heat, or formation of new crystallographic phase. The temperature at which the peaks occur are generally indicative of specific minerals.

Low temperature peaks are also dependent upon humidity variation and therefore 55% relative humidity was obtained, for both the samples and the inert materials before testing, by allowing them to stand at least for four days in Vacuo with a saturated solution of $Mg(NO_3)_2 6 H_2O$.

Interpretation of the differential thermographs (Fig. 15)

Bed 24 Bees Nest Pit

Inspection of the differential thermograph of the sample from the Bed 24 (top) reveals that the first endo-thermic reaction starts around 80°C and finishes around 180°C with a peak at 120°C. This peak is due to the loss of the non-constitutional water. The second endothermic reaction starts at about 185°C and finishes at about 365°C. This reaction produces a very strong peak at about 320°C which shows the presence of gibbsite (also confirmed by X-ray analysis - see page). Traces of a third endothermic peak can be seen at about 500°C. This probably indicates the presence of boehmite as a contaminant of the gibbsite but it was not possible to confirm this. The fourth endothermic peak occurs at about 595°C. This reaction represents the joint contribution of kaolin and illite. The endothermic-exothermic inversion at about 910°C confirms the presence of illite.

Differential thermographs of the samples from Bed 24 (middle and bottom) show that they have the same mineralogy as the Bed 24 (top) and from the size of the peaks they also reveal that the percentage of gibbsite is lower than in the upper part of Bed 24.

Bed 23 Bees Nest Pit

The differential thermograph shows the first endothermic peak at about 125°C; this is due to the removal of the nonconstitutional water. The second endothermic peak occurs at about 590°C and is probably due to illite. The endothermic-exothermic inversion at 885°C confirms the presence of illite.

Bed 22 Bees Nest Pit

The differential thermal curve shows a moderate peak at 125°C, attributable to the expulsion of non-constitutional water. The endothermic reaction commencing about 470°C and finishing about 700°C with the peak at about 590°C suggests the presence of illite, confirmed by the endothermic-exothermic reaction around 880°C.

Bed 21 Bees Nest Pit

The curve shows the first endothermic peak at about 125°C due to the loss of the nonconstitutional water. The second endothermic peak occurs at about 290°C which is immediately followed by an exothermic peak. This may be attributed to lepidocrocite. (X-ray analysis confirms the presence of this mineral in the sample). The third endothermic peak is at 590°C. This peak temperature and endothermic-exothermic inversion at about 890°C confirms the presence of illite.

Bed 20 Bees Nest Pit

The differential thermograph shows an endothermic peak at about 135°C which is attributed to the absorbed water. The second endothermic peak is seen at 310°C which is immediately followed by an exothermic reaction giving a peak at 335°C. A positive identification of this was not made but it is probable that these peaks are due to some hydroxide of iron. The third endothermic peak is at about 580°C and is possibly due to illite. (X-ray analysis does not show any line for hydroxide of iron which suggests an extreme crystal disorder).

Beds 19 and 17 Bees Nest Pit

The differential thermographs are almost identical to the sample from Bed 20.

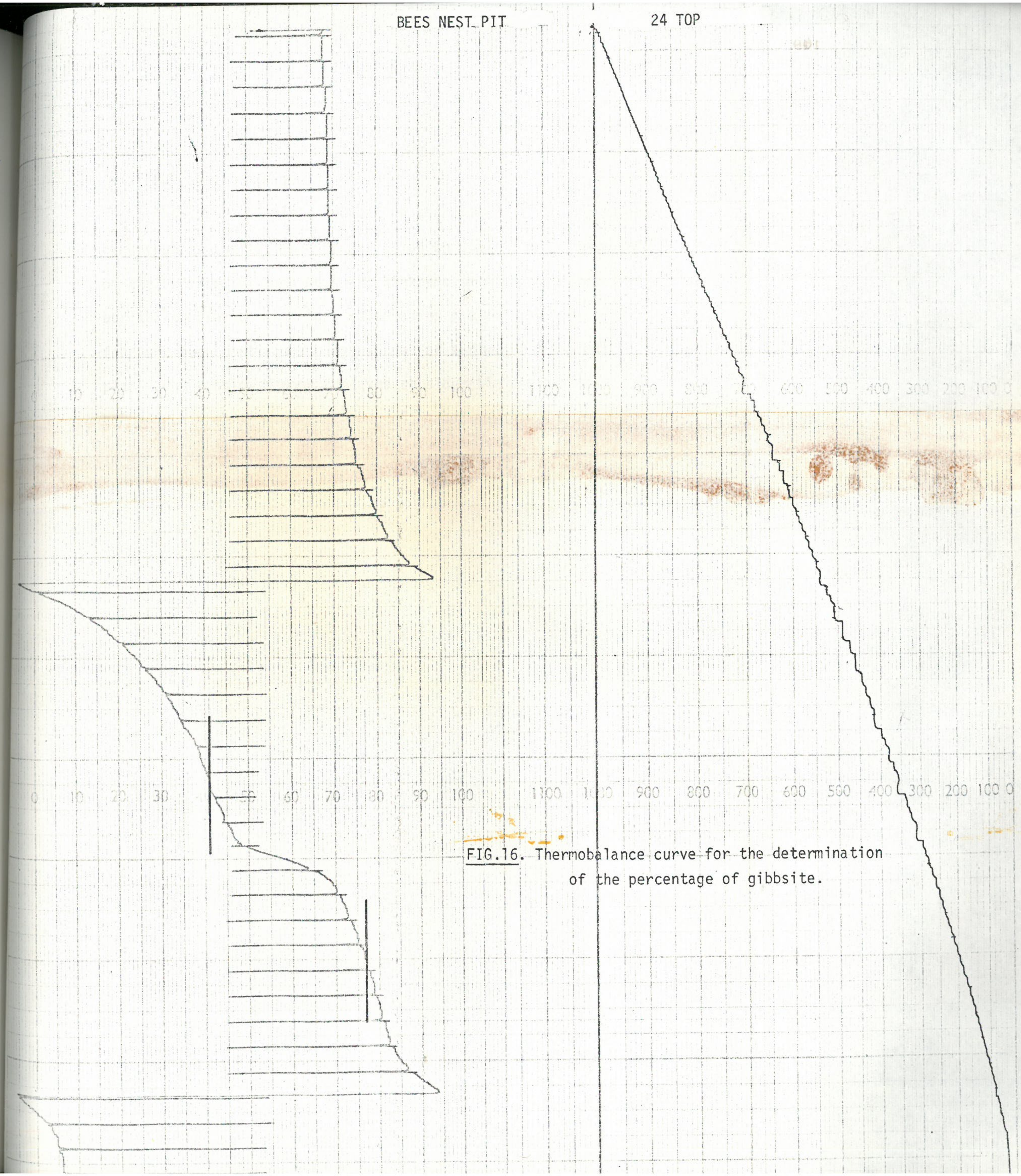


FIG.16. Thermobalance curve for the determination of the percentage of gibbsite.

Bed 11 Bees Nest Pit

The first endothermic peak is at about 125°C, due to the expulsion of absorbed water. The second endothermic peak is at 590°C which is the joint effect of illite and kaolin. The exothermic peak around 950°C is due to the formation of mullite.

Comparison of this curve with the one obtained by Grim (1968, page 349, curve B) reveals that the sample contains nearly twice as much illite as kaolin.

Bed 10 Bees Nest Pit

The curve shows first endothermic peak at about 125°C, due to the loss of nonconstitutional water. The second endothermic peak is at about 320°C which is immediately followed by an exothermic reaction giving a peak at 340°C. These peaks have not been identified positively but most probably are attributed to hydroxide of iron. The third endothermic peak appears at about 590°C and is due to the overlapping effect of illite and kaolin. The very broad and shallow endothermic-exothermic inversion at 900°C confirms the presence of illite.

Bed 9 Bees Nest Pit

Differential thermograph shows an endothermic peak at about 125°C, due to the expulsion of absorbed water. The second endothermic peak is at 595°C and is due to the combined effect of illite and kaolin. An exothermic peak around 950°C shows the formation of mullite and confirms the presence of kaolin. The typical endothermic-exothermic inversion indicative of illite is not present which suggests that Al^{3+} has not been replaced by any other cation to any extent.

Comparison of this curve with the curves of known mixtures of kaolin and illite shows that the ratio of illite to kaolin is 3 : 2.

Bed 2 Bees Nest Pit

Curve shows an endothermic peak at about 125^{o}C, due to the loss of nonconstitutional water. The second endothermic peak is at 600^{o}C and is due to the overlapping effect of illite and kaolin. No exothermic peak around 950^{o}C indicative of the formation of mullite is present. This probably indicates that the kaolin is highly disordered and the particles are very small.

Namurian shale Bees Nest Pit

The first endothermic peak is at 120^{o}C, due to the expulsion of absorbed water. A second very small peak can be seen at 220^{o}C. This has not been positively identified but it might suggest presence of montmorillonite (Mackenzie 1957, page 148 curve "C"). As the first endothermic peak is fairly large presence of some montmorillonite is further supported. The third endothermic peak at about 580^{o}C is due to the combined effect of kaolin, illite and probably also montmorillonite. The endothermic-exothermic inversion around 880^{o}C confirms the presence of illite.

Bed 31 Kirkhams Pit

The differential thermograph shows the first endothermic peak at 120^{o}C. It is due to the loss of the nonconstitutional water. The second fairly strong endothermic peak is seen at 320^{o}C. This confirms the presence of gibbsite determined by X-ray analysis. The small endothermic peak at 480^{o}C probably indicates presence of boehmite as a contaminant of gibbsite. The fourth endothermic peak occurs at about 590^{o}C. It is due to kaolin and illite.

Bed 21 Kirkhams Pit

The curve shows moderately sized low temperature endothermic effect with a peak at about 125^{o}C. It is due to the expulsion of absorbed water. A second very small and shallow endothermic peak can be seen at 300^{o}C which is immediately followed by an exothermic reaction with a peak at 340^{o}C. This probably indicates the presence of lepidocrocite. X-ray analysis, however, does not show any line for this mineral. This suggests that lepidocrocite is either extremely fine grained or highly disordered. The main endorthermic peak is seen at about 585^{o}C which indicates the presence of illite. Endothermic-exothermic inversion at 900^{o}C confirms this.

Bed 20 Kirkhams Pit

The curve is almost identical to that of Bed 20 Kirkhams Pit.

Bed 19 Kirkhams Pit

The curve shows a moderately sized low temperature endothermic effect with a peak at 120^{o}C. This is due to the expulsion of the nonconstitutional water. Presence of boehmite is indicated by a very small peak at about 500°C. Illite is indicated by the endothermic peak at 590°C. The endothermic-exothermic inversion at 870°C confirms the presence of this mineral.

Bed 15 Kirkhams Pit

The curve is similar to those of Beds 20 and 21. The only difference is that this curve shows smaller peak for lepidocrocite than the other two curves (20&21). There is a suggestion, then, that the quantity of lepidocrocite is less in the Bed 15 than the Beds 20 and 21.

Bed 6 Kirkhams Pit

The first endothermic peak at 120°C is attributed to the loss of nonconstitutional water. A very small endothermic peak at about 220°C was not positively identified but it possibly shows the presence of hydrated oxide of iron. A very small endothermic peak at 545°C is perhaps indicative of boehmite. The large endothermic peak at 590°C shows the combined effect of illite and kaolin. The endothermic-exothermic inversion at about 885°C confirms the presence of illite.

Namurian shale Kenslow Top Pit

The first endothermic peak at 120°C is due to the loss of absorbed water. This endothermic peak shows a shoulder at about 170°C which possibly is due to the presence of montmorillonite and a very small endothermic peak at about 730°C supports this notion.

The endothermic peak at about 300°C which is followed by an exothermic reaction giving a peak at 310°C suggests the presence of lepidocrocite. The endothermic peak around 590°C is due to the overlapping effect of illite and kaolin. The presence of kaolin is confirmed by an exothermic peak at 970°C which is due to the formation of mullite.

Kenslow Top Pit, Kenslow Member Clay

The differential thermograph shows a first moderately-sized endothermic peak at 120°C. It is due to the expulsion of absorbed water. The second and very strong endothermic peak at 590°C is due to the combined effect of illite and kaolin. The presence of kaolin is confirmed by the formation of mullite which is shown by an exothermic peak at 940°C.

The presence of illite is indicated by the low-temperature moderately-sized endothermic peak.

Note: For interpretation of the differential thermographs the author consulted mainly Mackenzie (1957), Grim (1968) and the curves of known clay minerals prepared at the City University.

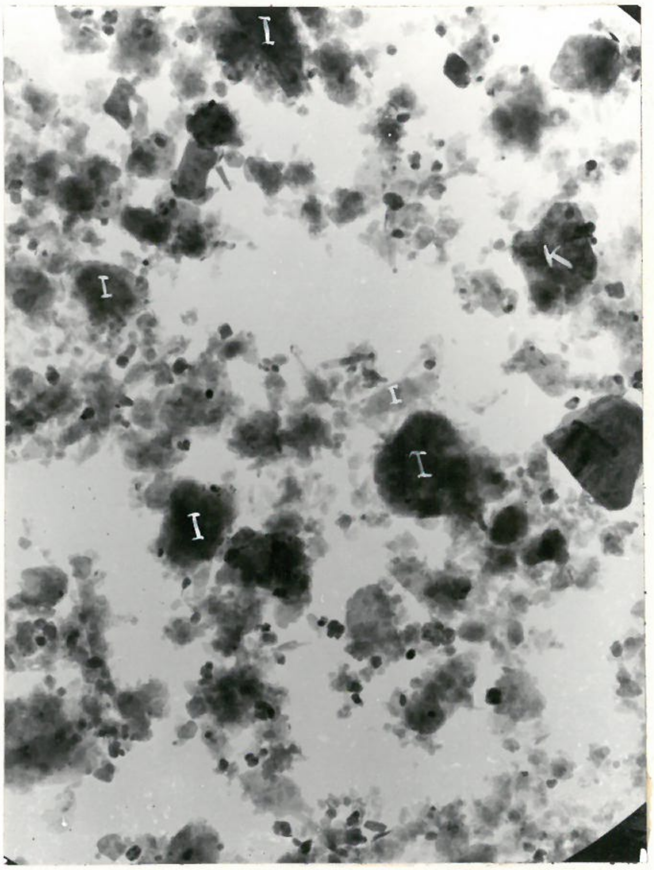


PLATE 9

X 15,000 (approximately)

Electron micrograph showing illite and kaolin.

(Bed 24 Bees Nest Pit)

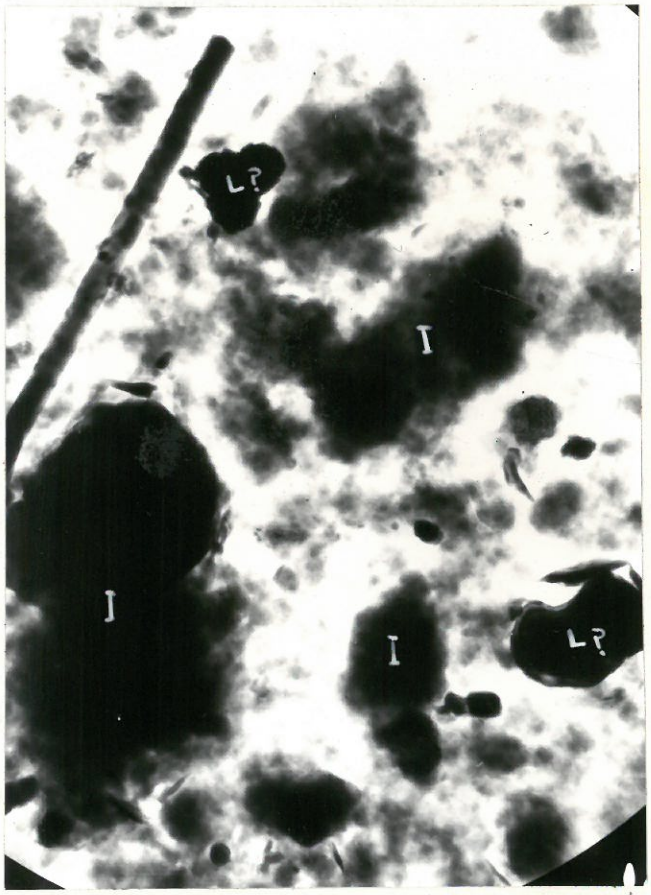


PLATE 10

X 15,000 (approximately)

Electron Micrograph showing lepidocrocite and illite.
(Bed 21, Bees Nest Pit)

(v) Percentage of gibbsite in the Kenslow Member at Bees Nest Pit

In order to determine the percentage of gibbsite in the sediments from Bed 24 (top) at Bees Nest Pit, the thermobalance curve was obtained (Fig. 16). From this curve the percentage of gibbsite was calculated by determining the percentage loss in weight at the temperature for the dehydration of gibbsite ($A\ell_2O_3.3H_2 \rightarrow A\ell_2O_3 + 3H_2O$).

Initial weight of the sample = 1.000 gm.

Ovendry weight of the sample = 1.000 - .026 = .974 gm.

$$\therefore \quad \% \text{ loss} = \frac{.036 \times 100}{.974} = 3.7$$

but using the atomic weights the stoichiometric reaction at 320^{0}C ($A\ell_2O_3.3H_2O \rightarrow A\ell_2O_3 + 3H_2O$) corresponds to a weight loss of 34.6%

$$\therefore \quad \% \text{ of gibbsite} = \frac{3.7 \times 100}{34.6} = 10.6$$

The percentage of gibbsite in Bed 24 (middle and bottom) was estimated simply by comparing the area of the D.T.A. peak for this mineral with the peak area for the same mineral in Bed 24 (top).

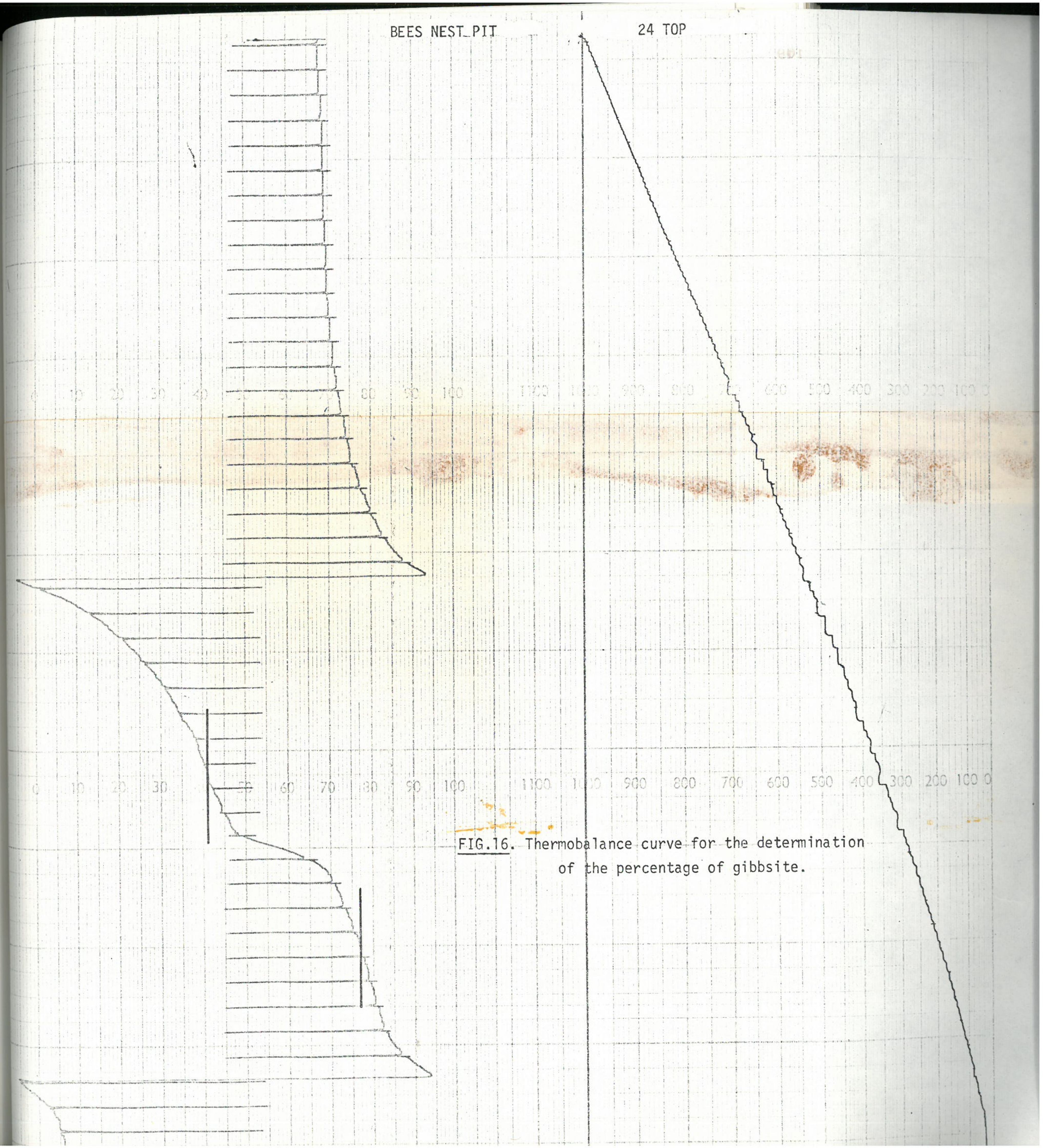


FIG.16. Thermobalance curve for the determination of the percentage of gibbsite.

(vi) Correlation (Fig. 17)

Although a complete bed by bed correlation is not possible nevertheless the sequence of variation in clay mineral composition of the beds in the Bees Nest and Kirkhams sections confirms the earlier conclusion that both successions are the remnants of a formerly once continuous single sheet of sediments. In both places the Kenslow Member contains considerable amounts of gibbsite and the Bees Nest Member clays are mainly illitic. The clay beds which are found in the Kirkham Member are at both localities mainly composed of Kaolinite and illite.

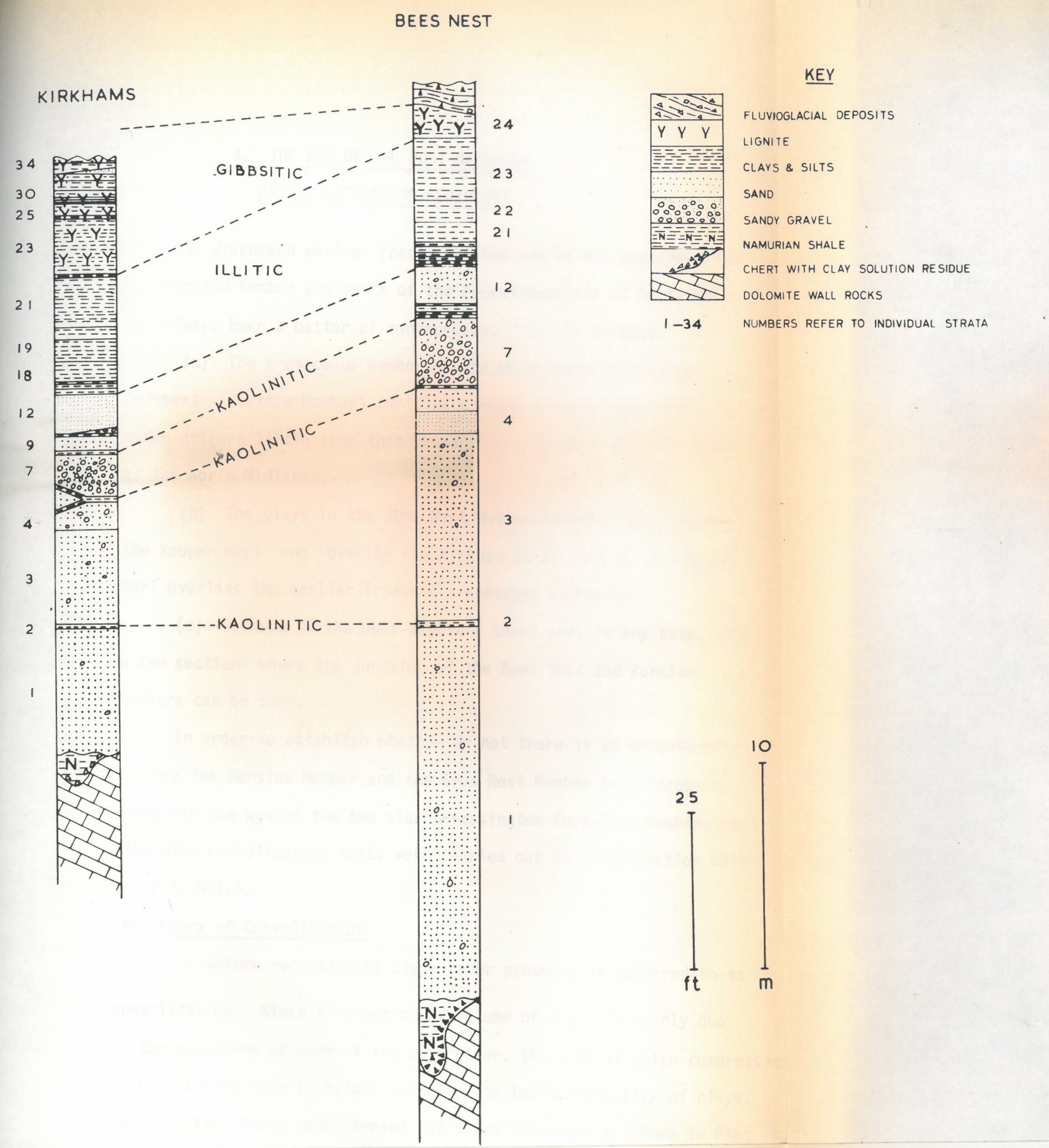


FIG.17. Correlation of the Kirkhams and Bees Nest Pits successions on the basis of clay minerals

4. THE AGE OF THE POST-NAMURIAN AND PRE-LIGNITIFEROUS SEDIMENTS

As discussed earlier (page 8) the age of the post-Namurian pre-Kenslow Member sediments of the Pocket-Deposits of Derbyshire has always been a matter of controversy. This is because:

(a) The arenaceous member of the Brassington Formation sediments (Kirkham Member) contains a heavy mineral assemblage which differs little from that present in undoubted Triassic sands of the North Midlands.

(b) The clays in the Bees Nest Member superficially resemble the Keuper Marl and overlie the Kirkham Sands just as the Keuper Marl overlies the earlier Triassic arenaceous sediments.

(c) Because of the poor exposure there are, in any case, only a few sections where the junction of the Bees Nest and Kenslow Members can be seen.

In order to establish whether or not there is an unconformity between the Kenslow Member and the Bees Nest Member and thereby to establish the age of the two older Brassington Formation Members one dimension consolidation tests were carried out in collaboration with Dr. P.T. Walsh.

The Theory of Consolidation

The volume reduction of clays under pressure is referred to as consolidation. Since a reduction in volume of clays is mainly due to the expulsion of some of the pore water, the rate at which compression occurs is very slow in nature owing to the low permeability of clays. Consolidation tests were carried out in an Oedometer as shown in Plate 11. The compression of the clay was measured by means of a micrometer dial.

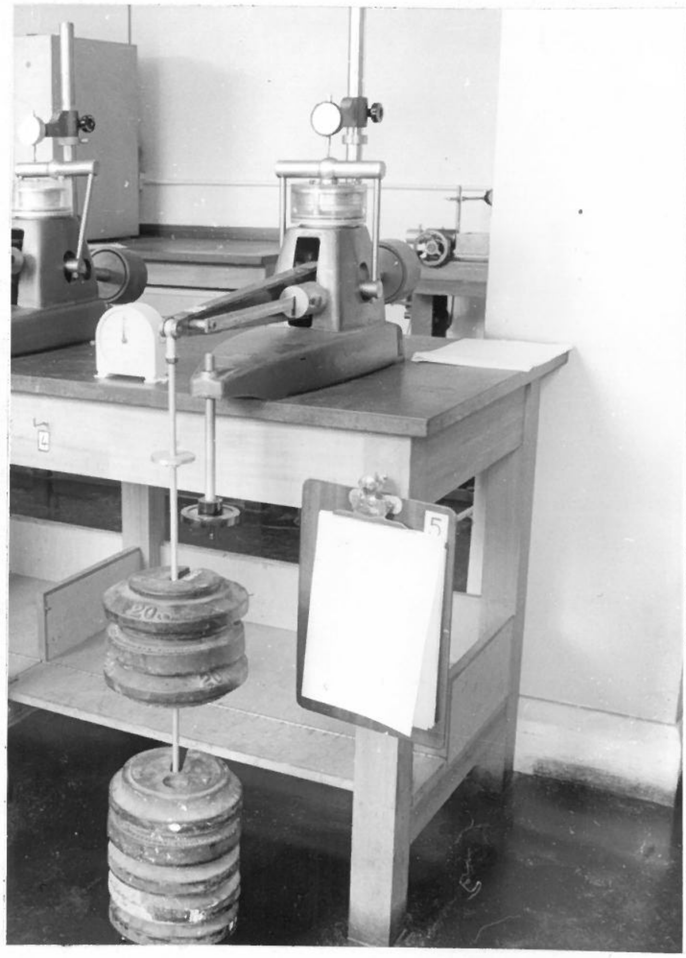


PLATE 11

Oedometer

Since the volume change is simply a change in the volumes of voids it is expressed in terms of voids ratio.

From the results of the consolidation tests a curve can be drawn showing the relation between the voids ratio "e" and the applied pressure "p". This curve is known as p - e curve. As it is convenient to plot values of "p" on a logarithmic scale, this is more usually termed a log p - e curve.

The maximum effective stress under which a clay has been consolidated is called preconsolidation pressure (p e). Where the present overburden pressure is the preconsolidation pressure the clay is said to be the normally-consolidated. Where, however, the present effective pressure is less than the preconsolidation pressure (due to the removal of some of the overburden) the soil is said to be overconsolidated.

Preconsolidation pressure of clays can be determined by reloading overconsolidated clays. It is due to the fact that when pressure is applied on overconsolidated clays, there is only a small further rearrangement of the particles until the previous maximum stress is reached.

The method devised by Casagrande is used to obtain preconsolidation pressure (Fig. 18).

From a maximum curvature A a horizontal line AB is drawn. Tangent CD is drawn at A. A line AL is drawn to bisect the < BAD. The straight part of 'e p' curve which reflects the virgin curve is projected as EF. The intersection of EF and AL indicates preconsolidation pressure.

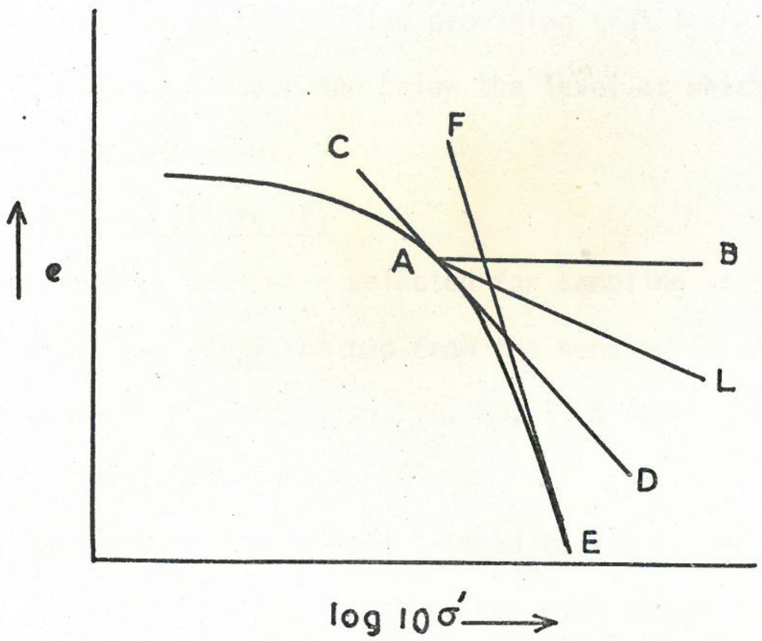


FIG.18. Casagrande's construction for determining the preconsolidation pressure

If the density of the clays is known the preconsolidation pressure can easily be converted into the thickness of the former overlying strata.

It is therefore quite obvious that in the absence of other clear-cut evidence for an unconformity this method might be relevant to the solution of the problem providing that there are undisturbed beds of clay both above and below the level at which a major unconformity may be present.

Field Sampling (Plate 12)

Four clay beds were selected for sampling at the Bees Nest Pit (Beds 24, 22, 10 & 2) and two from the Kenslow Top Pit (Beds A & B). These beds are shown in Figs. 19, 20, 21 & 22.

Sample Preparation

The test specimens were trimmed to fit either 76 mm or 63.5 mm (3 or 2½ inch) oedometer rings. From each sample two specimens were cut parallel with the bedding and one at a random angle to the bedding.

Test Method

The equipment used comprised oedometers of the fixed ring type. For most preliminary tests no less than twenty load stages have been employed. Each load stage lasted at least 24 hours in all tests.

Test Results and their stratigraphical implications

The log p/e (log pressure/voids ratio) plots obtained from the suit of tests are reproduced in Fig. 21 & 22. Whether or not the specimen was cut parallel with or randomly oriented to the bedding does not seem to have had much influence on the shape of the curve.

As one cubic foot of fully saturated clay weighs approximately 1 cwt (58 kg).

PLATE 12

Sampling of Kenslow clays for consolidation

A numerical compilation of the results shown graphically in Figs. 21 & 22 is appended as Table 19.

With regard to the preconsolidation load on the grey clay at the Kenslow Top Pit (Bed B), this corresponds to a load of 28 m.of similar clay or alternatively to 64 m.of an ice sheet. The locality sampled lies approximately 9 m.below the pre-extraction land surface; thus the figure of 28 m. for the clay obverburden estimate compares very closely with the figure of 14.5 m.for the comparable lithology at Bees Nest Pit (Bed 24) (which was sampled from less than 2 m.below the original land surface), when the difference in depth below the original land surface is taken into account. If nothing else these figures certainly suggest that the youngest preserved Brassington Formation sediments at these two localities have had a remarkably similar consolidation history.

At Kenslow Top Pit the preconsolidation values for the two beds (Bed A & B) sampled differs by 450 KN/m^2 which corresponds to a sedimentary load of about 23 m. It will be noted that this does not closely correspond to the author's field measurements in the admittedly obscured sections in the south-western corner of Kenslow Top Pit, 32 m. But it is emphasised that the current poor exposure permits only a very rough estimate to be made and it is interesting to note that Kent (1957, p.5, who in 1946 saw a much cleaner section than that available to the author) reported that the coloured clays, containing Bed A were only 14 m.thick, a somewhat closer figure than that obtained from the author's own field estimate.

The same order of relationship (though admittedly with less convincing figures) as is present between the two beds sampled at Kenslow Top Pit, is also shown by analysis of the data for Beds 24 and 10 at Bees Nest Pit. Here the difference of preconsolidation values corresponds to a difference of 35 m.of sediment which is more than twice the figure obtained by the author's own field measurement. However the section is very confused and it is just possible that faulting or subsidence attenuation of some of the beds is present between the sample points.

(Neither of the two other beds sampled at Bees Nest Pit are considered to be very reliable for consolidation load tests. Both samples were very fissured. In the case of Bed 22 the sample was collected from very close to the surface. The sample for Bed 2 was obtained from a loose block found lying in the floor of the pit.)

From the consolidation results it is, however, quite plain that all the preserved sediments have suffered a very broadly comparable degree of consolidation stress, and it could thus be argued that the existence of a major unconformity is unlikely. Certainly, the figures for the Bed 10 at Bees Nest Pit and the Bed A at Kenslow Top Pit hardly support the view that the Kirkham and Bees Nest Members are of Mesozoic age. In conclusion it may be confidently stated that if any "hidden" unconformity is present it is of the nature of a minor non-sequence rather than any break of great temporal magnitude.

Whether or not the permafrost, which is believed to have been present in the area of sampling, has affected the preconsolidation stress of the sampled clays is a matter which has not yet been resolved satisfactorily. For this reason the results recorded here must be

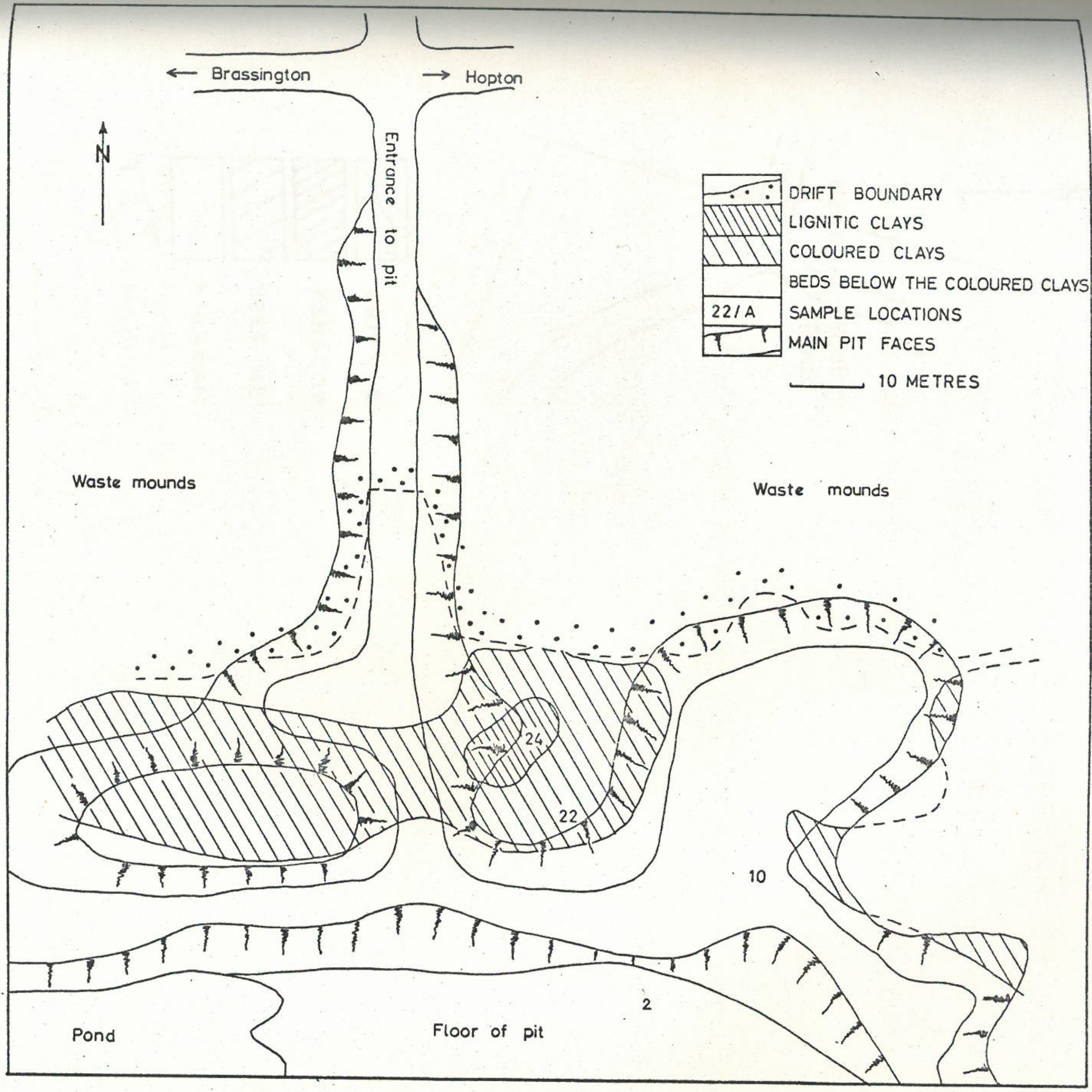


FIG. 19. Map of Bees Nest Pit showing locations of samples for the pre-consolidation pressure tests.

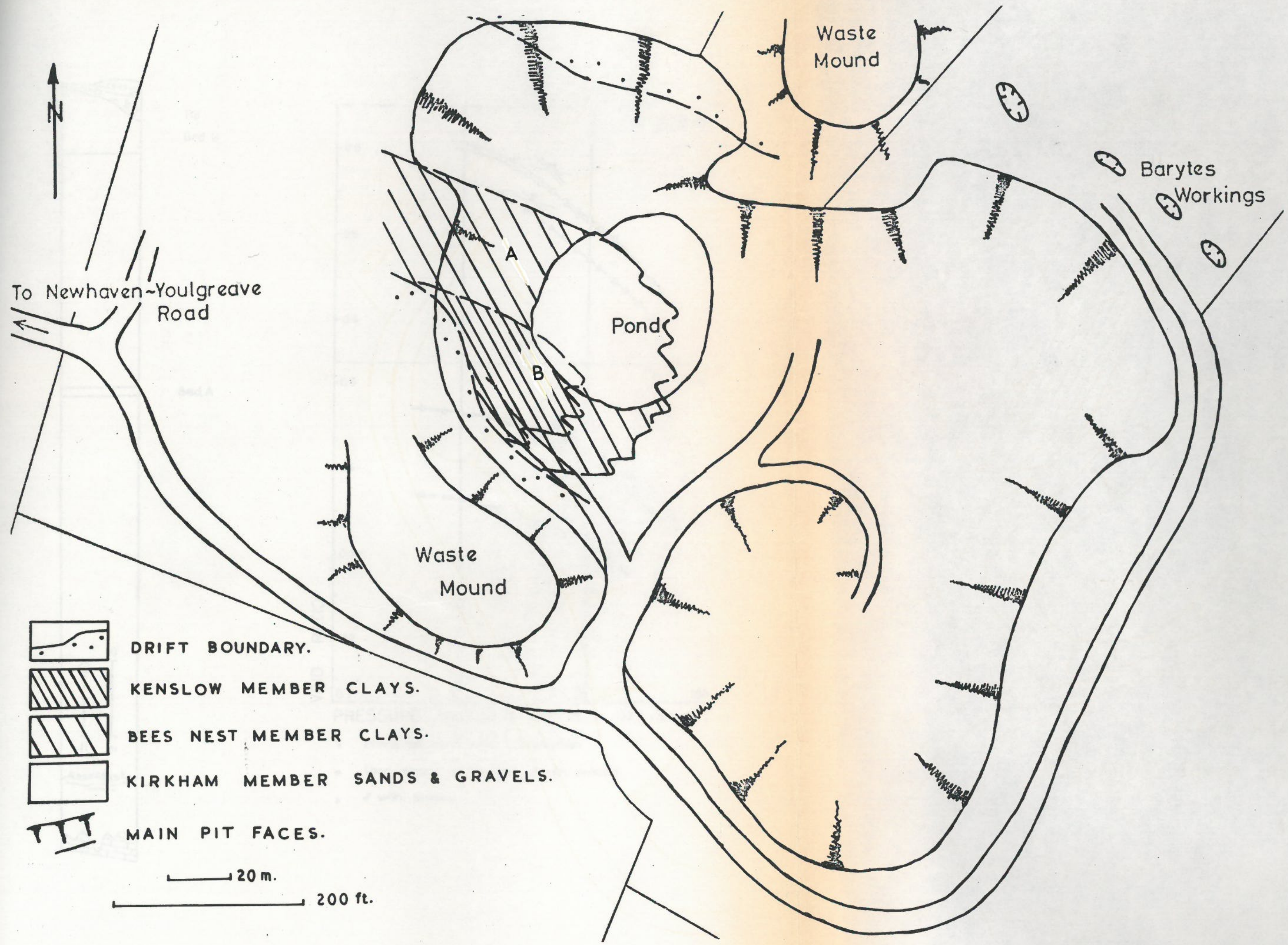


FIG.20. Map of Kenslow Top Pit showing the beds sampled.

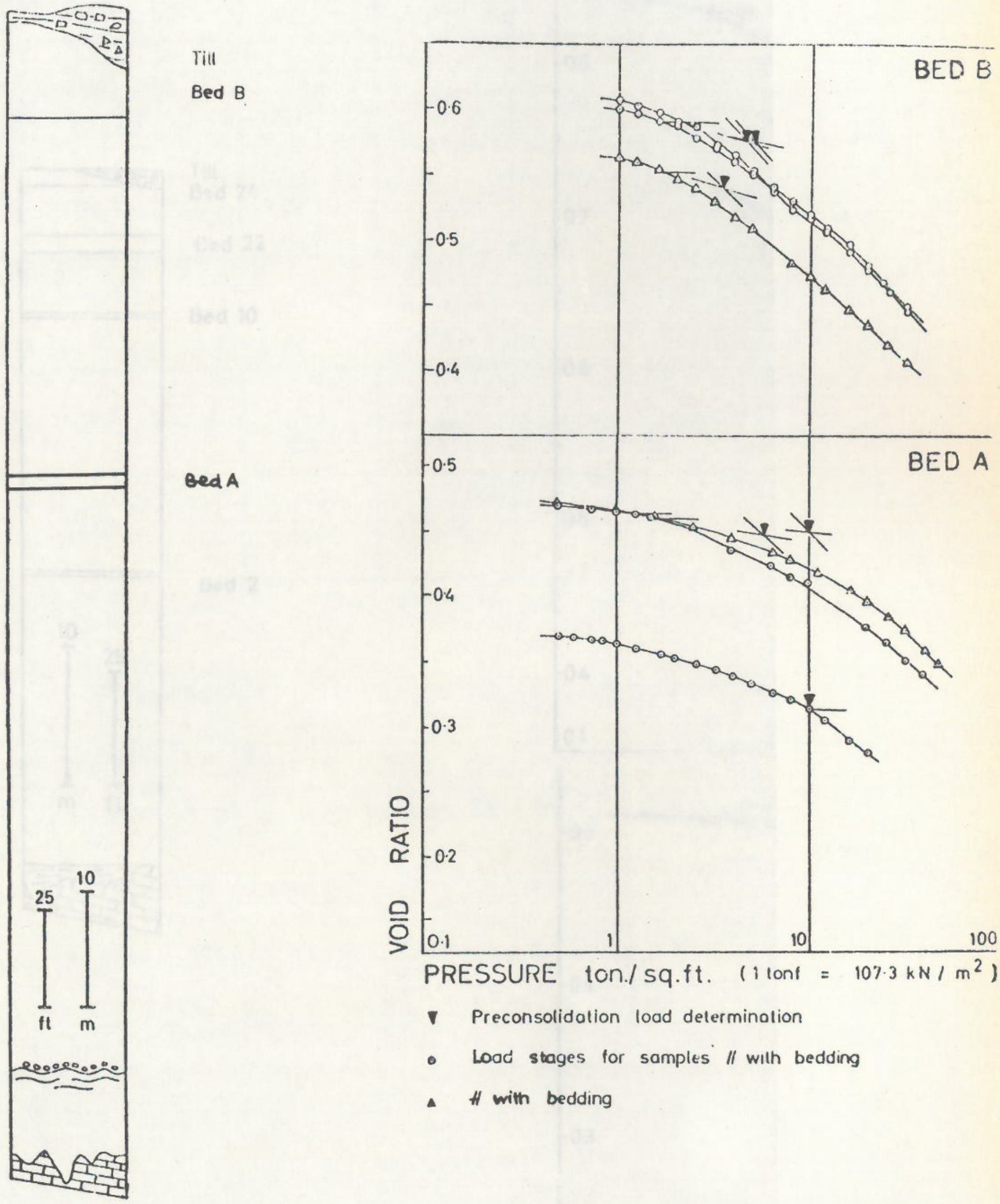


FIG.21. Preconsolidation load - Kenslow Top Pit

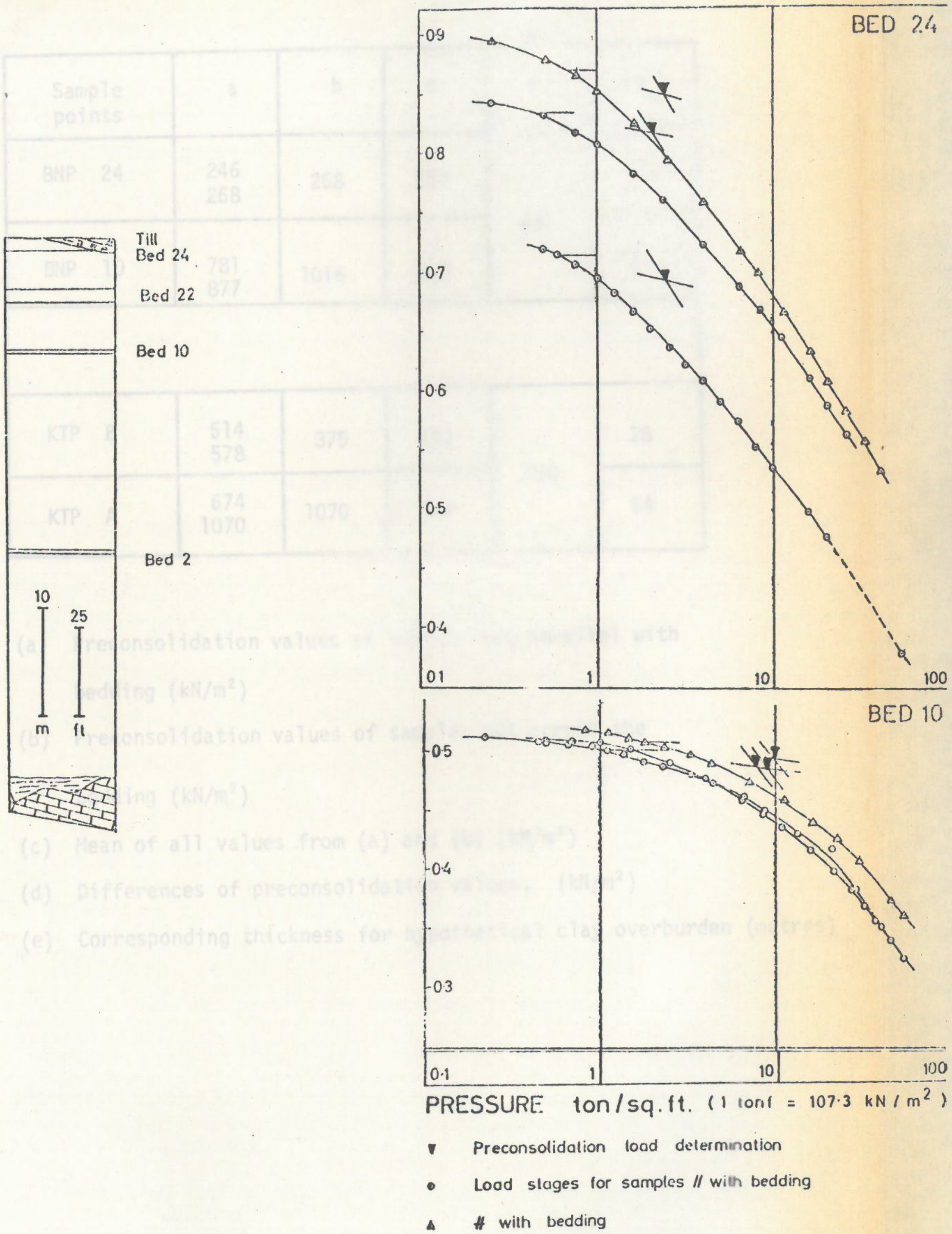


FIG.22. Preconsolidation load - Bees Nest Pit

TABLE 19

Sample points	a	b	c	d	e
BNP 24	246 268	268	257	631	14.5
BNP 10	781 877	1016	888		50
KTP B	514 578	375	492	450	28
KTP A	674 1070	1070	941		54

(a) Preconsolidation values of samples cut parallel with bedding (kN/m^2)

(b) Preconsolidation values of samples cut across the bedding (kN/m^2)

(c) Mean of all values from (a) and (b) (kN/m^2)

(d) Differences of preconsolidation values. (kN/m^2)

(e) Corresponding thickness for hypothetical clay overburden (metres) regarded as tentative until more experimental work has been done. However, one thing is certain, namely that the permafrost effect (if any) on the preconsolidation stresses of clays must have been similar at all the horizons sampled. In other words if permafrost disturbed the clay beds sampled and increased or decreased the apparent preconsolidation stress by 100 KN/m^2 at the Bed 10, Bees Nest Pit, for example, then more or less the same change should have occured at the Bed 24 at the same locality.

As stated above the results of the consolidation tests certainly point to the absence of any significant break. Since the uppermost beds ("24" Bees Nest Pit and "B" Kenslow Top Pit) contain plant fossils (Boulter & Chaloner 1970, Boulter 1971) of not younger than Lower Pliocene age the whole succession, on this basis, should be considered to be of Lower Pliocene/Upper Miocene age, at least until positive as opposed to negative evidence has been accumulated in favour of the alternative hypothesis.

Perhaps, however, the strongest line of evidence which bears on the problem of whether or not there is a major unconformity is simply the discovery of the mass of Kenslow Member clays at Kirkhams Pit in June 1971 (Ford 1972 b). At this locality the relationship between the Kenslow Member and the Bees Nest Member is yet again apparently quite conformable with a gradational colour change in the clay sediments making the choice of a boundary between the two members somewhat difficult.

It is interesting to note here that the Kirkham Member which has been considered to be Triassic by numerous authorities must have

Temporary Section 14 - 6 - 1971 (Kirkhams Pit)
Contorted and probably inverted Kenslow Member clays and lignites. The section at the top of the pit shows non-organic clays which are thought to represent the upper beds of the Bees Nest Member. Stratification roughly strikes across the pit face. The red stained material in the floor of the pit marks the line of the fault shown on Fig. 4.

PLATE 13

Temporary Section at Kirkhams Pit (2 - 10 - 1971), showing just to the right of the spade a gradational junction between what is plainly Bees Nest clays on the left hand side and organic grey clays, unmistakably Kenslow Member on the right hand side. The junction is nearly vertical as shown by the organic layer about 20 cm.to the right hand side of the spade.

PLATE 14

accumulated in a completely different environment from those in which the Bunter sandstone of Hulland Quarry and the Waterstones around Blake Low (SK 117465) were deposited. The Bunter sandstones and Waterstones have a log normal particle size distribution while the Kirkham Member sands of Bees Nest and Kirkhams Pits clearly show deviation from log normality (Fig. 23 - 29). Because of this difference it is reasonable to assume that the Kirkham Member was deposited at a different time from the Triassic beds, although this evidence in isolation does not prove that the Brassington Formation is of Tertiary age. Moreover the Bees Nest Member clays which have been regarded as a Keuper Marl by some authorities do not contain any chlorite, swelling chlorite and sepiolite which are the characteristic clay minerals of the Keuper Marl (Dumbleton & West, 1966). The author's work has shown that the clay mineral assemblage of the Bees Nest Member is completely different from the Keuper Marl and cannot possibly be correlated with this formation.

In conclusion it must be admitted that the evidence accumulated to date is still not unequivocal. But such different lines of positive and indirect evidence as have been derived from careful field observation and experimental work all point logically in the same direction. To the author's knowledge, no-one in recent years has been able either to detect in the field the non-sequence (with supposed Palaeogene or Triassic sediments below) or to find experimental evidence which denies a fundamental continuity of the Kirkham and Bees Nest Member sediments with those of the Kenslow Member.

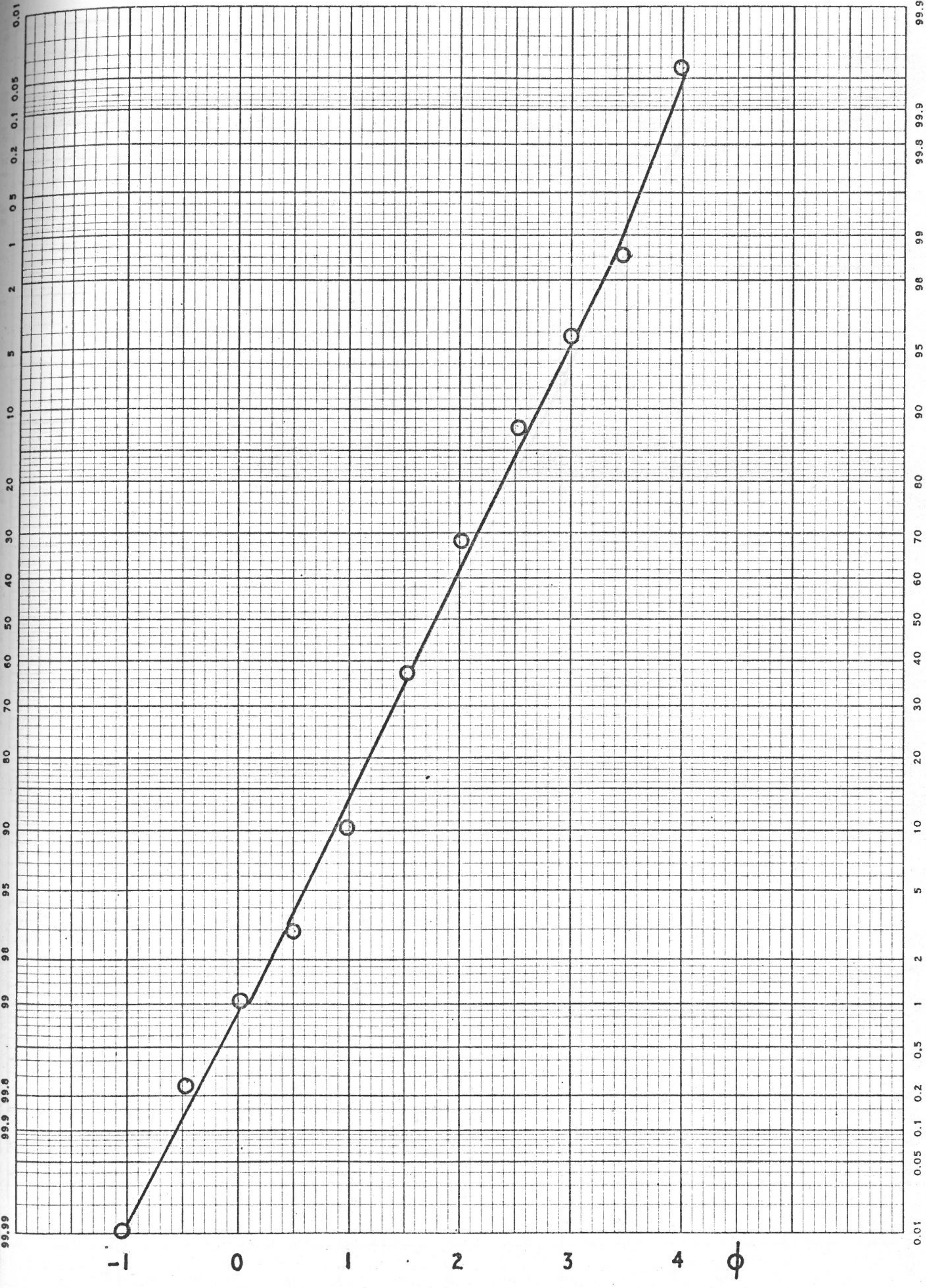


FIG.23. Particle size distribution of the Bunter sandstones from Hulland Quarry

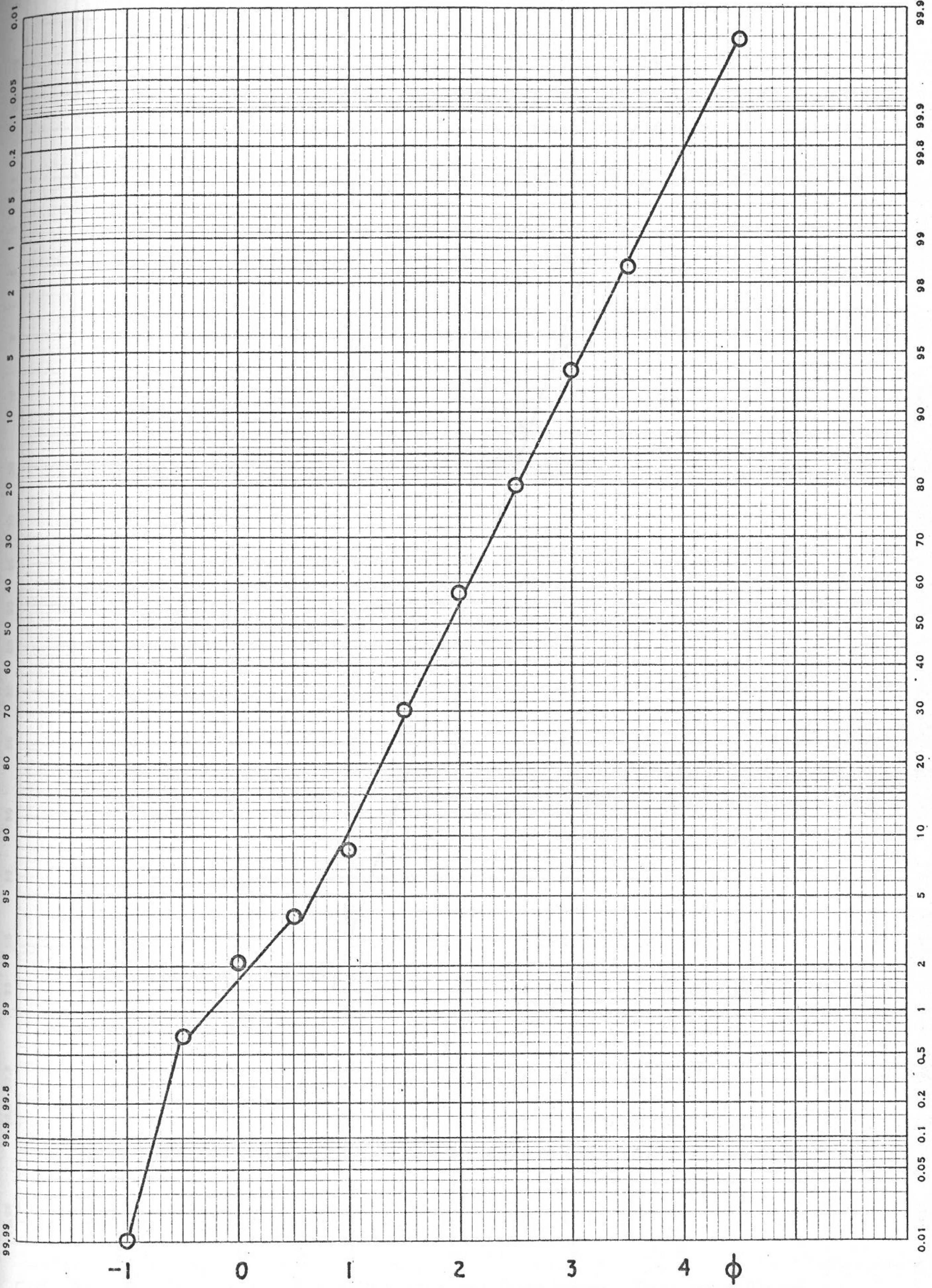


FIG. 24. Particle size distribution of the Bunter sandstones from the Hulland Quarry

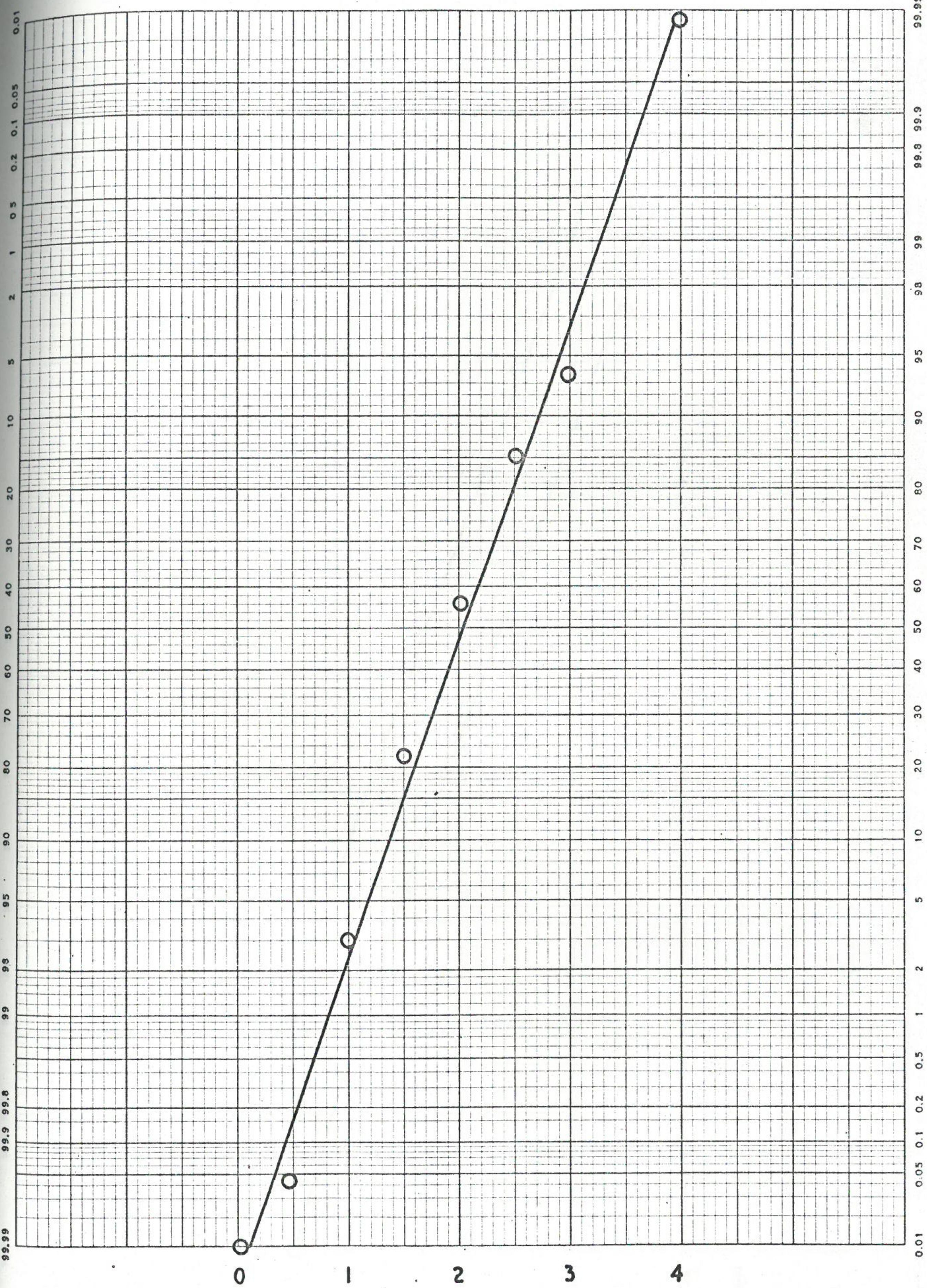


FIG. 25. Particle size distribution of the Waterstones from near Blake Low.

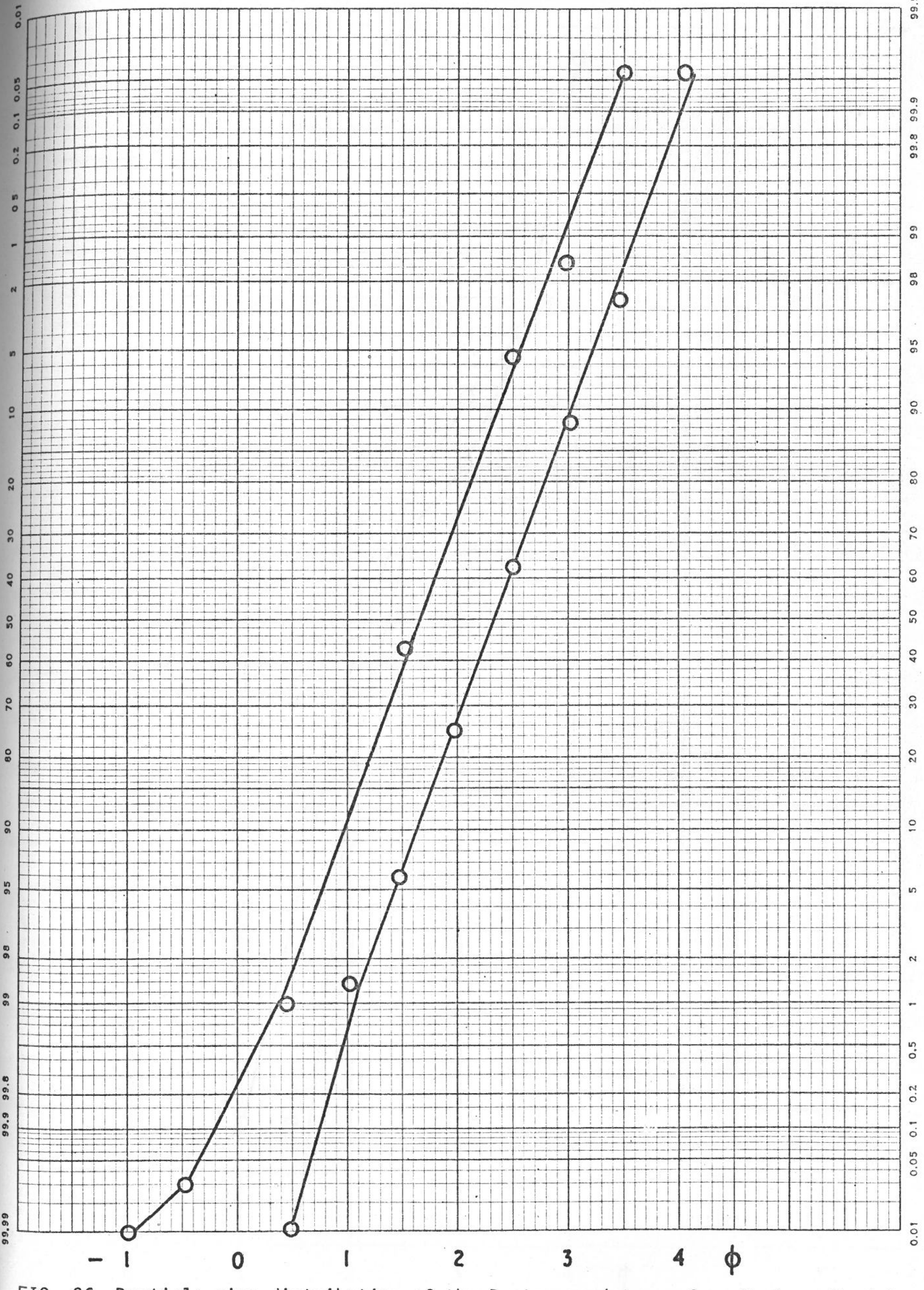


FIG. 26. Particle size distribution of the Bunter sandstones from Barbers Wood Quarry

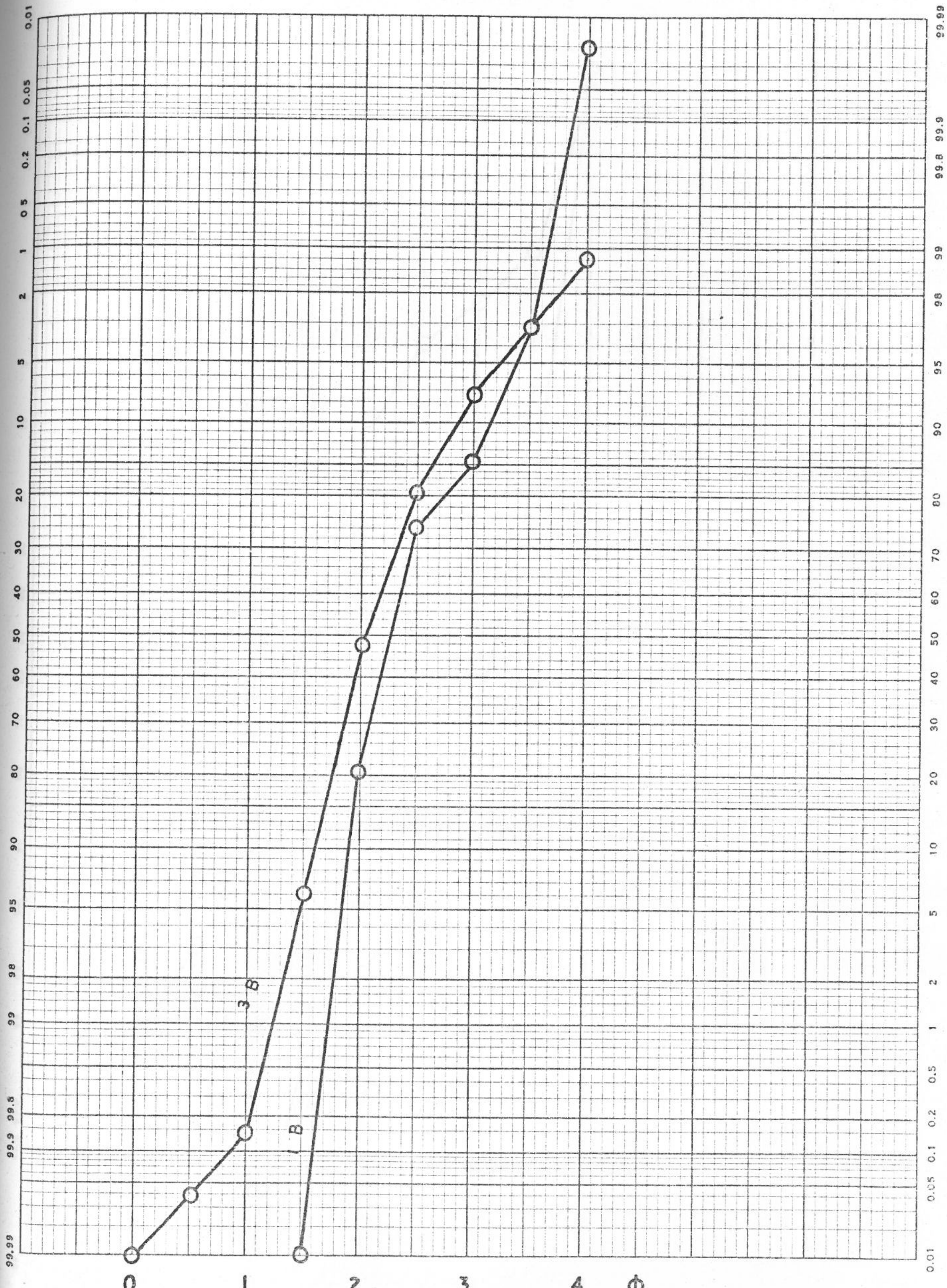


FIG. 27. Particle size distribution of the sediments from beds 1 and 3 at Bees Nest Pit

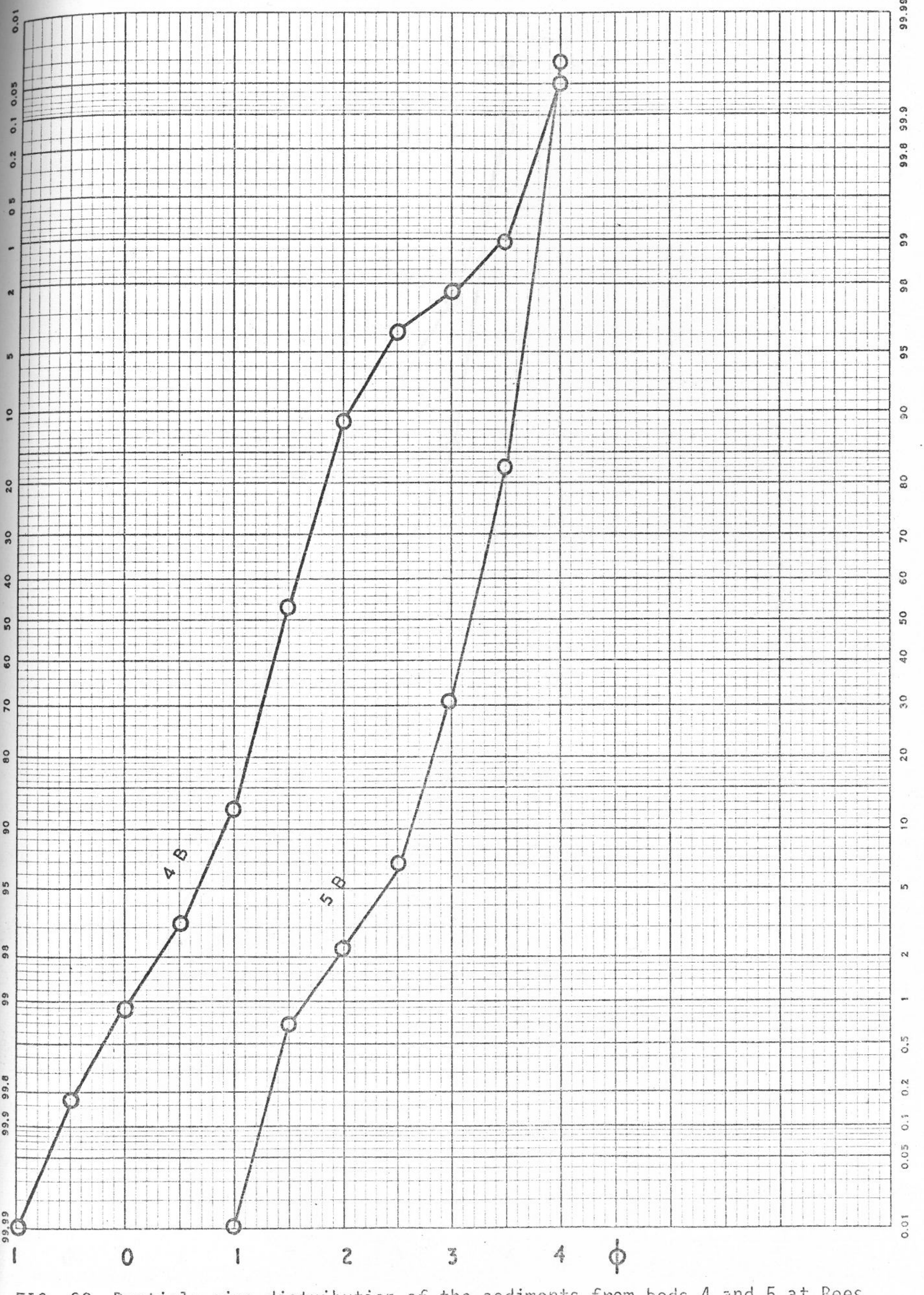


FIG. 28. Particle size distribution of the sediments from beds 4 and 5 at Bees Nest Pit

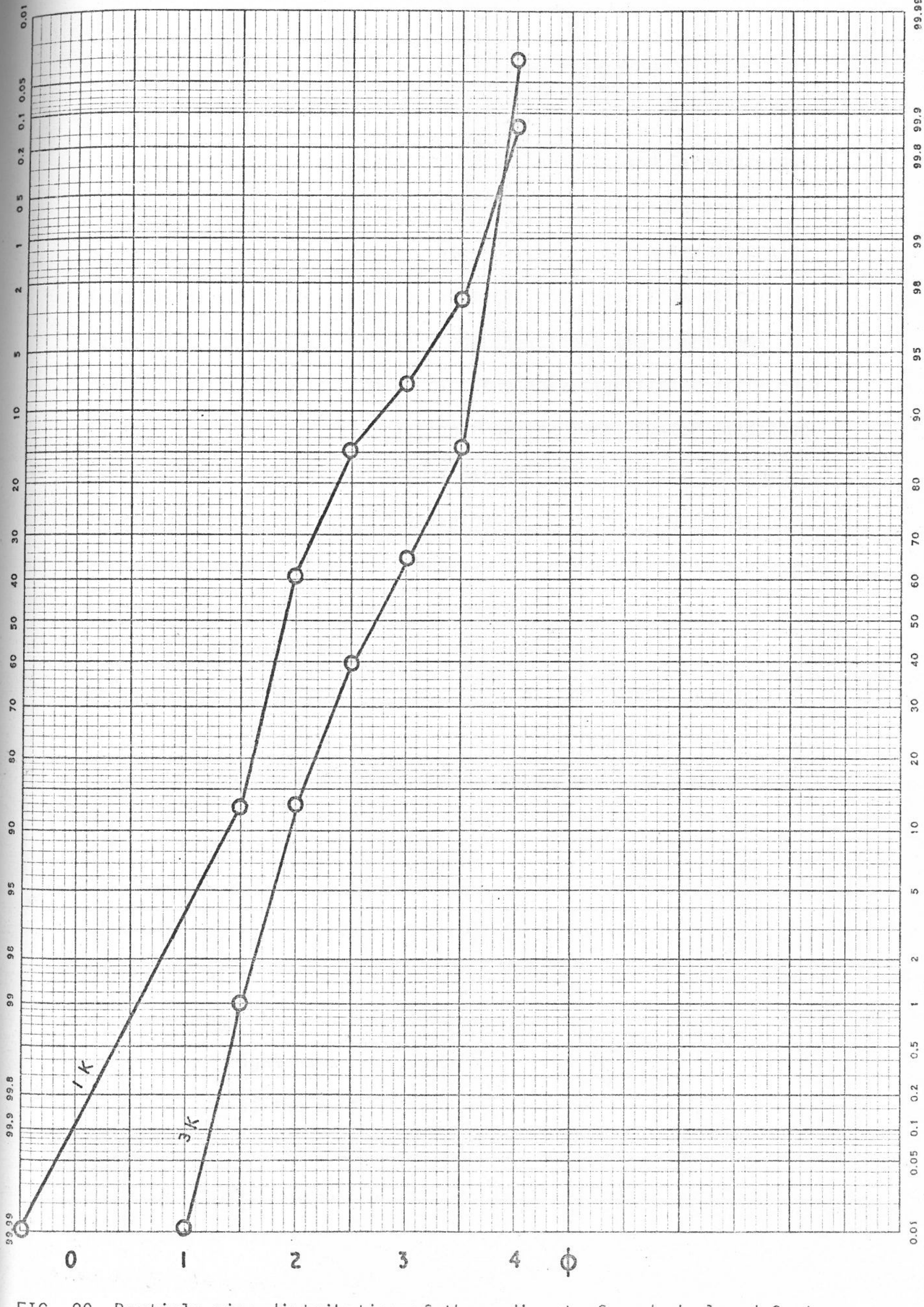


FIG. 29. Particle size distribution of the sediments from beds 1 and 3 at Kirkhams Pit.

5. THE PROVENANCE OF THE BRASSINGTON FORMATION

As stated earlier (page 10) local Triassic and Carboniferous rocks were investigated in order to establish the provenance of the Brassington Formation. A comparative study of the heavy minerals from the Brassington Formation sediments and those from nearby Hulland (SK 278456) Bunter sandstone shows that there are some remarkable similarities and in fact the only significant difference is that the heavy mineral fraction from the local Bunter sandstone contains about 11% (by number) of garnet. In contrast, this mineral is virtually absent from the Brassington Formation sediments (Fig. 14).

The scarcity of garnet in the Brassington Formation might be accounted for in a number of ways:

(a) Grading factors and hydraulic values

On the initial assumption that it is the lateral equivalent of the Bunter sandstone, grading factors and hydraulic values might be responsible for the absence of garnet in the area where the Brassington Formation was formed. But as garnet is virtually entirely lacking in the Brassington Formation sediments this seems to be at best only negative evidence in favour of a separate identity of the two sheets of sediments.

(b) Leaching

Garnet might have been leached out from the Brassington Formation sediments but as the Bunter sandstone seems to have more or less the same permeability as the sand and gravel in the Brassington Formation and if the hydrological histories of the Brassington Formation and the nearby Bunter sandstone sheet were similar, the garnet might be expected to be more common than it is in the former. However, their hydrological histories are plainly quite different. This particular factor then carries little weight in the discussion of both whether they are lateral equivalent of each other, or that the younger sediments were derived from the older.

(c) Destruction during transportation

Garnet is not a very stable mineral and can easily be destroyed during transportation. As the percentage of another metastable mineral, staurolite is also very much lower in the Brassington Formation sediments (Fig. 14) (the latter being assumed to have been derived at least partly from the former), this seems to be the most likely interpretation.

It is interesting to note that the Kirkham Member sediments from Bees Nest and Kirkhams Pits have virtually the same modal class as that of the Bunter sandstone sediments from the Hulland Quarry (Fig. 30). Since modal class often stays fairly constant even after the transportation this might be taken to give some support for the concept of a southerly derivation of Kirkham Member sediments from an area of Bunter sandstone to the South.

The size of cobbles in the gravel beds at Bees Nest and Kirkhams Pits is generally larger than that at Kenslow Top Pit. (After careful searches the author has found cobbles to a maximum of 18 x 12 cm at Bees Nest Pit, 15 x 10 cm at Kirkhams Pit and 13 x 7 cm at Kenslow Top Pit). As Kenslow Top Pit is about 9 km North West of Bees Nest and Kirkhams Pits, this also suggests that the source of the sediments for the Brassington Formation is southerly rather than a northerly.

Explanation of Fig. 30

a - Bees Nest Pit - Bed 3

b - Kirkhams Pit - Bed 3

c - Bunter sandstones (Hulland Quarry).

d - Bunter sandstones (Hulland Quarry).

e - Bees Nest Pit - Bed 1.

f - Kirkhams Pit - Bed 1.

g - Bunter sandstones (Hulland Quarry).

It is further interesting to note that Mr. T. Andrews, Pit Manager of the Derbyshire Silica Firebrick Company (which works Kenslow Top Pit) has informed the author that it is well known locally that the sand around Brassington area (Bees Nest and Kirkhams Pits) is coarser than the sand at Kenslow Top Pit. This again supports the concept of a generally southerly derivation.

It is, therefore, not unreasonable to assume that the bulk of the Brassington Formation sediments (Kirkham Member) is reworked Bunter deposits of the type that are present at outcrops in Ashbourne area at the present time.

This view has in fact already been adopted by Ford and King (1968) and Ford (1972 a) who impute a northwards - directed transportation of the Brassington Formation material.

Additionally Dr. T.D. Ford has recently pointed out (personal communication) that in the Bunter sandstone of North Midlands the Pebble Beds, bearing large pebbles (i.e. > 10 cm), die away about the latitude of Stoke on the West and Nottingham on the East. By inference one would not expect a former cover of the Bunter Pebble Bed with large pebbles in the High Peak District. This gives a strong support to the hypothesis of the southerly derivation.

In order to try to determine the source rocks for the Bees Nest Member sediments the author has analysed local Namurian shales. Differential Thermal and X-Ray analyses show that the Namurian shales are mainly illitic. One sample, however, also showed traces of kaolinite. As the Bees Nest Member clays are mainly illitic, this offers indirect support for the hypothesis that the Namurian shale provided the chief source of the sediment of the Bees Nest Member with the implication that in the source area the Bunter sandstone, which provided the sand for the Kirkham Member, had by that time been worn away to expose Namurian shales. This suggestion is strengthened considerably by the knowledge that in a low horizon of the Kenslow Member derived Carboniferous miospores are found in association with the Miocene plant fossils. (Boulter 1971). It might be argued that if the Namurian shale is supposed to have provided the sediments for the Bees Nest Member one should, therefore, also find derived miospores in the Bees Nest Member. None has yet been found but in view of the strong oxidation processes indicated by the redenning of clays it is possible that the spores may have been so destroyed before and during the transportation in Bees Nest Member times.

X-ray, D.T.A. and Electron Micrographs show that the Kenslow Member clays at Bees Nest and Kirkhams Pits are composed of assemblages of illite, kaolinite, lepidocrocite, anatase, quartz and gibbsite. The thermobalance curve shows that gibbsite forms about 10% of the Kenslow Member clays (by weight).

Gibbsite can be formed on any rock which contains Aℓ. Nevertheless the most favourable parent materials for the origin of gibbsite are aluminium rich minerals such as felspars and certain mafic minerals. Under intense conditions of leaching even acidic igneous and metamorphic rocks can produce considerable amount of gibbsite. Gibbsite may originate <u>in situ</u> either as lateritic residual deposits or, under certain conditions by the degradation of other clay minerals. Alternatively it may be transported from the area in which it originated.

If the gibbsite in the Brassington Formation was formed _in situ_ it should be present in all the places where the upper part of the sheet is preserved because the physical conditions controlling the formation of this mineral must have been broadly similar everywhere. But gibbsite has not yet been detected at Kenslow Top Pit (despite several analyses). The present author is therefore of the opinion that when this mineral is present in the Kenslow Member it is of detrital origin.

Moreover, the formation of gibbsite from clay minerals _in situ_ would involve intense leaching leading to de-silication of other clay minerals known to be present. This silica would have infiltrated downward and would presumably have cemented the Bees Nest and the Kirkham Member sediments below. But as silicified siltstones and sandstones are virtually absent from the Bees Nest and the Kirkham Members, this suggests that desilication (which is essential for the formation of gibbsite) did not occur at the places where this mineral is found at present.

Furthermore, the intense leaching would certainly have changed some of the Bees Nest clays into degraded illite or kaolin. As we do not find any degraded illite or kaolin in the Bees Nest Member, the author believes that the gibbsite was formed not from the clays in situ but from very much less resistant minerals. According to Jackson and his colleagues (Loughnan 1969) weathering sequence is as follows:

Weathering stage	Clay size minerals occurring at various stages of the weathering sequence
1	Gypsum (also halite)
2	Calcite (also dolomite, aragonite)
3	Olivine, hornblende (also diopside)
4	Biotite (also glauconite, chlorite, antigorite etc.)
5	Albite (also anorthite, microcline, stilbite etc.)
6	Quartz (also cristobalite)
7	Illite (also muscovite sericite)
8	Hydrous mica intermediate (degraded illite)
9	Montmorillonite (also beidellite)
10	Kaolinite (also halloysite)
11	Gibbsite (also boehmite)
12	Hematite (also geothite, limonite)
13	Anatase (also rutile, ilmenite)

It is quite clear from the above table that not all minerals weather with same ease. Some are rapidly destroyed and changed into different minerals whereas others are little affected under the same intensity of weathering. To extend the concept and in the knowledge that a relatively widespread local rock in the present day local outcrops is an olivine basalt, a basic igneous rock has been considered as a source for the Kenslow Member gibbsite.

The sequence of changes would presumably be:

OLIVINE	Amorphous	Ti.	Anatase
PYROXENES	hydrated and	Fe.	Hematite
FELSPAR	unhydrated		Geothite
	oxides		Lepidocrocite
		Aℓ	Gibbsite
			Kaolin

The time when this desilication occurred and the location and extent of the supposed outcrops of weathered igneous rocks in early pliocene time are not now determinable. However it seems fairly certain that the source must have been reasonably close to Bees Nest and Kirkhams Pits as gibbsite is apparently absent from the Kenslow Top section. At present, basalt is exposed near Matlock but this clearly does not necessarily imply that it was the source for gibbsite. Volcanic and pyroclastic rocks in the south of Brassington might equally be suspected as the source rock for the gibbsite.

6. THE DEPOSITIONAL ENVIRONMENT OF THE BRASSINGTON FORMATION

According to Folk (1965) the inclusive graphic standard deviation of Texas River sediments range between .40 - 2.5Ø. Tables 17 & 18 clearly show that the inclusive graphic standard deviation of all the samples from the Brassington Formation is well within these limits.

Comparison of the plots of mean size against standard deviation for the Brassington Formation sediments with the plot prepared by Friedman (1961) for dune and river sands also supports the concept of a fluvial environment for the Brassington Formation (Fig. 31).

The lower part of the Kirkham Member consists of poorly sorted medium grained sand with occasional scattered pebbles. Both lack of sorting and textural immaturity clearly show that sediments were transported under high energy conditions but came to rest in a low level energy environment by rapid deposition.

The author, therefore, considers that the Brassington Formation sediments were formed initially as fans or sheets at the foot of an escarpment (as shown in the area, Ford 1972 (a)). The process was perhaps similar to present day river-systems of parts of the Himalayan foot-hills. The great difference of thickness of the Kirkhams Member at Bees Nest and Kirkhams Pits may well be due to the nature of the fan deposition.

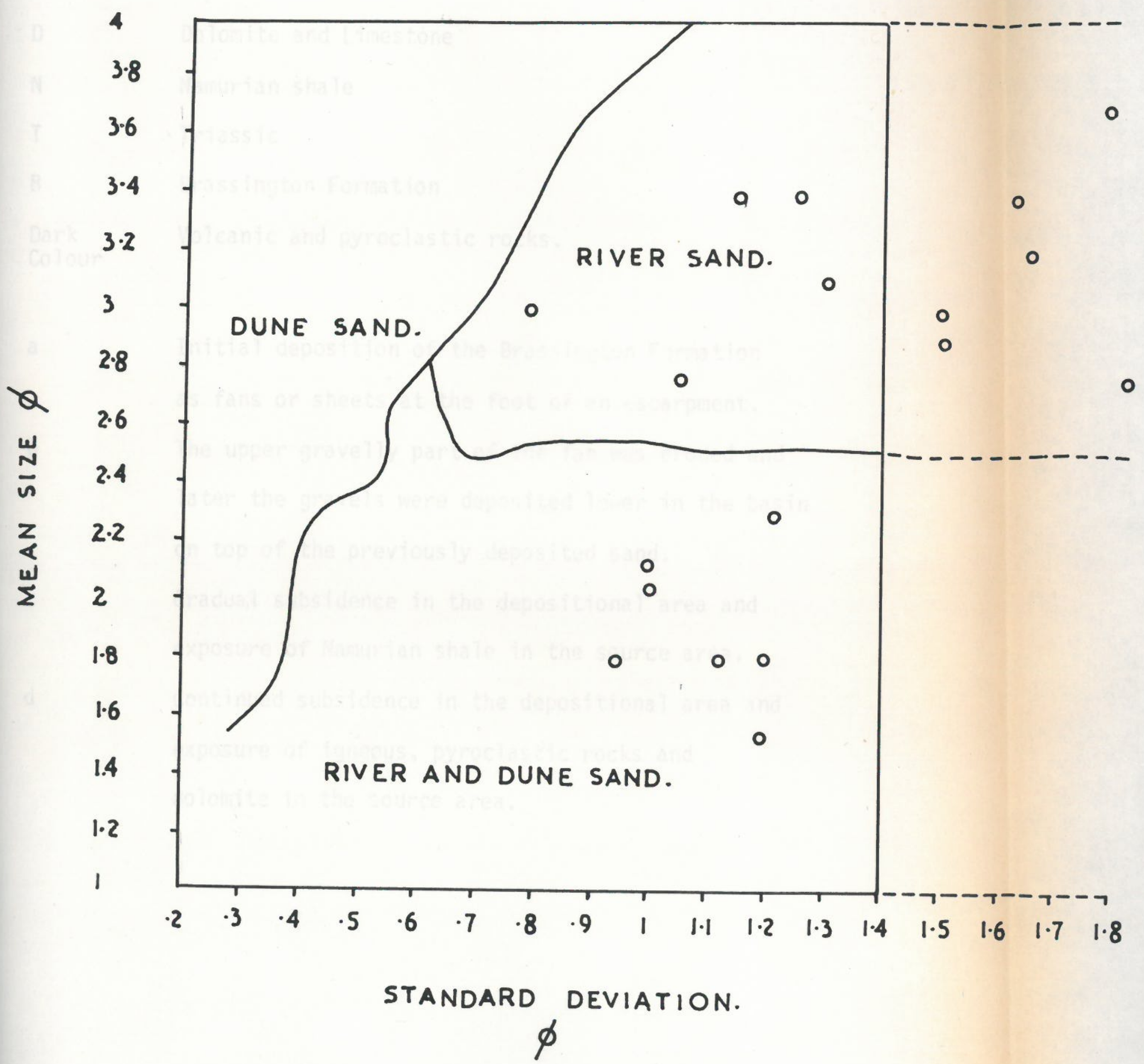


FIG.31. Plot of mean size and standard deviation for depositional environment - related to Fig.5 of Friedman 1961.

Explanation of Fig. 32.

D	Dolomite and Limestone
N	Namurian shale
T	Triassic
B	Brassington Formation
Dark Colour	Volcanic and pyroclastic rocks.

a	Initial deposition of the Brassington Formation as fans or sheets at the foot of an escarpment.
b	The upper gravelly part of the fan was eroded and later the gravels were deposited lower in the basin on top of the previously deposited sand.
c	Gradual subsidence in the depositional area and exposure of Namurian shale in the source area.
d	Continued subsidence in the depositional area and exposure of igneous, pyroclastic rocks and dolomite in the source area.

The middle of the Kirkham Member consists mainly of gravel. The sudden appearance of gravel in this part of the Kirkham Member is probably a reflection of the upbuilding of the fan on one hand, erosion and recession of the escarpment on the other. This perhaps altered the gradient which then enabled the river to remove the original upper gravelly part of the fan. The pebbly fraction was transported down the fan surface later to be deposited on the top of the previously deposited sand. (Fig. 32b).

As the Bees Nest Member clays have all the characteristics of a flood plain deposit, namely interbedded sand, general fining upwards, presence of lepidocrocite, it seems that sometime, between the deposition of the middle Kirkham Member and the Bees Nest Member, the river had attained a more or less permanent position and was not then behaving like a braided river system. The establishment of the permanent position of the drainage might have been due to further recession of the escarpment, but, whatever the reason, a lower inclusive graphic standard deviation for the upper part of Kirkham Member sediments clearly shows that it was deposited in an environment where energy dominated the load. This domination of energy over the load enabled the river to attain a fixed position.

As the sediments of the Bees Nest Member are much finer and less sorted than the Kirkham Member sediments, (Tables 17 & 18) it seems that, after the deposition of the upper part of the Kirkham Member, the depositional area began to subside. This subsidence reduced the energy of the river and compelled the deposition of the silt fraction in the fluvial regime whereas previously most of it, conceivably, was taken to the sea. However, one should also bear in mind the probability of a change of provenance with a removal of the supposed Bunter sandstone cover and the exposure of considerable areas of Namurian shale. In which case there would have been a proportionally greater supply of fine grained sediments. The increase in volume of the sediments during flood times led to overbank deposition on the flood plain. Gradually on this flood plain isolated lakes were formed, perhaps oxbow in character or possibly early subsidence depressions and swampy conditions developed. It is significant that lepidocrocite which is present in the Kenslow and upper part of the Bees Nest Member is believed to form under marshy conditions (Beutelspacher and Vandermarel, 1968, p.178).

It may be also of significance that some of the plants, namely Taxodiaceae and Nyssaceae found in the Kenslow Member also suggest a marshy environment (personal communication, Dr. M.C. Boulter).

Limit of the sheet of the Brassington Formation

The limits of the sheet of the Brassington Formation sediments are presumably wider than the present day outcrop of the southern half of the Carboniferous Limestone inlier of the Southern Pennines because there are indications of the Brassington Formation material along most of the southern extremities of the inlier. Existing information is summarised in Fig. 1 of Ford & King (1969). To this information must now be added the discovery of the plant-bearing clays (? Kenslow Member clays) in a limestone quarry at Hindlow (SK 080692). These are yet to be described but it is clear that they are not associated here with the Bees Nest and Kirkham Members as they are at Kirkhams and Kenslow Top Pits. There are indications, then, that the Brassington Formation sheet was at least 22 km across from both NW to SE (Hindlow to Bradbourne (SK 210527)) and from ENE to WSW (Matlock to Ribden). Within this area, though not necessarily relative to the full extent of the original sheet of sediments, the Bees Nest Pit lies to the southern margin, whereas the Kenslow Top Pit lies more or less centrally.

7. THE MECHANISM OF THE SUBSIDENCE

The author's work has demonstrated that the outliers of the Brassington Formation are the remnants of a once continuous sheet of sediments which once covered parts of the southern Pennines and which in places, during post-Lower Pliocene times foundered into solution cavities in the Carboniferous Limestone. Later the rest of the sheet was removed and no unfoundered outlier of the Brassington Formation has been positively identified.

As the preservation of these deposits is so intimately connected with the formation of cavities the author would like to conclude the thesis by trying to explain the geological processes which in his opinion led to the formation of caverns. In general the author agrees with Ford and King (1966 and 1969) that local dolomitisation was a major factor controlling the distribution of caverns. In some places there can be little doubt that the caverns originated at the junction of the limestone and more permeable dolomite. However, the author considers that this is not true in all cases.

At Bees Nest Pit, the author believes that the subsidence was very gradual because the beds are found in a relatively uncomplicated 'sag-syncline'. The distortion and disturbance of the stratification is so small that this seems to preclude the possibility of wholesale cave collapse having taken place. The concept of a gradual subsidence is in any case well supported by the scale model experimental work by Walsh et al (1972).

Because in Bees Nest Pit the Namurian shale lies directly on top of the Chert-residues the author concludes that solution did not originate at a limestone dolomite junction but at the contact of Namurian shale and dolomite. If the solution took place from the dolomite limestone junction upwards, as suggested by Ford and King, then one should expect at least some blocks of dolomite, which would have formed the roof of the cavern just before subsidence, to be present between the Namurian shale and the Chert-residues.

The Kirkhams Pit subsidence structure is apparently much more complex than at Bees Nest Pit. The presence of numerous faults, inversion and involution all support the concept of the dominance of wholesale collapse over gentle subsidence.

Probably in this locality a cavity was already present a few metres below the contact of the Namurian shale and dolomite. A downwards solution from the contact of the Namurian shale and dolomite reduced the roof of the previous cavity. This continued until the roof was so reduced in thickness that it could not support the weight of the sedimentary sheet above, and the collapse was thus initiated.

Chert Residues

The chert residues although not part of the authors research project, are an integral part of the Pocket-Deposits at both Bees Nest and Kirkhams Pits and merit some consideration. As in the case of many other aspects of the Pocket-Deposits, their origin is controversial. Walsh et al (1972) have claimed that they are wholly of late Tertiary origin, while Evans (in discussion of Walsh et al 1972) and Ford (1972-b) have argued the case for their being partly of pre-Namurian age.

For the following reason the author considers that the bulk of the chert residues found under the Namurian shale at Bees Nest and Kirkhams Pit is of post-Namurian age.

As stated earlier, the limestone in most of the area over which the Brassington Formation was deposited demonstrably had an unconformable cover of Namurian shales. This obviously shows a transgression of the Namurian sea over the limestone. If the bulk of the chert residues were already there at the time of this transgression one would expect to find, as a result of marine abrasion, rounded or subrounded chert masses at the base of the Namurian shale.

However, the chert which is found under Namurian shale at Bees Nest and Kirkhams Pits has suffered no such rounding, which to the author, suggests that it has not been subjected to any significant transport or abrasion. This can surely only be possible if it were formed by the solution of cherty Carboniferous Limestone under the cover of Namurian shale, in which case it is solution product of post-Namurian age.

8. CONCLUSIONS

The author's research on the Pocket-Deposits of Derbyshire leads to the following principal conclusions:

1) 'Pocket-Deposit' is still a useful term and may be retained to advantage but it is not to be used synonymously with Brassington Formation.

2) The term Brassington Formation should only be used when referring to those pocket sediments which are of post-Namurian and pre-Pleistocene age.

3) The Brassington Formation outliers are almost certainly the remnants of a continuous sheet of sediment which during Neogene times possibly covered a widespread area of the southern Pennines.

4) On the basis of lithology the Brassington Formation is logically divided into three members; the Kenslow, the Bees Nest and the Kirkham Members.

5) Botanical evidence shows that the Kenslow Member is roughly of late Miocene or early Pliocene age. The present sedimentological and geotechnical evidence suggests strongly that the whole of the succession is conformable and is therefore also of Neogene age.

6) Certain exposures of the Brassington Formation can be correlated virtually bed by bed by a knowledge of the constituent clay minerals and the statistical parameters obtained from the grain size analysis of arenaceous and argillaceous sediments.

7) Heavy minerals are not particularly useful for the detailed correlation of the Brassington Formation exposures.

8) Mechanical analyses clearly show that the Kirkham Member sediments of the Brassington area are quite different from the nearest Bunter and other Triassic sandstones.

9) The clay mineral assemblage shows that the Bees Nest Member clays which have sometimes been regarded as Keuper Marl are in many ways quite different from those in this formation.

10) The earlier belief that the Brassington Formation is of Triassic age is untenable.

11) The author's sedimentological investigations support the concept of a dominant southerly source for the sediments comprising the Brassington Formation.

12) The presence of large amounts of gravel in the Brassington Formation indicates that the initial source area was probably not very far away.

13) A comparative study of the detrital heavy minerals of the Kirkham Member with that of Bunter sandstone at Hulland Quarry indicates that the Bunter is almost certainly the main source for the Kirkham Member sediments.

14) The examination of the clay minerals shows that the Namurian shale is the most likely source for the Bees Nest Member clays.

15) The sudden change in the clay minerals within the mass of the Kenslow Member clays is more likely to indicate an abrupt change in source rock rather than an abrupt change of climate.

16) Much more geochemical and pedological work is needed in order to determine the source of gibbsite in the Kenslow Member with certainty.

17) Poor sorting, textural immaturity and great variation in thickness from place to place suggest that the lower part of the Kirkham Member is an alluvial fan deposit.

18) Presence of lepidocrocite in the Kenslow Member suggests that it was deposited in swampy environment.

19) The mineral gibbsite is significant as it is suggestive of lateritisation in the source area.

20) It is considered more likely that the area over which the Brassington Formation accumulated was gradually subsiding rather than there was a progressive rise of sea level during the deposition of the formation.

21) The extreme angularity of the chert residues indicates a negligible transport which in turn suggests that the chert residues originated under the cover of the Namurian shale and are therefore, post-Namurian in age.

22) Our knowledge of the Pocket-Deposits of Derbyshire is incomplete. Nevertheless a number of sedimentological, stratigraphical and geotechnical problems have emerged as a result of the present study that appear to be of more than local interest. In particular a more detailed regional study including a search for palaeocurrent indicators and the construction of isopleths should be undertaken in order to establish more precisely the provenance of the sediments of the Brassington Formation. There also is much more scope for research into the mode of preservation of the Pocket-Deposits, in particular into the hydrogeological regimes in Neogene and Pleistocene times. Much more detailed mineralogical and geotechnical work will be necessary in order to extend our present meagre knowledge of roles played by the local Palaeozoic and Mesozoic rocks as contributors of sediments to the Brassington Formation.

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