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The Geological Environment of the Shafton Seam and its Effect on Assessment of Production Capability.

N. BRYSON, B.Sc.

Thesis submitted for the degree of M.Sc., 1973.

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SUMMARY.

Ninety-two per cent of coal produced in British mines comes from mechanised faces. The large capital expenditure involved in equipping a mechanised face, and the inflexibility which is imposed upon the mining operations by mechanisation, means that sufficient coal, capable of being mined economically, must be known to be present over the planned area of extraction.

The success of planned production units in coal mining thus requires:- (1) a knowledge of the nature, both quantitative and qualitative, of the geology to be encountered and (2) an understanding, and if possible an estimation, of the effects which the geology will have upon production, In order to predict the geology of an unknown underground location the surrounding geology of worked areas must be known and stratigraphical and sedimentological continuity between the areas must be assumed to exist.

Various aspects of the sedimentology and stratigraphy of part of Riddings Drift Mine in Yorkshire have been investigated, using statistical methods where appropriate, with a view to extrapolating known and predicted features into 'unknown' areas. During the period of the current investigation some of these 'unknown' areas have been worked so allowing the validity of such extrapolations to be tested. A quantitative analysis of the capability of the mine is attempted in terms of the effect of given geological conditions upon production. This allows an assessment of production capability which is tested against actual production figures. The validity of such assessments, or predictions, has to some extent been proved.

Acknowledgements.

The author is indebted to Dr. G.A.L. Johnson for the instigation of this study, to colleagues within the National Coal Board for their assistance and to Mr. R.K. Taylor for his supervision of the preparation of this paper.

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INTRODUCTION

In the extraction of minerals as with other industries, production must be geared to demand, both in the short and long terms. These two aims are met in the coal industry by diversion of stocks to meet demand in the short term and by exploration and development of unworked reserves, so as to make them available to the machinery of production at some point in the future, as a long term policy.

The geological environment of the coal seam exerts a control over both present production and future development and it is the object of this thesis to analyse the relations which make up this control. This of course necessitates a detailed study of both geology and production, a combination not often found possible. An opportunity has however arisen with the introduction of the new mining techniques applied at Riddings Drift Mine. Here the first British attempt at 'dirtless' retreat mining is in operation.

Several papers have been written on this new technology (Round, 1970, Massey and Hirst, 1971) and so only a brief explanation will be given here. Basically it is an attempt to extract the coal with a minimum of dirt so as to give high efficiency. This is achieved by mechanized drivage of rapidly advancing roadways within the seam, allowing the operation of rapidly retreating mechanized longwall faces. The method of operation and price/ton of coal produced are compared in fig. 2 with those for nearby South Kirkby Colliery. Thus the thickness of the seam limits the area of applicability of the system, from the point of view of roadway height. By way of contrast, the face operation allows areas of severe geological disturbance to be worked, where other systems would have failed, in all probability.

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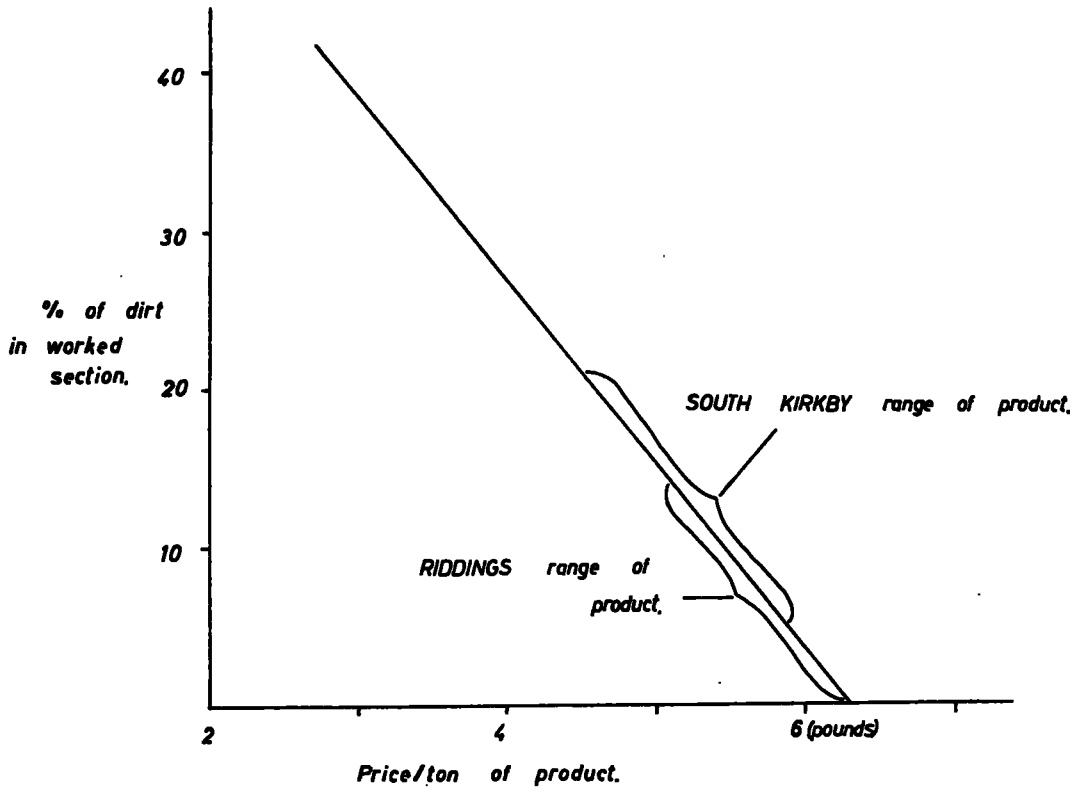
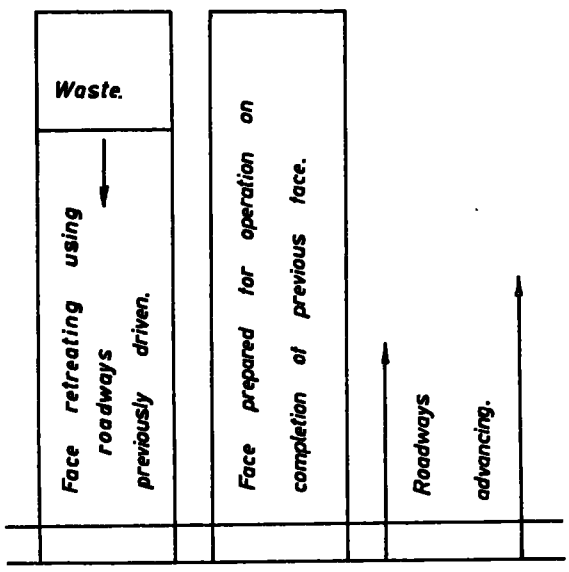
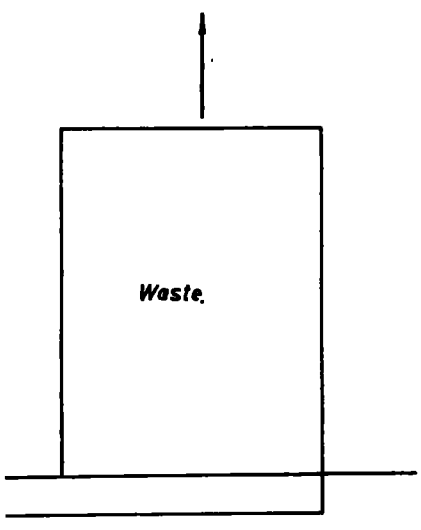




RIDDINGS

Face and roadways advancing together at the speed of the slowest operation.



SOUTH KIRKBY

A Comparison of the Methods of Operation and Resultant Price / Ton of Product for Riddings and South Kirkby Collieries.

Fig. 2

The system on the one hand affords an opportunity for defining the geology of a face panel before working, and on the other hand, the 'within' seam state of the roadway extraction limits the amount of strata available for observation. What is a help for the mining engineer is, as in most cases, a hindrance to the mining geologist. Perhaps what is most helpful is the standardisation of face design and machinery, allowing valid comparisons of production to be made between faces.

With this in mind the geology of the first part of the mine's take to be worked has been used in two ways:

(a) in the production of a scheme by which the inevitable changes in roof facies might be predicted, from a knowledge of the strata in those areas presently being worked

(b) to derive a system for the assessment of face performance and hence its profitability, before working.

CHAPTER 1

THE GEOLOGICAL SETTING

1.1 The Shafton Coal and Riddings Drift

Riddings Drift Mine is a new mine lying in one of the older mining districts of the country near Barnsley, in Yorkshire, (Fig.1). The mouth of the drift and surface machinery are accommodated by South Kirkby Colliery whilst the 'take' is the area of the Shafton Seam formerly held by that colliery. South Kirkby Colliery last worked the Shafton Seam in 1927, using pillar and stall methods, which although highly adaptable to most conditions proved to be incapable of overcoming the difficulties introduced by the geology. It is only with the recent advances in mining technology that the coal is able to be worked economically.

> "If one summarises the Shafton Seam as a hard cutting proposition, varying thickness, subject to faulting which changes over short distances, a roof and floor which varies and can be difficult and liable to a substantial make of water at short notice you will appreciate why it remains in the ground as a legacy from our forefathers, and it is really the seam which has had a very great effect on the layout of the workings at Riddings." (Massey and Hirst, 1971).

Against this background a detailed study of the geology was initiated and is continuing.

The Shafton Coal belongs to the supra-Aegir Grey Measures (palstage 2a, after Wills, 1956) lying some 30 ft. (9m) below the Shafton Marine Band and forming the top-most worked horizon in the Yorkshire Coalfield (apart from minor outcrop working of the Brierley Seam).

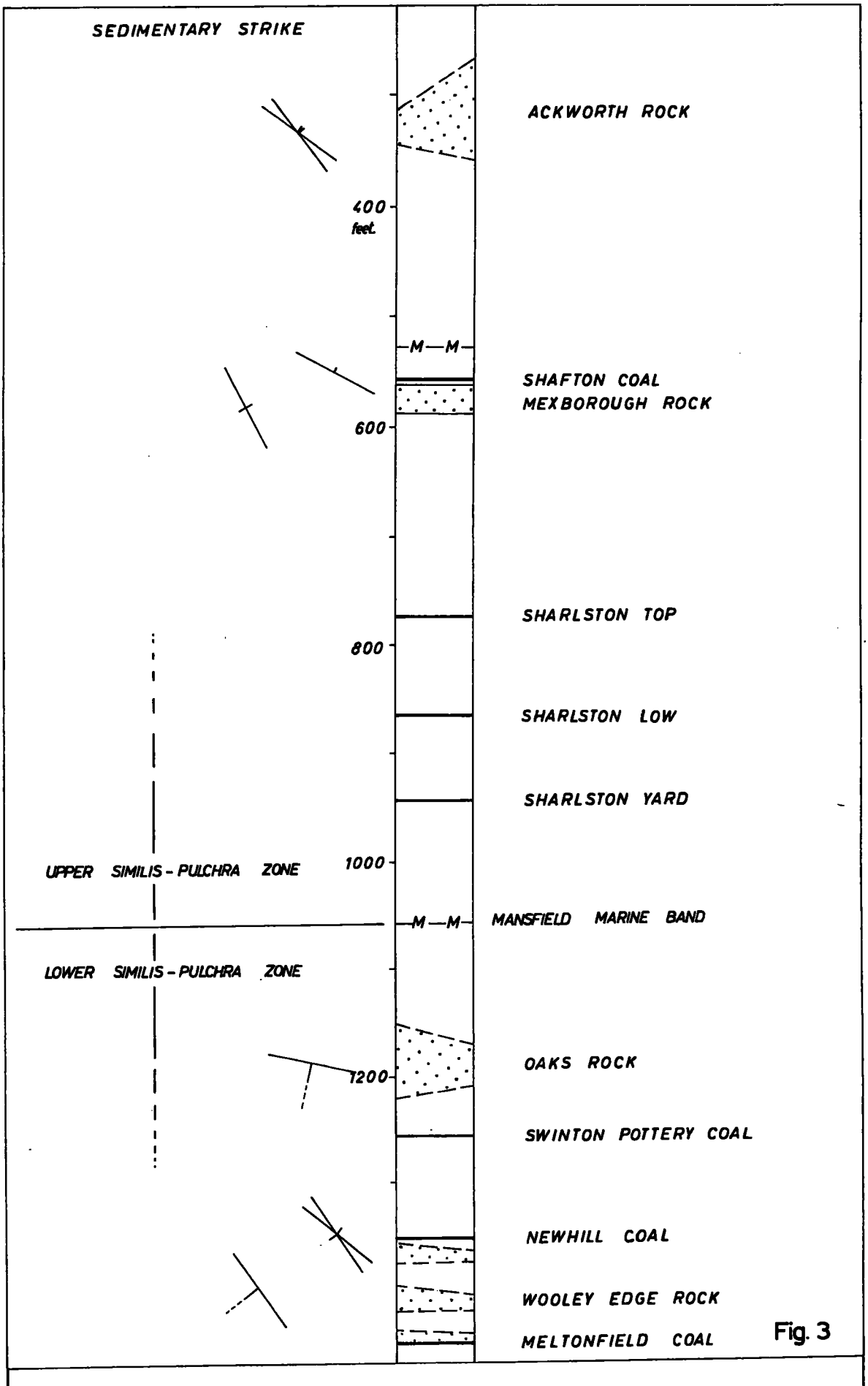


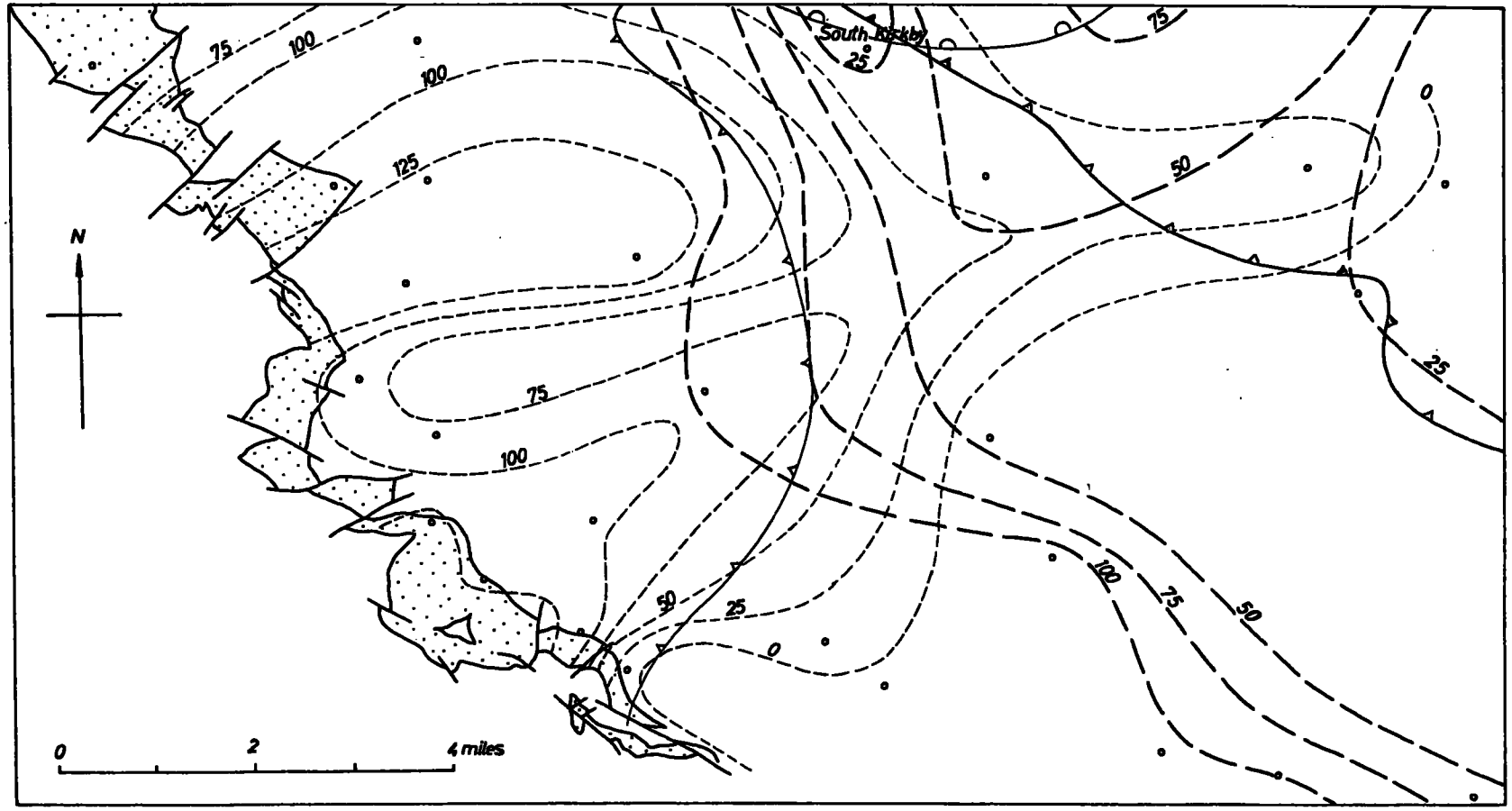
Fig. 3

A GENERALISED STRATIGRAPHIC SECTION FOR THE REGION

It is thus in the Upper Similis-Pulchra zone of the classification based on non-marine lamellibranchs. (Figure 3). If it is considered in relation to its contemporary sedimentary regime a better understanding can be gained of its varying environment and structure. Starting from an assumed regional sedimentary structure (see Geol. Surv. Memoir) as definedby previous workers, the seam structure can be fitted into tectonic a framework, - to be invalidated or upheld later.

It may be apposite here to trace the evolution of the Coal Measures basin leading to the deposition of the Shafton Coal. This is most easily accomplished by consideration of the underlying sandstones, with regard to their position at the far end of the cycle of coal formation, and of the lower seams themselves. From a study of the isopachyte map (fig. 4) of these lower horizons it would appear that during most of the preceding depositional period there was, in this area, a region of little subsidence. This could give rise to the possibility of sub-aerial or shallow water conditions during periods of regional emergence and favourable conditions for the formation of peat in the extreme case.

It is sufficient to cover the section from the Meltonfield Seam to the Ackworth Rock in order to gain an impression of the evolutionary sequence. (Fig. 3). Immediately above the Meltonfield Coal the Woolley Edge Rock lies like an open hand, with the fingers of sandstone extending to outcrop in the west. South Kirkby lies at the wrist, on the hinge of movement, remaining stable in relation to the palm and fingers which are free to move independently. Development of the Newhill Seam, which almost directly overlies the sandstone, follows the same pattern, the seam splitting to the south-west and thinning to the north-east.



The Main Sedimentary Features Underlying The Shafton Seam.

ISOPACHYTES ON THE WOOLLEY EDGE ROCK ---50--- ft.

" " " MEXBOROUGH ROCK ——50—— ft.

OUTCROP OF THE WOOLLEY EDGE ROCK

SHAFTON SEAM SPLITS

NEWHILL " "

" " DETERIORATES

COLLIERIES •

Fig. 4

Whilst the Woolley Edge Rock was absent and the Newhill Seam poorly developed to the north-east, the Mexborough Rock shows strong development on both this quarter and to the south-west, there being a ridge of low sedimentation passing through South Kirkby. The Shafton Seam, again almost immediately above a sandstone (Mexborough Rock) reflects this change in emphasis from a south-west sedimentary basin to one in the north-east, by splitting to the north-east along a line close to that of the ridge. This impression is reinforced by the Ackworth Rock which shows its greatest recorded thickness at Hampole, to the north-east of the postulated ridge.

If this fabric is assumed to be an expression of some form of basement control, which had acted throughout the sequence, it would be reasonable to expect a similar fabric to exist in those measures under study. It is the intention in the first part of this thesis to examine the possibility of this being the case.

1.2 The Floor of the Shafton Seam

The seatearth of a coal seam represents a soil, although there may be a non-sequential relationship between it and the coal. Moore (1968) visualises the formation of a seatearth by the migration of hygromorphic or sub-hygromorphic soils in the form of mud banks which support a hydrophitic vegetation. This view eliminates the need for an interrelationship between the seatearth and the coal on the basis of thickness and position in the cyclothem sequence. Colonisation of a seatearth by a xerophitic flora and subsequent peat growth may take place while further seatearth material is accumulating elsewhere. Seatearth formation is thus normal to a phase of regression within a region of broad, relatively flat, fresh or brackish shallow waters with an advancing sedimentation and flora. Assuming the mudbanks and their migration to be a product of shifting water courses, some relic of these palaeogeographic features should be discernible in the sediments of the seam floor. An example of such a feature is given below.

Over Block 1 and the surrounding areas there exists a system of linear depressions in the floor of the seam (see Fig. 5) in mining terminology referred to as swilleys. This network shows a directional trend of 063 degrees (standard deviation 19.3°) with a variance of 372. The individual form of a swilley is shown by Fig. 8 as derived from a consideration of the seam thickness over Block 1 in conjunction with surveyed topography of the floor. Associated with the depression in the floor is a thickening of the bottom leaf of coal. It is proposed that this is not a feature of the development of the coal itself but one which has been inherited from the previous fluviatile environment. The following discussion and the relation of the swilley to a pre-peat deposition river course follows the work of Elliott (1965) to a great extent. There is a

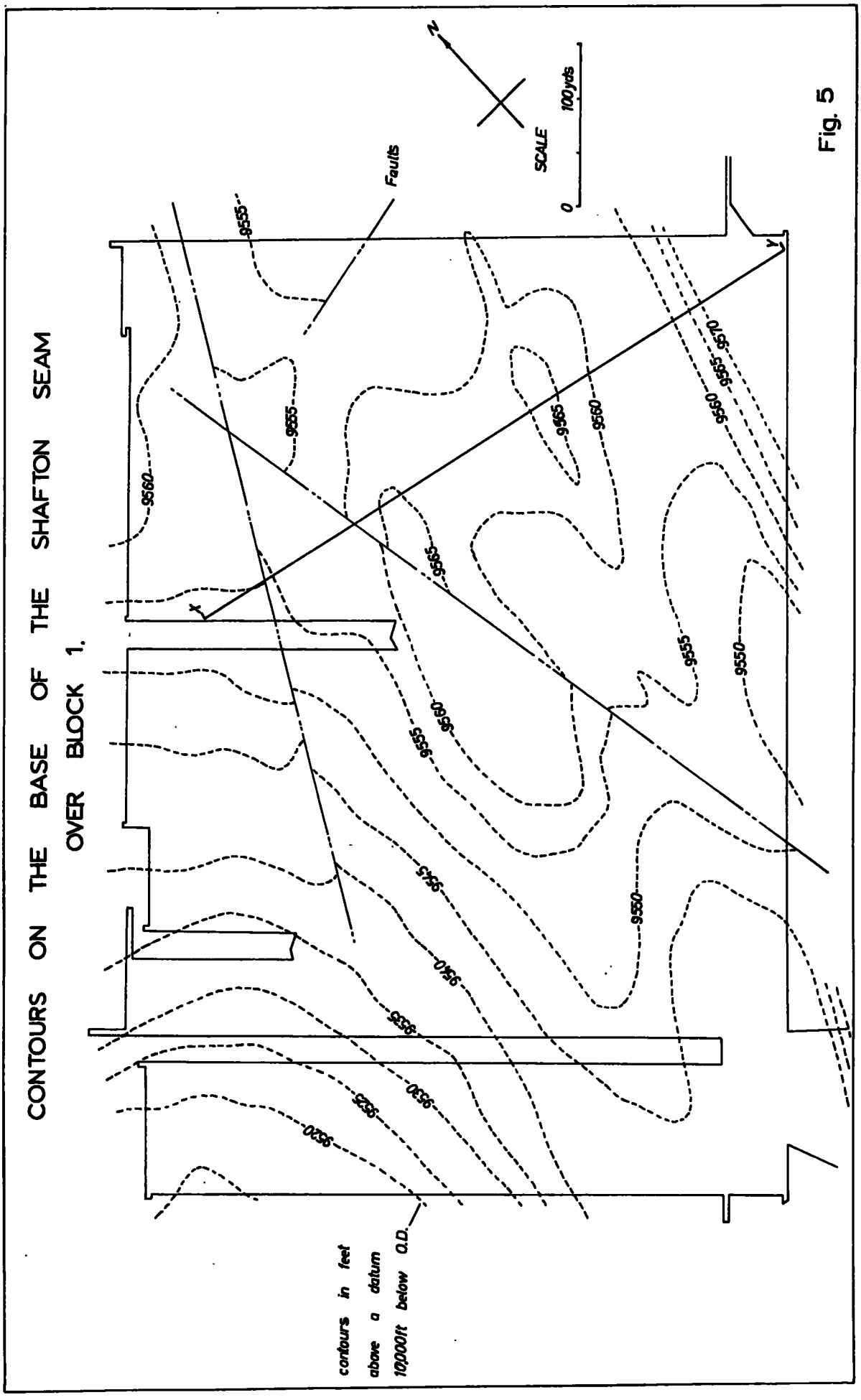
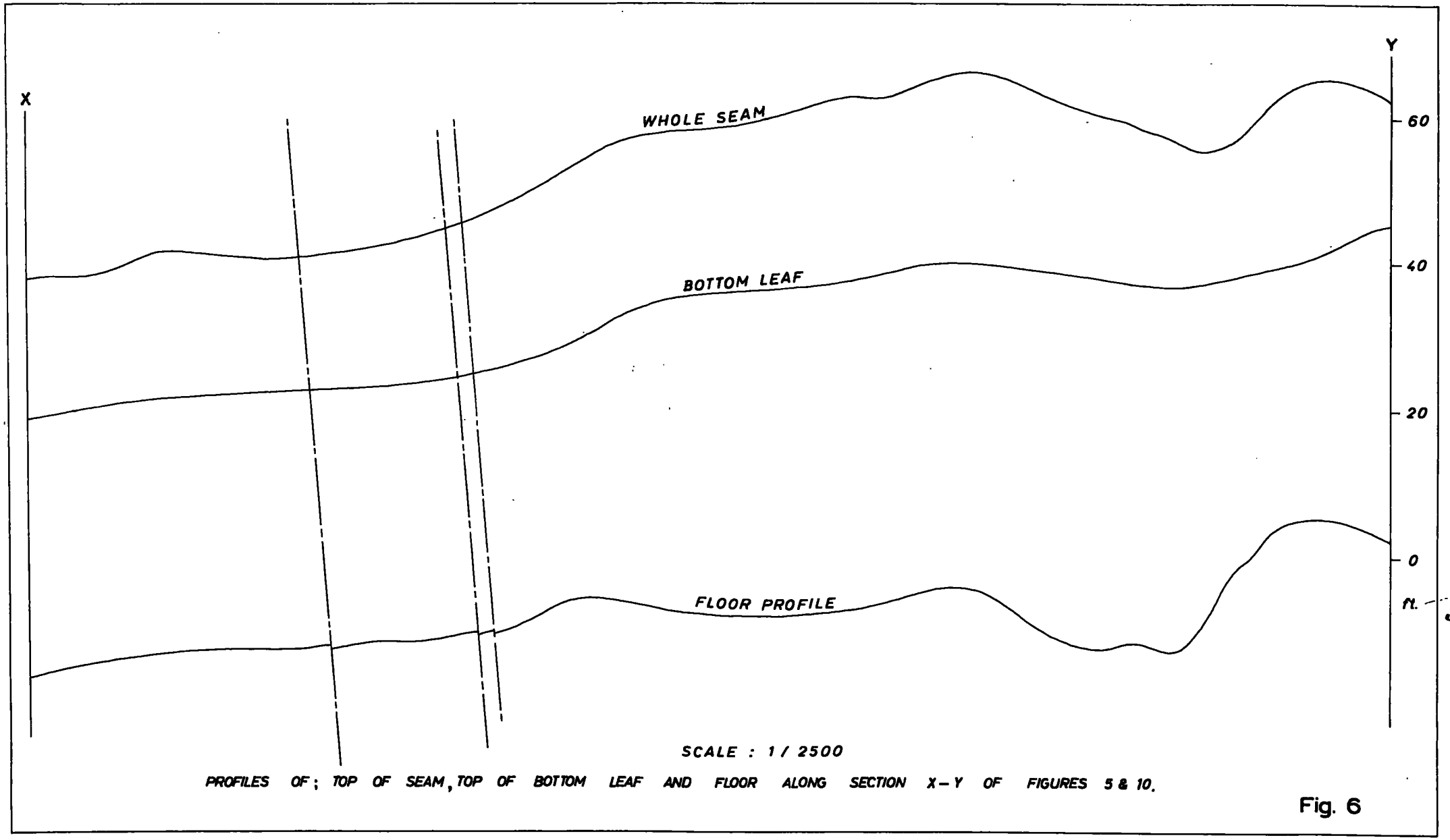

CONTOURS ON THE BASE OF THE SHAFTON SEAM
OVER BLOCK 1.
Faults
SCALE
0
100yds
N
X
Y
9560
9555
9550
9545
9540
9535
9530
9525
9520
contours in feet
above a datum
10000ft below O.D.

Fig. 5

pronounced thickening of the seam associated with an elongate hollow in the floor, the hollow showing a shallow inner side and a steep outer side (outer with respect to the curvature of the swilley course), along the line of which compactional or penecontemporaneous faulting is prominent.

In the first instance an attempt was made to relate the thickening of the whole seam over the swilley to the presence of an irregular floor topography at the time of peat accumulation. The thicker areas of the seam appear to coincide with hollows in the floor, after an irregular relief has been blanketed by peat deposits. This attempt is shown in Fig. 6 where it is seen to be an incorrect interpretation of the situation, the thickness of the seam in no way balancing the variation in floor topography. It may be noted that the shape of the coal horizon, based on isopachytes of its thickness may be dependent on both the underlying and overlying strata. With deposition of a peat blanket any irregularities of the floor will be infilled to give an irregular base to the seam. Further, irregularities may be introduced in the top surface by structural readjustments, slumping, differential compaction etc. and by erosive and depositional factors. In the Shafton Seam this effect of the overlying strata is immediately obvious where intrusive sandstone rolls cut out parts of the seam, obscuring its true top. Thus by using the whole seam one is attemtping to match two surfaces without having established a regular datum line. Because a middle dirt band is present, of possibly regular development, there remains the feasibility of achieving a balance by considering the bottom leaf of coal separately. Its top surface can be taken as the required regular datum line. When this is done a distinct relation does show although the line representing the top of the bottom coal is by no means a straight line or a simple curve, (fig. 6). What is evident is that those parts of



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PROFILES OF ; TOP OF SEAM, TOP OF BOTTOM LEAF AND FLOOR ALONG SECTION X – Y OF FIGURES 5 & 10.

Fig. 6

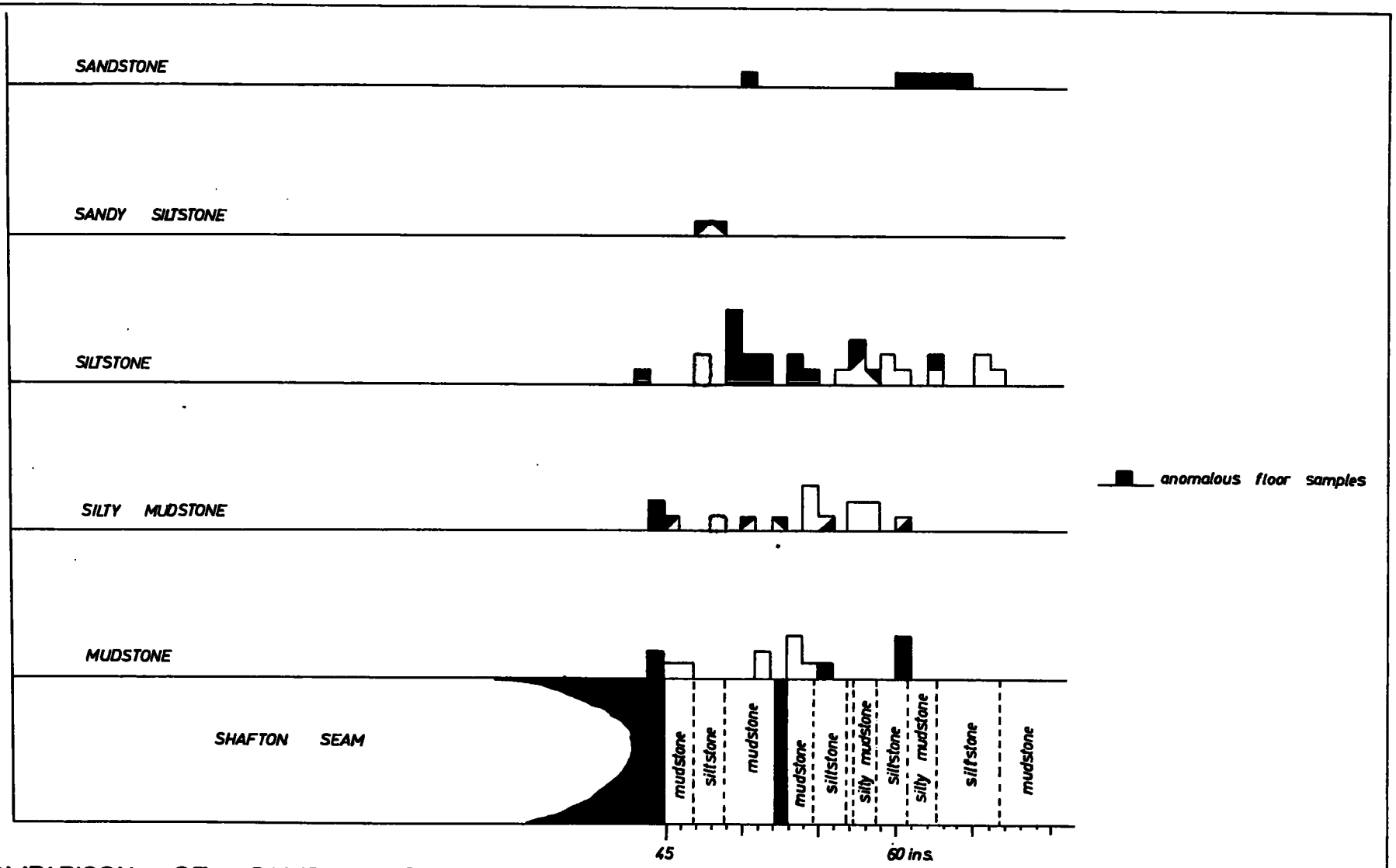
the curve which overlie regions of the floor without a strong relief, follow what relief there is very closely. This can then be attributed to tectonic adjustment, and can be removed by producing the surface as a straight line.

This having been done, the profile shown in Fig. 8 is produced. A flat area is established to the west, which after a small rise falls gently in two steps to the bottom of the swilley hollow, to rise again steeply on the other side. Unfortunately the area to the east of the swilley has not been worked recently and only one record is available with which to continue the construction past the outer brow.

Along this eastern brow are a number of compactional faults, similar to the structures recorded by Elliott (1965) showing a low dip of the fault plane into the swilley hollow and a strike running tangentially to the swilley course. In addition to these are normal faults showing high angles of dip and striking at various angles to the swilley. These latter appear independently to bear little relation to the swilley edge; however the zone of fracturing, which they as a whole produce, lies along the crest of the eastern wall.

No detailed study of the floor measures is available although a general pattern can be established. This is shown by Fig. 7 which compares the immediate floor strata corresponding to a given thickness of bottom coal with a vertical section of the floor located from the 35" (0.89m) level, having regard for the bottom coal at the sample point being 45 in. (1.14m) thick.* There does exist a certain degree of correspondence even though only one full floor section is available for comparison, with what can only be an approximate distinction of

* In the constructions coal thicknesses are exaggerated twelve times to allow for compaction, the 35 in. (0.89m) base is taken from the level region outside the swilley.



A COMPARISON OF SAMPLES OF THE IMMEDIATE FLOOR WITH THOSE OF EQUIVALENT DEPTH BELOW THE SEAM IN No.3 SHAFT.

Fig.7

rock type. With the topographic profile from Fig. 6 and this vertical distribution of floor types it is possible to produce the reconstruction of Fig. 8. This assumes the outer side of the swilley hollow to be undergoing active erosion and thus its structure is given as a horizontal stratification consistent with the recorded floor section. Anomalous sediment types from the vertical distribution have been placed on the inner side of the hollow, where contemporary deposition would occur. Sandstones are found at the deepest point of the swilley with siltstones making up the inner platform or terrace. Those sediment types found above the vertical section may be part of the original floor or, the levee and overbank deposits of siltstones and fine mudstones.

From these observations there appears to be a marked similarity at some levels, to the swilley in the Top Hard Seam of Nottingham described by Elliott (1965), whilst distinct differences do exist. The general form is one of an assymetrical hollow in the floor, its topography being divisible into 'hollow', 'brows' and 'flanks' with the attendant feature of compactional faulting. Where the main difference lies is in the relation of the swilley, as a whole, to the seam. The swilley of the Top Hard Seam shows brows and levee banks, which are extended laterally outwards in the form of clay flanges, effectively within the seam. The sedimentary features appear to be a product of a deltaic environment during the deposition of the coal itself. The Shafton Swilley on the other hand would appear to be a predominantly pre-peat feature, reminiscent of a flood plain environment. The situation would appear to be one of a deltaic front building outwards and followed by colonisation by the peat forming flora whilst conditions were favourable.

In order that the depression, which is the swilley, should be filled by an accumulation of organic detritus rather than by the

AN INTERPRETATION OF THE FLOOR STRUCTURE ACROSS THE SWILLEY FROM X TO Y *(see Fig.5)*

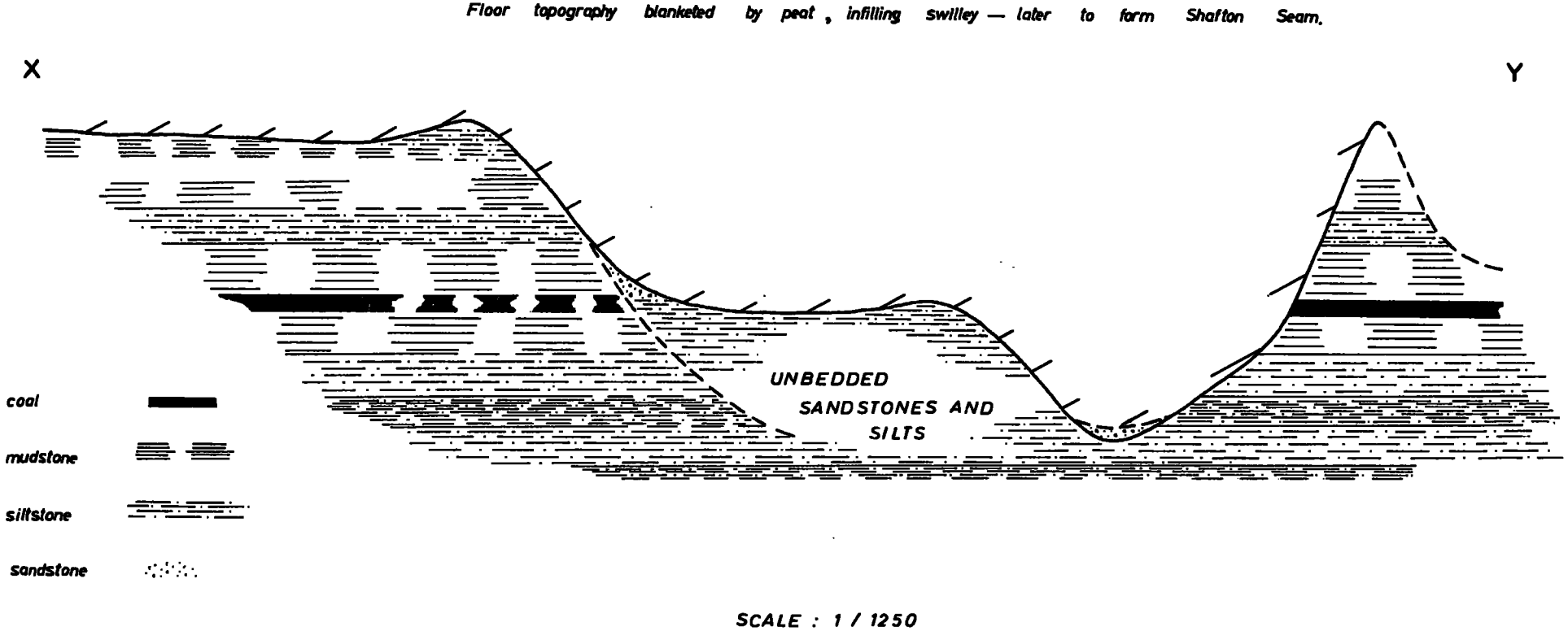


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Fig. 8

clastic load of the river system, it must be in some way isolated from the system. Isolation is favoured by the bed load of the main current being free to move towards the slack water of a cut-off lake thus damming the channel. Such sediment load as then reaches the lake is derived from the suspended load of the main current and hence it is relatively fine in size. In Russell's (1967) words "More persistent is the accumulation of clay in the lake resulting from a continuing supply of local plant remains that decompose into soft ooze." Dependent upon the biochemical conditions in the lake, and the amount and type of detritus available, this clay could be substituted by coal.

1.3 The Shafton Seam

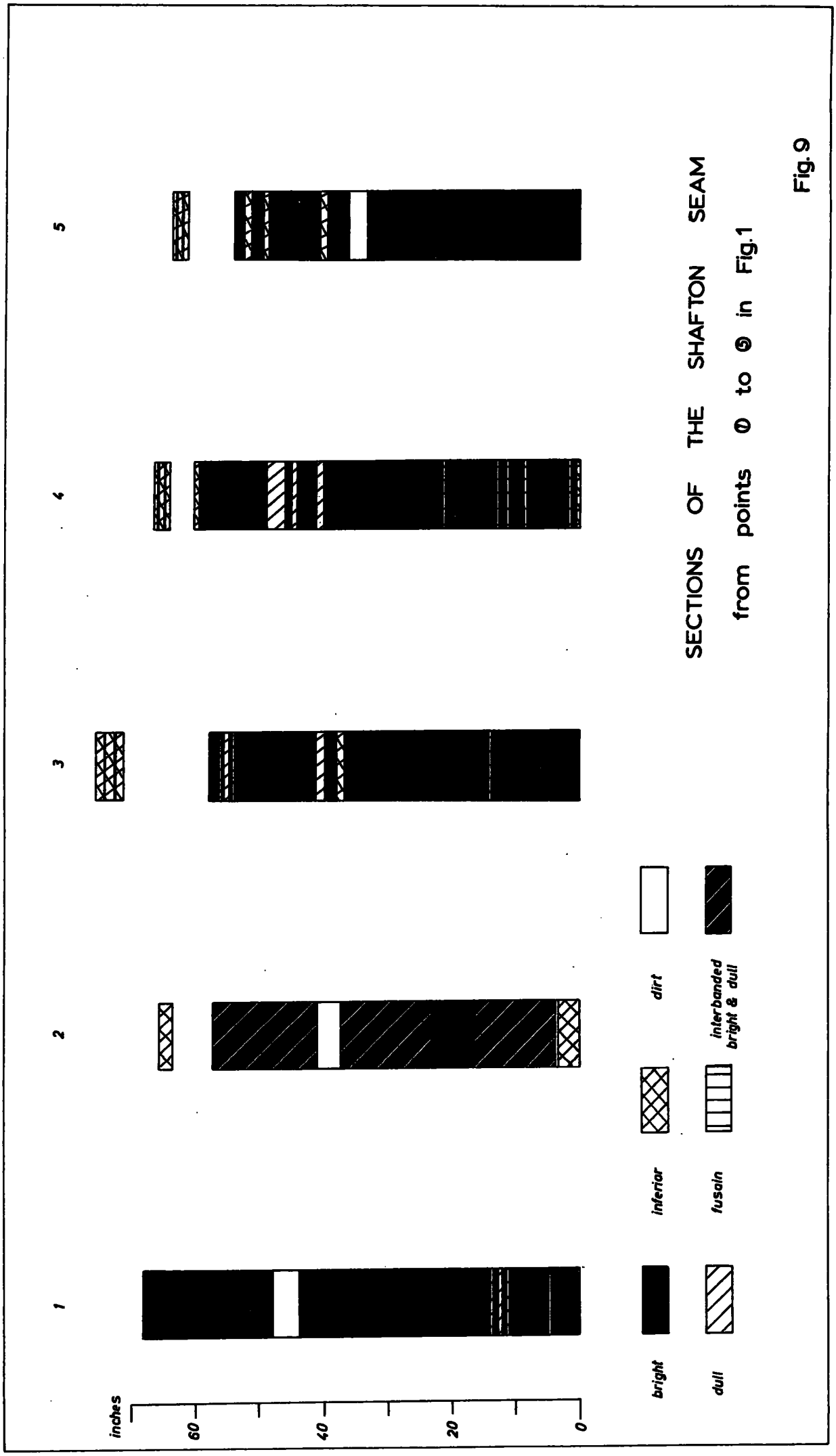
Although a separate lithological unit and considered apart from the floor measures there remains a relation not only of superposition but also of at least partial contemporaneity between the two. A brief summary of the seam structure is given here culled from the various reports of the Coal Survey Department of the Board, supplemented by the author's own work on certain aspects.

Data from four seam sections are shown in Figure 9 with the sample points shown in Figure 1. From these the expected characteristics of the seam for the first part of the 'take' were computed before production began. A typical measured section is given for comparison. It is clear from these that a wide lateral variation in seam structure is present, both in coal quality and thickness of sub-sections. These must reflect the varying conditions under which the seam was laid down.

The market for coal from Riddings is in the main (a) untreated material used as a power station fuel, and (b) washed coal for use in blends in the manufacture of smokeless fuels. This is a consequence of its poor quality, high sulphur in this case, which is compared below with a good quality coking coal.

	Sp.Gr.	Ash	Sulphur	Coal Rank Code
Shafton Coal	1.35	6.0 - 9.0	2.5 - 3.2	702
Coking Coal	1.35	3.0 - 9.0	< 0.75	301

With such a tolerant market more attention is paid to thickness of section than to quality, thickness being more directly relevant to production and mining problems.


SECTIONS OF THE SHAFTON SEAM
from points ① to ⑤ in Fig.1
Fig.9
inches
60
40
20
0
1
2
3
4
5
bright
dull
inferior
fusain
dirt
interbanded bright & dull

The productive seam is divisible into three major parts; the lower or bottom coal, the middle dirt or its equivalent and the top coal. The total thickness of these three is shown by Figure 10. Variation in this thickness is accounted for, seventy-five per cent. by the lower leaf and twenty-five per cent. by the upper. In the case of the lower coal the variation has already been explained by reference to the swilley and associated features. A large proportion of the upper coal variation is a product of a further fluviatile phase in the channel sandstones of the higher roof. The thickness of the middle dirt does not alter significantly over Block 1, although it is known to cause splitting of the seam to the north-east. What does alter is its composition, ranging from a mudstone seat-earth to inferior coal. It is however always represented in one form or another.

The upper leaf of coal, as previously mentioned, is affected by sandstone bodies which may be either a continuous downward development of the channel system of the roof, or they may be in the form of lenses enclosed within the seam. In the first instance the sandstone is seen to have erosive contacts with the lower roof measures and the coal, without any strongly deformational features. The lenses however, are in themselves distorted and are associated with distortion of the coal in the form of strong down-warping of the middle dirt and fracturing of the coal around the body. When the distortion is removed by making allowance for the compaction of the coal against the sandstone (similar to that made in consideration of the swilley) the lenses take on a flattened elliptical form. These can be partly or wholly superimposed on one another and may lead into the channel complex.

ISOPACHYTES OF THE SHAFTON SEAM SHOWING THICKENING ACROSS THE SWILLEY.

IN BLOCK 1.

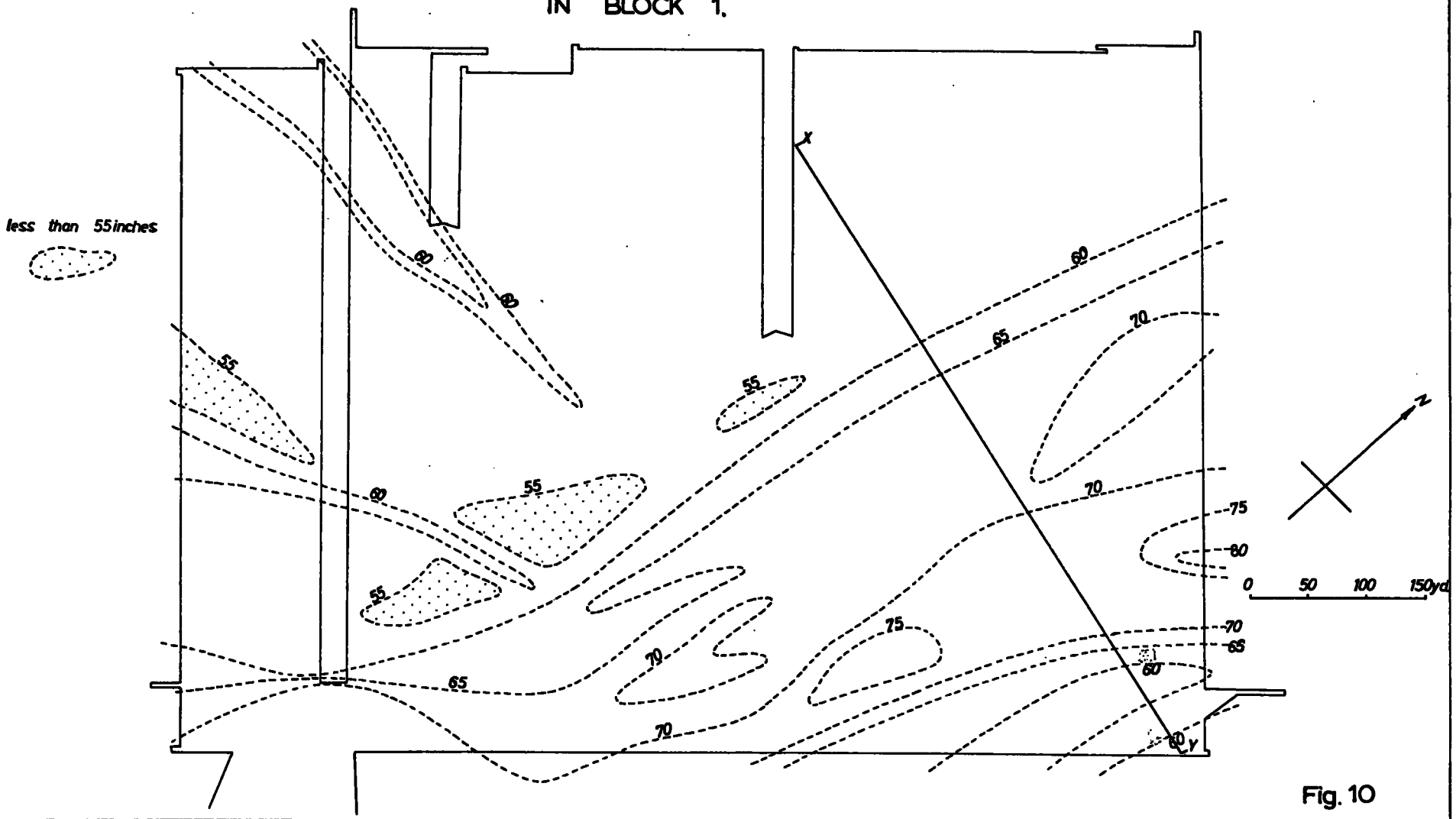


Fig. 10

In discussion of the floor strata, Fig. 7 showed the presence of a thin 'floor coal' at 78 (1.98m) inches below the main bed. When viewed on a regional scale it is seen that this coal thickens, reaching twenty inches in a zone 6 miles to the north-west. Here it is separated from the bottom coal by a thin (0.15m) mudstone layer. This would appear to represent a further split of the seam from this point to the east. Since this piece of information comes from outcrop there remains no further evidence relating to the unsplit seam.

1.4 The Immediate Roof Measures

Above the seam the roof measures can be divided into two main zones, the junction of which is the base of the fossiliferous mudstone. Below this and in depositional continuity is a varied assemblage of mudstone seatearth, siltstone, 'roof' coal, and fragmental clayrock (FCR). Above is the 'deltaic' sequence containing the channel sandstones and other lithologies. The junction is at first seen to be passive with the mudstone in continuity with the lower horizons; however on the basis of work carried out recently in development to the south-east it may be gently transgressive on these lower beds.

The mudstone seat-earth, as will be seen later, has a significant effect on the working of the face, and so has been mapped in quite fine detail (Figure 11). In its areal distribution it is limited to the northern and western corners of the block, over which areas it is patchily developed in terms of thickness ranging from a thin smear on the bedding plane of the top coal and the siltstone, to over 7 in. (0.18m) in thickness. The siltstone however is less variable maintaining its thickness over the areas of mudstone seat-earth, giving an impression of the mudstone filling hollows in the depositional surface of the coal. In view of its seat-earth condition it may be more proper to regard the areas as 'islands' of continued vegetation after the first inundation of the peat.

The roof coal itself again shows strong variation, being absent in some areas and up to 4" (0.10m) thick in others. Structurally it can vary from the position of having definite boundaries with the beds above and below, whatever lithology they may be, to being interleaved with them, so diffusing the boundary. In this way it can be reduced to zero thickness by virtue of its becoming disseminated throughout the adjacent material. Alternatively it is removed by the mudstone in places where this shows its transgressive lower boundary.

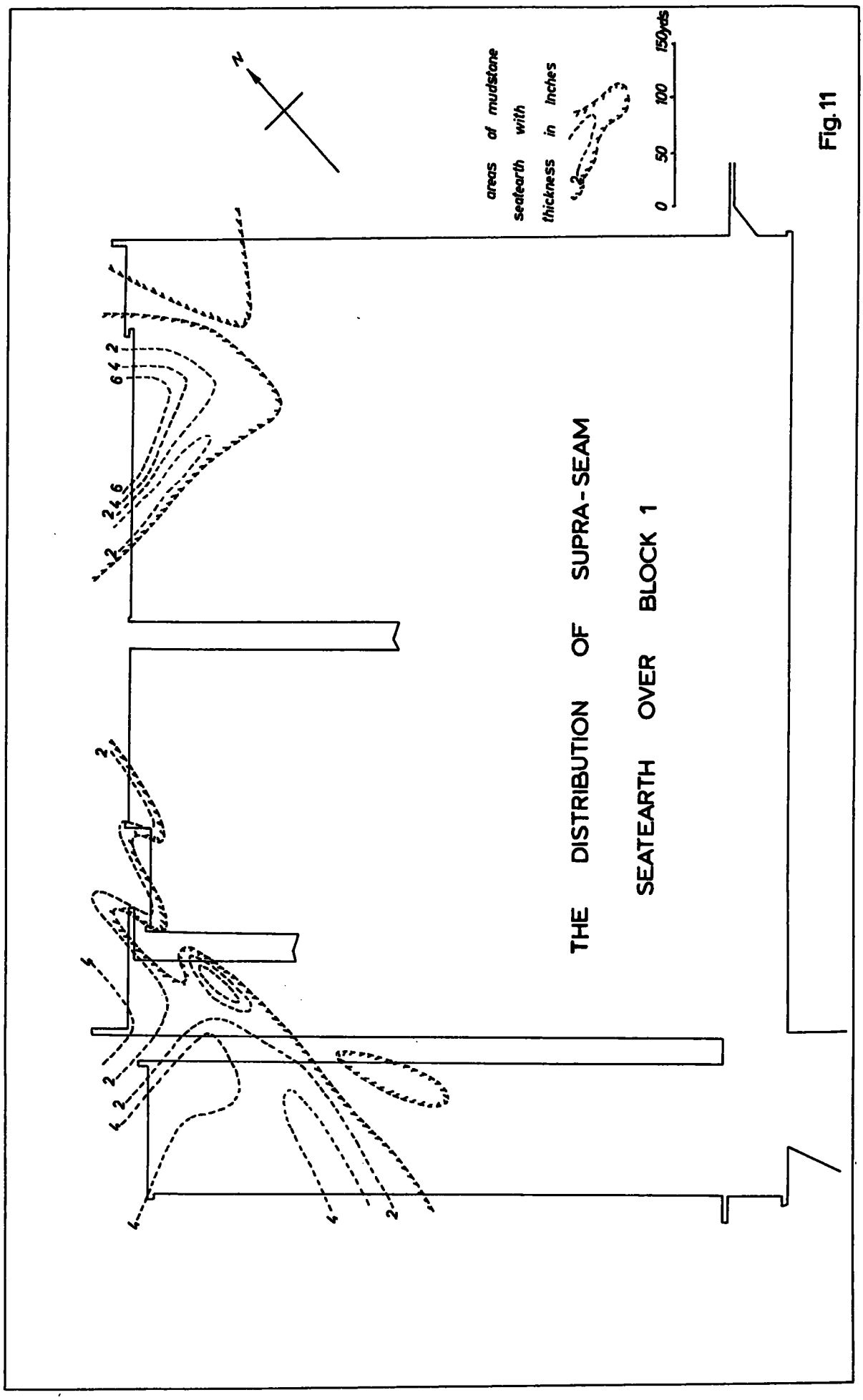

areas of mudstone seatearth with thickness in inches
0 50 100 150yds
N
THE DISTRIBUTION OF SUPRA-SEAM SEATEARTH OVER BLOCK 1

Fig. 11

This disseminated aspect together with the sometimes non-seat-earth condition of the siltstone points to a mode of formation for the coal, which is other than in situ - drifted organic debris (vegetation) in a shallow lake environment being that proposed.

Forming the top of this sub-sequence is the fragmental clayrock which is comparable with those found in other coalfields and consistent with the interpretations of mode of formation which have been placed upon such rocks, (Richardson and Francis, 1971). This F.C.R. consists of shards of clay, subelliptical to wispy in cross-section, and of colours ranging from grey to buff, green and brown, giving a brecciated appearance. It can have a diffuse, interleaved boundary with the roof coal, where that is present, and with the overlying mudstone, or it can have definite boundaries with both. A fragmentary fauna of estracod valves is present along with coalified plant remains. Microlistric surfaces occur, presumably formed after the brecciated texture since they transect shard boundaries, thin slivers of coal being sometimes aligned along the surface.

What is envisaged as the origin of the brecciated texture is the remobilisation of a highly sensitive layer, with a high colloid content interstitial pore fluid, under compactional stresses followed by redistribution, segregation and recrystallisation of the colloid material. The presence of sensitive layers is possibly a function of the original sediment composition allied with the leaching of electrolytes and the presence of dispersants produced by anaerobic decay of its organic content. Explanation of the various boundary conditions may be that only in areas where the F.C.R. is strongly developed is there any diffusion of the boundary with the coal or mudstone and where it is in contact with the stronger siltstone the boundary is always definite. Where it is strongly developed there has been brecciation of the material on either side of the sensitive layer. Some degree of

compaction prior to the flow of the sensitive layer is thought to be indicated by the angular aspect of the F.C.R. shards and by the brecciation of the surrounding material.

A compactional shock which would have given high levels of stress over a short period of time may be associated with the slump structures to be found in the sub-aerial levee deposits of the higher deltaic sequence (Chapter 22). Whether the slumps are the cause of the stress affecting the F.C.R. material or a further expression of the same external influence is impossible to ascertain.

The areal distribution and thickness of the F.C.R. is inconsistent. This is a characteristic which may be due to a combination of the deposition and subsequent erosion of the sensitive layer, or it may have been produced by redistribution during its subsequent flow.

A modern sediment which demonstrates the properties required for production of an F.C.R. has been cited by Dr. R.K. Taylor as the lacustrine volcanic clays of Mexico City. These are capable of supporting a sedimentary over-load (with associated compaction) and in their natural state behave as brittle elastic materials which on remoulding assume the character of a viscous fluid.

Following from this analogy and the facies types associated with the F.C.R. its designation as a deposit of a 'temporary shallow lake in a paludal environment on a paralic front' seems tenable. (Richardson and Francis 1971). The fact that syngenetic pyrite is present and that organic matter is by no means absent may mean, however, that the drainage was in this case less well developed than in that cited by Richardson and Francis.

CHAPTER 2

THE GEOLOGICAL SETTING (Cont'd.)

2.1 The Higher Roof Measures, General

In the higher roof measures a wide variation in facies type and thickness has been proved both laterally and vertically. This is shown well by the three sections of Figure 12 which lie within 15 ft (4.57m) of one another. This variation and the paucity of sections available for examination makes direct correlation well nigh impossible. It is only after integrating all the various geological aspects that a coherent picture emerges. The main parameters are the height of the sandstone above the seam, the general morphology of its base, the small scale structures (which are principally of directional interest) and facies variation.

Everywhere that the roof measures are visible to a height of 25 in. (0.64m) or more above the seam a sandstone or other arenite is present, with a second developed somewhat higher. Since, however, such exposures are limited in the main to areas of strongly developed channels, there is a possibility that the lower sandstone may be absent in some areas. In those areas in which it is known to be present, the thickness of strata between the base of the lower sandstone and the top of the seam has been mapped. The major value of this is in its mining applications although it does help to emphasise the areas of strong erosional activity which constitute the channels themselves.

The majority of information available comes from the base of the sandstone horizon which is the most readily accessible part. If an adequate understanding is to be achieved of the environment of deposition and mode of sedimentation of the overlying strata it would be desirable

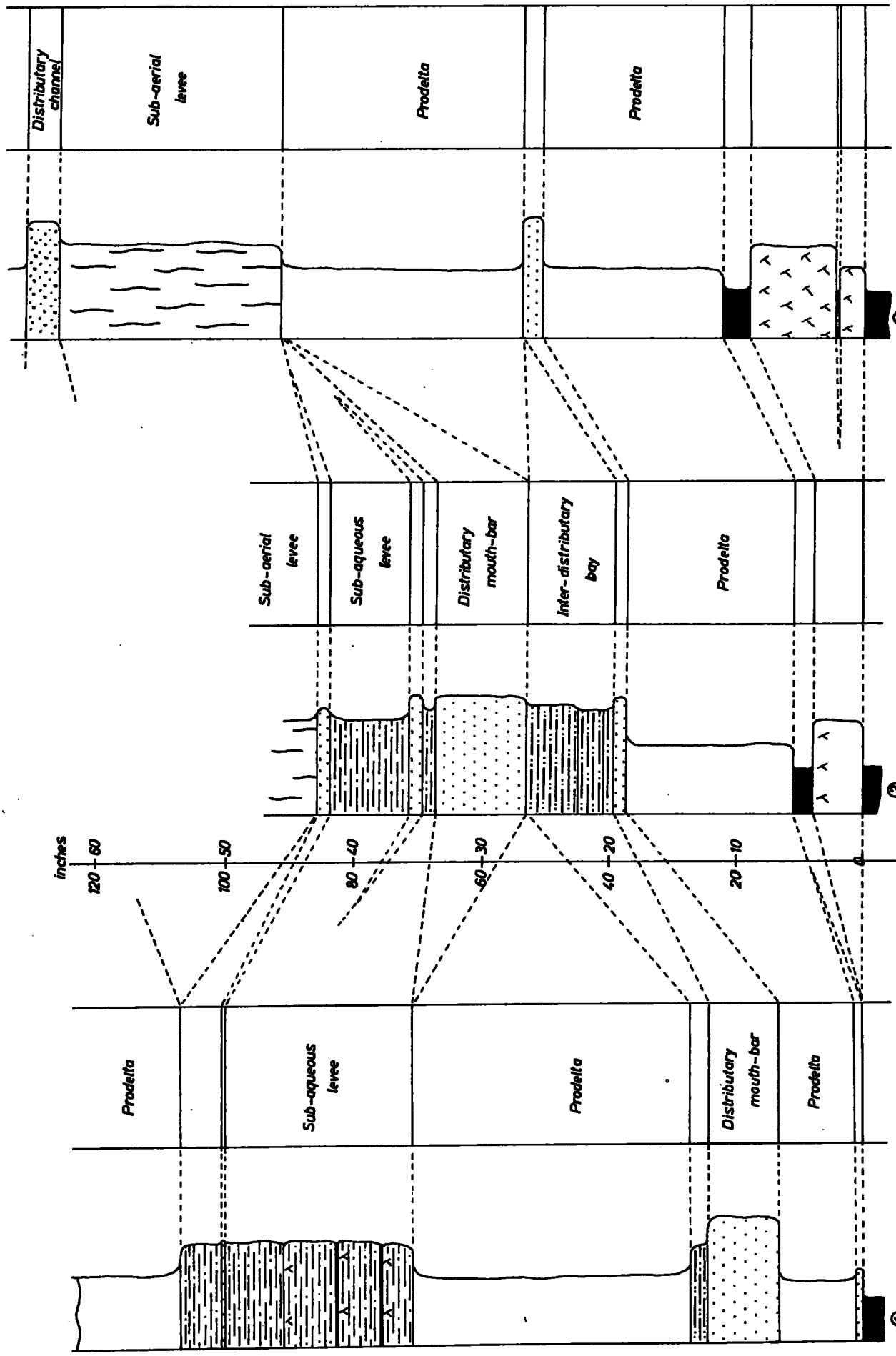


Fig. 12

SECTIONS OF ROOF MEASURES (as located on Fig. 1)

to attribute a distinct facies classification to each given bed-form. Each bed-form is a function of the nature of the depositing current and of its sediment load. Facies of sedimentation can also be defined in these terms. Such a distinction is attempted.

2.2 Lithological Units: their Description and Definition.

In the consideration of the deltaic series by Markov Analysis, in Chapter 2.3, eight lithological units were to be used. These are described here and an interpretation of the mechanism of formation and hence their facies is given. An attempt is made to consider the dynamics of the system in order to distinguish between those units produced by continual stream flow and by impulsive flow, - a distinction between normal and spate conditions of the depositing drainage system.

First is the division of massive or internally structureless sandstone. This can be further sub-divided on the basis of associated lithotypes and scale. When of small thickness such sandstones cover large areas of the seam and directly overlie a member of group 'E' or 'C', horizontally laminated siltstones or ripple-drifted sandstones. In the areas of channel sandstones where they increase in thickness the base is erosive upon any of the lowermembers of the succession. The bottom inch or so then contains flakes of this underlying material. Apart from this the sandstone itself is pure white with a calcitic cement. This would point to a mature (similar to the term applied to turbidity currents) current in both cases. In the case of the thin sandstones their associations would point to deposition from a current carrying a well sorted clastic load, with simultaneous deposition and reworking into the laminations by a traction carpet having a low applied shear, - with a later change in emphasis to gradual accretion of sand to give a structureless bed. In the case of the channel sandstones however, a high applied shear is envisaged with the dispersion of the traction carpet into the body of the current, the shards of underlying material being plucked up without reworking as such. As soon as the shear drops below a critical value the dispersive pressure is no longer

sufficient to retain the mass of grains in suspension and the load freezes, to be deposited as a structureless sandstone body, - the scour pool fill of a river's low stage. Although termed structureless there have been exposures of this unit which show large scale, ill-defined cross stratification in channel areas. This has been described as a lateral deposit, of bar formation during the river's flood stage.

Horizontally laminated sandstones consist of sheets of sand resting on one another, with little or no interjacent fine material. Each sheet has a consistent grain size whilst there may or may not be a difference in grain size between sheets. Allen (1964) has shown that sheets of sand, each with roughly the same grain size and showing primary current lineation, could form beneath a turbidity current of the "plane bed with movement" regime of Simons (1961, p.36), - either by primary deposition from the current or by reworking of previously deposited material. This may be the case here. A thin ungraded unit of laminations would suggest formation by reworking. A thicker unit with gradually decreasing grain size upwards would suggest primary deposition from the current. Discontinuous sediment supply is suggested by the individual layers, possibly by pulses of the current.

The ripples of unit 'C' may be composed entirely of sand, as when associated with the base of unit 'A' directly or, they may be picked out by silt or mud when removed from 'A'. In cross-section the amplitude is seen to be on average $\frac{3}{4}$ ins (0.02m) with a wavelength of up to $1\frac{1}{2}$ ins (0.04m). When seen on a bedding plane they are of a parallel crested type. Conditions for the formation of ripples are suggested by Albertson (1958) to be either fully turbulent flow in the current, as would be the case at the base of 'A'. On the other hand, a laminar boundary layer between the turbulent current and the bed is envisaged - an essentially quiescent flow - as removed from 'A'?

The first condition has been discussed in connection with unit 'A'. The second suggests a period of non-deposition with the reworking of previously deposited material, possibly of unit 'B'. Contribution of sediment by the current to the bed is low and takes the form of mud and silt size particles, which tend to accumulate in the lee of the ripple.

Unit 'D', the massive siltstones may show some semblance of internal structure in that a lateral change in particle size may occur, with a gradation of this into the other units. It is assumed that such a gradation is due to a waning of current velocity and consequent abandonment of its load according to grain size. The siltstone may or may not support in situ plant remains and transported plant debris. Internal slump structures are common, on occasion affecting lower divisions. Following previous work this unit has been designated 'sub-aerial levee deposit'.

The laminated siltstones of unit 'E' may be the upward continuation of 'B' when they are a primary deposit of the current. Siltstone is the top-most member of the gradually upward fining sequence. Alternatively, they may be the reworked equivalent of the massive siltstones. Their strong association with the laminated sandstones would however, favour the first suggestion.

As the name suggests the laminae of the inter-laminated sand and siltstone units are made up of alternating sands and silts. Their constant position with respect to the massive sandstones suggests a continuity of deposition, even though the mechanism may have altered. With the deposition of the sandstone after reduction of the internal shear of the fluid, turbulent flow would be expected to be curtailed.

A laminar boundary layer might then form, a condition suggested by Walker (1965) as influencing the appearance of laminations. Differential settling of grains through this layer allied to an intermittent supply of mixed sediment to the top of the layer would then produce the alternating laminae. The definition of the laminae would depend upon the frequency of the supply pulses, - whether sufficient time were available for settling of the grains.

The mudstones of unit 'G' although superficially monotonous show a wide variety in their fine structure and content. They range from structureless units to beds which are being formed of minutely thin laminae which are marked by colour change which is a result of the higher silt content. Continuous bands, layers or disseminated nodules of ironstone add to the permutations encountered. In fossil content there is again great variety, with large stems of Calamites and Lepidodendron scattered throughout the horizon whilst the smaller plant fragments are limited in the main to a thin layer at the upper junction. These include Alethopteris and Neuropteris leaves and fronds. The faunal content occurs in three ways; as disseminated body fossils, normally of mussels and Estheria, but on occasion (in fact twice) whole fish have been found. At around fifteen inches above the seam there is a distinct 'mussel band', containing Niadites in profusion. At the base of a number of ironstone bands there are accumulations of fish scales, those identified being of Rhabdoderma and Megalichthys. Along with these are trace fossils; sand infilled burrows and rootlets preserved by associated ironstone and marked by listric surfaces. This last feature is also prominent in the case of the mussels, again preserved by ironstone. All this indicates a low rate of sedimentation, low enough to allow organic colonisation of the waters. The sediment itself

is fine and is thought to represent the last fraction of current suspended load which settles in the still waters beyond the delta front.

Unit 'H' is a conglomerate of reworked ironstone nodules having a distinct non-planar boundary with the sandstones of 'A' and a more diffuse upper boundary. It thus represents the contact portion of the bed load and its blanketing of the channel bottom may be the cause of the off-setting of subsequent courses.

2.3 Markov Analysis

In an area of such widely varying lithofacies as that with which this thesis is concerned, and where there is little vertical exposure, it was felt that some justification was necessary for the projection of geology based on such scattered data. This justification was sought in a statistical analysis of the available data which would pick out significant factors. Recently, sophisticated statistical techniques, such as the Markov Chain Analysis, have been used in studies of the 'cyclic' nature of sedimentation in the Coal Measures (Doveton 1971, Duff and Walton 1962, Read 1969). These have in the main been applied to lengthy borehole sections, but it was here proposed to apply the method to a number of isolated exposures in order to produce some normative sequence for the area. Thus, if given one horizon in the sequence, it might be possible to say what lay above.

The sequences were analysed in terms of transitions from one state to another, a state being equivalent to a litho-type. It would be possible to consider the states also in terms of thickness, in which case there is the possibility of having a transition from one litho-type to itself, but across a thickness boundary. In this work, however, such a distinction was not applied, lithological units being considered as separate entities and free from thickness limitations. This aspect of the data modifies the presentation to an imbedded Markov Chain, in terms of a 'tally-matrix'. For example:-

	A	B	C
A	-	n_{12}	n_{13}
B	n_{21}	-	n_{23}
C	n_{31}	n_{32}	-

in which the rows represent any given state and columns the suceeding state. On that basis n_{23} is the total number of transitions from B to C.

Note that the principal diagonal of the matrix is not represented since transition from a given state to itself is precluded.

The Markov model is one in which the presence of a given state is dependent upon the preceeding state, for a first-order model i.e. a memory of length one step. In order to demonstrate the presence of such a memory a situation of independent events is set as a null hypothesis and a prediction calculated of the tally-matrix as it would be if the sequences were a random collection of the component states. The observed matrix is then tested against that predicted for independent events so as to indicate whether a significant Markov-1 property is present. The mechanics of the method are well covered by a number of authors (Anderson and Goodman 1957), and so only the results will be considered here.

Results

A one step transition tally-matrix was produced for the available data and this is shown in comparison with that for the independent events model in Table 2.1. When a Chi-squared test was applied to these the null hypothesis was seen to stand. In order to improve the possibility of success, which is restricted by the lack of data, the unit H was omitted and the procedure repeated, as in Table 2.2. This showed a rejection of the null hypothesis and hence the presence of a first-order scheme.

Each transitional cell tally was independently tested against its value predicted by the independent events model as a chi-square test (At this level, the data has only one degree of freedom and so appropriate allowance was made by the application of Yate's correction for continuity throughout.) Here again the lack of basic data is a difficulty in that although a Markov property is present when treated

as a whole, the data show no significant transitions when tested individually.

Although not of assistance in this case, there remains hope for successful use of the method if more new data can be obtained.

Table 2.1

Observed (O) and independent events model predictions (IE) of one-step tally matrices. (See Table 2.3 for key to states)

O

	A	B	C	D	E	F	G	H
A	-	6	2	2	6	5	0	1
B	3	-	5	2	10	2	5	0
C	3	3	-	2	1	2	1	0
D	3	1	0	-	2	0	0	0
E	6	2	3	3	-	2	2	0
F	2	8	1	4	0	-	1	0
G	4	6	3	1	1	8	-	0
H	1	0	0	0	0	0	0	-

IE

	A	B	C	D	E	F	G	H
A	-	5.50	3.16	3.16	4.21	4.01	1.91	0.40
B	6.01	-	3.80	3.80	5.93	5.19	2.45	0.57
C	2.31	2.74	-	1.48	2.11	2.00	0.95	0.22
D	1.11	1.59	0.70	-	1.00	0.95	0.45	0.10
E	4.32	4.34	2.34	2.34	-	3.16	1.49	0.34
F	3.20	3.78	2.03	2.03	2.91	-	1.34	0.29
G	5.17	6.11	3.29	3.29	4.70	4.45	-	0.48
H	0.18	0.28	0.11	0.11	0.16	0.15	0.07	-

Chi-square test value = 49.22

at 36d.f. and 5 per cent = 51.00

Retention of null hypothesis of independent events.

Table 2.2

Observed (O) and independent events model predictions (IE) of one-step tally matrices when modified. (See Table 2.3 for key to states).

O

	A	B	C	D	E	F	G
A	-	6	2	2	6	5	0
B	3	-	5	2	10	2	5
C	3	3	-	2	1	2	1
D	3	1	0	-	2	-	0
E	6	2	3	3	-	2	2
F	2	8	1	4	0	-	1
G	4	6	3	1	1	8	-

IE

	A	B	C	D	E	F	G
A	-	5.35	2.88	2.88	4.11	3.90	1.85
B	5.90	-	3.95	3.95	5.61	5.34	2.54
C	2.26	2.82	-	1.51	2.16	2.05	0.97
D	1.08	1.30	0.72	-	1.03	0.97	0.46
E	3.60	4.45	2.39	2.39	-	3.25	1.55
F	3.13	3.87	2.09	2.09	2.99	-	1.34
G	4.84	5.99	3.21	3.21	4.60	4.36	-

Chi-square test value = 44.55

at 25d.f. and 5 per cent = 37.65

Rejection of independent events in favour of Markov-1 property.

Table 2.3

States considered in the Markov analysis.

A - massive sandstone.

B - horizontally bedded sandstone.

C - ripple bedded sandstone.

D - massive siltstones.

E - bedded siltstone.

F - interlaminated sandstone and siltstone.

G - faunal mudstones.

H - conglomerate.

2.4 Sole Marks used as Current Indicators

The Sole marks considered here, although preserved as bottom structures of the sandstones, are features of erosional activity of a stream on a bed of cohesive clay, now mudstone. "The sculpturing depends on the fundamentally unbalanced transfer of matter from the bed to the flow." (Allen, 1971). There are those marks which can be described as longitudinal, being extended in the direction of the current. Others are of complex shape and fall into the category of transverse erosional marks.

There are two types of longitudinal erosion marks distinguished by scale and form and which are found in two distinct environments. The first is the large basal roll associated with the channel sandstone facies, of up to 3 ft (0.90m) in depth and 10 ft (3.05m) in width and of indefinite length. With a diminishing thickness of sandstone the scale of these features also diminishes. As the lateral change from massive sandstone to thinly laminated sandstone or inter-laminated sandstone and siltstone occurs the longitudinal erosion marks approach one dimension. That is in the flat based sandy facies they are superseded by lineations. This reflects the change in current action between the two facies, as the latter is an internal depositional feature associated with movement of sediment in the base of the flow. It appears as a 'bottom' structure due to the gradational aspect of the mudstone to sand/siltstone boundary.

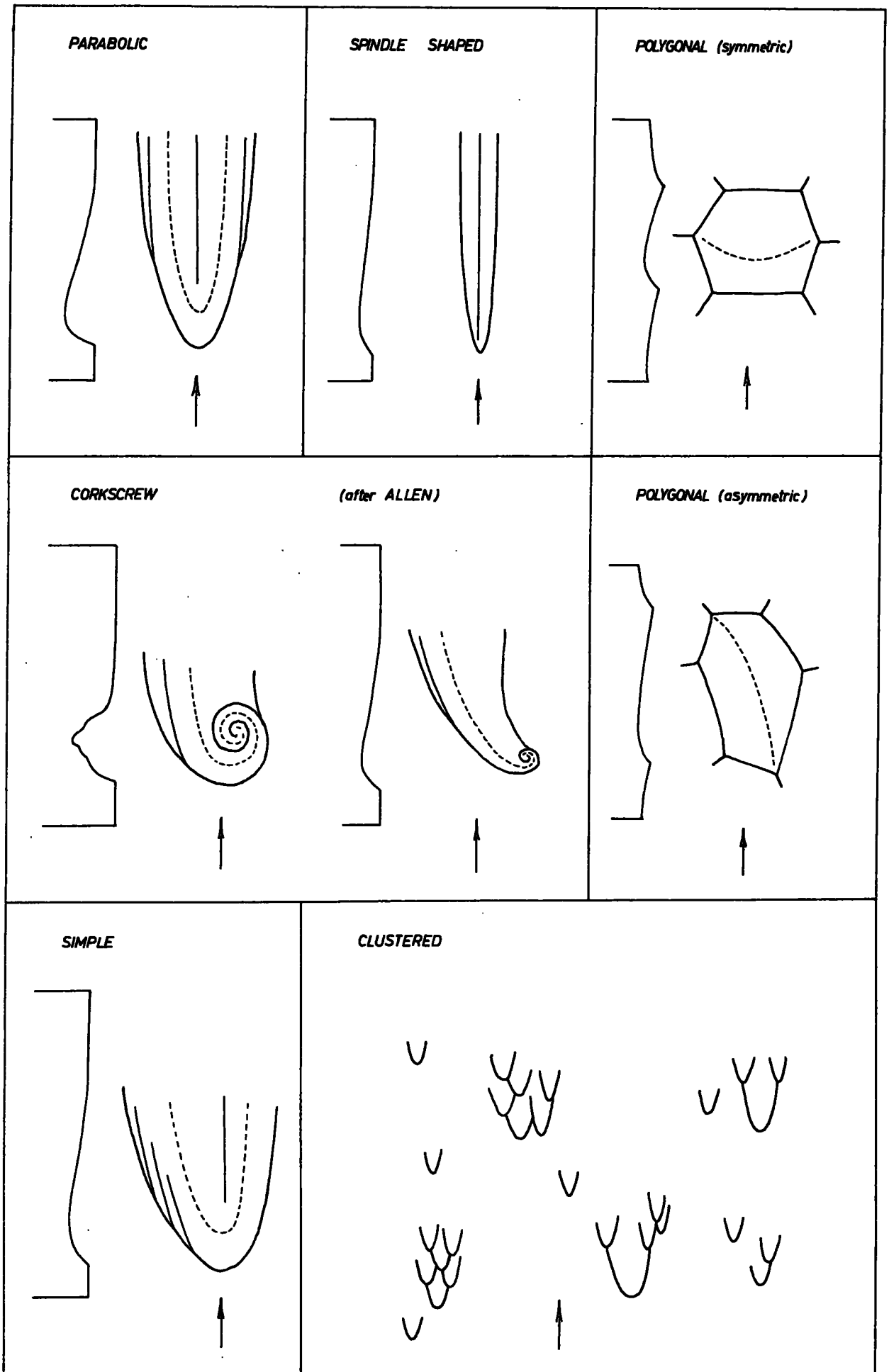
Numerous authors have noted that isolate flute marks, transverse erosional marks, in muds are sited where prior inhomogeneities existed on the mud surface. The shape of the erosional mark produced will be a function of the shape and orientation of the flaw, and of the current parameters. In such a complex interaction the number of marks which

might result from one original flaw and the multitude of paths which might end in the same mark, is great. Consequently only a qualitative description of the various forms is given without reference to the mechanism of formation.

The erosional mark is seen as a depression, of variable complexity, bounded proximally by a rim which may be either cusped or rounded in parts. The form of the depression is defined by the principal furrow whose axis joins its lowest points. Where this axis is crescentic in form it embraces a raised portion, distally the median ridge. On the basis of these features the marks may be classified and placed in the correct orientation with respect to the flow; this is with the proximal or leading point facing upstream.

Not all the forms described by Allen (1971) have been observed although representatives of each of his two categories, symmetrical and asymmetrical are present. These are shown in Figure 13 giving plan and longitudinal elevation. Most common of those depicted is the spindle-shaped erosional mark, which is a symmetrical form many times longer than it is wide and is in this respect similar to the longitudinal marks. Normally the median ridge is absent, apart from in the distal region. The parabolic erosional mark varies in dimensions from broad, with its width greater than its length to narrow when the opposite is the case. Unlike the axis of the spindle mark which is straight and aligned parallel to the current, the axis of the parabolic mark follows the rim in plan. The median ridge is strongly developed.

The simple erosional mark is asymmetrical, the lateral distortion being related to the flow direction. Its basic shape in plan is similar to the narrow parabolic mark with its crescentic principal furrow and its median ridge. It is the flanks however which show the



SCHEMATIC REPRESENTATIONS OF OBSERVED TYPES OF TRANSVERSE EROSIONAL MARK.

Fig. 13

difference. On the flank which makes the finer angle with the flow direction the principal furrow is strongly developed. The flank making the broader angle with the flow bears a group of sub-parallel secondary furrows, decreasing in size outwards.

The corkscrew erosional mark as described by Allen is generally longer than wide and has a distinctive form of rim divided into two parts. One part is cusped and twisted into a helical spiral about a vertical axis with the rim starting from the deepest part of the furrow. The axis of the principal furrow follows thisspiral and then curves out into the second part of the mark, the tail, as shown in figure 13, a shallow curve convex towards the flow. Unlike Allen's picture of this form one example has been observed in which the helical spire comprised the main bulk of the mark, the tail being vestigal.

Due to the close lateral association of marks they appear in placesrepresented by polygonal marks which have crests formed by overlapping of the rims. These may be symmetrical or asymmetrical. On the basis of shared crests these are classed as conjugate marks whilst the others are isolate.

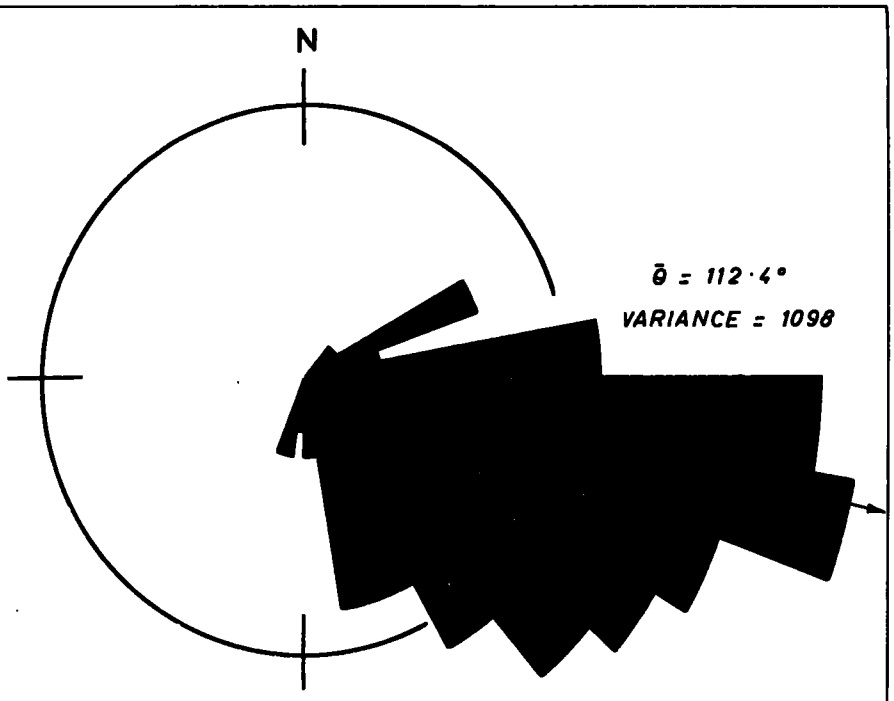
Further consideration of the associations of isolate and conjugate marks has led to the distinction between heterogeneous and homogeneous assemblages. "In a homogeneous assemblage there cannot be discerned in the arrangement of the marks a pattern whose elements are of a linear scale larger than the linear scale of the marks themselves," (Allen, 1971). Heterogeneous assemblages on the other hand show patterns with elements of a scale larger than that of the individual marks. Of these heterogeneous assemblages only the clustered class has been observed.

2.5 Palaeocurrent Analysis

As with the other geological observations made, the sampling grid has been determined by the layout of the mine, and the exposure (hence the samplepoints) determined by the roof conditions. The distribution of sample points is thus one of semi-random clusters with a bias towards areas of strongly developed channels, which is acceptable in this context. Thus areas of varying size and exposure have been demarcated and sampled, with some areas outside that of the immediate study being included in the analysis.

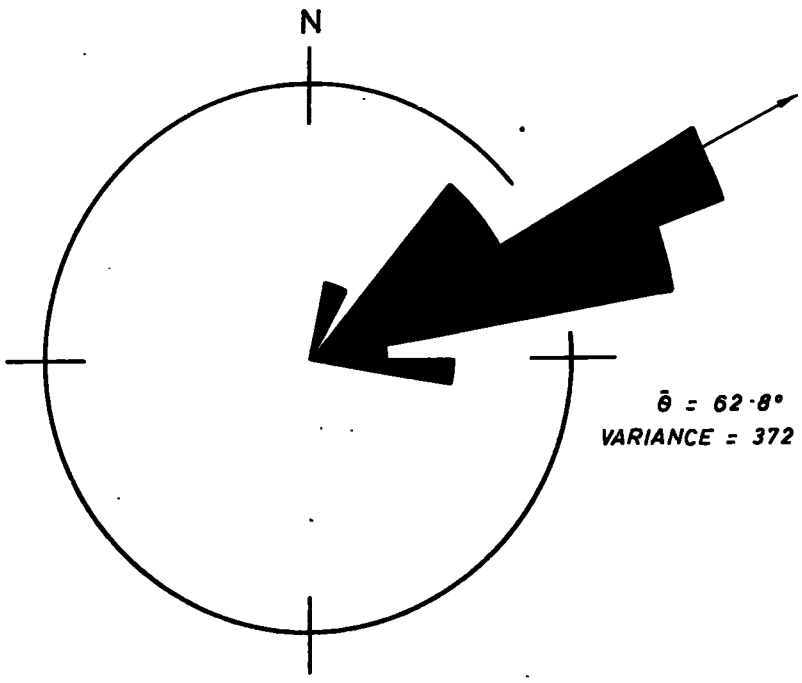
At the exposure level of sampling, data variance is low i.e. there is a well defined trend at that point, whilst there is great variation in the mean between exposures. When each area of exposure level upwards is taken separately, as shown in Table 2.4 variation of the mean and variance occur, the mean varying randomly at lower levels whilst the variance increases logarithmically with increasing area of sample coverage. This logarithmic function gives a limiting value of variance of the order of 1125 for an area of 0.575 km^2, which since it is low is considered to be indicative of a braided rather than a meandering pattern of drainage on a regional scale (Hamblin 1958, Allen 1968), having a regional azimuth flow direction of 112.4 degrees, (Figure 14).

This definition of the drainage pattern, independently of the mapping of the sandstone, is helpful in the interpretation of their areal distribution, which shows complications due to the intermeshing of directional data over areas just greater than that of exposure level. If a braided pattern is accepted and the supposition that the area is 0.575 km^2, for which the data variance becomes constant and represents the basic repeat area of the pattern (analogous to wave length), then a model pattern can be set up. Deviations from this



Directions of erosional marks on base of roof sandstones

A COMPARISON OF PALAEOCURRENT DETERMINATIONS FROM THE BASE OF THE ROOF SANDSTONES WITH THE AXIAL TRENDS OF SWILLEYS IN THE SEAM



Directions of swilley courses

Fig. 14

pattern can then be easily filtered out from the observed data and explained by recourse to relevant features of the sedimentation - usually in the form of a diachronous relationship between channel components or crevassing of levee banks.

Table 2.4: VARIATION OF MEAN AND VARIANCE OF CURRENT DIRECTION WITH SAMPLING AREA.

	Mean of current directions.	Variance	Area (km^2)
Total	112.40	1098.0	0.562
No. 1 Block, Riddings	110.66	1019.4	0.389
Ferrymoor retreat workings	92.52	676.7	0.107
9's Face, Riddings	130.80	278.9	0.056
Outbye corner of No. 2 block	155.90	80.6	0.010

In construction of the model it has been assumed that the area of 0.575 km^2 includes half of that area between laterally adjacent braids, the rectangle covering one braid being reduced to 0.365 km^2, with sides in the ratio of 1:6. The longest axis is given, the direction 112.4 degrees representing the regional trend. Nodes lying on this axis are given, the dual directions of the stream junctions ($\bar{\theta} \mp \sigma$). The curvature away from the junction out onto the limb of the braid is an approximation to that found by mapping of individually distinct braids.

$\bar{\theta}$ is the mean of current directions and σ the standard deviation on the mean.

CHAPTER 3

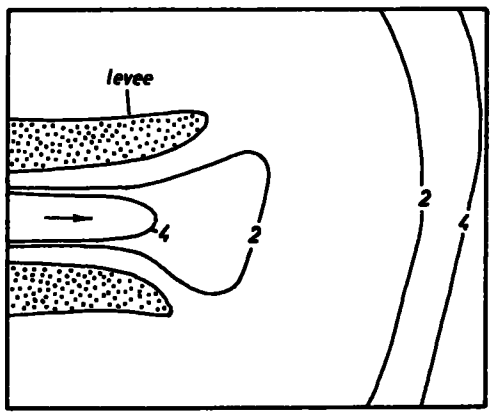
Synthesis.

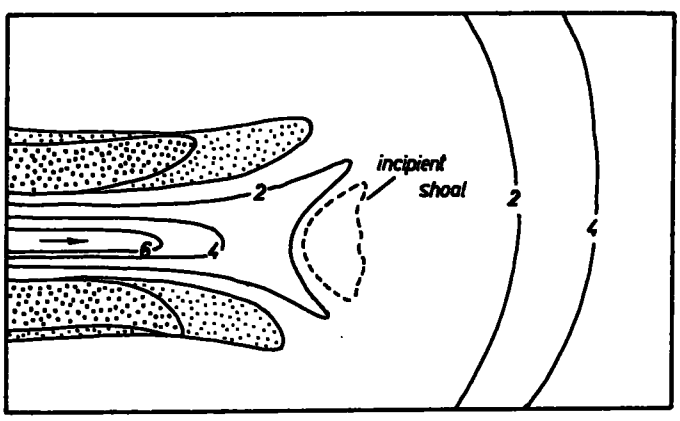
For each of the lithological sub-sections dealt with in the previous chapters a specific environment of deposition has been designated. The lateral and vertical distributions of these environments must be considered if a comprehensive picture is to be given of the evolution of the volume of rock which they as a whole form. Directional characteristics within facies, and those of facies as a whole, allow syntheses of the palaeogeographics to be made.

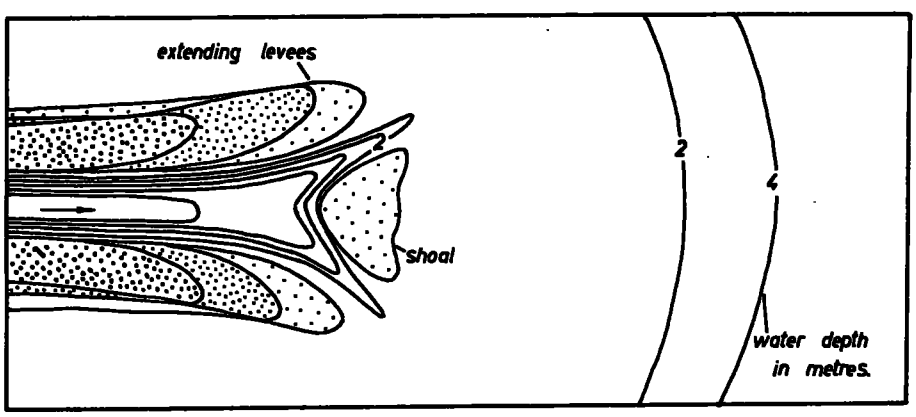
The formation of the seatearth horizon has been ascribed to the migration of mudbanks, which support their own hydrophitic vegetation, in advance of colonisation by the coal forming flora. An example of a relic water course has been given by which transport of the seatearth material may have been effected. An indication of the direction of transport, and hence the direction of advance of the coal swamp, is also given by this feature.

The inundation of the peat swamp would appear to have been followed by a period of slow deposition and the accumulation of banks of mudstone seatearth, dark siltstone, and clay in shallow lakes between the developing deltaic distributions. Although not found over Block 1., thin discrete sandstone lenses have been observed lying immediately above the coal and separated from the main deltaic sandstone of the higher roof. These are localised and have a directional trend of around 160 degrees.

Over Block 1 are found two sandstone channel systems of similar elliptical form with their major axes corresponding with the overall directional trend of WNW - ESE. In each case one branch of the





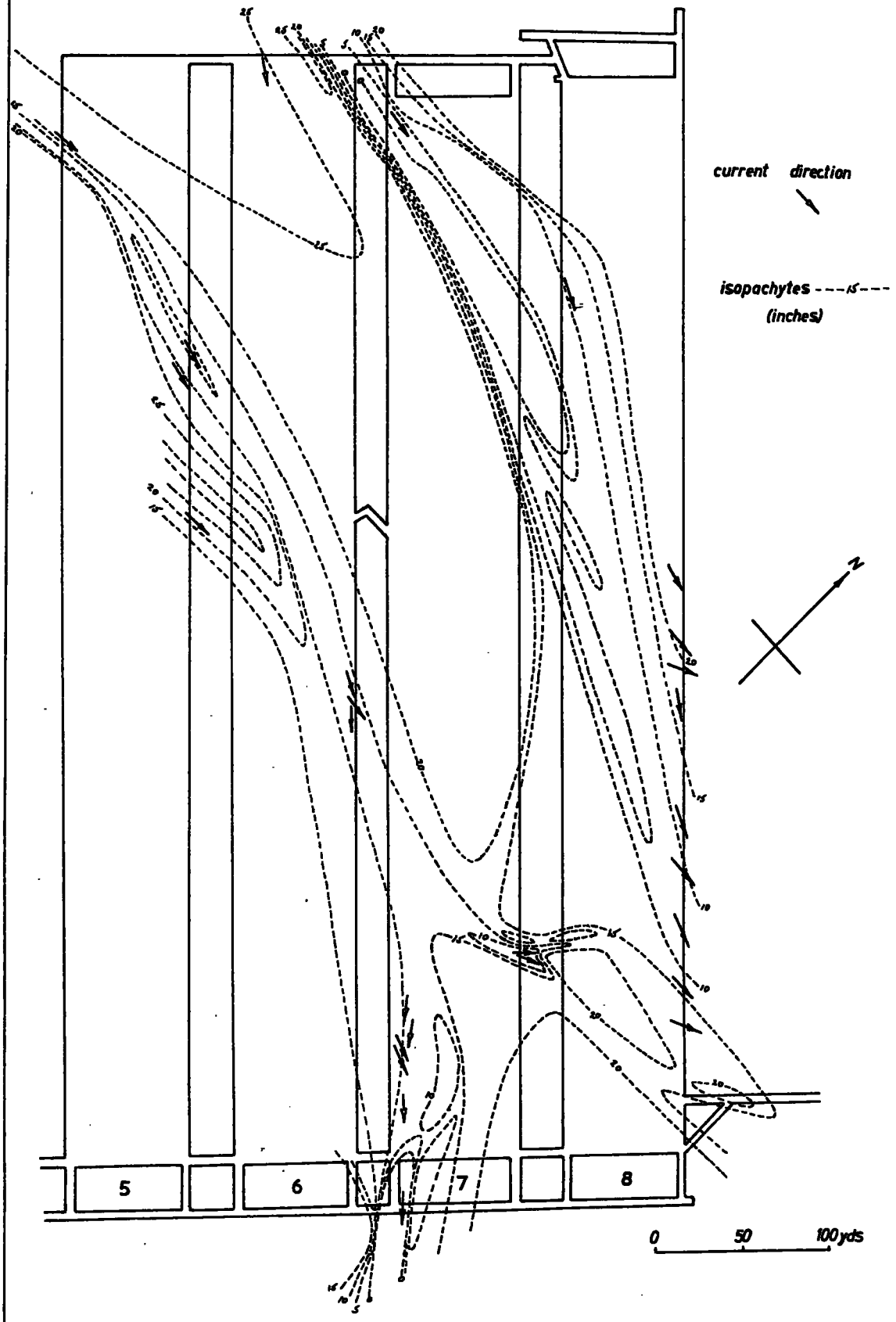


BIFURCATION OF A DISTRIBUTARY CHANNEL ABOUT A MID-CHANNEL SHOAL (after Welder, 1955)

Fig. 15

ellipse is in the form of deeply incisive channel sandstones, whilst the other is shown by grooves, erosional marks, and lineations on a more regularly based sandstone. Dispersal of current directions is greater over the latter branch where the thickness of sandstone is less, and the structures are generally of a smaller scale. On the other hand the deeply incisive branch shows thick development of sandstone, large scale cross-stratification, and erosional structures along with an almost constant, or only slowly varying, current direction. This is exemplified by the form of the sandstone shown in Figure 16.

This contoured plan of faces 5 to 8 (Fig. 16) shows the ribbons of sandstone to rise off the seam towards the outbye end of the panels, with a further incursion showing itself at the extreme edge of the area. Assuming this to be a feature of the channel itself and not one due to an undulating seam surface, it can be explained by the bifurcation of the stream around a mid-channel shoal. Major channel patterns in a delta are essentially those originally established under water (Welder, 1955). Separate threads of intense turbulent exchange of water and sediment particles normally occur somewhat below mid-channel depth, towards the channel sides (Leighly, 1932). Between these threads of high forward transport of the load, the water is more slack, favouring deposition of the load. A mid-channel shoal thus forms separating the channel into two lesser channels - this occuring in the region of the disdharge of the channel into a larger body of lacustrine or sea-water. (Fig. 15). One of these will normally take precedence probably due to the nature of the original channel - indeed, that which continues the outer erosional regime. In the low stage the river course will take on a complicated anastomotic or braided



ISOPACHYTES OF THE STRATA BETWEEN THE SEAM AND THE OVERLYING SANDSTONE, OVER THE NORTH-EASTERN PORTION OF BLOCK 1.

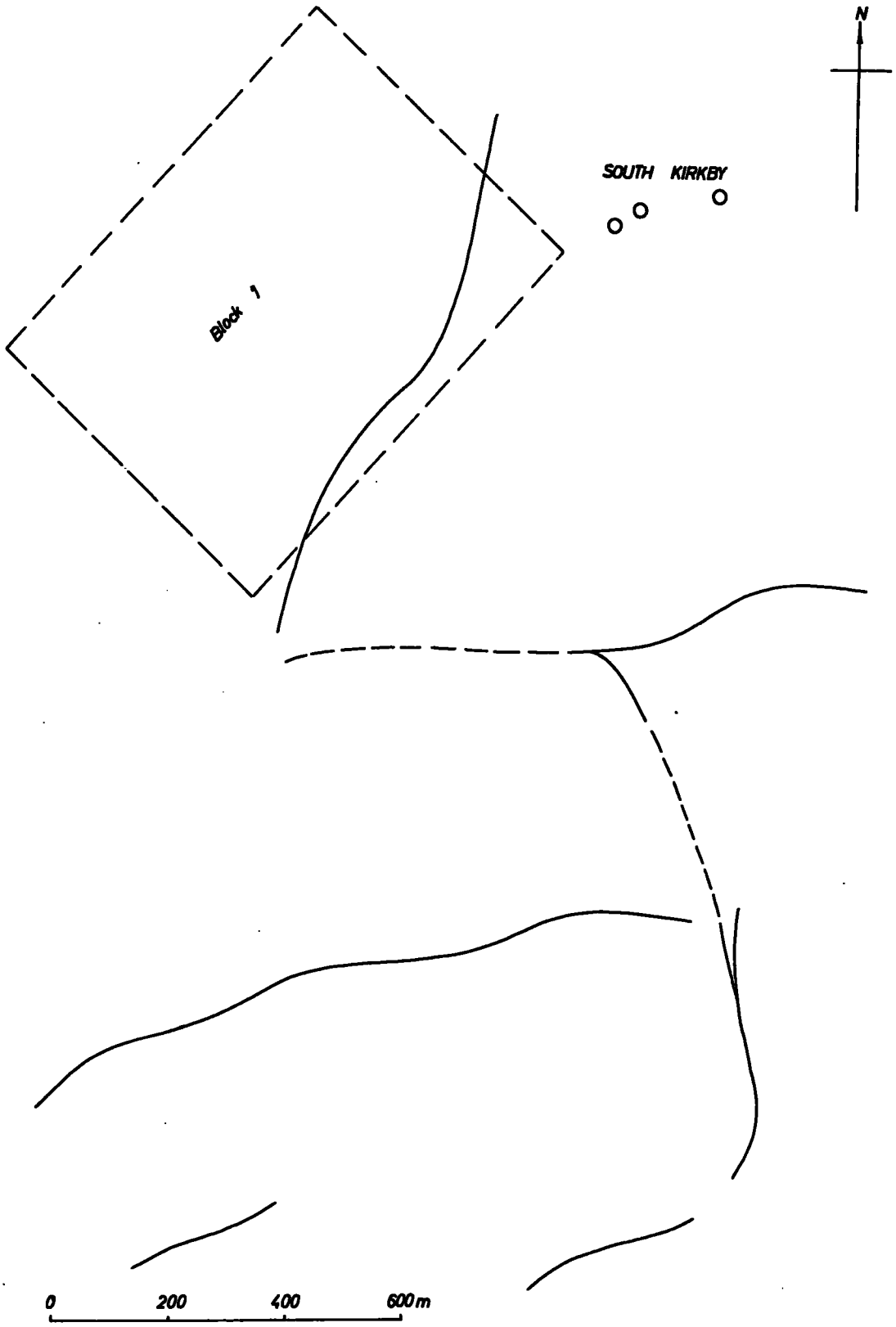
Fig. 16

pattern following these preferred branches. With the onset of flood conditions simplification of the pattern occurs with flow over each course and interjacent bars or shoals.

In contrast to the other areas of sandstone encountered, that sandstone which covers panels 10 and 11 shows extensive areas of flat base which in some places show a wide variation in current direction. Areas of erosive sandstone roof are limited and inconsistent, being split into a number of small channels not deeply incisive. Away from the immediate vicinity of the erosive sandstone there is, between the mudstone and sandstone horizons, up to 2 ins. (0.05m) of laminated mudstone, siltstone, and fine sandstone - the base of the sandstone proper being marked by a film of comminuted plant debris. The sandstone itself is around 7 ins (0.17m) in thickness, fine grained, and pure, with little internal visible structure. It may be overlain by another laminate horizon or followed directly by mudstone or massive grey siltstone.

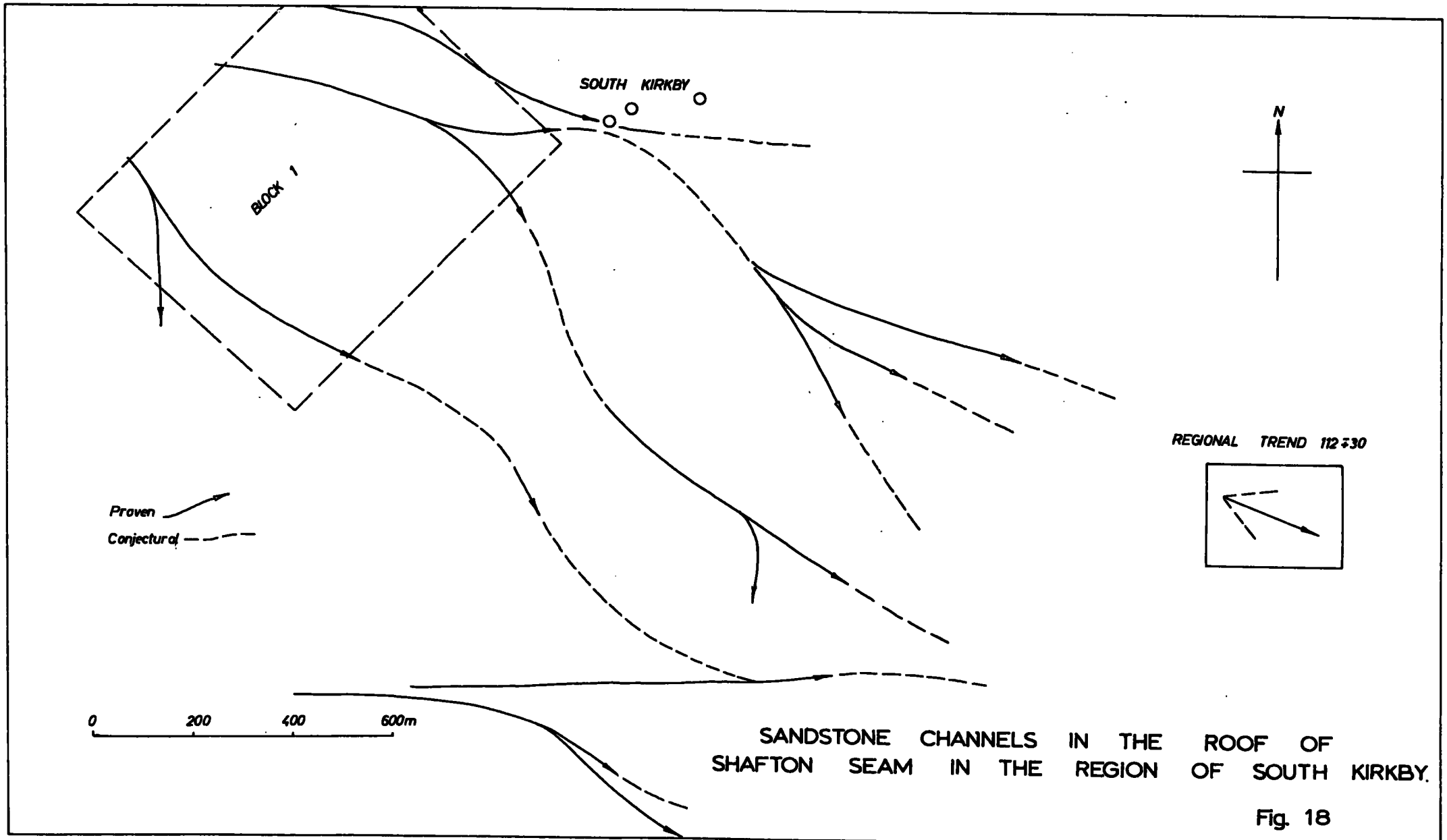
Although the amplitude of the basal rolls may be as much as 10 ins. (0.25m) at the outbye end of the panel, by the time the far end is reached they are lost. This is not by their rising off the seam, since the thickness of sandstone is not great enough to accommodate them, but by fanning out of the current into a larger body of water to give a rippled sandstone.

In moving downstream along this ribbon of sandstone the transition can be seen from the true channel sands, although in this case showing a braided form with shallows populated by a burrowing fauna, out onto the distributary mouth bar. This change from purely deltaic conditions to those of delta/~~marine~~ open water interaction has caused the failure of extrapolation on the basis of the Palaeocurrent Analysis. It may, however, prove valid to apply the same model to the second,



SWILLEYS IN THE SHAFTON SEAM IN THE REGION OF SOUTH KIRKBY.

Fig. 17



SANDSTONE CHANNELS IN THE ROOF OF SHAFTON SEAM IN THE REGION OF SOUTH KIRKBY.

Fig. 18

higher phase of channel sandstones as they overlap the first, to the south-east.

There appears to be a full cycle from accumulation of the coal swamp on the emerging mudbanks of the seatearth, to final submergence under a further deltaic advance - leading up to the marine incursion evidenced by the Shafton Marine Band. A seemingly anomalous point in this cycle is the wide range of transport direction between each phase and their sub-parallel relationship to the line of splitting of the seam. (Figures 17 and 18). On reflection it can be appreciated that the split may be due not to subsidence of the area to the north-east, but to a lateral facies change from coal swamp to a contemporary distributary channel, causing subsidence on compaction of the deposits. The difference in 'regional' trends appear then as mere local variations when viewed in relation to this large scale feature.

This view of an essentially north-westerly transport direction is consistent with the emergence of the north-easterly trending Lancashire - South Yorkshire upland of the Etruria Belt of Palstage 2b, (after Wills, 1956).

CHAPTER 4

GEOLOGY AND PRODUCTION

The following chapter is an attempt to relate variation in production to geological factors affecting the working face. Such variation is caused by loss of time available for productive effort, e.g. time spent correcting mechanical faults etc., or by factors which affect the rate of productive work directly, such as the slowing of cutting speed in tougher strata, which cannot be recorded.

Data available for the study comes from the daily records of the pit, in which is given the advance in shears and the time lost due to mechanical, geological, and other causes per day. From this information the following equation may be constructed:-

$$n = N - \frac{t_m + t_g}{s} \qquad \text{(1)}$$

where 'n' is the actual number of shears per day, 'N' the maximum number of shears possible per day without any delay time, 't_m' and 't_g' the time lost by mechanical and geological causes respectively, and 's' the time to complete one shear. Rearranging equation (1) gives a linear relationship of the form, $y = mx + c$.

$$\text{viz:} \quad Ns - ns = t_m + t_g = T \qquad \text{(2)}$$

The intercept on the y-axis is the time available for shearing per day, that on the x-axis the maximum possible shears per day, and the slope is the time to complete one shear. This equation is established for each individual face in order that the raw data may be corrected for mechanical delays before use in the determination of

standard rates of advance under specified geological conditions. This is attained by computing the least squares regression line of 'T' on 'n' (y on x) which gives values of 's' for the slope and 'N' for the intercept on the x-axis. Knowing the delay due to mechanical causes per day it is then a simple matter to obtain the corrected rate of advance, which is the potential advance under certain geological conditions, since on rearranging equation (1) again the result is:-

$$n + \frac{t_m}{s} = N - \frac{t_g}{s} \qquad \text{(3)}$$

Working from the left hand side of the equation, rather than using the recorded values of 't_g' directly, overcomes the difficulty of making allowance for the directly effective geological factors whose effect proves impossible to record.

The lack of correlation apparent for some of the T/n data sets is due to the somewhat subjective recording of delay times and causes, and also to the lengthening of the day (an increase in 'Ns' - the time available) by overtime work - a feature for which it would be extremely difficult to make allowance. Thus in cases where the correlation coefficient 'r', for the T/n data sets, may have arisen by chance, (determined by The Student's t value at the 99% confidence level), a mechanical smoothing has been applied to the corrected shears per day data.

Table 4.1: DATA RELATING TO EQUATION (2) FOR THE EIGHT FACES IN BLOCK 1.

Face	No. of Observ-ations	Equation:- T = Ns - ns	N	r	t	p
1	38	T = 768.8 - 14.09n	54.72	-0.805	8.12	3.60
2	40	T = 801.3 - 14.04n	57.07	-0.740	6.76	3.55
3	48	T = 654.5 - 5.53n	118.40	-0.455	3.45	3.50*
4	43	T = 806.5 - 17.57n	63.00	-0.671	5.79	3.55
5	26	T = 947.8 - 15.19n	62.40	-0.783	6.16	3.75
6	26	T = 813.7 - 11.64n	69.91	-0.738	5.35	3.75
7	27	T = 1066.5 - 20.60n	51.80	-0.491	2.80	3.75*
8	26	T = 985.6 - 18.10n	54.42	-0.888	9.46	3.75

(faces for which correlation is doubtful*)

The correlation coefficient 'r' checks the validity of the data for each face individually. However, differences in the other constants are present between the eight faces, even where 'r' is similar e.g. the values of 'N' between faces 2 and 6. When Chi-square tests are applied to this apparently widely varying parameter and also to the 's' and 'Ns' data sets across the six faces with 'r' greater than 0.5, it is seen that there is no significant difference in the values of 'N' and 's' at the 5% level. Nevertheless, the difference is significant for values of 'Ns'. This is probably a result of choosing the regression of 'T' on 'n' rather than 'n' on 'T', and is quite acceptable since the values of 'N' and 's' are for use in construction of equation (1) - which becomes on substitution of the above average values for 'N' and 's':-

$$n = 60.25 - \frac{t_m + t_g}{15.10} \qquad (4)$$

Having obtained this equation its use must be considered. The first use has been covered by Smith, 1971 (unpublished as yet) and gives an estimate of the rates of production to be expected during the

* $p > 99\%$ in both cases but have arisen by chance.

PREDICTED AND ACTUAL PRODUCTION FOR 6's FACE (after Smith 1971)

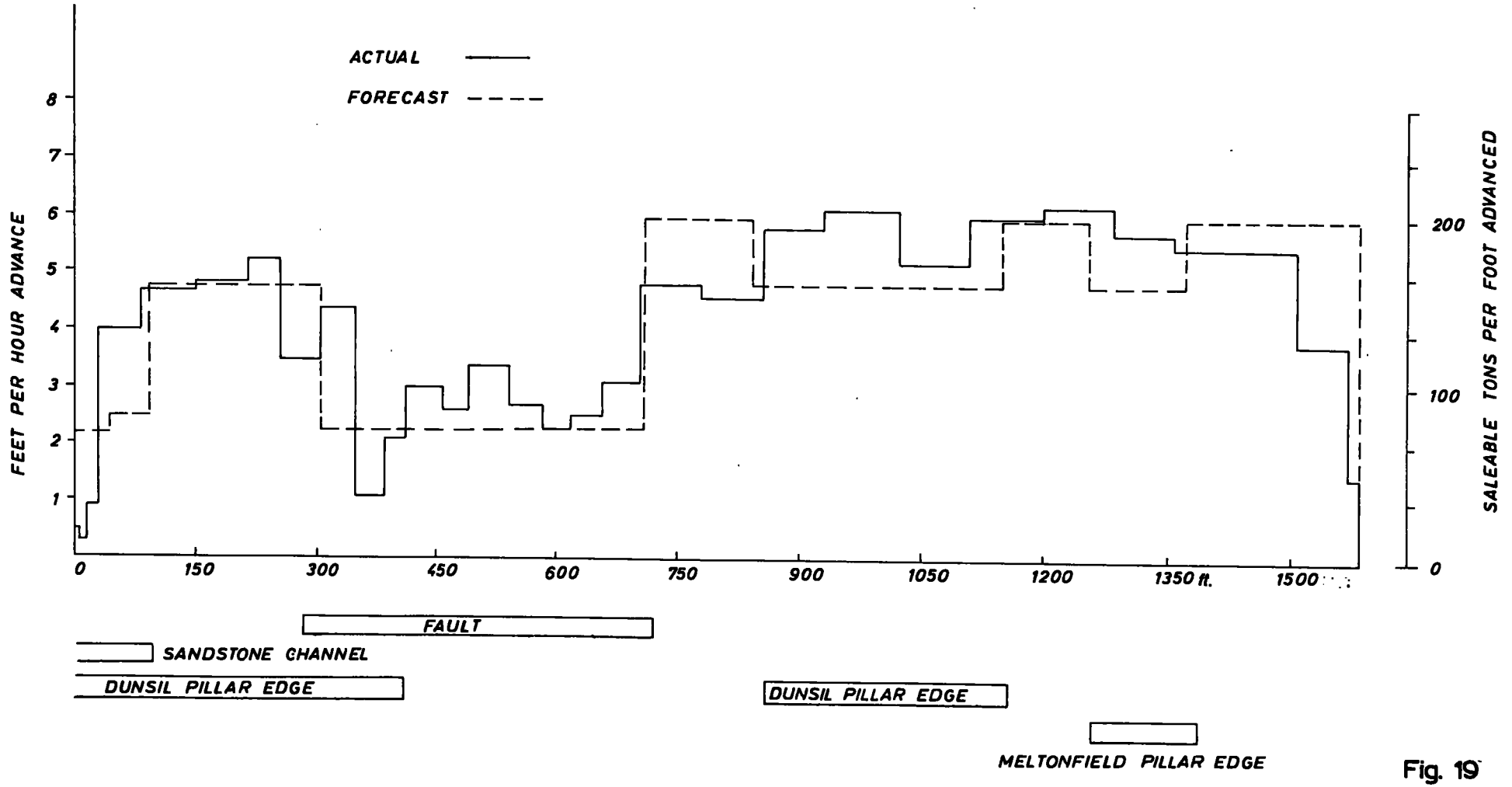


Fig. 19

life of a face. This estimate allows a balance to be maintained between production and development work at the pit and between production and consumer demand.

Table 4.2: FORECAST AND ACTUAL PRODUCTION RESULTS RELATING TO 6's RETREAT FACE.

	Forecast	Actual
Distance travelled by face.	1590 ft.	1595 ft.
Time in days to complete face.	31.56	30.66
Total number of strips.	924	1002
Average time lost per day due to mechanical failure.	317 mins.	247 mins.
Advance per strip	1.72 ft.	1.59 ft.
Saleable tons per shear.	55.8	56.0
Saleable tons per day.	1634	1810

In order to use the equation in this way, the term 't_m' must be specified in some way as well as 't_g', Smith having done this by assuming for 't_m' the value over the preceeding faces of the average daily delay due to mechanical causes. The results of prediction on this basis, (see Table 4.2 and Fig.19), summed over the life of the face, are found to lie within reasonable limits of error showing it to be a valid application. Although this is the case for the total life of the face, when the predicted rates for elements of the face advance, in this case days, are examined against actual rates, they are found to be inaccurate. This is due to the fact that when the face is considered as a whole the probability is relatively high (0.37m) that the actual average value of 't_m' for the face is close to that assumed. On the other hand, the probability is somewhat lower (0.15) that the actual value of 't_m' for an element of the face advance is close to that assumed. (See Appendix 2).

Thus in Smith's application equation (4) becomes:-

$$n = 60.25 - \frac{317 + t_g}{15.10}$$

$$n = 60.25 - 20.99 - \frac{t_g}{15.10}$$

$$n = 39.26 - \frac{t_g}{15.10}$$

giving a maximum value for 'n' which is frequently exceeded in practice.

If, on the other hand, the equation is used not to predict actual production rates but to assess the maximum possible rates under specific geological conditions, i.e. no delay due to mechanical causes, the term 't_m' becomes equal to zero and equation (1) becomes:-

$$n = 60.25 - n_g$$

The maximum value of 'n' is now much closer to reality than in the previous case. Providing sufficient geological evidence is available, this latter case could be used at any time to assess the viability of projected workings within the same system. It is then a quantitative assessment of the effect of geology in worked areas which can then be applied to qualitatively similar areas of projected workings.

The rate of production under specific geological conditions is found empirically by plotting the corrected rates of advance per day against the actual advance, the mean value of 'n' being taken for each condition. (Table 4.3 gives the values of 'n' so derived whilst the histograms are to be found in Appendix 1.) The significant variations in rates of advance per day are picked out by the use of control lines at $n = N \pm S_T$, where S_T is the standard error of estimate on the original T/n data, which covers the inate variations in 'N' caused by the use of the correlation of 'T' on 'n'.

Table 4.3: RATES OF FACE ADVANCE UNDER SPECIFIC GEOLOGICAL CONDITIONS

Geological condition.	Rate of advance (shears per day)
Normally competent mudstone roof.	60.25 ± 5.47
Channel sandstone with a regular base at around 15".	55.28 ± 2.50
Channel sandstone with 'ramble' base normally below 15".	44.71 ± 8.10
Channel sandstone with 'ramble' base intrusive into the seam.	41.20 ± 4.59
Channel sandstone with a regular base resting on or immediately above the seam.	59.00 ± 1.49
Mudstone seatearth lying above the seam.	39.00 ± 3.00

The results tabulated above are based on consistent variations in advance potential attributable to the geological conditions. It will be noticed that the highest rates of advance are to be found under a normal mudstone roof, although accompanied by a wide range of possible rates. This is in all probability a function of the competency of the roof material and is related to the amount of fracturing within it. Decrease in advance rates may thus be expected with the proximity of stress concentration caused by faulting, mine openings, and sedimentary discontinuities such as channel edges. Explanation of the effects of other conditions to some extent follows this line of reasoning. A regularly based sandstone a short way above the seam causes little disruption of the immediate mudstone roof and advance rates are correspondingly high. With decreasing regularity in the base of the sandstone comes an increased disruption and hence a decrease in advance. Here, however, other factors come into operation, for, when the 'ramble' base of the sandstone reaches the seam the problem changes from one of supporting an unstable roof to one of cutting a very hard material. This can produce some of the lowest advance potentials of all with a high rate of wear on machinery. If, however, an immediate roof of sandstone has a flat base then both

cutting, and the majority of support problems, disappear allowing high advance potentials. The only problem which remains is that associated with the size of the sandstone body - if competent and laterally extensive, its hanging back over the waste exerts a lever effect on the coal face causing weighting, crushing, and closure of the face. If broken, then individual blocks of sandstone may have a similar, albeit a more localised effect, giving the same reduced advance. The mudstone seatearth overlying the seam causes a general reduction in advance regardless of its own thickness, by virtue of its providing a plane of separation for the higher roof measures whatever its development.

Although the production histograms show that faults do have a strong effect on advance, it has proved impossible to produce any fully consistent quantitative assessment of the relationship. It is suggested that the factors governing such a relationship may be the angle which the fault system makes with the face line since this determines the time for which the face will be affected and the proportion of the face affected at any one time. Other factors include the throw of the fault, or faults, and the number of individual faults which make up the system as this is some measure of the disruptive effect on the roof measures. Similarly, underworkings have been omitted from the table although a possible correlation with advance rates does exist. It is felt that an interaction of tectonic and mining induced stresses may be the cause of some of the more anomalous data. This is especially so since the geometry of mine openings in lower seams is in a large part determined by the faulting and hence any effects of the mine openings are superimposed or overlap.

The effects of the variety of conditions tabulated are not normally additive, the resultant normally being equivalent to the

maximum effective component. Faulting and underworking do however have an additional effect.

The analysis set out in this chapter may prove to be an oversimplification in that a continuous spectrum of geological conditions and advance rates are broken down into a stepwise sequence. Also, the geology is based on observations in the gate roads for the face and thus may overlook variation along the face line although the effect on production does appear to be greatest where any given condition crosses the gates. The actual form of variation in advance rates is more complex involving excessive losses in advance, as adverse conditions are first met, followed by a gradual rise as these are brought under control. (Fig. 20a).

It has been noted that when calculating the regression equation, $T = Ns - ns$, for each face, some directly effective geological factors (t_D) have been overlooked, since it is impossible to record them in terms of delay. These normally result in a slowing of cutting speed, giving an increased instantaneous value for 's'. The same result is obtained by considering a decrease in the value of 'T'. The factor t_D is only operative during the actual cutting time and is therefore equal to zero when no advance is made and also when the geology has no effect i.e. when 'n' is a maximum. Between these two limits, however, t_D may be effective in causing a lowering in the value of 'n' for a given value of 'T', the data points being offset to the left of the true straight line function, as is the resulting regression line. (Fig. 20b). An underestimate of advance potentials is thus possible, although its magnitude is probably outweighed by the inaccuracy of the basic assumption of a step-wise treatment of advance.

The Effect of Geology on Face Advance.

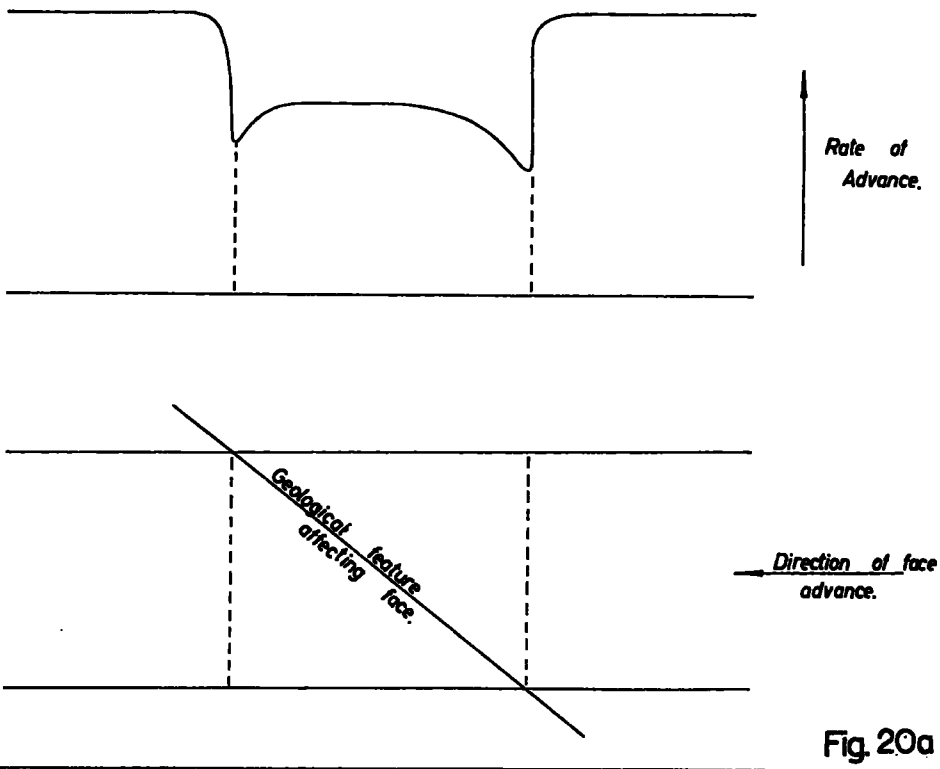
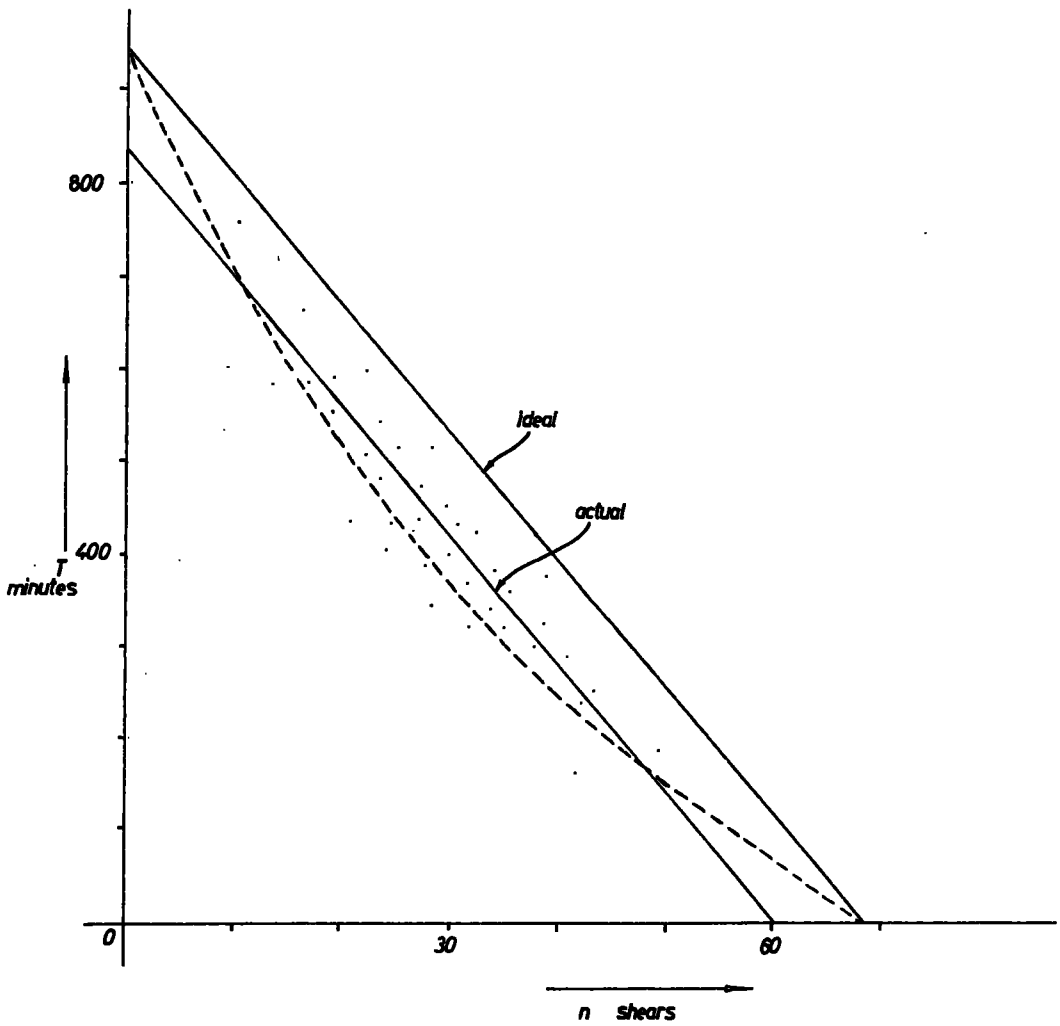


Fig. 20a

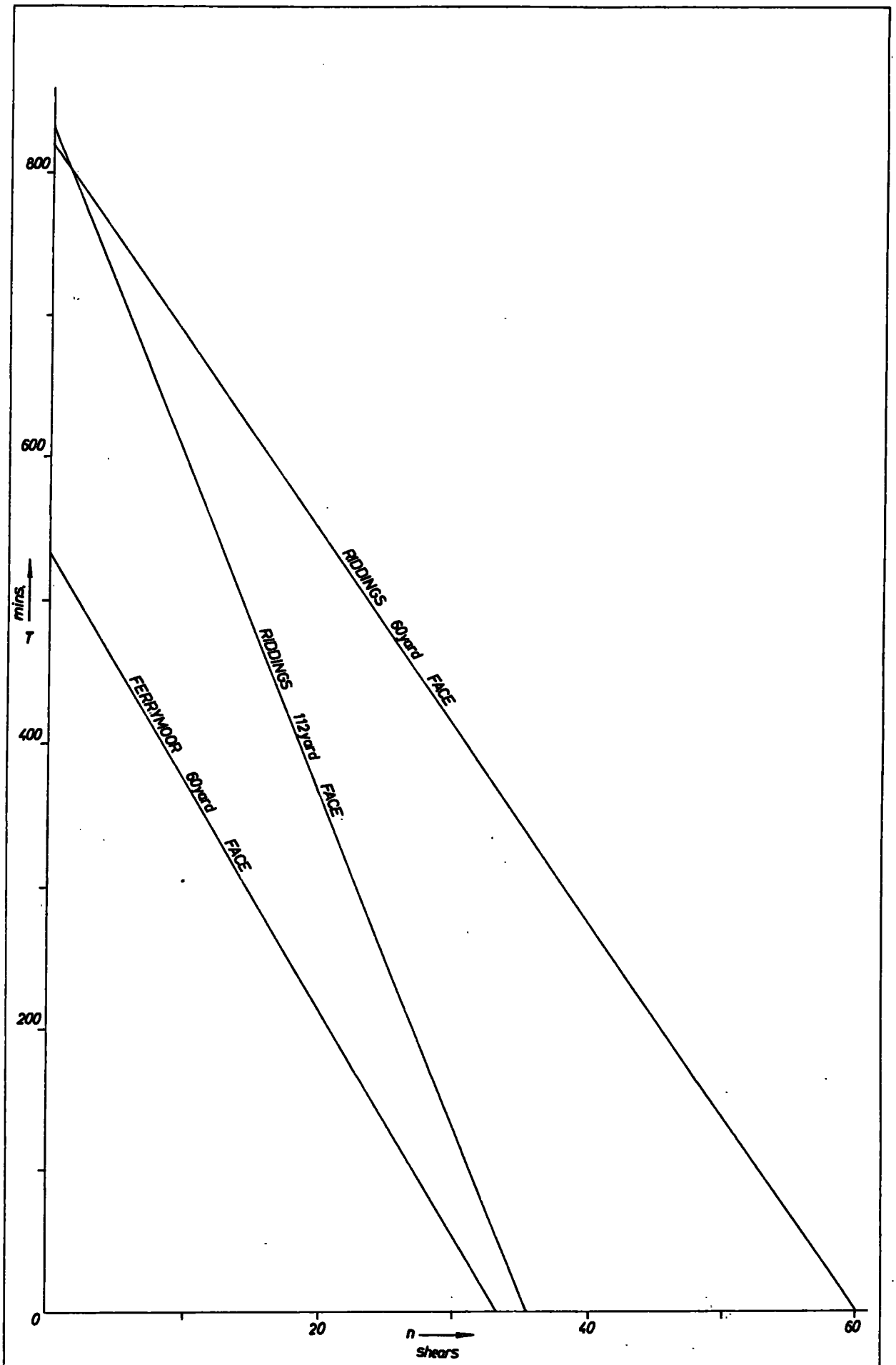


Ideal and Actual Regression Lines For T= Ns - ns.

Fig. 20b

Since the adoption of this technique of presentation of geology to management, improvements in advance rates have ensued. Whether this is due to a better understanding and anticipation of the effects of geology on working, or whether it merely provides an incentive to do better than the predictions, is difficult to say. What is noticeable is that although advance rates have increased, daily tonnage has not kept pace in some areas - an indication of coal being left in place as a control on the roof, in anticipation of problems.

A further point worthy of note is the difference in the times available for shearing and hence the differing potentials of the two collieries Riddings and Ferrymoor (Fig. 21) - even though the two collieries work the same system in the same seam. It had been assumed that the difference was due to a more intense effect of geology at Ferrymoor. This does not now seem to be the case - the analysis showing it to be a matter of logistics, effectively a shorter working day.



Comparison of the equation $T = Ns - ns$ for Riddings and Ferrymoor Collieries.

Fig. 21.

CONCLUSIONS.

Taking the two aims of the study separately, it can be seen that the attempt to project the geology of known areas into the unknown has met with only limited success. Although each geological environment is known, and it is hoped understood in itself and in its relations with others, the spatial distribution of the total environment is at present too complex a parameter to work with. An instance of this is that although it is understood that the swilleys may be fossil water courses, that their form stems from this, and that they are linear features, it is difficult to go much further. At present an inspired guess is all that can predict individual or small scale features, the more sophisticated statistical techniques being applicable only to generalities. For example, it could be confidently stated that the trend of sandstone bodies in the roof of the seam over Block 2 was 112 degrees - a piece of information which should have been helpful in planning the layout of extraction panels.

The method of assessment of capability has proved successful and useful and, assuming a constant revision to meet new conditions and the improved techniques which it fosters, may make a useful tool.

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APPENDIX I

PHOTOGRAPHY.

Due to the safety regulations applying to coal mines it is impossible to use a normal flash lighting arrangement underground. The quality of the photographs therefore on occasion leaves something to be desired. They do, however, give a reasonable impression of exposures and rock types found during the course of the study.

Equipment used was as follows:

Camera : Zenith B, a single lens reflex camera with an Industar 50 lens.

Lighting : By standard cap-lamp

Film : Kodak Tri-X Professional.

The camera was tripod mounted and a timed exposure used of between 50 and 65 seconds at f4 or f5.6 dependent upon the reflectivity and contrast of the subject. The subject was illuminated by 'painting' with the cap-lamp, which involves slowly moving the light beam back and forth across the subject. A point of practical importance is to ensure that the edges of the frame are given sufficient lighting and the centre not over illuminated in order to give an even exposure.

THE PLATES:

1. A strongly erosive sandstone roll in 8's main gate, cutting through the mudstone to the thin roof coal. Compactional stresses associated with the 'intrusive' sandstone body have caused the distortion of the roof coal seen to the right of the pencil.

   60 seconds - f5.6

2. Ripple-drifted sandstone with lenses of siltstone. 8's main gate.

   50 seconds - f5.6 Uneven illumination.

3. Large in situ stems of Calamites, preserved in sandstone in massive siltstone, a sub-aerial levee environment. 8's tail gate.

50 seconds - f5.6

4. Mudstone, becoming silty towards the rippled junction, with a fine silty sandstone which is in turn overlain by silty mudstone with a further sandstone band and then by massive sandstone. 8's tail gate.

60 seconds - f5.6

5. The junction between mudstone and sandstone, fairly regular with the mudstone parting to it. 8's tail gate.

65 seconds - f5.6

6. A cross-section of a small basal roll with a linear groove alongside. 8's tail gate.

60 seconds - f5.6

7. Large scale cross-bedding, 9" thick. 8's tail gate.

60 seconds - f4

8. A laminated sandstone cut by a body of massive sandstone, the whole being overlain by siltstones. 9's tail gate.

60 seconds - f5.6

9. A lens of laminated sandstone lying between the roof coal and mudstones. 9's tail gate.

65 seconds - f4

10. A large roll of massive sandstone causing difficult roof control problems.

60 seconds - f5.6

11. A compactional, rotational slip shown by silty mudstone lying discordantly upon a mudstone, the junction being a zone of crushed mudstone material. 9's development road.

60 seconds - f5.6

12. A contorted and massive siltstone cutting through horizontally laminated sandstone and siltstone, overlain by undisturbed

sandstone and siltstone. 8's main gate junction with the south side materials road.

60 seconds - f5.6

13. Small scale train-drift within horizontal laminae of silt and sandstone. 8's main gate junction.

50 seconds - f5.6

14. A small high angle fault on the outbye edge of the swilley in 7's tail gate.

60 seconds - f4

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Plate 1.

Plate 2.

Plate 3.

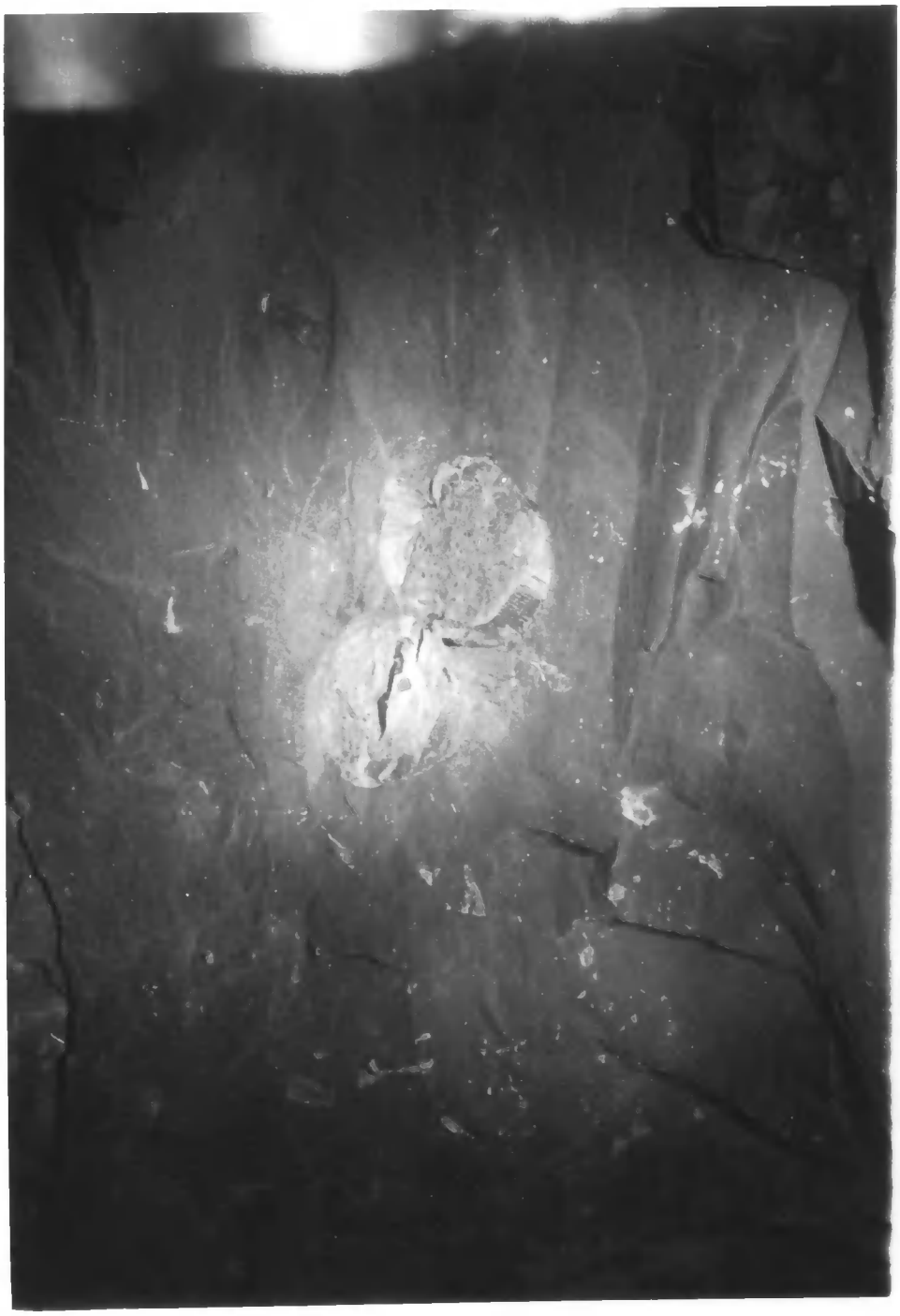


Plate 4.

Plate 5.

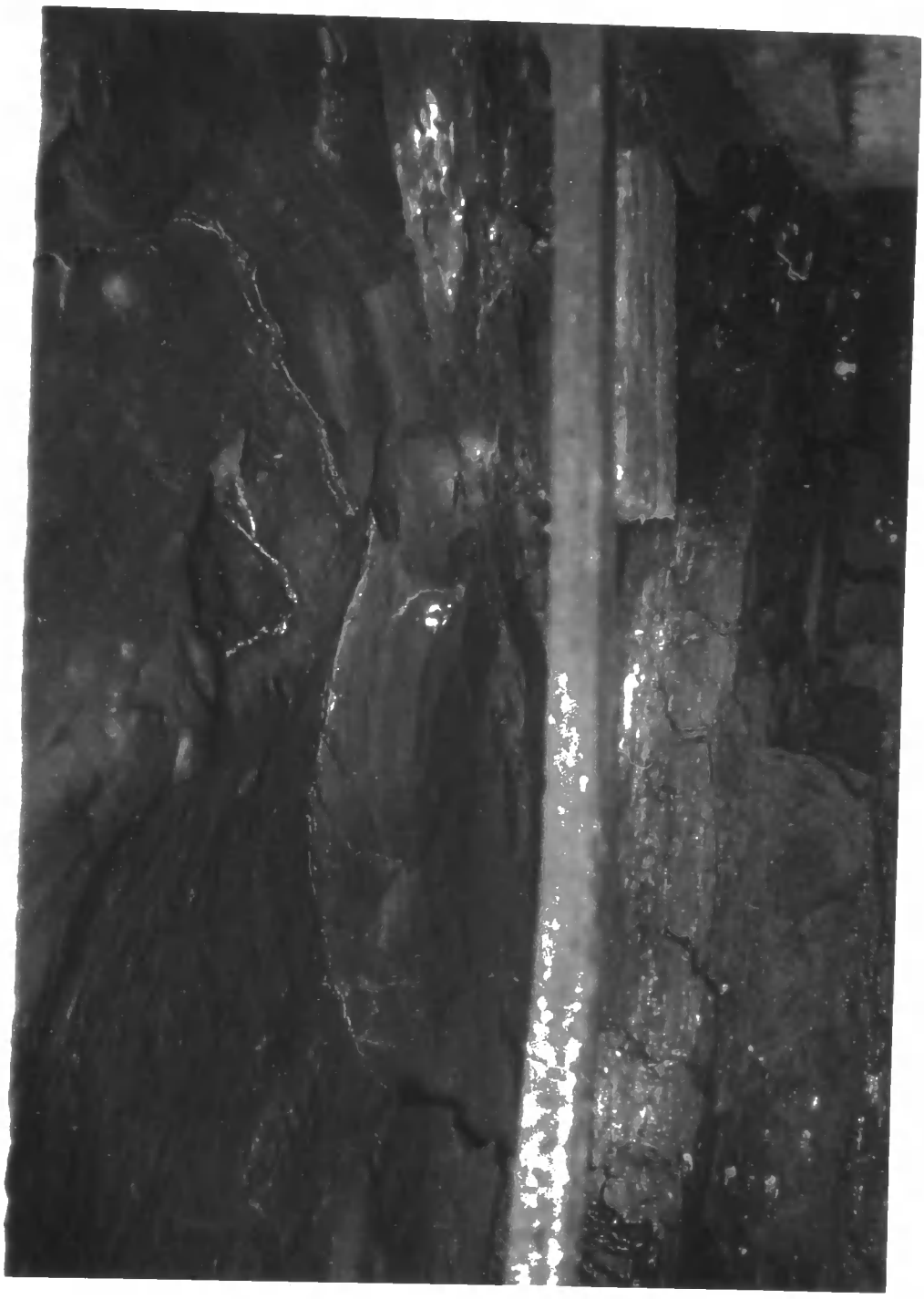


Plate 6.

Plate 7.

Plate 8.

Plate 9.

Plate 10.

Plate 11.

Plate 12.

Plate 13.

Plate 14.

APPENDIX II:

Production Data

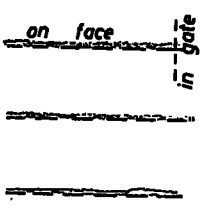
COLOUR CODE FOR GEOLOGIC CONDITIONS:

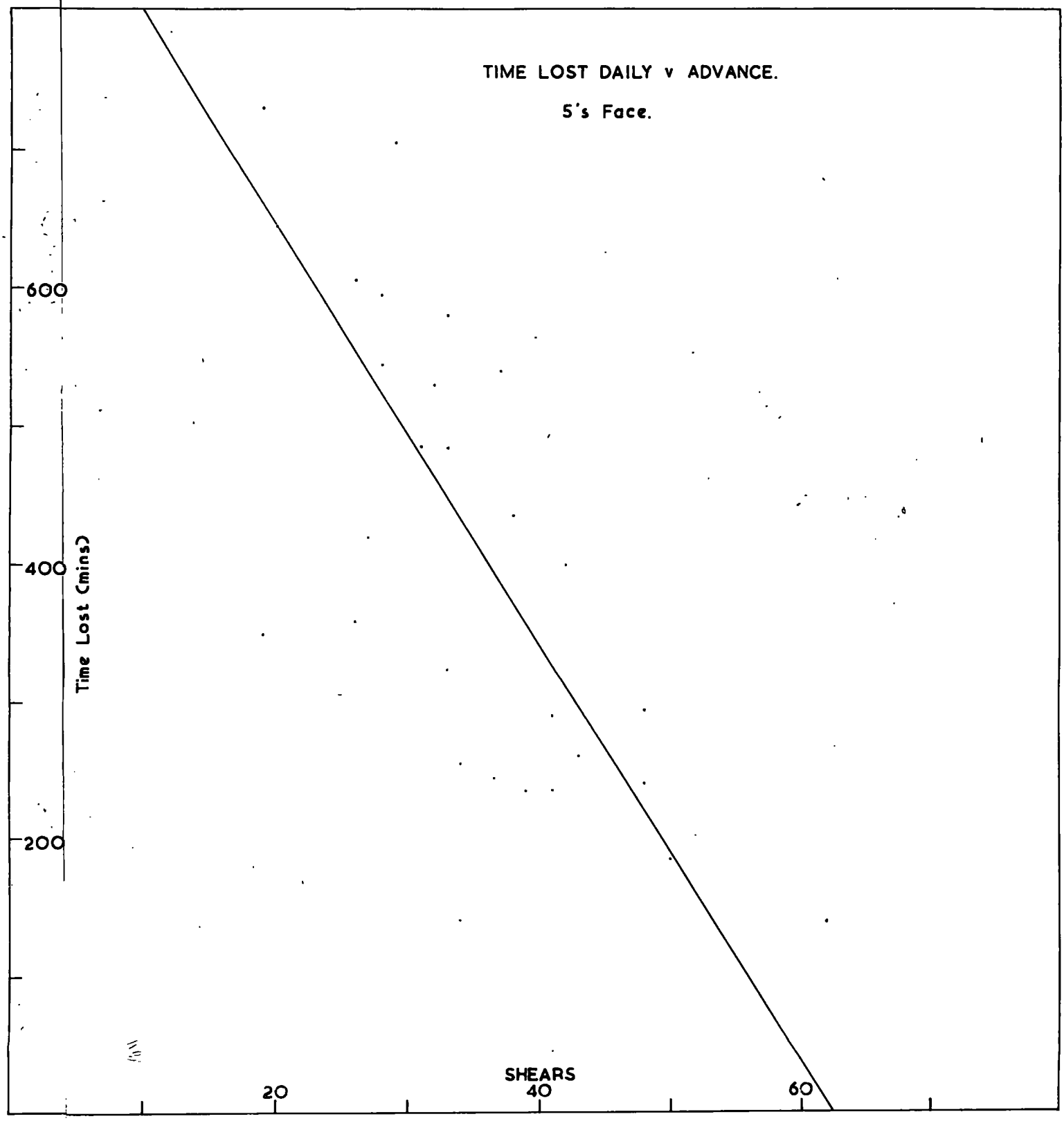
SANDSTONE CHANNEL

FAULTING

MELTONFIELD PILLAR EDGE

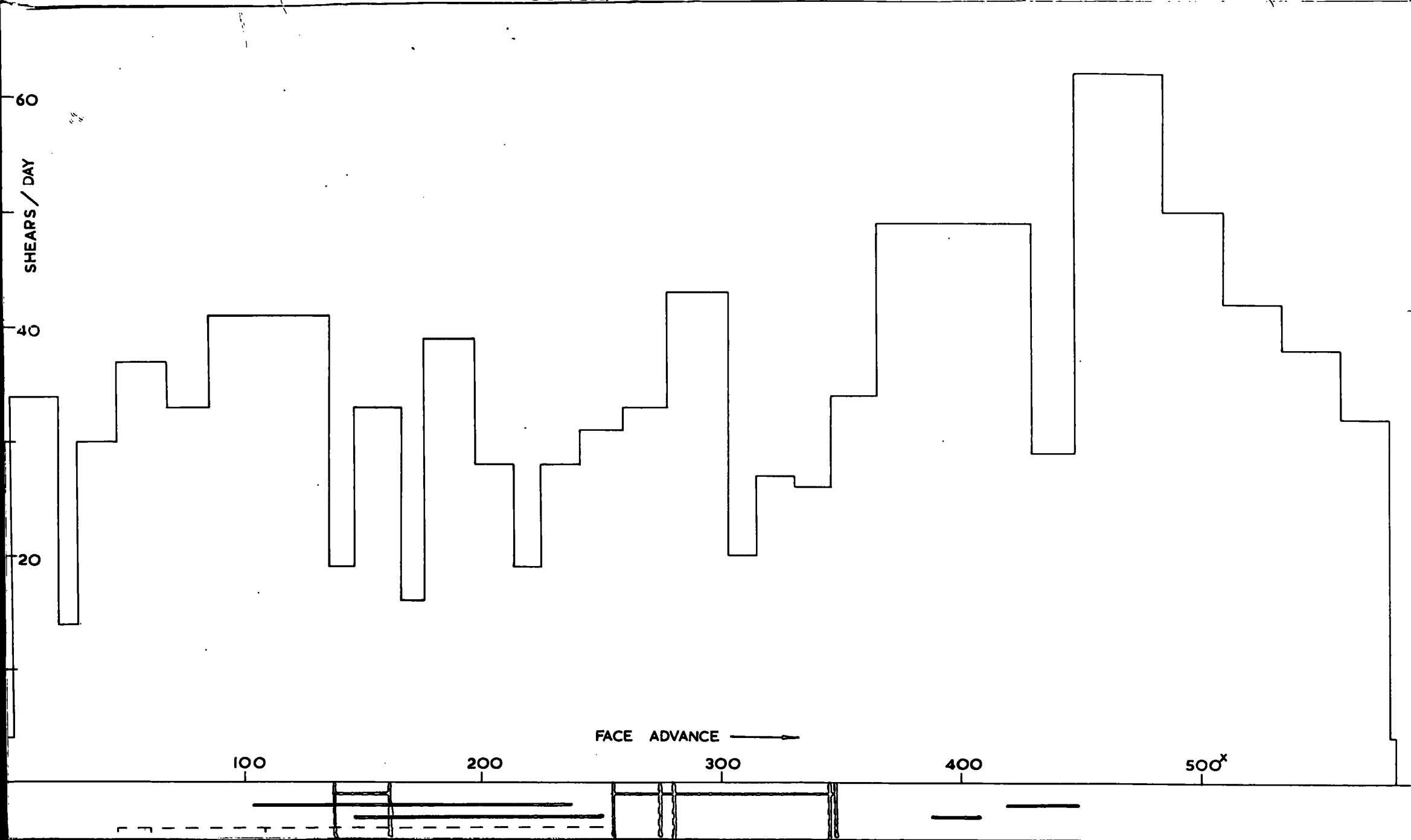
DUNSIL




TIME LOST DAILY v ADVANCE.
5's Face.
600
400
200
Time Lost (mins)
20
40
60
SHEARS

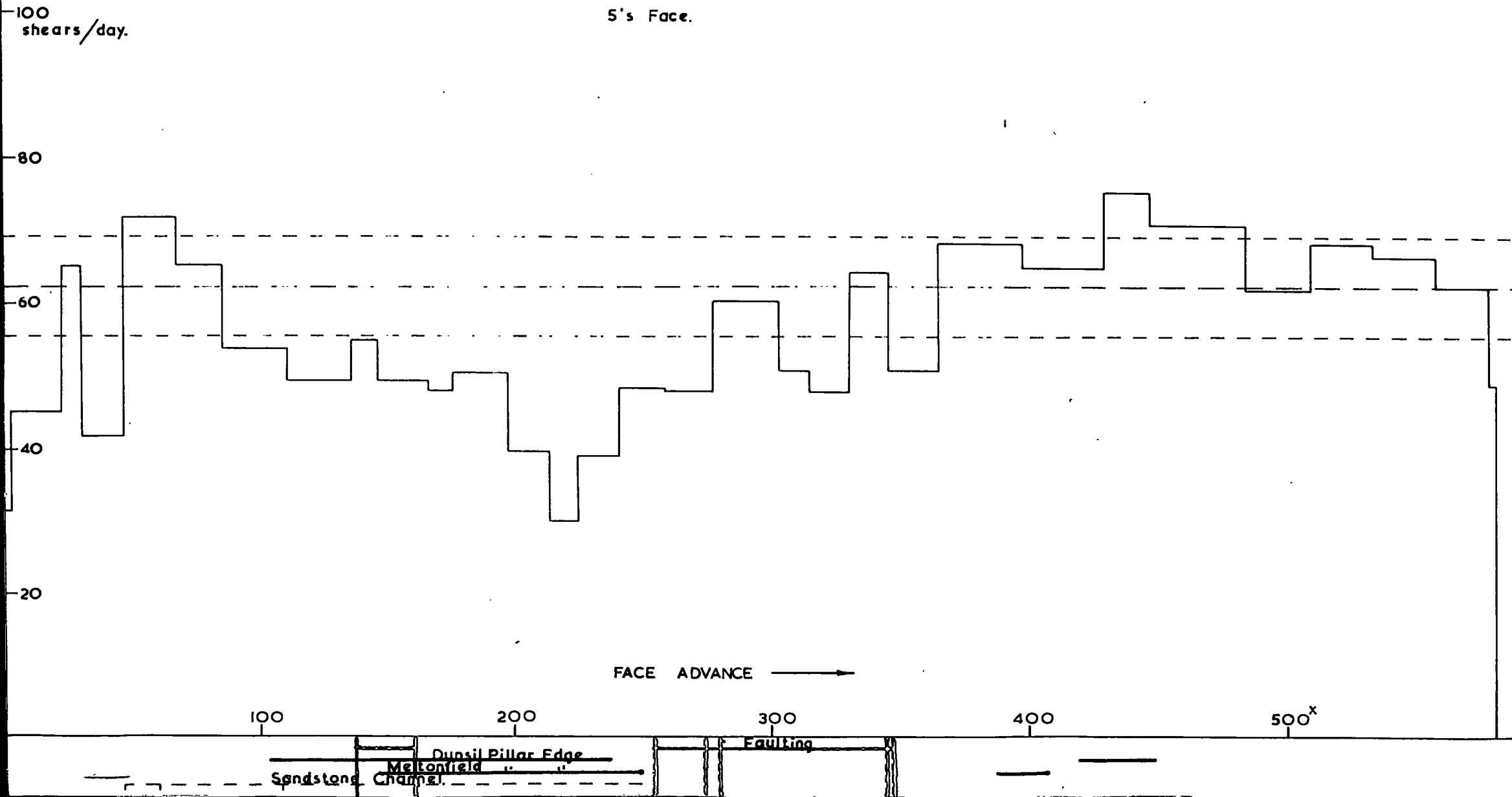
ACTUAL DAILY ADVANCE.

5's Face.



POTENTIAL RATES OF ADVANCE.

5's Face.



PRODUCTION DATA 10's FACE.

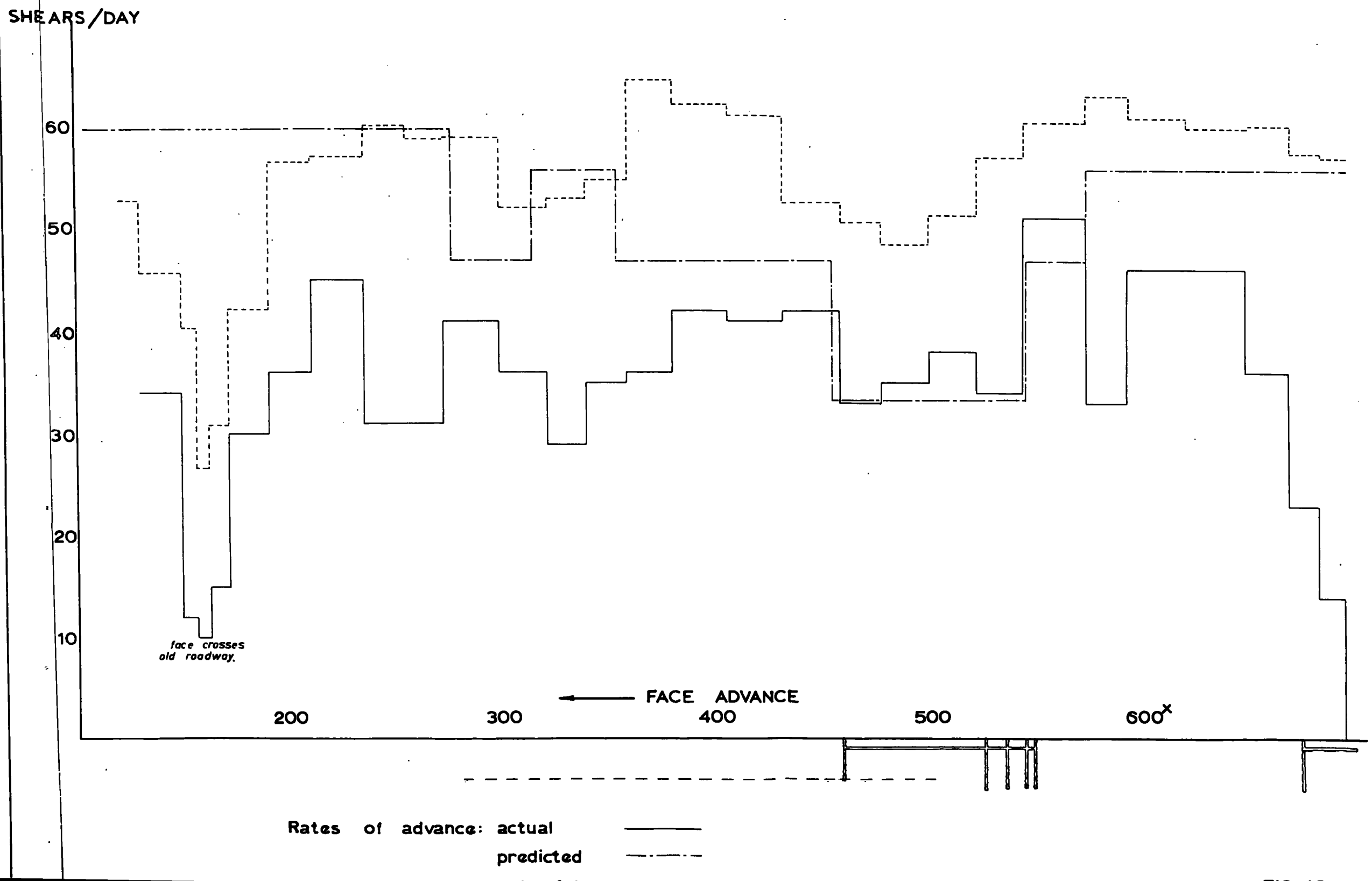
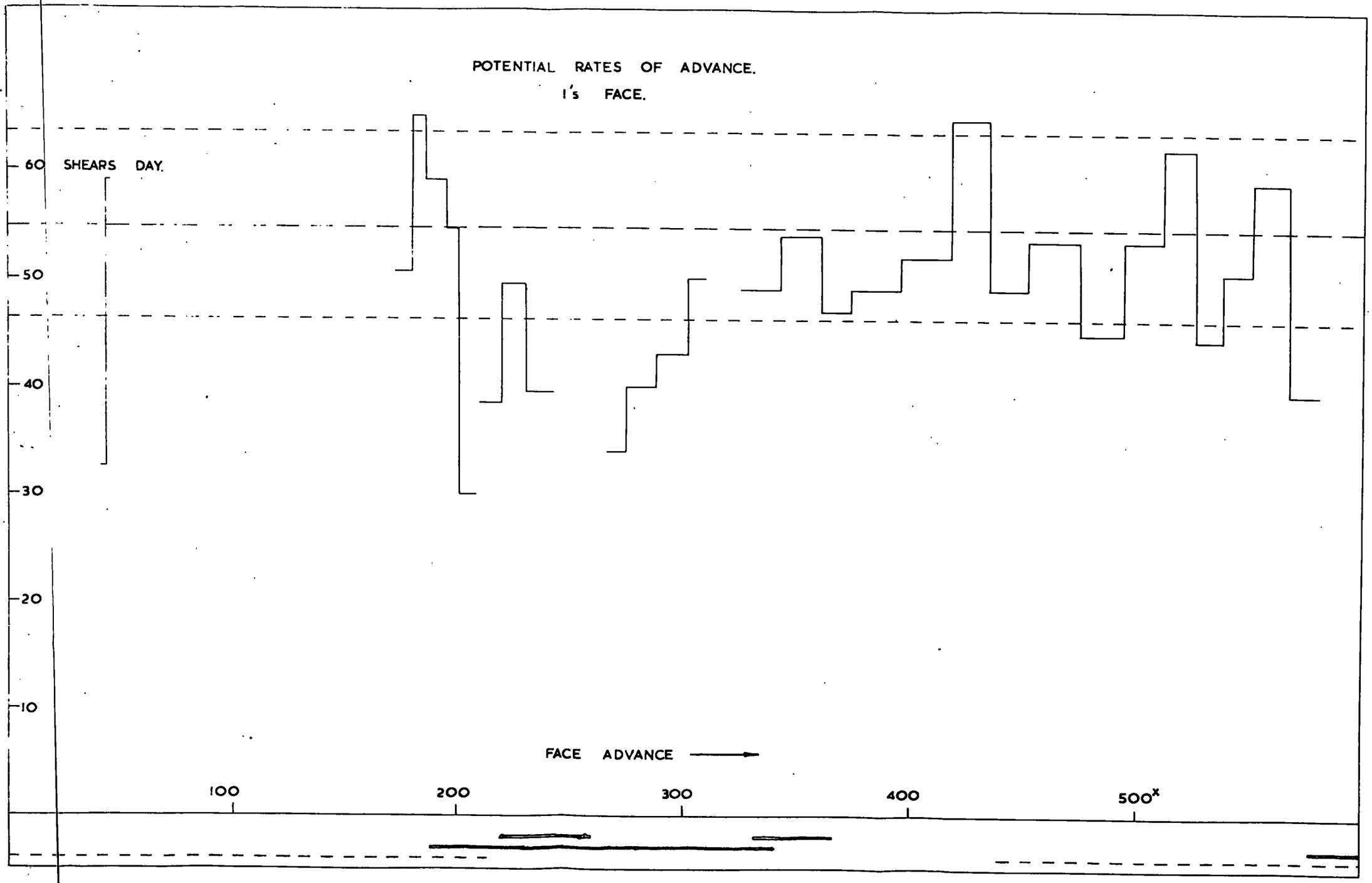
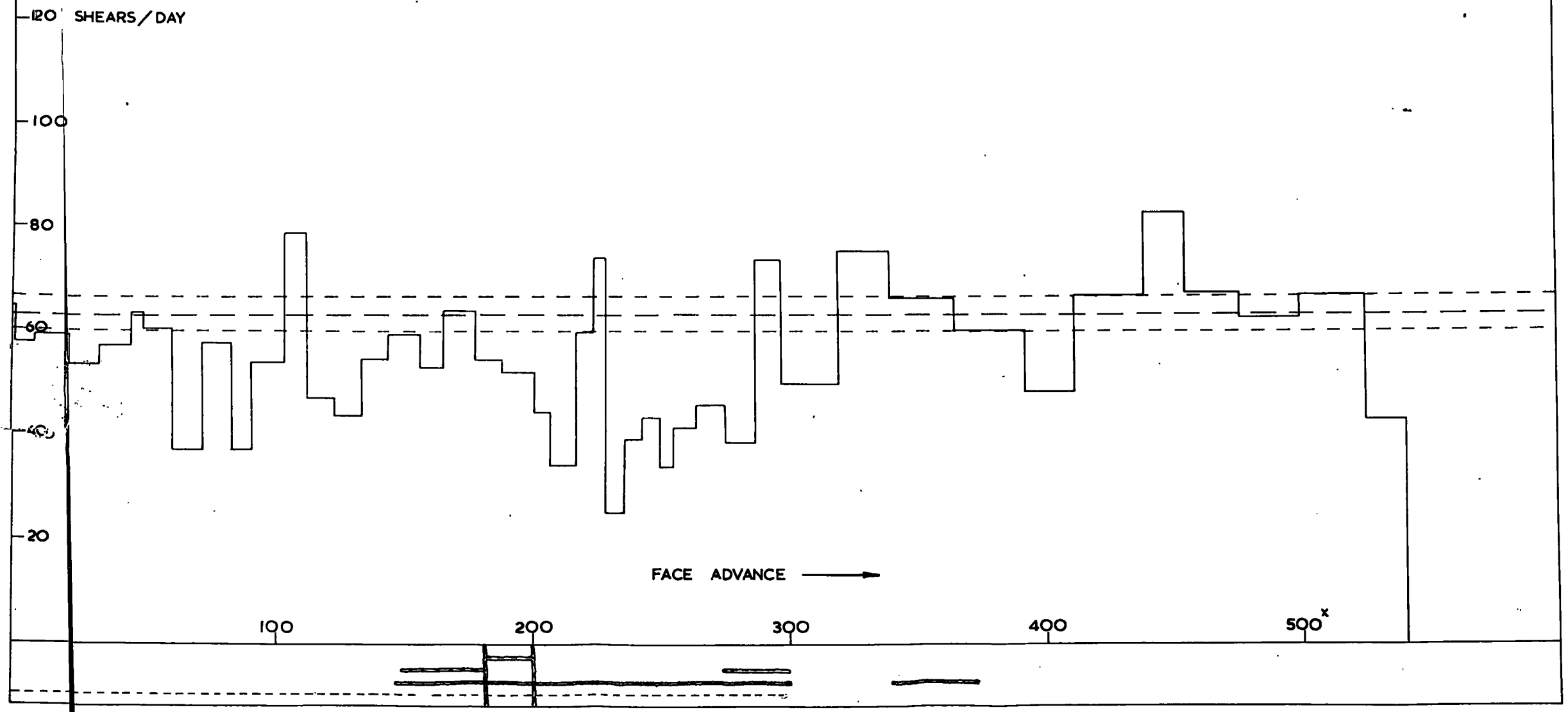


FIG. 16


POTENTIAL RATES OF ADVANCE.
1's FACE.
60 SHEARS DAY.
50
40
30
20
10
FACE ADVANCE
100
200
300
400
500x

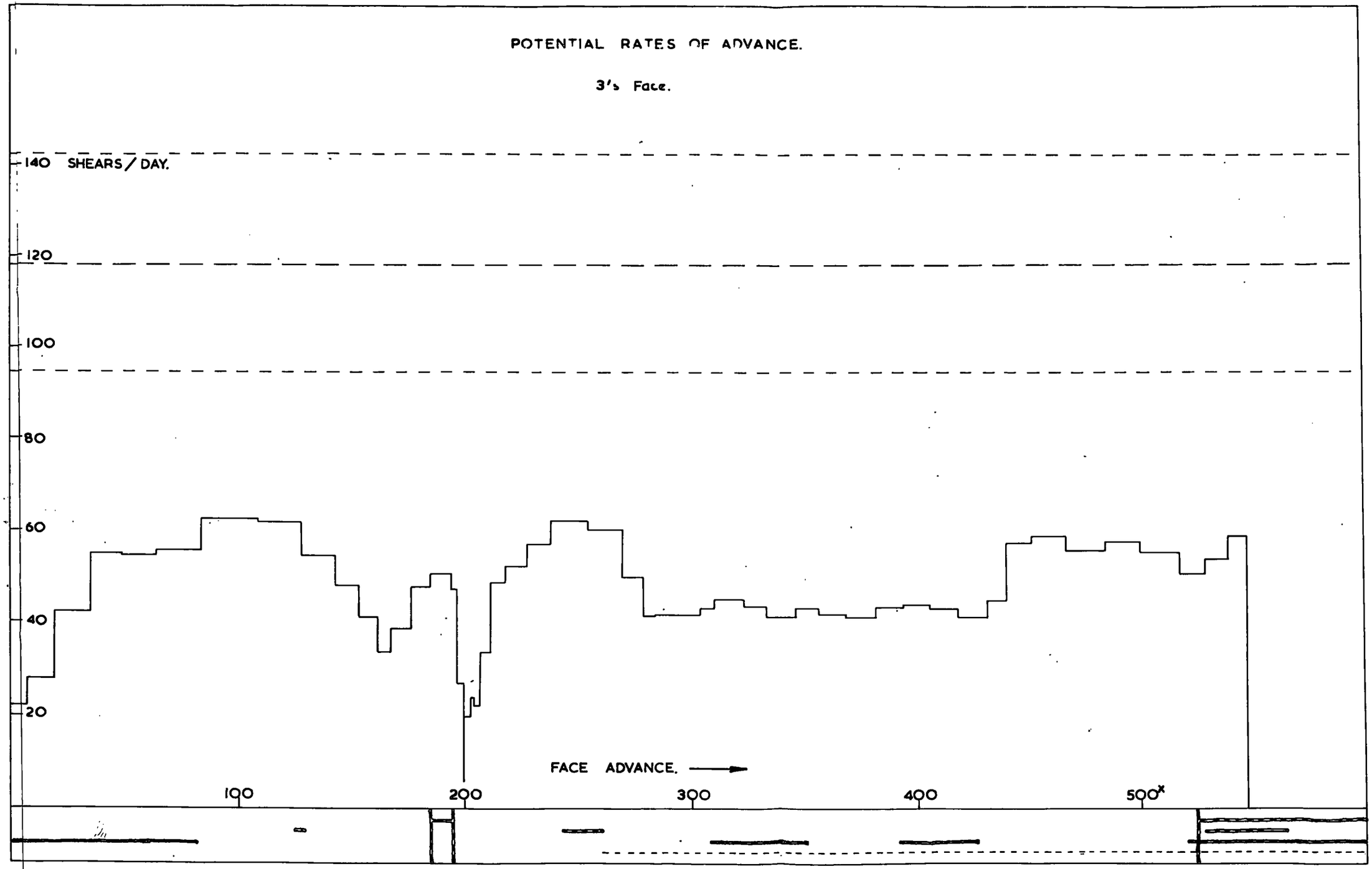
POTENTIAL RATES OF ADVANCE.

2's Face.



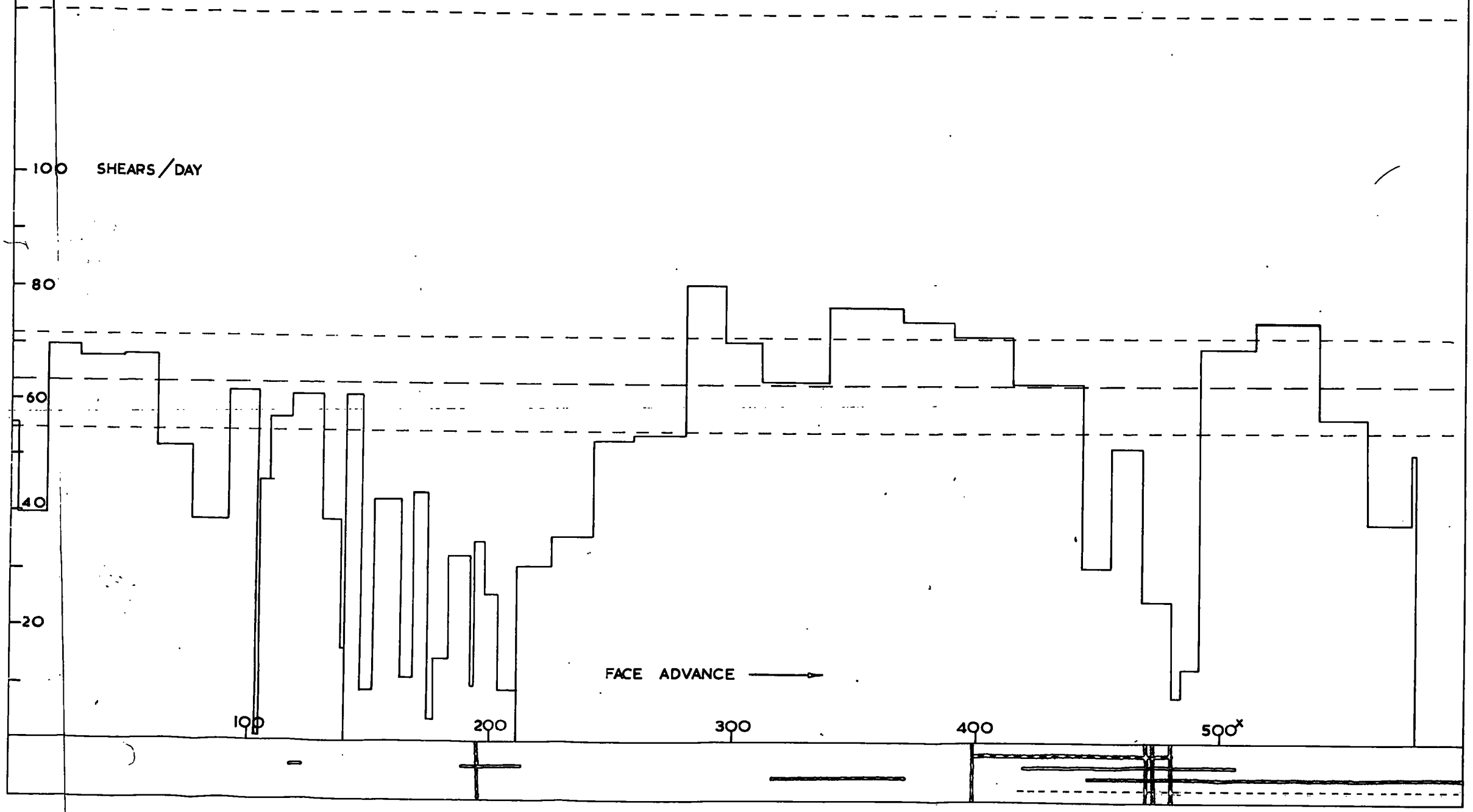
POTENTIAL RATES OF ADVANCE.

3's Face.



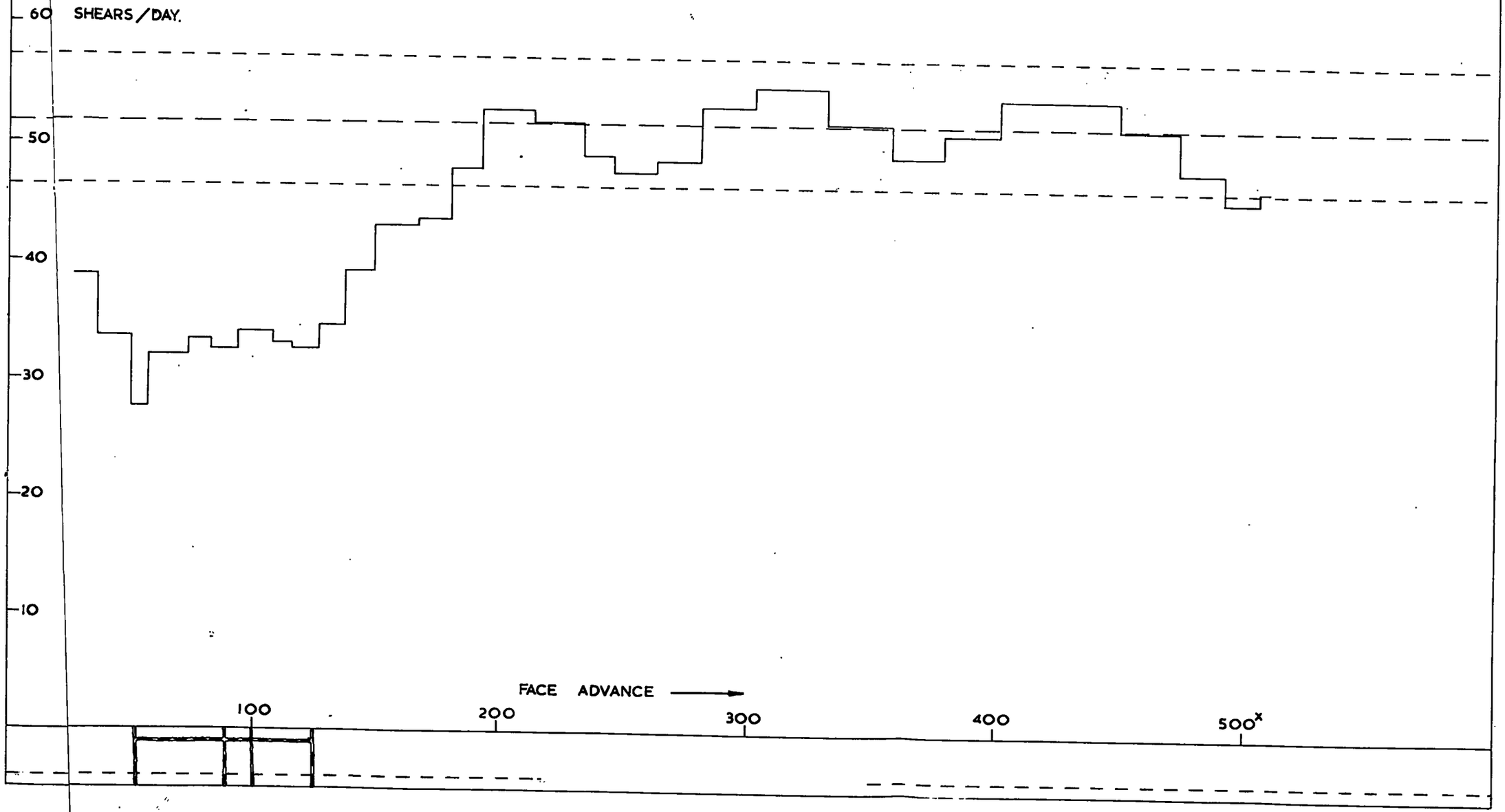
POTENTIAL RATES OF ADVANCE.

4's Face.



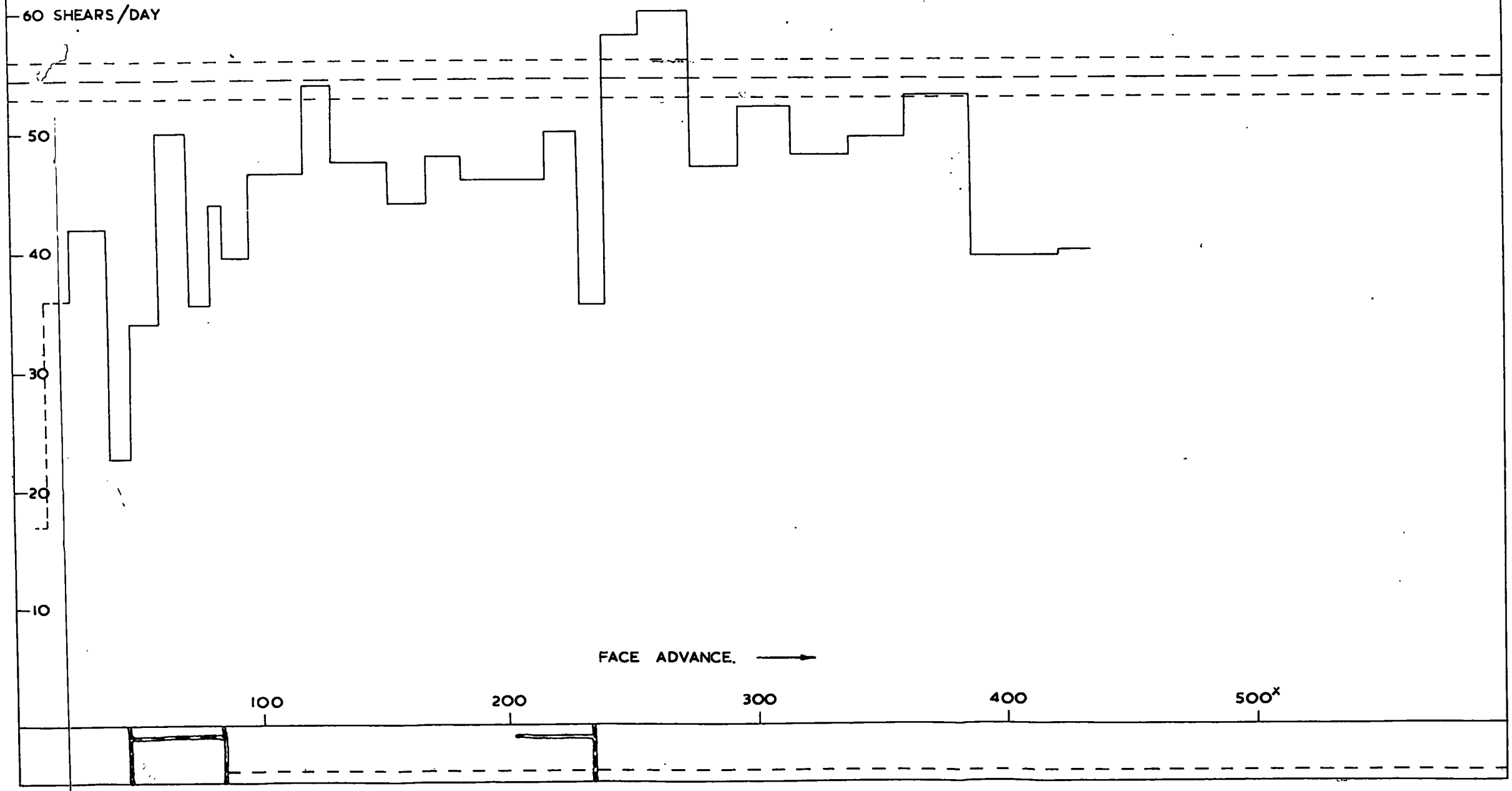
POTENTIAL RATES OF ADVANCE.

7's FACE.



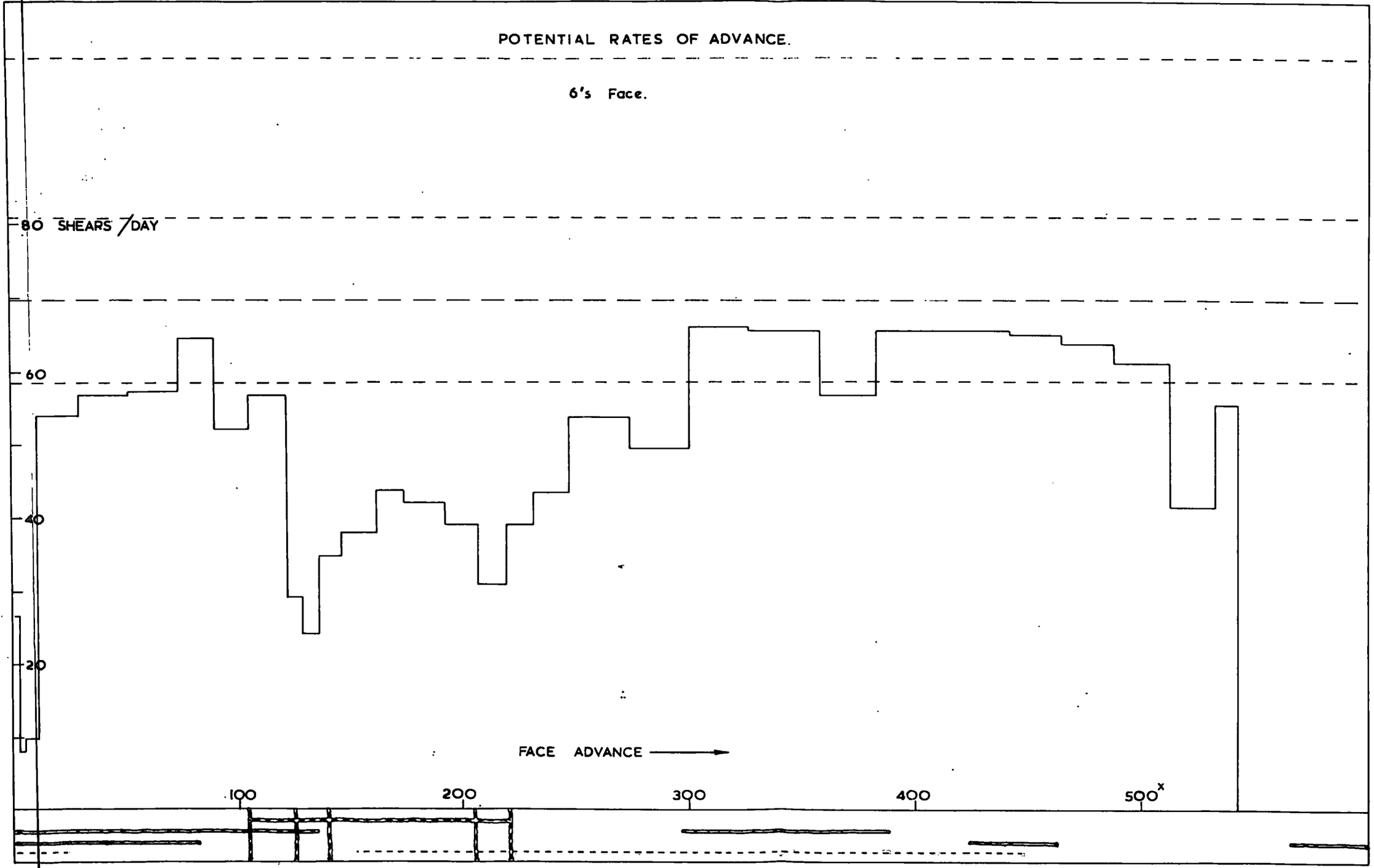
POTENTIAL RATES OF ADVANCE.

8's FACE.



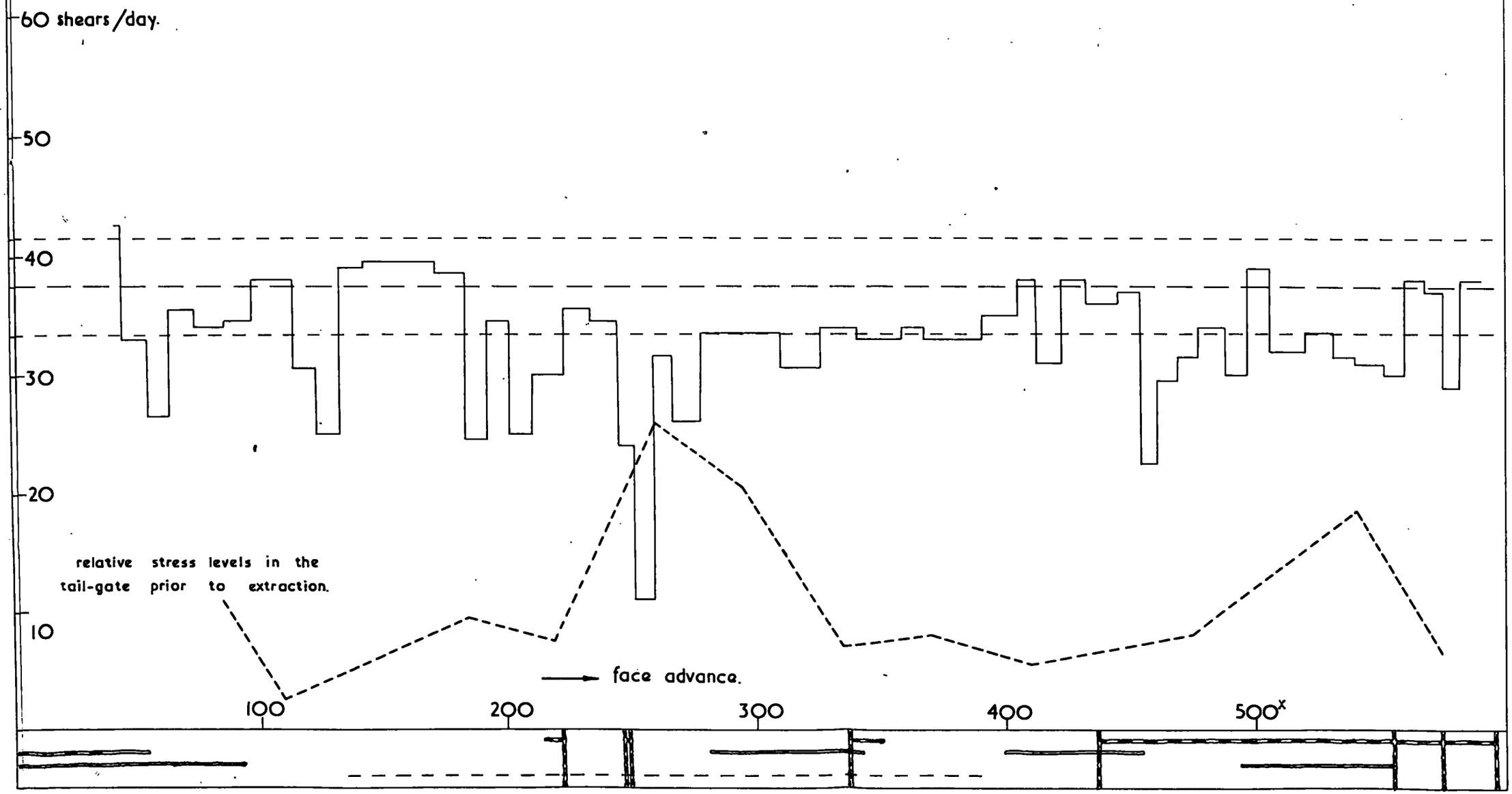
POTENTIAL RATES OF ADVANCE.

6's Face.



POTENTIAL RATES OF ADVANCE.

9s' Face.



Average value of t_m for faces 1 to 7 = 326 mins. standard deviation of this mean = 52 mins.

Probability of any actual average value of t_m for any one face lying within = 25 mins of this value = 0.368. This can be taken as the probability that the average value of t_m for face 8 will be 326 ± 25 mins.

Average value of t_m from the daily values over the life of face 8 = 330 mins.

Standard deviation of this mean = 134 mins.

The probability that the value of t_m for any one day would lie within the range 326 ± 25 mins = 0.151.

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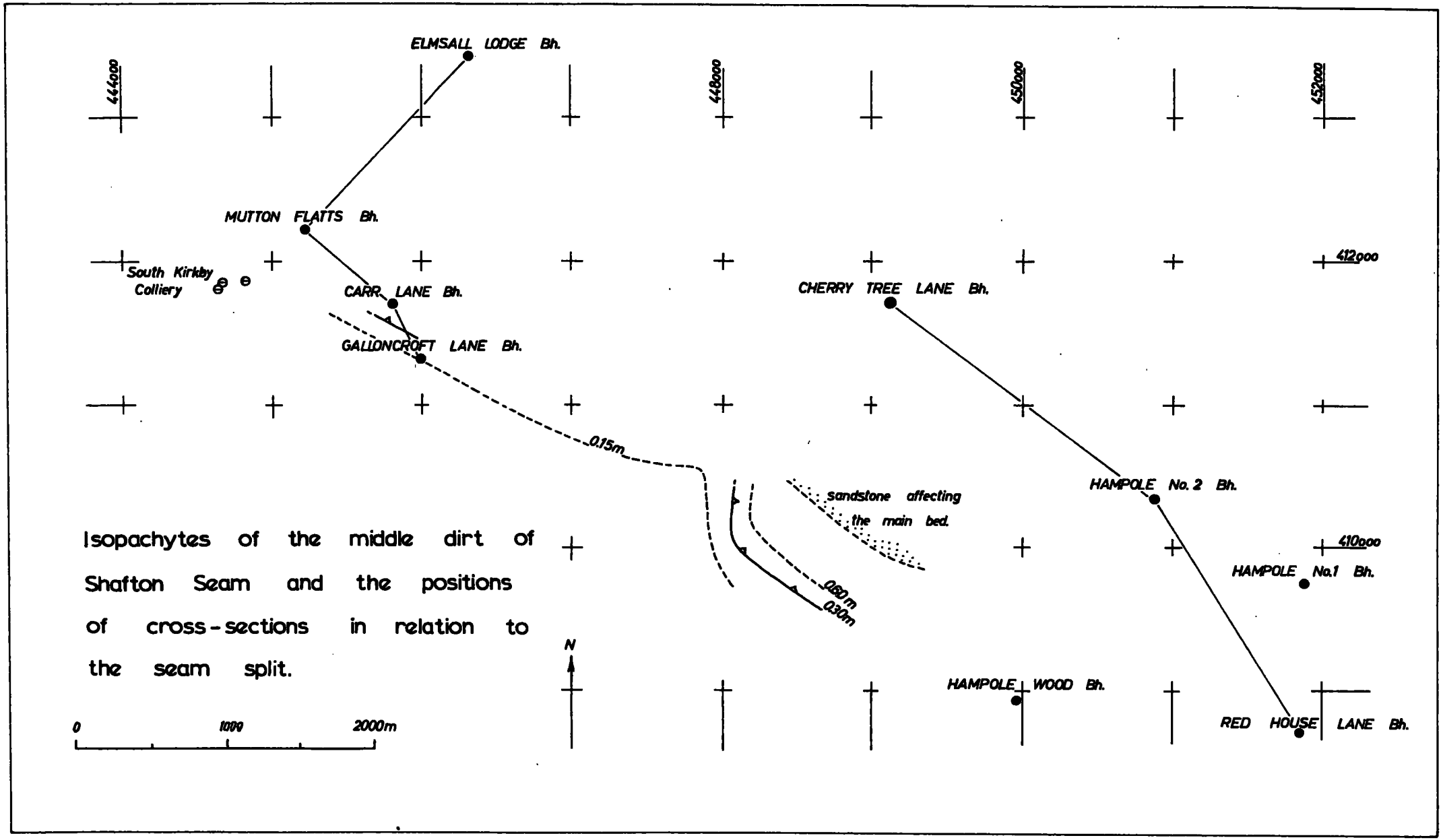
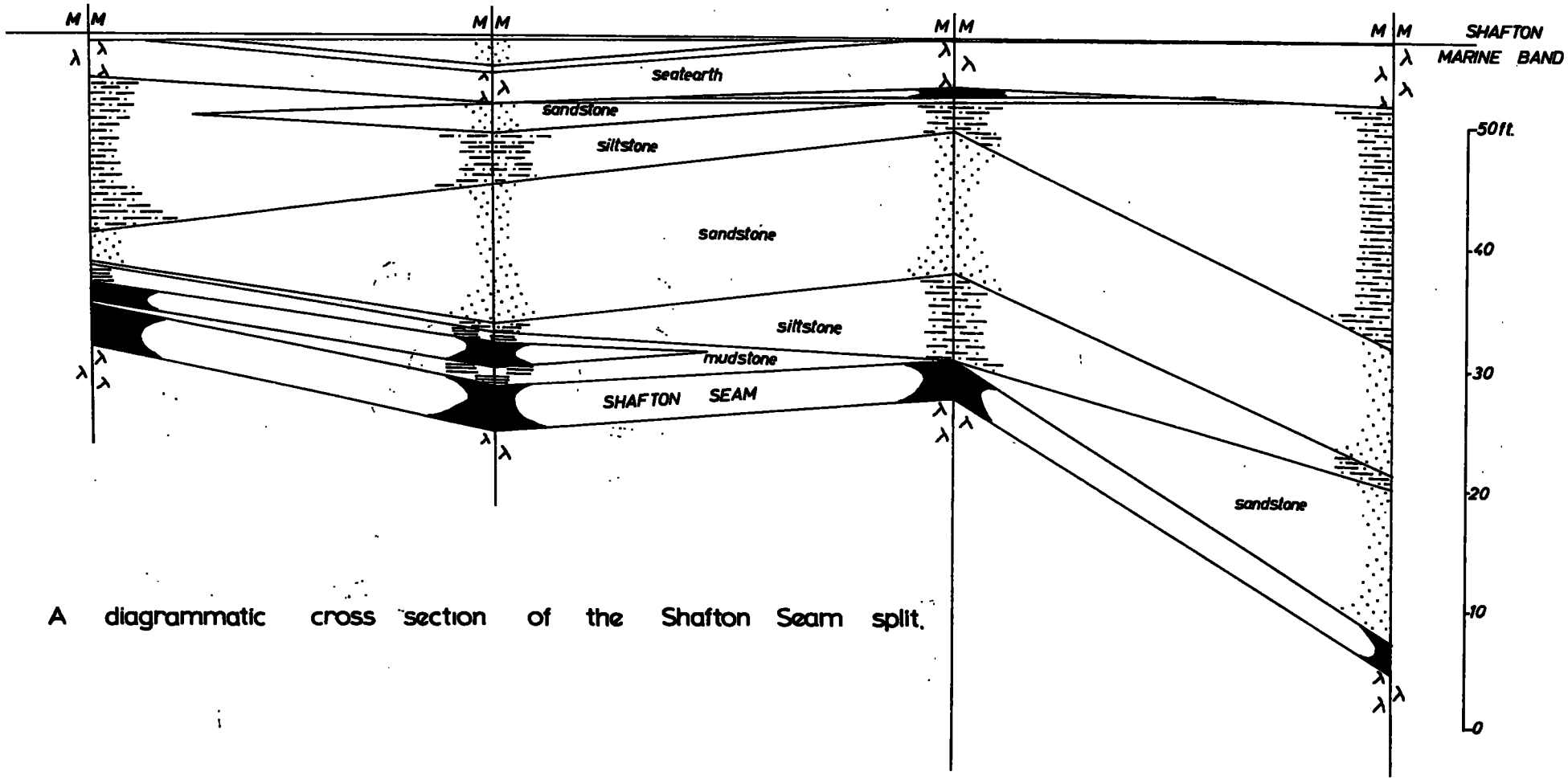
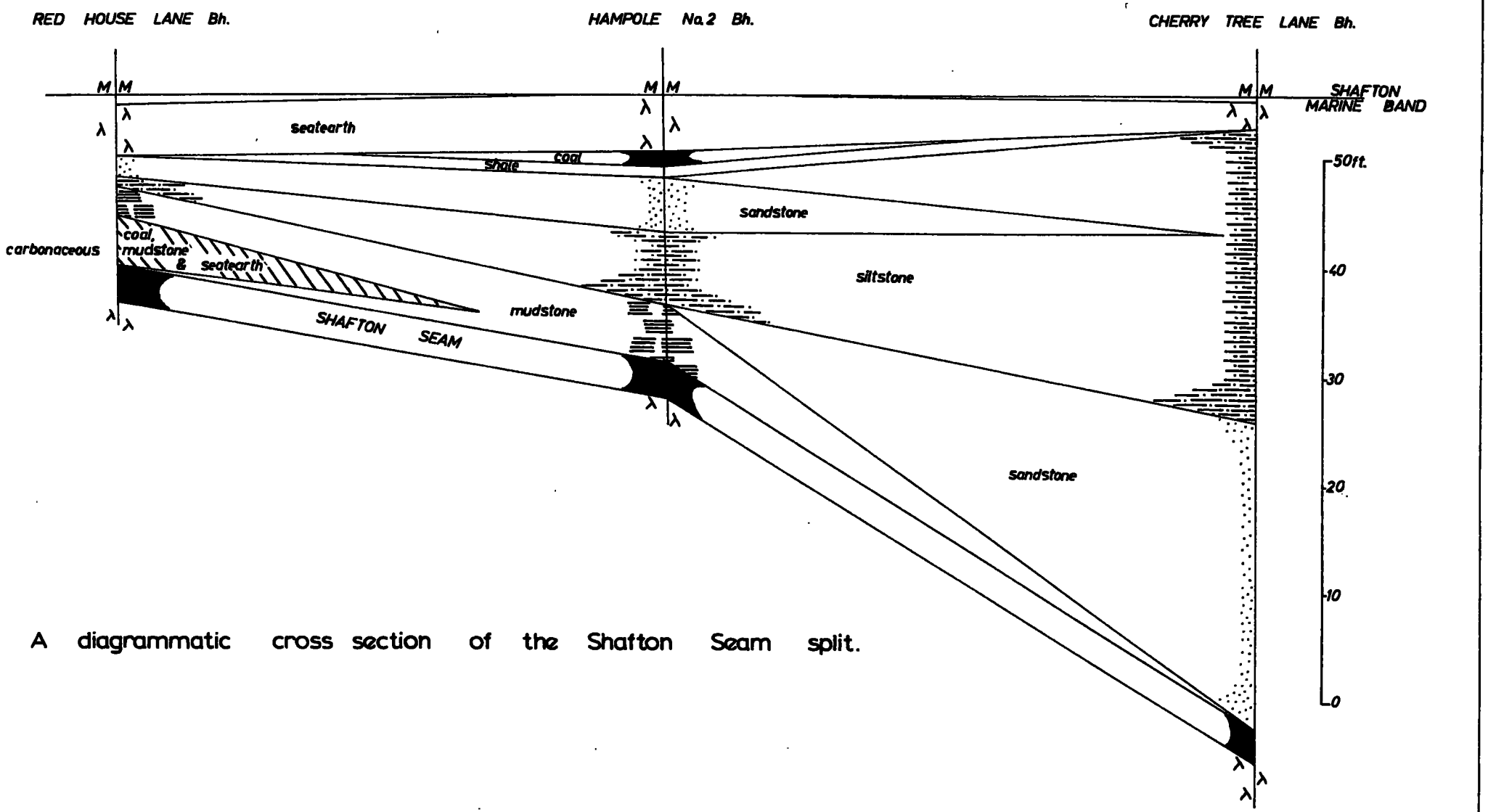
APPENDIX III

Diagrams relating to the Shafton Seam Split.


ELMSALL LODGE Bh.
444000
448000
450000
452000
MUTTON FLATTS Bh.
South Kirkby Colliery
CARR LANE Bh.
GALLONCROFT LANE Bh.
CHERRY TREE LANE Bh.
412000
0.15m
sandstone affecting the main bed.
HAMPOLE No. 2 Bh.
410000
HAMPOLE No.1 Bh.
0.60m
0.30m
Isopachytes of the middle dirt of Shafton Seam and the positions of cross-sections in relation to the seam split.
N
HAMPOLE WOOD Bh.
RED HOUSE LANE Bh.
0
1000
2000m



A diagrammatic cross section of the Shafton Seam split.



A diagrammatic cross section of the Shafton Seam split.