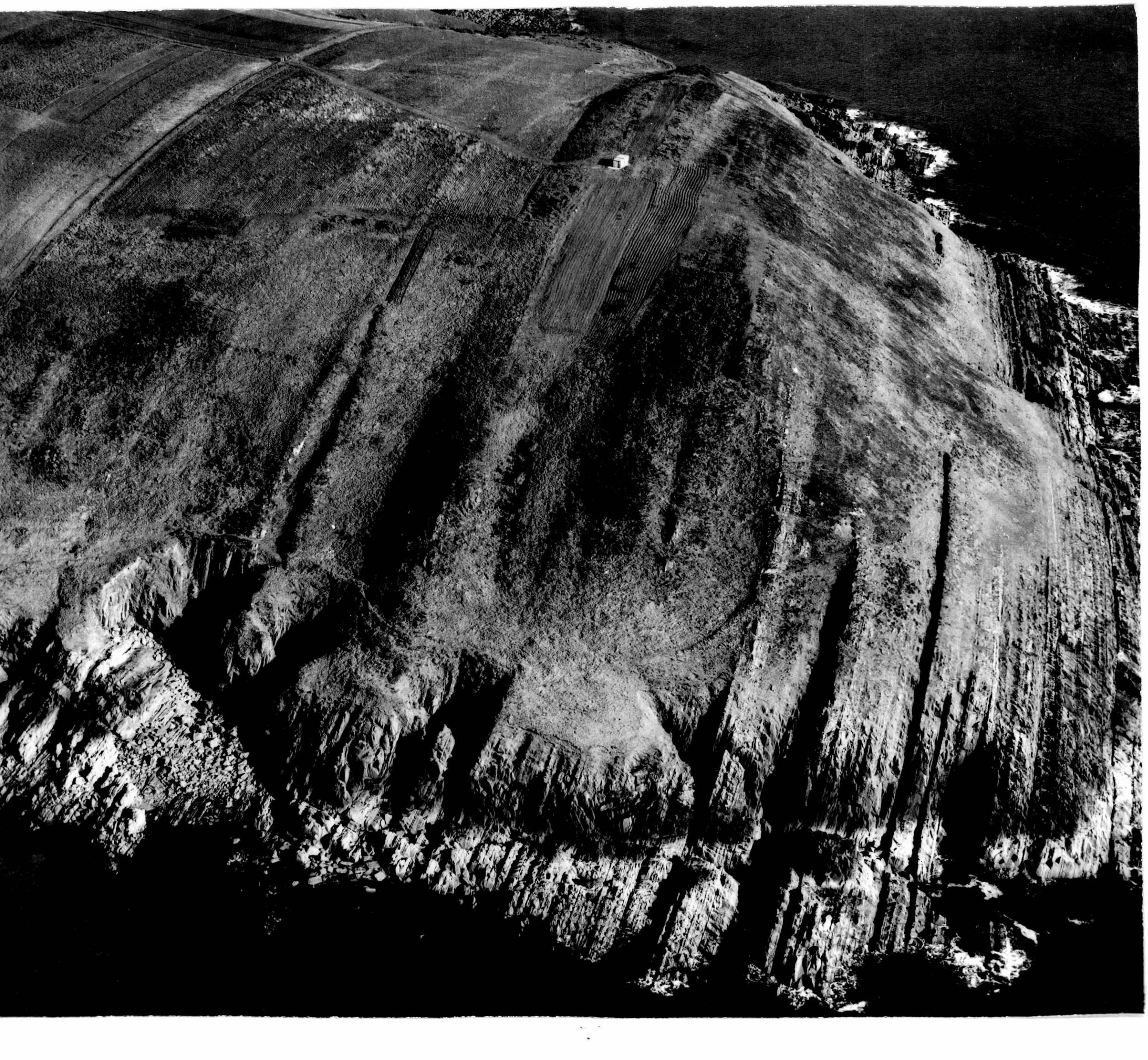

EAST MOOR CLIFF, PEMBROKESHIRE

Steeply-dipping strata at the coast appear as gullys, depressions, ridges and tonal lineations in the soil covered areas.

THE GEOLOGICAL SIGNIFICANCE OF NATURAL LINEAR FEATURES OCCURRING IN AREAS OF SUPERFICIAL DEPOSITS, AS REVEALED BY AIR PHOTOGRAPHS

by

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ABSTRACT

This Thesis describes an investigation of the geological causes and influences affecting the existence of linear features seen on air photographs of areas where the bedrock is obscured by superficial deposits.

Detailed stereoscopic studies were made of the appearance of these features, and their causes were then investigated in the field. During the fieldwork all the factors considered likely to influence their existence were recorded, and similar data were recorded where important linear geological occurrences had not been detected as linear features on the air photographs. The results were then studied in an attempt to find a relationship between the appearance of a linear feature and its cause, and also to discover factors that inhibit the detection of important geological data on air photographs.

The linear features selected were found to include nine tenths of the boundaries of different types of superficial deposits, three quarters of all the buried faults and three quarters of the buried rock contacts. Half the remaining soil boundaries, faults and rock contacts also showed as less distinct features on the photographs. Further information on the state of the hidden bedrock was shown by other linear features that were caused by bedding planes, joints, surface gullys, fracture

zones and dykes. Some natural linear features originated within the superficial cover, such as those caused by landslides, glacial effects, old coastlines and man-made features.

Each type of geological phenomena tended to have a varied appearance in different settings, and a series of characteristics were studied for each linear feature so that a variety of interpretation criteria were secured to give a photogeologist as sound a basis as possible on which to make decisions.

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1. INTRODUCTION

Sooner or later most geologists using air photographs in areas where the bedrock is obscured come across natural linear features that their instincts tell them have a geological cause. These features are often isolated and remote from any rock exposure in situations where every small particle of geological information about the sub-surface is of use, yet it seems that little is known about interpreting their cause and significance. One of the most common reactions seems to be to mark the features down as being 'possible faults or major joints'. An alternate and preferable approach is to use a separate symbol and classify them as 'linear features of possible geological significance'.

The aim of this inquiry is to see whether there is anything in the photographic appearance of these linear features which can be exploited to obtain a closer idea of their significance. Other workers have made studies of the patterns of these features in an attempt to establish the significance of their regional relationships, but the writer does not know of any publication which attempts the study of the significance of individual lineations in an environment of concealed bedrock, and it is felt that such an investigation would produce information that would give in at least some instances a better idea of the cause of the feature. This knowledge might in turn help to isolate more significant patterns on a regional basis by enabling the study to be made of selected groups of linear features of more importance or relevance to the investigation.

This Thesis reports an attempt to learn more about these features by sampling and studying them in the field on a planned basis. Almost all the discussion in the later sections deals with this project and its results, but the writer has occasionally drawn on his previous experience and reports by other geologists to fill in some of the gaps; it has been made clear in the text when this has happened.

This can only be regarded as a preliminary study, as an immense amount of work would be required to cover all the environments and situations needed to produce a comprehensive set of interpretation criteria, but at least it is hoped that the results will be sufficient to show whether further work would be justified.

2. REVIEW OF RELEVANT LITERATURE

In the last few years a number of textbooks and papers have appeared on photogeology, and the historical development of the subject seems adequately dealt with in the relevant sections of the MANUAL OF PHOTOGRAPHIC INTERPRETATION (1960), and in ALLUM* (1961).

In the Bibliography at the end of this Thesis there are included some thirty papers that deal with the study of lineations on air photographs, and this review deals with this group only, and mainly with those that deal with the lineation as such, rather than as regional studies of associations of lineations. There is a constantly varying nomenclature throughout this series of publications, but the original names will be maintained in quotation marks and the terminology will be reviewed at the end of the section.

Amongst the first publications dealing with the sort of features investigated in this study is that of RICH (1928), who described the jointing of limestone seen on air photographs.

The next in the field was KAISER (1950), who described a lineament as

> "a straight linear surface feature that is at least many hundreds of feet and commonly many miles long. Lineaments are well shown on aerial photographs and may consist of

* Names in capital letters followed by a date are referred to in the Bibliography at the end of this Thesis.

(1) linear topographic features, either trenches or ridges; (2) linear vegetation patterns; or (3) linear patterns of soil colour or texture. Gaps and stream segments typically form parts of lineaments".

GROSS (1951) carried out a statistical study of 'topographic linears' and suggested that where lineations obtained from air photographs and maps form statistical groups that do not coincide with such obvious causes as glacial striae, schistocity and bedding strike, they should be followed up with prospecting activities.

The following year DESJARDINS (1952) was writing of the detection of deep seated features such as salt domes by the study of surface fault patterns shown on air photographs.

BLANCHET (1956) introduced the term "Photogeophysics" in discussing the study of patterns of linear features, and again in the following year BLANCHET (1957) discussed "fracture analysis" as an exploration method. He defined fractures as "the generally abundant, natural lineations discernable on aerial photographs", and divided them into two principle classes, micro-fractures (about a ½ mile in length) and macro-fractures (2 to 50 miles, or more, in length). He considered the latter to be generated "at the level of the basement", whilst the micro-fractures were considered to have originated much further up in the geological column. He states that there is a systematic pattern of fractures created mainly by tides in the earth's crust. Furthermore,

> "The propagation of fractures upward to the surface, even through the unconsolidated soils and glacial overburden, is considered to take place as a result of the flexing action of the tides within the layers of sediments, magnified by the lever-action or rocking motion of the larger basement block, and including, in particular, the isostatic blocks".

In the same year MOLLARD (1957) was reporting that

> "aerial mosaics revealed fracture patterns on surface materials in Southern Saskatchewan and Manitoba".

In the next year LATTMAN and NICKELSEN (1958) investigated an area of 6 square miles of the Allegheny series where opencast coal mining has exposed bedrock locally. Joints were mapped independently of "photogeologic fracture-traces" and they stated

> "There appears to be a significant parallelism between the directions of photogeologic fracture traces and bedrock joints".

The area was covered by

> "A weathered mantle at least 2 feet thick supporting a heavy brush and tree growth..."

LATTMAN (1958) also reviewed the growing confusion in the nomenclature of linear features seen on air photographs, and tried to create order with the two following definitions:-

> "A photogeologic fracture trace (or simply fracture trace).
>
> A photogeologic fracture trace is a natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tonal alignments, visible primarily on aerial photographs, and expressed continuously

> for less than one mile. Only natural linear features not obviously related to outcrop pattern of tilted beds, lineation and foliation, and stratigraphic contacts are classified as fracture traces. Included in this term are joints mapped on aerial photographs where bare rock is observed.
>
> Photogeologic lineament (or simply lineament).
>
> A photogeologic lineament is a natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tonal alignments, visible primarily on aerial photographs or mosaics, and expressed continuously for many miles. The restrictions placed on the term "fracture trace" as regards origin apply equally to the term "lineament".

The first definition is unsatisfactory in that it tends to put a name implying a specific form of genetic origin to features that may be caused by a variety of different causes. To a certain extent the same criticism is applicable to the second definition for the length chosen (1 mile) for the division between lineament and fracture trace is based on the experience that the longer features tend to be the surface expression of deep and regional causes.

Lattman goes on to suggest the ways to map "fracture traces" and "lineaments", but his paper discusses means of collecting linear features from air photographs in an objective manner to permit statistical study on a regional basis. He does not discuss the significance of the appearance of individual linear features in detail.

In the following year MOLLARD (1959) confines the "fracture trace" definition more satisfactorily to:-

> "Any rectilinear to gently curvilinear trend on the natural landscape that bears the distinctive earmarks of sub-surface structural control. The term applies whether the bedrock surface is exposed or masked, but only to situations where there is manifest evidence of structural control".

This definition, of course, is again constructed for the purpose of regional investigations.

KUPSCH and WILD (1958) carried out an investigation in Saskatchewan of linear features appearing on air photographs and came to the conclusion that they

> "occur in two sets parallel with known faults and some appear to coincide with faults at the surface. They are therefore regarded as lineaments, which are the surface expressions of faults".

HENDERSON (1960) described a study of "air-photo lineaments" that was carried out as a regional statistical study. The only fieldwork was for a geological reconnaissance mapping programme finished before the lineament study started. Henderson also seemed to be of the opinion that most of these features are due to fractures or faults, but he also described a closer parallel series due to foliation in the bedrock and physico-chemical variations within gneiss. He stated the belief that the density, or frequency of the "lineaments" increases where there is a thinning of the soil.

LATTMAN and MATZKE (1961) attempted to assess the "Geological Significance of Fracture Traces" mainly by collating previous literature, and remarked that most workers "have considered that fracture traces are the surface expression of joints or zones of joint concentration. No investigator has been able to demonstrate this hypothesis conclusively. In most areas a cross section of a fracture trace cannot be found, owing chiefly to the absence of bedrock exposure at the critical locality. But in the Powder River Basin of Wyoming, a mapped fracture trace passes across a vertical sandstone cliff. Here a joint concentration can be seen to underlie the fracture trace".

In view of the fact that the title of this paper implies a content closely related to the subject of this Thesis, the Summary is given here in full:-

"The study of fracture traces is only beginning, and meaningful data are sparse and widely scattered. Later work may well contravene some of the generalizations suggested herein; the results summarized below are very tentative:

1. Fracture traces, which probably represent zones of joint (and small fault) concentration, are parallel to the trend of major joint sets in areas of flat to gently dipping rocks but are not parallel to the joint sets in areas of steep (greater than about 5 degrees) dip.

2. Within a small area fracture trace orientations are not the same on rock types that are markedly different. No significant differences in orientation are found on similar lithologic types within a small area.

3. Steeply dipping faults may bound areas of different fracture-trace orientations. The orientations are, however, relatively constant within blocks bounded by such faults. One low-angle fault studied did not separate areas of different fracture-trace orientation.

4. In folded rocks the fracture-trace orientations are not affected by local folds but do maintain a constant angular relationship to the regional structural trend".

Significantly in the last paragraph of the paper they state:-

> "The greatest need at the present is for detailed information on the origin of fracture traces and possible significance of different types of fracture traces".

The obvious paucity of evidence was in fact one of the main reasons for undertaking the work reported in this Thesis, and was commenced some time before the author saw this paper by Lattman and Matzke.

BROWN (1961) carried out a "Comparison of joints, faults and airphoto linears", but the joints were sampled statistically at field stations that were not chosen for coincidence with air photo features. He stated that

> "As a general rule, surface traces of faults in the semi-arid country of north-central Texas are accurately depicted by airphoto linears".

He also came to the following conclusions which

> "....may be wholly or partly applicable to other regions.
>
> 1. The distribution and orientation of airphoto linears and structural features on the ground do not everywhere agree.
>
> 2. Faults are accurately depicted as linears on the aerial photographs.
>
> 3. One or more sets of a joint system may be reflected by linears, but this relation is not consistent".

HAMAN (1961) in the course of describing a regional "Lineament Analysis on Aerial Photographs" briefly discusses lineaments in the three different categories of "topographic relief lineaments", "vegetal lineaments" and "soil-tonal lineaments", but does not appear to employ these distinctions separately afterwards. He also reviews the nomenclature and selects the terms micro-lineament (0.1 to 2 miles in length) and macro-fracture (over 2 miles in length) in a series of studies of the <u>patterns</u> of linear features in a selected area. It is interesting to note that he quotes a statement by MOLLARD (1957) and confirms that

> "To a large extent the patterns formed are quite independent of topography as well as the age, composition and depth of surface materials in which they are expressed".

In a study of the Tuscan Formation in part of North Carolina, BURNETT (1963) reached the following conclusions:-

> "The fracture traces were found to be the surface expression of swarms of near vertical fractures, each of which has a very small displacement. These fractures are parallel to gentle folds, both monoclinal and anticlinal-synclinal, and the fractures are thought to have originated by structural adjustment of the Tuscan Formation during this folding. The fracture traces are conspicuous on aerial photographs because the fractures have diverted the normal flow of ground-water which has increased the growth of vegetation along their surface extent. The fractures are related to mineral springs and natural gas seeps, and may have provided these fluids with access channels to the surface. The fracture traces are significant, beyond their relationship to the flow of groundwater, because they reflect the presence of known folding in the western zone and may predict the presence of as yet unrecognized folding in the eastern zone."

TRAINER and ELLISON (1963) compared samples of joint directions and "fracture traces" and commented on a recurring feature in the literature of this type of study in that some prominent joint directions are reflected by parallel groups of fracture traces, but other apparently important groups are not.

A possible reason for this was observed by VOÛTE (1964) who reported an example where tension joints which tended to be open, showed up better on air photographs than similarly covered shear joints which were closed in his area of study in Nigeria.

BOYER and MCQUEEN (1964) made a "Comparison of Mapped Rock Fractures and Airphoto Linear Features" and defined the latter as "relatively straight alignments of small-scale features that may be of natural origin, visible on aerial photographs and mosaics". Those observed ranged "from about 1/4 mile to 4 miles in length, although most are less than 1 mile long". Again the faults and joints were recorded separately, but when compared there appeared to be a close relationship between the fault and joint directions and the "airphoto linear features".

HAMAN (1964) revised his former lineament analysis and took into consideration the possibility of glacial features producing a directional bias. He also expressed the opinion that the situation where a large fault divides two rock types of differing properties can be revealed by a strong linear feature dividing areas of differing fracture patterns. This publication also reviews previous work on some possible causes of rock fractures.

LATTMAN and PARIZEK (1964) found that water wells drilled on fracture traces in a dolomitic area "showed values from ten to one hundred times as great as yields of wells drilled in zones between fracture traces", and found evidence that "fracture traces reflect nearly vertical zones of fracture concentration".

A year later, BELCHER and SCHEPIS (1965) indicated an application of the mapping of "lineaments" in areas of relatively young sediments by showing that they can reveal failure patterns that outline hidden structures, such as domes, during the consolidation of the superimposed materials.

SETZER (1966) reported a water prospecting programme similar to that carried out by Lattman and Parizek two years before. In his study "fault/fracture traces" were detected in the presence of 100 metres of unconsolidated sediments, but he also reported that "fault/fracture systems are not apparent, as a rule, in alluvial plains".

None of the names defined or in established use seem to cover adequately the features dealt with in the rest of this Thesis. The names are either based on an assumption of the cause of the feature, or on the premise that there is a relationship between length and cause. To avoid this dilemma, the name "Lineation" will be used, for the linear features concerned come within the definition of "lineation" made by CLOOS (1946). This will have the advantage of brevity as the name will be constantly repeated, and in this particular work the more restricted sense of lineation later used by some structural geologists will not be involved. In other situations where ambiguity might occur, the writer would prefer the additional qualification of "airphoto lineation".

3. OUTLINE OF THE INVESTIGATION

What seems to be missing from past investigations is a basic study of the causes of individual lineations. In areas where the rock is bare there is often adequate information on the photograph to be able to judge the cause, and this has probably led to the ignoring of the need to study individual lineations in the field. But where the bedrock is covered by a veneer of superficial deposit, the cause of individual lineations is usually far from certain, and it was decided that a study should be made of such lineations with the hope that sufficient information would be obtained to provide a better basis for interpreting their cause.

The first problem was to secure a means of sampling and field testing so that a satisfactory cause could be allocated to each lineation. The major problem here was the field determination of the cause of the lineation. Methods employing geophysics tend to leave ambiguities, and drilling and digging can be expensive both in terms of time and money, and have to be extensive if they are to avoid any doubtful answers. The choice of lineations terminating at ordinary exposures would tend to confine the investigation to samples that were in areas of thin cover only, and also where the cover was changing its nature. It was decided that the best approach would be to choose features that terminated at cliff edges where there was an opportunity to examine the vertical profile of the superficial deposit and bedrock at the terminating point of the lineation. The most extensive cliff exposure that would appear suitable for this work was considered to be the coast line, and an initial study was made to select lengths of coastline in England and Wales where there was sufficient active erosion to keep the cliff face reasonably clear of material, and where the cliff was composed of both bedrock and an overlying superficial deposit. The choice of coastal sections was also reduced by the need to eliminate those areas where the amount of human activity would have tended to interfere unduly with the evidence required. This did not exclude areas being farmed, but eliminated coastal sections where there was constructional activity or an undue amount of building. This unfortunately reduced considerably the amount of work done over younger and softer rocks.

Other factors reduced the representation in the sampling of the very old rocks for these were inclined to be bare or too thinly covered with superficial deposits to present a continuously obscured rock surface. This was primarily owing to the effects of their recent glaciation and slowness in developing superficial cover.

Within these limitations, an attempt was made to select areas that would give a reasonably wide selection of rock types, structures and superficial deposits. In the latter case, greatest emphasis was laid on the study of transported deposits, as from past experience the writer anticipated that residual deposits would show a reasonable proportion of bedrock geology, and such soils should tend to produce more readily interpretable information in respect of sub-surface geology than is the evidence in areas of transported deposits. Inevitably, the latter tended to be glacial deposits, and although areas of alluvium were investigated, in no case was there a satisfactory bedrock exposure below alluvium.

The areas chosen are shown on the map included as Figure A. Some aspects of the geological character of the areas is shown by the following distribution of some of the field characteristics of the lineations.

Fig.A. Areas investigated are coloured red.

TABLE 1. Geographical distribution by counties

(All figures are percentages)

	Pembrokeshire	Anglesey	Northumberland	Durham	Yorkshire	Sussex	Dorset
All lineation causes	13	27	9	9	21	13	9
Sedimentary Rocks	15	18	8	11	24	15	8
Metamorphic Rocks	-	100	-	-	-	-	-
Igneous Rocks	-	-	100	-	-	-	-
Caenozoic	-	-	-	-	-	25	75
Mesozoic	-	-	-	12	45	27	16
Palaeozoic	32	35	23	10	-	-	-
Proterozoic	-	100	-	-	-	-	-
Glaciated	16	34	11	12	26	-	-
Not glaciated	-	-	-	-	-	59	41

It will be seen that any references later in the text to metamorphic rocks (and incidentally areas of Pre-cambrian and also intense folding) refer to areas of Anglesey. All the samples of igneous rocks are confined to the Durham coast. The younger rocks are confined to the south coast, and the Mesozoic to the north-east and south coasts. Palaeozoic rocks were only met in Anglesey, Pembrokeshire, Northumberland and Durham. Sussex and Dorset were the only two counties in which there were not glacial deposits.

The following table is a brief summary of the geological distribution of the lineations caused by the process of selection of areas.

TABLE 2. Distribution of Lineations Sample

a) Rock type	
Sedimentary	91%
Metamorphic	7%
Igneous	2%
b) Soil History	
Residual	36%
Transported (including Glacial)	39%
Contacts of above	25%
c) Photographic appearance	
Landforms	25%
Tonal lineations	29%
Texture/pattern lineations	9%
Vegetal lineations	5%
Drainage lineations	18%
Combined forms	9%
Others	5%
d) Land type	
Arable	28%
Grazing	45%
Moor or waste	13%
Moor/farmland boundary	7%
Heath	2%
Wooded	1%
Residential	3%
Sport or parkland	1%
e) Lineation cause	
Soil boundaries	19%
Soil landforms (e.g. drumlins)	2%
Landslide phenomena	8%
Structural	29%
Lithological boundaries	8%
"Rock" landforms (e.g. dyke ridges)	4%
Artificial	13%
Unresolved	17%

The rest of the investigation fell into three main phases:-

1. A detailed study of the air photographs of the coastal areas during which the lineations were marked, numbered, and their characteristics recorded.
2. A field investigation of each lineation.
3. An analysis of all the data collected in an attempt to correlate field and photo information.

The results of these three phases are dealt with in the following sections of the Thesis.

4. THE COLLECTION OF DATA

4.1. The Collection of data from air photographs

Sheets of Astrafoil were attached to the top of alternate photographs of runs of air photographs covering coastal areas. These were then examined stereoscopically with the aid of a mirror stereoscope. Most of the work was done with a normal setting but a number of the photographs were 'split-twins', and for some aspects of the work these had to be tilted slightly to rectify the image. Each obvious lineation terminating at the coastal cliff was marked in red and given a serial number, and two classes of information were recorded for each:-

a) basic information concerning the nature and type of the photograph;

and

b) information that could be interpreted from the photograph concerning the appearance of the lineation, and its setting and environment.

For each lineation the following information concerning the air photograph was recorded:-

a) The photographic contract number or RAF sortie number, according to which was applicable, and the serial number of the photograph within that unit.

b) The time of day and the month in which the photograph was taken.

c) The nominal photographic scale.

d) The focal length of the lens used.

e) An assessment of the quality of the photograph.

The following features were measured on the air photographs:-

a) The length of the lineation.

b) The azimuth of the lineation, i.e. its bearing relative to True North.

c) The azimuth of the coast at the end of the lineation.

d) The azimuth of the direction of slope of the ground surface traversed by the lineation. The amount and type of slope were estimated visually. In the early part of the investigation the direction and degree of slope were measured in the field, but it was found that it was often difficult to generalise for the whole length of the lineation and a better overall view of the situation was obtained from an examination of the photograph. The surface slope was classified according to whether it was steep, medium, gentle or horizontal. These degrees of slope were combined with a qualitative description according to the type of slope i.e. flat, undulating, convex, concave. Mixed terrain which could not be classified directionally or by type was usually classified as 'chaotic'. Areas of sand dunes and terminal moraines often merited this description.

e) The curvilinearity of the lineation. This was a measure of the radius of curvature of the sharpest part of any curve that occurred in the lineation.

f) The amount of superficial deposit cover. This was originally intended as a measure of the amount of soil and bare rock proportions for each lineation, but the measure became redundant in the early stages of the operation as it was fairly easy to confine the lineation choice to those sections of the coast where the bedrock was completely covered with superficial deposits.

In addition to the foregoing, a series of qualitative characteristics visible on the photographs were classified. These fell into the following categories:-

a) Lineation type, i.e. the appearance of the lineation on the photograph.

b) The spatial form of the lineation.

c) The shape.

d) The family relationship to neighbouring lineations.

As the qualitative descriptions tended to be subjective, they will be dealt with at slightly greater length.

The "lineation type" was the classification based on the most prominent characteristic in the appearance of lineation. The characteristics mainly concerned appear to have been shapes, changes of tone, pattern and vegetation, and some boundaries of land use classes. The list was kept flexible and a new name was added as a new type of lineation was encountered. This procedure, which was common to all classification based on qualitative characteristics, resulted in a collection of names that appear to lack coherence and structural relationships in the sequence in which they are given in Appendix I. But this was considered a minor defect and was remedied where necessary by re-classification done automatically by the computer prior to printing out some of the tables. Thus the "lineation types" were re-grouped to form "lineation classes" and these derived classes are also given in Appendix I. By this means the total of 48 lineation types were re-grouped to form 6 lineation classes for such purposes as reducing the size of some of the larger matrices for the computer, and producing larger sample groups in order to test certain ideas about interpretation possibilities.

The spatial form was a characteristic of the lineation derived from an attempt to ascribe its cause or presence to the intersection of a surface with the ground surface. Thus where the ground was undulating it was sometimes possible to attribute the cause of the lineation to the intersection of a steep or vertical plane with the ground surface when examining the stereoscopic model. The evidence for detecting such relationships was often very tenuous and decreased rapidly according to the flatness of the ground surface. In approximately one third of the cases the spatial form had to be listed as indeterminate, and in a further fifth of the cases this characteristic could be resolved no further than being a straight line on a flat surface. The eleven classes are listed in Appendix I.

A set of typical lineation shapes was established as the work proceeded and this is illustrated in Appendix II. The shapes used were also re-grouped on certain occasions by means of the computer to form the more limited and broader classes of :- rectilinear, curvilinear and composite.

4.2. The Collection of Data in the Field

The photographs, complete with overlays and the tracings of the lineation, were taken into the field, and the coast examined where the lineations had been marked on the photographs. When accessible the site of the lineation was examined both from the top of the cliff and also from beach level.

Whilst at the cliff top, a sample was taken of the superficial deposit at representative sites so that a mechanical analysis could be made of the material overlying the bedrock.

The thickness of the superficial deposit was recorded at the time the cliff top was investigated. This was measured when it was less than 10 feet approximately in depth and fairly consistent in thickness, but greater thicknesses were estimated by considering the ratio of the thickness to the total height of the cliff. It was considered that any precise measurement in these circumstances was hardly worth while as the thickness visible at the end of the lineation at the cliff face was hardly likely to be representative of the thickness of the superficial deposit along the whole length of the lineation.

Whilst in the field the following items were measured:-

a) The direction and amount of dip of the strata in the case of bedded deposits.

b) The bearing of the horizontal surface intersection of the five most important bedrock joints. These were normally taken as the five most common directions amongst the longer joints visible, and where possible this was measured on wave-cut platforms rather than along the short joint surfaces visible in the cliff face. In some circumstances these were more readily extracted from good-quality aerial photographs.

Other items of information collected in the field were:-

a) the name of the bedrock.

b) the tectonic state of the bedrock.

c) the stability class of the cliff.

d) the geological cause of the lineation.

e) the nature of the land use.

In the areas sampled the bedrock was usually uncomplicated and easy to name, but in cases of doubt the name given by the Geological Survey was used.

The bedrock tectonic state was a class of descriptions adopted to record the nature of the degree of folding, faulting or jointing of the bedrock. They were recorded in case some of these aspects governed the occurrence and nature of the lineations, and the list of names used is given in Appendix I.

Cliff-stability was a group of class names designed to describe the tendency or otherwise of the cliff to collapse under the varying influences of erosion and gravity; in other words, landslide and other associated phenomena as distinct from normal bedrock structural geology. The list of names used is also recorded in Appendix I.

The geological cause of the lineation also had to be attributed in the field, and in view of the widely separated field work both in terms of time and place, the list of names again tended to grow haphazardly with possible slight overlaps. The list is given in Appendix I, and also a set of derived names designed to reduce the total number of names into a smaller series (known as 'Lineation Group'). It must be mentioned here that the decision to include separate names for 'active' faults came far too late in the programme of field investigations to be representative. This would seem to be a subject for a future separate investigation.

A careful note was made in the field of all contacts between different superficial deposits, lithological and stratigraphic contacts in the bedrock, and faults, which, whilst unambiguously present on the ground, had failed to show up obviously on the air photographs. The same data was recorded for these features as for a normal lineation, and on returning to the laboratory the photographs were reexamined to see if any evidence could be found of these features after their presence had been established in the field. Those that were found on this second examination were classified as "indistinct" and were included in a separate block of case numbers from 8,000 to 8,999. Those for which there was no obvious evidence on the air photographs were classified as "invisible" and were numbered from 9,000 to 9,999. This procedure was adopted to have at the end of the investigation some means of testing the adequacy of the air photographs in detecting the types of geological features mentioned. For this purpose, lineations selected prior to fieldwork were classified as "clear", and the clarity of a group was tested by comparing the proportions of "clear", "indistinct" and "invisible" lineations.

4.3. The collection of data from previous work.

The publications and maps of the Geological Survey of the United Kingdom were a major source of information and played a particularly important role in the investigation during the period when the coastlines to be examined in the field had to be selected. The work of the Survey was accepted without reservations for the purposes of determining the rock age and stratigraphic settings, and saved considerable time where the stratigraphic boundaries did not coincide with lithological changes. All other aspects of the Survey's work were checked in the field, and in view of the adequate exposures along the coastal cliffs, there was seldom scope for disagreement at the cliff face; but inland extrapolations were sometimes rejected.

The work of the Soil Survey was also accepted without reservations as the investigator felt that he was inadequately qualified to determine the location of pedological boundaries.

One other item of information concerning the lineation's environment was taken from the work of previous field geologists, namely the direction of the last glacial movement, where applicable. Two major sources of information were used in this case - Charlesworth's "Quaternary Era" together with some of the sources mentioned in its bibliography, and the records of the Geological Survey.

4.4. Non-geological influences affecting the data collected

4.4.1. Photographic influences

There are a number of photographic factors likely to affect the ability to detect linear features on air photographs, but only a few can be tentatively examined in the present investigation as the limited funds available precluded the commissioning of special photography, or of any controlled development and processing experiments. The air photographs used were all purchased from sets of photographs taken previously for other purposes, mainly by the RAF, and only a limited amount of information on their production was available. The photographs were all 'black and white' and all are believed to have been taken on panchromatic type film. In the following discussion the influence of scale will be considered, and also the time of photography will be considered in the section on environmental influences (4.4.2.2). Under the circumstances, the other factors such as the processing, exposure, type of lens, paper, camera, climatic conditions, etc., have had to be considered in terms of their combined influence under the heading 'quality'.

4.4.1.1. The influence of the scale of the photographs

The photographs were grouped into large scale and medium scale groups and the influence of scale on clarity studied. Scales larger than 1:15,000 were considered as large scales, and those between 1:15,000 and 1:45,000, medium scales. The results are given in the following tables for significant bedrock and soil boundary causes.

TABLE 3. The Relationship of Scale and Detectability

1. Significant Bedrock Data

Clarity	Large Scale	Medium Scale
Clear	84%	77%
Indistinct	10%	14%
Invisible	6%	9%
No. of cases	286	100

2. Soil Boundaries

Clarity	Large Scale	Medium Scale
Clear	90%	90%
Indistinct	7%	3%
Invisible	2%	7%
No. of cases	122	86

From these figures it appears that there is a reduction of clarity with smaller scale, but it is felt that the difference would have been less if the average standard of the quality of the photographs had been higher. The results also showed a substantial reduction in the less important soil features causing lineations in the smaller scale group.

The average minimum radius of curvature of the lineations is 1416 feet for the large scale, and 3180 feet for medium scale photographs. A contribution to this change may be the smaller proportion of minor soil features being recorded at the smaller scale, for, as will be seen later, lineations generated in the soils tend to have a greater percentage of curvilinear forms than those due to bedrock causes.

There is a relationship between the nominal scale of the air photographs and the average length of lineations detected. This is shown by the graph in Fig. B.

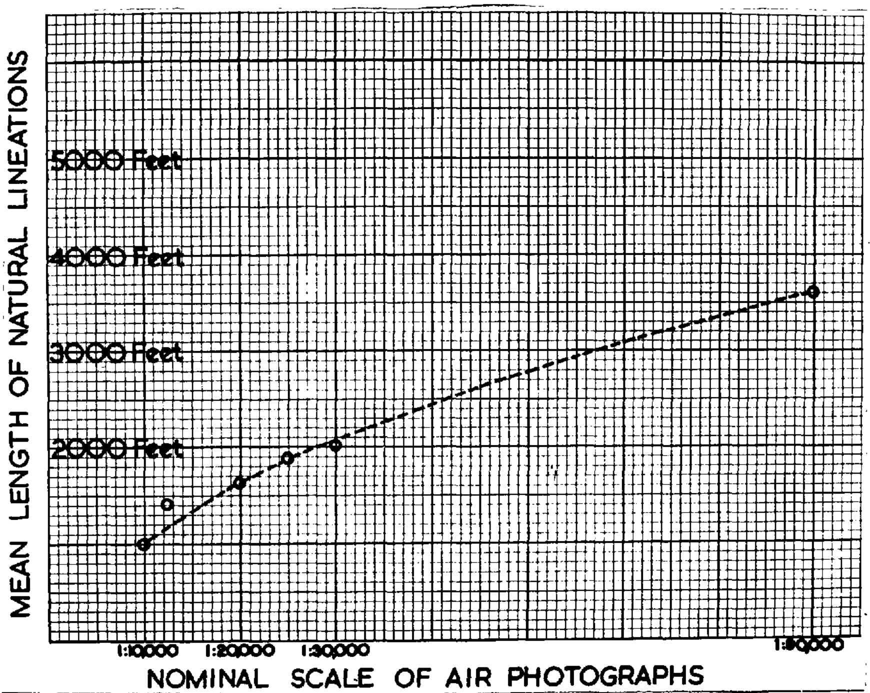


Fig. B. The relationship between the nominal scale of photographs, and the average length of lineations detected.

There are probably at least two factors involved in this increase in average **length** with decreasing scale. As the scale decreases a greater area of ground is observed on the photographs, and where a long feature, such as a lithological contact, might show as a series of short intermittent lineations at 1:10,000 scale, at smaller scales these lineations will tend to show as one long feature. Secondly, a reduction in the number of minor soil features observed at smaller scales is likely to increase the proportion of longer lineations in the sample.

4.4.1.2. The influence of the quality of photography

There does not seem to be a firm basis established for the classification of "quality" in respect of aerial photographs. For this study the photographs were examined and put into one of the five categories - excellent, good, average, poor, bad. This classification is highly subjective and was chosen to describe the clarity of the photographs from the photogeologist's point of view. It was in effect an amalgam of tonal contrasts, definition, presence of cloud or haze, the proportion of defects on the film or print, etc. It would be logical to believe that the clarity of the geological features would deteriorate with the quality of the photographs. Studies by workers in other fields have tended to confirm this in respect of targets that have set geometrical shapes and patterns.

The following tables were constructed to examine this aspect on the basis of the lineation study. There are two tables, one dealing with soil contacts and the other with bedrock features such as faults and bedrock contacts. There are only a limited number of samples available in which the photographs fall into category of excellent or bad, and the study is further unsatisfactory in that it refers mainly to a large number of different features rather than the same set of features photographed with five different qualities of photographs.

TABLE 4. The relationship between photo quality and the detectability of soil boundaries

Photo quality	Clarity of lineation			No. of cases
	Clear	Indistinct	Invisible	
Excellent	83%	0	17%	12
Good	92%	4%	3%	90
Average	91%	3%	6%	140
Poor	85%	9%	6%	53
Bad	80%	0%	20%	10

TABLE 5. The relationship between photo quality and the detectability of hidden faults and rock contacts

Photo quality	Clarity of lineation			No. of cases
	Clear	Indistinct	Invisible	
Excellent	77%	7%	15%	13
Good	81%	10%	9%	124
Average	68%	20%	12%	108
Poor	69%	15%	16%	55
Bad	100%	-	-	2

It will be seen that if one ignores the low sample columns of 'excellent' and 'bad', there is a general but small deterioration in the clarity of objects with a deterioration of quality of photographs. But the reduction in the ability to detect these features does not seem to be sufficiently serious to exclude the use of poor quality photographs for the type of terrain studied. It might be thought that the quality would be more important for smaller scales and an attempt has been made to examine this situation. Unfortunately the samples at the smallest scale covered (1:80,000), were so few as to preclude any sensible result from the small part of the scale spectrum. The remaining scales were grouped into two sections of"large" (1:10,000 and 1:12,000) and "medium", and the results of this grouping for those photo-quality classes which were well represented in the group of samples are given in the following tables:-

TABLE 6. The detectability of bedrock contacts and faults at various combinations of photo scale and quality

Scale	Photo Quality	Clarity of Lineation			No. of cases
		Clear	Indistinct	Invisible	
Large	Good	86%	9%	6%	141
"	Average	74%	17%	9%	94
"	Poor	96%	2%	2%	49
Medium	Good	89%	2%	9%	46
"	Average	85%	12%	2%	41
"	Poor	8%	62%	31%	13

TABLE 7. The detectability of soil contacts at various combinations of photo scale and quality

Scale	Photo Quality	Clarity of Lineation			No.of cases
		Clear	Indistinct	Invisible	
Large	Good	90%	10%	0	40
"	Average	87%	7%	5%	55
"	Poor	96%	4%	0	27
Medium	Good	89%	2%	9%	46
"	Average	92%	0	8%	12
"	Poor	50%	0	50%	6

These results are hardly conclusive, and although it may well be that taken in isolation the lineations on small scale photographs are more susceptible to quality changes, nevertheless with the smaller scale each feature is seen better in a larger environment, and as linear features tend to be interruptions of the existing pattern, then there is possibly a tendency for this to make them clearer at smaller scales, thus balancing out the other trend. Additionally, the features being sought are relatively large and simple in form, so that any local defective patch that may tend to obscure a feature on one photograph is compensated for by the image on the second photograph of the stereo pair.

4.4.1.3. Photographic Processes

It was not possible to obtain new photography for the investigation being reported and, as a consequence, all the photographs used were prints from sorties that had been made in the past, and for which there were no records of the details of processing. Obviously a series of controlled laboratory investigations and controlled photographic records would be required to examine the aspects of photographic processing that might affect the appearance of the lineations. To a certain extent, the previous section "quality" must be taken as the result of the combined influences of the photographic processes, but in this section it is proposed briefly to deal with the possible effects of using some different types of film that are available on the market at the moment.

It is probable that all the photography used was taken on panchromatic film, mostly, if not all, with a 'minus-blue' filter. This type of film has the merit of producing a picture in which the grey tones correspond approximately with the colour intensity observed by the eye. It has, however, an additional merit in that it is somewhat more sensitive to the presence of moisture than the human eye, and areas of damp ground occur as darker patches than one would normally expect.

Infrared film is even more dramatic in its recording of wet ground conditions but it has the effect of showing vegetation at a lighter tone than panchromatic. As moist ground is frequently a cause of stimulating vegetation, the resulting combination of the emphasised dark and light tones requires a careful comparison with panchromatic photographs before deciding whether it is an improvement.

Colour film produces the results most satisfying to the human eye, and has the additional advantage of storing information at three levels in the different layers of the film. FISCHER (1958) has investigated the possibilities of utilising this and showed that it is possible to obtain a clearer demarcation between different rock and soil types under certain conditions.

Distorted colour (camouflage film) is a variety of colour film in which the blue layer has been replaced by an infrared sensitive layer, and this film produces some interesting results which at first sight appear a little disconcerting. An interpreter using the film regularly would no doubt soon get used to the apparently weird colour distortion, and from the point of view of obtaining the best results it is important that colours and tones should be consistent rather than that they should be an exact replica of the original appearance of the ground.

Spectrozonal film is a variety of film for aerial photography produced in Russia (and not at present available in the West), which appears to have some interesting possibilities in that the result is a combined form of panchromatic and infrared layers, with the print dyed differentially to produce the best compromise between both films. It has proved extremely useful for forestry purposes and no doubt its peculiar characteristics would be helpful in photogeology, particularly where vegetal changes and damp ground are to be detected.

It would seem that all types of films have their own particular merits, and that what would be ideal to detect the maximum possible amount of data on linear features would be an aircraft equipped with more than one camera, so that several films could be used simultaneously. Much is to be gained by a comparison of the features recorded at different wave-lengths simultaneously. In particular, it would appear from the writer's experience that a combination of colour and a second camera with infrared film (with the visible part of the spectrum filtered out) would give the most satisfactory combination for only two films. There is obviously a need for careful and detailed investigations into the merits of different films for different geological purposes and this investigation would best be done under controlled conditions over an established area, where the ground conditions are intimately known and photographic sorties with several cameras can be made in different seasons and weather conditions. Until this is done, statements such as have been made in this section can only be regarded as opinions and hypotheses which have not been properly tested.

4.4.2. Environmental influences

Some of the non-geological influences having a more than local effect on lineations (and which are not considered elsewhere) will be discussed in this section. Human activities, which govern the degree of "naturalness" of the landscape, obviously need consideration.

Another factor is time, for the moment at which a photograph is taken determines a number of factors influencing the appearance of a lineation that vary with time.

Similarly, it is also conceivable that the general regional topography may have some influences that ought to be considered.

4.4.2.1. The influence of human activities

Man's use of the land usually has a dominating and dramatic influence on the appearance of an air photograph, and this in itself is likely to have a masking effect on the detection of natural features, apart from the results of his physical and chemical interference with the natural processes that create the appearance of the ground. It was assumed that it was not worth including built-up areas in the study, but in fact several contacts and faults were noted just outside the study areas which showed as changes of house top levels, or of the patterns formed by the buildings. The degree to which these effects showed depended on the extent to which construction was adapted to sites, or the sites modified to suit other requirements.

The following table was constructed by selecting a) significant soil, and B) significant bedrock features, and eliminating photographs that duplicated previous cover:-

TABLE 8. The influence of land use on the detectability of bedrock contacts and faults and soil contacts

Feature	Land category	Clarity of lineations			No. of cases
		Clear	Indistinct	Invisible	
Soil Contacts	Arable	77%	13%	11%	56
"	Pastoral	93%	5%	2%	93
"	Moorland	100%	-	-	29
"	Moorland/ farmland boundary	93%	4%	4%	27
Faults	Arable	48%	26%	26%	54
"	Pastoral	72%	5%	4%	81
"	Moorland	82%	12%	6%	17
"	Moorland/ farmland bdry.	100%	-	-	10
Rock Contacts	Arable	47%	17%	36%	36
"	Pastoral	80%	17%	2%	41
"	Moorland	75%	25%	-	16
"	Moorland/ farmland bdry.	92%	8%	-	26

These figures appear to show several trends, especially when it is considered that the first three columns consist of groups chosen to represent varying degrees of interference with the ground surface. Thus the prospects of detecting significant soil or bedrock features on the photographs varied inversely with the amount of agricultural interference with the superficial deposit. In all settings bedrock features were slightly less likely to be seen than soil contacts, but, in spite of this and the previous statement, useful information was detected even in land subjected to the intensive activity required by growing crops. This might well be the sort of situation in which a separate investigation would help to improve the results by comparing the clarity for different seasons with different crops.

Finally, it would appear that geological features often coincided with the boundary between moorland and farmland. This is hardly surprising when one considers the intimate relationship between ground conditions and agricultural yields.

4.4.2.2. <u>The influence of the time of the photography</u>

There are many ways in which the timing of a photographic sortie could influence the appearance of lineations on photographs. The majority of the time factors are probably linked to the sun's angular relationships with morphological features, varying weather conditions, seasonal growth of vegetation, and the rise and fall of the water table. The direct and indirect consequences of these influences do not seem to have been properly investigated. To obtain unequivocal evidence of the effect of the different variables, it is necessary to photograph carefully selected target areas sequentially at frequent intervals over several years with rigorous controls. Such evidence as is provided by a study of the data collected for this Thesis can only be regarded as a hint of what might be the real truth.

An attempt was made to establish the influence of the horizontal angle between the sun's rays and the lineations by comparing the proportion of clear and indistinct features within each 10 degree sector. The calculations were separated into two blocks according to whether the lineations had a morphological nature or not, as it was thought any superior detectability caused by shadows would be better detected in the former. No trend emerged, and the only thing learned from the exercise was that morphological lineations had an overall tendency to be more distinct (at all angles) than other features associated with tone, vegetation and pattern/texture characteristics.

A similar test was made on the influence of the sun's elevation by comparing the clarity of lineations for consecutive 2 hour periods throughout the day. The photographs were confined to a limited range of from 09.00 hours to 16.00 hours, and within these limits little significant variation appeared, apart from a slightly decreased clarity in the first 2 hour period. In fact the earlier and later parts of the day with no representative photographs in the sample probably would be interesting to investigate as the long shadows caused by a low sun might be better in revealing some types of morphological features.

The accompanying table gives the results of a comparison of the clarity of lineations in different seasons, subdivided into separate tables for faults, rock contacts and soil contacts.

It will be seen that in each subdivision the best results have been obtained in autumn, although a regrettably low number of samples was obtained for this season. Spring, winter and summer followed in that order, but with less distinctive regularity. It is interesting to

TABLE 9. The relationship between Season and the clarity of lineations

Season	Clarity of lineation			No.of cases
	Clear	Indistinct	Invisible	
A. Faults				
Spring	87%	7%	7%	60
Summer	64%	19%	17%	101
Autumn	100%	0	0	9
Winter	88%	13%	0	8
B. Rock Contacts				
Spring	85%	10%	5%	73
Summer	44%	32%	24%	41
Autumn	100%	0	0	8
Winter	57%	22%	22%	60
C. Soil Contacts				
Spring	95%	0	5%	144
Summer	91%	7%	2%	98
Autumn	100%	0	0	1
Winter	89%	6%	6%	35

note that the two best seasons are those in which there are the greatest changes in vegetation in the United Kingdom.

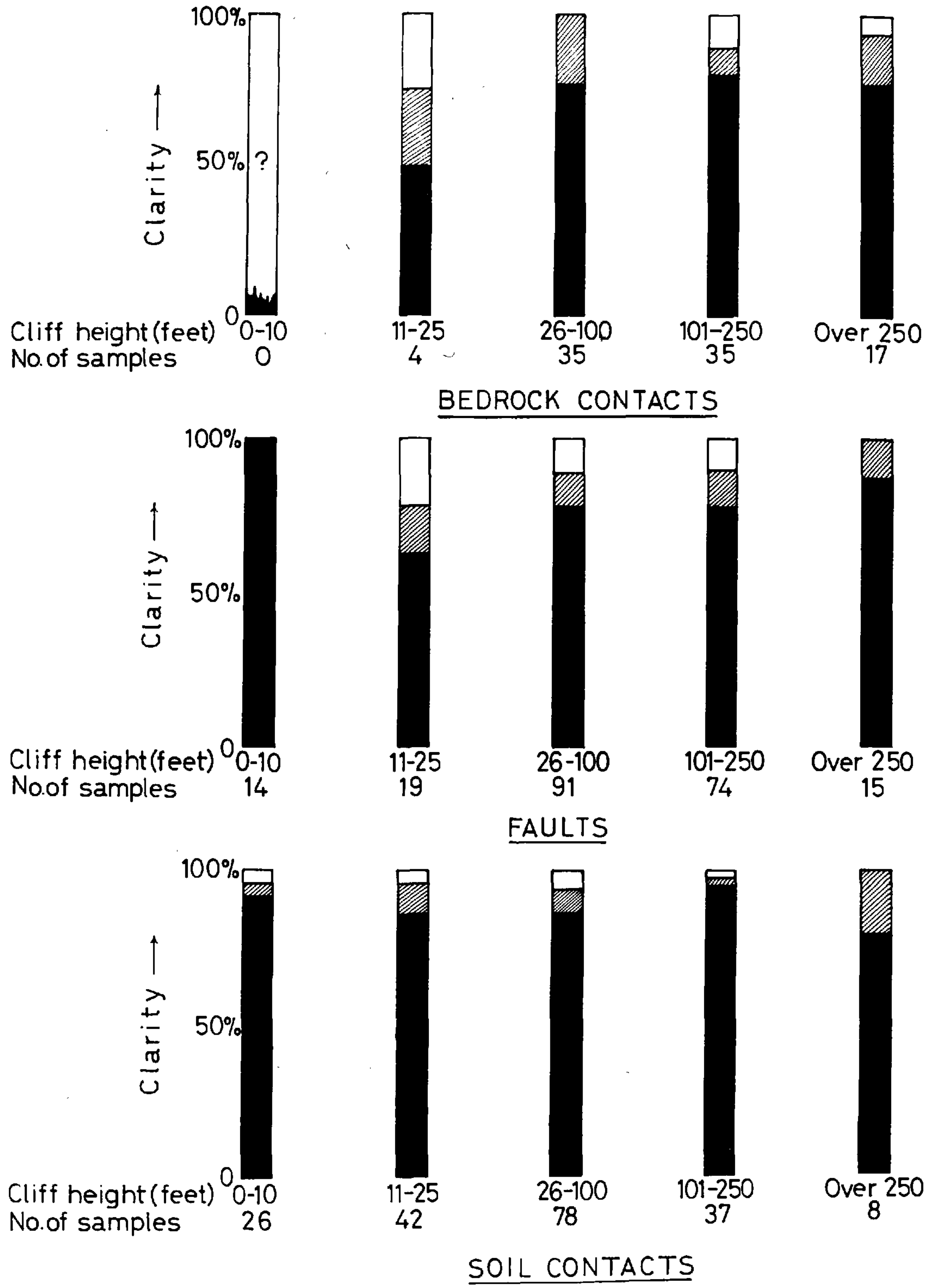
4.4.2.3. Effect of topography

After some years of photogeological work in varying terrains, the writer has gained the impression that more evidence is presented by the photographs in those regions where the regional topographic variation is greatest. This may be due to a different set of factors being dominant in altering the maturer type of landscape compared with those which mould and change ground where a young landscape is being more actively eroded. It was decided to test the validity of this hypothesis against the data collected during this investigation, but without unduly extending the scope of the investigation only two aspects of topography could be examined. These were the influence of dissection, and of the ground slope in the vicinity of the lineation.

4.4.2.3.1. The influence of the amount of regional dissection

There is no established system of classification of dissection known to the writer, but it would seem likely that the amount of erosional activity will often be related to the height of the cliff measured at the coast. This data has been used to construct the histogram shown in Figure 'C', which relates the clarity of the geological features according to various blocks of cliff height. In respect of bedrock features (rock contacts and faults) it will be seen that there

Fig.C THE RELATIONSHIP BETWEEN DETECTABILITY AND CLIFF HEIGHT



is a gradual increase in the amount of information with the increase of height of the cliff, with an important exception of the very smallest group of cliffs i.e. those under 10 feet high. This exception may be due to the requirement that all cliffs should have a portion of rock and soil visible, and hence wherever a cliff is only ten feet high the bedrock must be well within ten feet of the surface - thus often within easy reach of a stream bed which may then reflect the underlying rock forms.

The soil lineations on the other hand, show little trend with the change of cliff height. It may well be that the detection of soil contacts is improved by the amount of dissection, but additionally, the maturer land forms may help to offset this, for they have provided a stable condition in which the ecological assemblies on different soil types can stabilise, and also drainage systems can develop to their optimum according to the permeability and other features of the soil.

It would be interesting to make a study of an inland area, and compare the amount of information forthcoming from the photographs, according to the stream-bed gradients or to the slopes of the sides of the valley, both of which can in general be related to the rate of erosion. There is a further indication of the degree of dissection in the data collected in the slope of the ground surface at the coast, although this is probably a much less satisfactory measure of the dissection than the cliff height. This is dealt with in the next sub-section.

4.4.2.3.2. The influence of the ground surface slope

The slope of the ground surface was recorded in a semi-quantitative manner which consisted of a series of classifications based on a combination of the amount of slope and the general shape of the slope. This was done directly from the air photographs as it was found difficult in many instances to record a satisfactory angle for a slope in an earlier attempt to make a quantitative measure of this feature in the field. The measurement was simple for flat slopes, but frequently slopes were broken and chaotic, making it difficult to resolve an average which would be a fair measure of the overall slope. Figure D is a histogram of a regrouping of these slope classifications within a broad range of steep slope, medium slope, gentle slope, and horizontal ground. It will be seen that there is an overall increase in the clarity of significant bedrock and significant soil features with the increase of slope. This may again reflect the influence of the rate of erosion, but there is also a possible suspicion that the gravity component may have a somewhat higher influence on steeper ground in general.

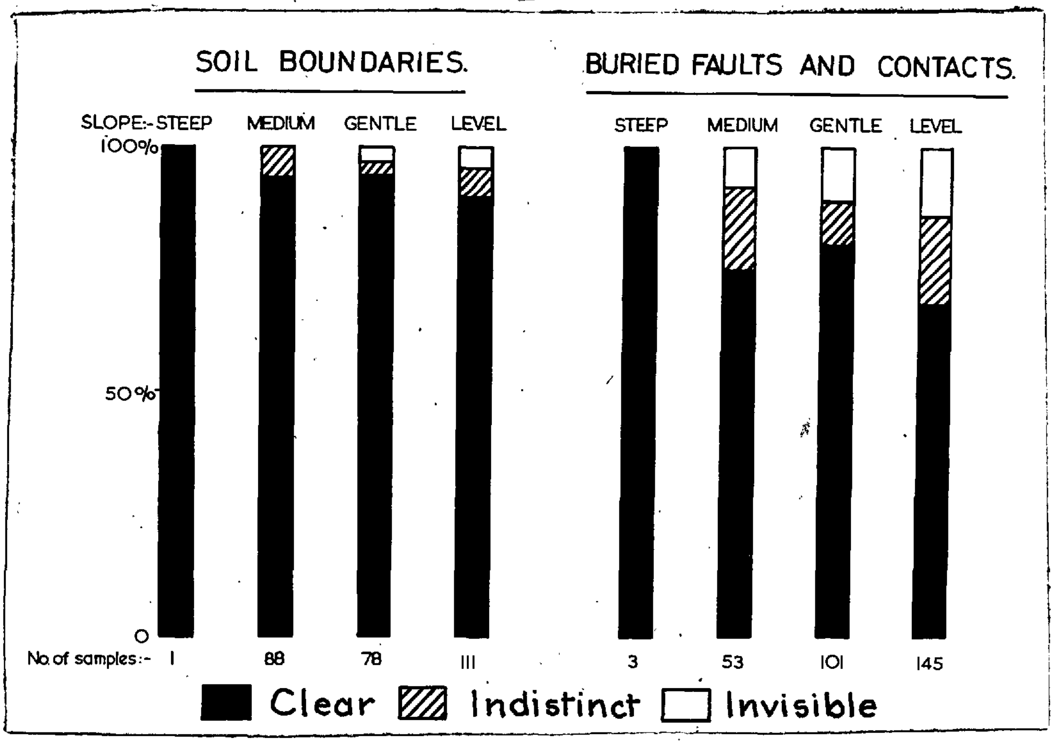


Fig. D. The relationship between the slope of the ground surface and the detectability of geological features

The proportion of lineations due to less significant bedrock features did not appear to show any distinct trend in relation to the slope, but the less significant soil features reduced with decreasing slope. This may indicate that the results of using air photographs to map soil conditions would be less confused by minor events in those landscapes where there is a mature topography.

A separate study of the nature of the slope surface also showed that there was a drop of clarity on uneven surfaces, compared with flat or gently curved surfaces, both for significant bedrock and significant soil features. The uneven surfaces were associated with such features as landslips and terminal moraines, and the nature of these would tend to account for the greater obscurement of other features, particularly bedrock features.

The following tables give the difference in clarity for each interval of 10° between the bearing of the lineation and the direction of slope of the land surface, bedrock features (faults and lithological contacts) and soil boundaries.

TABLE 10. The influence of the direction of the surface slope on the detectability of significant soil and bedrock data

Features	Angle between lineation and slope direction	Clarity of lineations			No. of cases
		Clear	Indistinct	Invisible	
Soil Boundaries	0 -10°	93%	7%	-	27
	11°-20°	94%	-	6%	18
	21°-30°	71%	6%	24%	17
	31°-40°	73%	13%	13%	15
	41°-50°	75%	20%	5%	20
	51°-60°	96%	4%	-	26
	61°-70°	90%	5%	5%	21
	71°-80°	100%	-	-	25
	81°-90°	95%	5%	-	41
Bedrock Data	0 -10°	89%	10%	2%	62
	11°-20°	74%	16%	11%	38
	21°-30°	79%	15%	6%	47
	31°-40°	82%	15%	3%	33
	41°-50°	76%	6%	18%	33
	51°-60°	79%	15%	6%	34
	61°-70°	96%	-	4%	23
	71°-80°	84%	11%	5%	37
	81°-90°	84%	9%	11%	85

It will be seen from the tables that in each case that there is an indication that the features tend to show more clearly when the lineation is either in the direction of slope of the land surface or over about 70° to this direction, i.e. within about 30° or so of a horizontal line along the surface slope. The difference is not marked, but shows roughly the same pattern for each investigation.

There may be an indication here that gravity is playing a part in revealing the data, by providing a force which helps to break or move the superficial material at critical points where the cause of the lineation is based. Thus a hidden fault in the bedrock which may be liable to slight movement, has assistance in propagating its fracture upwards into the superficial deposit owing to the fact that the materials concerned are already in a state in which any slight initiation of a break will be more readily extended upwards. This also might apply to a tendency for different types of material to separate more freely along these directions, and soil types with different angles or repose may be adjusted by the gravity component more readily into their final stable positions of slope.

4.4.3. Observational failings

In this section some of the many possible causes of human error in the collection of the basic data for the investigation are discussed. There is in fact no aspect of the collection of raw data that is foolproof, but some aspects seemed to be particularly hazardous.

During fieldwork there were many situations in which it was difficult to be certain of the exact coincidence of a lineation showing on an air photograph with a feature in the cliff face. For example, in East Sussex there were stretches of nearly vertical chalk cliffs hundreds of feet high with only a narrow strip of beach exposed briefly between tides. It was impossible to see the cliff top and the coast tended to appear featureless when seen from below, so that it was difficult to match with the vertical air photographs. In these circumstances, there would be a natural tendency to marry together an isolated major joint with a lineation that was, as far as could be seen, in the right vicinity, even if exact coincidence could not be established. Fortunately, this area, which was amongst the worst, turned out to be poorly provided with features of major importance.

There also may have been instances where several features coincided with the position of a lineation and the most obvious one was given undue credit.

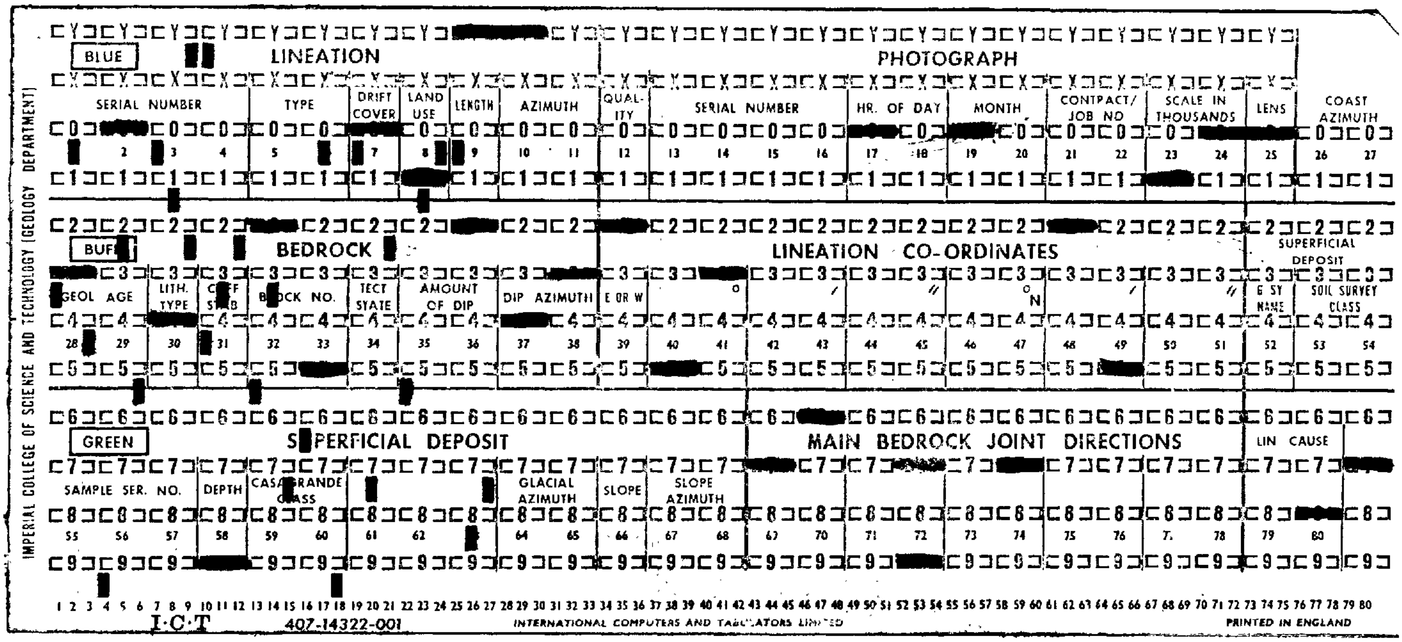
A further possibility exists that some geological features coinciding with the end of a lineation do not coincide when extended under the superficial cover inland, and have thus been wrongly attributed as the cause. It is doubted if this has often happened with significant geological features as the inland extension has normally been supported by a wider mapping programme by the Geological Survey.

Whilst working on the air photographs there was always the possibility of human error in making the various measurements and classifications, but in one aspect there was a bias that was difficult to avoid. In determining the spatial form it was impossible for the observer to avoid making an interpretation intuitively, and so be aware of what the spatial form ought to be before actually deciding from its appearance. Thus a lineation might be recognised immediately as a bedding trace in an area of gently dipping thinly covered sediments. Such a feature should appear as the intersection of a gently dipping flat surface with the ground surface, and it was virtually impossible to avoid looking first for this effect rather than approach the classification of the appearance uninfluenced.

5. PROCESSING THE DATA

5.1. The Use of mark-sensing cards

The data which had already been classified were given code numbers so that they could be recorded on to punched cards. As far as possible the information was recorded on to cards at the moment it was obtained. This was done by using mark-sensing cards which can be marked with a graphite pencil and punched later by a special reproducer which senses the electrical conductivity of the graphite markings on the card. The box provided for the pencil mark occupies the normal width of three columns of the conventional 80 column punched cards and so only 27 columns per card are available. As a result each lineation had three separate cards to store the relevant information, and these cards were coloured blue, buff, and green respectively. A special plate was designed (as will be seen in the example) to cover the headings of the data recorded; but as the investigation proceeded it was obvious that there were some additional parameters that could be usefully measured, and as a result the headings shown on the card had to be modified. In particular, the coordinate reference was abandoned, and to recover the position of the lineation it will be necessary to refer back to the individual photographs recorded elsewhere on the card.



An example of the type of mark-sense card used in the investigation

5.2. The preparation of the punched cards

The data on the three mark-sense cards was transferred to the final 80 column cards used by the computer by means of a Reproducer whose control panel had been specially wired for the process.

It was decided to put all the data on one card in order to facilitate sorting and checking prior to using the computer, rather than have to employ the computer and use additional time to 'debug' carded data, and also to enable rapid follow-up work to be done by means of a 'mechanical' sorter. This decision to a certain extent warped the design of the format so that it did not fit perfectly with the requirement of the programming language, and additional modifications of the programme had to be made, but it was felt that it was worth while in order to have the greater flexibility of a single card for each lineation. An example of a completed card and its contents is given in Appendix IV.

5.3. The M.V.C. Mark 5 Programme

M.V.C. Mark 5 is a programming language primarily designed for the analysis of survey data such as from sociological surveys, market surveys, etc. Its use is at present confined to the I.C.T. Atlas computer.

In addition to the cards containing the basic data, a specification describing this data had to be punched on seven hole tape, and a programme also punched on seven hole tape which stated the requirements and the form in which the data was to be printed out. M.V.C. Mark 5 had a number of facilities that made it particularly useful for the study, in addition to the normal statistical facilities, such as the ability to produce matrices, percentages, chi squares, correlation factors, means and standard deviations. It incorporates trigonometrical functions which permitted a

Fig.E. AN EXAMPLE OF MVC MARK V OUTPUT

INFLUENCE OF SLOPE R 44232

ALL SCALES RUN AND(NOT ARTIFICIAL)

LARGE

	SIG BEDROCK	LESSIG BEDROCK	SIG SOIL	LESSIG SOIL	IRRELEVANT	NO EVIDENCE	TOTAL
TOTAL	[illegible]	1	1	7	1	0	16
	100	100	100	100	100	-	[illegible]
CLEAR	[illegible]	1	1	7	1	0	16
	10	100	100	100	100	-	[illegible]
INDISTINCT	[illegible]	0	0	0	0	0	0
	[illegible]	0	0	0	0	-	0
INVISIBLE	[illegible]	0	0	0	0	0	0
		0	0	0	0	-	0

MEDIUM

	SIG BEDROC	LESSIG REDROCK	SIG SOIL	LESSIG SOIL	IRRELEVANT	NO EVIDENCE	TOTAL
TOTAL	7	27	37	45	14	1	198
	10	100	100	100	100	100	[illegible]
CLEAR	6[illegible]	26	36	45	14	1	188
	8	96	97	100	100	100	95
INDISTINCT		0	1	0	0	0	8
		0	3	0	0	0	4
INVISIBLE	1	1	0	0	0	0	2
	1	4	0	0	0	0	1

GENTLE

	SIG BEDROCK	LESSIG BEDROCK	SIG SOIL	LESSIG SOIL	IRRELEVANT	NO EVIDENCE	TOTAL
TOTAL	131	42	68	18	31	21	311
	100	100	100	100	100	100	100
CLEAR	110	40	63	18	31	19	281
	84	95	93	100	100	90	90
INDISTINCT	11	0	2	0	0	0	13
	8	0	3	0	0	0	4
INVISIBLE	10	2	3	0	0	2	17
	8	5	4	0	0	10	5

HORIZNTAL

	SIG BEDROCK	LESSIG BEDROCK	SIG SOIL	LESSIG SOIL	IRRELEVANT	NO EVIDENCE	TOTAL
TOTAL	181	45	104	32	65	44	471
	100	100	100	100	100	100	100
CLEAR	141	44	88	32	64	44	413
	78	98	85	100	98	100	88
INDISTINCT	25	0	10	0	0	0	35
	14	0	10	0	0	0	7
INVISIBLE	15	1	6	0	1	0	23
	8	2	6	0	2	0	5

certain useful exploitation of the data which will be described later. Also in the course of the specification it is possible to define new classifications and groupings of basic data. For example, new groupings of rock types could be made based on the competency or permeability, merely by exploiting the original lithology. Thus a lineation occurring over a shale would be automatically selected if a special study was called for based on impermeable sub-surface rocks, or incompetent sub-surface rocks. A full description of M.V.C. Mark 5 has been given by COLIN (1964).

6. CORRELATION OF FIELD AND PHOTO-INTERPRETATION DATA

6.1. The fundamental characteristics of air photo-lineations

6.1.1. General discussion

The next few pages deal with the various fundamental characteristics of the lineations seen in superficial deposits. By fundamental characteristics is meant those features which contribute to a description or classification of the lineations and which may be obtained by an examination or measurement of the air photographs alone. They include the relationship of the lineation to other features and are being dealt with in this manner as they are common to all lineations seen on air photographs, and may lead to a better understanding of the geological causes. The features fall under the following main headings : shape, length, azimuth, spatial form, frequency, and family relationship. Most of these have been described already in the section on the collection of data from air photographs (4.1.2.) and the following discussion is mainly concerned with the relationship between these features and the underlying geological cause. It is likely that all the visible characteristics of a lineation will have to be considered carefully before the underlying cause is interpreted. One obvious fact noticed during the investigation, and not catered for in the statistics, is that the prominence of a lineation often bears little relationship to the geological importance of its cause. An open joint can be seen as a dark dramatic line in a superficial dep)it alongside an insignificant faint trace of a major fault.

6.1.2. The shape

The shape is one of the first characteristics of a lineation to be noticed. It will be considered here firstly in the two broad groups of predominantly rectilinear or curvilinear lineations, and then the cause of combined, more complex shapes will be dealt with individually.

6.1.2.1. Rectilinear lineations

The following is a list of the main causes of the 709 lineations that could be classed as straight or nearly straight.

TABLE 11. The causes of rectilinear lineations

Faults	17%
Soil type boundaries	16%
Joints	12%
Landslide features	11%
Bedding traces	8%
Consequent gullys	8%
Lithological contacts	6%
Gullys etc. in bedrock surface	4%
Glacial effects	1%
Obscured or inexplicable	16%

These causes are understandable in respect of those features that are planar and would tend to intersect a flat surface as a straight line, or if steeply dipping would register as a straight line at any type of ground surface. Faults, joints, bedding traces and commonly lithological contacts, would come into this category. The scouring effect of material moving under the influence of gravity would also tend to form rectilinear marks as in the case of landslides, consequent gullys, glacial phenomena, and many of the bedrock surface features.

The reasons for the high placing in the list of lineations caused by soil boundaries is less obvious. Of the total of 271 soil boundaries causing lineations, 43% were classified as rectilinear. There is probably more than one cause contributing to this figure, and some of the possibilities are:-

1. A straight soil boundary controlled by a bedrock structural feature during formation.
2. A straight boundary between two residual soils formed above a straight lithological contact.
3. Superficial material being deposited against a flat sloping surface of rock or an older deposit.
4. Glacial erosion or deposition of one soil in what is virtually a straight line at the scale concerned.

Air photographs are found to show many rectilinear lineations caused by human activity, and those which were obviously so were not included in the investigation. Many were included which were considered likely to have been caused by man, but for which there was an element of doubt and thus it was considered should not be ignored for this particular study. In the final figures something of the order of 1 in 8 of the lineations turned out to be caused by human activity, commonly buried drains and old or indistinct pathways. It is the extreme straightness of man's constructional activity that tends to indicate the cause readily to an experienced interpreter, especially when the lineation can be associated with other features.

6.1.2.2. Curvilinear lineations

The lineations considered in this section include those that curve irregularly, as well as simple curves. A total of 440 was recorded and the general distribution of the causes is given in the following table.

TABLE 12. The causes of curvilinear lineations

Soil type boundaries	31%
Lithological contacts	13%
Faults	13%
Bedding traces	9%
Landslide features	7%
Consequent gullys	7%
Bedrock surface gullys etc.	5%
Joints	5%
Glacial effects	3%
Obscured or inexplicable	5%

Soil boundaries appear to be indisputably the most common cause of curvilinear lineations. The next three most important causes - lithological contacts, faults and bedding traces - also are prominent causes of rectilinear lineations. Faults can of course curve in their own right, but it is possible that the influence of topography in areas of low dip have a bearing on the presence of the other two features in this class.

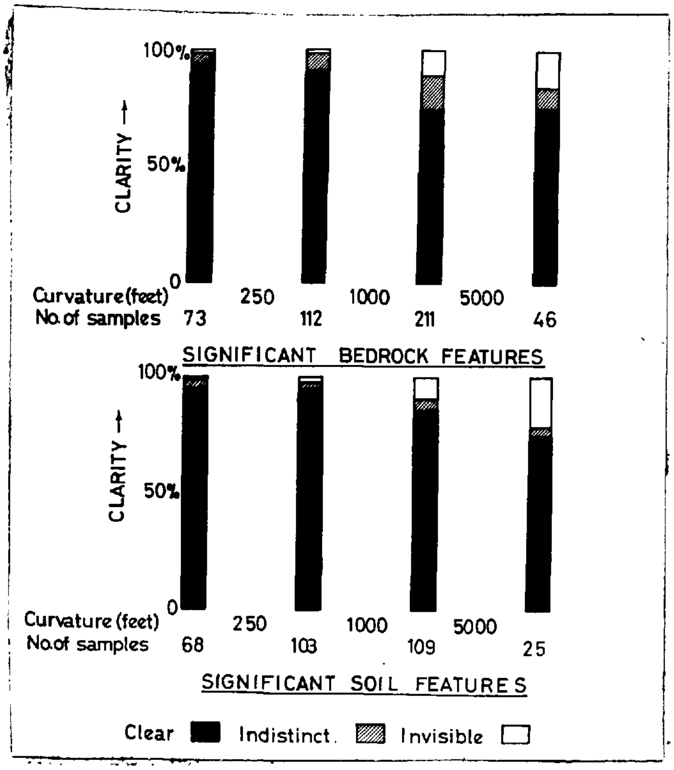


Fig. F. The relationship between the curvature and the detectability of lineations

There appears to be a relationship between the amount of curvature of a lineation and its clarity. An examination of the results of a test in Fig. F show a trend to increased clarity coinciding with increased curvature. This is a little surprising for it might be thought that straight lines appear more obvious to an observer in a natural environment, whereas these results show the lineations to be less obvious as the lines get straighter. The result is probably not entirely a function of the observer's reaction to curved or straight lines. All undetected features were searched for again on the photographs after being found in the field, and yet the proportion of "indistinct" features tends to remain constant throughout the curvature range. The fact that soil boundaries are a dominant cause of curvilinear features may provide the explanation for this phenomena, for these are amongst the clearest geological phenomena on air photos and will give a bias in the results in favour of curvilinear lineations.

6.1.2.3. Combined Shapes

Those lineations with shapes that were combinations of straight lengths, or compound curves will be dealt with in this section. The bulk of the lineations in practice turned out to be almost straight or of simple curving shape, and although a list of 37 different types of shape were compiled during the course of the study, only 5 of the combined forms exceeded 10 cases in number, and the others will be mainly ignored as being inadequately represented to provide reliable information.

Soil boundaries were the cause of 79% of the curves that had a complex irregular shape. The remaining causes were mainly structural features and lithological boundaries or bedding traces, probably often in areas of low dip.

Curved lines changing tangentially into straight lines were the next most frequent combined shape. This shape is typical of thinly covered bedding traces showing at the corners of a valley in an area of shallow dip. Such a bed often forms part of the "shoulders" of the valley where it opens out into a plain or another valley running across its path. Such features together with structural causes formed 52% of the causes, others being soil boundaries (19%), landslip features (10%), bedrock topographic features (10%), lithological boundaries (5%) and minor soil phenomena (5%).

The next commonest group in this section were curves that had a fairly small radius of curvature at one end and gradually tended to flatten towards the other without ultimately reaching as far as being straight. Of these 67% were associated with structural forms (probably mainly bedding traces), 17% with soil boundaries and a further 17% with lithological boundaries.

Two gentle curves joined to approximate an obtuse angle had very similar causes, with the addition of a small proportion of landslip events.

The last form worth noting was that of a simple curve with sinuous curving variations which were not of sufficient size to impair the overall impression of one dominant curve. This proved to be mainly caused by bedding traces, with a very small proportion of soil boundary and landslip phenomena.

6.1.2.4. Cross-sectional shapes

The investigation was of forms of very small width, and no attempt was made to study the cross-sectional shape of lineations. In many cases this would have been an observable feature if photographs had also been available at a considerably larger scale, or if sufficient detail on the photograph justified a very high magnification.

It is possible that an investigation into this characteristic might bring forth useful information for interpreting the cause of lineations. Mention should be made at this point of the work of Purdue University (MANUAL OF PHOTOGRAPHIC INTERPRETATION (1960)), where a helpful relationship has been established between the cross-sectional shape of gullys and the nature of the soil.

6.1.3. The Length

The length of lineations in feet were averaged for the main groups of causes with the following results.

TABLE 13. The average lengths of lineations due to different causes

Group cause	Average length (feet)
Soil boundaries	1540
Soil forms	1590
Landslide phenomena	900
Structural phenomena	1180
Lithological boundaries	1590
Bedrock topography	1550

The main item of note is that landslide induced lineations tended to be shorter than others. A table was prepared to show the distribution of the lineations in a series of length groups, according to the individual causes. The distribution pattern was remarkably consistent except for landslide lineations which are given with the overall distribution for comparison in the next table.

TABLE 14. Comparison of the lengths of lineations due to landslides with those of all lineations

Length of lineation in feet	Overall distribution	Landslide lineations
0 - 299	4%	14%
300 - 599	14%	35%
600 - 1099	30%	20%
1100 - 2499	41%	21%
2500 - 4999	11%	8%
Over 5000	1%	1%

With this exception, the length of lineations proved to be disappointing as a diagnostic feature. There was no significant variation in the length distribution for any of the rock or soil types that were adequately represented in the tables.

The variation of length with soil thickness was examined, and it was noticeable that there was an increased proportion of short lineations with a thin soil cover over bedrock.

There did not appear to be any appreciable change of length related to the cliff's height.

6.1.4. The azimuth

The azimuth was measured as the number of degrees between the line of the lineation and True North. It is a measurable characteristic for each lineation, but has little merit in its own right, being mainly a means of comparison with other directional features.

6.1.4.1. The bearing relative to other features

6.1.4.1.1. The coast

The angle between the lineation and the coast was calculated and the clarity of lineations examined when this angle was 1) less than 10 degrees, 2) between 10 and 80 degrees and 3) over 80 degrees. There did not appear to be any substantial difference involved, but there was a markedly smaller proportion of lineations in the range 0 to 10 degrees (i.e. nearly parallel to the coast) in respect of both soil and bedrock causes.

6.1.4.1.2. The slope of the land surface

This relationship has been discussed already in section 4.4.2.3.2.

6.1.4.1.3. The geological structure

The fieldwork was not extended to determining the overall geological structure in the various coastal sections sampled, but the local dip of bedded strata was recorded at each site. The lineations were divided into three classes with bearings of 0-10, 10-80, and 80-90 degrees from the dip direction. There was of course an obvious relationship between the latter block and lineations caused by bedding traces, metamorphic banding, and stratigraphic contacts.

The following tables show the relationship between the dip direction and the clarity of faults, lithological contacts and soil boundaries. In the case of the two former, there appears to be a superior clarity in the case of lineations that lie within 10 degrees of the dip or strike, compared with those between these two positions.

TABLE 15. The influence of the direction of dip on the detectability of faults, rock contacts and soil contacts

Cause	Bearing with dip	Clarity of lineation			No. of cases
		Clear	Indistinct	Invisible	
Faults	0 -10°	87%	2%	11%	115
"	11°-79°	76%	12%	12%	147
"	80°-90°	86%	10%	4%	21
Lith. Contacts	0 -10°	86%	14%	0	7
"	11°-79°	72%	21%	7%	72
"	80°-90°	94%	6%	0	17
Soil Boundaries	0 -10°	90%	10%	0	21
"	11°-79°	94%	5%	1%	155
"	80°-90°	100%	0	0	15

6.1.4.1.4. Regional lineation trends

The azimuths of all the natural lineations were totalled in 10 degree blocks, and the results shown in Fig. G. There seems to be a concentration in the north-east quadrant, and as this direction is normal to the dominating direction of the coastlines sampled there may be some bias involved. However, the same process was repeated for the 5 dominant joint directions recorded in the cliff face or on the foreshore with less likelihood of bias, and the results (shown below) reflect the same concentration. Only 8% of the total lineation causes were joints, so there is not an undue direct influence on the first by the second set of figures.

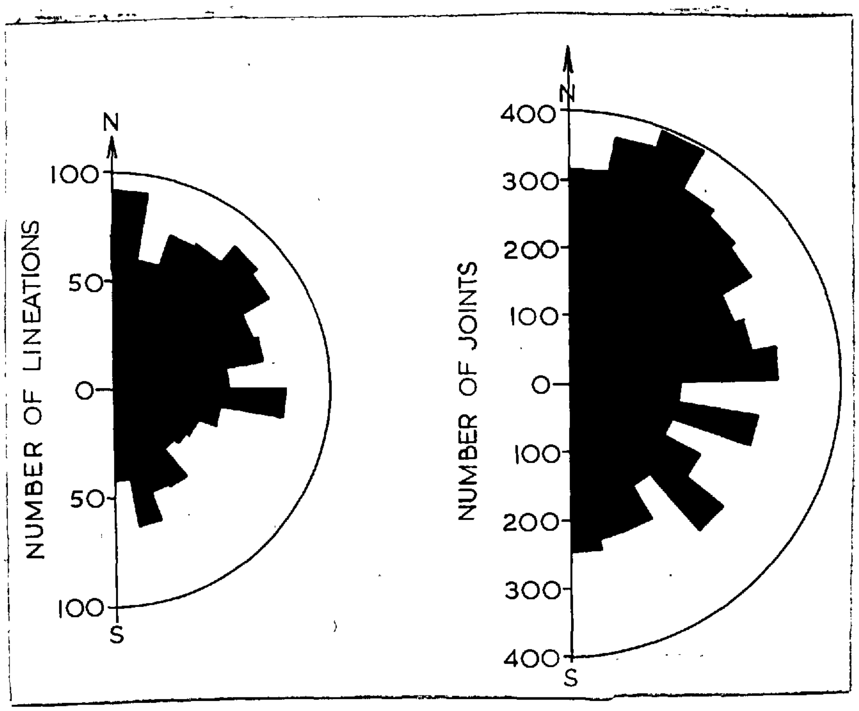


Fig. G. The angular distribution of (A) Lineation Azimuths and (B) Joint Azimuths

6.1.5. The Spatial Setting

The nature of the problems in determining the spatial form has been mentioned in section 4.1. A study was made of the connection between the nature of the surface slope and the spatial form classification. It was noted that the highest proportion of cases that had to be termed "Indeterminate" were obviously concentrated in areas where the surface slope was slight, or the ground was horizontal, and to a lesser extent this also applied to those lineations that could only be analysed as a straight line on a flat surface. These two classifications formed 53% of the total. The only other large group was formed by apparent steeply dipping flat surfaces (21%). The straight intersections that these make with the ground surface of any type makes them particularly easy to see on air photographs, although regularity and symmetry are probably as important as straightness, for the next highest class detected was steeply dipping curved surfaces (8%). The two latter frequencies are probably more closely related to the proportion of geological occurrences that are steeply dipping or vertical, rather than the clarity of the lineations concerned.

A comparison of the spatial form and amount of bedrock dip was also made. In this instance, the lowest proportion of "indeterminate" classifications applied for low dip or horizontal bedding. Soil boundaries appeared more difficult to classify in areas of low bedrock dip, and lithological contacts in areas of low and medium dip.

The greatest portion of undetermined spatial classifications were caused by faults (28%), closely followed by soil boundaries (26%). Lithological contacts (16%) and landslips (8%) came next. A somewhat similar set of figures was obtained for lineations that had to be classified as a straight line on a flat surface, but in this case landslides superceded lithological contacts.

The chief causes associated with the appearance of a steeply dipping plane were faults (33%), landslides (21%), bedding planes (14%), and joints (11%).

Medium or gently dipping flat surfaces tended to be bedding planes, lithological boundaries or landslide phenomena, the same causes, with the addition of soil boundaries, being associated with horizontal planes.

Steeply dipping curved surfaces represented faults (30%), soil boundaries (17%), landslides (13%), joints (11%) and bedding planes (10%). Only a small number of cases of gentler dipping curved surfaces were found, and these were predominantly soil boundaries.

A number of features appeared as roughly horizontal surfaces that tended to drape slightly over the land surface, i.e. the base of the feature appeared to be uneven and following the topography. Of these, 25% were soil boundaries, 25% glacial features, 20% landslides, and 20% lithological boundaries.

6.1.6. The frequency

The frequency of lineations is not obviously likely to give evidence to help interpret an individual lineation unless associated with direction as dealt with in the next section. But it may well have considerable use in interpreting areas. It was decided that it would be better to delay an investigation of the significance of frequency until a proper study could be made of an area, rather than of a linear feature such as a coastline with only short stretches of the various rock types, and with varying cliff heights possibly vitiating the results.

6.1.7. Family relationship

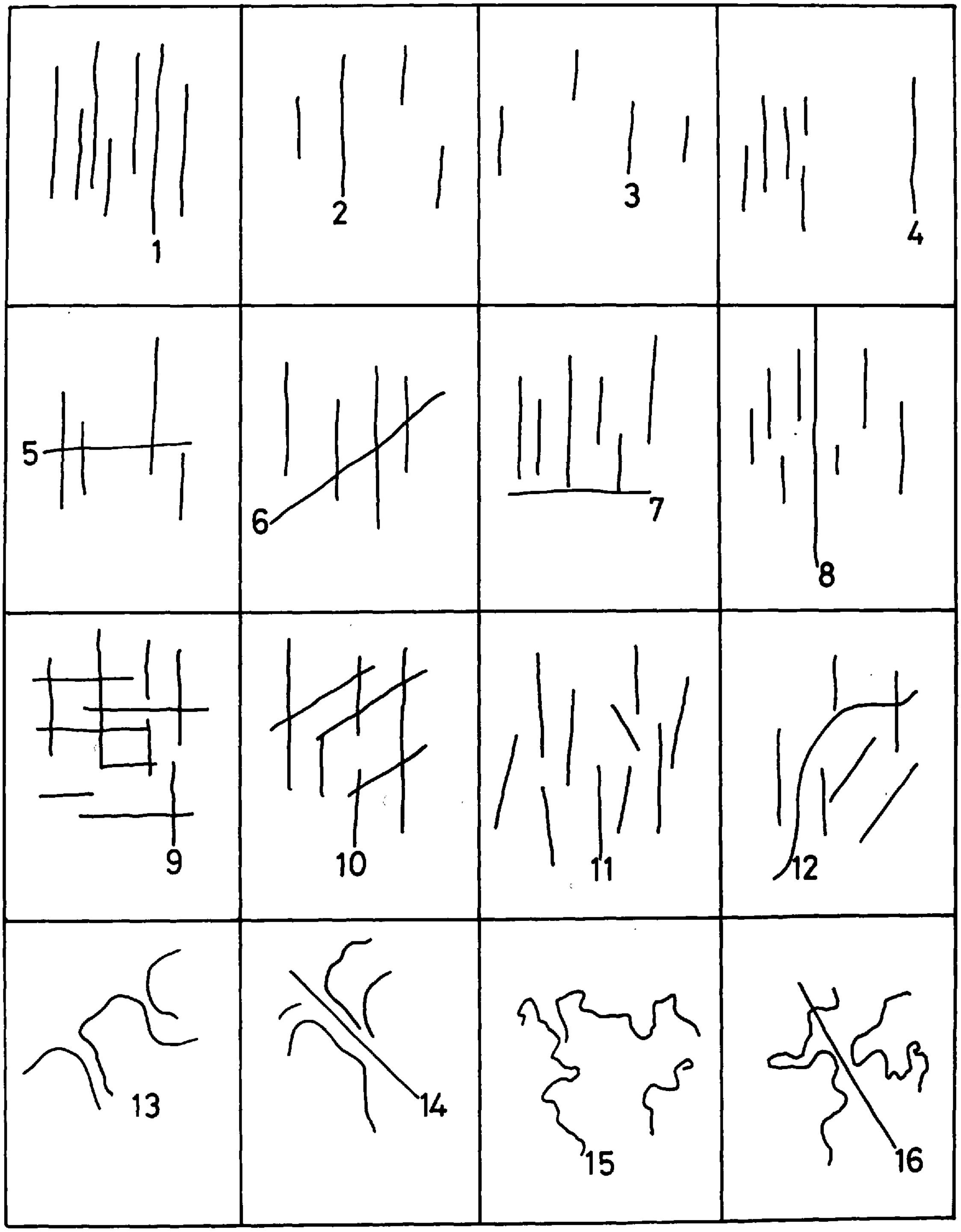
An attempt was made to see if there was any significance in the relationship between a lineation and its neighbours. The classification adopted was used to describe the lineation's connection with the others on the same photograph, but when it lay near the edge of a photograph the lineation pattern on the adjacent photograph was also taken into consideration.

The first step was to search for families of parallel lineations, which were subdivided into very close, close, and wide, according to whether the spacing between individuals was less than half, between a half and equal to, or greater than, the families' average length. (Fig.E,1,2,3).

Nearly half the typical, parallel, members of these groups turned out to have been caused by bedrock features, with a slightly higher proportion in the case of "wide" families. About a quarter were associated with soil boundaries, the rest being evenly distributed between minor bedrock and soil causes. There was surprisingly little difference of the causes between the spacing sub-divisions in the broad general analysis, but taken in local settings the spacing assumed greater importance. Thus in places where there were steeply dipping bedded rocks, very close parallel lineations usually represented bedding traces. HEPWORTH (1967) has used a family relationship such as this in the case of bedrock lineations to outline large areas of similar characteristics in East Africa.

A total of 19 lineations cutting across the parallel families at right angles was recorded. Fourteen were faults, two lithological contacts, and the remaining three were caused by landslides. (Fig.E,5).

Fig.II. LINEATION FAMILY RELATIONSHIPS



About two thirds of the 45 lineations cutting obliquely across the parallel families were associated with significant bedrock causes. All but one were faults. (Fig.H,6).

Some lineations were noted as being parallel to parallel groups, but being at the same time remote and not within the general group. One third of these were caused by significant bedrock events, the rest being either soil boundaries or minor bedrock features. (Fig.H,4).

Occasionally a single lineation would lie at the end of, or just outside, a parallel group in a position across the path of the normal members and in a manner terminating the group. Five out of seven of these were faults. (Fig.H,7).

Of the 60 members of parallel groups cutting across other parallel groups, 62% were caused by significant bedrock features (mainly faults), 12% less significant bedrock features, and 25% minor soil features. (Fig.H,9,10).

Occasionally a small area would be populated mainly by irregularly curving lineations. Three quarters of the sample of 17 were caused by bedrock features, chiefly bedding traces in incised areas of gently dipping or level strata. (Fig.H,15). The rest were boundaries of superficial deposits. Solitary straight lineations in such a setting were caused by faults (34%), other bedrock features (27%), soil boundaries (27%) and landslip phenomena (12%).(Fig.H,14). The converse, single curved features in an area dominated by straight lineations, were associated with a smaller ratio of faults (15%), and with bedding traces (22%), minor bedrock features (22%), soil boundaries (27%) and minor soil features (15%). (Fig.E,12).

When the cluster of curved lineations principally consisted of gentle regular curves, the causes were soil boundaries (44%), bedding traces and lithological boundaries (27%), faults (14%), and minor soil features. (Fig.E,13).

Four lineations dominated the local setting to the extent that they were at least twice as long as the next longest on the photograph. Three were faults, the fourth a soil boundary. (Fig.E,8).

6.2. The geological causes of different types of lineation

6.2.1. Causes of vegetal lineations

6.2.1.1. General discussion

In the MANUAL OF PHOTOGRAPHIC INTERPRETATION (1960), it is stated that "In California a survey of wildland area of fifty square miles showed that nearly eighty per cent of the significant soil boundaries corresponded with vegetation boundaries". Thus, linear soil contacts may be expected to be reflected as linear features on air photographs, as well as those lithological boundaries that influence the overlying soil.

During the course of time plant growth tends to settle down to a stable assemblage controlled by various environmental factors. Some, such as the mineral and water availability are directly related to the local geology, but there are others that can overshadow these in influence. For example, the writer has seen a valley side facing the sun in the Elburz Mountains where near desert conditions made it possible to count over 30 individual sandstone beds in a predominantly shale sequence. Three to five miles away, the same beds on a slope facing away from the sun into the moisture laden winds from the Caspian were covered with a thick growth of trees and shrubs; where these could be penetrated on foot, there were hardly any sandstone beds to be seen, as the weather conditions had stimulated the formation of a soil from the disintegrating shale. From this it will be seen that vegetal boundaries may be of only limited local use in some settings, and their sudden termination does not always mean that the geological setting has changed.

6.2.1.2. Dark lines of vegetation

Dark lines of vegetation are most commonly caused by stimulated or varied growth in a linear direction, and, when occurring naturally, they are mainly due to a local variation in the supply of water or mineral matter that is involved with the growth of the plants concerned. For example, increased plant growth giving a linear darker tone on an air photo has been observed along the length of a dyke containing apatite which presumably produced phosphates stimulating the plant growth. In arid areas, fractures in rocks which are normally dry, such as granite, will be the sites of moisture storage under certain conditions that will stimulate plant growth. Under such circumstances, the fracture pattern in the granite may be quite dramatically outlined on photographs taken from the air during the dry season. Lines of springs where an aquifer outcrops are often the loci of a series of small black linear features revealing the stimulated plant growth, which may be in the form of small plants or shrubs in an area normally bare of vegetation; or, in more temperate environments, the line of vegetation will be caused by the plants normally preferring swampy or waterlogged ground, and in such an environment the moisture tones in the soil would probably increase the dark appearance of the linear contact.

To a certain extent man may also cause dark lines of vegetation which emphasise geology when he allows hedges to grow in areas where it is convenient for him to leave a geological feature uncultivated, or exploited as a natural barrier. Examples are the exploitation of a natural barrier, such as a fault or a landslip scar, by placing a hedge on it, or allowing free growth on a dyke outcrop which has little agricultural potential.

Of the total of 13 cases of dark lines of vegetation investigated in the field, 46% were associated with landslip margins or scarps where local growth in an area that had been fenced caused a dark line of vegetation. Of the remaining cases, 31% coincided with a soil contact and may have been caused by variations in moisture content between the two soils. The remaining features (23%) coincided with the presence of joints and faults. Here again, water may have played a large part because in areas where the bedrock is normally dry or impermeable, a zone of fractured rock is usually a place for the accumulation of water and stimulated or varied plant growth.

6.2.1.3. Light lines of vegetation

Although this section was allocated to light coloured lines of vegetation on the aerial photographs, no such examples were encountered during the investigation. It is quite likely that these features occur; probably they are normally more readily resolved as changes of tone on the photo rather than the changes of tone of individual plant assemblages.

6.2.1.4. Linear interruptions in vegetation

This section covers situation in which the normal cover of trees or thick vegetation suffers an interruption in a linear manner. These can be misleadingly caused by paths and tracks of human beings and animals, but it seems that the most common geological cause is the presence of a natural fracture which has managed to exert an influence on the plant growth, even though the latter is confined to the superficial deposit. This can be caused in two broad ways - either by a physical interference with the roots of the plants concerned, which would imply a relatively recent movement in the vicinity of the lineation; or alternatively, by the change in the environment in which the plant lives that could have occurred during or subsequent to the formation of the bedrock. Examples of this may be the presence of a dyke containing inhibiting minerals to plant growth (e.g. copper sulphides, as seen in the "copper clearings" in the Copper Belt in Zambia), and the lack of growth in parts of East Africa, where quartz veins do not produce adequate soil for plants to become established.

During the field investigation associated with this Thesis, a total of eight linear interruptions in vegetation were investigated and of these a half were associated with the fracture of ground due to a landslip phenomenon. The remaining occurrences were associated with faults (3) and a joint. The fact that the landslips investigated were all fairly recent is a sufficient reason for their association with the break in the vegetation, but in the case of faults and joints it would seem more likely that the interruption in the vegetation must have been connected with some renewed movement along the old plane of weakness due to tidal or seismic influences from another source.

6.2.1.5. Vegetation boundaries

It is frequently possible to detect areas of different vegetation on air photographs and sometimes these boundaries are diffused and on other occasions they are clear cut. In the latter instance, the boundary between the two types of plant assemblages has been recorded as a lineation. Natural vegetation boundaries of this type are likely to be lines dividing different environments shown by selective plant growths. The most common causes detected during the investigation were changes of the rock type (36%) and changes in the type of superficial deposits (34%), which are to be expected as causes of vegetational changes in view of their influences on ground chemistry and the availability of moisture. Less common causes were faults (13%) and landslips (9%), which could have similar effects. Recent landslips would also destroy or remove vegetation in part or whole, and this would give the impression on the photograph of a different pattern of vegetation, and thus in some instances become recorded as a vegetal boundary.

A purely local coastal cause was the presence of old coast lines (6%), in which it is likely that the former brine covering of the soil has had a lasting influence on the plant ecology.

6.2.2. Causes of tonal lineations

6.2.2.1. General discussion

In normal photogeological interpretation it is frequently found that the photographic tone of a geological unit can vary across one photograph. For example, a ploughed field can appear almost white in tone when photographed with the sun reflecting from the side of the furrows polished by the share, and the same field photographed in the opposite direction on the next parallel run can be very dark in tone as the camera registers the rough broken sides of the furrows.

There are many parameters that affect the tones on a photo, most of which come broadly within the colour and reflectivity of the ground surface, and the influence of the lens-filter-emulsion combination. Even with completely bare rock and soil it is unlikely that any automatic recording of absolute tonal values would coincide with rock boundaries everywhere. It is relative tonal changes that are important, particularly where there is no change in lighting conditions across the tonal change.

6.2.2.2. Light tonal lines

This section deals with linear features of light tone between two areas of usually similar but darker tone.

The largest group of geological features causing this appearance on the photograph was the occurrence relatively near surface of bedding in sedimentary rocks and banding in metamorphic rocks, in areas of medium to steep dip where the soil cover was not very thick. The effect was produced by the differential erosion of the tilted beds causing ridging at the rock surface parallel to the strike, and this ridging would additionally tend to cause a different moisture content and sometimes soil thickness between the varying beds and bands. In the case of residual soils it is possible that soil colours contributed to the tonal changes where the rocks consisted of interbedded combinations of differing rock types. It is likely that dykes would also appear as light tonal lines, (and in fact the author has seen such examples elsewhere), but none occurred within the samples of the investigation.

Faults (23%) were also a common cause of light tonal lines and their influence was probably due to superior drainage conditions in the areas of the faults causing local sections of drier ground. This, of course, is the converse of the dark tonal line associated with faults where the fault would tend to form a more stagnant section of moisture, and not a route for free drainage. Joints (13%) and fractures due to landslips (13%) also probably caused light tonal lines for the same reason, but in the case of landslip fractures, the exposure of freshly broken ground would have the additional appearance of a light tonal line. Occasionally gullys in the bedrock surface (6%) also provided the means of drainage to give light tonal lines.

Soil boundaries (10%) were another cause of this lineation type, but the reason for the light tone in this instance was not so obvious in the field.

Where the sub-surface drainage appeared to be the main influence, the margins of the linear feature tended to be more diffused especially with thicker soil. But in cases of bedding, especially when the bedrock surface was thinly covered, the margins of the light tonal line tended to be sharper. This of course does not constitute an invariable rule, and particularly in those areas where soil colours contribute to the light tonal line, there are occasions where there is likely to be a lateral migration of soils, causing diffuse margins to the lineations on the photograph.

6.2.2.3. Dark tonal lines

These lineations are the opposite in appearance to those described in the last section and the largest proportion appear to be associated with various forms of fracture in the ground.

Faults (39%), joints (8%) and landslip fractures (4%) appeared to be the features falling mainly in this field. The lineations showing over such features often tend to be clear cut at the margins, and lineation number 3049 (~~Figure F~~ Appendix IV) is a good example of the appearance of such lineations, mainly in the section of it that lies away from the coast. The actual cause is probably due to the accumulation of moisture or of organic matter in the soil, as well as possible changes in plant growth due to the local availability of moisture. Similar causes would probably lie behind the appearance of glacial effects (8%) and dykes (3%) where these exist as depressed sections of ground.

Sedimentary bedding and metamorphic banding (13%) also registered in this manner and the appearance of a dark line is frequently sharp in these cases as it is emphasised by parallel bands of rock appearing as light tones. Dark tonal lines caused by bedding tend to be part of a group of parallel lines of alternating colour.

Soil boundaries (7%) also can cause dark tonal lines, and in this case there is probably some relationship with the change in ground water conditions along the line of the soil contacts.

6.2.2.4. Tonal boundaries

Tonal boundaries have been classed as a lineation when there is a fairly clear cut linear division between two areas of dissimilar tone, each area having a roughly uniform overall tone.

The largest group consisted of soil contacts (43%) and these of course have their variation in moisture, vegetation or colour recorded as tones on the photographs. Similar causes probably exist in the case of varied lithological contacts (14%) and probably a number of these were in fact in areas of residual soil, thus also reflecting a soil change.

Faults (15%) also coincided with tonal boundaries and in a number of these cases also coincided with lithological or soil contacts. Bedding traces (12%) seemed to cause this type of lineation in areas of low dip, particularly where extensive surfaces of individual beds were near the ground surface.

Landslide features (7%) probably registered as tonal boundaries where the disturbed vegetation and soil inside the landslip features tended to resolve themselves as a change of tone rather than of vegetation or pattern.

Joints (6%) also coincided with tonal boundaries. The exact geological relationship in this case seems to be rather baffling.

Consequent gullys (4%) showed as tonal boundaries when in fact there seems little reason for them to do so on a geological basis. However, it is possible that the change of slope direction on each side of the gully may produce areas of overall tonal difference when these slopes give a difference in the angle between the sun, each gully side and the camera.

6.2.3. Causes of pattern lineations

6.2.3.1. General discussion

The MANUAL OF PHOTOGRAPHIC INTERPRETATION (1960) defines pattern as : "the regular and characteristic placement of tones or textures".

There seems to be some confusion in the literature between pattern and texture, and it seems likely that the term texture is often used for fine patterns in which the components are difficult to discern, but give an overall impression of smoothness, roughness etc. In fact pattern itself seems dependent on scale and what appears to be a pattern on a photograph at one scale, when enlarged often resolves itself into a roughly regular assemblage of plant types, boulders, joint patterns and similar small scale features. For the purpose of this Thesis texture is being treated as being synonymous with pattern.

6.2.3.2. Pattern boundaries

Pattern boundaries are the lineations dividing two types of pattern or merely the boundary of a pattern against an incoherent group of features which do not resolve themselves into a pattern.

The main cause of patterns met on the investigation was the assemblage of vegetation into a distribution which was reflected in the appearance of the photographs locally as a pattern. It is interesting to note that in some 25% of the cases the pattern boundary coincided with a tonal boundary, which in turn was probably also controlled by the presence of vegetation or ground moisture influencing the vegetation.

The main geological features coinciding with the pattern boundaries were superficial deposit boundaries (44%), which is to be expected in view of their dominating influence on the local ecology. Similarly, the presence of a sub-surface lithological contact (14%) also probably represents a control of the environment exerted through the presence of a superficial deposit.

Surprisingly, faults (20%) also appeared to figure prominantly as a cause of the change of pattern and only about one in six of these coincided with a change in lithology or superficial deposit. It is possible that changes in sub-surface hydrology or the topography of the hidden bedrock caused by the faults may have had some influence.

Bedding of sedimentary rocks and banding in metasediments (9%) also had an influence on pattern boundaries, as did joints (5%), and it seems likely that these features all may have exerted their influence through changes in subsurface drainage or bedrock topography, particularly in areas of shallow superficial cover.

Landslides (5%) also showed up as pattern features, and these were mainly in the form of a physical disruption of the other pattern forming features, or due to the fact that some landslide areas form a rough chaotic pattern in their own right due to the broken and fragmented nature of the vegetation and soil within the area of earth movement.

6.2.3.3. Pattern disruptions

Pattern disruptions are linear breaks in the normal pattern, where the pattern still exists undisturbed each side of the disruption. It includes natural breaks in some man-made patterns such as the regular arrangements of crops.

From the definition, one would expect the main geological causes to be narrow features with no change of lithology or soil conditions each side of them, and it is not surprising that the dominant cause was the presence of a fault (60%). It is to be expected that other likely causes would be dykes and joints, but in fact these features did not figure in the small sample of pattern disruptions, which only totalled 12.

Two cases of superficial deposits contacts coincided with a pattern disruption, and a single example was found in each case of lithological contacts, consequent gullys, and the edge of a glacial feature.

6.2.4. Causes of lineations associated with landforms

6.2.4.1. General discussion

Most geologists versed in geomorphology find the interpretation of landforms on air photographs to be one of the easier aspects of photogeology, but in this section the word landform is used in the more restricted sense of linear features associated with changes in topography. Included with these are certain drainage characteristics such as local consequent gullys and abnormally straight sections of streams which in other sections of their course follow an irregular route.

For most of the features described it is desirable or essential to examine the photographs stereoscopically. The normal air base for most air photography produces a vertical exaggeration of the stereo model, so that the vertical scale is commonly 4 to 5 times as great as the horizontal scale. This exaggerates many landforms and gives the photo-interpreter a landscape which tends to be a caricature of what field geologists examine. Slopes are considerably steepened in appearance and what may appear to be a fairly steep bank in the field may appear on the airphotos as a vertical step in the ground; sharp long slopes may be exaggerated almost to the stage of being a cliff. The descriptions used in the headings of the following sections refer to the appearance of the landforms in the stereo model, and are not necessarily a correct description of what the form would appear to be on the ground. The exaggeration produces an important asset in interpretation by exaggerating small changes which would appear to be insignificant or even undetectable to a field geologist.

The most common forms are illustrated in Appendix III.

6.2.4.2. Gullys

Gullys are sharp linear breaks in the ground surface which have a linear trend. There is usually little alteration in the shape of the land surface each side of a gully and any substantial change of slope inwards to the gully would usually upgrade the gully into the classification of 'valley'. In practice most of the gullys were occupied by small streams, or appear to have been acting as a channel for a stream at some time in their history. Sometimes, however, the gullys were obviously disconnected with any orderly drainage system, and were merely the surface manifestation of a planar break in the superficial deposits. A total of 161 natural gullys is covered by the remarks in this section.

One of the more obvious causes of gullys that would be anticipated in a superficial deposit would be the presence of a line of weakness or fissuring in the material itself, propagated upwards from breaks in the bedrock. This may be the explanation of the apparent causes by faults (29%) and joints (15%), although the same geological features could make their presence felt by seepage in towards the fracture, or local subsidence where the fracture remains open.

Another source of fracture controlling gullys was the presence of earth movements (13%) but it is interesting to note that three quarters of these coincided with the margins of mudflows.

Pre-existing gullys in the bedrock (6%) independent of geological structure, was another cause of the presence of gullys; and in areas of steeply dipping sediments the less resistant layers of strata formed gullys along the strike and produced a small (1%) share of the causes. In fact this latter figure should have been much higher for in some areas, particularly in Pembrokeshire, steeply dipping beds showed up as groups of closely spaced parallel lineations when covered with only a thin soil, and to avoid overloading the statistics with repetitive information that would yield no further knowledge, only a few characteristic features were selected from these.

Consequent gullys (22%) produced a large portion of the sample and their nature was to a certain extent revealed on the photographs by their tendency to occur running straight down gentle slopes, and to be parallel to each other in long stretches of uniform boulder clay dipping gently towards the cliff. Lithological contacts (8%) also appeared to be the cause of gullys, but half of these also coincided with faults. In the cases of lithological contacts the changed conditions at rockhead presumably helped to produce a line of choice for stream drainage by the presence of a local depression or inwards seepage due to changed drainage conditions, or by soil or subsurface drainage barriers. Contacts of superficial deposits (6%) may have formed a cause of gullys due to the change in drainage conditions, or due to influences in their depositional history.

Glacial influences (2%) were probably also involved as a tendency was noted for small sections of gullys to be parallel to the direction of glaciation. A few gullys were also controlled by the edges of glacial depositional features.

An attempt was made to see if there could be any distinction between the causes of gullys lying solely in a superficial deposit and those which were likely to be in contact with the bedrock. During the classification of the gullys at the photo-interpretation stage, they were divided into three groups - shallow gullys appearing to lie completely in the superficial deposit, medium gullys appearing to be approximately the same depth as the superficial deposits and likely to be near or locally touching the bedrock, and thirdly, deep gullys which appear to be sufficiently incised to be in touch with the bedrock over most of their length. Unfortunately there were only 15 cases of 'deep' gullys, but they showed a considerable increase in rock joints as a control of the gully direction. The other factors did not significantly differ except that there was no example of landslide influences with this type of gully, possibly due to the thinness of the soils in most of the environments involved.

6.2.4.3. Cliffs

Only ten cliffs occurred in the investigation as linear features, and normally most of these would have been rated as steep banks when viewed from the ground.

Seven of the total were caused by the scarp of rotational landslips. Two were associated with superficial deposits boundaries, and this sort of feature can be expected when caused by the vertical exaggeration of the edge of such features as moraines, or areas of blown sand.

The remaining cliff coincided with a lithological contact.

6.2.4.4. Steps

Steps are abrupt changes in roughly flat horizontal or gently sloping surfaces, smaller in amplitude than cliffs. Sometimes they can be extremely small features, involving changes of elevation of less than a foot, and are made more prominent than would be noticed on the ground by the vertical exaggeration and overall view of the feature when seen in the stereo-model.

Soil boundaries (29%) form the largest cause, and these boundaries were often the limits of transported superficial deposits or the boundary of a superficial deposit controlled and coinciding with a change of topography, probably formed prior to the emplacement of the superficial deposit. An example of this occurrence would be a glacial channel in chalk, now filled with coombe deposit, with residual chalk soil still lying on the ground external to the channel. Such a feature could form a valley of which the stereo model would show the margins in the form of a step coinciding with the boundary between residual chalk soil and Coombe Deposit.

Lithological contacts (18%) seem to have formed steps by the differential erosion of the bedrock prior to the formation of residual superficial deposits, or by the varied compaction of material each side of the contact. Presumably when shale was one side of the contact the same effect could also be caused by the swelling of the shale and weathered material.

Bedding and banding in stratified rock (17%) occurred mainly where the rocks had a horizontal or shallow dip and individual beds forms steps, which were then reproduced in a subdued form in the overlying material.

Faults (15%) frequently showed as steps. The effect appeared to be due more often to erosion prior to the formation of superficial deposits (i.e. the land surface reflecting hidden bedrock topography), rather than to the fault movement forming different relative elevations of the soil each side of its fracture plane.

Landslips (13%) were an obvious cause of steps due to the downward movement of one side of the material, but the effect of a step (i.e. with fairly level surfaces each side) tended to be confined to the early part of a rotational slip movement when the moving mass was held temporarily by the formation of a 'set'.

Joints (6%) also formed steps, mainly due to their linear control of an erosional effect with lower ground existing one side of the joint.

An attempt was made to distinguish between large and small steps by subdividing the sample. The main difference was an increased influence of soil boundaries (41%) in the case of large steps compared with small steps (23%), due to the fact that soil boundaries forming steps were usually such features as terraces, glacial moraines and sand dunes. The difference was counterbalanced by a greater proportion of faults, lithological contacts and landslip features in the small step sample.

6.2.4.5. Valleys

Out of the total of 27 valleys examined, 26% coincided with valleys apparently formed in the bedrock surface prior to the deposition of the superficial deposit, and with no obvious evidence of bedrock control of the valley visible at the coastal section. The bulk of these features were in chalk areas and coincided with coombe type valleys. These are commonly believed to have been formed by glacial melt water which may in turn have been channeled by consequent gullys. This would particularly be applicable to the coombes running to the south in the stretch of Sussex coast that was studied.

Faults (22%) must have provided a line of weakness for erosional attack in the cases where they controlled the valley direction.

Joints (18%) must have had a similar influence.

Consequent gullys (18%) appear to have enlarged their role to that of a valley in a number of cases.

Landslide features (8%) also showed as valleys in two cases.

A lithological contact, bedding trace, and soil contact were each found to be the apparent cause of a valley in other instances.

6.2.4.6. Straight stream sections

Straight sections of streams that were otherwise sinuous or irregular in character were recorded separately, although many would have normally come in the section devoted to gullys. It is perhaps anomalous to isolate these features, but it has been done because many photo-interpreters study drainage systems as a whole, and commonly interpret straight sections of streams as being caused by faults or major joints. In fact the sample was disappointingly small, being only eight in number. Numerous straight sections occurred in other classifications such as gullys or valleys, but were excluded from this section when the straight portion ended before reaching the coast.

Of the sample, faults (2) and joints (2), caused half of these cases, the remaining being due to soil boundaries (2), a landslide (1), and a consequent gully (1), but again these last three features may also have been influenced by the presence of a joint or joints.

When considered in association with the discussion on the dominance of joints in the 'deep' gullys, the results tend to confirm the hypothesis that the drainage system must be virtually in contact with bedrock in areas where streams, normally meandering, suddenly develop a tendency to form straight lengths, often joined to form sharp angular sections.

6.2.4.7. Ridges

Ridges are linear features with sides sloping away from the lineation, causing the feature to be elevated above the general level of the surrounding country. For this study ridges were subdivided into high ridges and low ridges, according to the relative height above the surrounding ground surface, and also divided into thin and broad ridges according to whether the sides were steep or gentle in slope.

The sample was again small - only 11 - and within the scope of this number there appeared to be little fundamental difference according to the height of the ridge, but the relative width of the ridge did seem to have some relationship to the cause. Thin ridges tended to be associated with dykes (4) and faults (3). Broader ridges were associated with lithological and soil contacts, and a bedding trace, which was one of a numerous type of bedding traces as seen in environments similar to that of the oblique photo of the frontispiece, namely of steeply dipping beds with a shallow superficial cover.

A number of instances of ancient earthworks showed up as ridges, but their overall outline and siting generally gave an indication of their origin.

6.2.4.8. Changes in slopes

Only 15 samples are covered by this section, which deals with abrupt linear changes in the amount of slope of roughly flat sloping surfaces. The linear change was normally at right angles to the direction of slope.

Landslide features (33%) were a common cause of this phenomena and were usually recognisable by the ground being rougher below the linear change of slope, which was usually caused by the scarp break at the upper limit of the landslip area.

Bedding traces (27%) were the next most frequent cause, and this was usually due to the influence of a bed, somewhat more resistant than its neighbour, being fairly near the surface below the superficial deposit.

Lithological contacts (20%) sometimes showed up as changes in slope angles, probably due to the varying weathering characteristics of the two rock types and the slope stability of the derived soils.

Soil boundaries (13%) caused slope changes when two soil types of differing angles of repose were in contact along a general slope.

6.2.4.9. Breaks in the superficial cover

Occasionally linear features caused by a line of breaks or one continuous break in the surface of the superficial material were encountered. Although only 14 examples were involved, even this number is probably enlarged by the influence of the sea undermining and penetrating bedrock joints deep into the cliff face to remove loose material higher up.

These features were mainly linear breaks where no surface running water was likely to be the cause of the removal of the soil, and this implies that the missing material in the area of broken ground must have been disturbed by means of some form of ground movement or subsidence. Occasionally this is visible on a large scale in inland areas where a karst type of topography is developed and the roofs of underground streams collapse and carry downwards the overlying soil. In steeply dipping limestone beds, sink-holes can develop along certain susceptible horizons and coalesce to form a linear depression, sometimes giving the impression of broken soil.

During the investigation it was found that faults (56%) formed the cause of broken ground and this was probably associated with small renewed movement in the fault plane propagating the break up into the superficial cover.

Landslides (28%) caused breaks in the superficial deposit, and only one example coincided with a soil boundary.

6.2.5. Causes of some combined types of lineations

6.2.5.1. General discussion

A total of 106 combinations of previously described lineation types occurred during the investigation. These were most frequently combinations of a 'step' feature and such types as pattern, tonal or vegetal boundaries.

The causes tended to be what would be expected from a combination of the causes previously described under the individual types, but the ratio of significant to insignificant soil and bedrock features rose to 90:11 from 69:29 for the causes of the component types considered individually. It would thus seem that there is a greater possibility of a lineation being caused by a significant geological feature if it appears on the air photograph as the site of more than one type of change, or as a landform and a change. The impression was also obtained that this combined form of lineation should often be easier to interpret in terms of the underlying geological cause.

6.2.5.2. Combined pattern boundaries and steps

Soil boundaries (39%) formed the largest group of causes for this type of phenomena. Variation in soil types would be a natural cause for pattern variations, i.e. by causing variations in vegetal assemblies or drainage patterns, and the step component could be caused by a difference in level due to the two soils having different weathering characteristics or by having a different history of deposition. For example, a boulder clay over part of which sand is blown will show a change of level at the sand/boulder clay boundary viewed from above, and the pattern of the vegetation and tones on the two materials would normally contrast.

Bedding and metasediment banding (28%) formed the next largest cause which appeared to exist mainly in situations where the 'bedding' was horizontal or gently dipping. The individual beds formed flat surfaces, normally thinly covered, which dropped down to the next bed at their termination, and the resulting different drainage and soil conditions causes a change of pattern.

Landslides (11%) reflected their field characteristic by the pattern being partly represented by the rough ground in the landslide area, and the associated step being the fracture along the margin of the slide.

Lithological contacts (11%) also formed a natural cause for step and pattern combinations in areas of residual soil, or where a change of level between two weathering rock types acted as the limit of deposition for a different soil type.

Faults (11%) were a feature that, like landslides, produced a step by the mechanical displacement of one side of the pattern-step combination. Presumably this movement also caused different ecological conditions as the faults did not mark a change of rock type which could have produced a pattern difference. Causes of change would be the different drainage conditions each side of the movement of the fault plane, or different thicknesses of soil where the fault caused a step at the bedrock surface.

6.2.5.3. Combined tonal boundaries and steps

Soil boundaries (53%) were also the major cause of this type of combined feature, and lithological contacts (25%) were the only other important cause. The cause of the step component of the combined form was in each case probably similar to that described in the previous section, but the 'tone' component may be more frequently attributable to a change in moisture content of the soil. No doubt in some instances the change in tone was caused by a variation in plant types which could not be resolved into a vegetal boundary on the scale of photographs used.

Faults (7%) and bedding traces (7%) probably also caused a combined tonal boundary and step in the same manner as they formed combined pattern boundaries described previously.

Single examples of this type of linear feature coincided with a landslip and a fracture zone.

6.2.5.4. Combined vegetal boundaries and steps

Lithological contacts (40%) dominated the causes of this group followed by soil boundaries (24%), which again would be caused by similar processes as those described under these headings in combined pattern and step boundaries. It is perhaps noticeable in each of the combined types of linear feature involving a step with a pattern, tonal or vegetal boundary, that lithological and soil boundaries form the dominant cause in each case. In fact there is a frequent relationship between pattern, tone and vegetation in photo-interpretation and frequently plants that form the pattern on a large scale photo will appear as a vegetal unit on a smaller scale photo, and again on a very small photo will appear as a tonal unit. There are also undoubtedly other factors at work which give further grounds for the distinction between the three combined linear features than have been discussed so far.

Faults (13%) would also form a natural step (where displacement along the fault plane has made its influence register on the ground surface levels), combined with changes in ecology. It is interesting to note that in

40% of these cases the fault also controlled a soil boundary.

Bedding traces (8%) again represented the influences of step-like features forming in areas of horizontal or low dip.

Landslides (5%) formed an obvious situation where the normal vegetal pattern would be disrupted and changed along a feature causing a small step.

Old coast lines (5%) presented steps due to marine erosion in the recent past, and the change of vegetation might be caused by a number of features, one of which could be the presence of saline changes in the soils. The existence of an old raised beach along the coast would also give changes in the soil moisture and drainage characteristics, which in turn would affect the vegetation.

6.2.5.5. Combined tonal and pattern boundaries

Only 11 instances of this combined linear feature were detected. They represent linear boundaries of patterns which coincide with a change of the general background tone within the pattern compared with the other side of the linear feature.

There were no dominant causes of this type of lineation and the field causes were as follows:-

Faults 3
Bedding traces 2
Agricultural soil boundaries 2
Landslide 1
Soil boundary 1
Consequent gully 1
Dyke 1

The above list tends to show that combined tonal and textural boundaries are frequently an indication of a geological change, but taken on their own are likely to be difficult to interpret in terms of the geological cause, unless other factors are available that would help to narrow down the field of possibilities.

6.3. The appearance on air photographs of linear geological features in the presence of superficial deposits

6.3.1. General discussion

The data accumulated from the photographs and field will now be considered from a different aspect, namely by concentrating on the geological cause and noting the variations in appearance of each cause. This approach may bear fruit in the type of situation where known features have to be extrapolated under a superficial cover. This will involve some regrouping of information already dealt with under the significance of different types of lineation, but where possible additional criteria will be added to reduce ambiguities in interpretation.

The greatest attention has been paid to faults and rock and soil contacts as these were considered to be of most immediate importance for the solving of the geology of areas of concealed bedrock. Although other features are dealt with, their choice has been controlled by their presence in the coastal sections studied. Equally important features absent in the study areas are not considered.

6.3.2. Features connected with the superficial deposits

6.3.2.1. Boundaries of superficial deposits

The term "boundaries of superficial deposits" includes contacts where one type extends under the other, although perhaps from the air or on a geological map this is not obvious.

The greatest portion were curved, often irregularly, but many were also straight, and these tended to be controlled by topography (e.g. coombe deposit lapping against the sides of a straight valley), or by bedrock features. These influences may also explain the impression that the dominant spatial forms were steep or medium dipping curved or planar surfaces. The frequent irregular margins may explain the fact that as many as 54% had to remain "indeterminate".

The boundaries commonly occurred as groups of curves, or separate lineations remote from any pattern, or also as normal members of parallel groups (which again may be due to bedrock control).

The boundaries appeared chiefly as tonal boundaries (30%), pattern or texture boundaries (27%), and vegetal boundaries (26%). Of lesser importance were gullys (7%), vegetal boundaries (5%), and dark or light lines of vegetation (5%).

6.3.2.2. Landslide phenomena

The great majority of landslides were rotational landslips with associated mudflows, and also . a small number of detritus slides. The features of the landslides that tended to appear as lineations were the perimeter of the broken ground, the margins of the moved material (including mud), and tension fractures at the cliff top which were the precursors of new landslides. One or two of the latter were marking the site of potential rockfalls in chalk, but otherwise the landslide features were associated with very soft or unconsolidated material, and base failures in shales or clay were the most common. There seemed to be little connection with joint directions.

The lineations caused by margins appeared as gullys (28%), steps (19%), vegetal or pattern boundaries (13%), dark tonal lines or dark lines of vegetation (15%), and linear breaks in vegetation (8%). These were mainly rectilinear and often parallel to other lineations due to the same cause. In these circumstances the parallel family was spread along one steep slope; steep slopes were virtually an essential environment for the types of landslide encountered.

The scarp at the crown of the slides tended to be curvilinear, and showed as steps or small cliffs (55%), gullys (20%), and tone or pattern boundaries (15%). The scarp lineations tended to lie at 90° to the direction of the steep slope.

Nearly all the lineations marked dramatic changes in the appearance of the ground. Just over half were sensed as the result of steeply dipping surfaces cutting the ground surface. They rarely exceeded 800 yards.

6.3.2.3. Windblown features

Occasionally the wind is responsible for causing lineations, but these were limited to two "blowouts" from fixed sand dunes in the coastal sections. The cause of these was obvious to an experienced observer; the rough coarse texture of a dune covered area was broken by light coloured scars, mostly too broad and stubby to be termed linear. Inland examples often splayed outwards from a narrow neck at the point where the wind from the sea first obtained a purchase on the sand and overcame the anchoring vegetation.

Unfixed sand dunes can often display linear forms controlled by the wind and in areas of loess, the interfluves often show on air photographs as linear parallel or sub-parallel ridges, supposed by some to reflect the prevailing wind at the time of deposition.

6.3.2.4. Glacial influences

Glacial erosion effects removing soil completely do not come within the scope of this study, but four lineations were attributed to glacial scouring of superficial deposits. Three were shallow gullys and the fourth was a dark tonal line which could have been an infilled gully or depression.

The main effects of glacial deposition detected were the boundaries of boulder clay which have been included in section 6.3.2.1.

However, there were 19 cases of internal soil variations recorded which were usually the edge of a feature such as a drumlin or a kame terrace. These appeared as breaks in pattern or tone (36%), changes of slope (22%), pattern or tonal boundaries (22%), steps (11%), and depressions or gullys (11%). The knowledge that the photograph covered an area of glacial activity and the land form each side of the lineation were usually adequate to reveal the nature of the cause. Three-quarters of these lineations could not be given a spatial form other than "indeterminate" or a "straight line on a flat surface". The rest mainly appeared as the edge of an irregular blanket type feature gently draping on the former land surface. The lineations were usually curvilinear in shape.

6.3.3. Features connected with the bedrock

6.3.3.1. Lithology

6.3.3.1.1. General

The next sub-section deals with the influence of the nature of the rock, within the bounds of the sample group available. This is followed by a small sub-section dealing with the case where the rock age changed substantially without any clear-cut change in its other characteristics.

6.3.3.1.2. Contacts between different lithologies

Those lineations that coincided with changes of rock type underneath the superficial deposit had the following general appearance:-

TABLE 16. The distribution of types of lineation caused by rock contacts

Appearance of lineation	% of total
Stepped ground	35
Tonal boundaries	20
Vegetal boundaries	15
Pattern or texture boundaries	11
Gullys or straight sections of streams	11
Straight lines of vegetation and dark tonal lines	7

These were the most common occurrences noted, and in a number of cases there were combinations such as a change of pattern coinciding a small step at the ground surface.

It is interesting to note that 19% also coincided with soil contacts between residual and transported soils, or between 2 different types of transported soils. This points to a fairly frequent change of the soil type coinciding with hidden changes in the bedrock, for contacts between 2 residual soils are not included in the figure.

The clarity of the contact was better for low and medium dips, but where the bedded rocks were dipping more steeply the results tended to vary and the picture was somewhat confused by the poor size of sample in these higher dip groups.

In only 58% of the cases could a spatial form be allocated to the appearance of the lineation at the surface, and of those which could be classified, 78% appeared as planes intersecting the ground surface at various angles.

The shapes of the lineations were varied, and there were slightly more curvilinear forms than rectilinear, although hardly any of the lineations caused by rock contacts had a shape combining curved and straight sections.

The contact lineations showed a varied relationship to other lineations in the vicinity, although most commonly they were parallel to a group of parallel lineations. Presumably the other members of the parallel group represented traces of bedding. But there were also quite frequent lineations which tended to be independent of those seen locally in other parts of the surface cover.

The detectability in relation to the bedrock competency is shown by the following table.

TABLE 17. The influence of bedrock competency on the detectability of faults and rock contacts

Feature	Rock	Clarity of lineation			No. of cases
		Clear	Indistinct	Invisible	
Faults	Competent	79%	11%	10%	129
"	Incompetent	65%	18%	18%	34
Rock contact	Competent	81%	16%	2%	43
	Incompetent	44%	28%	28%	25

The incompetent rocks showed rather poorly compared to the others and this may be due to a number of factors - for example the tendency of this type of rock to seal up any fractures in the course of weathering and movement, and also the tendency of many of the types represented to form soils that may tend to conceal the nature of any fissures or fractures.

6.3.3.1.3. Stratigraphic contacts

This sub-section deals with contacts between beds involving a distinct break in time, but not involving a change of lithology or dip. Only five such events occurred in the coastal sections investigated, and of these one showed clearly, three indistinctly, and one gave no evidence at all of its existence on the photograph. The fact that the cause involves no change of geological structure or rock type perhaps makes it surprising that any showed at all.

Two of the samples showed as steps in weathering shales, and a possible mechanism for the cause of these features might have been over-consolidation of the clay forming one age group of shales causing a different rebound effect during weathering.

The other two features appeared as dark tonal lines on the air photographs, and an explanation of this seems even more difficult, except possibly by a tilted version of the previous process causing a locus for water accumulation which in turn affects the photographic tones.

In each case the linear feature appeared to conform to bedding traces and had no unique characteristics that would have pointed to its greater importance.

6.3.3.2. Bedrock structure

6.3.3.2.1. The appearance of faults

The coastal sections investigated included a total of 178 faults, and of these 75% showed as linear features before the field work, a further 13% were noted as less distinctive lineations after the fault's presence was known, and the remaining 12% were not detected on the aerial photographs. The faults were distributed among a variety of soil types but the bulk were confined to residual soils(42%)boulder clay (41%), and contacts between residual soils and boulder clay (5%). The remaining 12% of the total sample was spread over a variety of transported soils, and in each case of these other soils a lineation showed clearly above the faults.

It is interesting to note that the relative clarity of the faults under the residual soils was virtually the same as in the case of the boulder clay in spite of the fact that many would consider a cohesive substance like this, presumably transported to its position subsequent to the initiation of the fault in virtually every case, unlikely to show the faults clearly. The actual figures were:-

TABLE 18. The detectability of faults under residual soil and boulder clay

Soil	Clarity of lineation		
	Clear	Indistinct	Invisible
Residual	76%	14%	11%
Boulder clay	73%	15%	12%
Contacts between residual soil and boulder clay	100%	-	-

The faults appeared on the photographs as a number of different types of lineations. Steps (17%) and dark tonal lines or lines of vegetation (16%) were the commonest, but were closely followed in frequency by pattern/texture boundaries (15%) and tonal boundaries (13%). They also showed as light tonal lines (11%), disruptions in trees or crop patterns (9%), gullys or straight sections of streams (6%), valleys (4%), and vegetal boundaries (4%).

In the field nearly all the faults were found to be vertical or steeply dipping and it is not surprising to find that on the photographs the shapes were simple and were mainly in the form of rectilinear lineations (64%) or curvilinear (30%) and in the case of the latter mainly gentle curves. Only 96 lineations occurring over faults could be given specific spatial forms, and of these 49% appear as high dipping planes intersecting the surface, 25% as a straight line on a flat surface (i.e. the intersection of a plane of indeterminate dip with the flat ground surface), and 17% as curved surfaces with a high dip.

A study was made of the relationship between the amount of dip of the bedrock and the clarity of the faults. The relationships were not strong except that there was a general tendency for a better detection of the faults in horizontal and gently dipping beds, as opposed to medium and vertical or steeply dipping beds. There was not a regularly progressive improvement throughout the dip range as the beds' dip decreased.

A study was also made of the clarity in relationship to the age of the rocks, but unfortunately 99% of the sample fell into the Mesozoic, Palaeozoic and Pre-Cambrian groups only. There did not appear to be a significant variation in these three, but a complicating factor was a tendency in the sample for the older rocks to have a thinner superficial cover, and this may account for the fact that there was a better performance of the small sample of igneous and metamorphic rocks compared to the slightly poorer detection of faults in the sedimentary types. There appears to be a significant drop in clarity in shale or rocks containing a proportion of shales, compared with the other best represented rock types, limestone, sandstone, grits, chalk, marl and schist. This was also reflected in the study of the rocks grouped according to their relative competency; the following table indicates the results:-

TABLE 19. <u>The influence of rock competency on fault clarity</u>

Rock competency	Clarity of lineation			No. of
	Clear	Indistinct	Invisible	Cases
Competent	79%	11%	10%	129
Incompetent	65%	18%	18%	34
Competent/incompetent contacts	60%	27%	13%	15

The rocks and superficial deposits were also grouped into permeable, impermeable and permeability contacts, and a study was made of the results on this basis. The results are given below and show no undue variation except possibly for the occasion where a permeable superficial deposit conceals a contact between a permeable and an impermeable bedrock. In this situation for an admittedly small sample, it would appear that the clarity is the poorest. This is the reverse of what the investigator anticipated on the basis of his personal experience, and the results are presented without further comment.

TABLE 20. Influence of the permeability of the soil and bedrock on the detectability of faults

Rock permeability	Soil permeability	Clarity of lineation: Clear	Indistinct	Invisible	No. of cases
Permeable	Impermeable	76%	20%	4%	46
Permeable	Permeable	80%	3%	17%	30
Impermeable	Permeable	77%	7%	15%	40
Impermeable	Impermeable	65%	21%	15%	34
Imp/perm contact	Impermeable	100%	-	-	3
Permeable	Imp/perm contact	29%	29%	43%	7
Imp/perm contact	Permeable	100%	-	-	4
Impermeable	Imp/perm contact	71%	29%	-	7
Imp/perm contact	Imp/perm contact	100%	-	-	2

6.3.3.2.2. Joints

Amongst the lineations studied, 57 appeared to be caused by individual joints. These appeared on the air photographs as gullys or valleys (46%), tonal lines (22%), steps (10%), tonal and pattern boundaries (19%), and straight sections of streams (4%). As the joints coinciding with lineations were all vertical or very steeply inclined, it is not surprising that 76% were rectilinear compared with 14% curvilinear, the rest being mixed.

Of those which were allocated a spatial form, most were steeply dipping or vertical planar features (49%), vertical or steeply dipping curved surfaces (19%), or straight lines on flat surfaces (27%). They were prone to be members of parallel groups of lineations, and only one exceeded 1100 feet in length.

6.3.3.2.3. Bedding planes

There was virtually no difference in the characteristics of sedimentary bedding planes and meta-sedimentary banding in the areas studied, and they are treated as one in this section. The associated lineations appeared as steps (41%), dark or light tonal lines (29%), tonal or pattern boundaries (22%), changes of slope (5%), gullys (3%) and low ridges (2%). The distribution within these groups was governed by the dip of the beds; steep dips produced tonal lines, gullys and ridges, whilst the other types were normally manifestations of low or medium dips.

More were rectilinear (55%) than curvilinear (41%) in shape. It is likely that a proportion of the latter were caused by flat bedding intersecting curved topographic features, for the spatial form classifications showed that there were four times as many planar surfaces as curved detected. The planar surfaces dipped at varying angles, but the curved surfaces were confined to districts with steep or medium dips.

6.3.3.3. Bedrock topography

Linear erosional features on the surface of the bedrock, covered with superficial deposits, were responsible for 33 lineations. The majority of these features were gullys or valleys in chalk, and have been attributed to erosion by melt-waterfrom retreating glaciers. The compaction of the superficial deposit in the course of time is probably responsible for the fact that 54% of the lineations appeared as gullys, depressions or valleys, and possibly the 18% that showed as steps. The presence of a thicker quantity of soil on otherwise thinly covered chalk would help to account for 18% being tonal lines, and 9% tonal boundaries.

There were approximately equal numbers of rectilinear and curvilinear lineations, but the latter tended to occur as compound or irregular rather than simple curves. One in four could not be allocated a spatial form; of the rest, 45% showed as moderately dipping surfaces, 42% as steeply dipping, and 27% as straight lines on flat soil surfaces.

In areas where the bedrock surface had a fairly constant slope (e.g. the South Downs in Sussex, where the general slope coincided with bedding dip), these lineations were often members of parallel families owing to their direction being controlled by the downslope movement of melt-water. No doubt in some cases there was an influence on the direction of bedrock gullys caused by joints which were not visible in the field, but which also could cause a relationship with parallel families.

6.4. Lineations that could not be attributed to geological causes

6.4.1. Man-made lineations

Farm areas are frequently the loci of spurious linear features, but the vast bulk of these can be dismissed by their symmetrical relationship to the sides of the fields. Drains and the turning points of cropping machines often show as a group of features radiating from the centre to the corners of fields. Less distinctive are tracks running obliquely across fields, but a careful search for gates, or a convergence on buildings, or a change of direction at hedges, helps to eliminate many of them quickly.

Older abandoned features tend to deceive an interpreter more, by appearing more like natural weathered features, and ancient earthworks, when not in the form of an obviously unnatural shape, can resemble weathered dykes.

Nearer to areas of dense population there is a tendency for "artificial" lineations to become more frequent and to be made by a greater variety of causes, with a resulting increase in difficulties for photo-interpreters.

When there was the slightest possibility that a lineation might be geologically caused, it was included in the investigation, but this meant that many features were included that would, on the balance of evidence, have been rejected as artificial in a normal interpretative study. The final figure (195) represented 13% of the total lineations, but this reduced to 9% when counting features on the ground. The difference was mainly due to the repeated counting of a puzzling series of white scars on part of the Sussex coast that was covered by several runs of photographs. The scars were caused by the war-time movement of tracked vehicles which had not registered as the clear parallel line of normal tracks.

6.4.2. Lineations with no exposed bedrock

It was impossible to see the bedrock at 177 sites of lineations in the field. Various causes were landslides of superficial deposits, the dumping of rubbish over the cliff top and down the face of the cliff, and blown sand accumulations. In a few cases it was not possible to get at or near that part of the cliff face where the critical evidence might have existed. A proportion of the lineations probably had artificial causes.

All these cases have been eliminated from the statistics where they were not relevant.

6.4.3. Lineations with no obvious cause

No cause could be found for 54 lineations, 3½% of the total sample, in spite of the fact that the bare rock could be seen in the cliff face.

Three quarters were rectilinear in shape, which may point to artificial causes or joints. A quarter of the total also lay within 10° of an important joint direction. Only two of the cases came within 5° of the last glacial movement direction, thus ruling out glacial effects as an important cause. A test of the influence of slope showed that only 6 cases occurred lying within 10° of the slope direction, and the possibility that even these were caused by drainage is reduced by their appearances being mainly as tonal or pattern boundaries. Only one was close enough to the direction of strike to have been related to bedding.

It seems that without a more detailed investigation in the field, the cause of these lineations remains obscure.

6.5. Influences obscuring or confusing bedrock information

In part, this section will be a review of some of the negative aspects of previous sections, but in some applications of photogeology it is important to be able to know which areas are likely to produce the least reliable data or information.

Those aspects of the factors affecting the interpretability of the photos already covered in section 4 have not been repeated in this section, which deals mainly with influences involving the superficial deposits.

6.5.1. Influence of the thickness of the superficial cover

It is commonly thought that with increasing depth there is less prospect of obtaining information about bedrock conditions and changes. In order to test this hypothesis, the clarity of faults and lithological contacts were tested for different depths. Blocks of different thicknesses of the superficial deposit have been grouped together as follows:-

Range of thickness (in feet)	Name
0 to 2	Very thin
3 to 6	Thin
7 to 19	Moderate
20 to 50	Thick
51 to 150	Deep
Over 151	Very deep

The following tables show the clarity of faults and rock contacts for the various thicknesses concerned:-

TABLE 21. The influence of soil thickness on the detectability of faults, rock contacts and soil contacts

Soil thickness	Clarity of lineation			No. of cases
	Clear	Indistinct	Invisible	
Faults				
Very thin	95%	5%	-	21
Thin	69%	16%	16%	77
Moderate	73%	17%	10%	52
Thick	80%	8%	12%	25
Deep	50%	-	50%	2
Very deep	100%	-	-	1
Rock contacts				
Very thin	86%	14%	-	14
Thin	78%	17%	4%	46
Moderate	79%	18%	3%	34
Thick	52%	15%	33%	27
Deep	33%	-	67%	3
Very deep	-	-	-	-

It is interesting to note that there appears to be a general trend for a reduced amount of information with depth in the case of rock contacts, but that this change is not obvious for faults. A possible explanation for this phenomenon is that faults may have a tendency to propagate themselves through the superficial material when being moved regularly by earth-tides or other events over a long period of time.

It is appropriate to note at this juncture the clarity of superficial deposits contacts in the following table:-

TABLE 22. <u>The influence of soil thickness on the detectability of soil contacts</u>

Soil thickness	Clarity of lineation			No.of cases
	Clear	Indistinct	Invisible	
Very thin	94%	-	6%	69
Thin	94%	3%	3%	104
Moderate	89%	8%	3%	66
Thick	91%	3%	6%	34
Deep	100%	-	-	2
Very deep	100%	-	-	3

Again the clarity does not seem to be related to soil thickness, which is hardly surprising because the skin of material observed on the air photograph is representative of a change in depth at all levels. If however there is truth in the suggestion that faults propagate themselves by the regular movements of a fracture, then one would expect to find different "clarity" results for soils that would not be amenable to this movement. An attempt was made to break down the various soil types to various thicknesses and determine bedrock clarity in each case. Unfortunately the size of the sample when broken down into these fractions proved inadequate for most data. But the following tables give an indication of the results for residual soils, boulder clay, and other (undifferentiated) soils.

TABLE 23. The influence of varying thicknesses of different soils on the detectability of bedrock geology

Soil type	Soil Thickness	Lineation clarity Clear	Indistinct	Invisible	No. of cases
Residual	Very thin	88%	7%	5%	41
	Thin	82%	12%	6%	100
	Moderate	88%	8%	4%	24
	Thick	100%	–	–	8
	Deep	100%	–	–	1
Boulder clay	Very thin	100%	–	–	7
	Thin	73%	15%	12%	48
	Moderate	82%	14%	4%	71
	Thick	82%	12%	6%	17
	Deep	75%	–	25%	8
Other soils	Very thin	89%	11%	–	9
	Thin	83%	13%	4%	23
	Moderate	78%	11%	11%	18
	Thick	82%	6%	12%	16
	Deep	–	–	–	–

It will be seen that the residual soils gave virtually consistent results with increasing depths, but the boulder clay and the other soils gave fluctuating results, with uncertainties introduced by different size samples of various thicknesses of superficial cover. The results unfortunately are not conclusive, but they do indicate that for general interpretation in areas of residual soils, varying thicknesses of the cover are not very likely to have an undue influence on the ability to detect bedrock changes.

6.5.2. The masking influence of the nature of the superficial deposits

The following clarity tables indicate the variations in the effect of residual and transported soils:-

TABLE 24. The influence of the soil's origin on the detectability of bedrock contacts and faults

Feature	Soil	Detectability of lineation			No.of cases
		Clear	Indistinct	Invisible	
Rock contact	Residual	85%	10%	5%	40
" "	Transported	63%	20%	17%	54
Faults	Residual	76%	14%	11%	74
"	Transported	71%	15%	15%	89

The figures bear out the tendency for residual soil to be more reliable for showing changes in the bedrock than transported soil, as noted in the previous section when testing various depths of each soil. The tendency is less marked in the case of faults than it is for hidden rock contacts. This also could point to a possibility of slight movement in the fault plane being propagated through the transported superficial deposit, for this is one cause of its presence being detectable that would not be so likely to exist in the case of rock contacts.

The writer would say from his experience that there may often be a relationship between the length of time a transported superficial deposit has been formed, and the amount of underlying geology it reveals. Thus, blown sand areas near the coast formed gave the poorest detectability of the soils tested, and alluvial areas that have been frequently replenished in recent times are often devoid of sub-surface evidence. Older established material that has had time to compact and allow other processes to work seem less barren. The writer is grateful to Dr. Stringer of Burmah Oil Corporation for providing him with a good example (Fig.I), in which tonal lineations in loess reveal the strike of a steeply inclined sandstone-shales series some four to five feet below.

Fig.I. The arrows indicate faint light tonal lineations showing the trend of underlying steeply inclined beds. The superficial material is loess, and the sediments are sandstones and shales.

6.5.3. The influence of groundwater

Areas which are frequently flooded, or where the water table regularly reaches the ground surface in its seasonal movements, frequently show these conditions by changes of tone or vegetation. It is possible that this might add further lineations to an area and mask other lineations with a more direct use for photogeological interpretation.

An attempt was made to investigate this aspect by comparing the clarity of important geological features in areas where the superficial deposit was impervious with those having a pervious cover. The results showed little difference.

6.5.4. The influence of landslides

There can be little doubt that landslide phenomena obscure bedrock geology in some situations. The writer has seen an important fault some miles in length in the Dolomites completely obscured on a photograph by screes. In some of the sections studied there were extensive rotational landslips that confused the geological setting by moving large amounts of rock as a block, sometimes including an important contact. Air photographs can be one of the best ways of recognising such a situation, but are not infallible.

6.5.5. The influence of the tectonic state of the bedrock

During the fieldwork a rough classification of the degree of folding of the bedrock was noted for each lineation. Rocks with low or moderate dip were usually classified as gently folded, unless there was evidence to the contrary. This group was subdivided according to the nature of the jointing. Further groups were steeply inclined strata, tight folds, and contorted strata. The detectability of faults and rock contacts in these different situations were then examined and the results, shown below, did not give any indication that the amount of folding was a factor influencing the detectability of bedrock evidence through superficial deposits. There is a suggestion in the figures that detectability may be related to the amount of jointing, but some of the sub-groups contain too few cases for final conclusions to be drawn.

TABLE 25. The influence of folding and jointing on the detectability of bedrock contacts and faults

	Clarity of lineation			No. of
	Clear	Indistinct	Invisible	cases
A. Rock contacts				
Gently folded				
Joints confined to individual strata	68%	16%	16%	25
Joints passing through several strata	86%	11%	4%	28
Numerous major joints	-	-	-	-
Many joints	67%	33%	-	6
Columnar jointing	100%	-	-	1
Moderately folded	50%	50%	-	6
Tightly folded	-	-	-	-
Contorted strata	88%	8%	4%	24
B. Faults				
Gently folded				
Joints confined to individual strata	75%	16%	10%	51
Joints passing through several strata	85%	4%	11%	72
Numerous major joints	100%	-	-	2
Many joints	100%	-	-	4
Columnar jointing	100%	-	-	7
Moderately folded	75%	20%	5%	44
Tightly folded	-	100%	-	1
Contorted strata	85%	8%	8%	26

7. THE POSSIBILITY OF EXPLOITING LINEATIONS IN PHOTOGEOLOGICAL STUDIES OF AREAS OF SUPERFICIAL DEPOSITS

7.1. General approach

The results of this study show that air photographs can reveal a lot of information about bedrock geology where the latter is concealed, and even when the superficial cover has been transported to its present position after the underlying geology has been established. The basis for interpreting the significant data on the photographs may often be tenuous, and seldom can a firm decision be made on one characteristic alone. As in most aspects of photogeology, the interpreter will have to decide on the basis of converging evidence, but as the photographs do not present the evidence in a systematic manner, it is difficult to devise a systematic approach that will cover all situations. Whether there is merit or not in a set routine of investigation would probably be a subject for debate in a number of circles, but even if a routine procedure is adopted, its success is likely to be related to the geological insight of the investigator.

Two processes are likely to be involved in any useful attempt to extract information about concealed bedrock from air photographs; the elimination of irrelevant lineations, and the interpretation of the correct cause of the remainder.

Thus, after the photographs have been studied and the lineations recorded, there should be a visit in the field, during which man-made lineations can be rejected, and a careful note made of soil boundaries and other data that would have a geological bearing on interpretation. A careful note would have to be made of the depositional relationships of the superficial deposits, and this related to the shape and spatial form on the photographs. Straight sections of superficial deposit boundaries ought to be included in the field investigation.

Early in the investigation an attempt should be made to establish the nature and history of the superficial deposits, which then may explain some of the lineations. For example, when glacial deposits are recognised and the direction of movement established, then a shallow gully parallel to this direction may be understood; but a rectilinear lineation lying at an oblique angle to this direction has a greater likelihood of being caused by a bedrock feature.

Other forms of regional direction that might help to add weight to some interpretations are the main joint and fault directional trends. It is to be hoped that these may be available from fieldwork in the region, but if not, an intelligent study of selected lineation characteristics and family trends may make a tentative statistical summation of likely joints and likely faults of use. Other lineations that lie parallel to the main regional directions obtained are also likely to be faults or joints, but of course may still have a different cause to the trend cause, and the characteristics of the lineations still need to be the main consideration for their interpretation.

Co-linear lineations should be considered as possibly being caused by one geological feature, and a study of any variation in characteristics of a pair of co-linear lineations may help to remove some ambiguities in interpretation.

Any field or drilling data needs to be exploited to the full by careful extrapolation. This applies to information derived from just outside the area to be studied, as well as from within it. The use of such information extends beyond the location of faults and contacts for extrapolation, for any general information on the geology may help to clarify the significance of some of the lineation characteristics. For example, some lineations shapes may have a different significance if it is known that the area consists of steeply inclined metamorphic rocks, or flat-lying sediments.

One of the most difficult types of ground to interpret in the study areas were the regions obscured by boulder clay. This material was well represented in the sample and an approach to the interpretation of the significance of lineations in this material is given in Appendix VI.

7.2. The validity of using the results of the study in other environments

There are so many variables involved in the appearance and causes of lineations that it would be folly to attempt to create a universal "key" that could be used for identifying the cause of all lineations. Even within the confines of this study of mainly sedimentary rock areas in a temperate climate, the interpretation criteria that have emerged have been such that rarely can one ~~lima~~ characteristic be relied on, and the interpreter will often have to rely on his judgement of the converging evidence of a series of ambiguous clues. Nevertheless, the general concept of testing and considering a variety of characteristics for each lineation should be applicable in other settings, and if studies similar to this are repeated in other environments, many of the characteristics may remain unchanged. There seems little reason to suspect changes in the significance of spatial forms in a different climate, for example.

The most immediate problem for solution before the results of the study can be put to practical use, is to determine how far coastal areas are representative of conditions inland, for there are a number of geological and ecological factors that differ. Two which are possibly the most important from the photogeological aspect are the influence of the gravity component and the drop in the water table at the cliff face. An attempt was made to exploit the computer to investigate some aspects of these effects by dividing the lineations into two groups, one of which was confined to ground that would be unstable, and the other consisting of lineations that extended far enough inland to be in "stable" ground. An individual calculation was performed in each case, and on the advice of Dr. J. Hutchinson (Dept. of Civil Engineering, Imperial College), an "angle of draw" of 10° inclined upwards inland from the base of the cliff was employed. Lineations which reached inland beyond the zone traced out by the intersection of this line with the land surface, were considered to exist also in ground independent of the gravity component at the cliff face. The calculation had to allow a maximum for all materials, and no doubt a large proportion of the features within the zone were also in "stable" ground. It would be wrong to place much faith in the significance of the results.

Not surprisingly, the number of lineations caused by landslides was reduced by 85% outside the zone of potential instability. The number of joint-caused lineations was reduced by 84%, with a large portion probably being eliminated by their inherent shortness. It is possible that there is a tendency for open joint fractures to extend their influence upwards more readily in unstable ground. This was less convincingly shown by faults, of which the number extending beyond the zone (78) was only 26% less than those in it, and the faults "clarity" analysis was exactly the same each side of the zone. The proportion of soil contacts and lithological contacts that did not show on the photographs was also exactly the same inside and outside the zone, but there were variations in the distinctness of those that did show. These figures are sufficiently encouraging to show that this test alone does not give grounds to deter further testing work inland.

The free adaptation of interpretation criteria between different climatic and geological settings, however, is fraught with danger. Quite different and additional causes and characteristics to those reported in this thesis are likely to be obtained in polar regions, deserts, Mediterranean areas, monsoon jungles, and stable shields or alpine "mountain-building" belts.

7.3. Photogeophysics

Photogeophysical studies demand a long sustained effort of data collection and analysis, with little evidence of the possibilities of rewarding results until the end. Indeed, the impression is gained that in a number of published cases the "reward" did not seem sufficient for the effort involved. Notable exceptions to this state of affairs were two instances involving young sediments that were relatively unfolded (BLANCHET (1957), and BELCHER and SCHEPIS (1965)). Until more is known, it is likely that this type of environment will produce the best results. In older rocks with a more complex structure there is always the danger that folds with a simple related fracture pattern may have been further folded so that the directions of the lineations seen on the air photographs have now a meaningless distribution in direction.

The studies have been made on the assumption that the lineations have been caused by rock fractures, and in a number of cases areas of concealed rock have been involved. In the ground covered by the investigation reported in this Thesis, only one in four lineations can be related to a form of rock fracture. This figure is reduced to one in three if only rectilinear lineations are included, but even this seems to incorporate an objectionably high level of extraneous data which would make the extraction of significant relationships difficult. It seems desirable that a careful study of each lineation's characteristics should be made to reduce this volume of confusing material by better selectivity for photogeophysical studies.

There appear to be a number of aspects of photo-geophysics that would be helped by the application of computer techniques. The ultimate ideal would involve pattern recognition methods employed by instruments detecting the lineations automatically and analysing their significance on a regional and local basis. However, much more has to be done to justify the capital outlay involved in such a project, and some of the intermediate stages could involve the preparation of software that could be incorporated in the final ideal organisation. For example, the data on individual lineations could still be collected by human beings and punched on to cards or tape, but this data could then be analysed for significant relationships by using computer programmes capable of adaptation for more sophisticated techniques later.

7.4. Suggested lines of investigation for extending the usefulness of the results obtained

One of the most obvious means of extending the usefulness of this study would be to increase the overall volume of data to add more weight to the interpretation criteria obtained, and to test properly the influences of those parameters that are poorly represented in the total sample. Obvious weaknesses include:-

1. Lack of samples at small scales.
2. Virtually no information on the influences of photographic processes and materials.
3. Little photography taken in autumn and winter.
4. Restricted representation of rock and soil types.

The list could easily be extended to require many man-years of effort, but it must be borne in mind that many of the influences dealt with in this study have a bearing on the whole field of photogeology and some may also be of use to specialists in other fields of photointerpretation. Controlled tests of the clarity of lineations provide a practical means of field testing and investigating many aspects that could increase the yield of information from air photographs.

A simple repetition of the study in different climates is also needed. For example, tonal and vegetal lineations may take on a new significance in a desert.

The writer would like to see the establishment of a "photogeological test range" consisting of a strip of country of thoroughly known varied geology. This could be regularly photographed for tests based on the clarity of linear features to provide a sound basis for the testing of photographic materials and processes for photogeological use. It could also be used to provide more reliable information on the influences of scale and season than was possible in this study, which has had to rely mainly on comparing photographs of different areas.

8. ACKNOWLEDGEMENTS

The writer wishes to thank his colleagues at Imperial College for their encouragement during the pursuit of this investigation, and in particular, Professors D. Williams and W.D. Gill, who made it possible.

Past and present members of the University of London Institute of Computer Science gave frequent assistance with programming difficulties and overcoming the vagaries of the M.V.C. Mark 5 programme.

The writer also wishes to express his thanks to the University of London Research Fund for the grant of £100 towards the cost of the study.

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APPENDIX 1.

Some further details of classifications used in the photo analysis and field study of the lineations

Three types of names appear in the following lists of features used during the study. In the first column a code name is given that was used in the M.V.C. Mark 5 specification. These were chosen for descriptiveness and brevity, and had to be used in only one context. Thus the use of the word "steep" to describe a class of dip precluded the same word being used on its own to describe a steep slope. In practice the latter was classified as "large", and numerous other instances of incongruous names will be noted, but these have been revised in the main part of the Thesis to give more acceptable descriptions.

In the second column a more conventional name or brief description is given where an explanation has not been previously given. In certain cases additional columns are used to show how the feature has been regrouped or reclassified in the later stages of the analysis. For example, "Blown Sand" is reclassified as "Transported Soil", and "Permeable Soil" for some purposes.

A. Type classification based on photographic appearance

Lineation Type (Code name)	Remarks	Lineation Class (Regrouping in broader classes. Code name)
1. LOW THIN RIDGE	"Thin" implies ridge sides slope over 45°	MORPHOLOGICAL
2. HIGH THIN RIDGE	"	"
3. LOW BROAD RIDGE	"Broad" implies sides sloping less than 45°	"
4. HIGH BROAD RIDGE	"	"
5. PATTERN BOUNDARY		TEXTURE/PATTERN
6. VEG.BOUNDARY	Any linear change of natural plant community	VEGETAL
7. LINE OF TREES		"
8. BREAK IN TREES	A linear interruption in the pattern of a wooded area	"
9. DARK LINE OF VEG.	A line of dark tone caused by vegetal change	"
10. GAP IN VEG.	A linear gap in the normal vegetation	"
11. TONAL BOUNDARY		TONAL
12. LIGHT TONAL LINE		"
13. CLIFF		MORPHOLOGICAL
14. SHALLOW GULLY	A gully that appears to be neither deep nor likely to be in contact with bedrock	DRAINAGE
15. MEDIUM GULLY	A gully that might be in local contact with bedrock	"
16. DEEP GULLY	A gully bottomed on bedrock	"
17. VALLEY		MORPHOLOGICAL
18. DEEP VALLEY		"
19. STRAIGHT STREAM	A locally straight section of a stream	DRAINAGE

20.	STRAIGHT COAST	Abandoned as not being representative of inland areas	
21.	STEP		MORPHOLOGICAL
22.	STEP AND PATTERN BOUNDARY		MORPHOLOGICAL PLUS ANOTHER
23.	STEP PLUS HEDGE OR WALL		MORPHOLOGICAL PLUS ANOTHER
24.	SMALL STEP		MORPHOLOGICAL
25.	DARK TONAL LINE		TONAL
26.	CROP PATTERN OR TEXTURE BOUNDARY	A feature within growing crops	TEXTURE/PATTERN
27.	LARGE STEP BOTTOM	The foot of a step that is sufficiently large for both top and bottom to be seen on the photograph	MORPHOLOGICAL
28.	LARGE STEP TOP	The opposite of 27	"
29.	STEP AND VEG. BOUNDARY		MORPHOLOGICAL PLUS ANOTHER
30.	STEP IN ALLUVIUM		MORPHOLOGICAL
31.	PATTERN BREAK	A linear disruption inside a pattern	TEXTURE/PATTERN
32.	BREAK IN SD	A linear disturbance of the soil not apparently due to surface drainage or landslides	TEXTURE/PATTERN
33.	MAN MADE		OTHERS
34.	LINE OF SCRUB		VEGETAL
35.	DEPRESSION		MORPHOLOGICAL
36.	CHANGE OF SLOPE		"
37.	TEXTURE BOUNDARY		TEXTURE/PATTERN
38.	STEEP SIDED VALLEY		MORPHOLOGICAL
39.	U-SHAPED GULLY	A broad gully with a concave cross-section	DRAINAGE
40.	STEP AND TONAL BOUNDARY		MORPHOLOGICAL PLUS ANOTHER

41. LARGE STEP BOTTOM AND TONE LIMIT		MORPHOLOGICAL PLUS ANOTHER
42. TONE AND TEXTURE BOUNDARY		"
43. STEP TOP AND TONAL EDGE	A step coinciding with a tonal boundary	MORPHOLOGICAL PLUS ANOTHER
44. UNSEEN GEOL. FEATURE	A linear geological feature that did not show on the photograph	OTHERS
45. STEP TOP AND VEG. LIMIT	A step coinciding with a vegetal boundary	MORPHOLOGICAL PLUS ANOTHER
46. STEP BOTTOM AND VEG. LIMIT		"
47. STEP BOTTOM AND TEXTURE BOUNDARY		"
48. UNSEEN AG SOIL CONTACT	A boundary between different soils (agricultural) not visible on the photograph	OTHERS

B. The geological causes of lineations

Lineation Cause (Code name)	Remarks	Geological significance (Code name)	Lineation cause group (Code name)
1. MAN CAUSED		IRRELEVANT	ARTIFICIAL
2. ANCIENT EARTHWORKS		"	"
3. FAULT		SIG BEDROCK	STRUCTURAL
4. JOINT		LESSIG BEDROCK	"
5. SMALL FAULT	Only a few feet displacement	"	"
6. GULLIED BEDROCK	The lineation coincides with a soil filled gully in the top of the bedrock	"	ROCK FORM
7. COOMBE DEPOSIT LIMIT	The boundary of transported "soil"	SIGSOIL	SOIL LIMIT
8. CLAY WITH FLINTS LIMIT		SIGSOIL	SOIL LIMIT
9. UNOBSERVABLE	Field evidence inaccessible	NO EVIDENCE	UNRESOLVED
10. FRACTURE ZONE		SIG BEDROCK	STRUCTURAL
11. BURIED GULLY LIMIT	The edge of a wide variety of No.6	LESSIG BEDROCK	ROCK FORM
12. CLIFF OBSCURED		NO EVIDENCE	UNRESOLVED
13. NO OBVIOUS FIELD CAUSE		IRRELEVANT	UNRESOLVED
14. GROUP OF JOINTS		LESSIG BEDROCK	STRUCTURAL
15. LANDSLIP IN SD	A landslide not involving bedrock	LESSIG SOIL	LANDSLIP
16. VALLIED BEDROCK	A valley in the bedrock surface	LESSIG BEDROCK	ROCK FORM
17. LANDSLIP SCARP		LESSIG SOIL	LANDSLIP

18. LANDSLIP MARGIN	The boundary between moved and unmoved ground at the sloping sides of a landslide	LESSIG SOIL	LANDSLIP
19. LITH CONTACT	A contact between two rock types	SIG BEDROCK	LITHOLOGY
20. LAVA FLOW CREST	Upper edge of flat topped dipping lava flow or tabular intrusive	LESSIG BEDROCK	LITHOLOGY
21. SOIL CONTACT		SIG SOIL	SOIL LIMIT
22. SOIL LIMIT	Originally the edge of bare rock, but abandoned as not pertinent to study		
23. DYKE IN INACTIVE FAULT		SIG BEDROCK	STRUCTURAL
24. FAULTED LITH CONTACT	A rock contact caused by a fault	SIG BEDROCK	STRUCTURAL
25. BEDDING TRACE	The surface trace of a bedding plane	SIG BEDROCK	STRUCTURAL
26. POSSIBLE FAULT	A fault inferred from field evidence, but the rocks on the one side obscured or removed by erosion	SIG BEDROCK	STRUCTURAL
27. ACTIVE FAULT	Renewed movement during or after soil formation	SIG BEDROCK	STRUCTURAL
28. INACTIVE FAULT		SIG BEDROCK	STRUCTURAL
29. ACTIVE FAULT AND DYKE	A dyke emplaced in an "active" fault	SIG BEDROCK	STRUCTURAL
30. SAND BLOWOUT	Trace of windblown sand in or near fixed dunes	LESSIG SOIL	SOIL FORM
31. NATURAL DRAINAGE INTERRUPTION		IRRELEVANT	UNRESOLVED

32. MAN-MADE DRAINAGE INTERRUPTION		IRRELEVANT	ARTIFICIAL
33. GLACIAL EROSION		LESSIG SOIL	SOIL FORM
34. EDGE OF GLACIAL FEATURE		SIG SOIL	SOIL FORM
35. EARLY LANDSLIP FRACTURE	Tension crack formed prior to main movement	LESSIG SOIL	LANDSLIP
36. CONSEQUENT GULLY	A drainage gully controlled by the present surface slope	IRRELEVANT	UNRESOLVED
37. LITH CONTACT AND SOIL LIMIT		SIG BEDROCK	SOIL AND ROCK
38. SOILS CONTACT AND FAULT		SIG BEDROCK	SOIL AND ROCK
39. STRAT CONTACT	A "time break" not involving a fault or change in rock type or dip	SIG BEDROCK	STRATIGRAPHIC
40. STRAT UNCONFORMITY	As 39, but with change of dip	SIG BEDROCK	STRATIGRAPHIC
41. CREEP LINE	A terracette	LESSIG SOIL	LANDSLIP
42. OLD COASTLINE	Usually edge of raised beach	LESSIG SOIL	SOIL FORM
43. DYKE		SIG BEDROCK	LITHOLOGY
44. MET BANDING	Bedding trace of metasediment banding	SIG BEDROCK	STRUCTURAL
45. AG SOIL CONTACT	Agricultural soil boundary, not coinciding with a "geological soil" boundary	LESSIG SOIL	SOIL LIMIT

C. Cliff stability classifications

Programme code name	Remarks
1. LOW STABLE	A low cliff (less than 25 feet high) with no obvious tendency to landsliding.
2. LOW SD SLIPS	A low cliff with some landslides in the superficial cover, but not in the bedrock.
3. MODORHI STABLE	Moderate or high stable cliffs.
4. MODORHI SD SLIPS	Moderate or high cliffs. Some landslides in the superficial deposit, not in the bedrock.
5. MAINLY SD AND SLIPS	A cliff formed almost entirely of superficial deposits with some landslides.
6. SPALLING	A cliff suffering from frequent rockfalls.
7. STRETCHING	A cliff formed of seaward dipping beds that have a tendency to creep downdip.
8. DIP SLIDES	A cliff formed of seaward dipping beds with the superficial deposits and/or the beds tending to slide downdip.
9. ROTATION SLIPS	Cliffs composed of, or underlain by, material that fails by rotational shearing.
10. WITHIN LANDSLIP	Lineations recorded inside the moved ground of large landslides.

D. Spatial form classifications

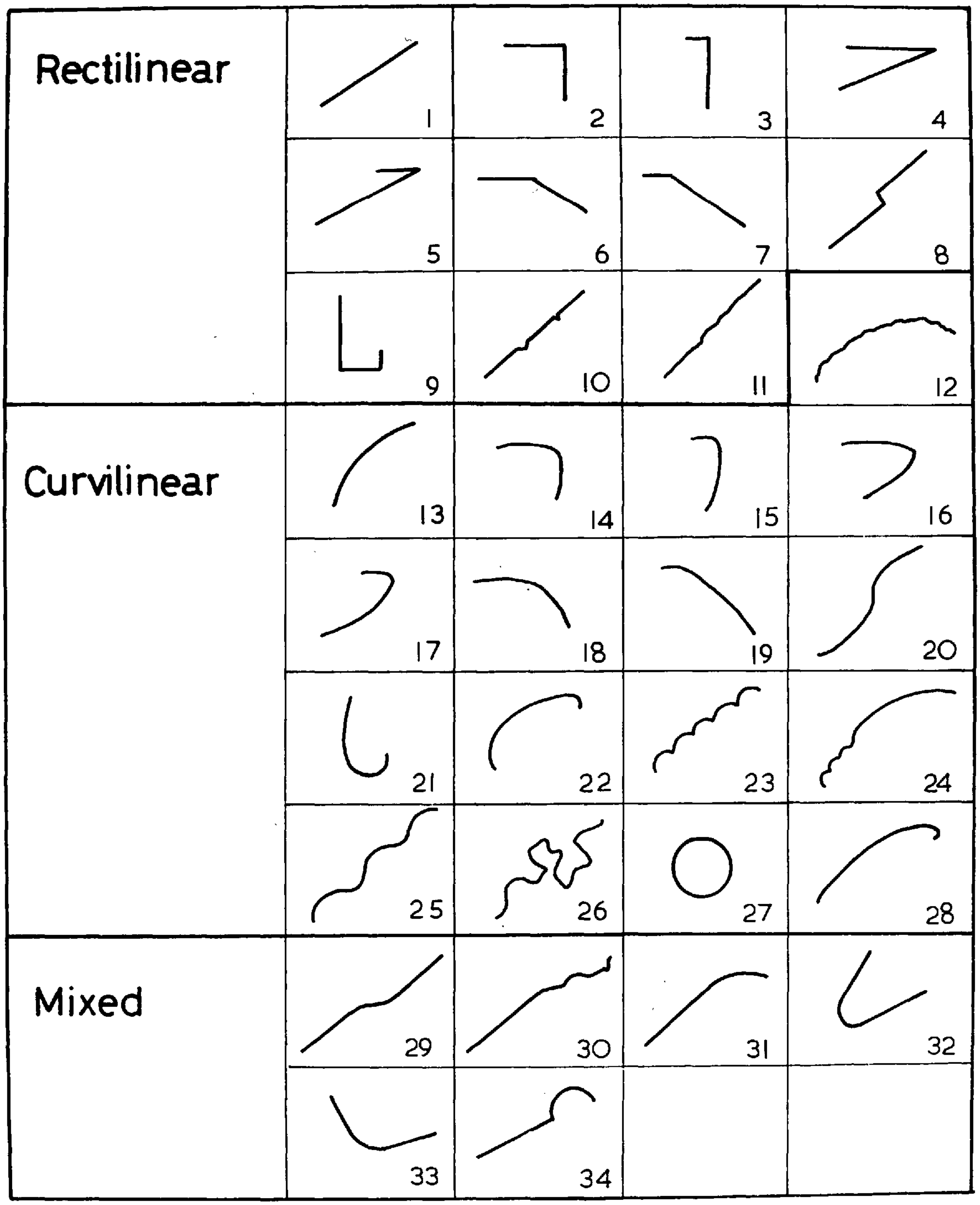
Programme code name	Remarks
1. INDETERMINATE	A lineation which could not be classified as the intersection of another surface with the ground surface.
2. ST LINE ON FLAT SURFACE	A straight line on a relatively flat ground surface which might possibly represent the surface trace of a dipping plane.
3. HIGH DIP	The apparent trace of a highly dipping plane.
4. MOD DIP	The apparent trace of a moderately dipping plane.
5. LOW DIP	The apparent trace of a gently dipping plane.
6. HORIZONTAL	The apparent trace of a horizontal plane.
7. IRREGULAR FOLLOWING TOPOGRAPHY	The apparent trace of an uneven surface that tends to lie over a previous surface. The base of blown sand lying on boulder clay is a typical case.
8. CURVED HIGH	The apparent trace of a highly dipping curved surface.
9. CURVED MEDIUM	The apparent trace of a moderately dipping curved surface.
10. CURVED LOW	The apparent trace of a gently dipping curved surface.
11. CURVED HORIZONTAL	The apparent trace of a horizontal curved surface with a horizontal axis.

E. The tectonic state of the bedrock

Programme code name	Remarks
1. UNJOINTED	Gently dipping beds lacking well defined joints.
2. JOINTS SUMBEDS	Gently dipping beds with local joints that do not normally pass from one bed to the next.
3. COLUMN JOINTS	Columnar joints, confined to the Whin Sill in this study.
4. JOINTED MODDIP	Well jointed moderately dipping beds.
5. JOINTED LOWDIP	Well jointed gently dipping beds.
6. FRACTURED ZONE	A zone of rock containing numerous shear fractures.
7. STEEP FOLDS	Folds with a steep axial plunge.
8. TIGHT FOLDS	Folds that are isoclinal or have a very small dihedral angle.
9. CONTORTED	Strata with many small folds of small amplitude. Confined to metamorphic rocks in this study.
10. STRONG JOINTS	Frequent joints penetrating most of the beds visible in the cliff face.
11. MULTIJOINTED	Beds containing many joints that are short and not tending to show pronounced directional trends.

APPENDIX II

SOME LINEATION SHAPES



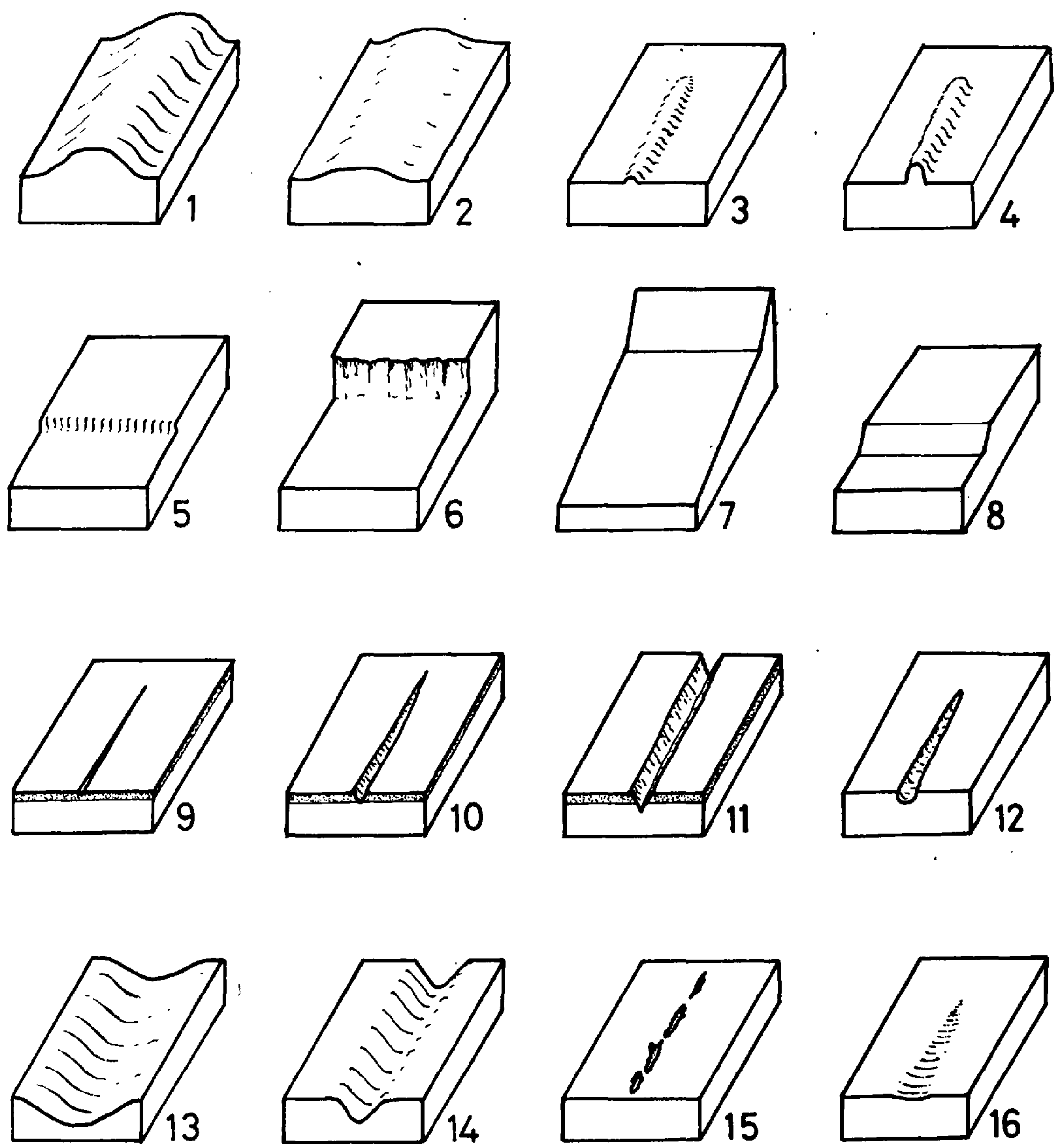
APPENDIX III

Examples of lineation landform types

The series of diagrams on the following page show the main landform lineation types involved in this study. They are numbered as follows:-

1. High broad ridge.
2. Low broad ridge.
3. Low thin ridge.
4. High thin ridge.
5. Step.
6. Cliff.
7. Change of slope.
8. Large step (top and bottom could form separate lineations)
9. Shallow gully.
10. Medium gully.
11. Deep gully.
12. "U"-shaped gully.
13. Valley.
14. Steep-sided valley.
15. Break in superficial deposit.
16. Depression.

LANDFORM LINEATION TYPES

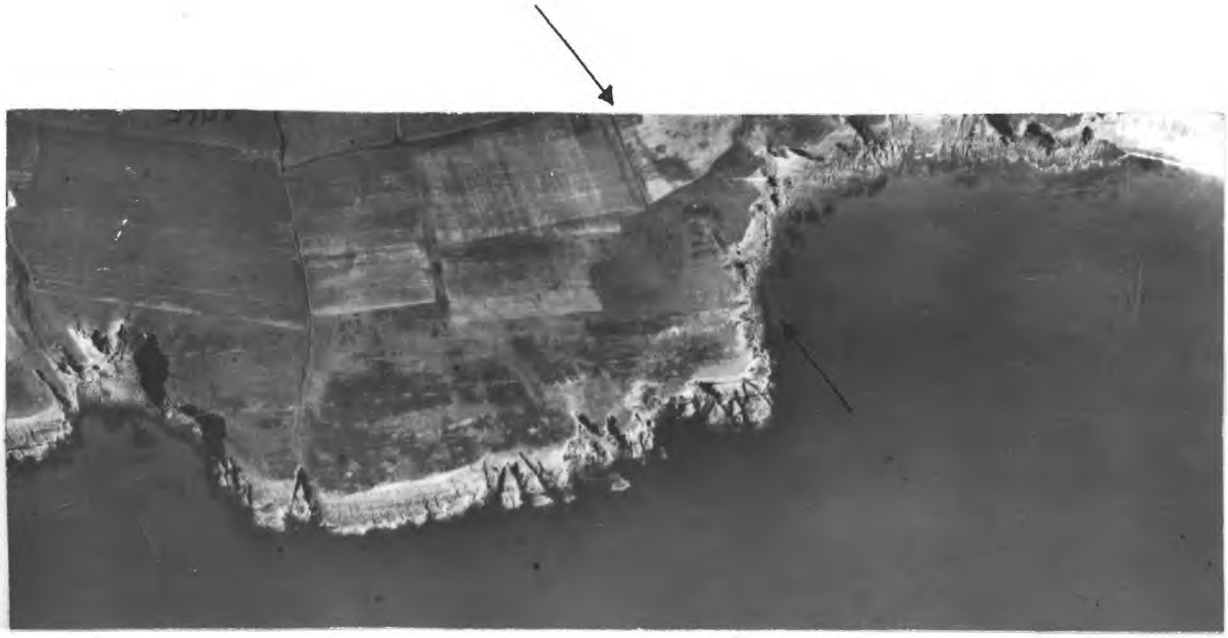


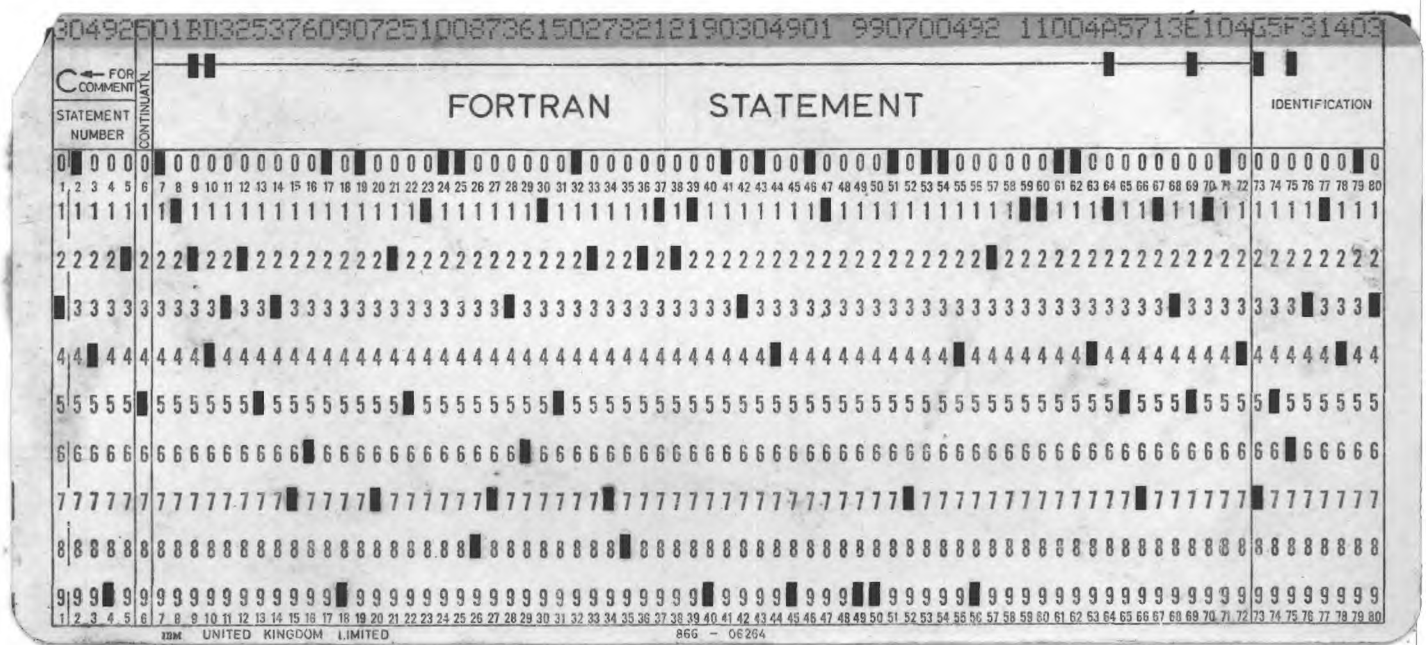
APPENDIX IV

Specimen lineation and punched card

The card on the next page contains the following raw basic data for the lineation shown in the accompanying photograph:-

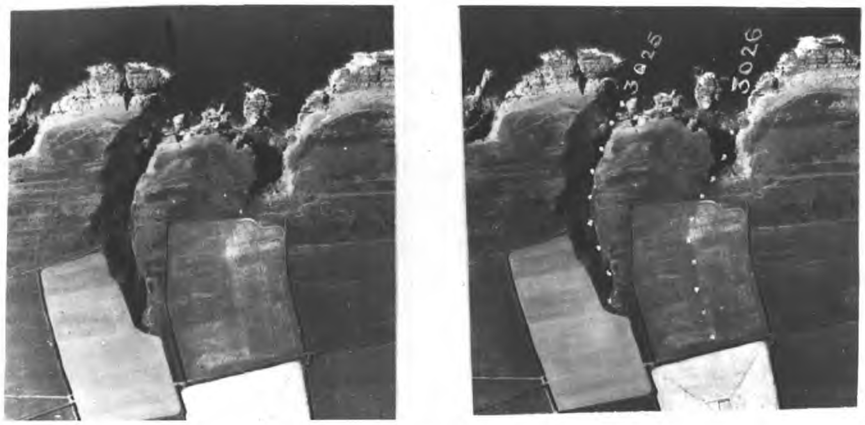
Its serial number is 3049.
It appears as a dark tonal line on the photograph.
The rock was completely obscured by soil.
The ground is used for arable farming.
Its ground length is 1,200 feet.
Its bearing 153° from True North.
The photograph is of good quality and was No.5376 of R.A.F. Sortie No.106G/UK/1625.
It was photographed at 9 in the morning in the month of July.
The nominal photograph scale is 1:10,000.
The lens type was not recorded.
The coastal bearing is 87°.
The bedrock was marl and of Lower Old Red Sandstone age.
The spatial appearance on the photograph was that of a vertical or steeply dipping plane intersecting the ground surface.
The cliff locally was free from landslide tendencies and was 190 feet high.
The bedrock dips at 82° with a bearing of 12° from True North.
The shape of the lineation is a straight line.
The superficial deposit is a residual soil and it is a "Sandy Clayey Silt", classified as ML under the CASAGRANDE scheme.
The lineation cuts at right angles a family of very closely spaced parallel lineations on the photo.
There is 4 feet of superficial material above the bedrock.
The area had been glaciated, the direction of the last movement being 115°.
The ground surface sloped evenly and gently with a bearing of 193°.
The main bedrock joint azimuths are 151° 4° 175° 163° 14°.
The geological cause of the lineation is a fault in the bedrock.



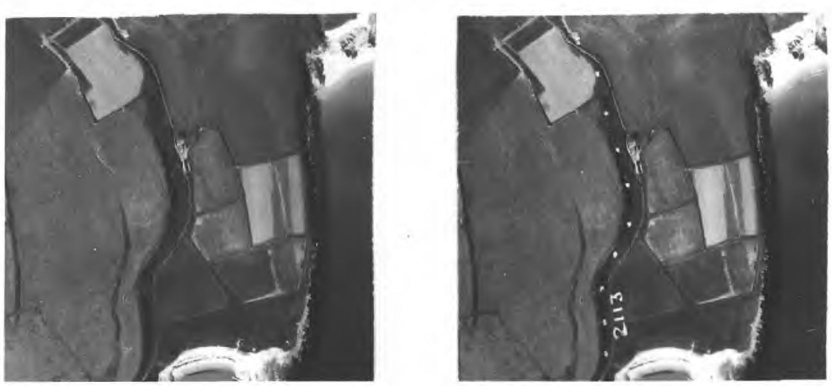

30492E01BD3253760907251008736150278212190304901 990700492 11004A5713E104G5F31403
C FOR COMMENT
STATEMENT NUMBER
CONTINUATN.
FORTRAN STATEMENT
IDENTIFICATION
IBM UNITED KINGDOM LIMITED
866 - 06264

APPENDIX V

Stereo photographs of different types of lineations

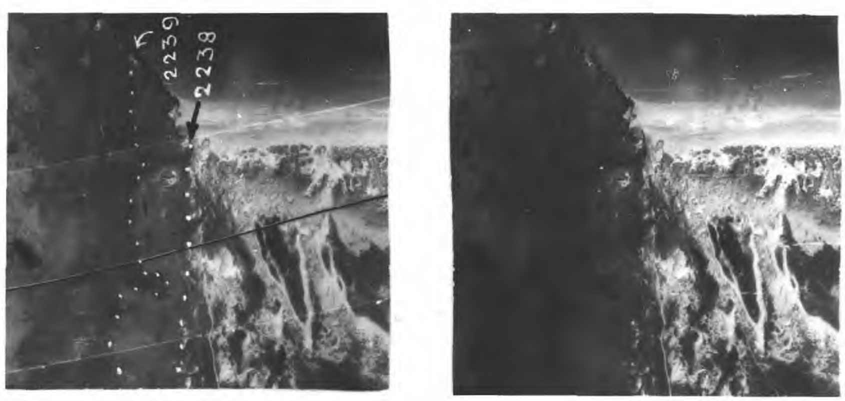


Lineation 3025 is a deep gully formed along a fault. Lineation 3026 is tonal boundary (and at its inland end a dark tonal line) that also coicides with a fault. These lineations cross normally a closely-spaced family of parallel lineations consisting of light tonal lines running from left to right. They are bedding traces of almost vertical marl and sandstones under a residual soil.

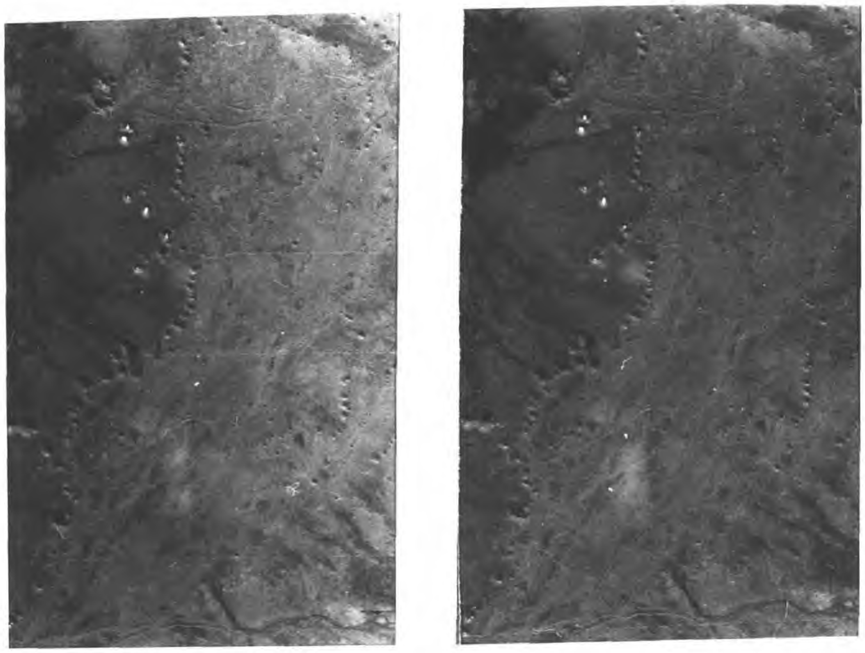


Lineation 2113 is a"large" step formed by a thick bed of gently dipping limestone. There is a general cover of 10 feet of boulder clay over the limestone.

Lineations 2018 and 2020 are both vegetal and tonal boundaries that are also locally steps and gullys. They are both faults coinciding with soil boundaries, and show the limit of a central, lighter toned, tongue of boulder clay between two areas of thin residual soil on limestone. The boulder clay boundary has also been selected by the farmer as the limit of regular cultivation whilst the limestone soil is only used for rough grazing.



Lineation 2238 is a texture/pattern boundary that marks the contact between an area of blown sand (with dunes vividly revealed) and boulder clay. Lineation 2239 is a tonal boundary marking the limit of a superficial sandy clay formed by "stray" blown sand intermingling with the boulder clay.



A tonal boudary coinciding with a line of sink-holes marks a contact between shale and limestone that is concealed beneath boulder clay. The lighter toned soil and general absence of surface drainage indicates the limestone side of the boundary. The white spots in some sink-holes are probably small patches of snow. Although these holes are a "line of breaks in the superficial deposit", they represent a special case, and the more common occurrences are elongate.

APPENDIX VI

Interpretation tables

The exploitation of the results of this type of investigation can be best achieved by an experienced photogeologist assimilating the data obtained in an environment similar to that which he is about to study. This information should be added to his experience and knowledge of principles to give him a basis for decisions. It would need a considerable accumulation of data to equip a computer-pattern recognition system adequately, or for that matter, another geologist new to the nature of photogeology. However, one scheme of operation in this respect is shown in the following tables, which, where relevant, incorporate only data involved in areas of sedimentary rocks concealed by boulder clay and with 1:10,000 scale photography.

The tables are divided into lineation characteristics, as described in the main body of the Thesis, and the number of occurrences is listed against the broad classes of possible causes as follows:

1. Soil contact.
2. Soil form (e.g. drumlin, esker, kame etc.).
3. Recent consequent drainage.
4. Landslide phenomena.
5. Glacial erosion.

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6. Fault.
7. Rock contact.
8. Bedding trace.
9. Joint.
10. Dyke.
11. Bedrock surface features.

The numbers in each column for every visible characteristic of an uninterpreted lineation should be added, and the magnitude of the final totals used as an indication of the relative likelihood of the different possible causes. Where an "X" occurs in a column, it is considered that the feature is so unlikely to be connected with the listed cause that this particular possibility should normally be ruled out. If the final totals do not give a dominant cause, then the possibility of several causes should be considered. For example, a single lineation could coincide with a fault, a rock contact and a soil contact. A careful check may be needed for table A, but in the remaining tables, not more than one characteristic description will be applicable.

It will be noted that causes 1 to 5 are confined to superficial deposits, and 6 to 11 involve the bedrock. If the final totals do not give a clear indication of the cause, the average column totals of each of these two blocks may indicate if it lies in the superficial deposit or bedrock.

The figures in the tables are based on percentage distributions, but some characteristics have been omitted in the case of small samples with possibly misleading results. The overall totals should only be regarded as crude indications, and no mathematical significance can be attributed to them as the contributing characteristics will have different importances. It is not possible to weight the results to compensate for this as the importance of characteristics will vary with environment, and insufficient data exists on this subject. At the end of the tables, a specimen tabulation is shown.

Cause:-	1	2	3	4	5	6	7	8	9	10	11
A. General type											
a) Morphological											
Thin ridge	0	36	X	0	0	10	0	28	0	28	0
Broad ridge	5	15	X	5	5	25	30	10	0	5	0
Shallow gully	0	3	26	3	8	29	11	3	13	0	5
Medium gully	0	0	37	9	0	31	9	0	6	0	9
Deep gully	0	0	27	0	9	18	9	9	18	0	9
Valley	0	0	27	0	9	18	9	9	18	0	9
Step	6	2	8	4	0	28	14	28	6	4	0
Large step	0	5	X	18	0	23	14	32	9	0	0
Change of slope	17	22	0	36	0	7	15	3	0	0	
Depression	0	0	44	13	6	0	6	6	12	6	6
b) Tonal											
Dark tonal line	0	0	24	3	3	33	12	6	12	3	3
Light tonal line	12	6	0	6	0	31	0	19	12	6	6
Tonal boundary	16	4	X	4	0	32	32	4	4	0	4
c) Vegetal											
Vegetal boundary	25	8	0	8	0	17	32	8	0	0	0
Dark line of vegetation	4	0	12	4	8	24	16	4	16	4	8
d) Texture/Pattern											
Texture/pattern boundary	29	3	8	3	0	21	21	8	5	3	0
B. Lineation shape											
Rectilinear	19	0	9	13	1	20	7	9	14	3	5
Curvilinear (regular or gentle curves)	31	3	7	7	0	13	13	9	5	0	5
Curvilinear (complex, irregular curves)											
a) in areas of high dips	79	8	0	4	0	0	4	0	0	0	4
b) in areas of low dips	53	15	0	10	0	0	9	9	0	0	3
Combined rectilinear and curvilinear	19	5	0	10	0	0	5	52	0	0	10

Cause:-	1	2	3	4	5	6	7	8	9	10	11
C. Spatial form											
Steeply dipping plane	5	3	2	21	1	33	4	14	11	3	3
Medium or gently dipping plane	3	0	0	24	0	7	19	38	0	8	0
Steeply dipping curved surface	17	3	0	13	0	30	8	10	11	3	5
Subhorizontal uneven surface	25	25	X	20	0	0	20	5	X	0	0
D. Length											
Length less than 300 feet	4	0	4	45	0	23	4	0	18	4	0
Length 300 to 600 feet	12	2	3	25	0	21	7	13	9	2	5
Length 600 to 1100 feet	25	4	10	7	0	27	11	8	8	1	2
Length 1100 to 2500 feet	28	2	10	5	1	32	14	10	6	2	5
Length 2500 to 50,000 feet	28	1	9	3	0	26	26	1	1	1	6
Length over 50,000 feet	44	5	5	0	0	33	22	0	0	0	0
E. Family relationship											
Normal member of a parallel group	13	5	14	9	6	8	.8	17	15	5	7
Cross-cutting a parallel group	12	7	3	8	2	33	5	0	15	11	3
Cross-cutting and terminating a parallel group	5	1	0	7	0	64	8	3	12	0	0
Member of parallel group crossing another parallel group	4	1	12	8	8	14	1	24	14	8	4
Member of a group of gentle curves	19	13	0	8	0	14	9	18	0	7	12
Solitary straight amongst a group of curves	7	5	11	12	5	21	3	7	16	4	11
Solitary curve amongst a group of straights	27	7	0	6	3	15	11	22	0	2	7
F. Lineation curvature											
Minimum radius of curvature less than 250 feet	30	9	0	6	0	17	13	25	2	1	0
Minimum radius between 250 and 1000 feet	20	5	3	15	1	22	16	8	4	1	6
Minimum radius over 1000 feet	11	2	7	19	2	23	10	9	14	2	3

The following tabulation has been made in respect of Lineation No.3049, which has been described in Appendix IV. The left hand column lists the relevant selection from the recorded characteristics.

LINEATION 3049

	Cause :-	1	2	3	4	5	6	7	8	9	10	11
A.	Dark tonal line	0	0	24	3	3	33	12	6	12	3	3
B.	Rectilinear	19	0	9	13	1	20	7	9	14	3	5
C.	Steeply dipping plane	5	3	2	21	1	33	4	14	11	3	3
D.	Length = 1100 to 2500 feet	25	4	10	7	0	27	11	8	8	1	2
E.	Cross-cutting a parallel group	12	7	3	8	2	33	5	0	15	11	3
F.	Minimum curvature over 1000 feet	11	2	7	19	2	23	10	9	14	2	3
	TOTALS	72	16	55	71	9	169	49	46	74	23	19

The order of probability of the cause is thus:-

	"SCORE"
Fault	169
Joint	74
Soil boundary	72
Landslide	71
Consequent drainage	55
Rock contact	49
Bedding trace	46
Dyke	23
Bedrock surface feature	19
A soil feature	16
Glacial erosion	9

The feature has been proved to be a fault by a field investigation.

APPENDIX VII

Certificate required by paragraph 32.4 of the "Regulations for Internal Students Proceeding to Higher Degrees"

1. This Thesis "embodies the candidate's own research or observations" except where it is stated otherwise in the text.

2. "His investigations appear to him to advance the study of his subject" in that

   a) a unique study of the appearance and causes of geological features on air photographs is reported, and

   b) new criteria for interpreting geological data from air photographs are established.

Signed

J.W. Norman

(J.W. NORMAN)