THE GEOLOGY OF THE LANGHOLM-ECCLEFECHAN AREA EASTERN DUMFRIESSHIRE

by

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Plate I

GILNOCKIE TOWER from the north-west, showing a syncline in Lower Limestone rocks in the foreground.

CONTENTS

INTRODUCTION.

The area studied lies in Eastern Dumfriesshire between the rivers Esk and Annan. The northern and southern boundaries are roughly defined by the Langholm - Lockerbie, and the Canonbie - Kirtlebridge roads, which follow, roughly, the junction of the Upper Palaeozoic rocks with the Lower, and the crop of the Permo Triassic deposits, respectively. Some additional work was also done on the Lower Carboniferous rocks extending north-eastwards from Langholm into Roxburghshire. The Esk section south of Gilnockie Bridge was not studied in detail and is not included, so that the rocks examined range in age from the Upper Old Red Sandstone to the Lower Limestone Group of the Carboniferous formation.

The thesis falls conveniently into two sections. The first consists of a stratigraphical account of the main rock groups of the Old Red Sandstone and the Carboniferous. It amplifies and amends the work of Peach and Horne, and is supplemented by a description of the tectonic relations of the strata. Zoning below the Lawston Linn Coal Group (D_1) is impossible because of the almost total absence of fossils. The second part is a petragraphical study of the Lower Tuedian sediments, that is the Whita Sandstone and Cementstones.

The research was made possible through a Shell Post-graduate Studentship and my deep thanks are due to the Company for their generosity and help in many other ways. I am/

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History of Previous Research.

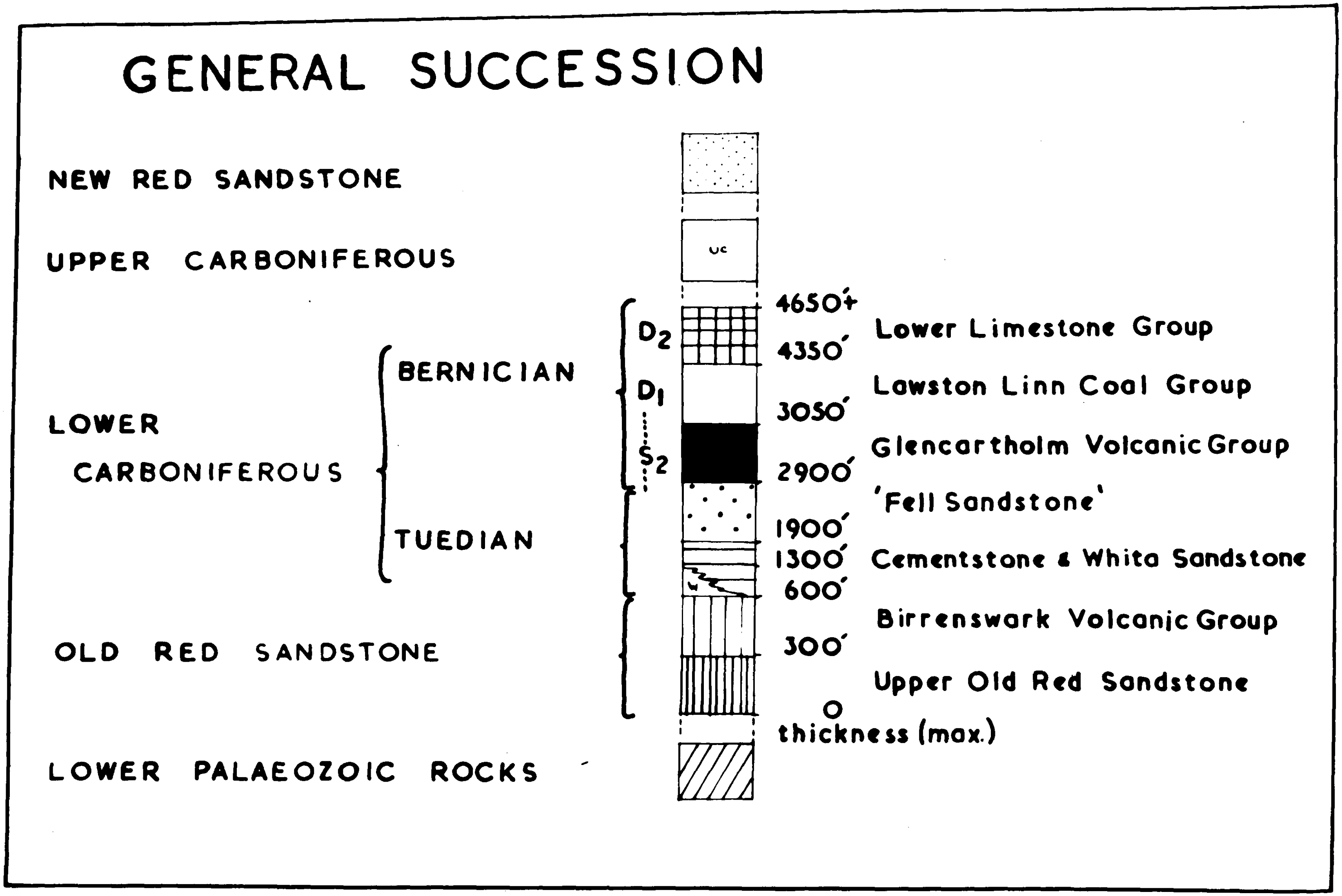
While the adjacent country in Liddesdale, Cumberland, and the Solway coast have attracted attention during the present century, eastern Dumfriesshire has been little studied since 1900.

The first map and account of the area formed part of a paper by Gibsone (1861). He made the broad stratal divisions of :-

Coal Formation	Upper or Thick Coal Series	5
	Lower Series	4
Carboniferous Limestone	Upper Series	3
	Lower Series	2
Old Red Sandstone		I

He stated that the Old Red Sandstone "... may be considered (as) the commencement of the Carboniferous strata, there being in many places a perfect blending of the Old Red Sandstone into the Carboniferous Limestone ..... but these divisions are useful indicating to the eye some well-known and distinctive strata in each to the eye."

Following upon the survey of Peach, Horne, Skae, Jack and Wilson, the one inch O.S. maps appeared, sheet II in 1883, and sheet IO two years later. No sheet memoirs were published. Only summary descriptions of the Lower Carboniferous rocks prefaced the paper on the Canonbie Coalfield by Peach and Horne (1903), in which the generally accepted Carboniferous succession, given below, was first put forward. The descriptions of the Lawston Linn Coal Group, and the Lower Limestone Group were based more on the better exposures in Liddesdale than on the Esk succession, and the faunal list of the former group is derived entirely from the Liddesdale area.


GENERAL SUCCESSION
NEW RED SANDSTONE
UPPER CARBONIFEROUS
LOWER CARBONIFEROUS
BERNICIAN
TUEDIAN
OLD RED SANDSTONE
LOWER PALAEOZOIC ROCKS
UC
D2
D1
S2
4650'+
4350'
3050'
2900'
1900'
1300'
600'
300'
0
thickness (max.)
Lower Limestone Group
Lawston Linn Coal Group
Glencartholm Volcanic Group
'Fell Sandstone'
Cementstone & Whita Sandstone
Birrenswark Volcanic Group
Upper Old Red Sandstone

SECTION I. Stratigraphy & Structure.

Upper Old Red Sandstone.

The series is made up of a variety of sandstone types. A basal conglomerate is developed which ranges from a pebble to a cobble conglomerate, and is of variable thickness. In general the grain size decreases upwards although pebbly and gritty bands may occur at any horizon. The sandstones are generally brightly coloured, reds and purple predominating, with pale colours rarely found. The finer sandstones are commonly micaceous. Marl horizons are developed and rare thin greenish cornstone bands occur. Bedding is commonly massive, and current bedding is not infrequent.

The maximum thickness is about 300' seen in the Mein Water, Water Beck, and on the west slope of Whita Hill(where some thirty to fifty feet from the top a Holoptychius scale has been found).

For convenience the Old Red Sandstone exposures can be grouped into those west of the Esk, and those of the Esk and Tarras to the east. By far the best exposed successions are seen in the adjacent valleys of the Mein Water, Water Beck, and a tributary of the Kirk Burn, lying north of Waterbeck. The basal conglomerate in each case is a red stained pebble conglomerate with pebbles of vein quartz, clay galls and sandstone and greywacké fragments in reasonably fresh condition. The underlying greywacké is also seen to be red stained. The Old Red here appears to be banked up against the lower/

lower/ Palaeozoic rocks.

In a tributary of the Mein Water the basal conglomerate is followed by several thick bands made up of sub-rounded red sandstone fragments set in a red sandstone matrix with other material such quartz pebbles absent. The conglomerate then is made up of broken up fragments of a barely consolidated sandstone. The succeeding sandstones show progressively finer grain, and the sporadic pebbly horizons which occur are more in the nature of pebbly sandstones than true conglomerates. In the Birrenswark range only one exposure is found west of the Mein Water. In a small quarry, a few feet below the base of the Birrenswark lavas, a coarse pebbly grit is exposed. The total thickness at this point is only half the thickness found in the Mein Water half a mile distant.

Between Waterbeck and the Esk are the two small outliers of Winterhopehead and Hallcroft. At Winterhopehead the thin basal, cobble conglomerate is followed by fine red sandstone with thin cornstone bands, although no more than 20' of strata is exposed. At Hallcroft exposures are better and the basin-like form is clear. The third exposure between Waterbeck and the Esk is seen at Cleuchfoot where Old Red Sandstone is conformably overlain by a lava flow, the base of which is weathered to a greenish clay like material.

The Old Red Sandstone is exposed on both White Hill and Warbla, and sporadically north-eastwards. The basal "conglomerate" is seen resting on a planed lower Palaeozoic surface in the Cooms Burn and on White Hill. In both localities it is more of a pebbly sandstone than true conglomerate, and in general coarse material is not as common as near Waterbeck. Northeast of White Hill the thickness is fairly constant averaging about 150'.

The Upper Old Red Sandstone represents the first deposits on an irregular Lower Palaeozoic floor.

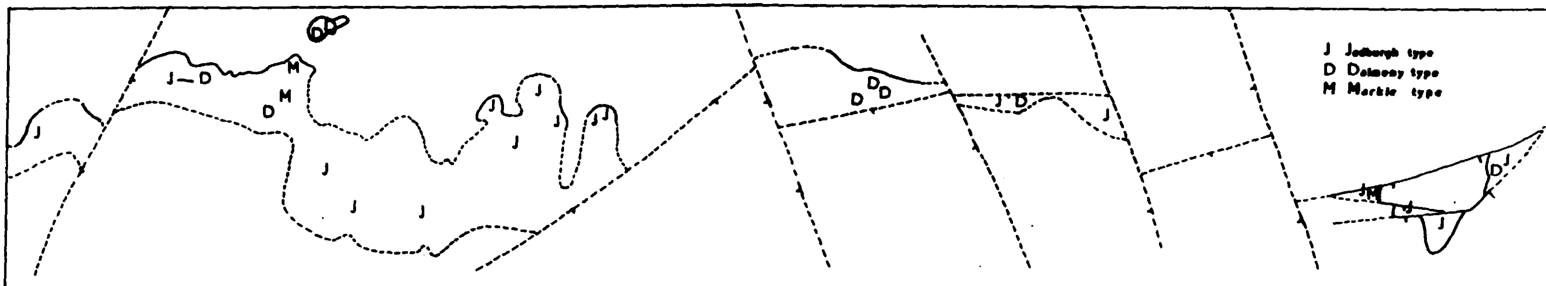


fig 1. DISTRIBUTION OF BASALT LAVA TYPES IN THE BIRRENSWARK VOLCANIC GROUP

Birrenswark Volcanic Group.

Petrographically the Birrenswark volcanics belong to the Scottish Permo-Carboniferous igneous province (Tomkieiff 1937, McGregor 1928, 1937). The succession shows more slaggy, vesicular, porphyritic Dalmeny type basalt flows at the base, followed by finer, more compact Jedburgh type lavas. In addition to Jedburgh and Dalmeny type basalts, Markle basalt flows are occasionally found, and the distribution shown in fig. 1, is based on some fifteen microscope determinations and a summary of the results of Pallister (1952). The lavas are invariably weathered to a greater or less extent and in the field their colour may range from grey to red, purple or blue.

The maximum thickness of the group is about 300' in the Birrenswark range, the almost unbroken outcrop stretching from the Annan to near Waterbeck. At Langholm there is only some 200', the thickness decreasing to the northeast there only being about 100' round Hog Fell and Cooms Fell.

Individual flows can be detected, the thickest of the five seen on Whita Hill is over 40', but owing to sporadic outcrop they cannot be traced any distance. Intra-basaltic horizons occur, the thickest on White Hill comprises some 5' of red marl. Resting on the uneven surface of the highest flow in Middlebie Beck is penecontemperaneously weathered lava material. It is made up of exfoliated /

exfoliated blocks of lava in a still more highly weathered lava matrix. The overlying beds are not exposed.

Alteration of the lavas has resulted in the replacement of olivene by iddingsite which itself shows signs of alteration; in the replacement of most or all of the ferromagnesian minerals and in the partial alteration of the felspars. Iddingsite zeolites, chlorite chloraphaeite, iron ores and calcite are common secondary minerals. Basalt was quarried on a small scale near Torbeckhill, for the extraction of copper, about the middle of the 19th.century. Small xenoliths have been found in the top of a flow on Warbla. Flow structure is commonly found, particularly in Jedburgh type lavas.

The base of the lavas is only seen at Cleuchfoot where Old Red Sandstone cores an anticline. Here the boundary is seen to be perfectly conformable, the lava base being weathered to a greenish clay material overlying soft red sandstone the top of which seems to be bleached. Near Arkletonshiels in Tarras the lava is in two leaves separated by some 30' of rather variable sandstone. The junction between the sandstone and the upper and lower leaves is not seen, nor is the lava junction with the Whita Sandstone above and the Old Red Sandstone below.

The upper boundary of the lava is only seen near Westwater where highly weathered lava is overlain by a greenish clay containing weathered lava fragments and followed by thin/

thin/ sandstones giving way in turn to a normal cementstone succession. Tuffaceous material is found on Whita Hill at what must be a high horizon, though inadequate exposures make certainty impossible.

The Birrenswark Volcanics have been taken as the base of the Carboniferous in this part of Scotland (Peach & Horne, 1903, South of Scotland Regional Handbook). It is here concluded however that the lavas are of Upper Old Red Sandstone Age.

The lavas lie, apparently, conformably on sandstones of the Upper Old Red Sandstone, as seen at Cleuchfoot, Arkleton-shiels and in the Birrenswark Range. Their highly weathered state associated with bright colouring is the product of conditions involving strong oxidation more characteristic of the Old Red Sandstone than of the Lower Carboniferous. (The probability of an unconformity above the lavas is discussed in the Cementstone section).

The conclusion agrees with M'Robert (1915) who, of Liddesdale stated that volcanic activity began in Upper Old Red Sandstone times and ".....passes up a little way into the Whita Sandstone which is the base of the lower Carboniferous in Liddesdale". Further east in Berwickshire, Manson and Phemister (1933) concluded that vulcanicity, as represented by decomposed basalts of probable Dalmeny type, ended before the beginning of the Carboniferous.

White Sandstone.

The Whita Sandstone is a pure, homogeneous, non-micaceous, white to grey fine-grained sandstone. It is usually massive and thick-bedded, with rare, thin, greenish siltstone partings. Calcareous lens and bands, in a more or less decalcified condition are found near the base. The bands containing a large amount of iron have a characteristic reddish brown colour when fresh and which, weathering to a yellow-brown contrast markedly with the surrounding pale-coloured sandstone. Towards the top pebbly horizons of predominantly vein quartz pebbles are developed, and these horizons too may have a rich iron staining. Current bedding is not common and is confined to near the top. The detailed petrography of the Whita Sandstone is given in Section 2, and summarised on Tables 1 and 2.

The maximum thickness of the Whita Sandstone is about 700' in the Esk. Due to faulting it is not seen west of the high ground of Warbla. Near Westwater some four miles west of the Esk the sandstone has died out, as Cementstones rest directly upon weathered lavas. This represents an average thinning of the sandstone, of one foot in every thirty over the four miles. The Whita Sandstone can be traced north-eastwards to the Roxburgh boundary, forming the dip slopes of Cooms Fell and Roan Fell Flow lying to the north of Langholm-Newcastleton "Moor Road". The sinuous form of the outcrop round Hog Fell is a reflection of the topography and

and/ not due to structural causes. Although the Whita Sandstone thins, the rate of thinning northeastwards is considerably lower than west of the Esk.

The base while not exposed in the Esk can be accurately located near Longwood and its position, north-east of Langholm can usually be narrowed to a 20' zone, since the underlying lavas are usually fairly well exposed. The upper junction with the Cementstone is transitional and not well exposed, the passage to Cementstone being only well seen in the Docken Beck, a tributary of the Esk.

Cementstone Group.

The Cementstone Group is made up of alterations of thin cementstone bands with similar thicknesses of sandy mudstones. Sandstone horizons are not uncommon, and become important near the top and near the base of the succession. Fossils are not common and almost entirely restricted to modioliform lamellibranchs, small gastropods, ostracods, and serpulid tubules. In only one locality, near Ecclefechan, have brachiopods been found. Plants are abundant in the sandstones in the Docken Beck where rootlet beds also occur. Small carbonised plant fragments are also found in some cementstone bands.

A typical Cementstone band is blue grey when fresh weathering to a yellow-brown. Bright yellow or brick-red staining is not uncommon. Bands are usually without lamination and with a somewhat modular appearance. They are normally very fine grained with a conchoidal fracture, but may occasionally have a saccharoidal-granular texture. Calcite vugs may occur and be either small, orcomparatively large and numerous in comparison with the thickness of the band.

The thickness of a cementstone band is variable, ranging from less than one inch to over a foot, and although variable in a single band, in general lies between two and six inches. A band may die out and may or may not be continued as a line of nodules before disappearing, with a consequent thinning of the succession. The thinning does/

does/ not quite equal the thickness of the band. These factors make it impossible to correlate sections in detail, particularly since no reliable marker horizons have been found.

Some of the problems associated with Cementstone formation are discussed in Section 2.

Owing to small scale folding and incomplete exposures, it is difficult to make a reliable estimate of the thickness of the Cementstone Group. In the Esk some 600' would seem to be present while westwards near Westwater the figure is about 1,000' and near Ecclefechan some 1100' was estimated. In the Esk region the juncture of the Cementstoneswith the Whita sandstone is transitional. This is well seen in the Docken Beck where the base is taken at the incoming of the first thick sandstone horizon. Above, some 100' of a normal Cementstone sequence ("normal" being alternations of cementstones and mudstones with subordinate sandstone) is well exposed. The lowest fossiliferous horizons are two "rootlet" beds, thin sandstone bands with mudfilled rootlet casts, one of which is visibly inconstant. About the middle of the Docken Beck succession a cementstone band with modioliform lamellibranchs and small gastropods in the lowest half-inch is found. A few feet higher, immediately under the road bridge a sandstone with a profusion of branch, and strap-like plant leaf remains occurs. Some of the leaves although incomplete reach up to 18" in length, and the branches are/

are/ correspondingly larger. At a still higher horizon a cementstone with gastropods and another with serpulid tubules separated by a mudstone with Modiola is found in the Esk corresponding to a position fairly high in the Docken Beck succession. The section ends where the Docken Beck enters the Esk and the next succession, seen in the Irvine burn, shows a passage up into "Fell Sandstone".

The Cementstone succession north of Ecclefechan differs from the successions found elsewhere in the development of fossiliferous sandy limestones seen in the burn and poorly exposed in a small nearby quarry. At an estimated distance of 250 feet above the top of the Birrenswark Volcanics a 7 foot limestone with well developed algae is found, containing a fauna linking it with the Syringothyris band found near the base of the Cambeck beds (a C_2 horizon of Garwood 1931) of Bewcastle and Liddesdale.

The following forms have been identified:

Syringothyris cuspidata cf exoleta Martin

Athyris sp

Rhynchonellid

Modiola sp

Mylina sp

Ortonella sp

Ostracoda, Serpulid tubules.

Such a correlation if valid implies either a marked westerly thinning of the Main Algal Series, Bewcastle and/

and/ Lynebank beds (= Lower beds of Liddesdale Garwood 1931) of nearly 3,000 feet, or, alternatively an unconformity.

Some evidence of unconformity is found in the one exposure of the Birrenswark - Cementstone junction in Green Cleuch, a tributary of the Glentenmont Burn near Westwater, where both rock-groups are exposed in the nose of a syncline. As a result of the disharmonic folding of the two series the nature of the contact is obscure. However, a greenish clay with rounded to sub-angular lava fragments is found resting on the top of a deeply weathered vesicular lava. The fragments all appear to be Jedburgh type basalt in varying states of decomposition, the less weathered being non-vesicular. The clay is overlain by a thin (2" - 3") irregular blue shale which is followed by a two foot fine grey sandstone, and a shattered grey cementstone.

Since in the Esk region there is a transitional passage from Whita Sandstone up into the Cementstones any unconformity must lie below the former. It further follows that the Whita Sandstone is diachronous representing a facies of the Main Algal series and lower beds in part at least, for, in Liddesdale Whita Sandstone lies below the Lower Beds.

In the Pokeskine Sike as in the Irvine Burn there is evidence of an upward passage into "Fell Sandstone". The transition is again seen near Hoddom Bridge on the Annan. Here a rhythm, repeated four times, from a basal pebble/

pebble/ conglomerate through a grit to a fine sandstone with a thin sandy limestone or cementstone welded on to the top is found. The rhythmic unit is some six or seven feet thick of which the conglomerate forms more than half. The sandy limestone is rarely more than about two inches in thickness, often less. The top unit ends in a thin fossiliferous limestone which contains Orthoceras , small gastropods and a Zaphrentoid coral.

Fell Sandstone.

The term "Fell Sandstone" needs to be used with caution, for it is by no means certain that the formation corresponds exactly with the true Fell Sandstone of Northumberland, or that they both lie at precisely the same horizon.

The "Fell Sandstone" is dominantly a massive, non-micaceous sandstone. The colour is commonly a mealy yellow-brown varying to a greywhite. Thin bedded and calcareous horizons occur, and current bedding is common. The grain size varies from fine to coarsely conglomeratic with quartz and sandstone pebbles and clay-mudstone galls. It is generally unfossiliferous, but occasional plant remains are found, and towards the top a thin sandy ostracod limestone occurs.

The thickness cannot be reliably estimated owing to discontinuous outcrops, but is probably about 1,000' (at a minimum). Of that thickness only some 200' at most are exposed, near the top, and near the bottom.

The upward passage of the Cementstones into the "Fell Sandstones" with the incoming of thick sandstones is seen in the lower reaches of the Irvine Burn, and less clearly indicated in the Pokeskine Sike. At the latter locality the pebbles of a pebbly sandstone near the base of the "Fell Sandstone" have a westerly orientation. The thick gritty and pebbly sandstones of Gown Muir lie at a somewhat higher/

higher/ horizon. Westwards there is a break in the outcrops, and the next exposure, some 20' of cobble conglomerate and coarse grits, is the only exposure in Brownmoor Wood, although it forms a marked scarp feature. In the River Annan, east of the Hoddom bridge exposures near the base of the "Fell Sandstone", forming fairly continuous outcrops of fine to coarse and pebbly, occasionally muddy, sandstones with variegated mudstone partings are found. Current bedding indicates a source lying to the north-west.

The "Fell Sandstone" is overlain by rocks of the Glencartholm Volcanic Group and consequently the upper contact can be closely defined. It is well seen in both the Palling and Irvine burns and is taken below a sandy mudstone which immediately underlies tuff.

Glencartholm Volcanic Group.

The rocks of the group reach their maximum development in the Esk, where tuff is the main member. Interbedded in the tuff, and lying near the top, are richly fossiliferous shales, sandstone, porcellanous limestone, and chert bands. Sections of the porcellanous limestones and nodules found in the tuff show traces of "Algal dust" (Wood 1941). In addition to porcellanous limestone nodules, fragments of pebble and cobble size and usually rounded, of vein quartz, chert, and fine yellow-brown and white sandstone are found. The tuff itself is strongly weathered and decomposed. The richly fossiliferous horizon does not extend as far west as the Palling Burn. No undoubted lava has been found, and the basalt of the Palling burn might well be regarded as a plug-like intrusion. The beds are of no great thickness, with some 150' in the Esk, although the section is truncated to the north by faulting.

The Esk locality was made famous by the work of Peach, Horne and Macconachie, who obtained an extremely rich and varied fauna from the interbedded shales. The shales are best seen on the east bank, being poorly exposed on the western side, and they are probably represented by poorly exposed black shales seen in the Irvine burn.

The Esk succession is:-

2' fine porcellanous limestone with chert nodules.
1' sandy grey mudstone with plant rootlets.
12' Tuff, sandy towards the top, muddy basally.
15-20' sandy, fossile shale, calcareous in part. "Fossil horizon".
18"-2' porcellanous limestone.
4' chert.

Small gap

4' Porcellanous limestone, section with algal dust.
6-10' Tuff
4' massive green pebbly sandstone
6-10' Tuff.
1' fine blue hard sandstone.
8" soft fine muddy sandstone with three coal streaks.
4'6" Tuff.
18" nodular porcellanous limestone
3' massive fine blue hard micaceous sandstone
about 70' Tuff.

Glencartholm Wood Fault.

The Irvine burn exposures, half a mile west of the Esk, show a marked thinning of the succession, now represented by about 50' of strata. The succession, poorly exposed in a river cliff, is:-

1' fine porcellanous limestone
6" Chert.
2-3' gap.
18" Chert.
9" Tuff.
3' massive somewhat nodular porcellanous limestone.
30-40' gap, showing black shale about the middle.
7' Red sandy marl with irregular bands and lens of pale green fine soft sandstone.

In the Palling burn, only the tuff, basalt, and marl-mudstone underlying the tuff are seen, but with a break in exposures above the tuff one cannot be certain that cherts and porcellanous limestones do not occur. The exposed thickness of tuff is some 40-50'. Basalt which is exposed only in the burn, and is not seen in a parallel stream 200 yards away, lies entirely within tuff. It is an extremely fresh Dunsapie type basalt, and is considered to be a plug-like intrusion, although the field evidence is not conclusive. Near Allfornought some three feet of tuff with an anomalous dip is found. It seems probable that the group is thinning westwards and may disappear west of Allfornought.

A correlation of the Glencartholm Volcanic Group with the Cockermouth lavas (described by Eastwood 1927,1946) has been suggested, and hence an age not earlier than S_2 and said to be about C_2S_1 (Pringle 1948 p.57) is given. However, with sporadic volvanic activity from Upper Old Red Sandstone times onwards, such a correlation is at best dubious, and fossil evidence from the immediately overlying Lawston Linn rocks suggests that the age of the Glencartholm rocks may be higher than was thought.

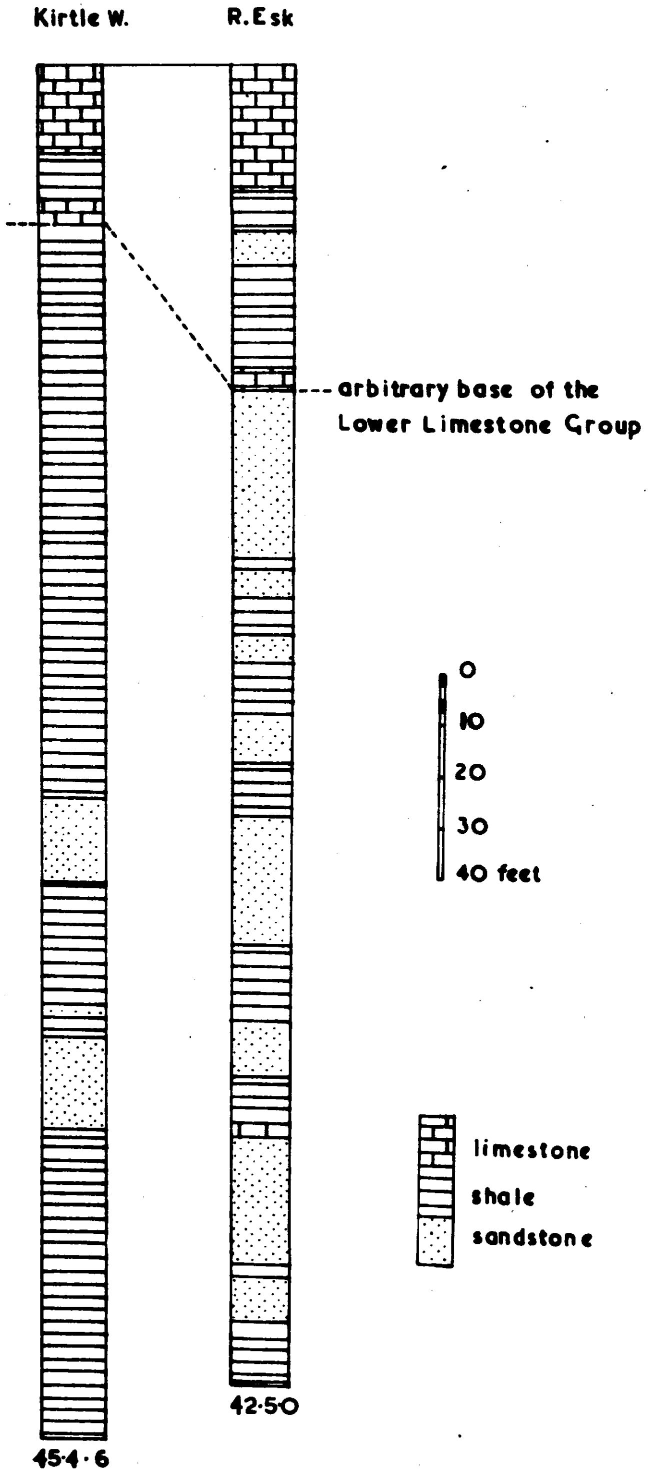
Lawston Linn Coal Group.

The group is made up, in the lower part, of thin muddy limestones, shales, in part calcareous, and thin sandstones; and in the upper part, mainly of sandstone with subordinate shale bands. While the group takes its name from a locality in Liddesdale where coal has been worked, the coal horizons in, and west of, the Esk are never more than a few inches thick. The best development of the group is found in the Esk, and in the Kirtle, where the sandstones of the upper part of the succession, appear to be both thicker and coarser.

Away from the two main areas, exposures are poor, and coupled with both folding and faulting, makes the thickness difficult to estimate. Some 450' are seen in the Esk, and the thickness there, making allowance for faulting, is probably 750'. Well south of the Palling Burn, the Bogra bore passes through 450' of sandstone and shale without touching limestone, and a thickness of the order of 1200 to 1500' for the western districts is estimated.

The Esk and Kirtle outcrops both conveniently fall into two groups separated by faulting. In the Esk, the lower group of shales, muddy limestones and thin sandstones is brought against the upper part of the succession, which although having calcareous shale and muddy limestones near the base, is made up mainly of fine yellow-brown, thin bedded, occasionally micaceous, commonly current bedded sandstones,

fig 2
Comparative sections
below lowest thick limestone



sandstones,/with thin shales. Of the Kirtle outcrops,one group is found near Linnbridgeford Mill, and also seen to a smaller extent in the Kirk burn flowing parallel, and is made up largely of gritty sandstones, with thin shales. Opposite the Mill itself is a highly carbonaceous shale with coal streaks which was once locally worked for fuel. The other group of exposures, near Blackwoodridge exposes beds immediately below the Lower Limestones. They comprise an alternation of red marls and sandstones, the marls disappearing at lower horizons while the sandstones may become gritty or even conglomeratic. The lowest horizon of the group is a richly fossiliferous sandy mudstone with productids,chonetids,various lamellibranchs and gastropods. East north east, near Conhess beds, mainly sandstone, with a similar dip and strike are found, the sandstones sometimes containing brachiopod casts.

The thickening and coarsening of the upper beds of the Lawston Linn group westwards is illustrated by vertical sections of the Esk and Kirtle strata (Fig. 2). The Kirtle section, taken from the Howarth bore-log stops about 150' above the fossiliferous shale horizon, while the Esk section goes down to the appearance of muddy limestones and shales.

The lower Lawston Linn horizons of the Redstones, Cadgill, Smallholmes and Hall burns are much like the Esk, with muddy limestones containing dendroid lithostrotions and occasional productids as common fossils, shales and sandstones.

While the base of the group, resting on the Glencartholm Volcanic rocks, can be easily defined, the choice of an upper boundary is purely arbitrary. In each of the three main areas where the Lower Limestones are exposed, the Esk, Kirtle and Kirtlebridge, the lowest thick limestone is underlain by a thick shale and a thin limestone. This thin limestone, 3' in the Esk, 5' in the Kirtle (bore record) and apparently 8' at Kirtlebridge, is taken as the base of the Lower Limestone Group. Although a definite correlation of this limestone between Kirtlebridge and the Kirtle is possible, since the overlying thick limestone has a distinctive conglomerate roof, equivalence with the Esk cannot be definitely maintained.

Since the Lawston Linn faunas listed by Peach and Horne (1903) were not collected in Eskdale or the area to the west, although they claim "...Similar fossil lists might be supplied from the limestones.... ...and in the Esk", a list of localities is appended.

The forms found are: (microfauna identified by Dr. Cummings):-

Lithostrotion irregulare	Phillips	7,14,15,17
Lithostrotion scoticum	Hill	14, 18.
Lithostrotion clavaticum	Thomson	15, 17
Syringopora sp		12,17.
Syringopora ramulosa	Edwards & Haime	5.
Caninia juddi	Thomson	17.
Caninia cornucopiae brockleyensis	Thomson	18.
Koninckophyllum (Lophophyllum) cf tortuosum	Michelin & Carruthers	5.

Athyris sp		9, 16, 17
Camarotoechia sp.		3, 4, 5.
Camartoechia (Rhynchonella) pleurodon	Phillips	4,
Chonetes sp.		5, 6, 9, 15.
Chonetes hemisphaericus v.Semenew		1, 2,
Chonetes laguessianus de Koninck		5, 9
Phiochonetes (chonetes)buchianus de Koninck		5,
Echinoconchus sp		18,
Echinoconchus (Productus) elegans	M'Coy	5,14,
Orthotetid sp		18,
Schellwienella sp		17,
Rhipidomella (Orthis) Michelini	L'Eveille	5,
Streptorhynchus crenistria	Phillips	5
Spirifer spp.		9, 13, 14, 17
Spirifer cf bisulcata	Sowerby	5, 9,
Spirifer duplicicosta	Phillips	18,
Spirifer cf striatus	Martin	16,
Spiriferina sp		1, 3, 4, 9
Spiriferina octiplicata	J de C. Sowerby	4, 5,
Linoproductus (Productus) undatus	Defrance	1, 5
Linoproductus sp		2, 16, 17, 18
Dictyoclostus sp		1, 2, 5, 14, 16, 18
Gigantella sp		5
Aviculopecten spp		1,2,3,13,14,15,16,18
Aviculopecten cf plicatus.	Sowerby	1,2,
Aviculopecten Knockonniensis.	M'Coy	16
Aviculopecten cf clathratus	M'Coy	5,
Actinopteria persulcata	M'Coy	2,
Actinopteria sp		1,
cf. Allorisima sulcata		5,

Edmondia sulcata	Phillips	1,2,6,16,
cf. Lithodomus		15,
cf. Lithodomus carbonarius	Hind	18,
Modiola sp		1,2,4,6,15,16,18,
Modiola Macadami		5,
Myalina sp.		18,
Nucula sp		11,
cf. Parallelodon		2,
cf. Pinna		14,
cf. Protoschizodus		6, 18
Protoschizodus axiniformis	Portlock	1,
cf. Pterinopecten		5, 16,
cf. Pteronites		5,
Sedgwickia ovata	Hind	5,
Solenomya primaeva	Phillips	5,
Sanguinolites sp		5, 13,
Sanguinolites clavatus	R. Etheridge jnr.	16,
Loxonema spp.		5,9,11,14,15,16,
Euomphalus cf pentangulatus		2,
Stroparolus sp.		14,
Stroparolus minutus de Koninck		1, 2, 16,
Macrocheilus cf monodontiformis de Koninck		5, 16,
Pleurotomaria sp		2,
Bellerophon sp		14,
Orthoceras sp		16, 14,
Fenestellid		5, 17,18,
Griffithides cf seminiferus	Phillips	5,
Brachy metopus sp		5,

Plectogyra sp
Plectogyra bowmanni
Plectogyra Baileyi
Endothyra sp
Endothyranopsis crassus
Archaediscus sp
Archaediscus georgei
Archaediscus cf karreri
Saccamminopsis fusuliniformis

Cribrostomum sp
Bradyina sp
Nodosinella sp
Globivalvulina sp
Valvulinella youngi
Cornuspira sp
Calcisphaera
Stacheoides sp
Glomospira sp

List of Fossiliferous Localities in the Lawston Linn Coal Group.

1. Kirtle Water; river cliff east of Nether Albie, near Waterbeck, red shales and muddy sandstones.
2. Kirtle Water; river cliff south of Hotts near Waterbeck; red shales and muddy sandstones.
3. Burn north of Chapelhill, massive purple sandstone
4. Burn east of Conhess, massive white sandstone and east north east at Alder Well, red coarse sandstone.
5. Burn mouth west of Berclees near junction with Cadgill burn, sandy shale and mudstone.
6. Burn mouth north of Berclees near junction with Cadgill burn, sandy shale,
7. And near head of burn, muddy limestone and calcareous shale.
8. Burn due south of Highstenries, tributary of the Cadgill burn, muddy limestone.
9. Burn south west of Highstenries, tributary of the Cadgill burn, limestone and muddy sandstone.
10. Cadgill burn one quarter of a mile north north west of Auchengyle, sandy mudstone and muddy sandstone
11. Cadgill burn calcareous sandstone at west end of Cadgill Wood, and tributary near boundary fence of Cadgill Wood.
12. Thorntour Sike, north north west of Smallholms, tributary of Smallholms burn, muddy limestone.
13. Burn, east of Sarkshiels, tributary of Logan Burn, massive white sandstone.
14. Redstones burn at Bakethin bridge, sandy limestone, and several outcrops of muddy limestone and sandy shale near Fairyknowe.
15. Palling burn at junction with tributary 220 yards south

15.(Contd.) south/ west of Palling burn Wood, red limestone, another thin limestone in tributary.

16. Hall burn in Hallburn wood, south east of Barnglieshead, red shale and red sandy limestone.

17. Hag burn, Esk tributary in the lower reaches and in Hagburn Wood.

18. R. Esk from south of Glencartholm wood to near Gilnochie Tower.

Lower Limestone Group.

The group is characterised by thick fragmental limestones, some exceeding 20' in thickness. The limestones are generally massive, light coloured with muddy matter confined to thin partings and although the macrofauna is not always abundant, there is a profuse microfauna. The limestones form part of a generally rhythmic sequence with shales, sandstones and thin coals, although the rhythms are not always well developed. The limestones are readily distinguishable from the thin, muddy, Lawston Linn limestones.

The thickness of the group cannot be estimated since the top is never seen. There is only 150' exposed in the Esk, but boreholes at Blackwoodridge pass through over 300'. In an isolated, overgrown quarry north of Eaglesfield, a limestone interbedded with coarse grits and conglomeratic sandstone is found, and which if in a direct sequence from Blackwoodridge indicates a considerable thickness.

The succession in the Esk, truncated by the Gilnochie fault is as follows:

18"	blue black Shale
4'	massive Limestone
6"	blue grey Shale-Mudstone
3'	exp. of wellbedded fine white micaceous current-bedded Sandstone with rootlets.
4'	gap
25'	massive blue limestone with corals, crinoids and brachiopods.

2" sandy grey Shale-Mudstone

6-7' massive fine white Sandstone thinning locally to 4'

4' blue black Shale with plant remains, lamellibranchs, and gastropods.

10' massive fine white Sandstone with carbonised rootlets.

5' black Shale with ironstone nodules.

9' massive fine white Sandstone, current-bedded, micaceous and ripple marked.

6-8' black Shale

6' massive blue Limestone with crinoids and brachiopods.

3" Coal

18" sandy Shale-Mudstone

6' fine white micaceous current bedded Sandstone with coaly plant remains

6' black Shale

8' massive blue Limestone with corals,crinoids and brachiopods.

4' massive fine white micaceous Sandstone with coaly plant remains.

10" grey Mudstone with ironstone nodules

2" Coal

6' massive fine white Sandstone with shaly partings and coaly plant remains

9' Sandstone-Shale in thin alternating bands with shale dominant basally.

2'6" massive muddy blue Limestone

6-10' finely bedded yellow-brown to grey Sandstone with ironstone nodules.

24' massive light coloured Limestone with corals, crinoids, and brachiopods.

25-30' black Shale with thin fossiliferous calcareous bands

3' massive blue Limestone.

This succession is separated by four miles of dead ground from the Kirtle exposures and at Caldronlee east of, and Blackwoodridge west of, the river. At Caldronlee an old/

old/ quarry has almost worked out a 26' limestone lying in a tight, closed syncline. Blackwoodridge lies one mile to the west, and the rocks are divided into two groups by a fault, which running ENE - WSW, separates rocks striking NNW - SSE north of it, from those striking roughly parallel to it, on the southern side. The fault is associated with a certain amount of overturning. The lowest thick limestone of the Lower Limestones is found in the northern group, and being overlain by a sandstone with a conglomeratic base, is easily recognised again at Kirtlebridge. Exposures above this horizon are not good since the quarries are largely overgrown or flooded. However supplementary information is available from boring records.

Immediately south of the fault two limestones are found, the upper, the better exposed, being tightly folded into an anticline and a syncline. These folds gradually die out in the overlying sandstone. There is then a break in exposures downstream to the New Red Sandstone unconformity, the basal member of which formation in the Kirtle is a brockram. Immediately downstream of the unconformity a small truncated synclinal fold in limestone is seen in a small inlier.

Between the Kirtle and Caldronlee a number of small quarries expose generally thin limestones.

Very few outcrops are seen in the largely flooded and/or overgrown Kirtlebridge quarries. The limestone with/

with/ the conglomeratic roof is recognised, and below it an 8' limestone taken as the base of the Lower Limestone group, has also been quarried. The outcrops form a faulted basin with a plicated margin.

From boreholes put down, due south of Caldronlee, near the New Red unconformity, thick limestones of the Lower Limestone group were found at shallow depths.

Corals have been collected from all areas, and Brachiopods, lamellibranchs and gastropods also found. Hill (1938-41) has re-identified some of Thomson's old collection (from Blackwoodridge and Kirtlebridge), while faunal lists of material from the Esk are found in Peach and Horne (1903). The following forms have been identified (Foraminifera identified by Dr. Cummings).

Clisiophyllum keyserlingi	M'Coy
Dibunophyllum sp.	
Dibunophyllum bipartitum bipartitum	M'Coy
Dibunophyllum bipartitum konincki	Edwards & Haime
Caninia sp.	
Caninia juddi	Thomson
Koninckophyllum magnificum	Thomson & Nicholson
Carcinophyllum cf kirsopianum	Thomson
Aulophyllum fungites	Fleming
Syringopora sp.	
Lonsdaleia floriformis floriformis	Martin
Alveolites depressa	
Lithostrotion junceum	Fleming
Lithostrotion clavaticum	Thomson
Lithostrotion (Nemaphyllum) decipiens	M'Coy
Lithostrotion pauciradiale	M'Coy

Diphyphyllum lateseptatum M'Coy

Athyris sp.
Cleiothyridina (Athyris) Roysii L'Eveillé
Camarotoechia sp.
Camarotoechia (Rhynchonella)pleurodon Phillips
Chonetes sp.
Chonetes papilionacea Phillips
Pustula sp.
Pustula cf. defensa Thomas
Gigantella gigantoides Paeckelmann
Thomasina (Productus) cf margaritaceus Phillips
Spirifer spp.
Spirifer duplicicosta Phillips
Spiriferr bisulcatus Sowerby
Linoproductus sp, Gigantella sp, Dictyoclostus sp.
Eomarginifera sp.

Aviculopecten spp.
Aviculopecten cf interstitialis Phillips
Lithodomus sp.
Modiola sp.
Pinna sp.
Sanguinolites (Sanguinoloria) cf plicatus Portlock

Euompholus sp.
Loxonema sp.
Naticopsis sp.
Straparolus sp.
Capulid

Brachymetopus sp.

Ostracoda
Plectogyra
Plectogyra bowmanni
Plectogyra baileyi

Endothyra sp.
Endothyra radiata
Archae discus sp.
Archae discus georgei
Archae discus cf karreri
Cribrostomum sp
Bradyina sp.
Nodosinella sp.
Nodosinella concinna
Tetraxis sp.
Tetraxis cf conica
Spirellina grandis
Endothyranopsis crassus
Globivalvulina sp
Volvulinella youngi
Cornuspira sp.
Glomospira sp.
Glomospirella sp.
Saccaminopsis fusuliniformis
Textularia sp
Climaccamina sp
Millerella ammonoides
Yanischewskina sp
Calcisphaera sp.

The coral fauna belongs to Hill's coral zone 2 (D_2) which conforms with a Hurlet horizon indicated by the foraminifera according to Dr. Cummings.

New Red Sandstone.

The New Red Sandstone lies unconformably on the Carboniferous and oversteps from the Barren Red Measures at Canonbie on to rocks of Lawston Linn and Lower Limestone age to the west. The outcrops run roughly east-west from the Esk to the Kirtle, and then swing south-west.

In the Water of Milk a small, oval-shaped outlier, north of the 'scarp formed by the Birrenswark Volcanics is found. The deposits are distinguished from Upper Old Red Sandstone by containing lava pebbles. The outlier appears to be part of the fill of a pre New Red Sandstone valley, which the present stream is re-excavating.

Superficial deposits.

There is a thick cover of boulder clay over most of the area, particularly in the lower ground to the south near the Solway. Two boulder clays are present, the upper, inconstant, grey, resting on a gently undulating surface of the red, constant, boulder clay. The boulder clay is overlain by peat. Sand and gravel deposits in a series of drumlin like features are locally worked. Drainage channels have been described, in the Ecclefechan area, (Pallister, 1952b)

Igneous Activity.

The dating of the several vents and plugs found, is difficult, and in all cases the latest date only, is possible, post Lower Palaeozoic in one case, and post Whita-Sandstone in the other instances. The former case is an explosive vent north of Langholm made up of shattered blocks of greywacké with a small amount of slaggy basalt. Two plugs are found in that part of Cooms Fell mapped, both are made up mainly of tuffaceous material, though one has a basaltic core. Perter Rig to the south is mapped as a basaltic plug, for while there are no exposures in the old quarry, small, fine-grained, fresh basaltic fragments are found.

Two dolerite intrusions of post Lower Limestone date and pre New Red Sandstone age are found in, and west of, the Esk. The more southerly of the two, which maintain remarkably parallel courses, is undoubtedly a dyke. The other which can be traced for a short distance near Auchengyle, and which in the Esk lies sub parallel to the strike of the beds is questionably sill-like. However, in view of the parallel mature of the intrusions cutting across regional structures it is best regarded as a dyke which may assume a sill-like form.

Tectonics

A. Folding.

The area was subjected to a NW-SE compression after the close of the Carboniferous and before the deposition of the local New Red Sandstone. The time interval was sufficiently long for erosion of the folded structures to occur. The compression resulted in both faulting and folding.

The 'type' or 'intensity' of the folds produced was controlled by the thickness and competence of the beds involved. Thus, in the thick competent beds such as the "Fell Sandstone" and the Birrenswark Volcanics, broad, open fold structures are found, while in the Cementstones, typically cement-stone-mudstone alternations, sandwiched between them, small, low amplitude, adjustment folds occur. The Lower Limestones, containing thick limestones and comparatively little sandstone, are the most tightly folded beds, lying in a series of en échélon periclines, while the underlying Lawston Linn rocks lie in more open folds. The fold axes for the most part run NE-SW and pitch SW. The structural trend lines in the Waterbeck triangle, a rather disturbed area, are shown in fig. 4.

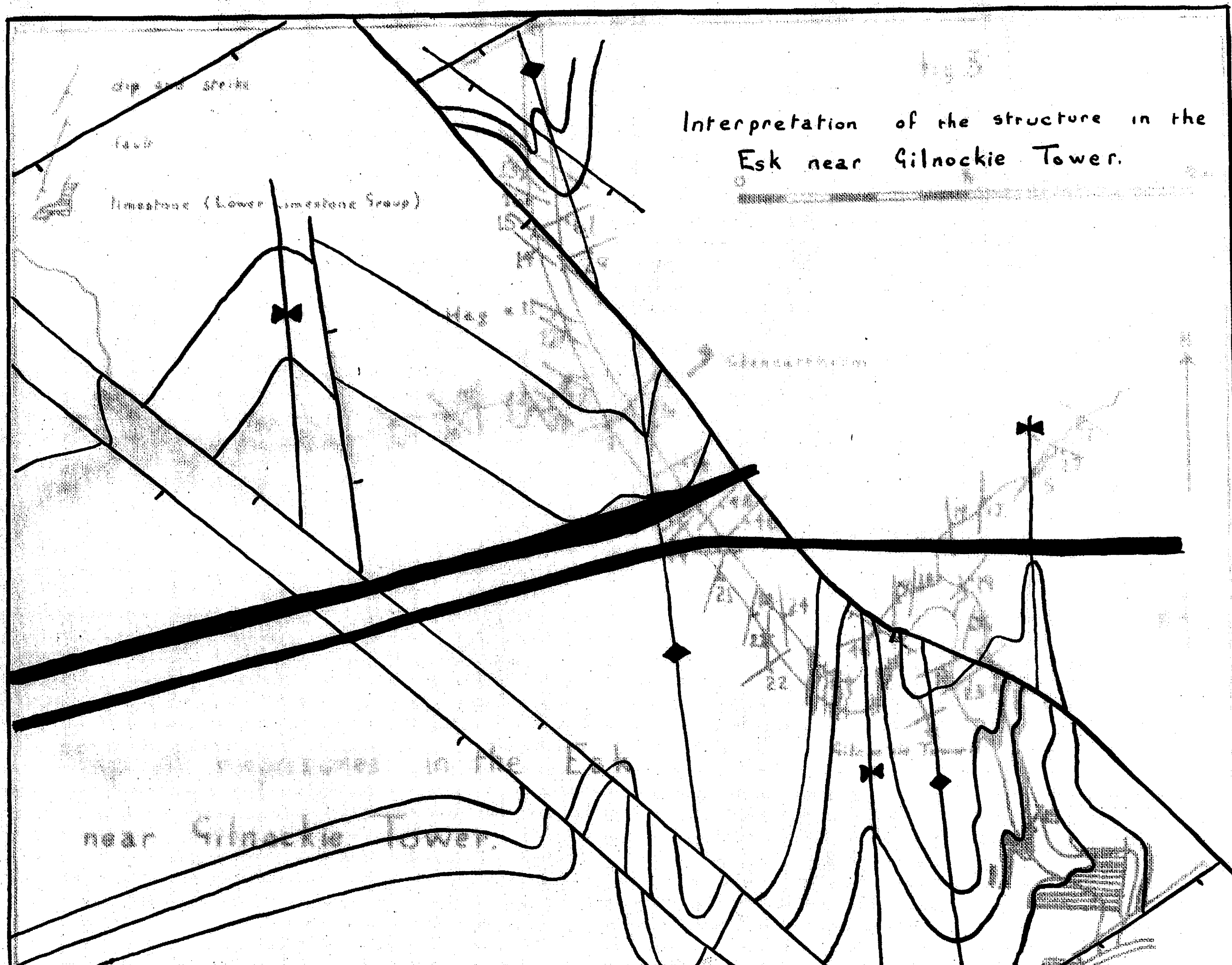
The faults fall into two sets, mutually at right angles, the one, running NNW-SSE making a small angle with the direction of transmission of pressure, are dextral tear faults while the other running ENE-WSW are strike faults. The former have an effective westerly downthrow and displace/

displace/ the latter, faults which downthrow to the south. Numbers of small faults are found, and with small downthrows and no great extent, are probably in the nature of minor adjustments.

What appear to be good anticlinal and syncline structures north east of Langholm at first sight, are in fact an expression of the togrophy aided to some extent by faulting.

Two broad, low, anticlinal folds, one in the Birrenswark lavas north of Ecclefechan, and the other in the "Fell Sandstone" between Callisterhall and the Palling Burn, both with a south-westerly plunge, are found. A complementary syncline is found to the north in each case, in the lavas the nose of the syncline is probably formed by the Burnswark Hill outlier, while the syncline in the "Fell Sandstone" closes south of Callisterhall. The "Fell Sandstone" structures are truncated to the west by the Kirtleton fault. Eastwards between the Callisterhall and Cleuchfoot faults the embayed form of the lava suggests a further open synclinal structure, but further east towards the Esk the open fold structures are absent.

The small scale folding is confined to the Cementstones. The folds are symmetrical and have an amplitude of 6-10', and a 30' + wavelength, with axes in general running N-S, except in the neighbourhood of faults as near Callisterhall where there is an E-W orientation. They are well exposed in the/



Interpretation of the structure in the Esk near Gilnockie Tower.

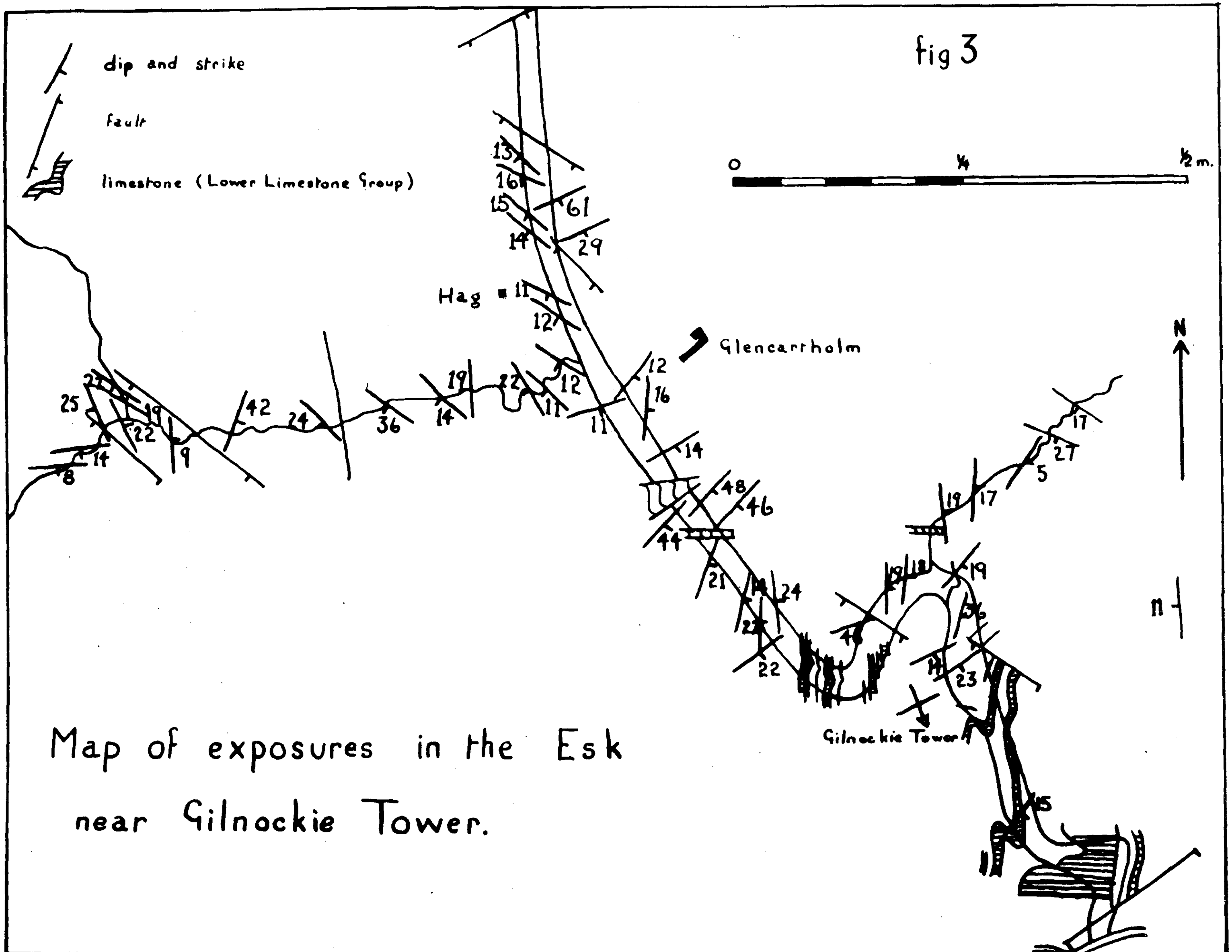


fig 3

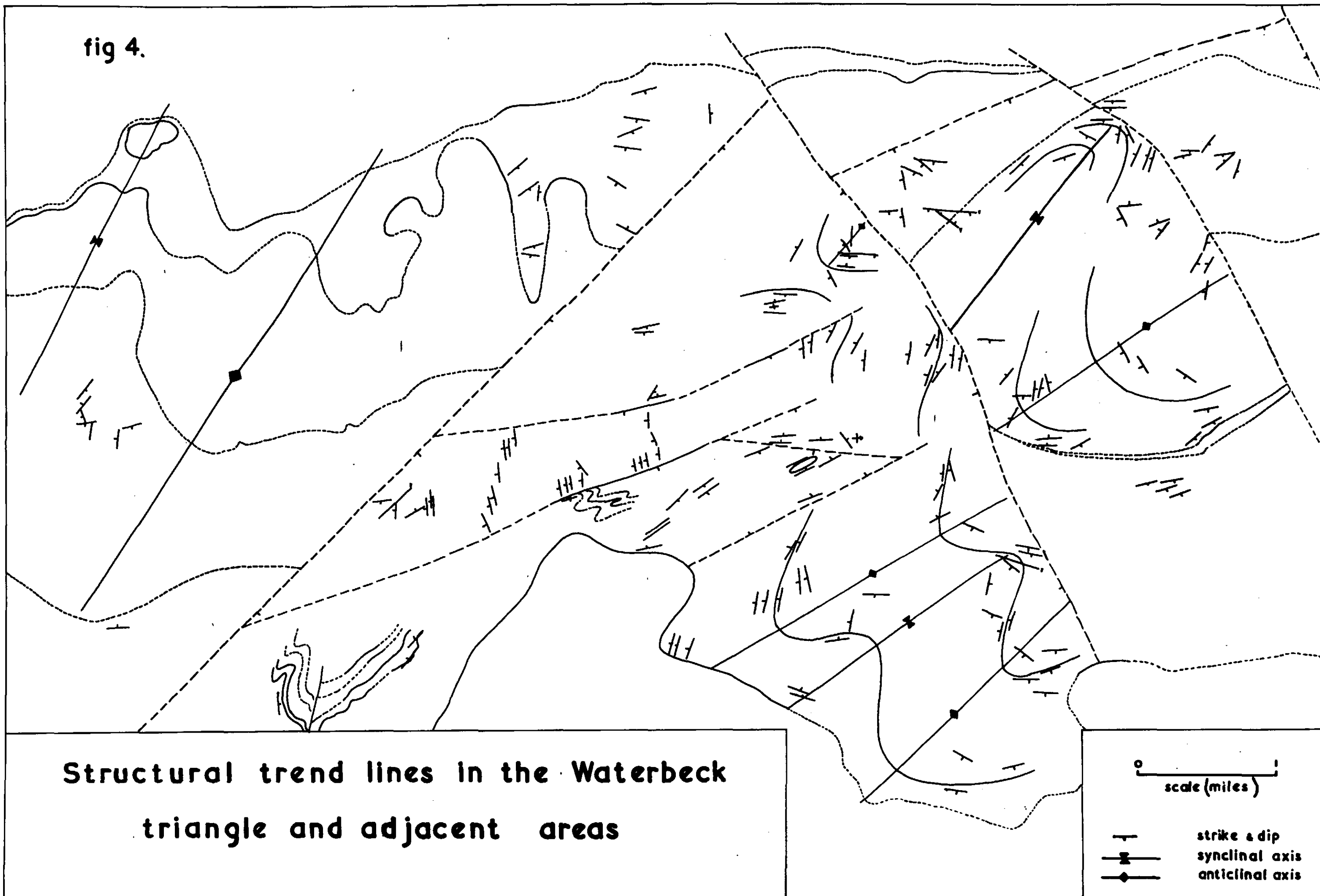
Map of exposures in the Esk near Gilnockie Tower.

the/ Bigholms and Collin burns, and again in the R. Annan.

The folded Lawston Linn and Lower Limestone rocks of the Esk area are separated from exposures in the Waterbeck triangle (i.e. the area enclosed between the Waterbeck and Kirtleton faults and the New Red Sandstone unconformity) by a wide expanse of poorly exposed ground, in which the few exposures are of low Lawston Linn horizons, showing the regional, low dip and strike. In the R. Esk and the Hag Burn, the fold axes run N-S the folds pitching to the south. Lawston Linn rocks are well-exposed in the Hag Burn where a section through a syncline is seen, the western limb of which forms the eastern limb of a small anticline. Further west, the outcrops, having the regional strike, suggest that the folding dies out. The eastern limb of the syncline links up closely with outcrops in the Esk, which have an essentially anticlinal form. Downstream, near Gilnockie Tower, tightly folded Lower Limestone rocks are found, and the eastern limb of the Esk anticline forms the western limb of a syncline, which is succeeded to the east again by an anticline. These structures are both truncated by the Irvine Fault. An interpretation of the structure is given on Fig. 3.

The Lower Limestones, in the Waterbeck triangle, lie in a graben to the west, and are surrounded on three sides by folded Lawston Linn rocks. From borehold evidence there is a further small area of Lower Limestones lying in an/

fig 4.



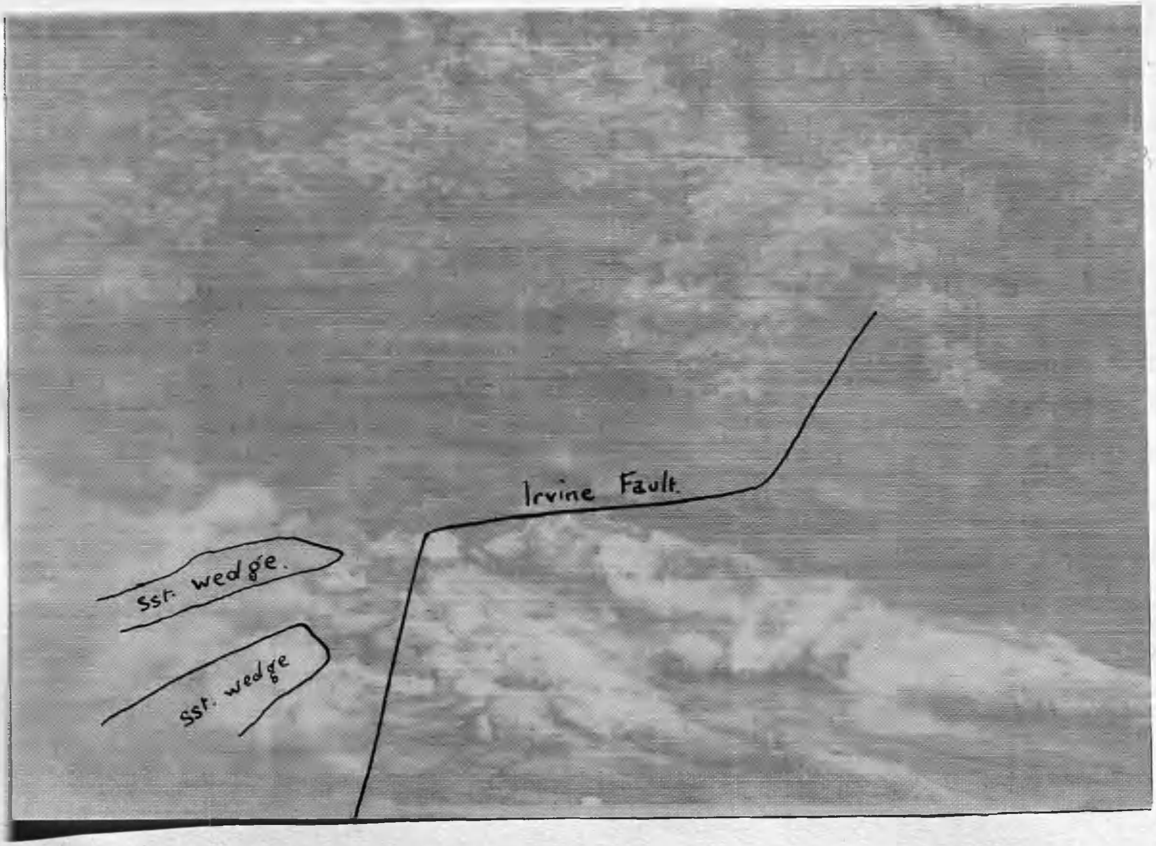
Structural trend lines in the Waterbeck triangle and adjacent areas

an/ embayment in the New Red Sandstone outcrop to the south. In the south are two southwesterly pitching anticlines separated by a syncline. Northwards the outcrops narrow, partly due to steeper dips, and partly to faulting, with the strikes indicating a sweep round to the regional direction near Waterbeck village. The structural trend lines are indicated in Fig. 4. Quite an extensive area of Lawston Linn rocks is enclosed between the Albie and Howath faults, and in the extreme south-west there is a further small area, although there are no outcrops. Between the Howath and Springkell faults the limestones form a series of en échélon folds, the axes again running NE-SW, and of which the closed syncline on High Muir (Caldronlee) is the most easterly. However, because of poor exposures a definite correlation of the limestones cannot be made. The folds at Kirtlebridge, forming essentially a closed syncline with the edges plicated by minor folds belong to the same group. No evidence of folding can be seen in the limestones between the Howath and Albie faults, that is, the group of limestones quarried at Blackwoodridge.

B Faulting.

Between the Kirtle and the Esk a number of tear faults are developed, their transcurrent nature being indicated by the shift apparent in the folded structures. The most easterly, the Irvine Fault, cuts twice through the folded limestones at Gilnockie Tower with an effective downthrow/

Plate II



RIVER ESK north-east of Gilnockie Tower, showing the Irvine Fault cutting through folded Lower Limestone Group limestones.

downthrow / of 300' to the west. It crosses the river a third time near Hag, with little disturbance apart from a swing in the strike. In Irvine Wood the shift of the Glencartholm horizon is evidence of faulting, but the positioning of the fault has to rely on abrupt changes in strike, on which grounds two faults are postulated. The second fault is tentatively linked with a minor fault within the Glencartholm Volcanic Group. The Irvine Fault further north crosses the Wauchope Water and brings Cementstones against Lower Palaeozoics, so that its effective throw has increased northwards from 300' to about 1200'. Running at an angle of 30° to the Irvine fault a small fault associated with a considerably disturbed belt can be seen in Glencartholm wood, and near the mouth of the Irvine burn, and it probably continues through a fold zone, near the base of the Cementstones, in the Esk into the Whita Sandstone.

The evidence for the Cleuchfoot fault rests on the cutting off, of the gently folded lavas at Cleuchfoot. Some displacement of features, too, can be seen. The Callisterhall fault explains the juxtapostion of the "Fell Sandstone" of Gowd Muir against Cementstones to the east, and the proximity of lavas to the north-east. The combined effect of the Cleuchfoot and Callisterhall faults, is to step forward the Glencartholm horizon, which indicates a throw of 400' for each fault. The Kirtleton fault cuts off the "Fell Sandstone" and the Cementstones, which do not appear in the Waterbeck triangle. The fault is never seen, but high dips/

dips/ in some of the Kirtle tributaries may indicate its proximity. The throw is greatest near Kirtleton where Cementstones are brought against a Lawston Linn horizon. The Cowdens fault, is a normal fault with a downthrow of 400' to the east, and running nearly N-S, is included with the tear faults because of the similarity of orientation.

Three normal faults are found in the vicinity of Langholm. The most northerly brings the lavas capping Warbla and part of Whita Hill into contact with the lower Palaeozoics, while the lavas are cut off to the south by the Whita Hill fault which splits into two west of the Esk. The Langholm fault has a throw of 300' while the Whita Hill fault has a throw of 500'. The continuation of the line of the Langholm faults is displaced northwards by the Irvine fault, and here the throw must be greater than the combined throws in the Langholm area, a throw of about 1,000' being necessary to bring Cementstones down against lower Palaeozoics. The faults north of Westwater and the westward continuation displaced by the Callisterhall fault have comparatively small throws although they continue the line of the Langholm faults.

The Waterbeck fault forming the western margin of the Waterbeck triangle is a large and important structure, and bringing down Lawston Linn horizons against lavas has a throw of nearly 2,000'. The Glencartholm Wood fault in the Esk is responsible for cutting out the "Fell Sandstone" and therefore has a throw of the order of at least 1,000'. It is/

is/ responsible for the narrowing of the Lawston Linn outcrop west of the river, but seems to die out rapidly.

Within the Waterbeck triangle there are three parallel faults forming the Lower Limestone graben two of which throw to the south with throws of the order of a few hundred feet. The central fault, the Howath fault, is associated with considerable disturbance in the Kirtle, and there is evidence from Blackwoodridge of overturning.

The most southerly of the three, the Springkell fault, is not seen.

Table 1	Column 1			Column 2		Column 3				Column 4				Column 5
Specimen.	Thin Section Analysis.			Chemical Analysis.		Size Analysis.				Shape Analysis.				Orientation.
	Felspar propn. plag-microcline	Felspar-mosaic propn.	Mosaic propn. fine-coarse	CaO%	MgO%	a_{50}	Skewness	Kurtosis	Sorting (Trask's coeff)	Roundness 44grade	Roundness 85grade	Sphericity 44grade	Sphericity 85grade	
37	Pg > Mic	Qm > Flsp.	Qmf > Qmc			·300	·965	·205	1·277	·372	·393	·699	·669	W.
39	Mic > Pg	Qm > Flsp	Qmf > Qmc			·309	·986	·282	1·250	·379	·453	·697	·624	N–NNW.
40	Mic > Pg	Qm > Flsp	Qmf > Qmc			·450	·925	·312	1·118	·428	·446	·673	·669	NW.
41	Mic > Pg	Qm > Flsp	Qmf > Qmc			·295	·920	·224	1·456	·398	·374	·673	·666	N–NNE.
42a(calc)	Mic > Pg	Qm > Flsp	Qmf > Qmc	11·4	1·51	·380	·940	·280	1·288	·391	·400	·674	·671	
42b						·375	1·001	·270	1·280	·370	·390	·675	·649	WSW.
43	Mic = Pg	Qm > Flsp	Qmf > Qmc			·380	·978	·273	1·243	·375	·408	·718	·646	
45 (calc)	Mic > Pg	Qm > Flsp	Qmf > Qmc	15·4	1·58	·245	·945	·212	1·221	·437	·446	·691	·649	N.
46	Mic > Pg	Qm > Flsp	Qmf > Qmc			·278	1·08	·230	1·310	·366	·423	·693	·681	
47a(calc)	Pg > Mic	Qm > Flsp	Qmc > Qmf	16·8	1·3	·338	·965	·265	1·280	·412	·420	·672	·653	N.
47c	Pg > Mic	Qm > Flsp	Qmc > Qmf							·396	·407	·713	·669	NNW.
48	Mic > Pg	Flsp > Qm	Qmc > Qmf			·410	·870	·276	1·241	·437	·404	·693	·664	N–NNE.
49	Mic > Pg	Flsp > Qm	Qmc > Qmf			·281	1·01	·262	1·233	·392	·433	·719	·669	N–NNW.
50(calc)	Mic > Pg	Qm > Flsp	Qmc > Qmf	10·8	1·67	·281	1·06	·195	1·241	·408	·416	·686	·641	N.
51	Mic > Pg	Flsp > Qm	Qmc > Qmf			·253	·930	·276	1·400	·404	·419	·689	·670	N.
53(calc)	Mic > Pg	Flsp > Qm	Qmf > Qmc	16·2	not estimated									
54	Mic > Pg	Flsp > Qm	Qmf > Qmc			·370	·890	·263	1·292	·400	·408	·682	·668	WNW.
55	Mic > Pg	Flsp > Qm	Qmc > Qmf											

Table 2.	Column 1			Column 2.	Column 3				Column 4				Column 5.
RT 1.	Mic > Pg	Qm > Flsp	Qmf > Qmc		·305	·980	·302	1·23	·410	·423	·717	·668	NE.
RT 2.	Pg > Mic	Qm > Flsp	Qmf > Qmc	all	·318	1·09	·371	1·26	·391	·421	·718	·685	N.
RT 3.	Mic > Pg	Qm > Flsp	Qmf > Qmc	non-calcareous	·355	·940	·284	1·35	·418	·422	·724	·703	
RT 4.	Mic > Pg	Qm > Flsp	Qmf > Qmc		·395	1·03	·280	1·25	·380	·419	·706	·674	NNW.
RT 5.	Pg > Mic	Qm > Flsp	Qmf > Qmc		·330	·945	·268	1·26	·371	·424	·698	·658	NNE.

Section II. Sedimentary Petrography.

Whita Sandstone.

The study of the Whita Sandstone was based on a vertical sequence of 18 specimens from Whita Hill quarries, and a series of 5 samples from the Rottenbush Sike, a tributary of the Tarras Water lying some three miles east-north-east of Whita Hill. They were studied under the following seven headings:

1. Thin Section Analysis.
2. Chemieal Analysis.
3. Heavy Mineral Analysis.
4. Size Analysis.
5. Shape Analysis.
6. Orientation Analysis.
7. Porosity (and density) Determinations.

A number of other specimens were examined, though not in the same detail.

The absence of a marker horizon meant that the examination concerned itself mainly with the possibilities of vertical variation. Comparisons were made between the two areas mentioned, and also with the Old Red Sandstone below and the Fell Sandstone above.

Thin Section Analysis.

The mineralogy of the Whita Sandstone is comparatively simple, quartz invariably forming more than 95% of the detrital minerals. Felspar the second most abundant mineral never exceeds about 1 - 2%, and includes orthoclose, microcline, and acid plagioclose all in a fresh condition.

Microcline is generally more abundant than either orthoclose or plagioclose. Occasional scraps of mica can be detected occurring as flakes bent between quartz grains. Ilmenite and leucoxene are not uncommon. Rock fragments are rare, a fine-grained greywacke fragment being the only one detected.

The cementing material of the main mass of the Whita Sandstone is secondary silica with a subsidiary amount of secondary limonite, and the sandstone thus falls into the orthoquartzitic group of Tallman (1949). Near the base calcareous lenses and bands are found in a more or less decalcified condition. The calcareous material may form as much as 40% by weight. The bands and lenses invariably contain a relatively higher proportion of iron in the form of limonite, either coating the grains or in the matrix, than the non calcareous sandstone. The limonite in the matrix sometimes brings out a rhombohedral form suggestive of dolomite, and analysis indicates that a small amount of magnesium is present. In the calcareous developments secondary silica is present, in reduced amount, and the quartz grains commonly show signs of corrosion.

Strained quartz is common but is always subordinate to the unstrained variety. Inclusions in quartz are, seemingly, ubiquitous and using Mackie's (1893) classification the order of frequency is invariably acicular, regular and irregular. Grains commonly show inclusions of two orders, acicular and regular. The nature of the inclusions shows/

shows/ considerable variety, andrutile, zircon, tourmaline, quartz,magnetite and muscovite are all found.

Quartz mosaics occur. The mosaics have been considered by Eckford and MacGregor (1948) who note their occurrence in the Silurian greywackes of the Southern Uplands, in the Lower Old Red Sandstone and Downton of North Ayrshire, in the Upper Old Red Sandstone and Lower Carboniferous of the South of Scotland and finally, fairly rare occurrence in the Northumberland Fell Sandstone. The mosaics are comparable in size and shape with ordinary quartz grains. Texturally they may be classified as fine or coarse with a gradation between the two. Inclusions can be detected in the components of the coarse mosaics, but the fine tend to be crystocrystalline with individual components.barely distinguishable under 400x. In some instances the mosaics appear to result from a recrystallisation of the quartz grain. Eckford and MacGregor suggest that some may be derived from chert, and yet others from the alteration of plagioclose and thus look for the source of the mosaics in chert and acid keratophyric rocks.

Two trends are indicated. The coarse mosaics are replaced near the top by the fine variety as the commoner form, and the combined number of mosaics becomes greater than the combined number of microcline and plagioclase grains, again towards the top (Table 1, col. 1). Since neither the coarse mosaics nor the felspars appears to diminish in quantity the two trends would seem to result from the/

the/ increase in the number of fine mosaics.

Chemical Analysis.

Some of the calcareous samples were quantitatively analysed and the amounts of calcium, magnesium, and iron calculated as the oxides. The methods employed were based on those suggested in Glowes and Coleman (1918). The calcium and magnesium results are listed on table 1, col. 2. Iron estimated as ferric oxide, averages about 8%.

Heavy Mineral Analysis.

A heavy mineral suite cannot be characterised by a single grade separation. It has been shown that the size frequency curves for any heavy mineral differs from that of quartz with the peak displaced towards the finer grades. The alternatives are the separation and comparison of equivalent grades or separation from a whole sample. Mackie (1915-24) Rubey (1933 a & b) Cogen (1935) Russell(1936) Rittenhouse (1943) Brajnikov (1944) Allen (1944-48) Allen and Walder (1945). The method used, that of separation from a whole sample, seems the more satisfactory, particularly if grain counts are to have any significance. Bromoform was the common heavy liquid used, though Thoulet's solution and methylene iodide were both occasionally employed. When small quantities were used, a hand centrifuge speeded separation. The heavy mineral fraction was mounted on a/

a/ graduated scale and the minerals identified. Although some thousand grain counts weremade, most of the work was qualitative. The lack of a reference horizon makes detailed studies of the type of Smithson (1939) and Allen (1948) impossible.

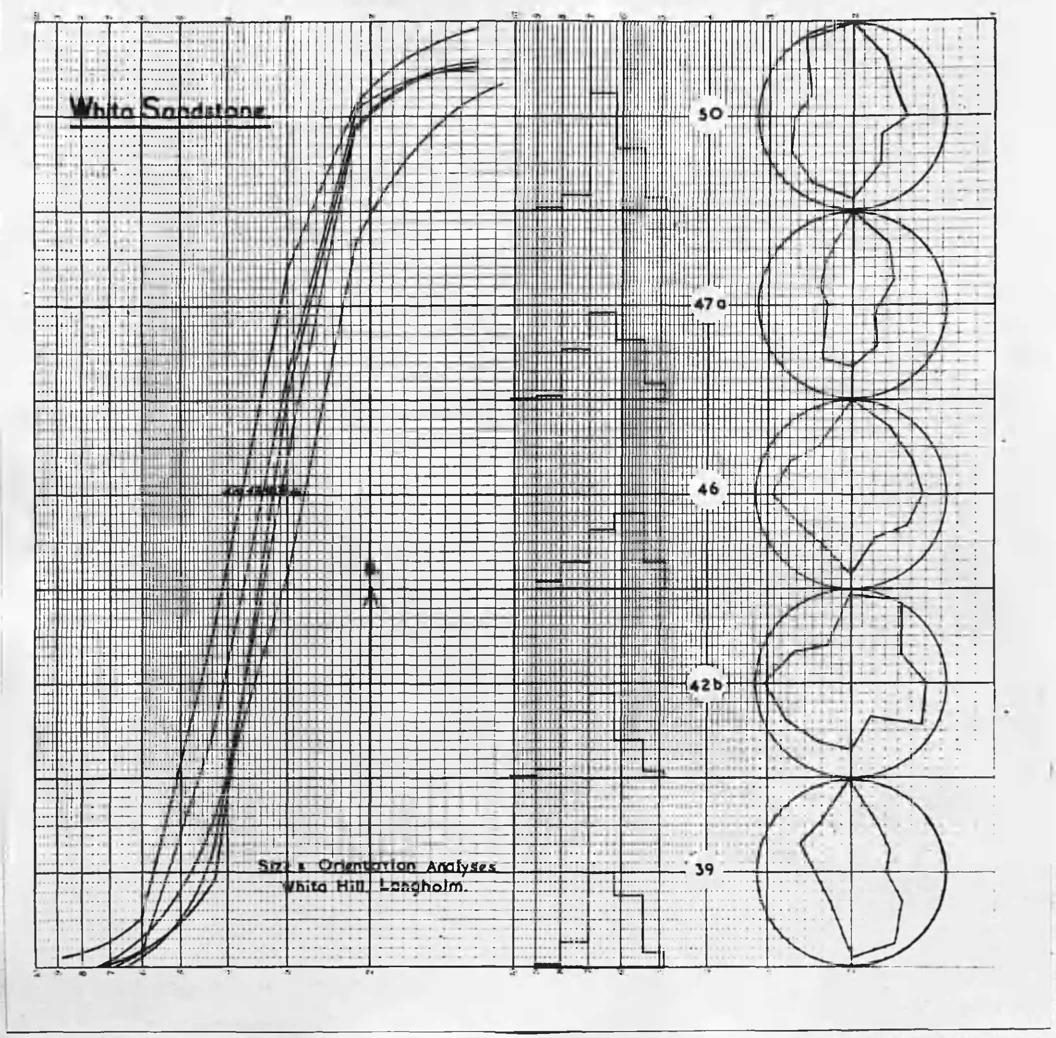
The yield of heavy minerals was low, never exceeding .05% and averaging .03%. The iron ores and zircon are the only common minerals. Iron ores made up well over half the suite, being two or three times more plentiful than zircon. Ilmenite and leucoxene are the common varieties. A certain amount of secondary limonitic material is also found. Two generations can be recognised in zircon, tourmaline, and rutile, the one characterised by almost euhedral grains, the other, usually the commoner, by well rounded material. Colourless, brown, and purple zircon and brown tourmaline are found belonging to both generations. Colourless zircon is about twice as common as the brown variety, while the purple form is not common. Occasional green, ragged, mica-like flakes of tourmaline occur. Rutile differs in the two generations, in the one it is represented by foxy-red prismatic crystals, and in the other by larger, rounded deep red-brown grains. Well rounded brown-yellow grains of monazite occasionally occur. Small, yellow andradite garnets are found in only one separation. Apatite too occurs but rarely. Nearly colourless, small, euhedral, crystals of anatase, almost certainly anthigenic are also/

also/ found.

There are two possible explanations for such an impoverished suite, that it has suffered subsequent loss or was derived from an area, itself poor in heavy minerals. The stability of heavy minerals has been dealt with by Boswell (1941), Pettijohn (1941) and Smithson (1941) and only apatite of the latter's very unstable and unstable minerals is found in the Whita Sandstone. However, a comparative test such as that of Bramlette (1941) has not been carried out. The Whita Sandstone, from orientation studies was derived from a source lying to the north, but metamorphic minerals which are according to Boswell(1928-31) among the minerals characteristic of the Scottish Lowlands Carboniferous, and for which he advocated a northerly origin (Boswell 1912), are absent. The sandstone,then, would seem to be derived from the Lower Palaeozoic rocks of the Southern Uplands. Mackie (1928) listed the heavy minerals of the Silurian of the Peebles area. The list is given below (the number following each mineral species indicates the number of samples in which it was found out of a total of 61 investigated).

Peebles Silurian	Whita Sandstone.
Augite 34,enstatite 14,hypersthene 1	
Hornblende 22, glaucophane 5.	
Zircon 52,(purple var. 34)	Zircon (pur.zircon)
Garnet 38, melanite 38	Garnet
Apatite 21, tourmaline 16	Rutile, tourmaline.

Fig 5



Cumulative curves, histograms, and orientation rosettes, of Whita Sandstone, Whita Hill Langholm.

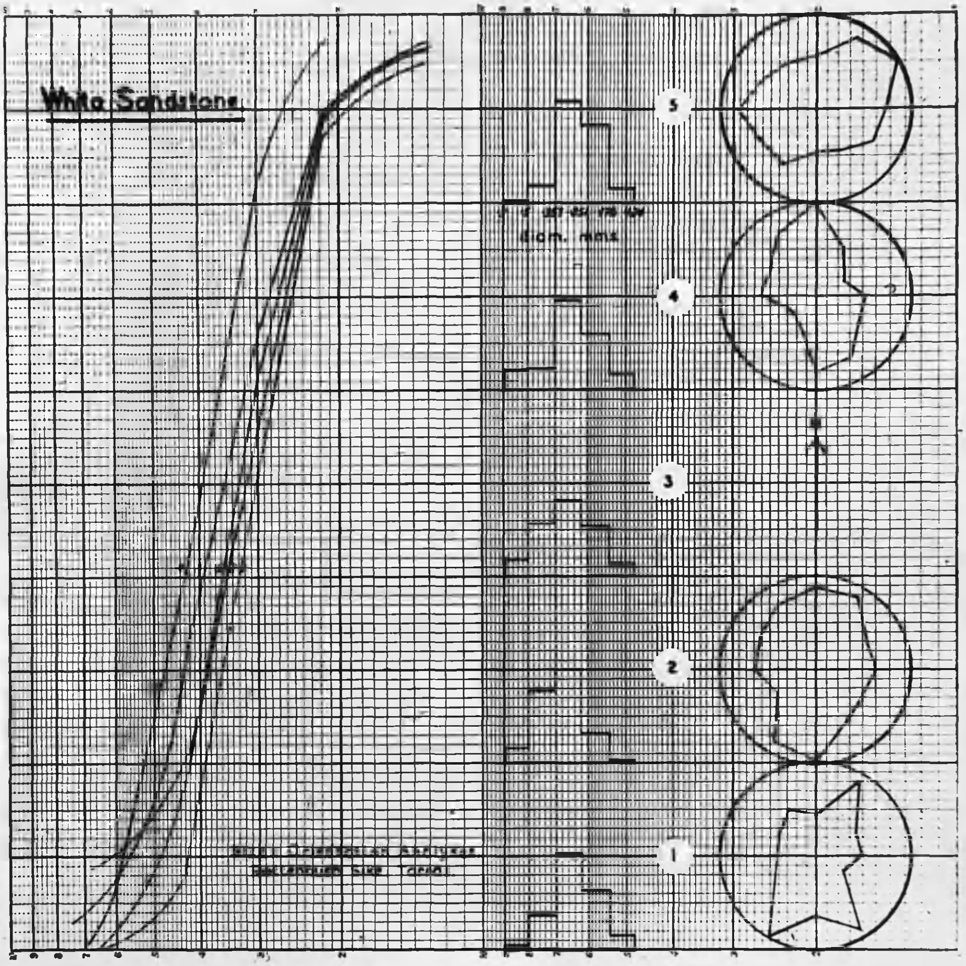
Peebles Silurian	Whita Sandstone
Chlorite 11, pyrite 7	
Anatase 2, brookite 1	Anatase
Magnetite 1, dolomite 1, flnorspar 1.	
	monazite, leucoxene
Metamorphic minerals absent	metamorphic minerals absent.

It is immediately clear that the Whita Sandstone contains only the most stable elements of the Peebles suite, with the addition of monazite. While this alternative, of a sandstone derived locally from rocks poor in heavy minerals, the problem of accounting for the monazite and for the fact that the heavy minerals seem to be of two generations presents some difficulty.

Size Analysis.

No entire satisfactory method for disaggregating a sandstone with a siliceous cement is known (for a discussion of the methods see Taylor and Georgeson (1933)) and Krumbein and Pettijohn (1938)). Since Whita Sandstone is friable it was crushed between the fingers and the remaining obdurate granules crushed with a pestle in a mortar. After this treatment the amount remaining on a 22 mesh sieve was rarely more than a couple of grams out of an initial 100 grams. The calcareous samples were prepared by leaching with dilute hydrochloric acid. The disaggregated samples were then sieved using a column of 22,30,44,60,85,100,120 B.S. sieves, for the most part on a Ro-Tap allowing twenty minutes per 100 gram samples and correspondingly less for smaller samples.

Fig 6



Cumulative curves, histograms, and orientation rosettes, of Whita Sandstone, Rottenbush Sike Tarras.

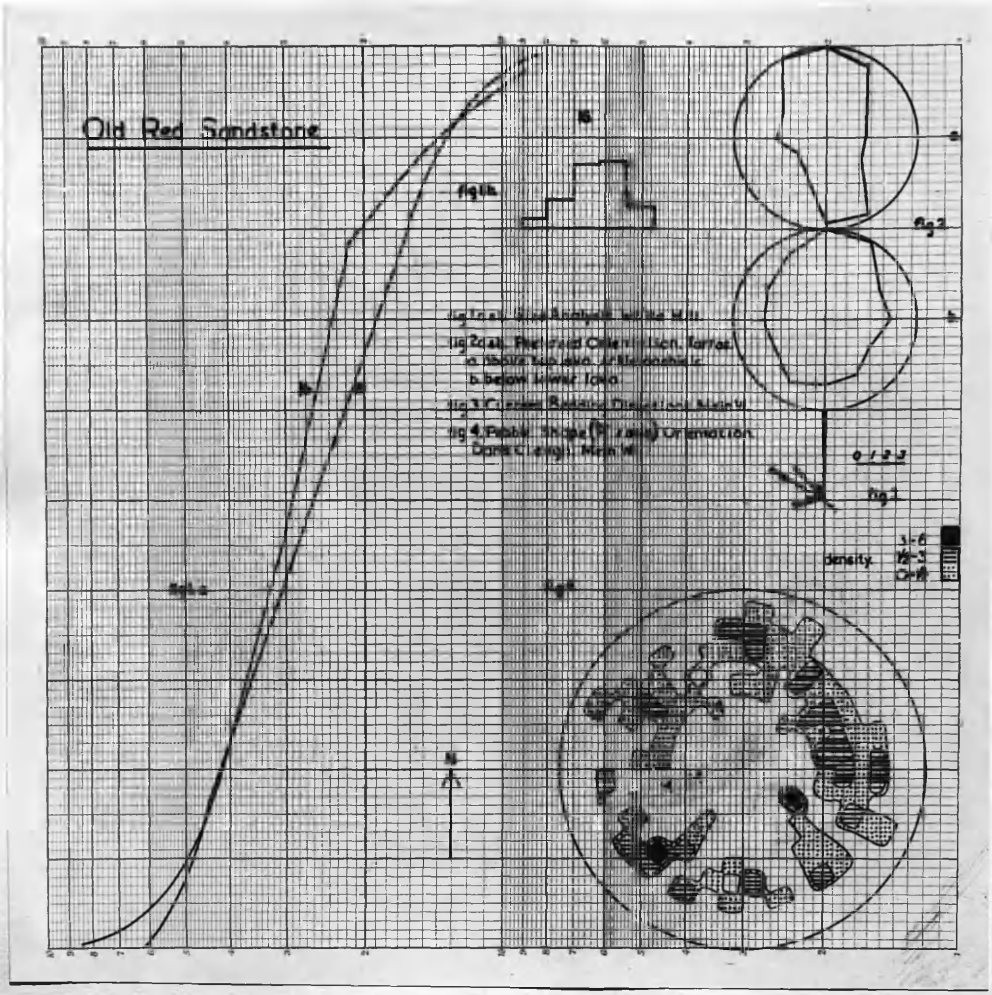
Examination under binoculars showed that, in most cases, disaggregation was incomplete in the 22,30 and 44 grades; but it was felt safer to apply a correction rather than attempt further crushing. There is the danger that size analysis may become more representative of the disaggregation method employed than of the original size distribution. As a check a sample was prepared by two methods, crushing as described, and by the force of crystallisation method, and the results compared using the chi-square test. The result of the test, expressed as a 'P' value obtained from tables in Fisher (1925) was high enough to suggest that the danger was avoided, and that the crushing method compares favourably with the force of crystallisation method.

The correction was based on the assumption that the aggregates in any one grade were made up of grains from all the finer grades in the same proportions as indicated by the size analysis. Thus the weight of the aggregated grains in any one grade was divided up proportionately amongst the finer grades. The form of the calculation is given below: In sample Y aggregated grains occur in the 30 and 44 grades.

Grade size	Weight from analysis	1st. correction	2nd. correction	Corrected analysis
30	A grams	a grams aggregated		A - a grs.
44	B "	B/X .a = B'	b grams aggregated	B' - b grs.
60	C "	C/X .a = C'	C 1/Z.bC"	C"
85	D "	D'	D"	D"
100	E "	E'	D1/Z.b.	E"
120	F "	F'		F"
Pan	G "	G'		G"

Wt of B-G = X grs. Wt of C'-G' = Z grs.

Fig 7

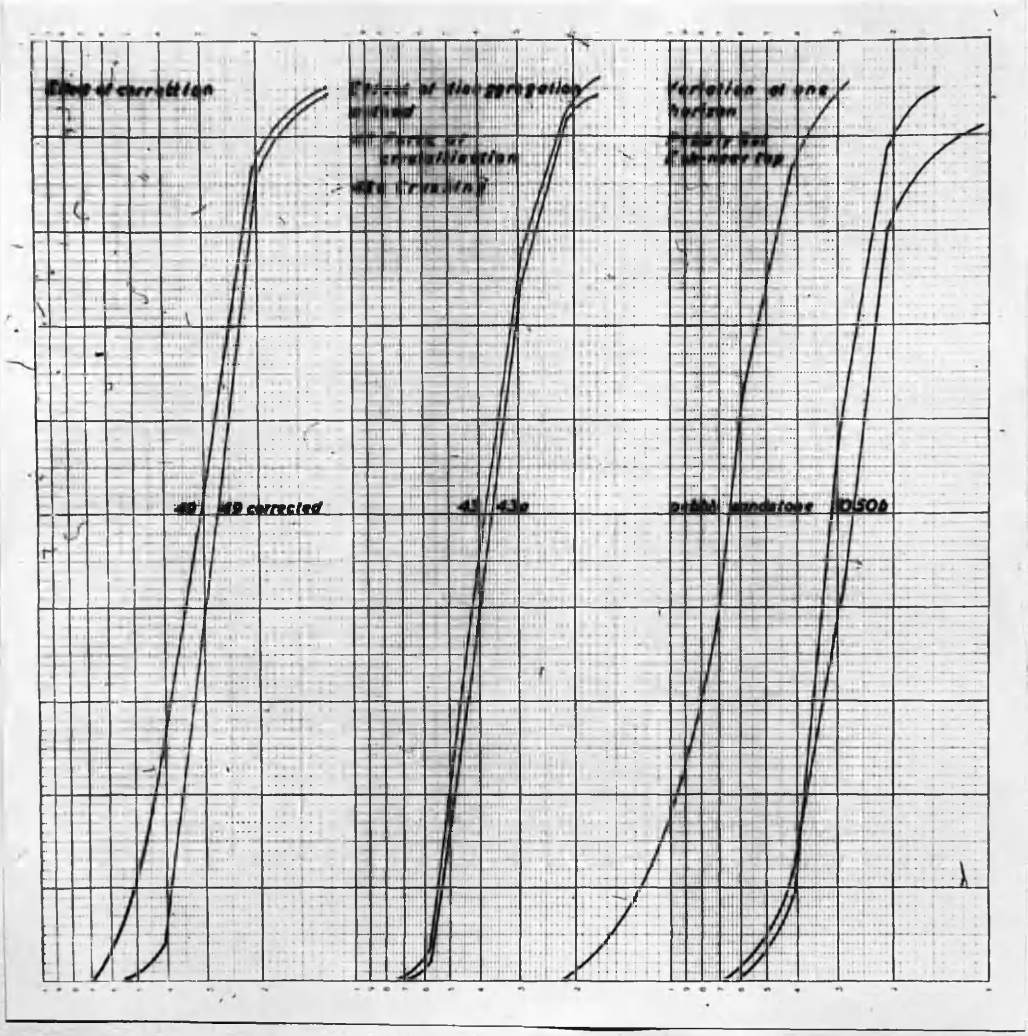


Cumulative curves, histograms, orientation rosettes, and current bedding directions from the Upper Old Red Sandstone of Mein Water near Waterbeck, Whita Hill, and Tarras.

Since the correction is a reflection of the development of secondary silica, a comparison by the chi-square test, of the corrected, and the original size analyses indicates the limit beyond which size analysis is no longer an accurate measure of the original size distribution. This limit when the P value obtained is less than .05, a limit approached by one Whita Sandstone sample (Sp.49).

The size analyses were plotted as histograms and cumulative (weight percentage) curves (Figs. 5,6. Fig. 7 gives comparable results for Old Red Sandstone material). There seems to be little advantage in drawing up cumulative (number frequency) curves of Marschner (1953). The cumulative curves all lie within a narrow belt indicating a high degree of homogeneity of samples. A measure of this homogeneity is to be gauged from the fact that a comparison between two samples from different horizons by X^2 test may show greater similarity as shown by a higher P value, than between two samples from one of those horizons. From the histograms a check on the frequency with which the second most abundant grade is coarser or finer than the most abundant suggests that the samples belong to Keller's (1945) beach sand category, although the value of the test is dubious, and additionally may be affected by the choice of sieves Krumbein(1934), Galliher (1933). There is no size difference between the detrital matter of the calcareous bands and the non-calcareous sandstone.

Fig 8



Comparative cumulative curves showing the effects of:

a) the correction applied for aggregated grains,

b) the disaggregation method used,

c) the variation at one horizon, and that of a pebbly sandstone for comparison.

The common statistics skewness, kurtosis and Trasks sorting coefficient were calculated and tabulated with the median diameter (tables 1 & 2, col. 3) and summarised as below:

Statistic	M_b mm	Kurtosis	Skewness	Sorting
Average and standard deviation of 15 Whita Sp.	.329±.059	.255±.039	.964±.056	1.282±.235
Old Red Sandstone Sp.3	.264	.165	.963	1.546
Sp.16	.395	.236	1.06	1.321

The appreciation of the statistics is handicapped by the lack of relevant data. Caution is required in their application, too, since quite different sandstones may have one or two of the statistics closely similar.

The homogeneity from the size aspect is broken only by the incoming of pebbly horizons near the top, a sample cumulative curve being given (Fig.8); the figure also illustrates the variation caused by the correction, the variation due to crushing methods and the variation at one horizon.

Table 3.

Test	Sp.	No. of Grains	Roundness 44	Roundness 85	Sphericity 44	Sphericity 85
For the minimum number of grains	40 70 150	47A	.404 .417 .411	.428 .420 -	.680 .679 .677	.666 .653 -
1. * indicates 70 IMM sieve used (.178 mm)	50 90	41	- -	.358 .374	- -	.652* .666
Chosen as being those in which error most likely to occur, being those which did not fit indicated trends.	50 90 130	42A	- - -	.384 .392 .402	- - -	.680 .670 .671
	50 100 140	45	.477 .452 .437	.446 .439 -	.680 .688 .691	.649 .649 -
	50 90	48	.442 .437	- -	.696 .693	- -
2. Using different disaggregation methods A. force of cryst. of (Na_2 SO_4)	50 100	43A	.369 .372	- .381	.692 .705	- .657
C. normal crushing method	50	43C	.367	.398	.695	.658
3. Using different samples from the same horizon (Calcareous)	50 50	50 50_R	.406 .410	.387 .444	.686 .687	.641 .640

Table 4.

Sample	30 spher.	30 round.	44 spher.	44 round.	66 spher.	66 round.	85 spher.	85 round.
Series expt. 43A	.728	.333	.705	.372	.675	.399	.645	.408
47A	.683	.390	.676	.409	.668	.435	.653	.420

Shape Analysis.

Early attempts at measuring shape Sherzer(1910), Wentworth(1922 a & b), Trowbridge and Mortimore (1925), Cox (1927), Tester (1931) were not highly successful and the study of shape was really established by Wadell (1932, 1933,1934,1935), whose methods have since been modified by Riley (1941) Rittenhouse (1943) and others. The method used here, employs an occular with graduated circles in conjunction with a mechanical stage permitting all the necessary measurements, for the calculation of roundness and sphericity, to be speedily carried out. By a combination of occulars and objectives, grains are magnified to approximately the same size so that the results are strictly comparable.

Fifty grains were measured from each of the 44 and 85 grades, and since three quarters of any sample is included in the 44,60, and 85 grades, a measure of shape on both sides of the mean (50 percentile, or median diameter) is obtained. Before any conclusions can be reached a series of tests is necessary, to see whether the number of grains used is large enough to see whether the crushing method had affected shape, and finally to see whether one sample can be taken as representative of its horizon (within a limited area). The results, of the tests given in Table 3, indicate that a 50 grain sample is adequate.

A plot of the calculated sphericity, and of roundness on probability paper (Harding 1949) shows that their distri-/

fig 9 PLOT OF PEBBLE SIZE IN WHITA SANDSTONE (R. ESK)

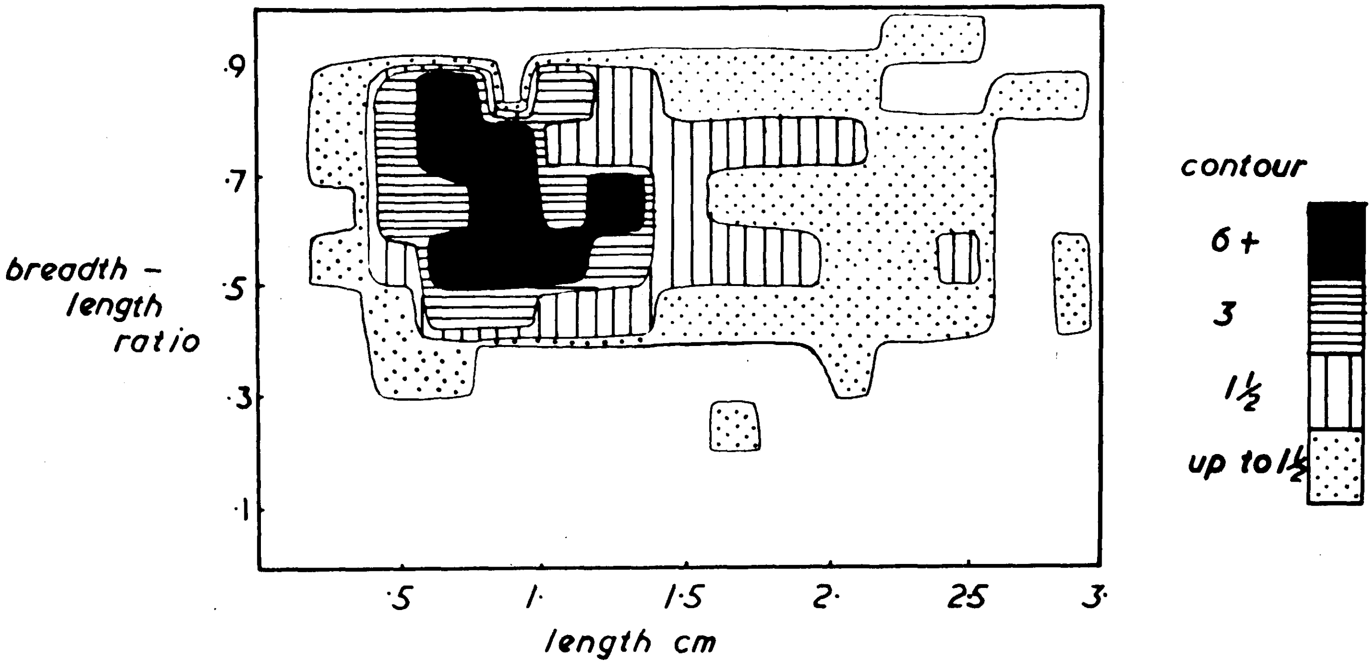
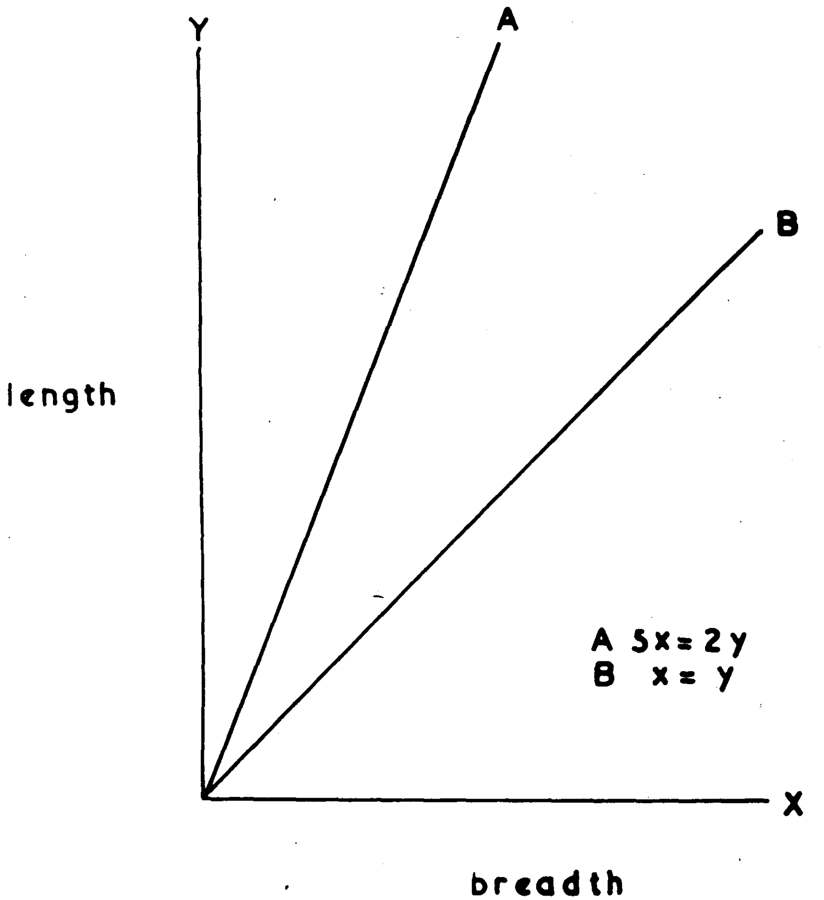


Illustration of the distribution of pebbles from a high Whita horizon on a modified Hagerman diagram distri-/bution is unimodal. In all but two of the samples examined, including Old Red Sandstone, and a gritty Lawston Linn sample, there was an increase in roundness and a decrease in sphericity in the finer grade (Tables 1 & 2, col. 4). This "trend" is well brought out in a series of measurements including the 30,44,60 & 85 grades (Table 4). Comparable results are those of MacCarthy (1933), who notes a progressive rounding up to the 80 mesh, above which the trend is reversed, and Russell and Taylor (1937) who found a decrease in sphericity with decreasing grain size, and also a decrease in roundness.

In view of the general constancy of the results from Whita Hill and the Rottenbush Sike, a statistical comparison of the mean values from the two areas, using "Students' t Distribution" Moroney (1951) was considered valid despite the absence of a reference horizon. A significant difference between the 5% and 1% levels could be established for sphericity, although the roundness values are not significantly different. Two conclusions are, tentatively, drawn, that sphericity and roundness are independent of each other to a certain extent, and that the differences in sphericity between the two areas is related to transport prior to deposition. The lower sphericities found on Whita Hill indicate longer travel, cf. Russell and Taylor (1937), MacCarthy (1933,1935). Comparing the sphericity values of Whita, Old Red and Lawston Linn Sandstones, shows that the values are similar grade for grade, despite the differences/

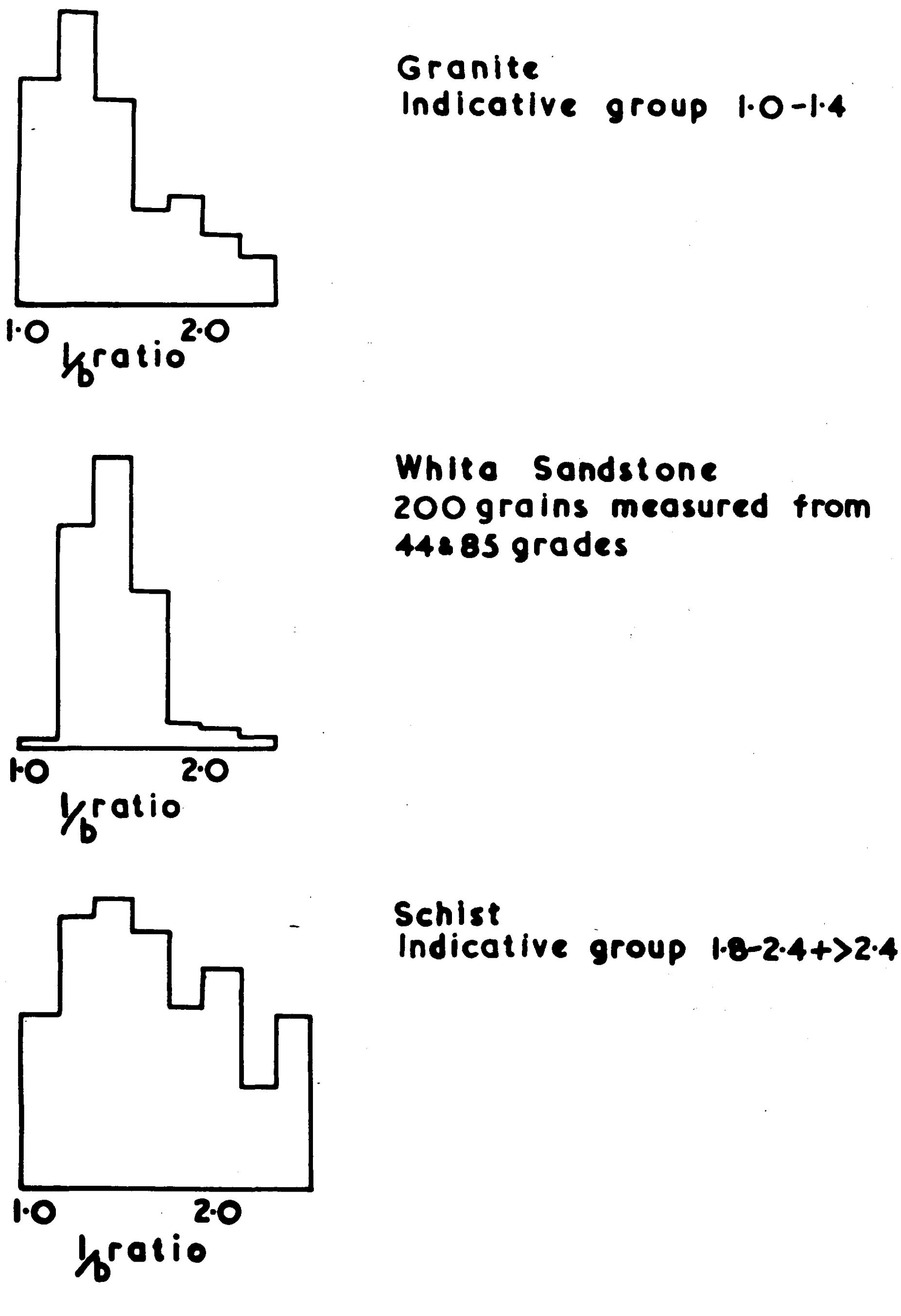
fig 10 GRAPHICAL REPRESENTATION OF LENGTH & BREADTH OF QUARTZ PEBBLES & GRAINS



Limiting field of quartz pebbles & grains defined by lines A & B differences/ between the sandstones, (fine well sorted, less well sorted, and a grit), which suggests again within certain limits, the sphericity is a function of the grade size although statistically small differences may be detected.

The shape of pebbles from near the top of the Whita Sandstone was not studied in detail, but some general information can be obtained from a modified Hagerman diagram (Fig19), or from a density-shape or size-direction diagram. All give some idea of the field of distribution of the pebbles, while the shape is in the form of a breadth-length ratio. A graph (Fig. 10) made by plotting length against breadth shows that the pebbles lie within a zone fairly closely defined by the lines $x = y$ and $5x = 2y$. The pebbles plotted are mainly quartz pebbles, and when quartz grains are similarly plotted, using the circumscribed and inscribed circle diameters, it is found that they lie within the same zone, despite the exaggeration introduced by the use of the inscribed circle diameter. If the sphericity of the 48 and 85 grades is superimposed on this diagram, the lines lie, as would be expected, in the centre of the zone. The inference drawn is that reduction in size takes place in such a way that the length : breadth ratio remains essentially constant. Should this inference prove to be generally applicable, then Bokman's (1952) clastic quartz ratios as indices of provenance becomes important. Bokman tried to show that the length:breadth ratio could be used to indicate whether quartz had been derived from granite or schist. Using the class intervals/

fig 11 CLASTIC QUARTZ RATIOS (BOKMAN)



intervals/ he developed, Whita Sandstone quartz (Fig. 11) does not quite fall into the granite class (32% of the ratios as against his 50%), but if the granite class interval is extended from 1-1.4 to 1-1.6 then 72% of Whita quartz ratios fall into the granite class compared with 67% of his example.

The conclusions are briefly that size reduction takes place in such a way that the length:breadth ratio remains constant, which explains why, grade for grade, the sphericities of quite different sandstone types are not dissimilar. In quartz grains the sphericity and roundness can act independently of each other. In the Whita Sandstone there is a decrease in sphericity and an increase in roundness in progressively finer grades, up to the finest examined. The statistically significant difference between the sphericities of material from Rottenbush Sike and Whita Hill is interpreted as indicating the Whita material is further travelled.

Orientation Analysis.

Of the two field methods of studying orientation, current bedding is not common, and preferred pebble orientation can only be measured at one place in the Esk. At the latter locality, the "least projection elongation" Dapples and Rominger (1945) of 150 pebbles was measured. The results were plotted as density-size-direction and density-shape-direction diagrams. (Fig. 12), but since the "end positions" of the pebbles were not determined the orientation can only be given as an axis and not a direction. The preferred orientation was/

fig 12 WHITA SANDSTONE PEBBLE SIZE & ORIENTATION

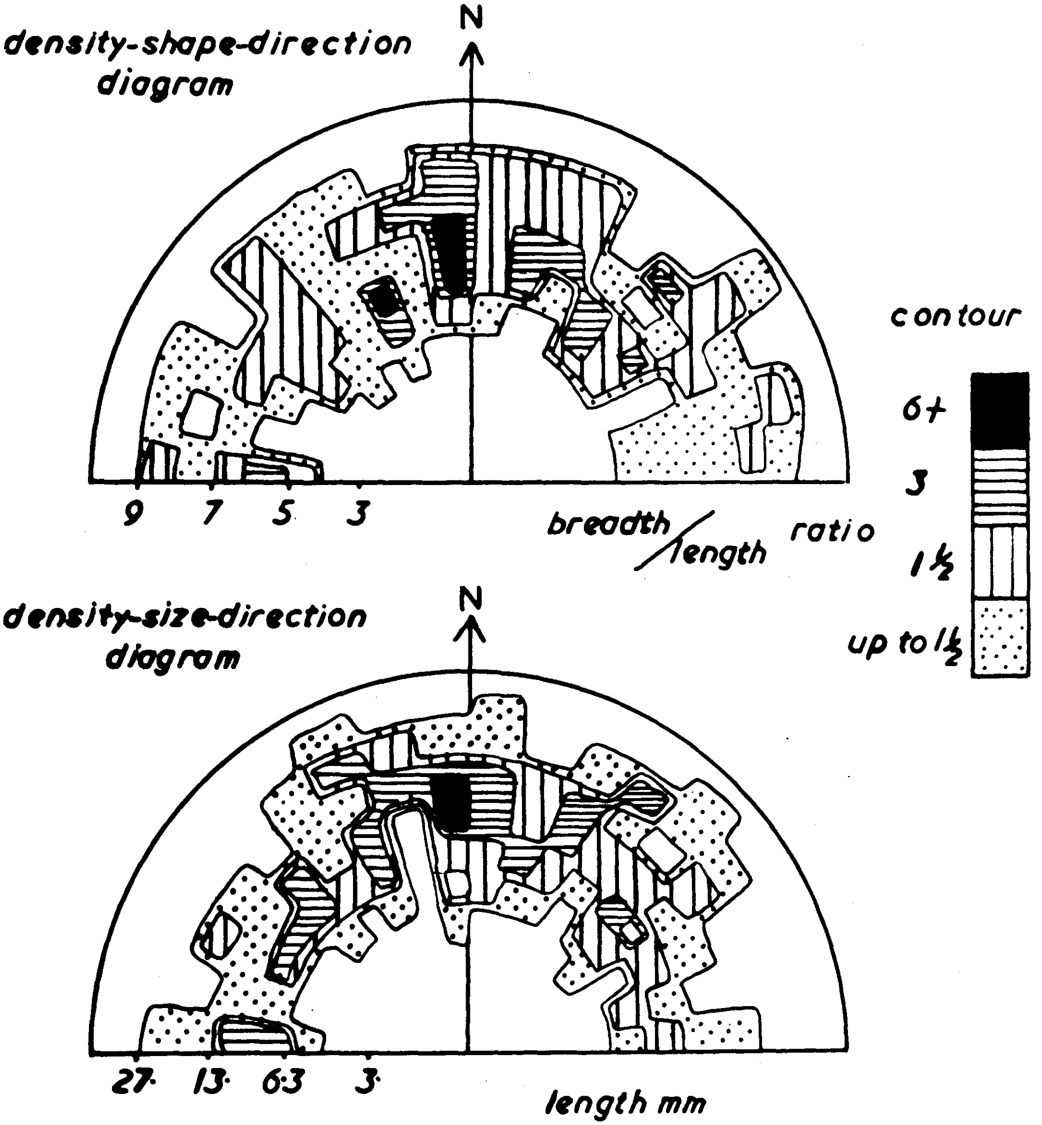


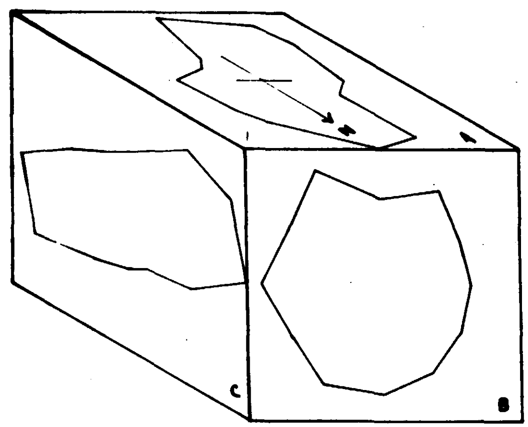
Illustration of the distribution & orientation of pebbles from a high Whita horizon in the R. Esk was/ about a N-S axis with a subsidiary NE-SW axis indicated. The few current bedding readings indicate a northerly current direction.

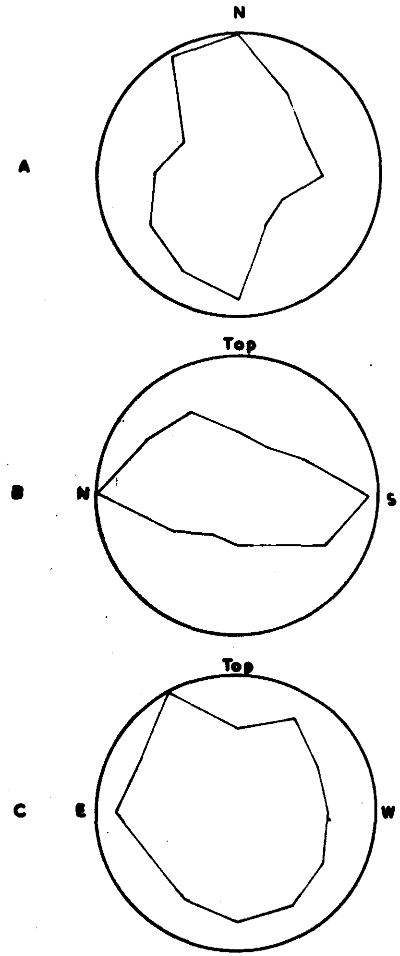
Preferred orientation was found in the finer, non-pebbly sandstones. Three thin sections cut mutually at right angles, paralleling the bedding plane, dip and strike directions respectively, were photographed. In each case, the least projection elongation and end position of every grain which could be measured with certainty, usually about 200 grains per section, was determined. The results were plotted in 30° intervals as orientation rosettes. Each of the sections has a characteristic pattern. The dip section shows a pronounced orientation parallel to the bedding plane, and an absence of imbrication, while there appeared to be no preferred orientation parallel to the strike. This is taken to indicate that the long axis of a grain tends to lie parallel to the bedding with the shortest axis in a vertical plane, so that for orientation purposes the bedding plane section showing the long and intermediate axes is the only one necessary (Fig. 13).

The orientation can be assigned to depositional conditions because of the variation in the results, because there is no sign of disturbance in the banding of the calcareous matrix of some samples, and finally because the results agree with current bedding measurements. While attributing the orientation to current action Schwarzacher's (1951)/

fig 13 ORIENTATION ANALYSIS

Illustration of the relation of three sections cut mutually right angles





A Section parallel to the bedding plane

B Section parallel to the dip direction

C Section parallel to the strike direction

(1951)/ conclusion "…. on the other hand, the relative uniformity of the monoclinic fabrics studied suggests that they do not reflect current conditions as much as had been hoped", is applicable.

There is a northerly orientation with over half the results lying between NNW and NNE, the remainder lying to the west of north, (Table 1, col.5). The Tarras samples show the same northerly trend but with a stronger easterly component (Table 2, col.5).

Porosity.

An indication of the effective porosity of a number of specimens was calculated from the increase in weight after a period of immersion in water under reduced pressure. The volume was measured directly by displacement. In several instances a variety of different weights and shapes were used with comparable results. The average porosity based on six non-calcareous samples was 19.9% $\pm$ 5.4, the average of five calcareous samples was 5.3 $\pm$ 1.17.

Provenance summary and Deposition.

On the basis of the restricted heavy mineral suite it is suggested that the Whita Sandstone was derived from the Southern Uplands largely from the weathering of sedimentary rocks. The euhedral heavy minerals and monazite suggest additionally that part of the heavy mineral suite may have come from the deep weathering of an acid igneous rock. The current/

current/ direction indicated a northerly source of materials. The currents may have been responsible for transport and partly for sorting and the elimination of muddy material.

The depositional area was restricted, the maximum westerly extent being some four miles west of Langholm, and passing northeastwards from Langholm into Roxburghshire, Whita Sandstone is found on both sides of the Arnton Fell inlier.

Orientation of three sandstone bands within the Esk Cementstone sequence is the same as in Whita Sandstone. The conditions in the early stages permitted the deposition of calcium carbonate and it seems possible that current action may have inhibited large scale deposition of carbonate.

Table 5.

Comparison between Whita, Old Red, and Fell Sandstones.

Old Red Sandstone	Whita Sandstone	Fell Sandstone
Purple, red, yellow-brown, rarely grey-white	Grey-white	Yellow-brown, grey-white
Massive thick-bedded to thin bedded	Massive thick-bedded	Massive thick-bedded, occasionally platy bedded
Occasionally highly micaceous	Non micaceous	Non micaceous.
Sorting variable, commonly not well sorted	Well sorted	-
Fine grained to coarsely conglomeratic	Fine grained, pebbly sandstone developed at top	Ranges from fine grained to gritty and conglomeratic
Pebbles of greywacke, quartz, sandstone and clay galls	Pebbles of quartz and sandstone	Pebbles of quartz, sandstone & red clay galls.
Current bedding not infrequent	Current bedding uncommon	Current bedding common
Muddy material as fine red sandy marls	Muddy material rare, thin green sandy mudstone partings	Muddy material not common, some red marl near top
Occasional cornstones	Calcareous bands and lenses near base	Calcareous bands uncommon, a thin sandy limestone near top.
Fossils rare Holoptychius scale (Whita Hill)	Unfossiliferous	Fossils rare, occasional plant remains: limestone fossilif.
Orientation N	Orientation N	Orientation W

Cementstones.

Chemical Analysis.

The only complete analyses of cementstones and mudstones are those of Young (1867), but the estimation of lime (C_aO) in Esk cementstones and mudstones gives comparable results. The spectrographic analyses of these Esk cementstones and mudstones are given below: (results in parts per million).

	Al	Ba	Ca	Cr	Co	Pb	Mg	Mn	Ni	Si	Sr	Sn	T_1
D_1C	2%	500	2%	300	trace	400	2%	1000	200	2%	300	200	1000
D_2H	2%	1000	2%	300	trace	1000	1.5%	200	200	2%	200	400	1000
D_3C	2%	150	2%	300	trace	400	2%	1500	200	2%	300	400	1000
D_4C	2%	100	2%	300	trace	400	2%	1000	200	2%	300	300	1000
D_5M	2%	500	2%	300	trace	1000	1.5%	150	200	2%	300	400	1000

The following elements were not detected, Be, Bi,Mo,V Eu,Yb,Lu, Tb,Ho,Sc,Y,DY,La,Pr,Nd.Ru,Ta,Ga,Rh,Zr,TI. Tests indicated the presence of traces of Cl^-, and SO_4^{--} radicles, and also PO_4^{---}, more abundant than the other two.

In the absence of comparable results, little can be made of the spectrographic analyses beyond nothing the tendency of both barium and lead to concentrate in the mudstone, and manganese in the cementstone.

Cementstone Formation.

The pyhsico-chemical factors controlling the formation of Cementstones are not well known, but evidence is accumulating that the older ideas, which inferred that the calcium and/

and/ magnesium carbonates were chemical precipitates as a consequence of concentration (e.g. Glasgow memoir 1911) need to be considerably revised. While traces of chloride and sulphate do occur, phosphate is found in a quantity unlikely to have been derived purely by precipitation from sea-water. Additionally fossils such as lamellibranchs and gastropods are occasionally found in typical cementstone bands (from the analytical point of view), and had deposition of the carbonates been due to concentration of salts, conditions would have been expected to be toxic.

It seems more likely that the factor controlling the deposition of calcium and magnesium was the lowering of the concentration of carbon dioxide in sea-water. Johnston and Williamson(1916) Revelle (1934) Deposition of the carbonates was continuous, and it may be that a cementstone was formed, on shallow marine flats, as a result of the concentration of those salts within a mud-water sludge, much as Young (1867) suggested. However, a concentration of salts by evaporation did occur, evidenced by the occasional appearance of thin muddy siltstone with thin bedding plane surfaces covered with salt pseudomorphs.-

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APPENDIX.

Bore-hole records. (from Springkell Estates Ltd.) put down by Robert Hannay in the search for coal, ironstone and haematite.

Bore-hole No. 1 1873.

	fath.	ft.	ins.
Surface	3:	3:	6
Blue Shale	1:	4:	6
Red & Grey Shale	3:	2:	0
Red & Grey Lime	1:	4:	0
	10:	2:	0

Red & Grey Shale	1: 3: 8
Grey Lime	2:10
Red Parting	6
Grey sparey Lime	2: 6
Red & Grey Shale	2: 3
Grey sandy Lime	1: 4
Red & Grey Shale	1: 4:11
Grey Sandstone	1: 6
	59: 2:10

Bore-hole No. 2. 1873. Ashyards Meadow.

Surface	5: 4: 0
Red Shale	1: 3: 0
Grey Shale	5: 0
Red Shale	1: 0: 0
Grey Shale	2: 0
Red Shale	2: 5: 0
Grey Shale	2: 0
Red Shale	4: 3: 6
Conglomerate	1: 0: 0
Grey Sparey Lime	2: 1: 6
Red Sandy Lime	1: 1: 0
Red & Grey Shale	5: 3: 0
Red Lime	2: 0: 0
Red & White Shale	3: 0
Lime & Shale Mixed	5: 0
Red & Grey Shale	4: 4: 6
Grey Sandstone	3: 3: 6
Red Sandstone	3: 0
Grey Sandstone	4: 0
Red & Grey Shale	2: 2: 0
Grey Shale	1: 1
Grey Sandstone	2: 0;10
Red White & Grey Shale	8: 1: 0
Grey Sandy Lime	5: 6
Shale Parting	1
Red Lime	3: 5

Contd.

Bore-hole No. 3 1873. Howgillside

Red Clay Surface	3: 1: 6
Sand & Gravel	1: 0
Grey Sandstone	1: 3: 0
Red & Grey Shale	1: 0
White Sandstone	4: 2: 0
Iron Gravel	3: 0
Red & Grey Shale	3: 3: 0
Grey Sandstone	4: 4: 0
Red & Grey Shale	4: 3: 0
Grey Sandy Shale	6: 5: 6
Blue Shale	2: 0: 0
Red Lime	1: 3: 0
Grey Shale parting	4: 6
Grey Sandstone	4: 0
	34: 2: 6

Bore-hole No. 4. 1873. Blackwoodridge.

Surface	1: 6
Millstone Grit	3: 6
Horn gravel	1; 2
Broken Lime	4:10
Grey Sandstone	3:3: 6
Red & Grey Shale	3: 3
Sandy Lime	1:0: 0
Red & Grey Shale	6
Grey Lime	1: 6
Grey Sandstone	5: 3
Grey Lime stone	1:5: 6
Shale Parting	3
Lime stone	2: 6
	10:3: 3

Bore-hole No. 5 1873. Meadow Quarry

Surface	11: 5: 0
Red Lime stone	2: 0: 0
Red & Grey shale	3: 1: 6
Grey sandstone	1: 4: 6
Red & grey shale	1: 2: 0
Grey sandstone	5: 1: 6
Red & grey shale	4: 6
	26: 1: 0

Bore-hole No. 6. 1873. Howgillside

Sand & gravel surface	5: 0: 0
Grey sandy lime	3: 1: 4
Grey sandstone	5: 0: 0
Red & grey shale	2: 3: 6
Grey sandstone	1: 1: 0
Red & grey shale	2: 1: 0
Grey sandstone	3: 4: 0
Blue shale	3: 1: 6
Grey sandy lime	1: 6
	26: 1:10

Bore-hole No. 7 1873. Blackwoodridge.

Surface	4: 4: 0
Broken Lime	4: 5: 6
Grey Sandstone	4: 4: 0
Red & Grey Shale	1: 3: 6
Grey Sparey Lime	3: 6
Red Sandy Lime	3: 0
White Lime	3: 2: 6
Red Sandstone	2: 0
Red & Grey Shale	1: 3: 6
Grey sandy lime	1: 0: 0
Red Shale parting	1: 0
Grey sandy lime	1: 1: 6
Sandstone	1: 0: 9
Grey lime stone	4: 3
Grey sandstone	1: 5: 0
Grey Shale	5: 9
Grey Lime	1: 2: 3
Red Shale	1: 0
Red Lime	1: 0
Grey sandy shale	1: 4: 6
Red Lime	5: 0
Shale Parting	1
Grey sandy lime	3: 5: 5
Shale parting	1
Grey sparey lime	1: 4
Grey shale	2: 0
Broken lime	1: 6
Grey Shale	1: 6
Grey sandstone	4:10
Red & Grey shale	1:4: 0
Stone & Iron mixed	1: 0
Red Shale	3: 0
Grey sand & Lime	4: 2
	43: 2: 5

Bore-hole No. 8. 1873. Howath.

Surface	2: 1: 0
Grey Sandstone	4: 3: 0
Shale parting	1: 0
Grey lime	2: 5: 0
Grey shale	1: 2: 6
Dark grey lime	5: 0
Red & grey shale	18: 2: 6
Grey sandstone	2: 4: 0
Iron parting	3
Some sandstone	3: 6
Red & grey shale	3: 3: 0
Grey sandstone	2: 0
Red & grey shale	3: 9
Grey sandstone	4: 1: 6
Red shale	1: 6
Red & white shale	10: 0: 0
	52: 3: 6

Bore-hole No. 9. 1873 Howgill-side.

Surface	2: 0: 0
Red and grey shale	12: 0: 0
Grey sandy lime	1: 3: 0
Red and grey shale & gravel	4: 0
Grey sandstone	1: 5: 0
Red & grey shale	2: 3: 0
Grey sandstone	2: 4: 6
Red & grey shale	1: 0: 0
Grey sandstone	9: 4: 3
	33: 5: 9

Bore-hole No.10.1874. Blackwoodridge Old Quarry.

Surface	1: 1: 0
Lime stone	3: 0
Grey shale	1: 1: 0
Sandstone	4: 0
Grey shale	4: 6
Broken lime	4: 6
Grey shale	2: 2: 0
Grey Sandstone	1: 0: 0
Red Sandstone	1: 0: 0
Red & grey shale	1: 3: 6
Red & grey sandstone	2: 2: 6
Red shale	2: 0
Grey lime	2: 2: 6
	16: 0: 6

Bore-hole No.11 1874. Howgill-side

Surface clay and gravel	5: 0: 0
Shale with sandy barss	22: 0: 0
	27: 0: 0

Bore-hole No. 12. undated. Howgillside.

Surface	3: 0: 0
Grey sandstone	4: 0
	3: 4: 0

Bore-hole 1.B. 1854-56. Hillhead.

Red and brown clay	2: 3: 0
White post (freestone)	5: 8
Red and grey metal	3: 3: 9
Red and white post	3: 4: 9
Grey post	1: 2: 5
Red and grey metal with water	4: 3: 2
Red post with metal partings	1: 2: 3
Grey metal	1: 0: 0
Red and grey metal with freestone girdles	2: 4: 0
Red and grey metal	3: 1: 4
White post with water	2: 2: 5
Dark grey metal stone	5: 1:11
Grey metal with post partings	1: 5: 8
Red post with grey metal partings	1: 0: 6
Grey metal stone	1: 5: 9
Red and white post with water	6: 0: 8
Red and grey metal	2: 3: 7
Red and white post	4: 4: 8
Red and grey metal	5: 2: 3
Grey metal stone	3: 0: 7
Blue lime stone	5: 6
Grey metal stone	3: 0: 2
White post	2:10
Stony hard post	5: 0: 3
Grey metal	7
Coal	1: 2
Grey metal with post girdles	5: 9
Coal	3
Hard post	1: 3: 2
Grey metal with hard post girdles	1: 0: 0
Dark blue metal (soft)	3: 2
Strong grey post	4: 2: 4
Grey metal with post partings	2: 0: 6
Coal	11
Dark grey metal with post girdles	4: 0: 8
Coal	1½
Grey metal with post girdles	4: 0: 0
Post girdles and grey metal girdles	3: 0: 9
Hard stone post	4: 1
	92: 0: 6½

Bore-hole No.2.B 1868-69 Glen Kirtle Cottage.

Surface		4:	4
Red shale	4:	4:	0
Red lime stone		4:	11
Parting			6
Red lime stone		2:	2
Parting			9
Red lime stone		2:	4
Parting			9½
Lime stone	1:	3:	8½
Parting			5
White and blue fireclay	5:	1:	11½
Hard, red shale with signs of iron		2:	0
Lime stone	1:	3:	5
White (potters)clay	1:	2:	4
Sparry lime stone		1:	10
Very red clay		2:	0
Do. mixed with white		1:	1
Sandy lime stone and parting		4:	7
Red lime stone	2:	0:	1
Dark parting			2
Sandy lime stone	2:	3:	6
Blue shale parting			4½
Sandy lime stone		2:	9
Limons shales	4:	5:	10½
Sandy lime stone	1:	0:	4
Limons shale	1:	1:	11
	31:	4:	1½

Bore-hole No. 3.B. 1870. Caldronlee.

Surface	1:	0:	0
Red sandy shale		5:	9
Grey sand and shale	2:	4:	9
Grit		1:	3
Sandy shale		5:	0
Iron shale		4:	3
Iron sandy	1:	0:	0
Red shale		3:	2
Sandy shale	1:	1:	5
do.		2:	7
Red sandy shale		4:	6
Limey shale	1:	1:	11
Red sandstone	5:	3:	9

Bore-hole No. 3.B. 1870. (Contd.) Caldronlee.

Red sandy shale	3: 4
Limey and sandy shale	3: 0
Grey sandstone	1: 5: 2
Red Sandstone	3: 0
Grey shale	1: 6
Red sandstone	1: 1: 9
Red shale	3: 0
Red sandstone	2: 9
Grey shale	1: 6
Red sandstone	4: 0
Grey shale	2: 6
Red sandstone	3: 0
Grey sandstone	2: 6
Red sandstone	3: 0
do.	1: 0: 5
Grey and red shale	3: 4: 9
Red sandy shale	1: 1: 8
Red s andstone	9
Slip	1: 6
Red sandy shale	4: 5
Slip	3: 0
Red sandy conglomerate	1: 0: 7
Red shale	2: 0: 7
Red sandy shale	2: 2: 6
Red sandstone	1: 3: 0
Red shale	2: 0: 0
Red and grey sandy shale	4: 0
Red morly shale	1: 0: 0
Red and grey sandy shale	1: 2: 0
Red shale	2: 3: 8
Red sandy shale	1:10
Red strip of shale	1: 3: 6
Red sandy shale	3: 6
Grey sandy shale	7: 1: 0
	58: 1: 0

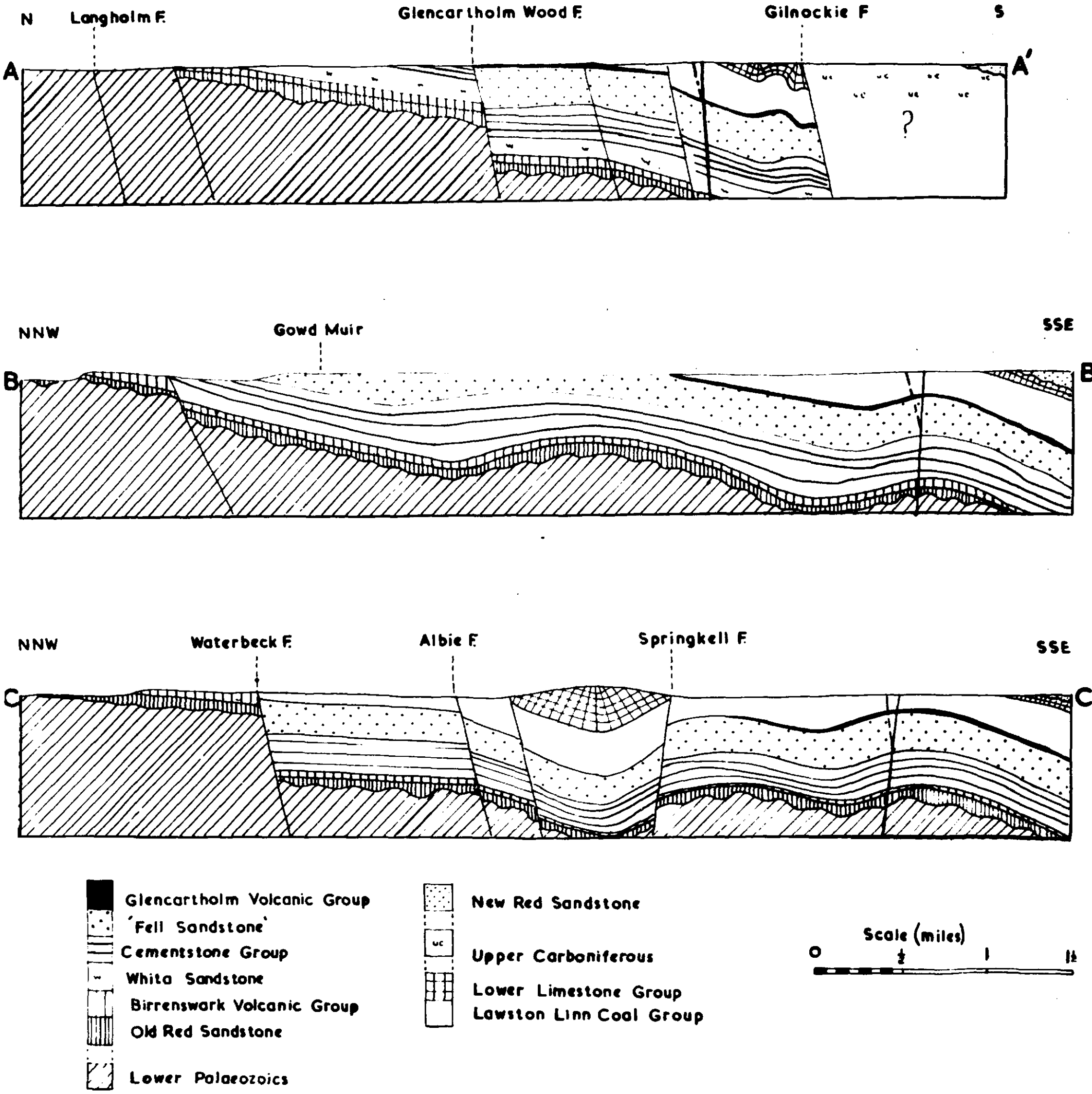
Bore-hole No. 4.B 1870. Bogra.

Surface			7
Coarse clay		4:	6
Gravel			9
Sand and gravel	6:	3:	3
Fireclay	3:	0:	6
Coarse clay	1:	4:	0
Quick sand	1:	0:	11
Coarse sand and gravel	2:	2:	1
Coarse clay	4:	3:	5
Soft red shale	5:	3:	0
do. harder	9:	0:	2
do. with freestone bands	2:	5:	0
Freestone bands		2:	8
Red shale and freestone bands	2:	2:	9
Freestone bands		1:	11
Soft red shale	3:	5:	6
do. with freestone bands	1:	2:	4
Red freestone bands	1:	4:	4
Red and grey freestone	4:	0:	11
Red bley			4
Red freestone	2:	0:	8
Hard bastard freestone		2:	10
Red shale with freestone	1:	3:	5
Red freestone	1:	1:	4
Red bley or shale		2:	5
do. with freestone		3:	6
Red shale		3:	9
Hard red bastard freestone			2
Red shale with freestone		4:	8
Red and grey freestone mixed with shale		5:	0
Red shale		4:	3
Red and grey freestone	1:	1:	7
Red and grey bley	1:	4:	4
do. with freestone		5:	0
Grey freestone mixed with bley	1:	0:	7
Red and grey freestone bands	1:	0:	8
Red and grey freestone	5:	4:	5
	70:	0:	6

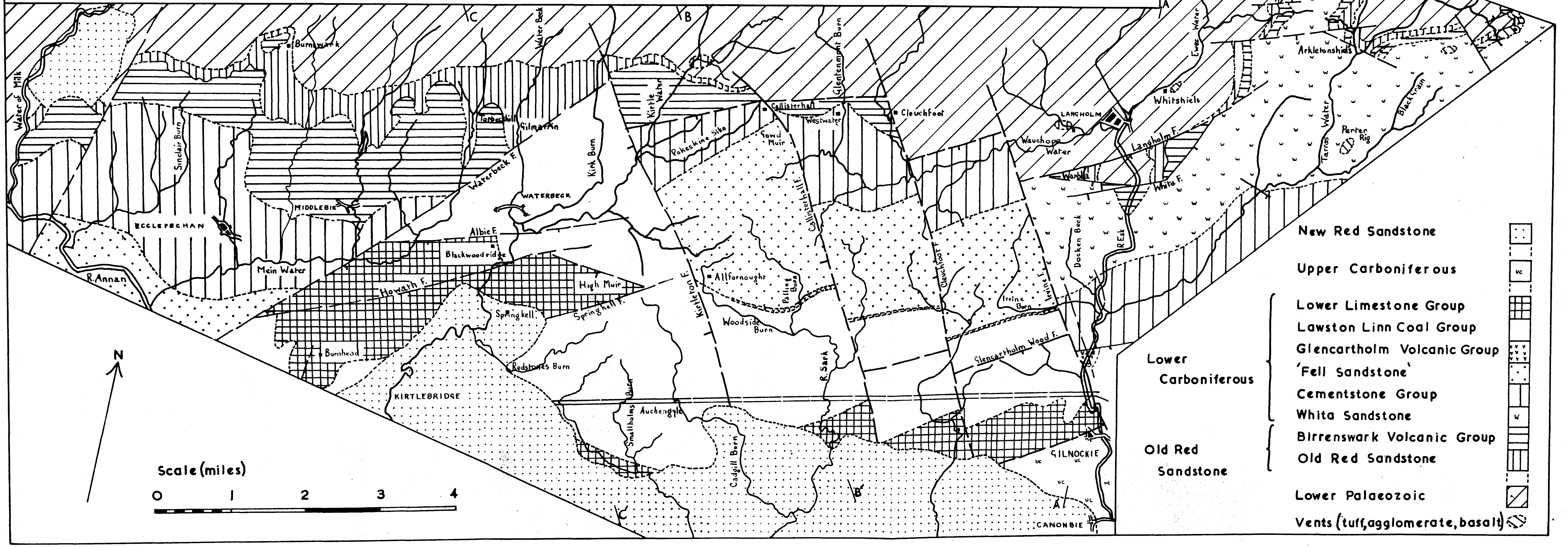
Bore-hole No. 5.B 1871 Neds Beck over Cadgillhead.

Surface	1: 0
Gravel	2: 0
Clay mixed with sand	3: 5: 7
Hard sand	2: 0: 1
Red sandstone	2:10
Red bley with freestone	1: 1
Red freestone	1: 0: 6
Red bley	5
Red freestone	1: 4
Red bley	2:11
Red freestone bands	2: 0;10
Red bley with freestone	4: 2
Red freestone	1: 0: 7
do. with bley partings	3: 4: 2
Red bley	1: 9
Red freestone and bley	2: 6
Red bley with freestone	5: 3
Red freestone with bley	3: 1: 8
Red freestone bands and bley partings	1: 4: 1
Red freestone	2: 5: 1
Red freestone fakes	1: 4:10
Red freestone	2: 2: 4
Red freestone fakes	5: 1: 5
Red freestone	1: 0: 9
Red bley with freestone	2: 5: 3
Red bley	1: 5: 6
Red bley with freestone	3: 5: 3
Red freestone fakes	1: 5: 8
Red freestone mixed with grey	5: 3
Red freestone	5:10
Red and grey free-stone bands	2: 0
ironstone	5
Red freestone	5
ironstone	2½
Red bley with freestone bands	2: 3: 11
Red freestone and white shale	1: 5
Hard bastard freestone bands	2
Red freestone and white shale	1: 2
Hard bastard freestone bands	2
Red freestone and bley	1: 0: 10
do. with red and white shale	3: 1: 11
do. do. very soft	2: 0
Red and grey freestone bands	1: 2: 9
Red bley with grey freestone	2: 3
Red and grey freestone	3: 5: 7
Red bley with free-stone	10
Red and grey freestone	1: 0: 4
do. very hard	1: 5
Red and grey bley with freestone	5: 8
Red and grey freestone bands	3: 0
Red bley with freestone	1: 4: 1
Red and grey freestone bands	1: 1: 3
Red freestone	1: 0: 8
do. with grey	2: 9
Red and grey freestone with bley	5: 6
Red and grey freestone	2: 0: 4
Red and grey freestone with bley	2: 2: 7
Red bley with free-stone	2: 1: 5
Red and grey bley with freestone	4: 11
Red and grey freestone and bley	1: 2: 11
	80: 2: 9½

CROSS SECTIONS IN THE ESK & WATERBECK AREAS



The Geology of the Langholm-Ecclefechan Area



Session 1953-54

HIGHER DEGREES AND SPECIAL STUDY AND RESEARCH