No. VII.—The Lower Carboniferous Outlier of Kirkbean, Kirkcudbrightshire. By G. Y. Craig, B.Sc., Ph.D., F.G.S.

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Contents

1. Introduction

The Lower Carboniferous outlier of the Kirkbean district lies some 11 miles due south of Dumfries on the south-east flank of the Criffel granite, and covers an area of about ten square miles (Fig. 1). The strata are well exposed on the shore between Carsethorn and Southerness for a distance of nearly four miles, but, apart from sections in streams flowing off Criffel, inland exposures are few.

The area lies athwart the boundary of the one-inch Geological Survey Sheets 5 and 6 (published in 1879, second edition Sheet 5 in 1927) and the first detailed account of the geology is contained in the Explanation to Sheet 5 (1896), in which Horne recognised four divisions of the strata on the shore, assigning them to the Calciferous Sandstone Series:

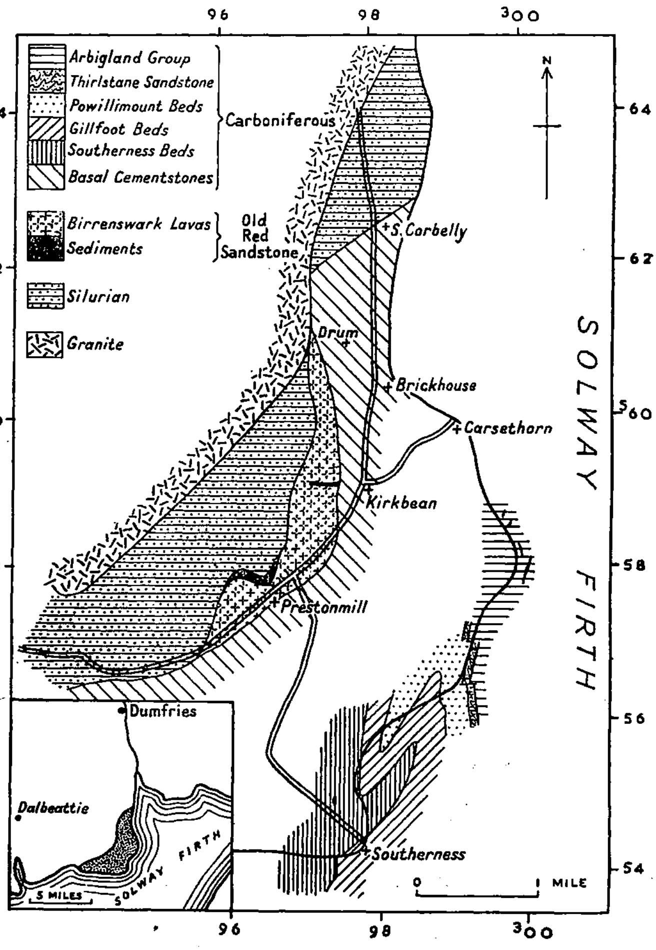

FIG. 1.—Sketch-map of the Kirkbean Outlier.

4. Coralline limestones of Arbigland Bay.
3. Sandstones, shales and thin marine limestones.
2. Thirlstane sandstones.
1. Sandstones and shales with marine bands and cementstones.

In the Regional Geology handbook for the South of Scotland (1935, 2nd edition 1948), Pringle, adopting Horne's division of the shore strata, correlated the basal beds with the upper part of the Cambeck Series of North Cumberland, and the Coralline Limestones with the Lawston Linn and Lewisburn Coal Group of the Eskdale-Liddesdale district. The Thirlstane Sandstone was taken as the equivalent of the Fell Sandstone of Liddesdale.

The succession now established by the present writer for the Kirkbean outlier is shown below:—

Liddesdale			Kirkbean Outlier (*Craig*, 1956)	(*Horne*, 1896)
Lawston Linn Coal Group			Arbigland Group	4 and 3
Fell Sandstone Group		=	Thirlstane Sandstone	2
			Powillimount Beds	3
			Gillfoot Beds	2
Cementstone Group	Cambeck Beds	=	Southerness Beds	? 3
	——		Basal Cementstones	? 1
			unconformity	
Old Red Sandstone		=	Birrenswark Lavas	
			Sandstones, siltstones and shales	
			unconformity	
Silurian			Greywackes and shales	

Early accounts of the geology of the district are to be found in Jameson (1814), Jolly (1869), and Smith (1910). The last-named appended to his account of the lithology a very full list of fossils, and described as new species some problematical borings and casts.

2. Lithology

(a) Old Red Sandstone

Thin red sediments and basaltic lava arbitrarily assigned to the Old Red Sandstone system are exposed in Kirkbean Glen and Prestonmill Burn. The sediments are unconformable on an uneven basement of strongly-folded Silurian greywackes and shales. A typical succession is well exposed in Kirkbean Glen, below the second footbridge, some 600 yards west of the village:—

	Ft.	In.
Basaltic lava		
Greyish-purple and green shales and sandstones	30	—
Chocolate-coloured siltstone	—	10
Greenish-grey siltstones	2	—
unconformity		
Silurian greywacke		

In the same glen, 300 yards west of the village, the succession is:—

	Ft.
Basaltic lava	
Brownish-grey sandstone	8
Pale brown siltstone breccia	8
Greyish-purple micaceous siltstone	5
Pale brown siltstone breccia and conglomerate	? 7
unconformity	
Silurian greywacke	

In the burn at Prestonmill cornstones appear among the shales, but the contact with the underlying Silurian is not exposed. These rocks are the most westerly remnants of Old Red Sandstone sediments in the south of Scotland.

The basaltic lavas, although not more than 50 feet in thickness, occupy a relatively broad tract of fertile ground between the main road and Criffel and form the westernmost extension of the Birrenswark volcanic horizon (*see* Pallister, 1952).

(b) Carboniferous

(i) *Basal Cementstones.*—The only visible contact of the lava with the overlying sediments lies in the stream section immediately below the smithy at Prestonmill. Calcareous mudstones clothe an uneven surface of lava and in thin section are seen to contain rounded fragments of mudstone and lava. A hundred yards downstream dark-grey micaceous shales have yielded *Spirorbis*?, *Nuculopsis*? and fish scales.

Lava is not encountered north of Brickhouse Wood, and at the north-westernmost outcrop of the Carboniferous rocks, Basal Cementstone beds lie in faulted contact against the granite mass of Criffel. The strata there disappear seawards to the immediate south of the porphyrite intrusions at South Corbelly. Both here and to the south the Basal Cementstones are assumed, on the positive evidence provided by the erosion of the lava together with the somewhat negative evidence of absence of exposures, to overstep the lava and lie directly on Silurian rocks. Support is lent to Nairn's interpretation (1956) of an unconformity between the Birrenswark lavas and the overlying Cementstones in the Esk district to the east.

Basal Cementstones are faulted against lava in Kirkbean Glen. The strata consist of at least 70 feet of greenish-grey, somewhat carbonaceous siltstones with irregular cementstone stringers carrying small crystals of galena. Cementstone strata occur also to the north, in stream sections near Brickhouse and at Drum, as sandstones and grey fine-grained limestones carrying a poorly-preserved molluscan fauna.

It is not possible to estimate accurately the thickness of this series, though it may reach several hundreds of feet

(ii) *Southerness Beds*.—The main outcrop of this sub-division occurs as a broad anticline on the shore to the west of Southerness Point. The contact with the underlying Basal Cementstones is not seen, the oldest visible rocks outcropping in the core of the anticline. The junction with the overlying Gillfoot Beds is taken at the base of the sandstone with calcareous rods seen some 500 yards to the north of the lighthouse. The exposed thickness of the sequence is estimated to be 450 feet.

The rocks in the West Southerness sequence are mostly thin grey limestones, sandy limestones and limy shales together with four thin, grey, flaggy sandstone bands, which have proved to be useful marker horizons in determining the structure of this part of the shore. The limestones are extremely fossiliferous and are dominated by brachiopod and molluscan faunas. Two unusual algal horizons are also well developed. The basal beds carry mainly a molluscan fauna:—

Aviculopecten
Lithophaga lingualis (Phillips)
Modiola megaloba (McCoy)
Nuculopsis gibbosa (Fleming)
Nuculana attenuata (Fleming)
Pseudamusium anisotum (Phillips)
Sanguinolites plicatus Portlock
Bucaniopsis sp.
Loxonematids
Crinoid ossicles

The 55-ft. thick Syringothyris Limestone (see Fig. 4) contains:—

Athyris glabristria (Phillips)
Crania quadrata (McCoy)
Derbyia ambigua Muir-Wood
Dictyoclostus teres Muir-Wood
Echinoconchus punctatus (Martin)
Punctospirifer scabricosta North
Pustula sp.
Syringothyris exoleta North
S. cf. *cuspidata* (Martin)
Crinoid ossicles
Polyzoa

Zaphrentoides delanouei s.l., the only coral specimen collected from the beds, came from this horizon. *Orbiculoidea nitida* occurs in shaly partings above the limestone.

Two algal bands, the lower 4 ft., the upper 3½ ft. thick, immediately succeed thin, grey, flaggy sandstones and lie 45 and 90 ft. respectively above the top of the Syringothyris Limestone. The bands contain algal aggregates up to 11 inches in diameter, which are referable to the form-genus *Somphospongia*.

Other species include ?*Orthoceras breyni* frequently associated with algal growths, *Dictyoclostus teres*, small gastropods, polyzoans and crinoid ossicles.

By far the most abundant species in the succession is *Dictyoclostus teres*, of which some beds are almost entirely composed. The fauna is comparable with that listed by Garwood (1931) from beds of the Main Reef and Cambeck Series in North Cumberland, 30 miles to the east-north-east.

The upper part of the Southerness Beds, exposed to the north of the lighthouse, is less calcareous than the beds below and consists of thin limestones (5-14 inches) carrying ostracods and crinoid débris, and two current-bedded and contorted sandstones of Fell Sandstone type (see p. 125).

(iii) *Gillfoot Beds.*—This sub-division, estimated to be 400-600 ft. thick, is dominantly composed of reddish-brown sandstones and conglomerates. Subordinate shales and fossiliferous marine bands occur above the dark-grey calcareous sandstone forming the base of the series. This sandstone is riddled by carbonate rods which appear to be the remains or infillings of original structures (? burrows) traversing the bedding. Two thin sandstones of Fell Sandstone facies, showing contorted structures (see p. 125), occur near the base of the succession. They are succeeded by reddish-brown breccias carrying quartz and carbonate fragments, the latter of which are lithologically indistinguishable from the reddish-brown carbonate nodules in associated shales, suggesting penecontemporaneous erosion.

A greyish-red limestone (12-14 inches thick) overlying breccia exposed some 70 yards north of the lighthouse has yielded:—

Dictyoclostus cf. *teres* Muir-Wood
Modiolid
Nuculana attenuata (Fleming)
Nuculopsis gibbosa (Fleming)
Euomphalus pentangulatus Sowerby
Fenestella
Ostracods

The overlying fossiliferous veneer of shell débris at the top of the sandstone on which the lighthouse stands, carries:—

Aulopora
Lithostrotion scoticum ? Hill
Punctospirifer scabricosta North
Fenestella
plant casts?

This is the lowest occurrence of *Lithostrotion* in the succession and indicates a Viséan age for the strata.

Further to the north, on the shore near Gillfoot, purplish-brown conglomerates crop out. The matrix is calcareous and the pebbles (up to four inches in size) consist of quartz-porphyry probably derived from the adjacent Old Red Sandstone intrusives in the Silurian rocks to the north (*see* King, 1937), vein quartz and quartz mosaics (*see* MacGregor and Eckford, 1947), sandstones, greywacke and carbonate rocks. Some of the quartz mosaics have a weak foliation and are indistinguishable from certain Highland rocks. MacGregor suggested that the quartz mosaics in Old Red and Carboniferous sandstones in the Border district might be chert fragments derived at second hand from Southern Upland greywackes. Whatever the genesis of the mosaics here under discussion it seems probable that they have been secondarily derived. A few small black pebbles (up to one inch) of a fine-grained igneous rock, showing affinities with the Ballantrae igneous suite, may also be secondary. It is most likely that the sources of these fragments lay somewhere within an arc to the north or north-west. Higher felspathic beds are almost entirely composed of porphyrite débris, certainly derived from local intrusions in the Silurian rocks to the north and north-west.

The top of the Gillfoot Beds is defined and easily identified by a grey calcareous breccia/conglomerate with fragments less than one inch in size.

It should be added that the sands of the Solway are constantly shifting between Gillfoot and Powillimount, in turn exposing and concealing the outcrops.

(iv) *Powillimount Beds.*—This sub-division occupies part of the coastal stretch of strongly folded rocks outcropping in patches between Powillimount and Gillfoot and in thickness measures about 450 feet. The rocks are mostly grey sandstones and shales together with thin fine-grained limestones of cementstone type and algal oolitic limestones. A six-inch coal streak and ripple-marked sandstones indicate the shallow-water nature of the sediments. Carbonaceous fragments are common in the sandstones.

Even within the limited area exposed there is a distinctive facies change. The basal beds near Gillfoot are more arenaceous, algal and oolitic, than their equivalents on the shore near Powillimount. The most prominent algal limestone, 30 inches thick at the southern end of the outcrop, thins to three inches at Powillimount; quartz pebbles (up to two inches) occurring in the limestone in the south are absent in the north; and the immediately overlying beds are more arenaceous and oolitic in the south, contain algal pellets, and are current-bedded.

Fossils collected include:—

Girvanella
Bevocastria conglobata Garwood
Ortonella furcata Garwood
Gastropods
Ostracods

Some of the *Mitcheldeania* nodules containing the algae show evidence of rolling and fresh growth. Ooliths are formed around nuclei of quartz and crinoid ossicles, but are most frequently associated with fragments of ostracods, many of which appear to have been broken and only partly recoated. Rare red grains with a grey calcareous coating may well have been derived from the Old Red Sandstone.

Shales below the coal streak bear *Spirorbis* cf. *helicteres*, ostracods, algal fragments and an orthoceratid. Coral horizons with *Lithostrotion* and *Syringopora* are developed near the top of the sub-division, which passes up abruptly into the Thirlstane Sandstone.

Horne (1896, pp. 30, 31), misled by the apparently large displacement of the E-W fault on the shore at Powillimount, correlated the Powillimount Beds on the south side of the fault with the lowest part of the Arbigland Group (Series 3 of Horne). The Gillfoot Beds he identified with the Thirlstane Sandstone and apparently included the Southerness Beds in his Series 3. This mistake led to the omission of the Gillfoot and Powillimount Beds from his succession. Horne, unfortunately, was not explicit in his division of the strata and it would appear that the west Southerness beds (i.e. Southerness Beds of the present writer) were taken by him as the equivalent of Series 3, while Series 1 (noted as containing cementstones) was designated to cover the inland beds overlying the lava. Pringle (1935) — stratigraphically correct, as it has turned out — interpreted the west Southerness beds as underlying the Thirlstane Sandstone.

(v) *Thirlstane Sandstone.*—The sandstone is about 80 ft. thick and forms a conspicuous ridged outcrop for a distance of about a third of a mile northwards along the shore from Powillimount. The sandstone is strongly current-bedded and contorted structures are present (see p. ??). The colour is mostly pinkish grey with limonitic mottling, but is occasionally dark red. Thin sections reveal that medium-sized (0.2-0.5 mm.), subangular grains of quartz are predominant, with occasional felspar and mica, set in a silica cement. Quartz mosaics, consisting of intergrowths of strained quartzes similar to those described by MacGregor and Eckford (1947), are present; some of the quartz grains show secondary growth. The facies is typical of the Fell Sandstones in the Scottish Borders and N. England.

The overlying strata and the folding at the south-east end of the Thirlstane outcrop, recorded on Sheet 6, are now obscured by sand.

(vi) *Arbigland Group.*—Beds of the Arbigland Group crop out almost continuously along the shore northwards from the Thirlstane to Hogus Point, forming the highest ground of the coast at Borron Hill (100 ft.), and are at least 1,000 feet in thickness. The lowest exposed beds are separated from the underlying Thirlstane Sandstone by a reversed fault of unknown throw. Limy argillaceous sandstones bearing *Echinoconchus, Fenestella* and crinoid ossicles form the oldest beds. Two thin (1-2 ft.) gritty limestones are developed in the succeeding gritty and limy sandstones. These limestones contain algal débris and crinoid ossicles and in the grittier bands are slightly oolitic. The ooliths (0.2-0.5 mm. diameter) have nuclei of angular quartzes or, infrequently, of carbonate material. The larger quartzes (1-2 mm.) are uncoated. Coalified plant-casts up to two feet in length occur in the sandstones.

The succeeding beds of the group crop out north of the Arbigland Garden fault and form an almost circular synclinal basin east-north-east of the House-on-the-Shore. They differ from the underlying beds in being more calcareous and in places highly fossiliferous. Massive, grey, carbonaceous sandstones and calcareous sandstones are intercalated with impure sandy limestones, limestones and poorly exposed shales. The sandstones are usually coarse grained with occasional pebble bands, and ripple-marked. Many of them exhibit well-developed 'cast' structures of irregular branching and twisting sandstone rods which, when not decalcified, can be demonstrated to be the moulds and casts of branching corals and polyzoa. Ironstone nodules are common in the limy beds.

The Arbigland strata have long been famed for the abundance and excellent state of preservation of compound corals. Massive hemispherical colonies of *Lithostrotion clavaticum* are recorded (Smith, 1910) as reaching dimensions of 6 ft. x 4 ft., but the more usual dimensions are up to 30 inches. An indication of the depositional environment is provided by several overturned colonies one of which has a diameter of 27 inches. On the other hand, in the limestone overlying the Erratic Boulder Sandstone (boulder indicated on Fig. 7) immediately north of Arbigland Garden, specimens of *Edmondia sulcata* preserved in their inclined burrowing position can be obtained from the ironstone nodules.

The Arbigland Bay fauna includes:—

Aulopora
Caninia benburbensis Lewis
Caninophyllum archiaci (Edwards & Haime)
Carcinophyllum kirsopianum Thompson
[1]*Koninckophyllum* cf. *dianthoides* (McCoy)
Lithostrotion clavaticum Thomson
L. scoticum Hill
Syringopora
Hapsiphyllum enniskilleni (Edwards & Haime)
[1]*Michelinia*
Cladochonus (recorded by Hill, 1938-1941, p. 29)

Echinoconchus punctatus (Martin)
E. elegans (McCoy)
E. cf. *elegans*
Dielasma hastata (Sowerby)
Gigantoproductids
Punctospirifer scabricosta North
Punctospirifer sp.
[1]*Martinia glabra* (Martin)
Spirifer bisulcatus (J. de C. Sowerby)

Stenopora obliqua Lee
Tabulipora howsei (Nicholson)
Fenestella

Euphemites urei (Fleming)
Euomphalus pentangulatus Sowerby
Murchisonia

Dentalium

Orthocones
[1]*Beyrichoceratoides*? (identified by Dr. E. D. Currie)

Actinopteria persulcata (McCoy)
Aviculopecten spp.
Edmondia sulcata (Phillips)
E. spp.
Myalina spp.
[1]*Pinna flabelliforme* (Martin)
Pseudamusium spp.
Pterinopecten
Sanguinolites
Schizodus

[1] Identified from specimens in John Smith's Collection, H.M. Geol. Survey, Edinburgh.

At the north end of Arbigland Bay the strata swing round parallel to the shore line and are succeeded by more arenaceous beds which in places are overturned. Beds of the Arbigland Group crop out on the Hogus shore and from the Hogus Limestone the following fossils were collected:—

Aulopora
Caninia benburbensis Lewis
Caninophyllum archaici (Edwards & Haime)
Lithostrotion clavaticum Thomson
Lithostrotion scoticum Hill
Syringopora

Echinoconchus punctatus (Martin)
Buxtonia scabricula (Martin)
Gigantoproductids
Punctospirifer scabricosta North

Fenestella
Stenopora
Tabulipora scotica

Euomphalus pentangulatus Sowerby

Echinocrinus urii (Fleming)

On structural grounds these beds are considered to be the highest exposed members of the Arbigland Group.

3. Contorted Sandstones

Two sandstones at the top of the Southerness Beds, two sandstones in the Gillfoot Beds, and the Thirlstane Sandstone have bands of contorted strata. All five sandstones are of Fell Sandstone facies — strongly current-bedded with medium-sized quartz grains and occasional felspar and mica; they are usually pinkish grey but occasionally dark red in colour. The Thirlstane sandstone is 80 ft. thick; the others vary between ten and 17 feet.

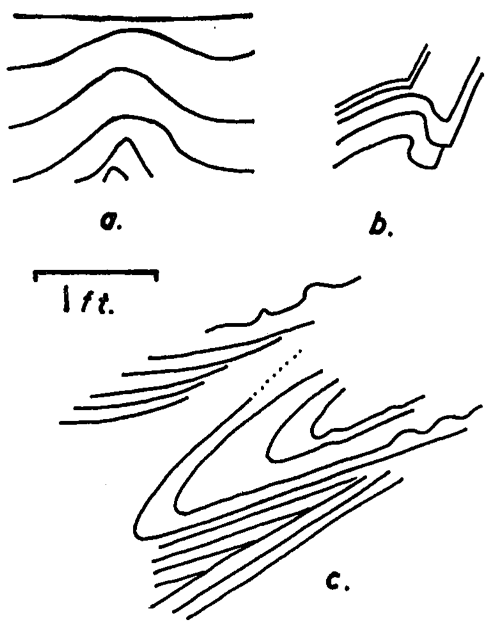

Fig. 2.—Contortions in sandstone.

The contortions (see Fig. 2) vary from pseudo-ripple marks to overfolds and are overlain by undisturbed current-bedded strata, showing that the contortions must have occurred before the deposition of the succeeding stratum. Marine erosion has emphasised the irregular bedding of the contortions and has resulted in unusual and characteristic outcrops of curled and warped strata, particularly in the case of the Thirlstane Sandstone which has not been planed to sea-level. Irregularities of bedding, however, are not obvious on unweathered surfaces.

Pseudo-ripple marking was found only in the lower contorted sandstone of the Gillfoot Beds, the axes of the crests (2-2½ inches amplitude) symmetrically flanking the strike within an arc of 60°. They might easily be mistaken for normal ripple-marks were it not for the fact that the peaks on one flank of the arc steepen into sharp crests and small overfolds. Such small-scale structures appear to develop into sharp anticlinal crests about a foot in height. The strongest expression of these contortions is as overfolds, best seen in the Thirlstane Sandstone. Three observed fold-plunges of overfolds are directed within a 123° arc (N 35° E - E 68° S) flanking the 37°, 112° ESE. dip of this sandstone. Two of the overfolds close against the dip of the current-bedding. The overfolds, up to three feet in width, are traceable along their axes for visible distances of up to 20 ft. In all cases the flakes of mica lie parallel to the surfaces of the folded planes.

There is little doubt that the contorted structures in these Kirkbean sandstones have resulted from flow within surface layers of sand, presumably with a critical admixture of water, under the action of gravity. Pebbly sandstones and limy sandstones in the intervening beds are not contorted and it is apparent that the lithology of these contorted sandstones is the key to two of the factors influencing movement — the depositional environment and the physical properties of the unconsolidated sediment. An indication of the shallow depth of water at which this flow may have occurred is provided by the presence of vertical plant rootlets at the top of the upper slumped sandstone of the Southerness Beds. The wide arc within which the observed directions of slumping occur suggests an uneven surface of deposition.

4. Structure

The beds form part of the north-westerly limb of the Cumbrian trough and strike *en échelon* along the coast, dipping generally towards the ESE. The oldest beds of the coastal strata are exposed on the west Southerness shore, the youngest to the NNE. at Hogus Point. The strata dip steeply — indeed on the

Borron shore some of the beds are inverted — and are folded into a series of anticlines and synclines plunging to the NNE.

Faulting is dominant along a WNW.-ESE. line (see Fig. 3). The dominant faults, with three exceptions, are normal faults downthrowing towards the north (i.e. towards the nose of the major fold). The exceptions are the hinge fault opposite Arbigland Garden, the 'reversed' fault[1] separating the Thirlstane Sandstone from the Arbigland Group, and the tear fault on the W. Southerness shore. The hinge fault is developed in the core of a plunging anticline, bringing two sets of beds into a position at right angles to each other. The throw increases westwards in a distance of 360 ft. from nil at the seaward end to 210 ft. at the shore end of the fault. The dextral tear fault lying parallel to, and some 150 yards from, the shore has a lateral displacement of about 270 ft. as shown by the displacement of the axis of the anticline.

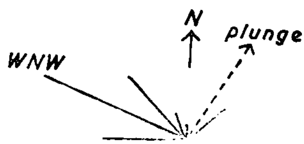

FIG. 3.—Rosette of fault directions.

The dominant fault pattern is parallel to the 'a-c' joint system of about E 28° S in the core of the Southerness anticline and E 21° - 40° S joints of Thirlstane Sandstone, the latter of which have been greatly enlarged by marine erosion into fissures and geos. The other system of joints in the Southerness anticline is directed N 13° E.

5. CORRELATION

The correlation of the Lower Carboniferous of the South-West of Scotland is based on the succession established by Peach and Horne (1903) in the Canonbie district and by Garwood in North-East Cumberland and Roxburghshire. A link between these areas and Kirkbean is afforded by Nairn's work (1956) on the succession between the Rivers Esk and Annan, Dumfriesshire. The correlation between the two areas is shown by Fig. 4.

[1] Although a reversed fault relative to the horizontal, it is a normal fault relative to the plunge.

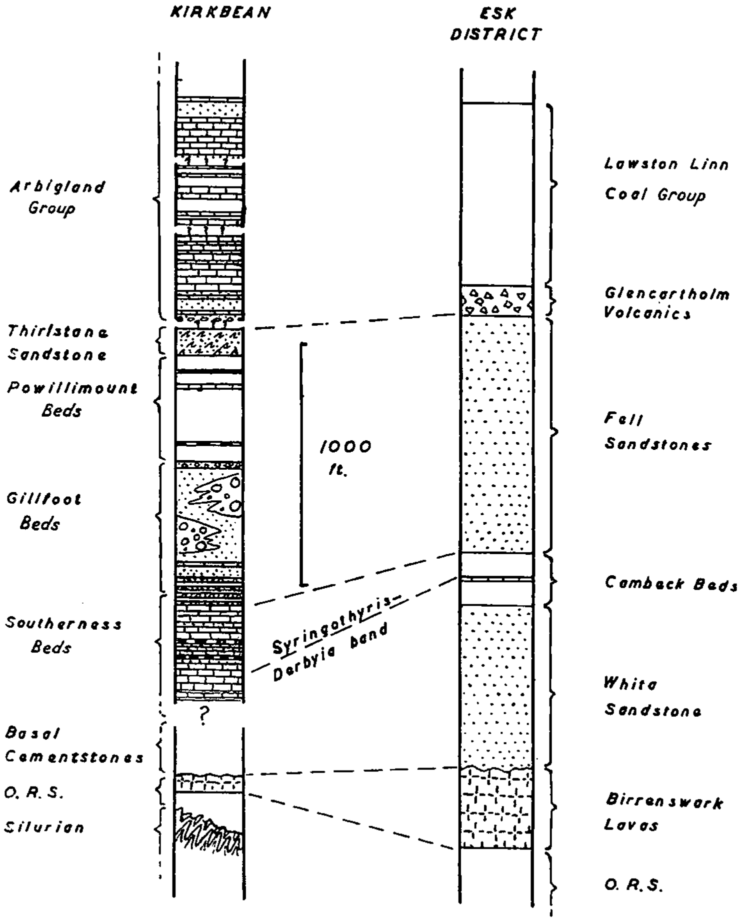

FIG. 4.—Comparative vertical sections of the succession in the Kirkbean and Esk districts.

(For explanation of ornament see Fig. 7).

The Kirkbean succession differs from its nearest eastern counterpart in the Annan-Esk District, in:—

(1) a thin Birrenswark Lava horizon followed directly by a cementstone facies;

(2) a greater marine development of the Cambeck Beds;

(3) the virtual replacement of the Fell Sandstone facies by conglomerates, grits and sandstones of local origin, and by a sandstone-shale-limestone succession with algal and oolitic horizons;

(4) a greater marine development of the local equivalent of the Lawston Linn Coal Group.

6. Summary and Acknowledgments

Summary.—The Cementstones, Fell Sandstones and Lawston Linn Coal Group are represented by some 2,500 ft. of strata. The Basal Cementstones lie unconformably on Birrenswark Lava and are succeeded by the Southerness Beds, a limestone-shale succession which can be correlated with the Cambeck Beds. The Fell Sandstones are represented by red conglomerates, sandstones, shales and felspathic grits (Gillfoot Beds), followed by grey sandstones, shales and limestones with algal and oolitic beds (Powillimount Beds) and capped by the Thirlstane Sandstone.

Contorted strata of Fell Sandstone facies, interpreted as 'slump sandstones', occur at the top of the Southerness Beds, in the Gillfoot Beds and in the Thirlstane Sandstone.

The Arbigland Group with abundant corals is a more marine development of the Lawston Linn Coal Group.

The strata are folded into a series of anticlines and synclines plunging to the NE. and are cut by WNW.-ESE. faults mostly downthrowing to the NNE.

Acknowledgments.—The writer wishes to express his indebtedness to Professor T. Neville George and Professor Arthur Holmes for reading the manuscript of his paper. Acknowledgments are also due to Dr. A. E. M. Nairn for a pre-publication copy of his paper on the Lower Carboniferous Rocks between the Rivers Esk and Annan, and to Dr. E. D. Currie for the identification of a goniatite from Arbigland Bay.

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Appendix

Note on Structure Analysis

The use of statistical techniques in geology is a logical trend in the development of the science. Palaeontological and petrological workers are making increasing use of statistics in the analysis of data, and structural workers, particularly in Europe, have for some years applied statistical methods to the interpretation of folded rocks. The Kirkbean strata provide a straightforward example of the use of one of these techniques—the β-diagram.

In the β-diagram the dips and strikes of bedding or foliation surfaces are plotted on a geographically oriented equal-area net. This particular application among others is described by Phillips (1954, p. 63).[2] The method in its simplest form can be applied to the determination of the spacial position of the line of intersection of two mutually inclined planes. If these planes represent the limbs of a simple fold then the line of

[1] F. C. Phillips, *The use of the Stereographic Projection in Structural Geology*, 1954, London.

intersection is given on the projection by the intersection of two great circles, the trend and plunge of which can be read directly from the equal-area net. If the representation of several geographically related folds on one diagram results in the concentration of intersections about one axis then the body of folded rocks is structurally homogeneous with respect to this axis.

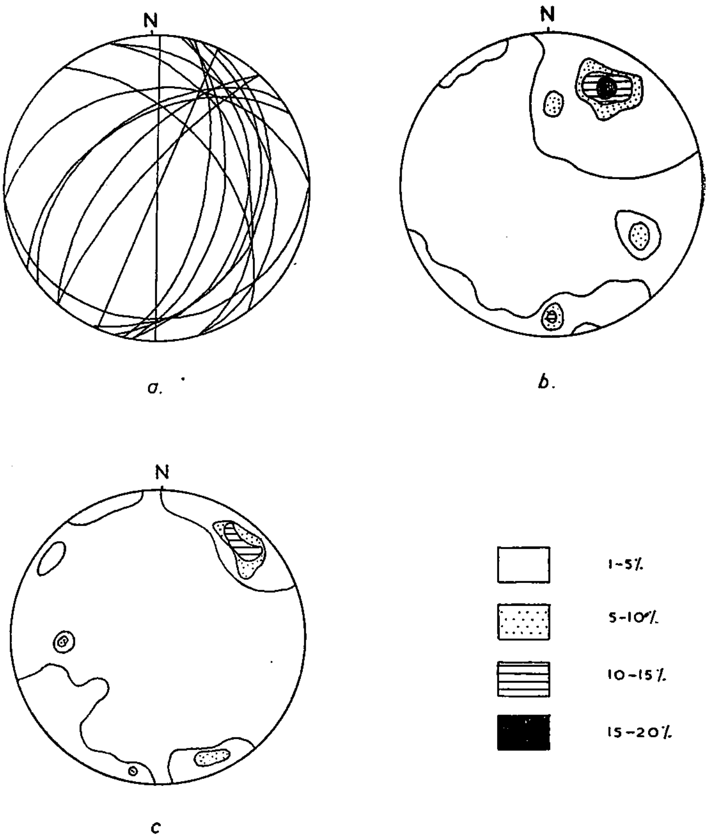

FIG. 5.—a, β-diagram (lower hemisphere) of bedding-planes between Gillfoot and Borron Point.

b, Contoured density plots of *a*.

c, Contoured density plots of intersects of bedding-planes on the Southerness shore.

The traces of the orientation of bedding-planes outcropping between Gillfoot and Borron Point are shown by Fig. 5a. Contoured density plots of the intersections (Fig. 5b) define a statistical maximum N30°E, 25° dip which is the prevailing fold axis of that area. There is a minor axial depression in Arbigland Bay, possibly influenced by the strong hinge fault opposite Arbigland Garden (the orientation of these beds is shown by the anomalous arc in the SW. of the net).

The fold axis of the rocks at Southerness (Fig. 5c) is not so

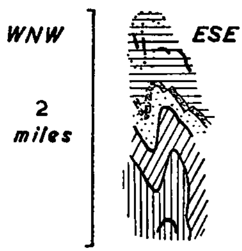

FIG. 6.—Profile of shore strata.

well defined as the axis further north, but the statistical maximum N40°E, 16° dip is in close agreement. There are insufficient data from the Hogus beds in the extreme north to reveal the orientation of the fold axes; and the critical area between Borron and Hogus is obscured by sand.

The profile of the shore strata (Fig. 6) constructed normal to statistical fold axes shows the style of the folding and reveals the northward continuation of the anticlinal structure at Southerness, through Powillimount to the area between Borron Point and Hogus Point. Inland from Hogus Point the strata must dip steeply if the thickness shown by the beds to the south is maintained in this relatively narrow stretch from the shore to Kirkbean.

The structural homogeneity of the area is thus established together with the trend and plunge of the fold axis. The determination of the fold axis enables the most accurate profile to be constructed.

The writer is grateful to Dr. L. Weiss for his helpful discussions concerning structural analysis.

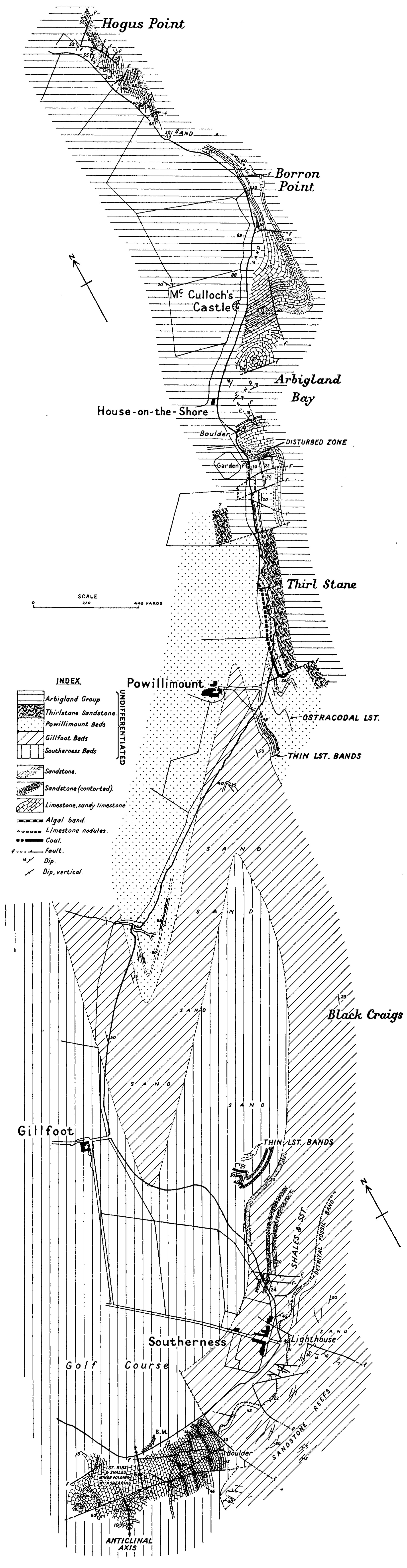

Fig. 7.—Geological map of the shore strata of the Kirkbean Outlier.

facing p. 132