THE CEMENTSTONE GROUP OF THE WEST MIDLAND VALLEY OF SCOTLAND

by

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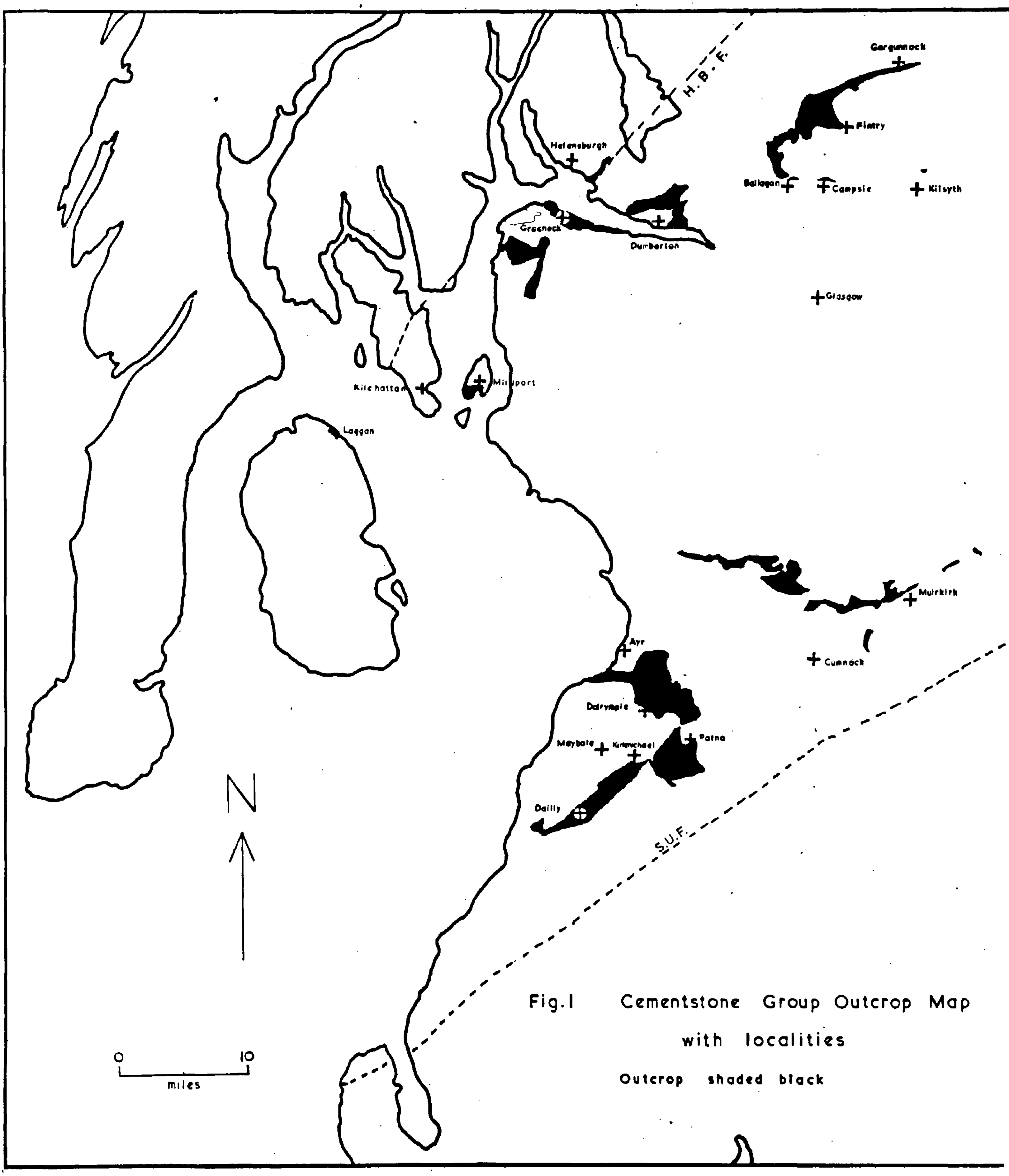


Fig.1 Cementstone Group Outcrop Map with localities

Outcrop shaded black

Chapter 1. Introduction.

The Cementstone Group of the Midland Valley is the group of sediments forming the lower formation of the Calciferous Sandstone Series of the Carboniferous system in Scotland. In its typical development, as on the flanks of the Campsie Fells, it lies between the Old Red Sandstone, and the Clyde Plateau Lavas, but while it always appears to rest on Old Red Sandstone, it is not everywhere clearly limited by the volcanic episode. South of the Inchgotrick Fault, the lavas rapidly thin and locally disappear, and the Cementstone Group is followed directly by the yellow and the generally non-calcareous deltaic sandstones of the Upper Calciferous Sandstone Group of the Calciferous Sandstone Series.

The Cementstone Group tends to form fairly narrow outcrops surrounding the major basin folds of the Midland Valley. It is missing over a large area about the Lesmahagow inlier, and to the north and east. It is also missing in the Ardrossan - Largs area and probably in the area stretching east then on to the Lesmahagow inlier. (See Fig. 1)

Where the group was first studied (Young 1867 pp. 209-212), in the outcrops of the South Campsies, the rocks consist mostly of dolomitic red and grey marls, dolomitic limestones, and micaceous sandstones, capped by thick coarse sometimes conglomeratic sandstone known as the Spout of Ballagan Sandstone. The presence of the Cementstone Group is indicated farther south in the Midland Valley by the occurrence of the characteristic cementstone and marl lithology, although at Dailly these rocks are only present in small proportion of the great thickness of Cementstone Group sediments. The absence of typical cementstones and marls in the southern areas often leads to difficulty in deciding the top and the base of the group; and at Dailly the earlier editions of the Geological Survey maps (1910) show the lower sandstones and shales of the Cementstone Group as belonging to the U. Old Red Sandstone. It is necessary to use certain arbitrary criteria to define this group in different parts of the area.

(a) The Base.

Field evidence generally indicates that there is a disconformity between the Upper Old Red Sandstone and the Cementstone Group. No angular difference can be seen between them in any one exposures, and they always run together, with the Cementstone Group never coming to rest on rocks older than U. Old Red Sandstone in age. The only evidence of a break takes the form of an eroded and weathered surface at the top of the Upper Old Red Sandstones. In the region of Sorn and Muirkirk, the basal Carboniferous rests on different rock types of the U. Old Red Sandstone, sometimes resting on a red marl, sometimes on a sandstone, sometimes on a cornstone, each exposure exhibiting signs of erosion at the junction (Pl.2. Fig. 11). Evidence of the break can also be seen north of Glasgow and in the Ayr region; and widely in the Midland Valley it appears to precede a Carboniferous marine incursion, which in most areas, brings about a marked change in lithological type, making recognition of the junction relatively easy.

(1) <u>Dailly - Patna - Cumnock</u>.

This area presents particular difficulties because of the occurrence of thick sandstones of Old Red Sandstone type within the Cementstone Group. Four criteria are convenient in mapping, though all four are rarely available at any one outcrop.

(i) The last occurrence of massive cornstones with associated sandstones defines the top of the Upper Old Red Sandstone.

(ii) The first occurrence of grey shales or true cementstones indicates Carboniferous rocks.

(iii) The occurrence of such fossils as <u>Anthraconaia</u>, <u>Naiadites</u>, and ostracods, points to a Carboniferous age.

(iv) The occurrence of carbonaceous plant remains also points to a Carboniferous age, as opposed to the occasional non-carbonaceous plant impressions of the U. Old Red Sandstone.

The last three criteria are directly correlated with the incursion of the Carboniferous sea.

(2) <u>Ayr - Kilmarnock - Muirkirk, and Northern Region,</u>

(Arran - N.E. Campsies).

It is relatively easy to determine the base of the Cementstone Group in this area. It occurs at the change from the red cornstone - sandstone lithology to the grey shale - cementstone lithology.

(b) <u>The Top</u>.

In most parts of the Western Midland Valley, the first appearance of lavas or at least of ashes of the Clyde Plateau Lavas, is taken to mark the base of the Upper Calciferous sandstone Group. The only regions where lavas or ashes are locally missing are about Kilmarnock and Coalburn and at Cumnock. The use of the volcanic group to limit the top of the Cementstone Group is only valid if none of the lavas are as old as any sediments of the group, (see p. 22). Rocks hitherto referred to the Cementstone Group at horizons above the base of the Clyde Plateau Lavas, as in a burn north-east of Corrie reservoir (700790), and from Greenan Castle, Ayr, are not true cementstones and marls. The beds of the first locality are ashy mudstones and hard limy sandstones, and the beds of the second are non-limy black shales and nodular ferruginous limestones all atypical of the Cementstone Group. ( ).

(1) <u>Dailly - Patna - Cumnock.</u>

At both Dailly and Patna there is an ash band beneath the yellow sandstones and conglomerates. This is used to find the base of the Upper Calciferous Sandstone Group. South-east of Cumnock lavas and ashes also occur, resting directly on U. Old Red Sandstone; but in the only exposure of Cementstone Group that is available, immediately to the east of Cumnock in the Gass Water, there is a gap of about 210 feet between the top sandstones, shales and cementstones of the Cementstone Group, and the yellow sandstones and bioclastic limestones of the U. Calciferous Sandstone Group. (See p. 13).

(2) Ayr - Kilmarnock - Muirkirk.

In this area in nearly every place where there is complete exposure, ashes and lava flows occur. When no volcanics can be found, the change from fine yellow calcareous sandstones, shales and cementstones, to the coarse yellow deltaic sandstones and bioclastic limestones is taken to be the junction.

(3) Northern Region. (From Arran to the North-eastern Campsies).

Sometimes as in Arran there are a few feet of thin ashy sandstones, coaly shales, and fine conglomerate just beneath the first Lava flow. These sediments are included in the Clyde Plateau Lavas Group, and are taken to be above the top of the Cementstone Group, as they are more akin in lithology to the Upper Sedimentary Group.

Lithology and Palaeogeography.

Over the western Midland Valley the lithology of the Cementstone Group shows considerable variation from the Ballagan type sediments of the Campsies (see p. 21) to the coarse sandstones and conglomerates of the Dailly - Patna region. A characteristic of all the sediments is the high carbonate content, even in the coarse sandstones, some sandstones being dolomitic.

The mode of deposition, and the palaeogeography of the Cementstone Group has received some attention in the past. The cementstones themselves have usually been assumed to be chemical precipitates in non-marine lagoons (Bailey 1925 p.12), but of late they have been compared with the dolomites of the back reef lagoons of the Zechstein sea (George 1958 p.304). Some reference has also been made (George 1958 p.309) to the palaeogeography of the Cementstone Group. The suggestion that the L. Old Red Sandstone, and in particular the Old Red Sandstone lavas, stood up as land in Cementstone times (George 1958 p.309) is reinforced in this present study by the indications of the cross bedding and the facies variation.

Chapter 2. The Stratigraphy of the Cementstone Group.

Over the western part of the Midland Valley the Cementstone Group can be divided into an upper division and a lower division, (fig. 2). In the northern region the upper division is usually referred to as the Spout of Ballagan Sandstone; in the south it is probably

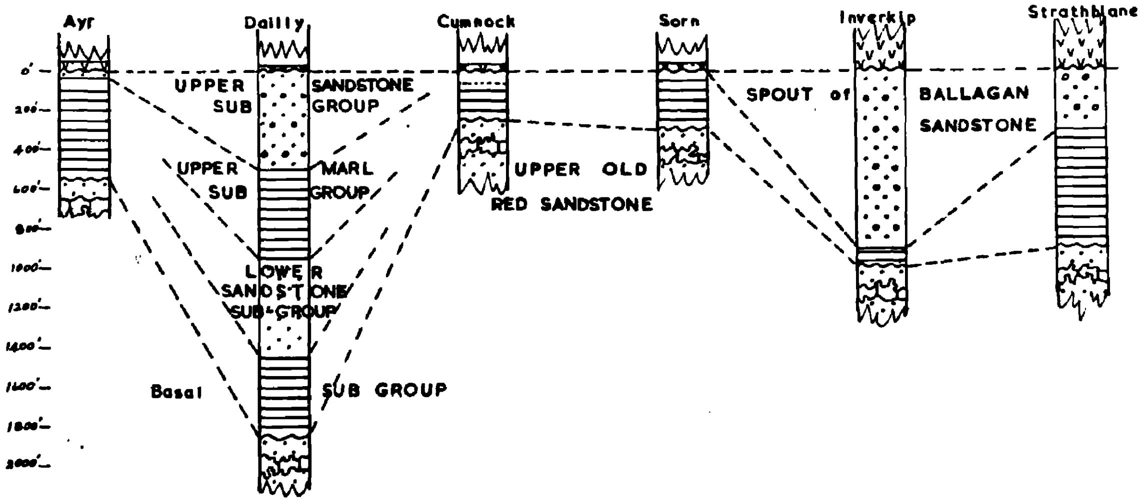
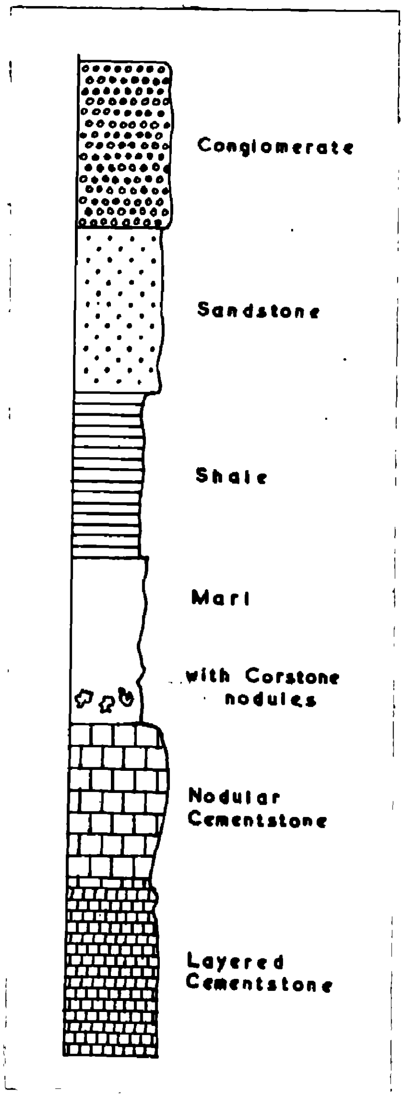


Fig. 2. The Stratigraphical Correlation of the Cementstone Group in the West Midland Valley.



Key for Figs. 3 - 5, 7 - 10, & 13 - 22. (Further lithological detail on sections).

represented by the upper sandstone sub-group of Dailly, (p. 28). To the east of Kilmarnock the upper division is absent. The lower division is represented by a thick sequence of marls, cementstones and sandstones in the north, by a similar sequence east of Kilmarnock and at Ayr, and by the basal, lower sandstone, and marl sub-groups of Dailly (pp. 7-11) in the south.

Dailly - Patna - Cumnock Region.

This region is characterised by a great thickness of sediment (1850 feet at Dailly), and a predominance of coarse clastics.

Dailly.

The Dailly sequence can be divided into four sub-groups - from bottom to top.

(a) Fine sandstones and shales (400 feet),

(b) Sandstones and conglomerates (500 feet),

(c) Marls and cementstones (450 feet),

(d) Red sandstone and conglomerates (500 feet).

(a) The Basal Sub-group.

The junction of this sub-group with the U. Old Red Sandstone is not well exposed. In most cases it is faulted, and in one exposure above Kilkerran in the Toddy Burn (310025), where it appears to be unfaulted, there is a gap in exposure of a few yards between the Cementstone Group and the U. Old Red Sandstone.

The contrast in lithology with the U. Old Red Sandstone is very marked. Near the top of the U. Old

Red Sandstone is the massive cornstone of Lannielane (313018), above which in the Toddy Burn there are 200 feet of soft pink and white calcareous sandstones. Immediately following a gap in exposure, there are beds of fine calcareous sandstones with intervening shales and ripple marked siltstones and with occasional very sandy cementstones. In the shales and limy sandstones lamellibranchs identified as Niadites obesa (Etheridge Jun.) occur with plants, fishes and ostracods. The change from cornstone-sandstone lithology to sandstone-grey shale-cementstone lithology marks a significant palaeogeographical change - the first incursion of the Carboniferous sea. The outcrop of Silurian shown on the 1" to 1 mile Geol. Survey Map 14 does not exist. The shales mapped by Richey (1949 p.59), and mentioned by him belong in fact to the basal sub-group and contain plant remains.

(b) The Lower Sandstone Sub-group.

The sections to be seen in this sub-group are in Lady Burn, Kilkerran, the Toddy Burn just above Kilkerran House, and Lindsayston Burn (275010). The sub-group contains predominantly calcareous sandstones, mostly very massive, white, pink, red, and green. Some of the sandstones are very pebbly, becoming conglomeratic at times. Subordinate to them are grey shales with plant remains, and red and green marls with cornstone nodules. No massive cornstones similar to those of the U. Old Red Sandstone are seen.

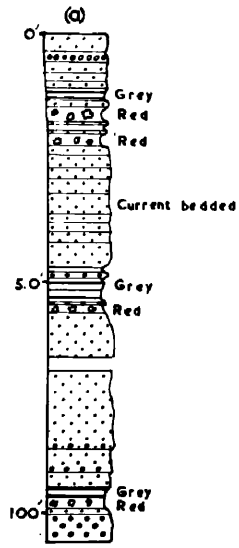
A typical sequence is illustrated by J. E. Richey (1949 p.59) (see fig. 3a); as he noted, a definite rhythm is to be seen in this sub-group. An eroded contact often occurs at the base of the conglomerates, which are conveniently regarded as the base beds of the cyclothems (fig. 3b). There does not appear to be any break in sedimentation between this sub-group and the basal sub-group, merely an increase in the ratio of shale to sandstone, and a disappearance of the marls containing cornstone nodules. One or two cementstones occur low down in the lower sandstone sub-group.

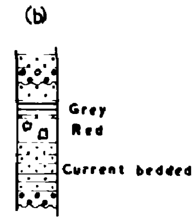
Towards the top of the sub-group thin bedded red and green micaceous sandstones appear, and these grade up into the sediments of the marl sub-group.

(c) The Marl Sub-group.

This sub-group has the closest resemblance to Ballagan sediments (p.21), except that there is a much higher proportion of sandstones than at Ballagan. Well over half of the thickness is sandy red or grey green marl, with a lesser development of fine hard yellow sandstones. Sandy nodular cementstones are subordinate, as are thin fine conglomeratic bands. The sections are to be seen in the Lindsayston Burn below the cemetery at Dailly, in the Baldrennan Burn (285041) near Kilkerran Station, and in the streams above Maxwellston Farm (262003). The measured cliff section from Lindsayston Burn shows a typical lithological sequence (fig. 4).

Key for representative sections after fig 2.





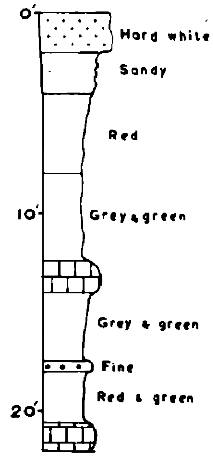


Fig. 3a. Fig. 3b. Fig. 4.

Fig. 3a. Representative section of lower sandstone sub-group from Lindsayston Burn, Dailly. Clastic Ratio 4.1 / 1.

Fig. 3b. Idealised cyclothem from 3a.

Fig. 4. Representative section of marl sub-group, Lindsayston Burn, Dailly. Clastic Ratio 0.135 / 1.

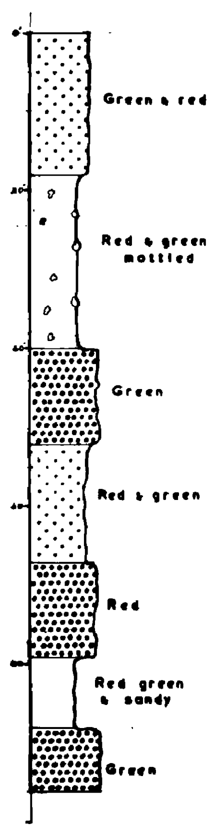


Fig. 5. Representative section of upper sandstone sub-group, Baldrennan Burn, Dailly.

The marls and fine conglomerates (fig. 4 , B and C), contain '<u>Anthracomya minima</u>', (Ludwig), the ostracods <u>Paraparchites okeni</u>, (von Munster) and <u>Glyptopleurs spiralis</u> (Jones & Kirkby), <u>Spirorbis sp</u>., fish and plant remains.

'<u>Anthracomya minima</u>' occurs also in the marls of the Baldrennan Burn. Towards the top of the sub-group the beds become very red; probably due to staining from the red upper sandstone sub-group.

<u>The Upper Sandstone Sub-group</u>.

In lithology this sub-group is very similar to the U. Old Red Sandstone, although there are no massive cornstones. It consists mostly of red and green sandstones, sandy and bright red marls, and red and green polygenetic conglomerates. Some of the marls contain limy nodules showing replacement of detrital quartz by calcite as in the cornstones of the Upper Old Red Sandstone (Burgess 1961). A typical lithological sequence is summarised in Fig. 5.

Numerous signs of sedimentary breaks are to be seen, such as coarse conglomeratic sandstones containing fragments of marl similar to that of the underlying marl sub-group, resting on eroded red marls with cornstone nodules. No organic remains were found in this sub-group. The sub-group is exposed in the Baldrennan Burn, the Lady Burn, Bargany and other streams below Maxwellston Farm. In the Baldrennan Burn and in the Lauchlan Burn (241999) the red sandstones and marls are followed by green ashy

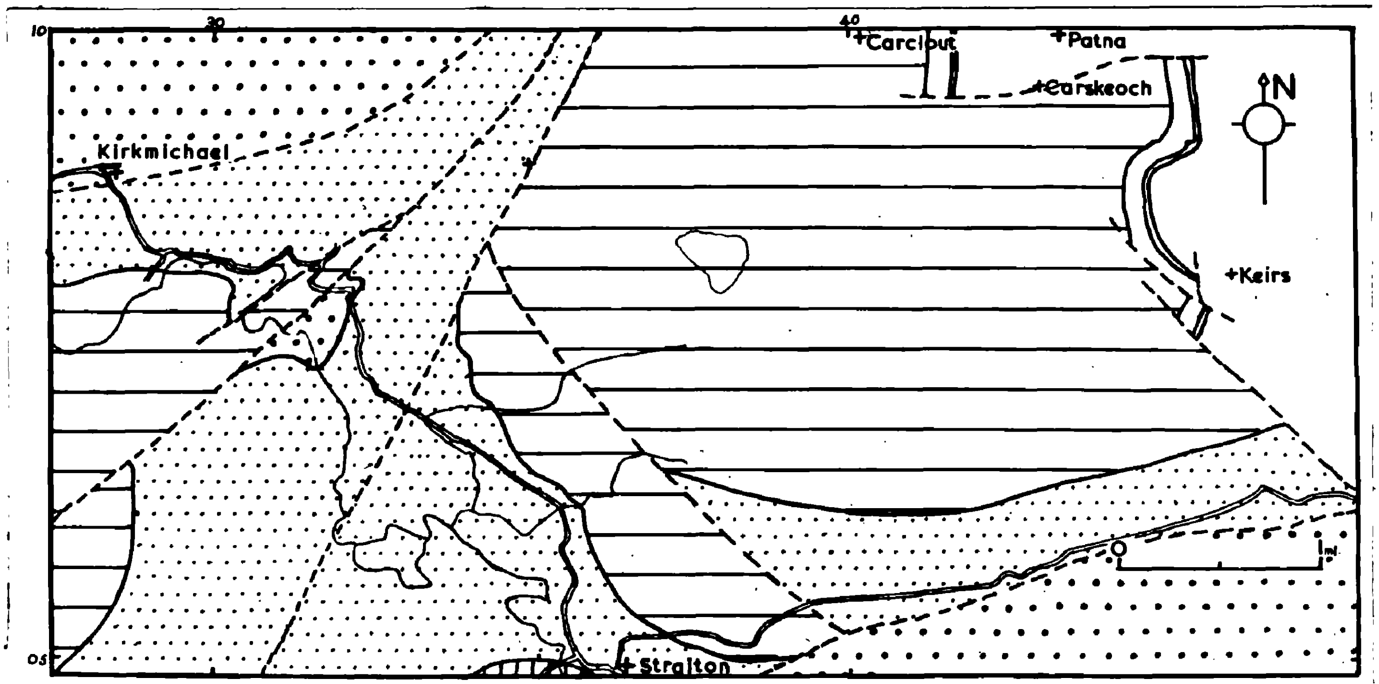


Fig. 6. Revised Geological Map of the Kirkmichael - Patna Area.

Vertical ruling	Lower Palaeozoic.
Coarse dots	Lower Old Red Sandstone.
Fine dots	Upper Old Red Sandstone.
Horizontal ruling	Cementstone Group.
No ornament	Carboniferous Limestone Series and Upper Calciferous Sandstone Group.

sandstones and fine conglomerates, above which rest yellow deltaic sandstones and conglomerates, containing plant remains, of the U. Calciferous Sandstone Group.

Patna.

The stratigraphy about Patna is obscured by the numerous faults cutting the low-dipping strata, and the general paucity of outcrops. The Geological Survey maps in the region between Kirkmichael and Straiton have been revised, rocks exposed in the River Doon being transferred from the Calciferous Sandstone series to the U. Old Red Sandstone. Rocks formerly mapped as U. Old Red Sandstone, between Straiton and Patna, are now assigned to the Cementstone Group, since carbonaceous plant remains occur low down in them, and since shales and sandstones of Carboniferous aspect appear to underlie them in the eastern tributaries of the River Doon, notably the Littleton Burn (379063) (see fig. 6).

The general sequence however is similar to that at Dailly. The outstanding difference is the absence of a representative of the Dailly basal sub-group, the U. Old Red Sandstone being followed, near Straiton, by rocks very similar in lithology to the lower sandstone sub-group of Dailly. The rhythmic sequences of conglomerate, sandstone, marl, grey shale and sandstone are again to be seen as at Dailly (fig. 3), although the conglomerates are much finer and contain different pebble types.

Evidence of local tectonic unconformities can often

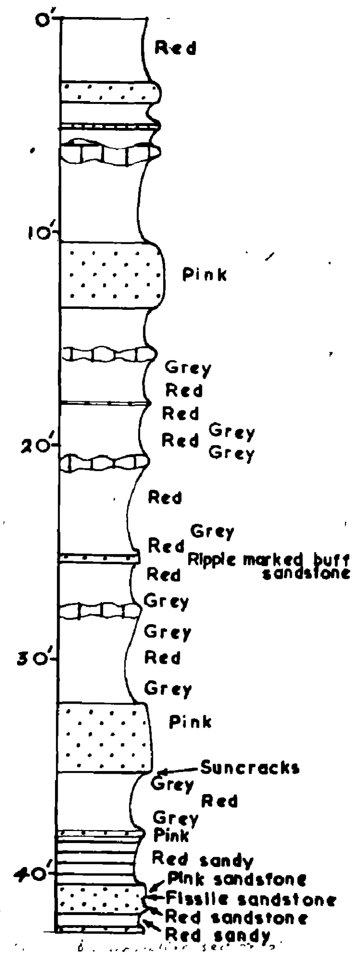


Fig. 7. Representative section of marl sub-group, Patna. Clastic Ratio 0.315 / 1.

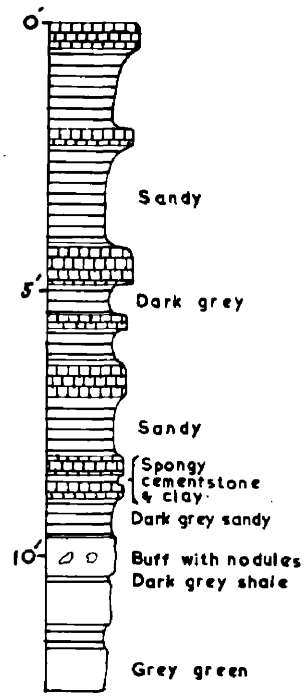


Fig. 8. Representative section, Heads of Ayr.

be seen at the top and the bottom of the 'grey shales and thin sandstones', parts of the rhythmic sequences typified by Fig. 5. Angular differences may amount to as much as 3°, as in Lambdoughty Burn, Straiton, (pl. 1).

The base of the Cementstone Group can be seen both in the River Girvan below Cloncaird (355076), where hard sandstones, cemented with silica, and grey shales with cement layers rest on purple, green and yellow sandstones and cornstones, and in the Littleton Burn near Straiton. The top part of the sub-group consists of an uncertain thickness of pink, red, green and yellow sandstones, with red and purple marls. The exposures are poor and the dips are low and rolling, and the thickness for the sub-group as a whole may be no more than 600 feet, in spite of its wide outcrop.

Overlying the sub-group, as at Dailly, there is a sub-group containing marls and cementstones, with a few sandstones. This is best seen in the Meikleholm Burn (417087) near Patna; a typical measured section is shown in Fig. 7. Ostracods are very abundant in some beds, along with worm tracks.

Red micaceous shaly sandstones are particularly common near the top of the sub-group, although the top was not seen. From borehole information the sub-group is at least 500 feet thick..

Above the representative of the marl sub-group there appears, in two or three exposures, to be a thin development of red sandstones and marls, probably to be

Pl. 1. Unconformity, Lambdoughty Burn, Straiton.

Pl. 2. Base of Cementstone Group near Sorn.
N.B. Photograph reversed in printing.
(see Fig. 11).

correlated with the upper sandstone sub-group of Dailly. It seems to be succeeded by an ash overlain by yellow sandstones and conglomerates of the U. Calciferous Sandstone Group.

Cumnock.

Only one section of the Cementstone Group is to be seen in the area south-east of the Kerse Loch Fault near Cumnock in the Gass Water (638228). About 190 feet of the group is exposed, with a gap of 210 feet above. The lowest beds above the gap are ashy mudstones and micaceous sandstones, obviously at a higher horizon than the Cementstones. The thickness of the Cementstone Group calculated as a residual thickness by subtracting the thickness of U. Calciferous Sandstone Group known to be present in this area from the total thickness of Calciferous Sandstone Series, appears to be approximately 250 feet.

The section in the Gass Water consists of massive yellow current-bedded sandstones with grey shales, and occasional very sandy cementstones. The basal sandstones and sandy green shales rest on yellow sandstones with a cornstone of the U. Old Red Sandstone.

Dalrymple - Ayr - Kilmarnock - Muirkirk Region.

This region is bounded on the north by the Inchgotrick Fault, on the south by the Kerse Loch Fault, and on the east by the L. Palaeozoic area of the Lesmahagow Inlier. It comprises two separate outcrops (fig. 1), that of Kilmarnock-Coalburn, and that of

Ayr-Dalrymple.

The thickness of the Cementstone Group over most of the region is never so great as at Dailly and Patna: it ranges from 100 feet at Glenbuck and Coalburn, 300 feet between Muirkirk and Kilmarnock, possibly 600 feet at Ayr, to 1,000 feet near Dalrymple.

The most complete section to be seen is on the shore on either side of the volcanic vent at Heads of Ayr. The succession is almost complete apart from a faulted gap near the base, and the interruption due to the volcanic vent. The base has hitherto been mapped as faulted, but in fact it can be seen at low tide on the extreme west side of Bracken Bay. The E.W. fault through Bracken Bay cuts through a few tens of feet above the base, but probably does not remove much thickness. At the base, a conglomerate of cornstone pebbles, overlain by grey current bedded sandstones, and grey, green and black shales rests on yellow sandstones and cornstones of the U. Old Red Sandstone. In the sequence beyond this fault dark grey shales continue to the vent, and contain cementstones principally of the type called 'layered' (see p.54) in the next chapter. Fine green calcareous micaceous sandstones are fairly common, and increase in upward sequence in number and thickness. The sandstone on the steep bank south of the vent is hard, white and calcareous, showing slumping and current bedding.

To the east of the vent the sequence continues in

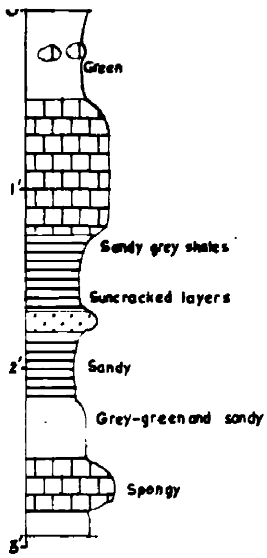


Fig. 9.

Representative section, De'ils Dyke, Ayr.

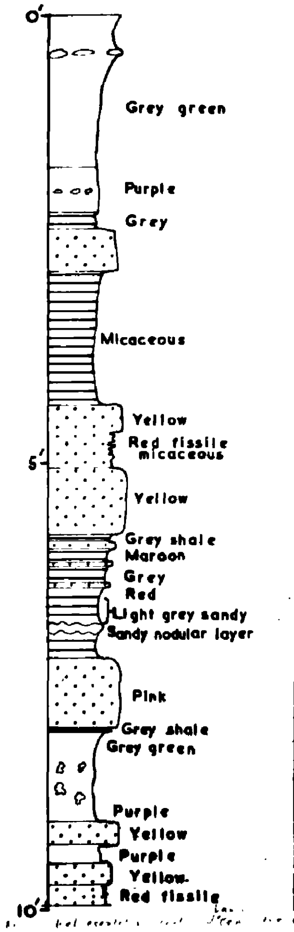


Fig. 10.

Representative section, River Doon, Dalrymple.

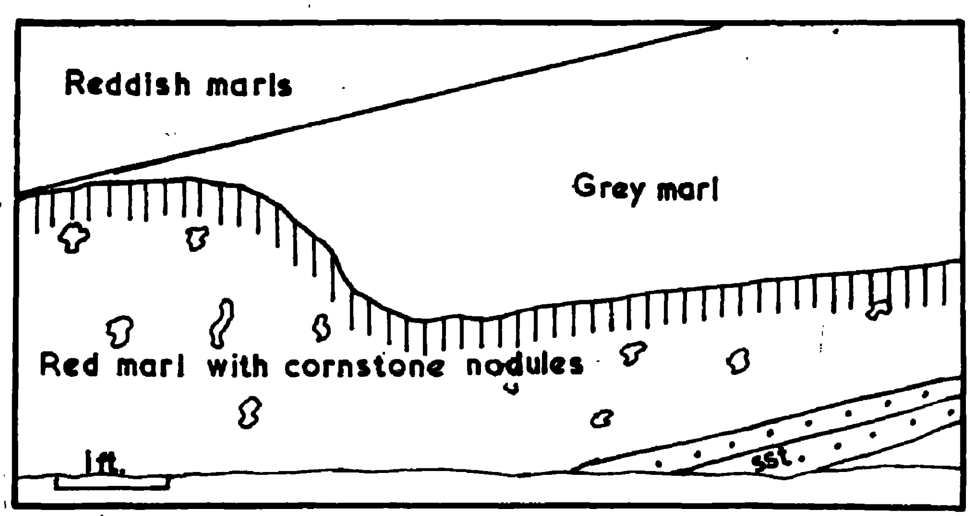


Fig. 11. Basal Cementstone Group marls resting on eroded Upper Old Red Sandstone near Sorn.

micaceous sandstones, some full of coaly plant remains, shales with abundant ostracods, fish remains and lamellibranchs; and layered cementstones, and Spirorbis limestones. There also occur some Ballagan-type marls and nodular cementstones, but these are probably faulted down.

A section measured on the shore 500 yards west of the vent is summarised in Fig. 8. In ascending the succession towards De'il's Dyke (307193), the proportion of grey shale and layered cementstone diminishes, and there is an increase in sandy dolomitic marls, green and red shales, and nodular cementstones; ostracods, lamellibranchs and spirorbids remain common in these higher beds. A lithological sequence typical of the upper part of the succession is quoted in Fig. 9. Nodular cementstones are very common just east of the De'il's Dyke, but in the last few feet they disappear, leaving only fine silty red and green shales with thin sandstones.

The topmost few feet of the Cementstone Group just below the Greenan Castle ash consist of grey and red micaceous current bedded sandstones. Information from bores and one exposure at Lindston Loch (370163) shows that inland from Ayr there is a sequence of brown, green and grey sandstones, conglomeratic sandstones, and red marls with corny nodules at the top of the Cementstone group. Their position and their lithological similarity to the upper sandstone sub-group of Dailly suggest a possible correlation.

The thick succession in the vicinity of Dalrymple is not well exposed, only the basal few hundred feet being seen, mainly in the River Doon and its tributaries near Skeldon and Hollybush. The rocks seen are mostly red shales and sandstones, a few cementstones, and some red marls with cornstone nodules. Some conglomeratic beds occur, and thick sandstones packed with large plant fragments. The sequence shows remarkable similarity to the lower sandstone sub-group of Dailly. (Fig. 10.)

The rocks of the Kilmarnock-Coalburn outcrop show a strong resemblance in lithology to those of the Heads of Ayr section, although no representative of the upper sandstone sub-group can be differentiated. At several localities where it is clearly exposed, the base of this group appears to rest with unconformity or non-sequence on the U. Old Red Sandstone, for example in the Wyndy Burn (587265), where the basal yellow sandstones, containing plant remains and fish fragments, overlie an eroded massive cornstone; and in the Mare Burn (540370), grey carboniferous marls rest abruptly on red marls with cornstone nodules and sandstones, the red marls being reduced to a yellow colour at the junction, (Pl. 2, Fig. 11).

The top is nearly always marked by ashes, and sometimes lavas, as at Upper Heilar (602361) on the River Ayr, where more than 20 feet of lavas, ashes and ashy sandstones are seen to rest on the Cementstone Group. Above the volcanics there are yellow sandstones and bioclastic limestones of the U. Calciferous Sandstone and L. Limestone Groups.

Sandy shales and marls with cementstones are by far the dominant rock types, both the nodular and the layered varieties of cementstone occurring. Again as at Ayr there is a tendency for nodular cementstones to be commoner in the upper half of the sequence. The spirorbid limestones common in the lower part of Ayr are rarer in this area. Some of the limestones contain gypsum, and according to information from the Doura bore (Bailey 1930, p. 62) (446306), beds of gypsum occur at depth. Sandstones are perhaps more common in the Kilmarnock to Sorn area than at Ayr, and are usually of a buff colour.

In the Back Burn (670290), north of Glenbuck (755313), and at Coalburn there is a great increase in sandstones and red sandy shales, particularly near the base, and cornstone conglomerates become very abundant. The thickness is usually about 300 feet, but at Glenbuck and at Coalburn it is reduced to 100 feet or less.

Further evidence of local unconformities is to be seen in the Cessnock Water at Craighead Farm (491323), and in the Back Burn, Muirkirk. The example at Back Burn is very obvious and in a cliff section 20 feet high and 40 feet long, the angular discordance of dip above

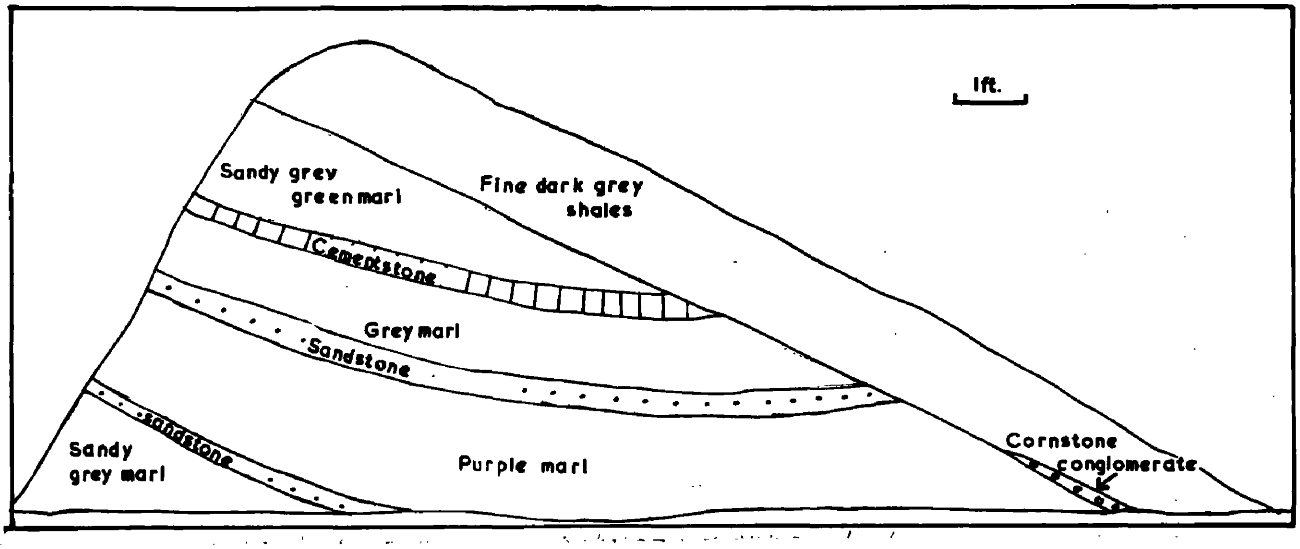


Fig. 12. Unconformity in cliff at Back Burn,
near Muirkirk.

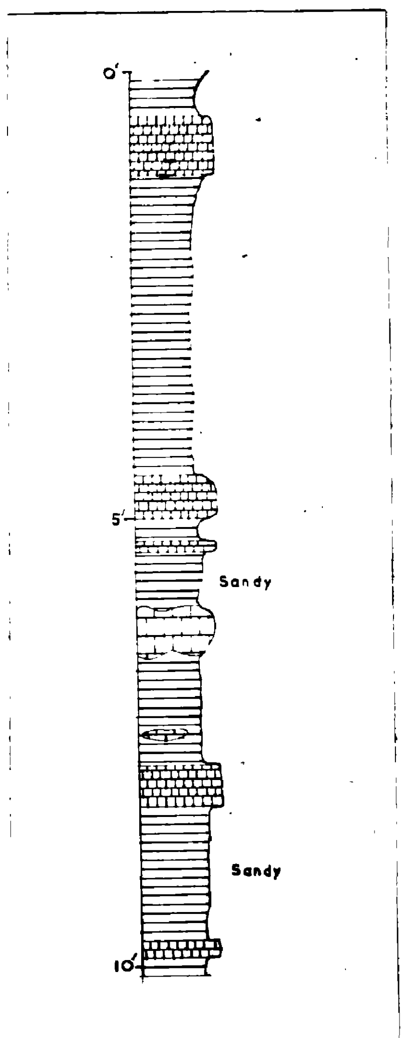
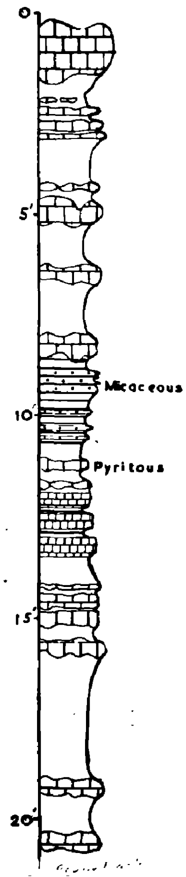
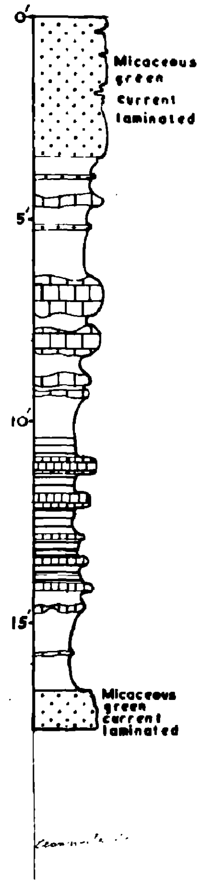


Fig. 13. Representative section
Cessnock Water, Carnell.





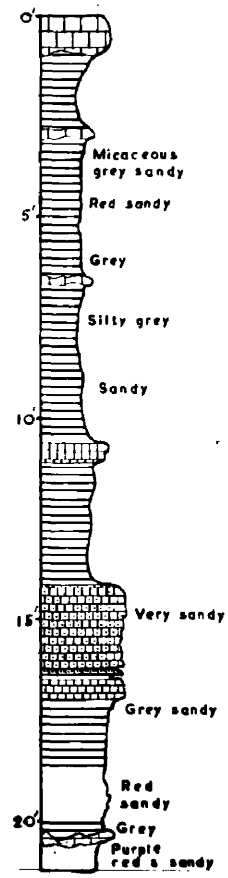


Fig. 14. Fig. 15. Fig. 16.

Fig. 14. Representative section, Cessnock Water, Craighead Farm.

Fig. 15. Representative section, Cessnock Water, Craighead Farm.

Fig. 16. Representative section, Cessnock Water, Blairkip.

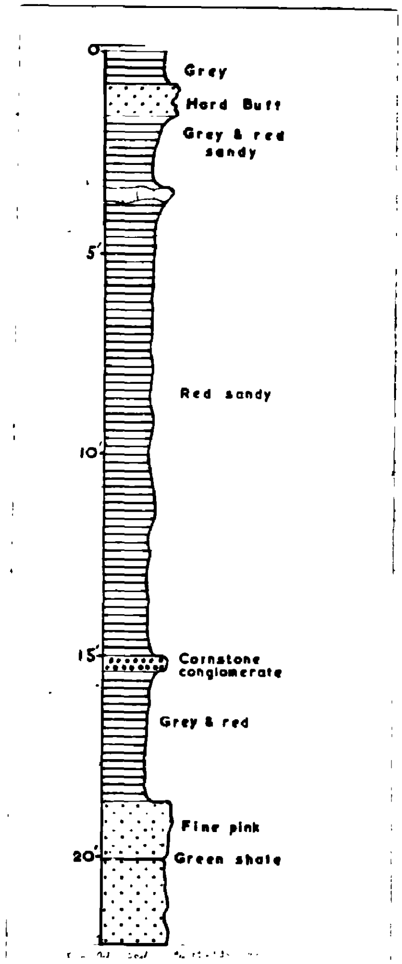


Fig. 17.

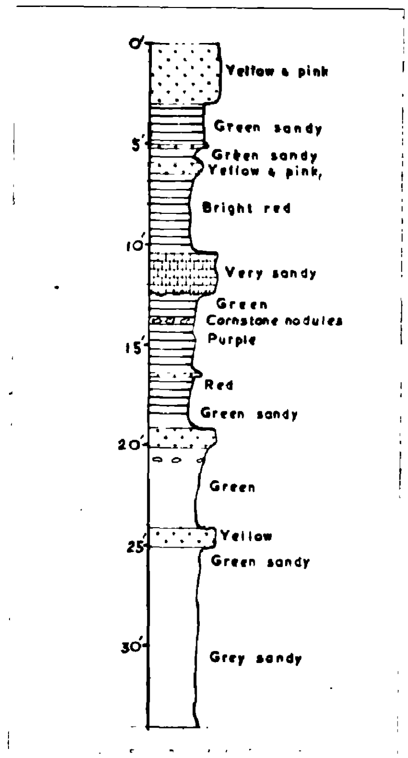


Fig. 18.

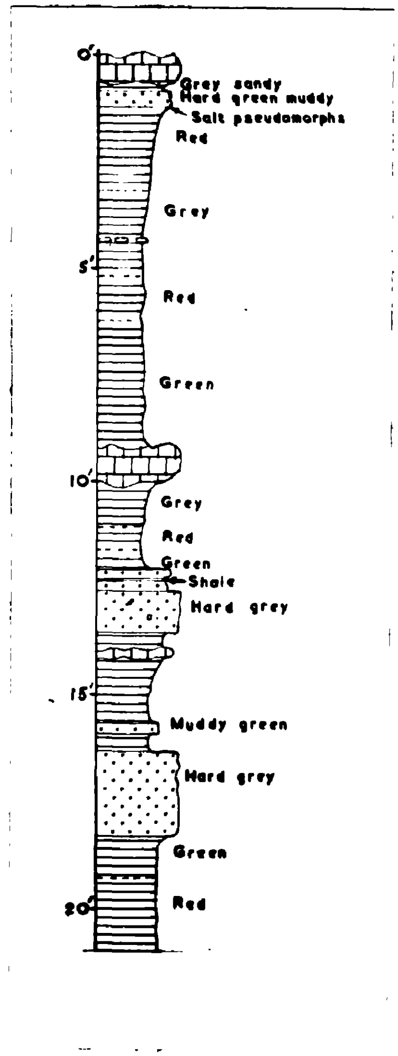


Fig. 19.

Fig. 17. Representative section, Back Burn, Muirkirk.

Fig. 18. Representative section, CoalBurn

Fig. 19. Representative section, Lower Cementstone Group, Auchenreoch Glen.

Pl. 3.

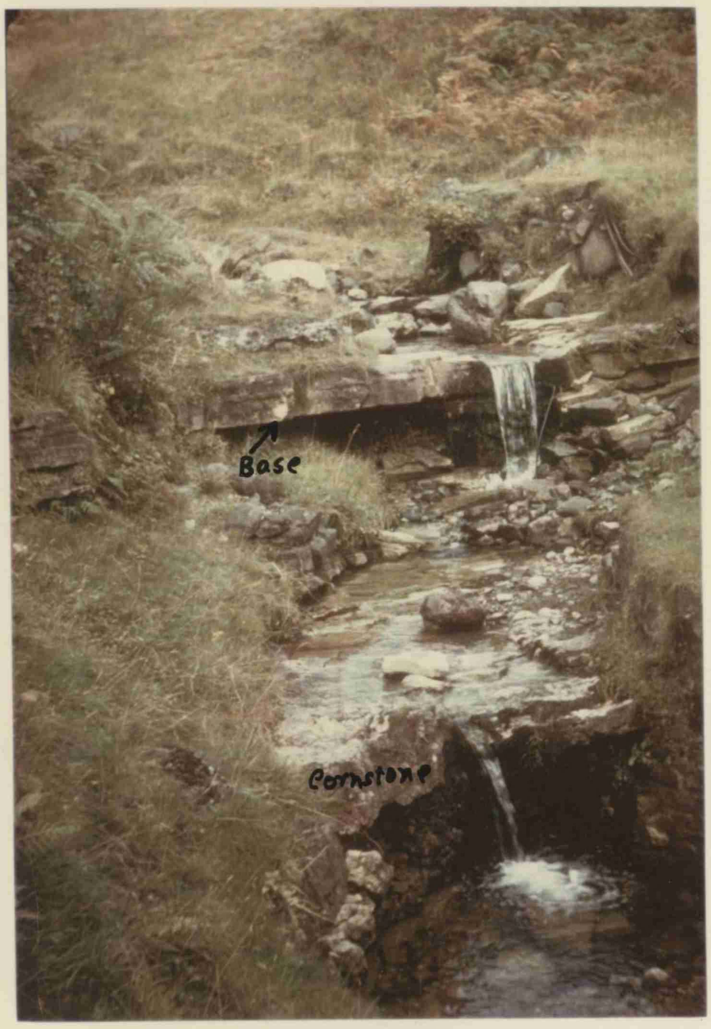
Pl. 3. Nodular and layered cementstones,
Meikle Carleigh, Sorn.

L. layered. N. nodular.

Pl. 4. Basal sandstone and cementstone,

Auchanmannoch Burn, Sorn.

Pl. 5. Base of Cementstone Group, Glenbuck.



Pl. 6. Base of Cementstone Group at Strathblane.

and below the unconformity is 15 degrees. (Fig. 12.) Typical lithological sequences are quoted along the outcrop from Kilmarnock to Coalburn in Figs. 13-18. (See pls. 2, 3, 4, 5.)

The Cementstone Group is absent in the vicinity of the Burn Anne (530350) near Galston, and again at Stonehouse, north of the Lesmahagow Inlier, and east of Coalburn, where the Clyde Plateau Lavas come to rest on L. Old Red Sandstone.

The absence of Cementstone Group to the north and east is probably due to some extent to overstep.

The Northern Region.

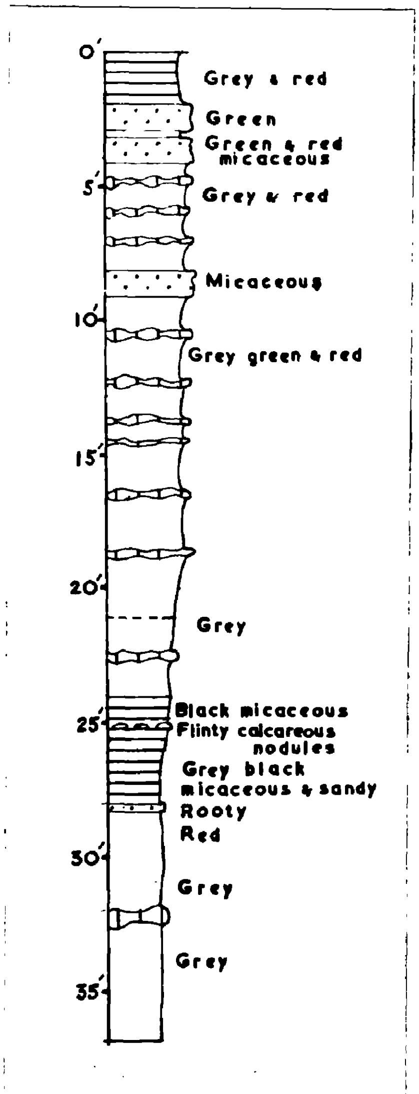
This region runs S.W. - N.E. between the Highland Boundary Fault and the line of the Dusk Water Fault.

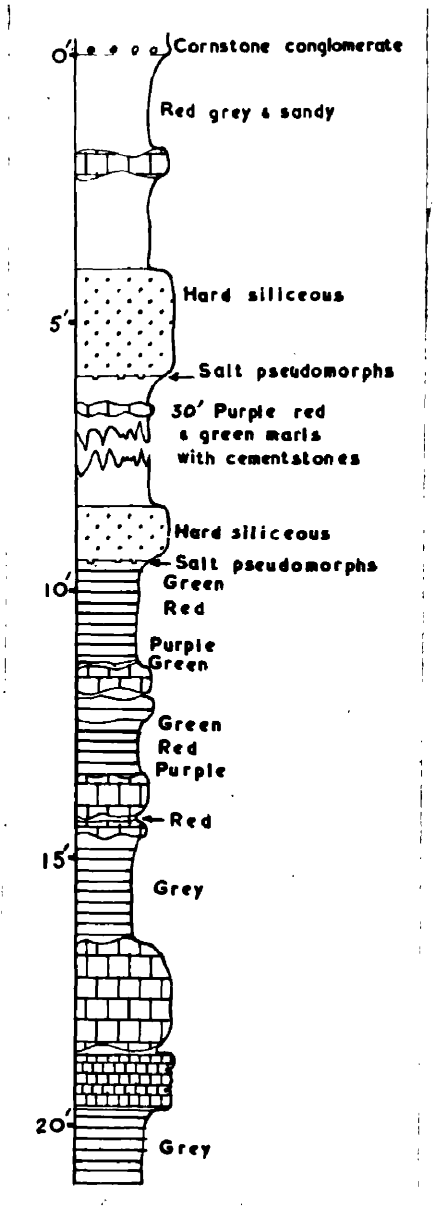
The succession in this region consists of an upper sandstone arenaceous part, the Spout of Ballagan Sandstone, and a lower cementstone part. The fullest development of both parts occurs in the outcrop running from Stirling to Strathblane, and in the Dumbarton area. At Strathblane the cementstone part of the group is 600 feet thick, and consists of grey and red marls and shales, with nodular cementstones and some thick sandstones. At the base about 50 feet of limy sandstones with green sandy shales rest on eroded red marls with cornstones (Pl. 6). They are overlain by the first cementstone bands, almost all of which are nodular. About 250 feet above the base thick hard buff current bedded sandstones occur amongst the shales and cementstones. Towards the top, red shales and marls become more common. Gypsum is common in sheets parallel to the bedding and in vertical joints.

In the Strathblane area the junction with the overlying Spout of Ballagan Sandstone is not seen. The sandstone is 300 feet thick, and consists almost entirely of buff and yellow sandstones and conglomerate, with a little sandy marls; sometimes plant remains are found in the sandstones. Auchenreoch Glen (420783) is similar to Strathblane and provides an excellent section, red shales and hard yellow calcareous sandstones being perhaps more abundant than at Strathblane (Fig. 19.) In the Overtown Burn (422760), (Fig. 20), 2 miles N.E. of Dumbarton Castle, a good section in the Spout of Ballagan Sandstone is exposed. Again it consists of 200 feet of yellow sandstones and conglomerates, but cornstones, one a few feet thick, also occur.

The cementstones and the Spout of Ballagan Sandstone are interbedded, a thin sequence of marls and cementstones occurring among the massive basal sandstones of the Spout of Ballagan Sandstone, at the top of which lie the Clyde Plateau Lavas.

N.W. of the Dumbarton area the cementstones appear to thin out. Near Ben Bowie (340830), Helensburgh, the Spout of Ballagan Sandstone is probably about 200 feet thick, and the cementstones about 100 feet. The





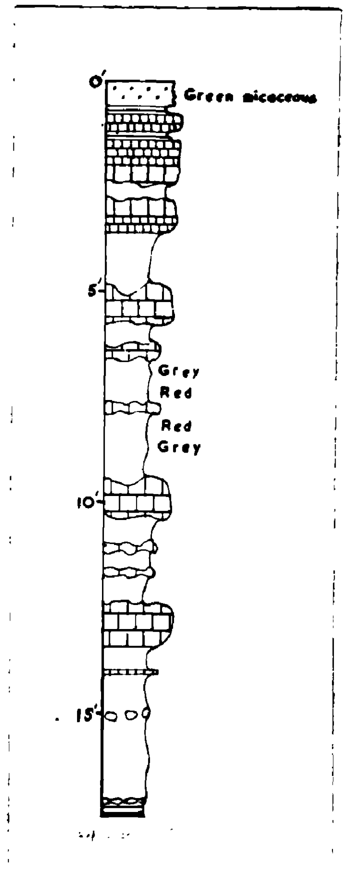


Fig. 20. Fig. 21. Fig. 22.

Fig. 20. Representative section, Lower Cementstone Group, Overtown Burn, Dumbarton.

Fig. 21. Representative section, Lower Sandstone Group, Little Corrie of Balglass, Fintry.

Fig. 22. Representative section, Lower Cementstone Group, Campsie.

cementstone part seen in a few burns to the S.E. of Helensburgh shows a diminution in grey shale and nodular cementstones, and an increase in red sandy shales and marls, and the nodular cementstones that occur are red.

N.E. to Fintry and Stirling both parts persist, the Cementstones (Fig. 21) maintaining a thickness of 500-600 feet, but the Spout of Ballagan Sandstone seeming to thin from 200 feet at Little Corrie (575845) to 150 feet just before Gargunnock (710930). The thinning of the outcrop of the Cementstone Group is probably due to an extension of the Abbey Craig Fault, (Dunham (1932) p.9). In Gargunnock Burn the cementstones are faulted against the Spout of Ballagan Sandstone which is downfaulted to the south, with a consequent loss of an unknown thickness of cementstone sediments. The interpretation of this fault as an extension of the Abbey Craig Fault, is different from the arrangement shown in Fig. 1 of the Stirling and Clackmannan Coalfield Memoir (1959), where the Abbey Craig Fault is shown separating the U. Old Red Sandstone from the Cementstone Group. However, there appears to be an unfaulted sequence without a break from the U. Old Red Sandstone into the Cementstone Group.

In lithology the Group does not show great variation to the N.E.; the basal green shales and sandstones are thicker than at Strathblane, and layered cementstones are more common. The Spout of Ballagan Sandstone contains cornstones amongst the massive and often conglomeratic sandstones; cornstone conglomerates are common at the base.

Exposures on the South Face of the Campsie Fells.

These sections along the front of the Campsie escarpment are mostly incomplete, the base being down through below surface level by the Campsie Fault. The sections are to be seen at Ballagan (575800), Fin Glen (600799), Campsie (610798 (Fig. 22)) and Kilsyth (750820).

At Ballagan 200 feet of the topmost part of the cementstones are exposed. The sequence mostly consists of grey and red marls with some dark grey shales, with numerous nodular cementstone bands, as many as 100 bands in 130 feet, (Bailey & Others 1925, p. 11). Micaceous current-laminated sandstones are common, and gypsum occurs in the marls and nodular cementstones, both in horizontal and in vertical sheets. Towards the top, one or two buff sandstones are interbedded with shales and reddish cementstones. These beds are overlain by the current bedded Spout of Ballagan Sandstone, 30 to 40 feet thick, and finally by the Clyde Plateau Lavas. Within the Spout of Ballagan Sandstone are red and green sandy marls.

At Fin Glen the succession is faulted at both top and bottom, but in Campsie Glen, one mile further east, the cementstones are clearly followed by lavas and sandy ashy mudstones, the Spout of Ballagan Sandstone being absent. At Corrieburn (700795) the lavas rest on U. Old

Red Sandstone, and in the Garrel Burn (710798) just to the east of Corrieburn, only a few feet of sandy green shales, and rotten yellow weathering nodular limestones, which may represent the Cementstone Group, intervene beneath the lavas. Some 50 feet of normal Ballagan type cementstones and marls are present in the Banton Burn (731803) north of Kilsyth, at a horizon presumably far below the Spout of Ballagan Sandstone.

It has been suggested (Bailey & Others 1925, p.12) that most of the Cementstone Group at Ballagan and Campsie is equivalent to the basal lavas at Corrieburn, as shown by an interbedding of lavas and cementstones at Corrieburn and Kilsyth, and by the continuity of lavas of Jedburgh type from the top of the U. Old Red Sandstone into the Clyde Plateau Lavas. The dating of the lowest lavas is, however, based on misidentification of Cementstone Group sediments, or on the misinterpretation of the local relationship of the Cementstone Group to the lavas; and the local occurence of Jedburgh basalt in the uppermost part of the Old Red Sandstone is probably a sill, geophysical evidence interpreted by Dr. D. W. Powell indicating a discrepancy in dip between the igneous rock and the Old Red Sandstone of 10 degrees.

The regional break at the base of the Cementstones in the west of the Midland Valley suggests on the contrary that the lavas are resting discordantly on the

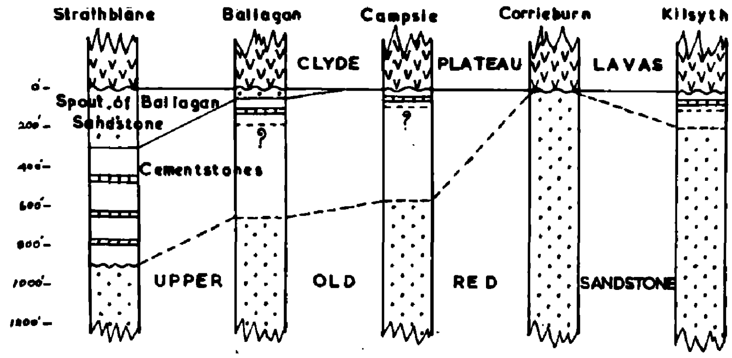


Fig. 23. Stratigraphical relationship between the Clyde Plateau Lavas, the Spout of Ballagan Sandstone, the Cementstones, and the Upper Old Red Sandstone along the south face of the Campsies.

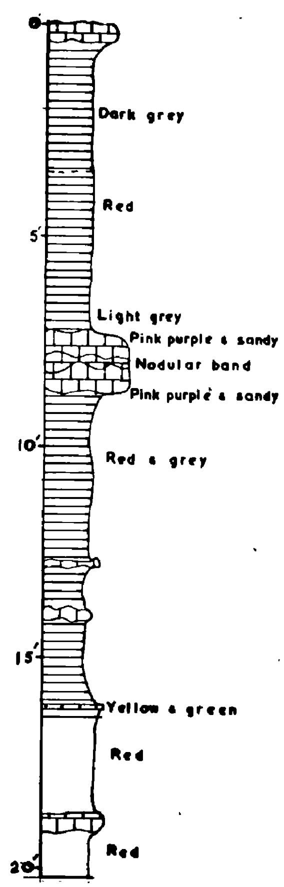


Fig. 24. Representative section, Lower Cementstone Group, Loch Thom, Greenock.

U. Old Red Sandstone at Corrieburn, the Cementstones being overstepped or overlapped (Fig. 23). The Spout of Ballagan Sandstone at the top of the Cementstone Group is 300 ft. thick at Strathblane where it is definitely conformable to the beds beneath, thins eastwards to 45 ft. at Ballagan, and finally disappears west of Campsie, where lavas rest on cementstones presumably by overstep of the order of 1 1/4 degrees. East from Corrieburn the Cementstones gradually appear again, in the other side of the inferred upwarp, until at Kilsyth they are at least a few tens of feet thick.

Greenock Area.

The Greenock area extends for several miles south of Loch Thom to Greenock itself; in it the Cementstones are generally thin - less than 100 feet. At Outerwards (230670), 5 miles N.N.E. of Largs, where they consist mostly of very sandy red and green shales and sandstones, with a few cementstones, they rest, with a basal conglomerate with cornstone pebbles, on marls and cornstones of the U. Old Red Sandstone. Further north at Rottenburn (250690) the thickness seems to be of the order of 50 feet, increasing to 70-100 feet west of Loch Thom, and to 170 feet just south of the loch (Fig. 24; Pl. 7). Around Greenock itself exposures are meagre, but the thickness seems to be more than 100 feet, and the lithology is more akin to that of Ballagan.

Succeeding the Cementstones is a thick representative

Pl. 7. Cementstone Group at Loch Thom.

Pl. 8. Nodular cementstone and red grey marls, Cumbrae.

of the Spout of Ballagan Sandstone. At Outerwards it appears to be of the order of 300 feet thick, but west of Loch Thom it may reach 900 feet, unless there is repetition by strike faulting. Lithologically it is normal in consisting of massive white and pinkish current bedded sandstones, sometimes conglomeratic, with occasional thick cornstones, cornstone conglomerates, and red marls. Further west on the shore south of Gourock there are no exposures of undoubted Cementstones, and it is difficult to distinguish the Old Red Sandstone from Spout of Ballagan Sandstone.

Bute and Cumbrae.

In Bute the sequence is broken by faulting, and although it is not possible to measure the full thickness, both the Cementstones and the Spout of Ballagan Sandstone may be identified. The exposures on the west side of Millport on Cumbrae are much more complete.

The lower part of the Cementstones, its base faulted out, is composed mostly of red marls, with frequent bands of cornstone conglomerate, and is succeeded by grey sandy shales with plant remains, hard limy conglomeratic current bedded sandstones, grey marls and nodular cementstones (pl. 8); a minimum thickness of 100 feet is suggested. The Cementstones are succeeded by typical Spout of Ballagan Sandstone, with marls and cornstones, which has a minimum thickness of 150 feet, but which may be almost 300 feet thick.

Arran. The Arran succession compares closely with that at Cumbrae. In the Laggan (990500) section (Tyrrell 1928, p. 49) 20 feet of grey marls, cementstones, thin current laminated sandstones and cornstone conglomerates, resting on cornstones and red sandstones of the U. Old Red Sandstone, are followed by perhaps 300 to 600 feet of white and pink conglomeratic current bedded sandstones, with red marls and cornstone nodules, lithologically typical of the Spout of Ballagan Sandstone. These sandstones are succeeded by thin yellow sandstones, ashy sandstones, grey and black carbonaceous shales, which appear to rest on the eroded top of the pink and white sandstones. These ashy beds, from which Wunsch (1865) obtained his fossil trees, pass upward into ashes and lavas of the Clyde Plateau Lavas. To the south at Corrie (023442) the lavas come to rest directly on the U. Old Red Sandstone (Tyrrell 1928, p. 52), and it must be assumed that the disappearance of perhaps 400 feet of the Cementstones in a distance of 3 miles is due mainly to overstep, as overlap to the south appears to be contradicted by the cross bedding (fig. 28). Further to the S.W. near Campbeltown, (McCallien 1930, p. 600), the Clyde Plateau Lavas rest with angular unconformity on the U. Old Red Sandstone (pl. 9).

N. Ireland.

Cultra, Belfast Lough.

Rocks of Cementstone Group type occupy a small strip on the coast at Cultra and Holywood (Lamplugh, 1871, p. 33). The relationship to the surrounding L.

Pl. 9. Lavas resting on Upper Old Red Sandstone cornstone at Machrihanish.

Pl. 10

Pl. 10. Shales, fine sandstones and lamellibranch mudstones near Draperstown, Co. Londonderry.

Palaeozoic rocks is obscure and might well be faulted. The beds are also faulted against Permian and Triassic rocks. At the base of the visible section are 20 to 30 feet of red yellow and green sandstones with red marls. Above, grey and red shales with sandstones and cement-stones are found, overlain to the west of the quay at Culgra by typical layered cementstones and marls, with lamellibranch mudstones and sandstones.

Apart from the similarity in lithology between the Cultra rocks and those of the Midland Valley, the ostracods found at Cultra provide evidence for assigning these beds to the Cementstone Group (see pp.71-73) Algal remains similar to those found in the main Algal Series of N. W. England have also been found. At one time these beds were referred to the Lower Lime-stone Group, Lithostrotion junceum, having been recorded (Lamplugh 1871, p. 33). In the present examination no fossils of this type were seen, and the nature of the sediments suggests that they would not contain fossils such as L. junceum. The sediments are, in fact, comple-tely different from the nearest representative of the Lower Limestone Group at Castle Espie.

Draperstown, S. Londonderry.

Sediments resembling the Cementstone Group of the Midland valley are to be seen in the White Water and the Altagoan River near Draperstown. They rest on red, pink and yellow calcareous sandstones and marls, with cornstones which were originally mapped as Calciferous Sandstone Series (Egan 1881, p.20), but they are now believed to belong to the U. Old Red Sandstone. The base of the Cementstone Group is not exposed, and the lowest beds seen are red and grey sandy marls with thin sandstones. The rest of the group consists of grey shales and lamellibranch mudstones, fine current bedded sandstones, and layered cementstones. The beds overlying the Cementstone Group are conglomeratic bioclastic limestones of the limestone series, (probably equivalent to the Upper part of the Calciferous Sandstone Series, and elsewhere known to be of S_2 age (Padget 1952, p. 4). To the north, near and beyond Dungiven, the Cementstone Group seems to have disappeared; at Ballycastle, volcanic rocks, probably to be correlated with those of S. Kintyre, rest with overstep on the U. Old Red Sandstone.

CHAPTER 3. THE SEDIMENTS of the CEMENTSTONE GROUP

Section 1. Facies Variation

In order to discuss the variation in facies it is convenient to consider separately an upper and a lower division of the Cementstone Group, the Spout of Ballagan Sandstone and its equivalents in the Northern Region, and the upper sandstone sub-group of Dailly and Patna comprising the Upper Cementstone Group; and the mixed group of sandstones, shales and cementstones beneath these units comprising the Lower Cementstone Group (see Fig. 2). Since there is no indication of differential erosion at the base of the Cementstone Group between Ayr and Dailly, it is suggested that the basal sub-group of Dailly is equivalent in age to the lower part of the Cementstones at Ayr. The marl sub-group, because of its strong resemblance to the upper part of the Cementstones at Ayr is also thought to be represented there. The absence of the equivalent of the lower sandstone sub-group from the Ayr area would therefore involve a large break in the succession, but no evidence of this is seen. Thus the Cementstones of Ayr and Kilmarnock are correlated with the basal, lower sandstone, and marl sub-groups of the Dailly - Patna region. Since the Spout of Ballagan Sandstone and the upper sandstone sub-group both consist of coarse conglomeratic - sandstone - marl - cornstones and form the topmost part of the Cementstone Group in both regions, they are tentatively correlated.

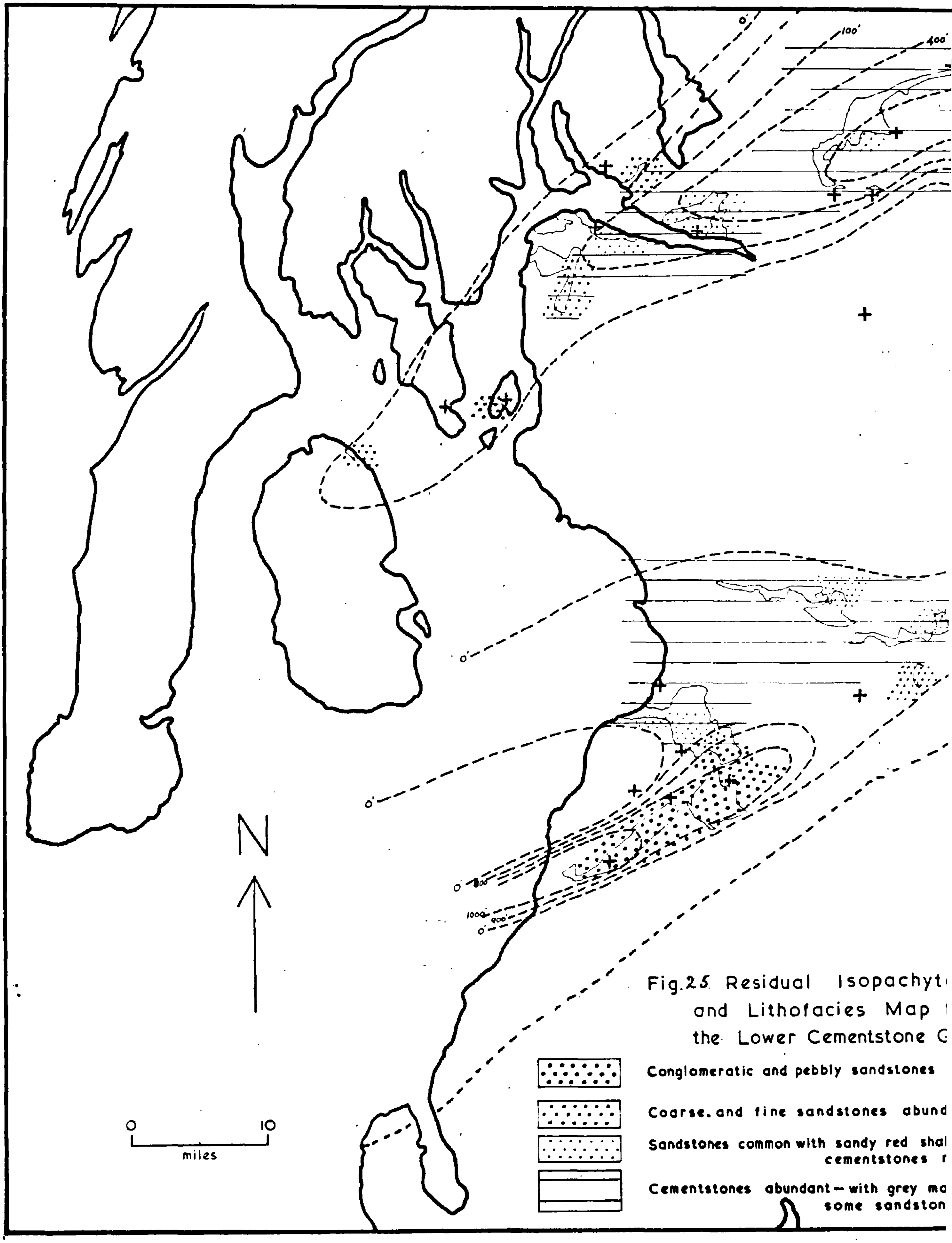


Fig.25. Residual Isopachyt
and Lithofacies Map
the Lower Cementstone G

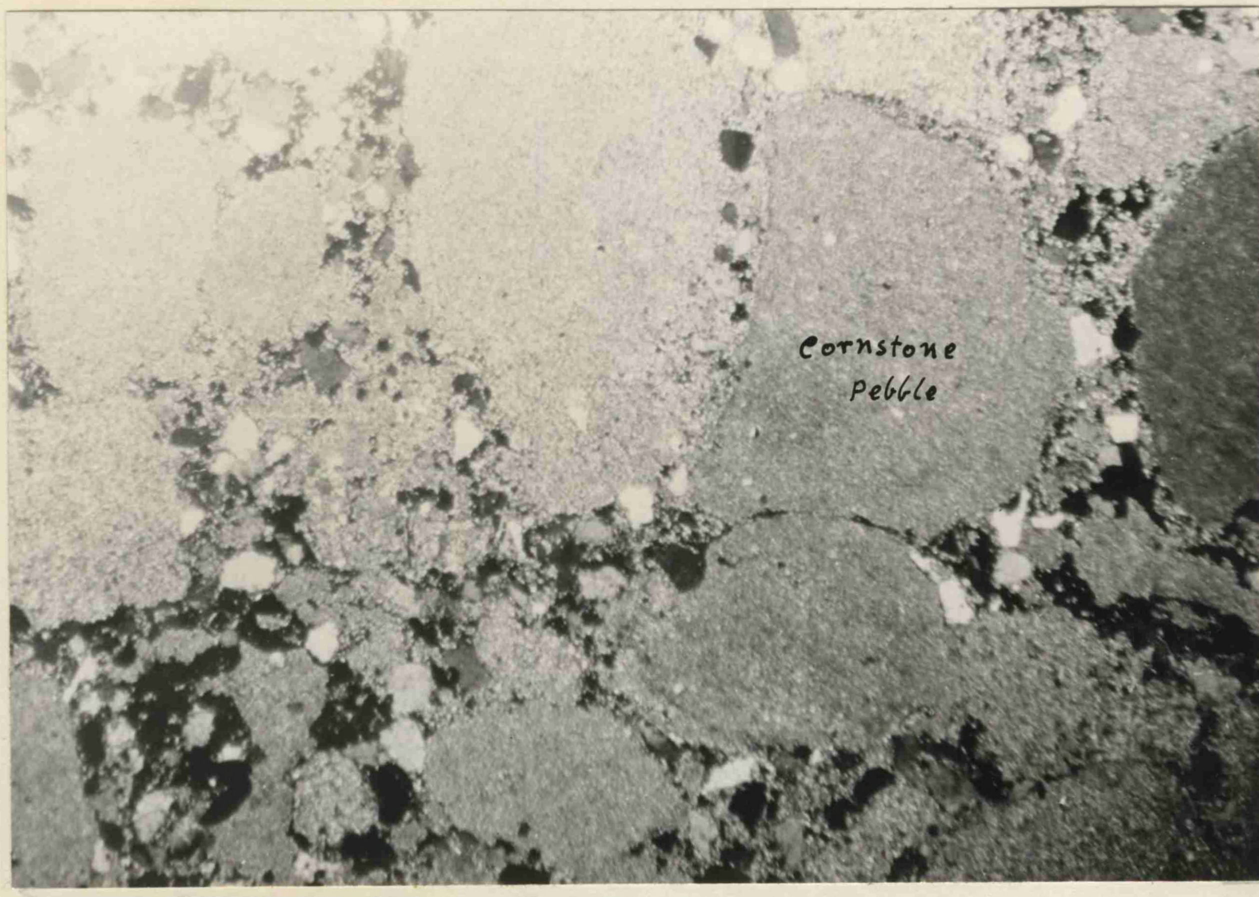
(1) The Lower Cementstone Group.

It is not possible to construct anything more than very general isopachyte and lithofacies maps, as there is not a sufficient spread of two-dimensional information (Fig.25). The outcrops in N. Ireland are too remote from the main areas of sedimentation in Scotland to be included in the maps.

(a) Dailly-Patna - Cumnock Region.

The total thickness of the Lower Cementstone Group in this region varies between 1,300 - 1,400 feet at Dailly, approximately 1,100 feet at Patna, and 200-250 feet at Cumnock. The zero isopach (fig. 25) lies to the east and the south-east of Cumnock. From later palaeogeographical considerations (p.81) it can be deduced that it continues in a south-westerly direction, passing a few miles to the south-east of Dailly.

The most noticeable feature of the lithology in this region is the abundance of coarse clastics in proportion to shales and limestones. Even in the marl sub-group of Dailly there are many sandstones and fine conglomerates. The sub-group with the largest proportion of coarse clastics is the lower sandstone sub-group, in which conglomerates with pebble sizes up to 2" occur. Figs. 3, 4, 7 exemplify the abundance of coarse clastics in the Dailly-Cumnock region; some sand-shale thickness ratios are quoted alongside these representative sections. Those quoted for the marl sub-group at Dailly and Patna are deceptive in that the marls often contain a high propor-



Pl. 11. Cornstone conglomerate, Dailly. x30.

Pl. 12. Coarse sandstone with quartz mosaics,
upper sandstone sub-group, Dailly. x 30.

tion of sand-grade clastics.

The Clastics of the Dailly Region.

The clastic sediments of the Dailly - Patna region differ markedly from those of Cumnock, in colour, texture and coarseness.

Dailly - Patna.

Conglomerates. These are particularly common in the south-west of the area. They are yellow to purplish in colour, and contain pebbles (up to 2" or 3" long axis) mainly of greywacke and acid porphyry. The only present-day exposures of comparable igneous rock occur in the faulted strip of the L. Old Red Sandstone, 1 - 3 miles to the south-east; other conglomerates and conglomeratic layers found in the sandstone contain fragments of cornstones, usually subspherical in shape, with internal structures like those of the nodular part of the U. Old Red Sandstone cornstones. (Pl. 11)

This suggests that either U. Old Red Sandstone was being eroded elsewhere, or that cornstone formation was proceeding on the hinterland to the south-east at the same time as the deposition of the Cementstones, a fact known to be true in the Dailly area from the presence of cornstones in the lower sandstone sub-group.

Conglomerates become much less common north-east along the Dailly basin, where the outcrops lie at progressively greater distances from the Southern Uplands Fault and the associated Straiton Fault.

Sandstones. The colours of the sandstones in the L.

Cementstone Group range through white, deep red, pink, yellow and green. A few analysed by point counter proved to be felspathic sandstones or protoquartzites (Pettijohn 1957, p. 291).

		Specimen No.	Quartz	Felspar	Lithic Fragments.
Marl sub-group		M1	94	4.3	1.4
	Top	O2A	78	11.5	10.7
L. Sandstone	"	O3A	85	8.7	3.0
sub-group	Middle	M 4	90	7.1	3.4
	Lower	M18	91	3.0	5.9

Often the sandstones are interbedded with red and green marls, some containing cornstone nodules, especially in the lower sandstone sub-group, which shows a reversion to U. Old Red Sandstone conditions. The sandstones have the same general appearance as the outwash fan sediments of the U. Old Red Sandstone, and the presence of cornstones suggests climatic conditions similar to those of the U. Old Red Sandstone. It is possible, in fact, that the same climatic conditions persisted right through from U. Old Red Sandstone times to the base of the Lavas, where the occurrence of lateritic boles indicates a rather different climate. The introduction of grey shales and yellow sandstones at the base of the Cementstone Group is then to be attributed to a change in sea level, a regional sinking with a marine incursion. The recurrence of coarse outwash-fan clastics and pedocal soils indicates a strong relief in the hinterland which lies at a very short distance to the south-east.

The rhythmic sedimentation of which one cycle is illustrated in Fig. 3b. can be interpreted as follows. The deposition of the coarse current bedded sandstones and conglomerates results from a high relief to the south-east, with a well developed fault line scarp and intermittent strong rainfall, followed by a period of stability when pedocal soils (marls with cornstone nodules), apparently similar to those of the U. Old Red Sandstone, were formed in the land surface of the out-wash-fan sediments. The grey shales and fine grey sand-stones at the close of the cycle represent a marine or brackish incursion into the area, this being terminated by a recurrence of the conditions peculiar to the deposition of the sandstones and conglomerates.

The marl sub-group has no coarse clastics, and only moderate quantities of fine sandstones. A few bands of very coarse greywacke occur, the lithic fragments them-selves being mostly greywacke, obviously derived from an area of L. Palaeozoic rocks. On the whole however the presence of grey and red marls and shales indicates relatively quiet sedimentation, with occasional bursts of slightly coarser clastics caused perhaps by an increase in rainfall, or movement along one of the faults associa-ted with the fault line scarp.

Patna.

Essentially the same facies of the Cementstones is to be seen near Patna. Fine cornstone conglomerates are common, but the coarse mixed conglomerates seen at Dailly are missing, apart from one comparatively fine bed found in several outcrops running parallel to and less than a mile from the Straiton Fault. The pebble content is greywacke, occasional spilite, some chert and jasper.

Cumnock.

At Cumnock the facies differs from Dailly - Patna in an absence of red and green coloured sandstones and conglomerates, although the sand/shale ratio remains high. The sandstones are all yellow in colour, and are intimately associated with grey shales, siltstones and very sandy cementstones, thus suggesting that the clastics were deposited under water in conditions of low oxidation or low reduction, and not as outwash fans in conditions of high oxidation. The abundance of sandstones indicates a hinterland with considerable relief. Wedges of conglomerate may originally have occurred in this area further south-east, but any sediments of the Cementstone Group that were present in the area of Glenmuir Water were eroded before the overstep of the lavas and ashes.

Ayr - Kilmarnock Region.

The thickness of the Cementstones in the Ayr - Kilmarnock region shows a general reduction from 500 feet in the Ayr - Dalrymple area, (at Dalrymple it may be as much as 1,000 feet), to 300 feet between Kilmarnock and Muirkirk, and to 100 feet or less at Glenbuck and Coalburn.

Although the facies is vastly different from that of Dailly, it shows comparatively minor variations within the Ayr - Kilmarnock region. Coarse conglomerates are completely absent, but cornstone conglomerates occur at several horizons, all showing the same characters as in the Dailly region.

The facies is mainly a shale-limestone facies, with a comparatively small development of clastics (figs. 8, 9, 10, 13-18).

Ayr Area.

The lowest part of the Cementstone Group at Ayr has few sandstones. About 100-150 feet above the base, 100 feet of micaceous current laminated sandstones occur. They are interbedded with some cornstone conglomerate, sandy shales and ostracod limestones. These coarser beds may be equivalent to the lower sandstone sub-group of Dailly, and although they in no way resemble it in appearance, their occurrence could be due to the same tectonic movement that produced the equivalent at Dailly. Some of the uppermost beds of the sandstones are often full of coaly plant remains. It is possible that a coal may occur within these sandstones, although it is not exposed at present. (See 'Ayrshire at the Time of Burns', in which coal is reported as having been dug in a pit at the junction of the boundaries of the farms of Corton, Mt. Oliphant and Broomberry (353168). The pit is now filled in and there is no evidence now to be seen; but there are exposures of cementstones and marls in the Corton Burn just beside the pit.)

Above these sandstones the sediments become much finer, the coarsest clastics being of silt grade, some of them coloured red and greenish. All the shales and silty layers are very limy, and frequently contain 50% soluble matter. The clastic ratio, as regards bulk composition by weight, may be as low as 0.78/1, although no individual cementstone beds need occur in the section analysed. The cementstones have a Ca/Mg ratio (by weight) varying between 1.5/1 and 30/1. Organic limestones are found with the cementstones, including ostracod limestones, 'spirorbis' limestones, and lamellibranch limestones. The uppermost 50 feet consist of red and green calcareous siltstones without limestones.

Dalrymple Area.

The basal beds are very much coarser than at Ayr. Sandstones and fine conglomerates are common, with thick micaceous shales, (fig. 10). The colours are often red, with some green and some yellow; cornstone nodules are commonly found in red marls, thus indicating terrestrial conditions, and the facies is like that of the Dailly - Patna area. This type of lithology continues for about 100 feet up the succession, then grey shales and cementstones come in, with some micaceous yellow sandstones full of plant remains. The highest sediments seen are of the type seen nearer Ayr.

Kilmarnock - Coalburn Area.

The lithology of this area is virtually the same as at Ayr, except that sandstones are more common, and red colours are far commoner in the shales and marls, especially towards the east. 'Spirorbis' limestones and ostracod limestones are absent, although some shales are crowded with spirorbids (figs. 13-18). The only sections that show a great deviation from the facies of Ayr, and from the rest of the region, are in Back Burn (Fig. 17) to the north of Muirkirk, north of Glenbuck, and at Coalburn (Fig. 18).

The Cementstones of Back Burn are at least 250 feet thick and differ markedly in lithology from the Cementstones to the west, in the abundance of thick sandstones and bright red sandy shales, and the rarity of cementstones and grey shales, particularly in the lowest 100 feet (fig. 17). Cornstone conglomerates which are very common in this lowest part, become very coarse and thick at the base, some of the pebbles being as much as ½" in diameter. The upper part of the sequence consists of very sandy grey marls and nodular cementstones with frequent grey sandstone layers.

Only four or five miles to the south-west, the basal sediments belong to a quite different facies, and are relatively fine and muddy above the thin basal sandstones. This fairly rapid change in facies suggests that the cause of the change is very near. At Glenbuck and Coalburn (Fig. 18) the thickness is less than 100 feet and 100 feet respectively, and the rocks consist almost entirely of sandy clastics with very few cementstones, red being the dominant colour of the sediments.

The general facies of the sediments in this region suggests relatively quiet currents, and a low hinterland, with slow streams bringing in fine sediment. The only exception is in the Dalrymple area, the sediments of which seem to be derived from a hinterland which was similar to that of the Dailly sediments.

Northern Region.

Strathblane - Campsie Area.

The predominant rock types are red and grey marls, nodular cementstones and micaceous sandstones, the dark silty shales, containing ostracods, common at Ayr and Kilmarnock, being rarer. Massive sandstones are absent from the Cementstones at Ballagan and Campsie, but occur commonly at Strathblane.

Greenock - Dumbarton Area.

At Auchenreoch Glen (Fig. 19) the rocks differ from those of Strathblane in an increase in proportion of hard buff limy sandstones and red marls. The thickness is reduced to 300 feet, to 100 feet at Ben Bowie, and to less than 100 feet at Loch Thom and Outerwards. At these last three localities, sandstones and shales, often red, are dominant, and cementstones rare (Fig. 24). To the south-west the thickness is still small, 100 feet at Cumbrae and less in Arran, and the rocks are conglomeratic in places, with an abundance of red marls; only a few nodular cementstones occur near the top. Cornstone conglomerates are abundant, particularly in the lower part. The conglomerates other than cornstone conglomerates contain mainly quartz pebbles. The facies of the Cementstones in a belt stretching from Ben Bowie through Loch Thom to Arran indicates a close proximity of a shoreline, probably to the north-west.

Corrie of Balglass - Gargunnock.

North-east from Strathblane (Fig. 21) the thickness, proportions and grade of the clastics remain constant, and the only variation is an increase in the darker silty shales and layered cementstones. Thus there is no evidence of a shoreline in a north-easterly direction. From the general grade of the clastics it would seem that the hinterland, probably to the north-west, was of low relief, with rapid inflows of moderately coarse sandstones near the edge of the basin.

Northern Ireland.

Cultra. The basal beds at Cultra are mostly fairly fine siltstones and sandstones, indicating the near proximity of a shoreline. They are overlain by grey shales, limy sandstones and cementstones, both nodular and layered. The facies in the upper part bears a strong resemblance to that of Ayr, except for the occurrence of lamellibranch mudstones and algal remains , akin to those found in the Main Algal Series of Liddisdale.

Draperstown.

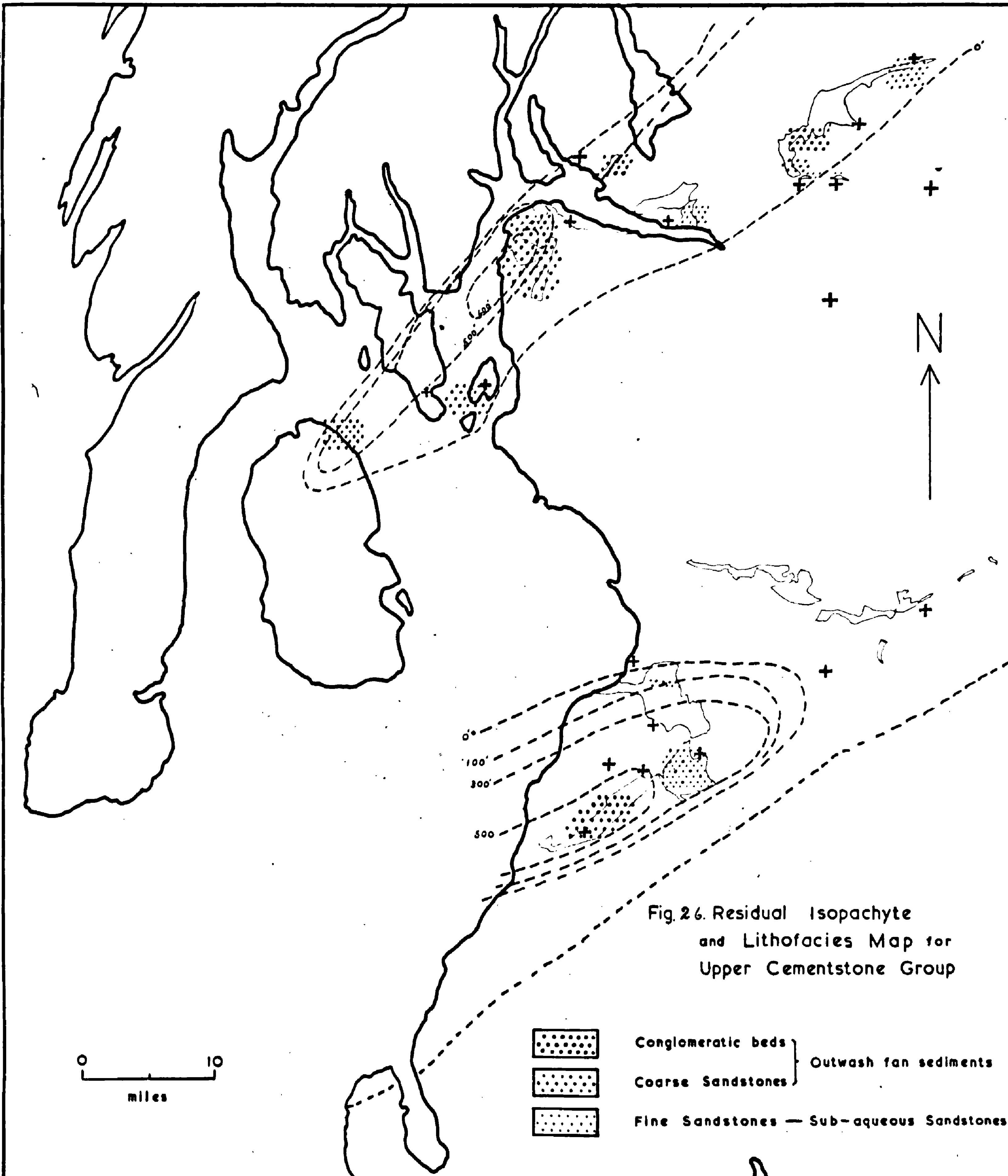


Fig. 26. Residual Isopachyte and Lithofacies Map for Upper Cementstone Group

The rocks at Draperstown are mainly mudstones and shales, though sandstones and siltstones are common; as at Cultra the beds nearest the base are sandiest, Cementstones, mainly layered, are found only in the higher beds, in the usual context of shales and micaceous sandstones. Lamellibranch mudstones similar to those of Liddisdale and Cultra are also seen. In the White Water section there occurs a conglomerate, mainly of quartz pebbles.

The sediments from the Draperstown area suggest that there was an adjacent hinterland of a moderate relief, although the greater part of the sedimentation is fairly quiet.

The Upper Cementstone Group (Fig. 26).

The upper division is confined to the Dailly area, and the Northern Region. It displays a similar facies in both regions, that is, a recurrence of outwash fan sediments like those of the U. Old Red Sandstone. At Dailly the dominant features of these sediments are their coarseness and bright red colour.

Conglomerates are very common, some red and some green, in which the pebbles are of L. Palaeozoic spilites, cherts, jasper, greywackes and metamorphic rocks, the last sometimes very common. Some contain fragments of bright red marls, similar to beds immediately below. The pebble content is suggestive of derivation from an area of Arenig rocks in particular, and the present larger outcrops of these rocks occur to the south-east.

Red and green sandstones which form the bulk of the sediments at Dailly fall into the greywacke and sub-greywacke groups of sandstone. Commonly they show poor sorting, many sandstones having as much as 30% clay grade content. Slumping is frequently to be seen, with strong current bedding and erosional features, but graded bedding is not found. This agrees with outwash fan sedimentation. Bright red marls, some with cornstone nodules, are common, and are again comparable with some of the cornstones of the U. Old Red Sandstone. These beds form a thick prism of sediment, thickest at Dailly, and thinning to less than 100 feet of micaceous current laminated sandstones and red marls in the Ayr area. At increasing distance from the probable source the sediments cease to be outwash sandstones, as their micaceous and current laminated nature shows; they are the result of the same tectonic disturbance and rejuvenation of the relief of the hinterland however, and are merely deposited under water in the centre of the basin instead of in outwash fans near the margins.

Northern Region.

The Spout of Ballagan Sandstone shows essentially the same features as the upper sandstone sub-group of the south. The most noticeable difference is the colour; the rocks are predominantly white and pink, with only occasional red beds. The conglomerates contain quartz pebbles rather than the L. Palaeozoic types found in the south. Red marls and cornstones occur, notably at Laggan, Greenock and Dumbarton, some of the cornstones at Greenock being 5 feet or more thick.

The thickness of this upper division may be as much as 600 feet at Laggan in Arran, more than 300 feet at Cumbrae, and 900 feet at Greenock. This indicates a great thickness along a line running from Laggan, through Cumbrae, west of Loch Thom, and possibly passing up between Helensburgh and Dumbarton (see Fig. 26). To the north-west of this line at Ben Bowie there cannot be more than 200 feet of Spout of Ballagan Sandstone. To the south-east it falls to 300 feet at Outerwards, and 200-300 feet from Dumbarton to Little Corrie of Balglass near Fintry. Along the south face of the Campsie Fells it thins to disappearance, probably by overstep (see p.23), though current bedding evidence indicates that thinning may also be due to a tectonic swell to the east.

The great difference in colour between the Spout of Ballagan Sandstone and the upper sandstone sub-group of the south can be explained by the provenance of the clastics. In the oxidising conditions that existed during the deposition of both the upper sandstone sub-group and the Spout of Ballagan Sandstone, ferric iron would be available in greater abundance from the breakdown of L. Palaeozoic greywackes and spilites than from the Dalradian metamorphic rocks.

It may be inferred that the setting of the Upper Cementstone Group was one of a basin with hinterlands of high relief, and of contrasted lithological composition;

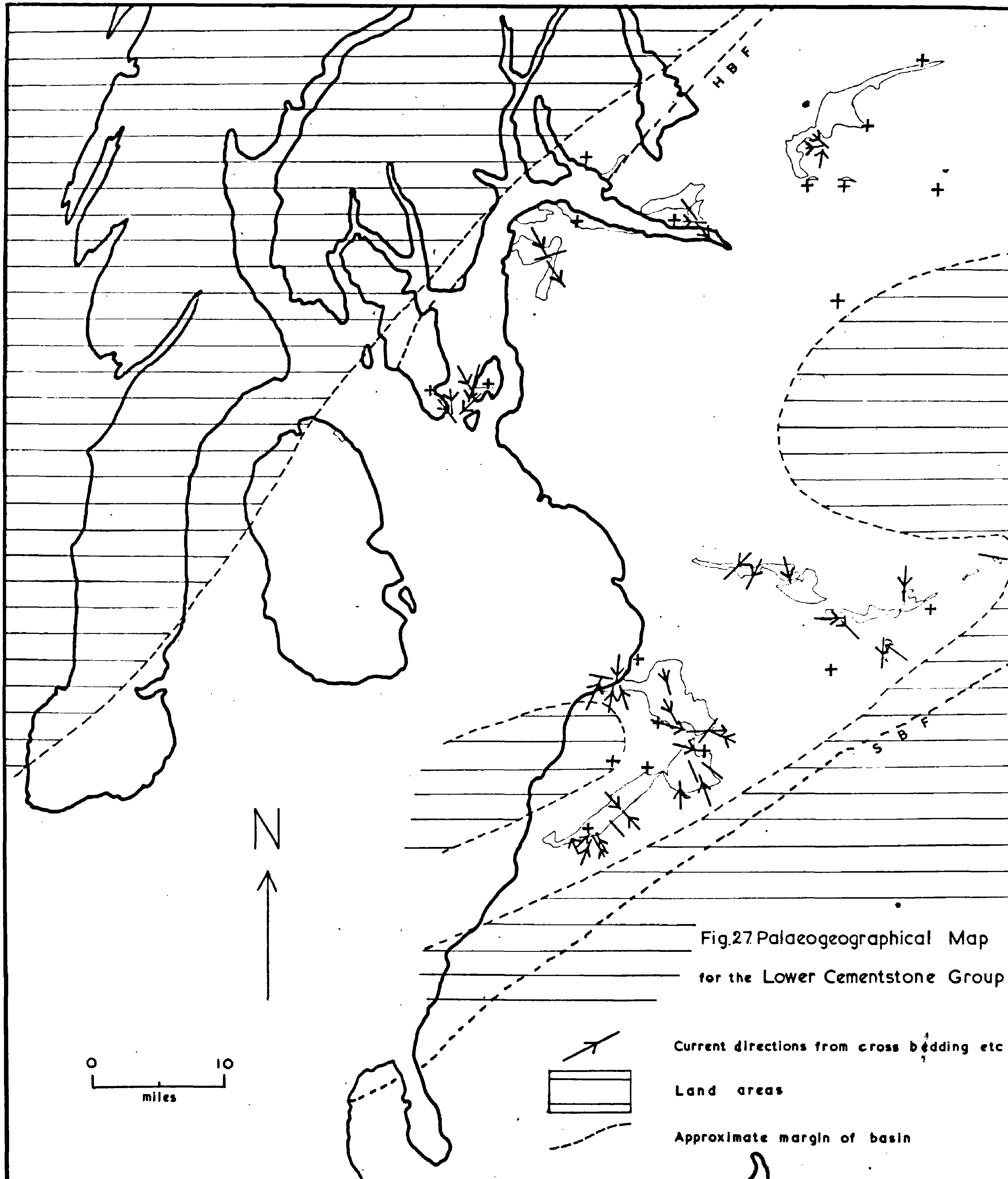


Fig.27 Palaeogeographical Map for the Lower Cementstone Group

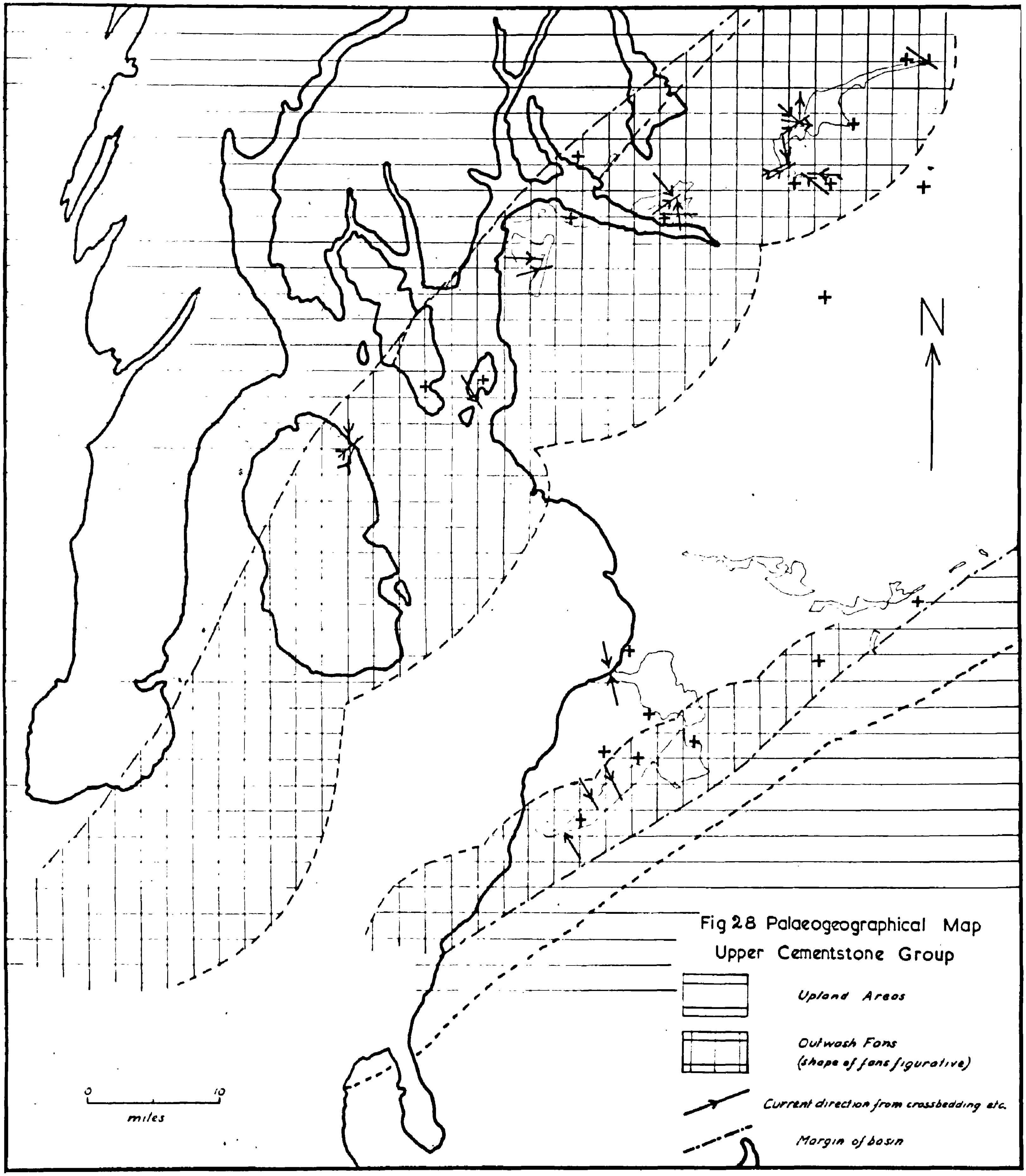

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Fig 28 Palaeogeographical Map
Upper Cementstone Group
Upland Areas
Outwash Fans
(shape of fans figurative)
Current direction from crossbedding etc.
Margin of basin
0
10
miles

but from both north and south there accumulated outwash fans in the wide basin between. Originally the two prisms of marginal sediments formed may have met in the centre, but the sediments representing this junction have been removed by subsequent erosion.

Section 2. Sedimentary Structures.

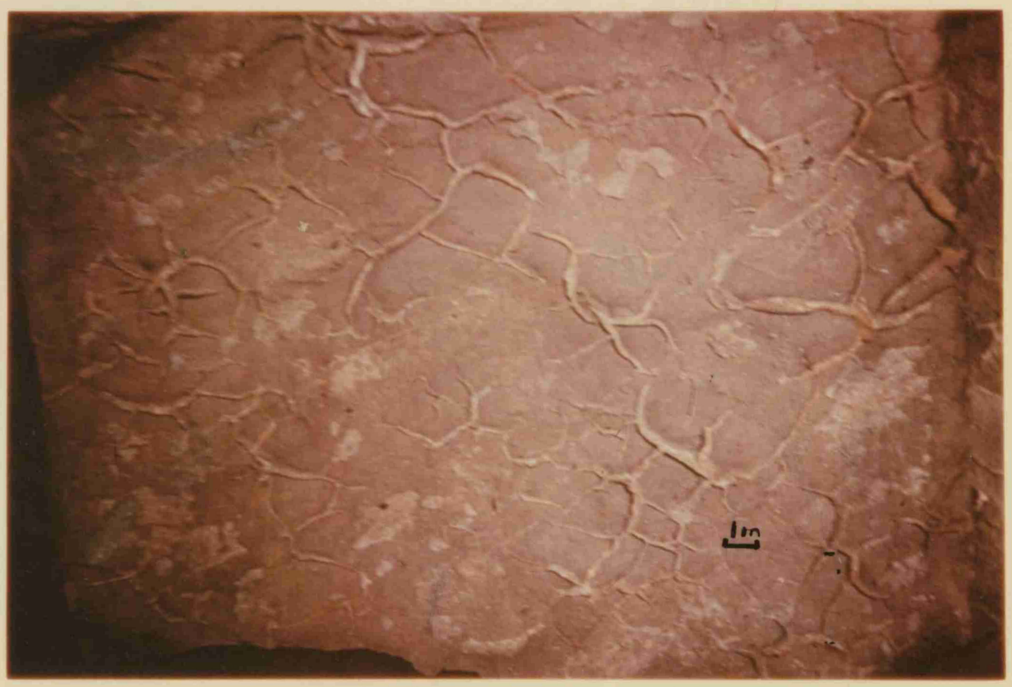
(a) Indicators of Current Direction.

Cross bedding provides the greatest number of measurements for an analysis of directions of sediment transport, particularly in the Upper Cementstone Group. Measurements from ripple marks are less common and provide only the (local and temporary) current direction, but not the sense. Primary current lineations, and most groove casts (Pl.13), also reveal only trends, although some casts show a steeply scooped-out up-stream end.

From the current directions on Figs. 27, 28, the general current pattern in the various areas of the Western Midland Valley can be deduced. The readings from the Upper Cementstone Group show much more variability than those from the Lower Cementstone Group.

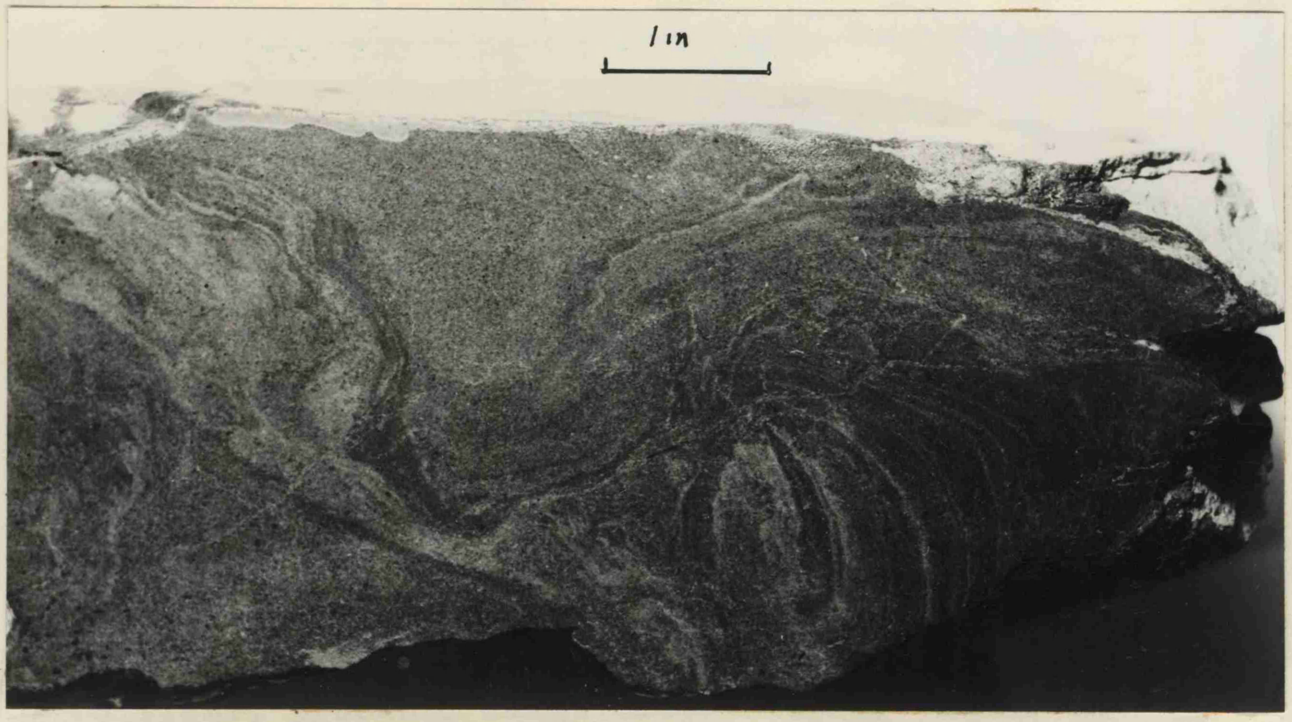
The general inference is of a basin with a system of currents flowing south-east and east from an area at present consisting of metamorphic rocks, and another system coming from the region of the Southern Uplands, and flowing north-west. Another system seems to have originated in the L. Palaeozoic Area of the Lesmahagow

Pl. 13. Groove casts and drag marks in sandstone near Ayr.



Pl. 14. Cast of suncracked surfaces, Lambdoughty Burn, Dailly.

Pl. 15. Slumping in sandstone, at Heads of Ayr.



Pl. 16. Slumping in silty shales near Ayr.

Inlier, and to have flowed to the south and the south-west.

(b) Conditions of Deposition.

(i) The Depth of Water.

The abundance of ripple-marked bedding planes suggests shallow water, as does the occurrence of numerous examples of suncracked surfaces and dessication breccias.

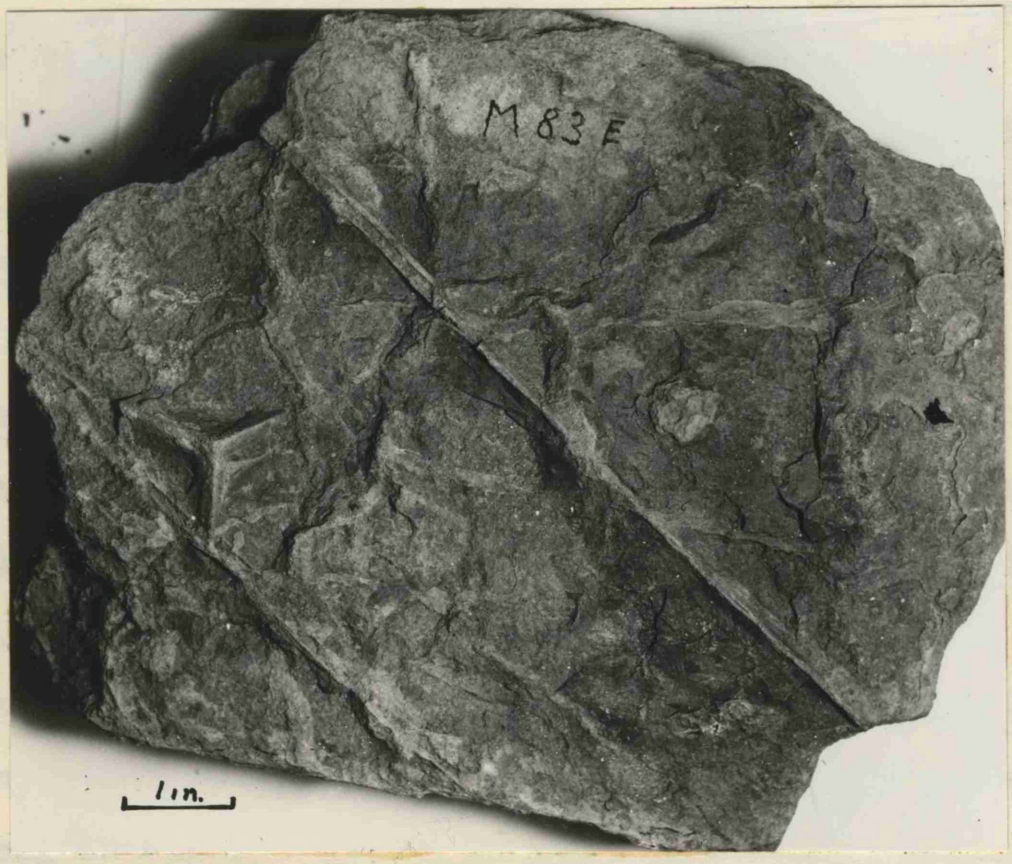
(ii) Strength and Variability of Current.

The large size and inconstancy in the direction of many examples of cross-bedding in the Spout of Ballagan Sandstone, and the conglomeratic nature of the beds, points to the existence of strong and very variable currents during the deposition of the sandstone.

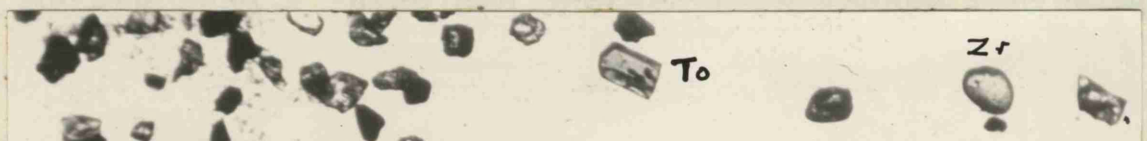
The thicker non-micaceous sandstone found in the Lower Cementstone Group often contains large cross-bedded units, but they show much more consistency of direction, thus indicating a much more stable current pattern during infrequent periods of sandstone deposition. The micaceous sandstones which are very common in the Lower Cementstone Group are usually current-laminated, suggesting very gentle flow.

(iii) Local Tectonic Conditions.

The occurrence of slumping in sandstones and in marls at Ayr and at Dailly (Pl, 15, 16) may indicate unstable tectonic conditions, probably fault disturbances. Later in Carboniferous times faults such as the Kerse Loch Fault were active (Richey 1935, pp. 93-110). The great change in thickness between the Ayr - Dalrymple area and Dailly



Pl. 17. Drag marks and salt pseudomorphs from near Dalrymple.



Pl. 18. Heavy mineral separation from sandstone at Heads of Ayr

To.- Tourmaline; Zr. - Zircon ; Ga. - Garnet ; Ru.- Rutile is suggestive of contemporaneous fault movement along the line of the present Kerse Loch Fault, (Fig. 25). It is thus possible that such movement triggered the slumping in the Cementstone Group sediments.

(iv) Salinity.

Pseudomorphs (pl.17) after salt are often abundant at the base of sandstones and silty shales and indicate that hypersaline conditions existed at least temporarily and locally. They are restricted to the Cementstones, but are found in all regions, even as far away as Draperstown in Northern Ireland. Some of the cubes may be as large as an inch along an edge.

Section 3. Heavy Minerals and Pebble Analysis.

The pebble content of the conglomerates suggests a dual origin from a 'Highland' metamorphic source indicated by the quartz pebbles in the Spout of Ballagan Sandstone, and a L. Palaeozoic source of pebbles of greywacke, spilite, chert and jasper (see p.39.). At Dailly the conglomerates of the Cementstones contain only a L. Palaeozoic suite, but the conglomerates of the upper sandstone sub-group contain small pebbles of such metamorphic rocks as quartzite (pl.12.), besides larger pebbles of spilite, jasper and chert.

Heavy minerals in the Cementstone Group, separated by bromoform and sometimes by acid treatment to remove iron coating include in order of abundance, zircon, tourmaline, rutile, garnet, staurolite, monazite, kyanite and hornblende.

Zircon. Zircons occur mostly as prisms, unabraded or abraded. Some are clear or pink in colour, with inclusions; others are purple, commonly sub-spherical as products of several cycles of sedimentation.

Tourmalines. Two principal varieties of this mineral include large usually abraded fragments, deep brown pleochroic tourmaline, and small unabraded stumpy prisms of pink pleochroic tourmaline, (see Krynine 1954, p.   ).

Rutile. Two varieties, one well rounded and a deep foxy-red, the other light yellow and often unabraded occur.

Garnet. Pink to clear in colour, up to 500μ in size, rounded or ragged in outline.

Staurolite. Only a few occurrences noted, typically with yellow-colourless pleochroism, and saw-tooth fracture.

Monazite. Small unabraded grains, yellow with a high refractive index, optically biaxially positive.

Kyanite. Very rare, as fibrous aggregates.

Hornblende. A few grains seen.

A number of possible source rocks were also examined for heavy mineral content.

The heavy minerals found in the metamorphic rocks depended very much on the grade; garnets, primary yellow rutile, pink-brown pleochroic primary stumpy tourmaline, and primary zircon coming from the high grade rocks, and abraded secondary zircon, tourmaline, and rutile coming from the low grade rocks.

The Lower Palaeozoic rocks of the S. Uplands contain mostly abraded zircon, brown-pale brown pleochroic tourmaline, and rutile, and are poor in metamorphic minerals such as garnet (Kelling 1958).

The L. Old Red Sandstone in the vicinity of Turnberry (246127) contains abundant garnet with abraded zircon, but inland towards the S. Uplands only rounded tourmaline and zircon.

The heavy minerals of 'Highland' origin found in the sandstones of the Cementstone Group include unabraded garnet, pink-brown pleochroic tourmaline, zircon, yellow rutile, staurolite, kyanite, and hornblende. Often these minerals may be secondary in origin, derived indirectly from the metamorphic rocks via the L. Old Red Sandstone, but then they tend to show some rounding, particularly the garnets, where the fresh extremely irregular fracture that characterises the primarily derived garnet is lost and the grains become sub-spherical with a rough pitted surface. The occurrence of staurolite and kyanite suggests a primary derivation, because of their lesser ability to stand several cycles of erosion when compared with garnet and zircon.

The S. Upland provenance of L. Palaeozoic and L. Old Red Sandstone rocks is typified by the presence of abraded heavy minerals, mainly zircon, tourmaline and rutile. The zircon can be clear, pink or purple, and the tourmaline consist mostly of large rounded fragments. The rutile which is found is almost all foxy-red in colour.

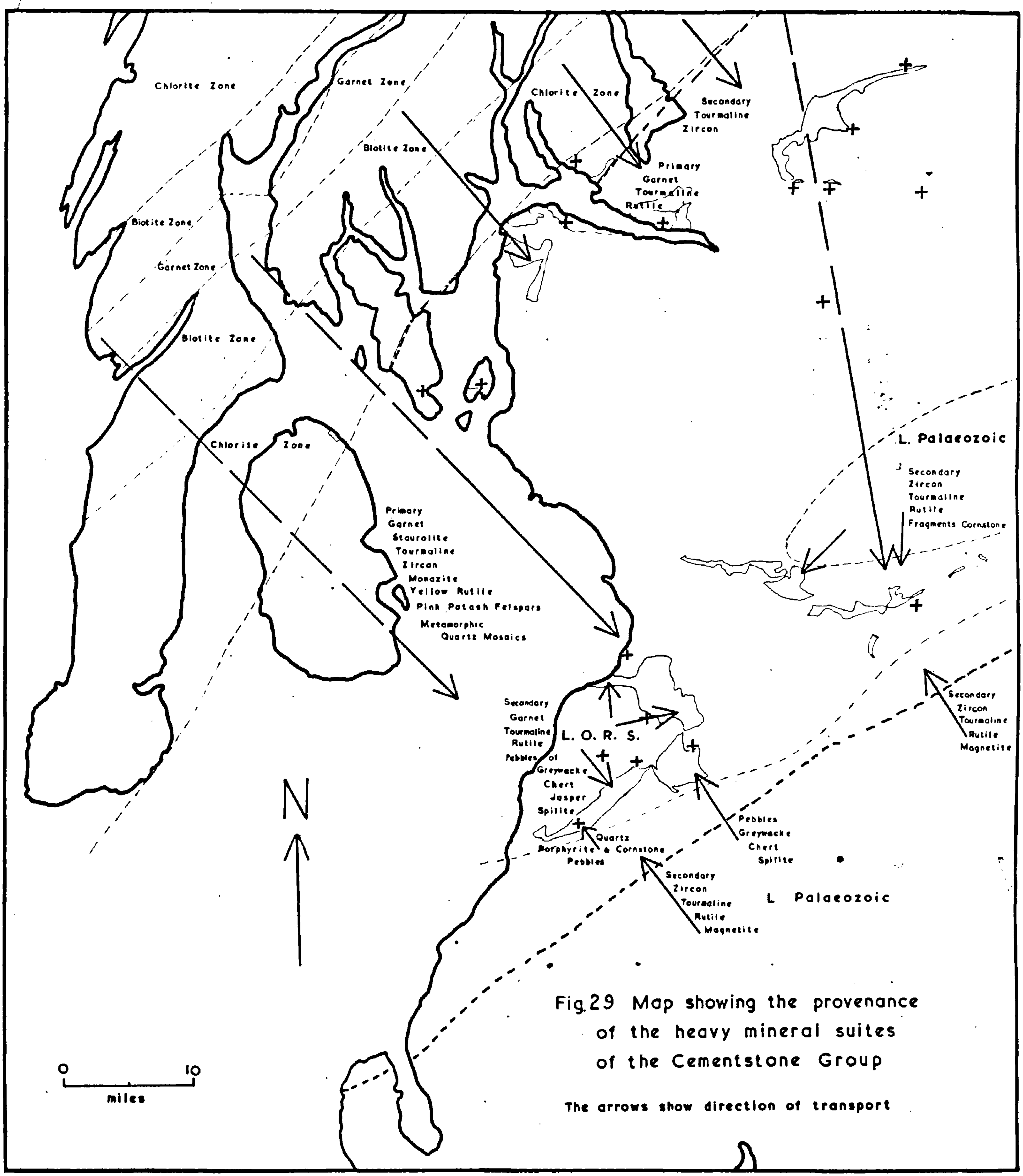


Fig.29 Map showing the provenance of the heavy mineral suites of the Cementstone Group

The arrows show direction of transport

Dailly - Cumnock Region.

In this area the two suites of heavy minerals can be recognised. In the lower sandstone sub-group a large number of the sandstones tested yielded garnet and other metamorphic minerals, along with zircon, tourmaline and rutile, although the garnet is frequently rounded. It is not likely that the garnet could have come from nearby sources, or from the south-east, as the only rocks available as source rocks in this area, the L. Old Red Sandstone, and the L. Palaeozoic rocks, contain insignificant quantities of garnet or staurolite. A more probable source is the metamorphic rocks to the north-west, although the Old Red Sandstone in that direction is also known to contain such minerals as garnet. The remainder of the sandstones from the lower sandstone sub-group contain highly rounded zircon, tourmaline and rutile, with abundant rounded opaque minerals, which are probably derived from the hinterland of greywackes to the south-east. The upper sandstone sub-group shows much the same mixture of such primary metamorphic minerals as garnet and yellow rutile, and such rounded secondary minerals as zircon, tourmaline and red rutile. The mixture of L. Palaeozoic cherts, jasper and spilite pebbles, and Dalradian metamorphic pebbles could be due to reworking of the L. Old Red Sandstone sediments to the north-west, some of which contain cherts, spilite and jasper pebbles. The metamorphic pebbles would be derived from further north-west (see Fig. 29.)

The rounded zircon tourmaline, rutile and abundant opaque minerals, and absence of garnet, in the sandstones in the Cumnock area show that the sediments are all derived from a L. Palaeozoic source. Present outcrops show L. Palaeozoic rocks both to the north-east and to the south-east.

Ayr Area.

Most sandstones examined in this area contain a heavy mineral suite typified by garnet, usually angular, rounded and unabraded zircon, unabraded yellow acicular rutile, unabraded pink-clear tourmaline, and occasional kyanite. This suite indicates a primary derivation in metamorphic rocks, probably to the north-west. The coarse basal sandstones and conglomerates of the Dalrymple area contain heavy minerals, such as garnet and yellow rutile, characteristic of a metamorphic source. The garnet however is well rounded, and the rutile slightly, thus suggesting a secondary derivation from the L. Old Red Sandstone; the nearest area of L. Old Red Sandstone occurs to the west. The pebbles in the conglomerates are of greywacke, quartzite and quartz, and a pink orthoclase is very common in the finer grades of grain size 500-2,000 u. The only local sources for pink potash felspar are acid gneiss and pink granites. No pink granites are found locally, but large areas of Lewisian gneiss are present to the west of Kintyre, as in Islay. The felspars would not necessarily come direct from the Lewisian, but could come via the L. Old

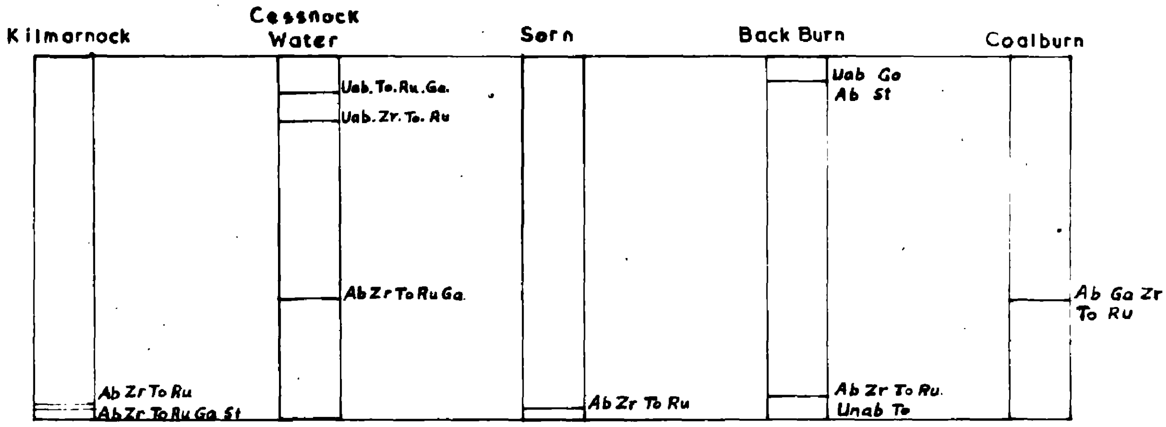


Fig. 30. The occurrence of heavy minerals at various horizons in the Cementstone Group in the Kilmarnock - Coalburn outcrop.

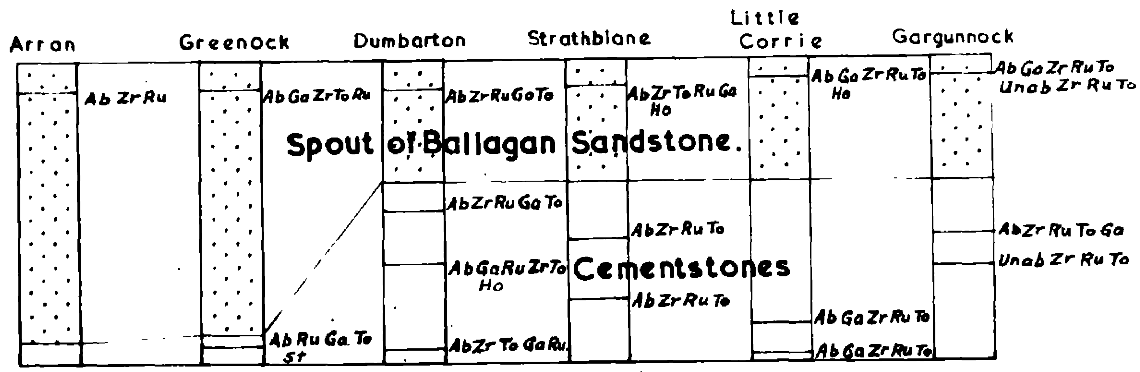


Fig. 31. The occurrence of heavy minerals at various horizons in the Cementstone Group of the Northern Region.

Figs. 30 & 31. Abbreviations.

Ab.	Abraded.	Unab.	Unabraded.
Zr.	Zircon.	To.	Tourmaline.
Ru.	Rutile.	Ga.	Garnet.
Ho.	Hornblende.	St.	Staurolite.

Red Sandstone as the heavy minerals suggest.

Kilmarnock - Coalburn Area.

The basal sandstones are characterised by an almost complete absence of such metamorphic minerals as garnet; they contain instead rounded zircon, tourmaline and rutile, although at one locality near Kilmarnock rounded garnet and stauralite occur (Fig. 30). The only middle horizon sandstone bed sampled also contains the rounded zircon - tourmaline - rutile suite, and only in the higher sandstones do abundant and unabraded garnets appear. They are often accompanied by staurolite, yellow rutile and small pink tourmaline. The occasional occurrence of rounded metamorphic minerals in the lower sandstones suggests that they are derived from the L. Old Red Sandstone. The incoming of fresh garnet from the north suggests that a barrier, presumably of L. Old Red Sandstone, was reduced, and that sediments came directly from a source in metamorphic rocks to the Kilmarnock - Muirkirk area, (Fig. 29).

Northern Region.

The assemblages of heavy minerals obtained from the sediments of this northern region are unusual in seldom showing a typical primary suite of metamorphic origin, despite their proximity to the Highland outcrops. This is particularly true in the south-west, the Spout of Ballagan Sandstone at Laggan, Arran, for instance containing nothing but rounded zircon and rutile, (Fig. 31). At Greenock similar rounded zircon, rutile and tourmaline occur, but large rounded garnet (up to 450 u) is very abundant. This garnet may not be secondary, but may be rounded simply because of its large size. North-eastwards the proportion of large garnets increases in the sandstone, in samples of which from Gargunnock, in the extreme north-east, unabraded tourmaline, zircon and rutile appear. This increase in primary heavy minerals probably reflects the grade of the adjacent metamorphic rocks.

The abundant rounded heavy minerals that occur throughout the Northern Region could not have come directly from a high grade metamorphic terrain, but must be derived either from low grade metamorphic rocks, or from the Old Red Sandstone.

The heavy minerals of the Cementstones are almost exclusively rounded zircon, tourmaline, rutile and smaller garnets, and only in the Gargunnock area do unabraded minerals appear. This suggests that over a great part of the 'Highland' area there was a cover of Old Red Sandstone, particularly in the earlier part of the Cementstone Group, which later became deeply dissectee, especially in the east, where metamorphic rocks of various zones were progressively exposed.

The comparative abundance of garnet in West Ayrshire could be due to a thinner and more fragmented cover of Old Red Sandstone on the nearest adjacent metamorphic rocks of Kintyre. The Lewisian rocks which occur to the west, e.g. at Islay, may also have provided abundant metamorphic minerals.

Section 4. Tectonic Control on Sedimentation.

Control by contemporaneous faulting on the sedimentation of the Cementstone Group, similar to that recognised in the Limestone Series, (Richey 1937, pp. 93-110), is particularly notable in the Dailly area, where the outcrops of U. Old Red Sandstone and Cementstone Group are bounded on the south-east by the Straiton Fault, and on the north-west by the Kerse Loch Fault. The influence of the Straiton Fault on the deposition of the lower sandstone sub-group is indicated by the pebbles of acid porphyrite in the conglomerates, which could have been derived only from the outcrops to the immediate south-east of the Straiton Fault, upthrown along a fault line scarp; the great variation in the coarseness of the clastics may then be due to repeated movements along this fault.

The sudden facies change with increased thickness between the Ayr - Dalrymple area and the Dailly - Patna area suggests, as it does at higher horizons in the Carboniferous, that the Kerse Loch Fault was an influence on sedimentation. From the ~~very~~ heavy mineral suites, it seems that metamorphic minerals could gain easy and frequent access from the north-west to the Dailly - Patna region, but the secondary minerals coming from the L. Palaeozoic rocks were carried no farther north than the Dailly - Patna area. This one way flow of heavy minerals from north-west to south-east is suggestive of an asymmetric control on the regional currents by a gradient such as would be formed by contemporaneous faulting, the numerous local unconformities provide evidence that such tectonic movements were taking place.

The Highland Boundary Fault does not appear to have exercised a control on the sedimentation of either the Cementstones or the Upper Cementstone Group. In the Helensburgh area both units are found to the north-west of the serpentine belt, although they are comparatively thin; and although the shoreline may not have been far to the north-west, the Highland Boundary Fault does not appear to have been represented by a fault line scarp.

The only evidence that folding had any influence on sedimentation is found along the south flank of the Campsie Fells. It has already been suggested (p.23) that there was warping of the Cementstone Group before the eruption of the lavas, along an axis running through the Corrieburn area (700709), in a direction between north-west to south-east, and north-east to south-west. There is an indication from the cross bedding directions found in the U. Sandstone Unit at Ballagan that some sediment was being derived from an easterly and south-easterly direction, possibly from a swell caused by incipient folding in the area of Corrieburn.

Section 5. The Limestones and Associated Sediments.

The limestones found in the Cementstone Group may be divided into usually unfossiliferous 'cementstones' and organic limestones, such as 'spirorbis' (Pl. 19), ostracod, and lamellibranch limestones, though this division is not sharp, as some cementstones contain spirorbids or ostracods.

Cementstones.

The term 'cementstone' is a purely descriptive term that has been applied, not only in the Cementstone Group but at higher horizons also, to homogeneous fine-grained limestones that resemble artificial cement.

The cementstones at Ballagan (Bailey 1925, p. 11) are "argillaceous dolomite----grey in colour, with a somewhat flinty fracture, weather a cream white, and are practically unfossiliferous. They are nodular to a slight extent,----"

The associated sediments are pale grey-green, deep blue-green or red shaly and micaceous sandstones. A particularly noticeable characteristic of the cementstones is their highly developed rhythmic occurrence.

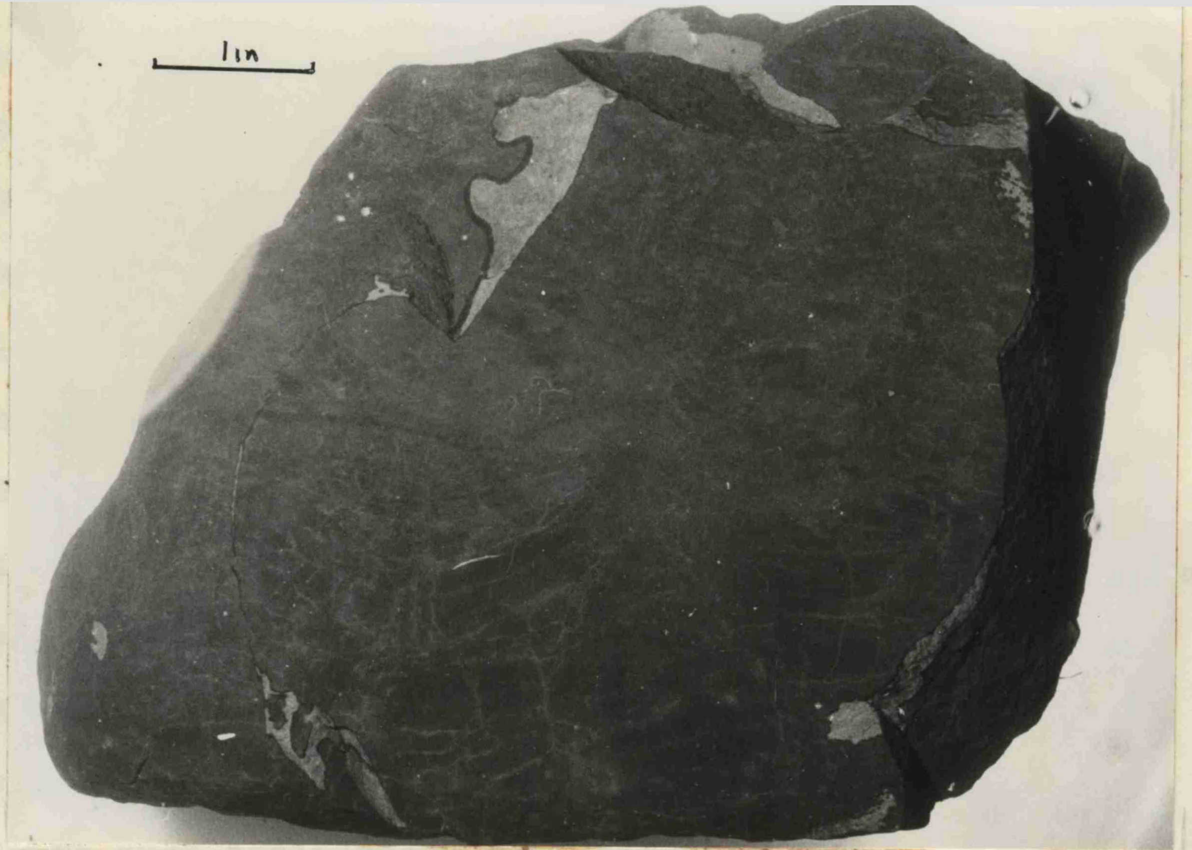
This description, which applies to Ballagan alone, does not take account of other associated limestones still called cementstones on their cement-like appearance, but which do not occur in a nodular fashion. These two types of cementstone are easily differentiated in the field, and they will be referred to by the descriptive terms 'nodular' and 'layered'.

(i) Nodular Cementstones.

Nodular cementstones occur as beds with irregular top and base (though the base is frequently planar), or as

Pl. 19. Spirorbis limestone, Heads of Ayr. x 30.

Pl. 20. Nodular cementstone, Heads of Ayr.



Pl. 21. Polished surface of nodular cementstone, showing brecciation in upper part of nodule.

Pl. 22. Polished surface of nodular cementstone, showing brecciation in upper part of nodule.

layers of nodules completely separated from each other (pl.20). These cementstones, whether continuous or discontinuous, are interbedded with the calcareous shales and marls in which they lie. They are grey in colour, although they often weather a pale yellow-brown. When they are cut and polished many show a brecciation and a streaky appearance due to films of argillaceous material (pls.21/22). The surrounding shales and marls show a distortion round the nodular shape of the cementstones, due to compaction, the lamina appearing to run through the top part of some of the nodules.

No such sedimentary structures as ripple marks or sun sracks can be found on the top of this type of rock. Nodular cementstones are always overlain and underlain by marls or shales, and never directly by sandstones.

(ii) Layered Cementstones.

The main feature which differentiates the 'layered' type from the 'nodular' type is their completely regular upper and lower surfaces. The upper surface commonly shows such structures as ripple marks and sun cracks, (pl.24). Internally the bed is stratified, often laminated with silty or sandy streaks. Disturbed bedding, scour marks, sun cracks, and fine cross-lamination are commonly associated in these layers (pls.23-28), and occasionally they contain laminae of spirorbids, ostracods, or lamellibranchs. All the evidence suggests the deposition of layered cementstones as primary sediments, the nodular cementstones as secondary segregations.

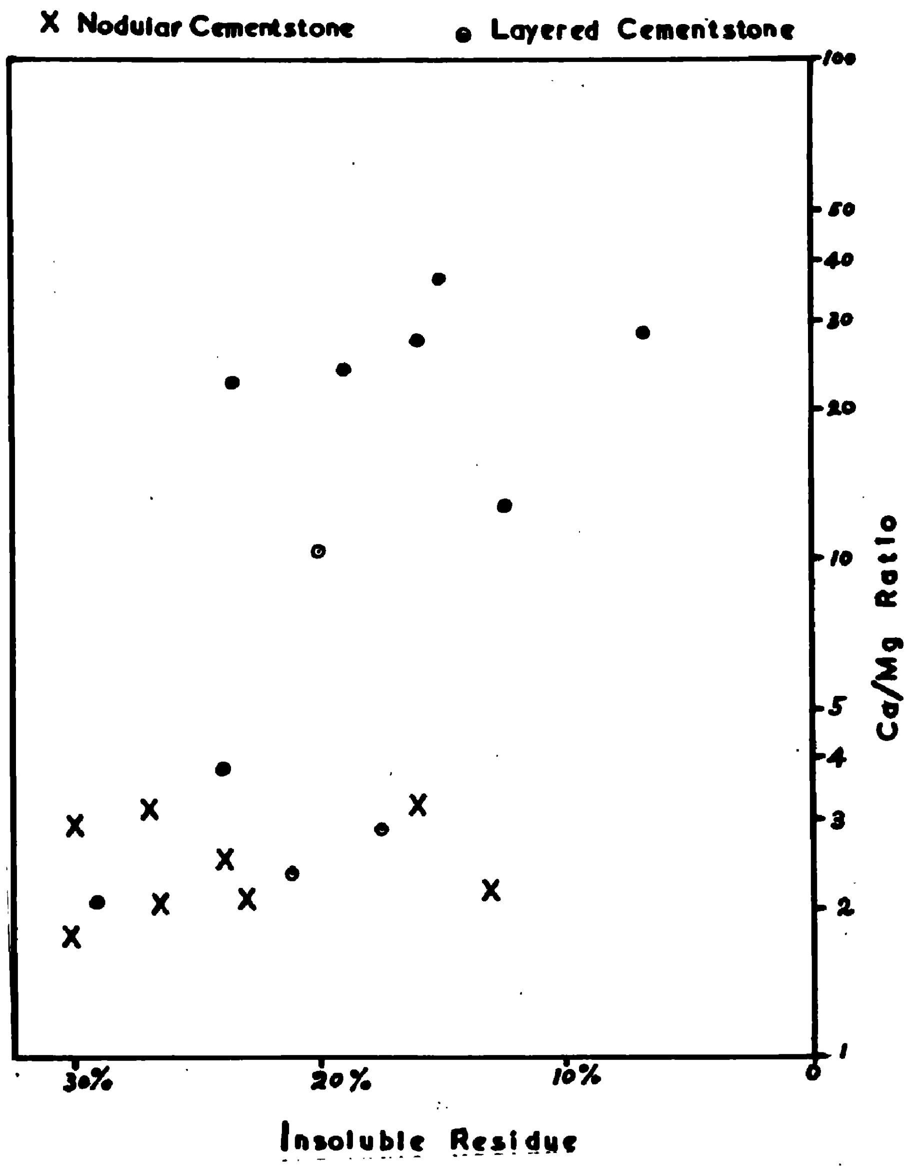


Fig. 32. The insoluble residue content, and the Ca / Mg ratio of some nodular layered cementstones.

Chemical analysis (Table 1) for calcium, magnesium and insoluble residue was made on a number of limestones from Heads of Ayr. The estimation of the calcium and the magnesium was carried out by titration with versene. The indicator for the calcium was calcein, the titration being done in U.V. light, and the indicator for the combined calcium and magnesium was Eriochrome Black T. The magnesium was found by difference, and the percentages of each as carbonates, the Ca/Mg ratio (by weight) being calculated.

Table 1.

	34	36	37	39	40	41	42a	42b
$CaCO_3$ per cent	70.0	31.5	38.0	41.0	77.0	36.0	56.0	70.0
$MgCO_3$ per cent	4.4	38.0	27.0	28.0	8.6	29.0	21.0	7.0
Insoluble residue	21.5	22.1	26.0	28.0	11.6	28.0	23.6	19.0
Ca/Mg ratio	22.4	1.2	2.0	2.1	12.8	1.75	3.77	10.2
Type of Lst.		N	N	L	L	N	L	Ost

	43	44	45	47	48	49	50	52
$CaCO_3$ per cent	47.0	67.0	44.0	47.0	51.0	48.0	48.0	57.0
$MgCO_3$ per cent	27.0	7.7	30.0	19.0	33.0	22.0	29.0	24.0
Insoluble residue	24.0	23.0	22.0	29.0	12.0	26.0	20.0	15.0
Ca/Mg ratio	2.47	12.2	2.07	3.88	2.13	3.13	2.36	3.28
Type of Lst.	N	Spir	N	N	N	N	L	N

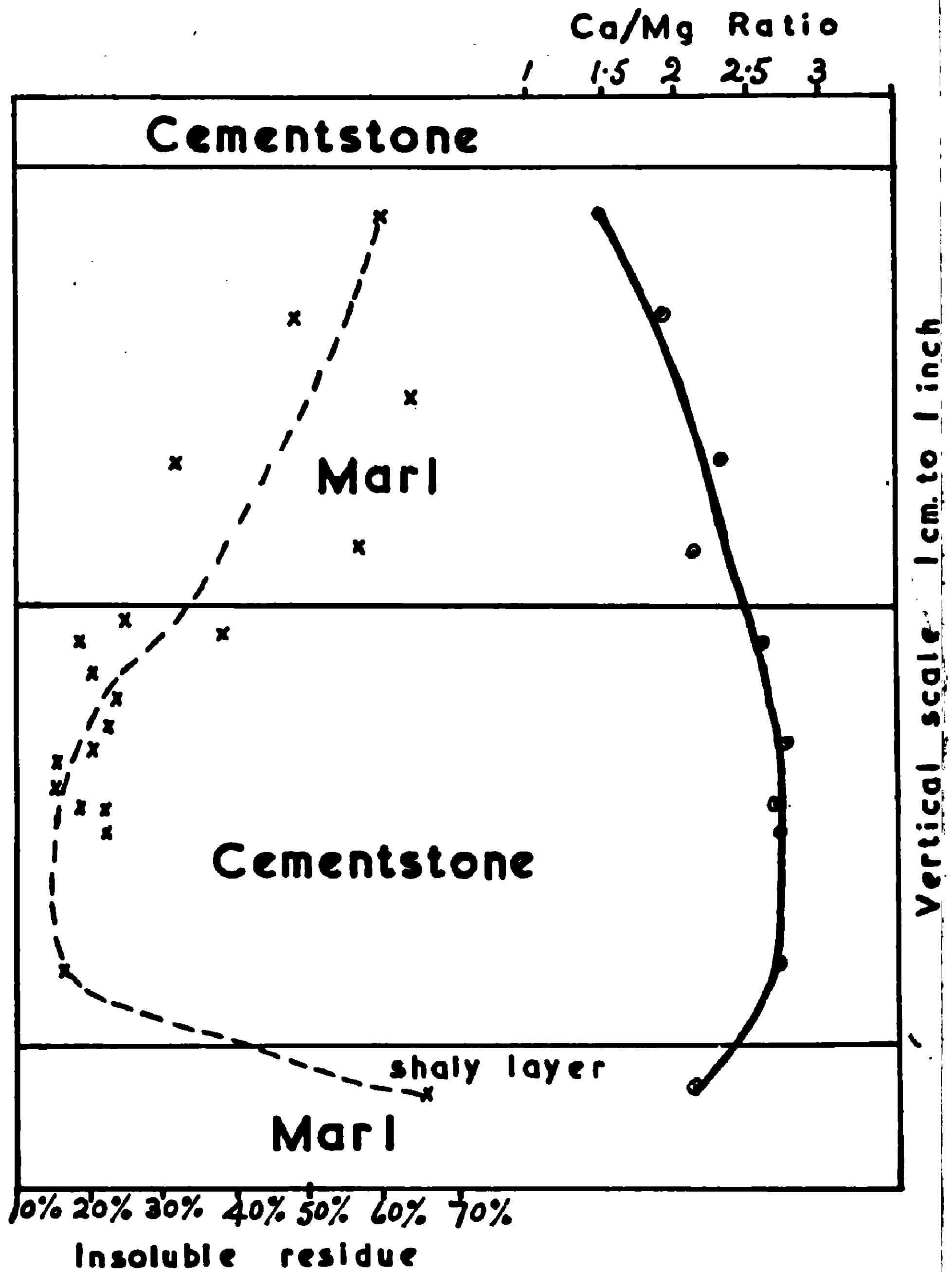


Fig. 33. A series of analyses through a nodular cementstone and associated marl.

	53	56a	56b	57a	57b	57c	60a
$CaCO_3$ per cent	86.0	48.0	75.0	77.0	34.0	53.0	86.0
$MgCO_3$ per cent	1.5	29.0	4.4	3.9	6.3	27.0	4.3
Insoluble residue	12.0	22.0	17.0	15.0	56.0	16.0	6.0
Ca/Mg ratio	83.0	2.2	23.9	27.2	7.5	2.85	28.6
Type of Lst.	Ost	L	L	L	Ost.sh.	L	L

N - Nodular. L - Layered. Ost - Ostracod limestone.
sh - shale. Spir - Spirorbis Limestone.

The nodular cementstones all tend to concentrate in a group with a Ca/Mg ratio varying from 1.2/1 to 3.28/1, and an insoluble residue content varying from 13 per cent to 29 per cent (Fig. 32). Thus it can be seen that the nodular cementstones are highly argillaceous and dolomitic (see Young 1867, pp. 209-212) in character. The 'layered' type however have a much wider range in Ca/Mg ratio, 2.1/1 to 28.6/1, and the insoluble residue percentages range from 28 to 6.

Nodular Cementstones.

The Ca/Mg ratio in a selected nodular cementstone (Fig. 33) shows a fairly sharp rise from 2.1/1 to 1.5/1 in the shale beneath the cementstone to a fairly constant value of about 2.8/1 in the cementstone. Above the cementstone it falls sharply back to 2.1/1, and then gradually to 1.5/1 beneath the next cementstone above. The percentage of soluble residue is much more variable, but a general pattern can be discerned. Beneath the cementstone the insoluble residue content is 66 per cent, and it falls rapidly to about 16 per cent at the base of the cementstone. Upwards through the cementstone it displays an erratic rise from about 16 per cent near the base, to about 25 to 38 per cent near the top.

The increase across the top of the cementstone is not nearly as sharp as at the base, and occasionally there is a lack of definition as the cementstone passes up into the marl above. The marls above the cementstone show an irregular rise in insoluble residue from 32 to 57 per cent, to 48 to 64 per cent.

The internal structures visible in polished sections are all indicative of segregation of the carbonate in pre-existing dolomitic marls and shales (Pls.21,22). In some specimens the clay content has been forced into thin films surrounding regions of carbonate segregation (Pls.21,22). In others the original laminae of the shale and marl have been disrupted, particularly in the upper part of the bed, by the increase in volume due to the introduction of carbonates. This disruption strongly suggests that segregation took place when the sediments were not lithified, in fact it probably occurred a few inches below the depositional interface immediately after deposition, through a change in the pH of the interstitial water.

If during the deposition of the marls and shales the

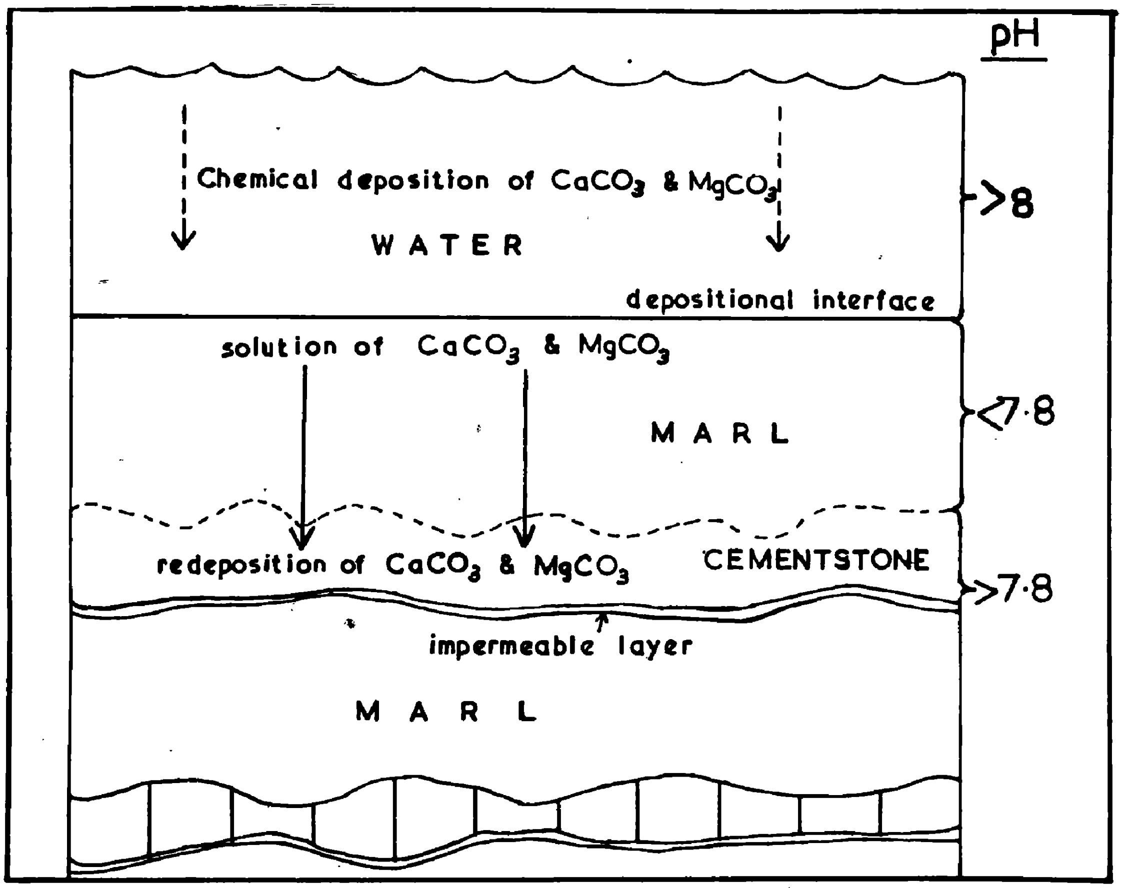


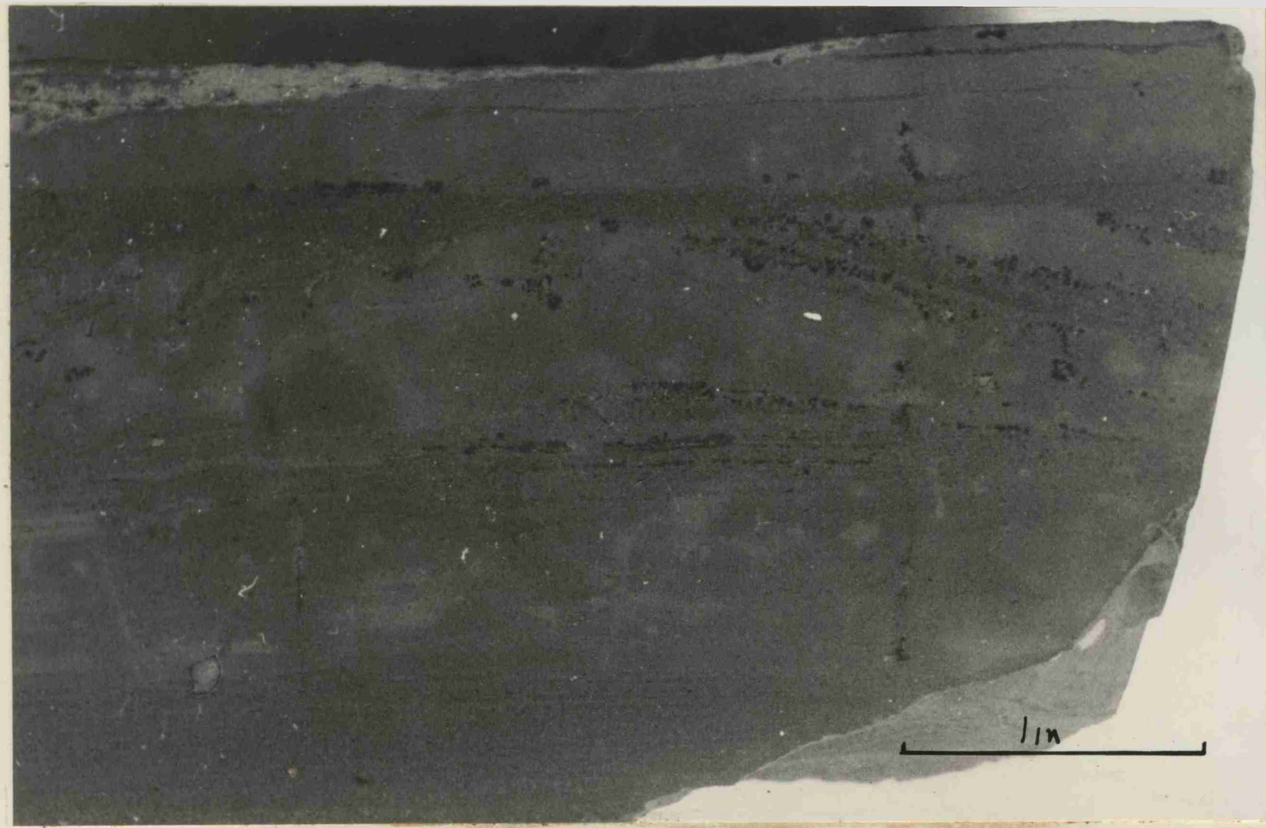
Fig. 34. To illustrate the suggested mode of formation of nodular cementstones.

pH was over 8, as seems probable (p.62), then the temporary drop in pH to below 7.8 in the interstitial water of the sediments immediately below the interface (Bruevich and Vinogradova, 1947, summarised by Chilingar 1958, p. 213; Sisler 1960, p. 192), would cause solution of the carbonates, which would be deposited further down in the compacting sediments where the pH once again rises (see Fig. 34.)

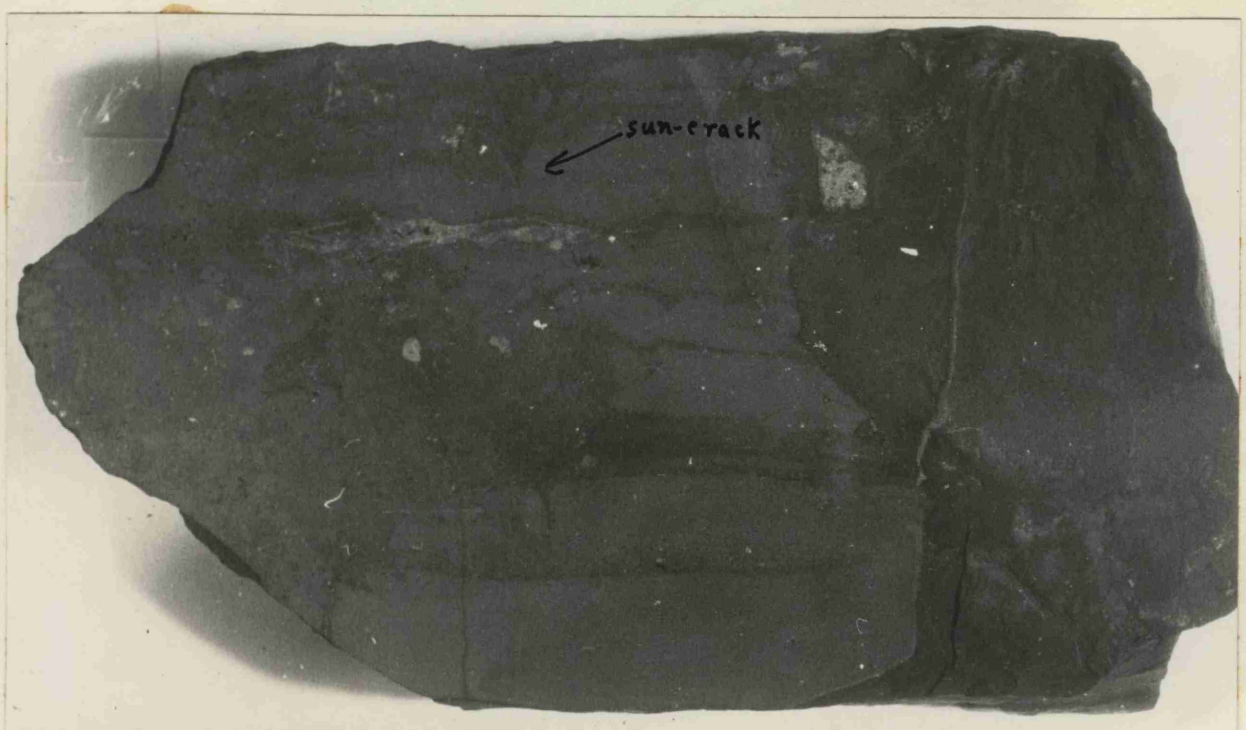
The reason for the rhythmic formations of these levels of redeposition on segregation may be found in the variation in permeability of the marls and shales in the sequence. Thus if a series of marls were deposited in rhythmic layers with more impermeable shale, then the shales could provide a relatively efficient barrier to the downward permeation of carbonates. Such shaly layers can be seen to exist below the cementstones, a fact brought out by the insoluble residue content (Fig. 33), which is highest just beneath the cementstones. A mode of formation such as this would account for the increase in the soluble residue of the cementstone towards the top. The difference in Ca/Mg ratio between the marl and the cementstone could be a result of differential leaching and segregation between the two ions, this being controlled by the pH of the leaching and depositing solutions.

Microscopic Description of Nodular Cementstones. (Pl.29).

Under the microscope the cementstones are seen to be composed of an extremely fine-grained mass of recrystallised



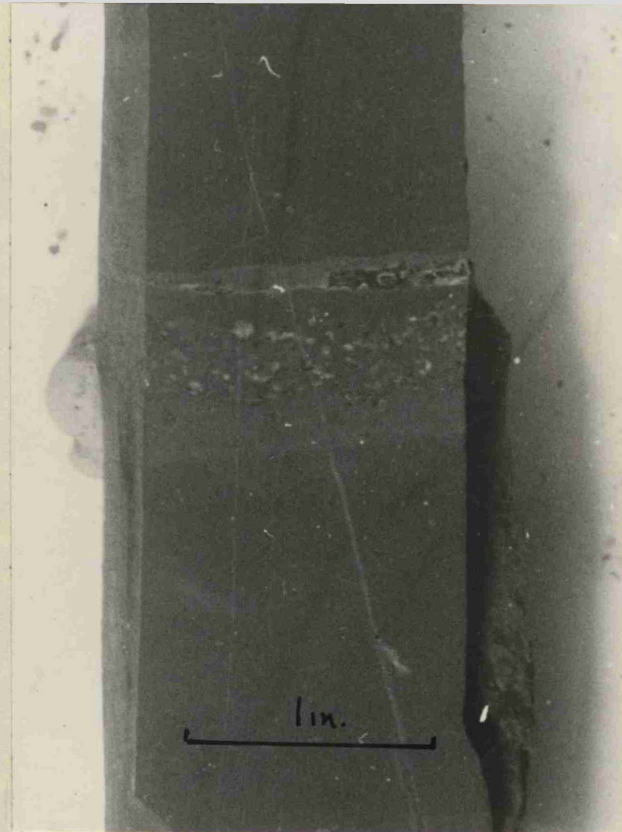
Pl. 23. Layered cementstone showing current laminations, from Heads of Ayr.



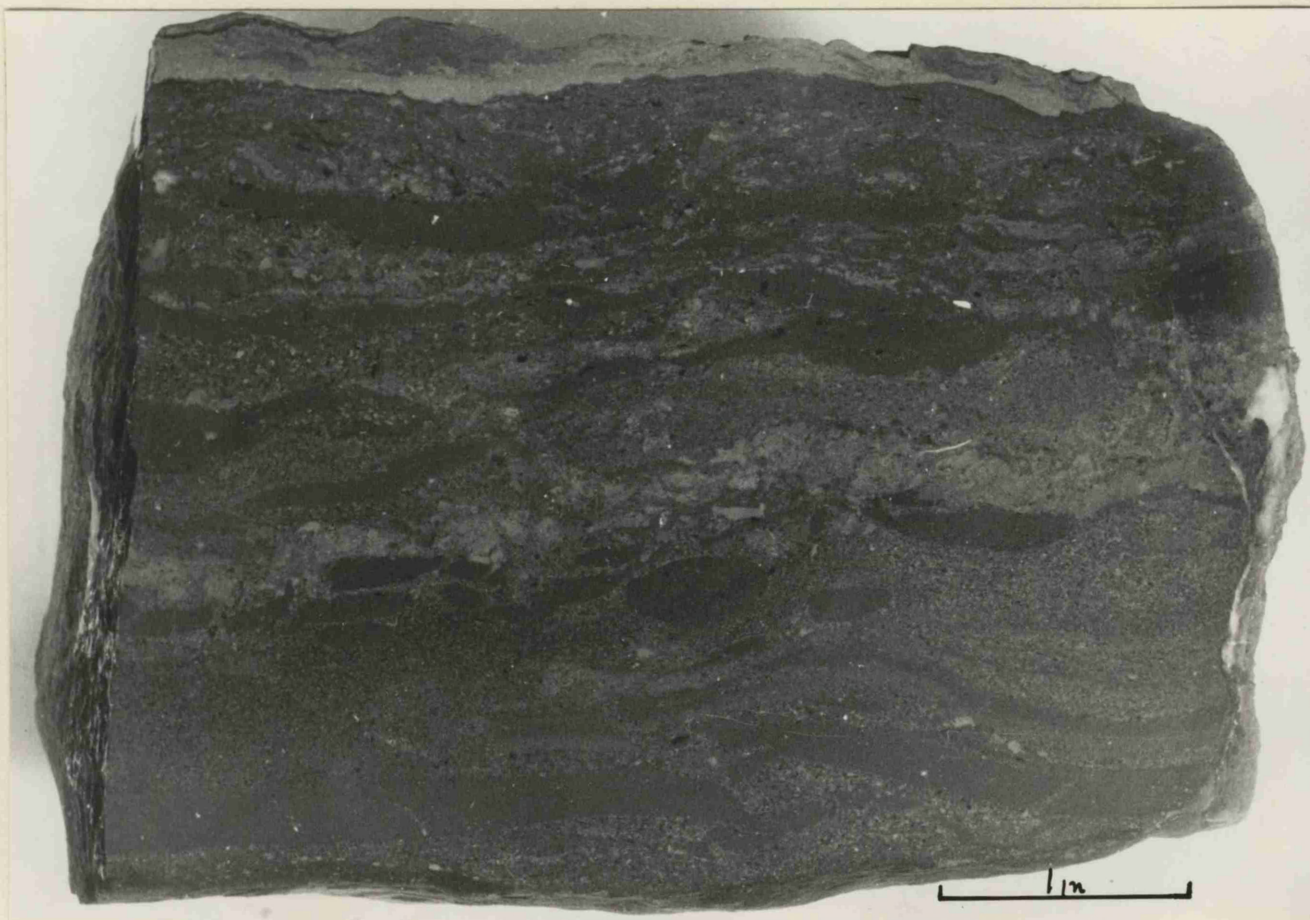
Pl. 24. Layered cementstone showing disturbed bedding at left hand side.

Pl. 25. Layered cementstone showing bedding

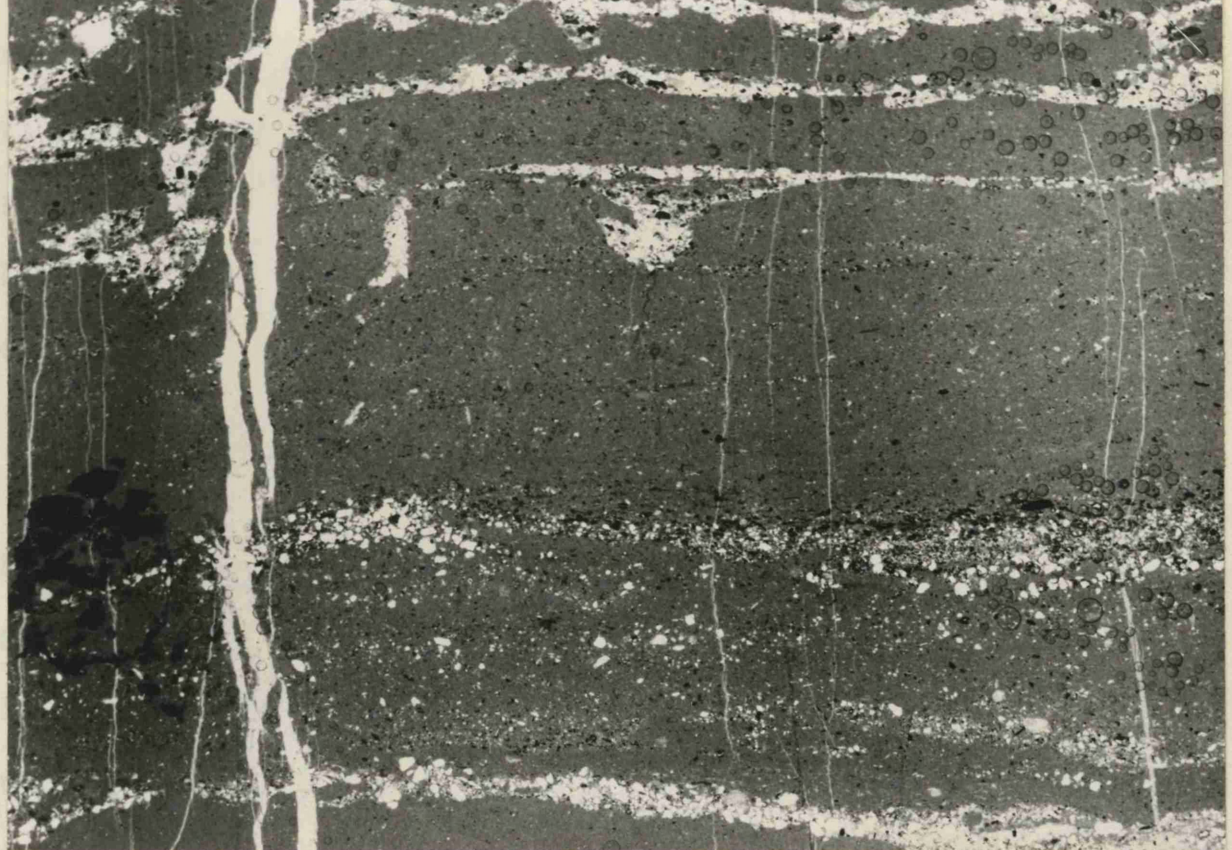
broken by rising gas bubbles.



Pl. 26. Layered cementstone with band of spirorbis,



Pl. 27. Dark coloured sandy layered cementstone with flat pebble conglomerate and plant fragments.



Pl. 28. Thin section layered cementstone with dark carbonaceous fragments and worm burrows.

Pl. 29. Thin section nodular cementstone showing even grained rhombic crystals of dolomite. x200.

dolomite; the individual rhombohedra of dolomite range in size from 7 to 11 u. Grains of quartz and felspar, often corroded by dolomite, are scattered throughout the rock. The only fossils are spores, and an occasional recrystallised ostracod valve.

Layered Cementstones.

The internal structure and the external relationship of the layered type of cementstone to the associated sediments indicate that they were deposited as beds of limestone in shallow water with gentle currents. The analysis in Table I show that these rocks are dolomites and dolomitic limestones, (c.f. Chilingar, 1957, p. 187).

The origin of the dolomite is obscure, but it is almost certain that it is for the most part not of epigenetic or late diagenetic origin, since the cementstones show a uniform fineness of grain, lack porosity, and any fossils they contain are often completely unrecrystallised.

The sedimentary structures such as cross-lamination are perfectly preserved, and show no evidence of obliteration such as is found in epigenetic or late diagenetic dolomites.

It is suggested that the layered cementstones were deposited either as primary precipitates of dolomite, or as a high magnesium precipitate of drewite or aragonite, which subsequently were converted by early or contemporaneous diagenesis to dolomite. The layered cementstones are only abundant in the Ayr - Kilmarnock Region, being almost completely absent from the Northern Region, i.e. they are only found in the region with the strongest marine affinities (p.65). The possibility that some organism, which could only tolerate conditions near to marine, was responsible for the deposition of these rocks cannot be overlooked. It is possible that they were deposited by the disintegration of algae, but no algal remains have been recorded from these rocks.

Depositional Environment of the Cementstones and their Associated Strata.

The various parameters that make up the environment are the current strength and turbulence, the depth of the water, the degree of oxidation or reduction (Eh), the salinity, the hydrogen ion concentration (pH), and the temperature of the water.

Some of these parameters have already been mentioned (pp.43,44), viz. the strength and turbulence of the currents, and the depth of the water, but they will be commented upon here in more detail.

(1) Strength and Turbulence of Current.

In general the extreme fineness of the grains of the non-carbonate clastics indicates very gentle currents. At times nothing but clay grade material was brought in, as in some of the grey marls, when deposition must have been slow and uniform. During the deposition of the layered cementstones, hardly any non-carbonate clastics were brought in at all, the current laminations found in them indicating gentle sifting of the primary chemical precipitates. The silty and fine current-laminated sandstones indicate periods of stronger in flow of sediments from the land surfaces, while cross bedded sandstones indicate strong currents.

(ii) Depth of Water.

The depth appears to have been highly variable, but it seems probable that the depth never exceeded a few feet, with frequent periods of local emergence and shoaling, during which ripple marking and sun cracking took place.

(iii) The Redox Potential.

The main index of the Redox potential is the state of the iron compounds, which in the case of the dark shales, and in some of the 'layered' cementstones is in the form of pyrites. Some of the layered low-magnesium cementstones of the Sorn and Ayr areas are fairly rich in dark organic material, and contain abundant iron pyrites in stringers throughout the bed. In a bed of shale at Heads of Ayr (see Fig. 42), both disseminated crystalline iron pyrites, and individual perfect crystals of sphalerite were found, suggesting a Redox potential of at least Eh - 0.25, i.e. below the 'sulphate - sulphide' fence (Krumbein & Garrels 1952, Fig. 8).

Although the presence of iron sulphide in a sediment indicates that at some time it has been under reducing conditions, this does not necessarily mean that the depositional conditions were reducing. It is possible for the water above the depositional interface to be oxidising, and the sediment beneath can be under a reducing influence (Krumbein & Garrels 1952, pp. 19, 20 Fig. 5). In shallow evaporite conditions like those of the Cementstone Group, the circulation of water in most places would be enhanced by convection, and thus bottom conditions would tend to be oxidising, although this does not preclude the formation of pyrites in the bottom sediment.

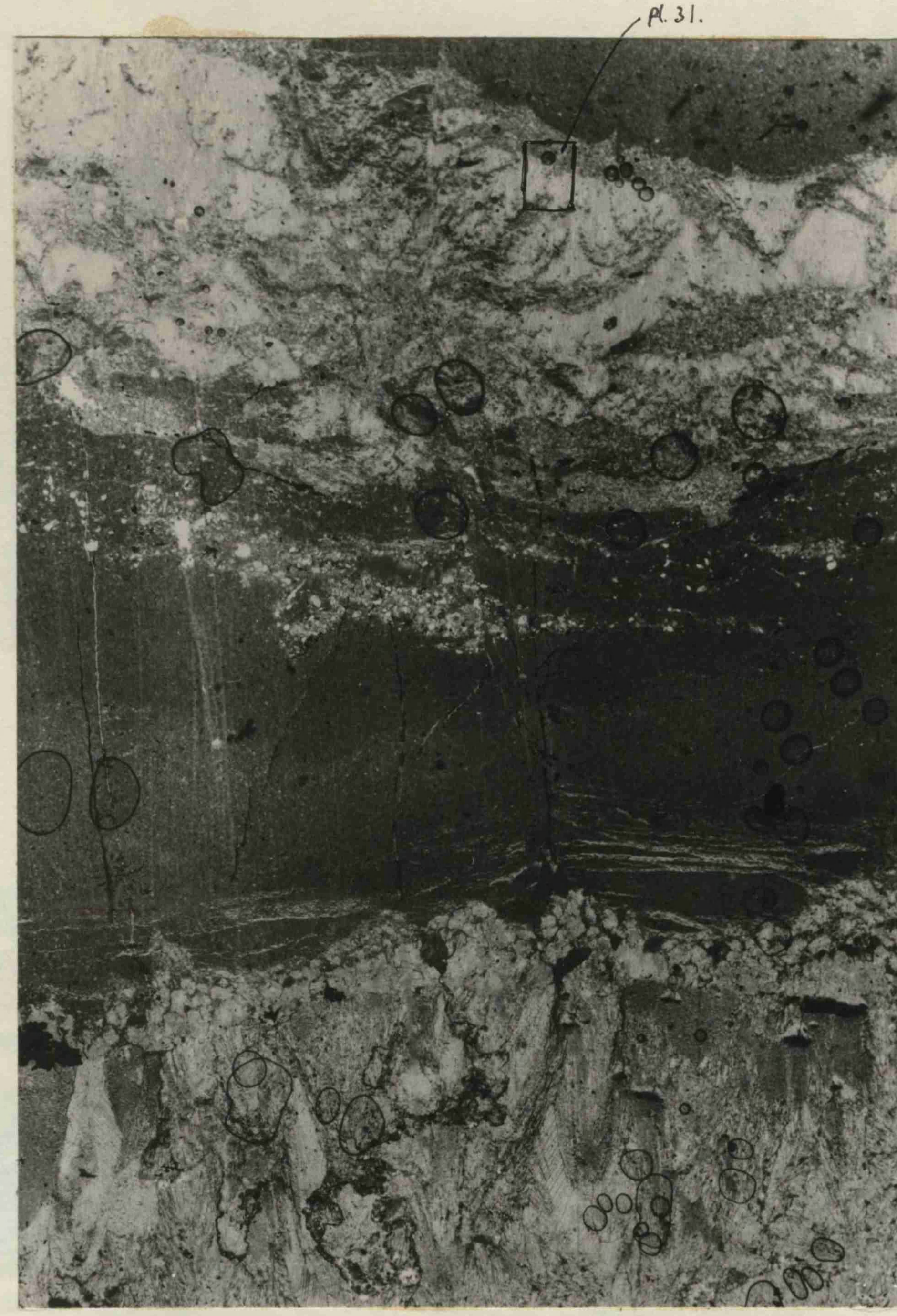
(iv) pH.

The only evidence regarding the pH of the water is mineralogical, the main indicators being the carbonates and silica. Calcite will not precipitate in an acid environment (Krumbein & Garrels 1952, Fig. 8), and the precipitation of magnesium ions is favoured by a high pH (Chilingar 1953, p. 55), higher than that necessary for the precipitation of calcium ions. The abundance of highly magnesian limestones in the Cementstone Group is very suggestive of conditions with a pH well above 8, and possibly tending towards 9.

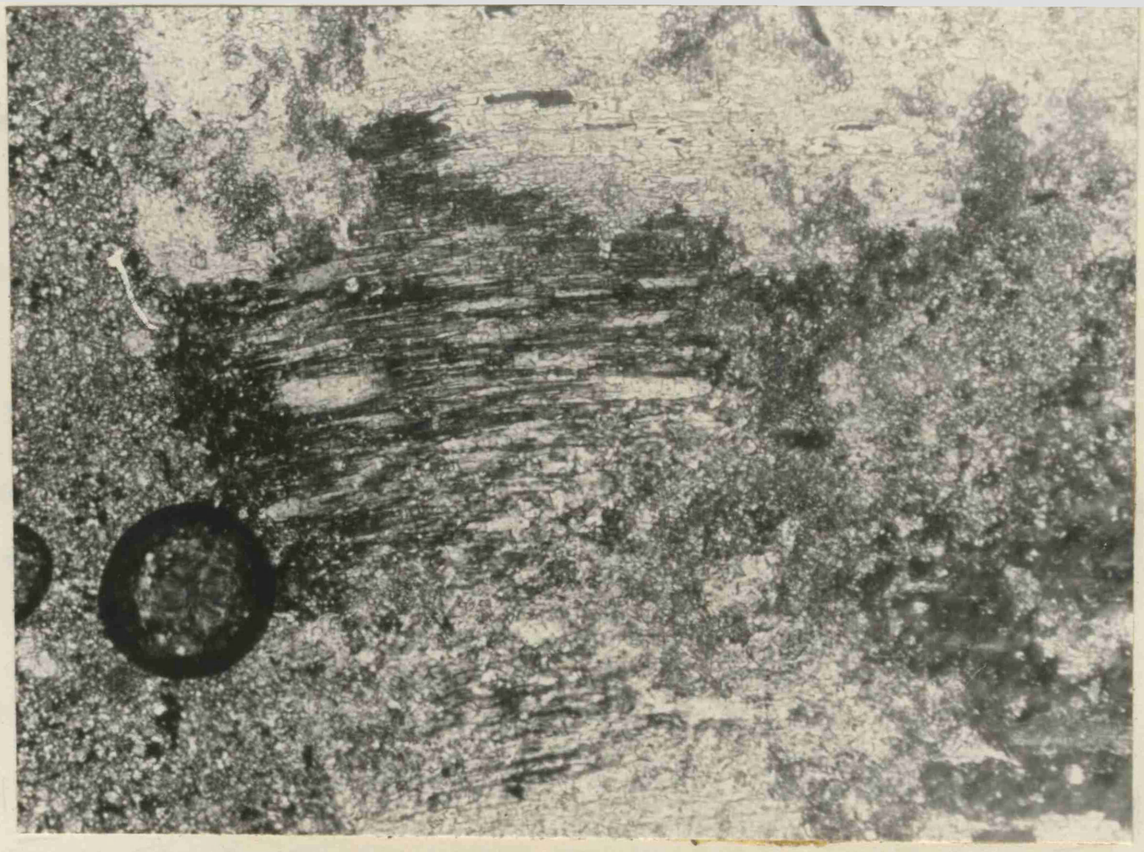
Salinity.

The sedimentary structures indicate that high salinity was frequent (see p.44). A further indication of high salinity is the presence of gypsum, which is found in two different conditions:

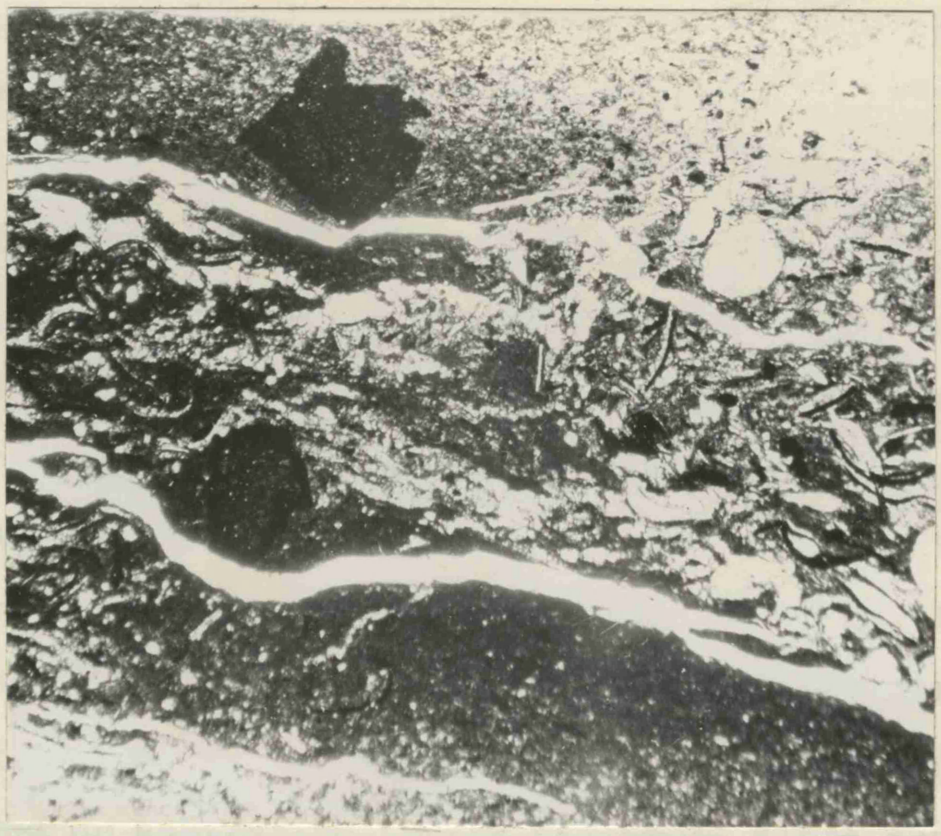
(1) as irregular veins in joints and bedding planes in marls and cementstone sequences. This occurrence is



Pl. 30. Layered cementstone with recrystallised calcite intergrown with gypsum. x 30.



Pl. 31. Calcite and gypsum intergrown. Cross Nicols. From Pl. 30. x 200.



Pl. 32. Crystal of sphalerite in ostracodal shale. x 30.

obviously not primary, but came from primary gypsum previously concordant with the bedding. In some cases it is found in irregular masses within the nodular cementstones;

(2) as completely recrystallised layers ('beef') within the layered cementstone. The fibrous gypsum is intergrown with the calcite crystals, and appears to be near its original position of deposition (see Pls.30,31).

No other evaporites occur, and evaporation could not have been intense or prolonged.

The occurrence of sandstones and red-green silty beds, particularly in areas marginal to the basin of deposition, suggests that at times large amounts of fresh water were introduced. This would have the effect of reducing the salinity of water that doubtless fluctuated from fresh to brackish to marine to penesaline.

Temperature.

The presence of evaporites and the occurrence of abundant sun-cracked surfaces points to a high climatic temperature. The cA/Mg ratio may be used as a relative measure of temperature (Chilingar 1953, pp. 38-47), its use as an absolute thermometer being barred because of the control that is also exerted on the Ca/Mg ratio by the hydrogen ion concentration and the depth of water. Assuming that no appreciable quantity of magnesium has been added or subtracted to the sediments since early diagenesis, then the extremely low Ca/Mg ratio of some of the layered cementstones does seem to indicate a water temperature greater than that for instance of the Bahama Banks, where the Ca/Mg ratio of the limestones is higher. A higher water temperature does not infer that the air temperature was higher, because a shallow more restricted basin of water such as the Cementstone Group was deposited in would become much warmer for a given air temperature than an open area of water such as the Bahama Banks.

The presence of pedocal soils similar to those found at the marginal areas of the basin, in the lower and upper sandstone sub-group, of Dailly, and in the Spout of Ballagan Sandstone, often indicates infrequent but heavy rainfall, which would produce the flash floods to transport the outwash-fan sediments down into the basin, and to lower the salinity in the evaporite basin particularly at the margins.

The association of gypsum, laminated dolomites, marls and marginal red beds is a typical evaporite assemblange more indicative of penesaline than of hypersaline conditions (Sloss 1953, pp. 143-161).

The absence of thick evaporites in sections available for examination may be due to the location of the sections near marginal areas, where the rocks were influenced strongly by fresh water influx. It is more likely however that in the penesaline conditions which existed no more than minor quantities of gypsum would be deposited.

Chapter 4. Palaeontology.

The fauna of the cementstones is sparse and restricted, especially in the areas where dolomitic marls and nodular cementstones predominate. The rocks in which fossils are commonest are the dark silty shales, and the associated layered cementstones. Varied and plentiful faunas are found only in the Ayr area and in the Cultra outcrop. The Kilmarnock-Coalburn outcrop has a relatively poor fauna, and virtually nothing is to be found in the Northern Region.

The dominant element in the fauna of the Ayr area is the ostracods, represented in five genera and eight species. Spirorbis is also abundant, as are lamellibranchs and fish remains. A camarotoechiid brachiopod occurs at one horizon at Heads of Ayr, with Lingula mytiloides. The fauna obtained at Cultra is very similar in general content to that of Ayr.

Spirorbis, probably Spirorbis helincteres, occurs abundantly in the Heads of Ayr section, as scattered individuals in shale, as bands in some layered cementstones, and as the major constituent in 'spirorbis' limestones (Pl. 19.). Spirorbis appears from palaeoecological records (Etheridge 1880, pp. 109, 171, 215, 258, 304, 362; Haack 1923, pp. 560-594) to be tolerant of a great variation in salinity ranging from penesaline to fresh water.

The two genera of lamellibranchs recorded are probably non-marine; they include *Niadites obesa* found near the base in a limy sandstone at Dailly , and '*Anthracomya minima*' Ludwig found widely in the Ayr - Dalrymple area and occasionally in the Sorn area, usually in sandy sediments.

The Ostracods.

The ostracods studied were collected mainly at Heads of Ayr, although some came from Ballagan, from Patna, and from Dailly. Outside the Midland Valley samples were collected and examined for comparison from Cultra, Draperstown, Liddisdale, Ravenstonedale, Forest of Dean, and the Avon Gorge. More attention was paid to the ornamented types, viz. *Glyptopleura*, *Beyrichiopsis*, and *Geisina*, although such unornamented types as *Paraparchites* often made up the bulk of the fauna. The fossils were collected chiefly in shales amenable to disintegration with hydrogen peroxide, although some were removed mechanically from limestones.

Systematic Descriptions.

FAMILY GLYPTOPLEURIDAE Girty.

GENUS GLYPTOPLEURA Girty, (1910 p. 236).

Glyptopleura plicata, (Jones & Kirby), 1885.

Kirbya plicata Jones & Kirby,	1885,	p.184, pl. 3, figs. 9, 10, 10b.
" " " " "	1886,	p.250, pl. 7, figs. 1a, 1b, 2, 3a, 3b.
" " " " "	1896,	p.188.
Kirbya variabilis " " "	1886,	p.249, pl. 7, figs. 4a, 4b, 5a, 5b, 6, 7, 7a, 7b, not 8a, 8b.
Glyptopleura plicata, Coryell & Brackmier,	1931,	p.511, pl. 2, figs. 8, 9.

Glyptopleura plicata, Latham, 1932, p. 372, text fig. 21.

Description. The carapace is sub-ovate to sub-rectangular. Both the hinge line and the dorsal margin are straight, while the ventral margin is convex. The posterior and anterior margins are well rounded, with the anterior sometimes but not always smaller than the posterior. The antero-dorsal angle is more acute than the postero-dorsal angle, when the anterior is smaller in size than the posterior. The carapace bears a marginal costa which is common to all glyptopleurids, and which in the better preserved specimens of *G. plicata* can be seen to carry a spinose-striate fringe along the ventral, posterior and anterior lengths of this costa. Within the marginal costa there is a ventral costa, a short distance from and parallel to the ventral margin, and another above the last forming a loop which may be complete, open at one end or open at both ends. It can be sub-parallel to the dorsal margin, or falls from the anterior-dorsal region to the posterior ventral region. Two pits occur, one on either side of the dorsal part of the loop costa, and are situated noticeably posteriorly. The surface of the carapace is densely punctate.

Dimensions. Length 0.7 mm. - 1.1 mm.,
Height 0. 4 - 0. 6 mm.

Distribution. The species occurs in abundance at Liddisdale, Cultra, and in lesser abundance at Heads of Ayr, Mitcheldean, and Stone Gill, Ravenstondale.

Remarks. *Kirbya variabilis* is put in synonymy with

G. plicata, it being a very early type of G. plicata with poorly developed and unclosed loop.

Glyptopleura spiralis. (Jones, 1884).

Kirbya spiralis		Kirby 1880, pp. 564, 568, 578, 588 (name only).
"	"	Jones 1884, p. 323, pl. 2, figs. 12, 13.
"	"	Jones & Kirby 1885, p. 184, pl. 3, figs. 11a, 11b.
"	"	" " " 1896, p. 188.

Description. Carapace sub-quadrate, hinge line short and straight, the ventral margin slightly divergent from the hinge line, and is usually slightly concave. Both the anterior and posterior margins are well rounded, with the posterior bigger than the anterior. The marginal costa spirals in towards the posterior from about halfway along the hinge line, and forms a loop sub-parallel to the margin. The costae occurring within this loop are very variable in detail and number. There are usually four, parallel to the ventral margin, and elliptical in shape; they may or may not close at either end. A large elongate pit interrupts the two top costae, and is located slightly nearer the hinge line than the ventral margin, and slightly to the posterior.

Dimensions. Length, 1.3 - 0.8 mm.,
Height, 1 - 0.6 mm.

Distribution. Cementstone Group of Scotland, N. England, and N. Ireland.

Found in abundance at Ballagan at one horizon, at Patna and Dailly, and not so commonly at Heads of Ayr, Cultra, Draperstown, Liddisdale and Brunt Hill Farm, Ravenstondale.

FAMILY KLOEDENELLIDAE. Ulrich & Bassler.

GENUS BEYRICHIOPSIS. Jones & Kirby, 1886.

Beyrichiopsis fimbriata, Jones & Kirby, 1886.

Beyrichiopsis fimbriata	Jones & Kirby, 1886, p. 434, pl. 11, figs. 3-10, pl. 12, fig.5.
" "	Ulrich & Bassler, 1908, p. 323, pl. 43, figs. 22-24.
Beyrichiopsis fortis	Jones & Kirby, 1886, p. 435, pl. 12, fig. 13.
Beyrichiopsis subdentata	Jones & Kirby, 1886, p. 437, pl. 11, figs. 1, 2.

Description. Carapace sub-ovate sub-rectangular, hinge line straight, fairly long, ventral margin convex; the anterior is usually smaller than the posterior. Both the anterior and the posterior margins are well rounded, with the postero-dorsal angle being larger than the antero-dorsal angle. The carapace is lobate, with a broad low lobe in the anterior area, and a smaller more definite post-median lobe near the dorsal margin. This produces quite a deep median sulcus, and al ill defined sulcus behind the post median lobe. On the surface there are one to four flange-like ribs, a marginal one carrying a fringe which is striate posteriorly, but spinose anteriorly. The other ribs are sinuous and variable in height. One often runs near and parallel to the ventral margin, and the others are usually short and cross the dorsal side of the lobes, although in one variety a large dorsal rib joins the ventral rib at the posterior end of the carapace, and forms an open ended loop.

Dimensions. Length, 0.7 - 1.1 mm.
Height, 0.35 - 0.6 mm.

Distribution. Cementstone Group of Scotland, N. England, Cultra, N. Ireland.

Localities in present investigation.

Heads of Ayr (abundant, Cultra (abundant).

Discussion. B. fortis, and B. subdentata are included in B. finbriata because the similarities between them are very great, and there is more variation in the arrangement of the flanges of different specimens of B. finbriata than there is between it and B. fortis and B. subdentata.

GENUS GEISINA. Johnson (1936).

Geisina crateriga. Jones & Kirby (1885).

Beyrichia crateriga Jones & Kirby, 1886, p. 439, pl. 12, fig. 7a, 7b.
" " " " " 1896, p. 186.

Jonesina crateriga Ulrich & Bassler, 1909, p. 324, pl. 44, figs. 13, 14.

Diagnosis. Rather oblong - subovate, reticulate Geisina, with strong median sulcus and poor posterior sulcus.

Description. Carapace subovate - oblong, hinge line straight, although the antero-dorsal margin bulges above it. Ventral margin convex, usually diverging slightly from the hinge line towards the posterior margin. The posterior margin is higher than the anterior and more sharply curved, with the postero-dorsal more obtuse than the antero-dorsal angle. A deep median sulcus extends down from the dorsal margin, and is situated

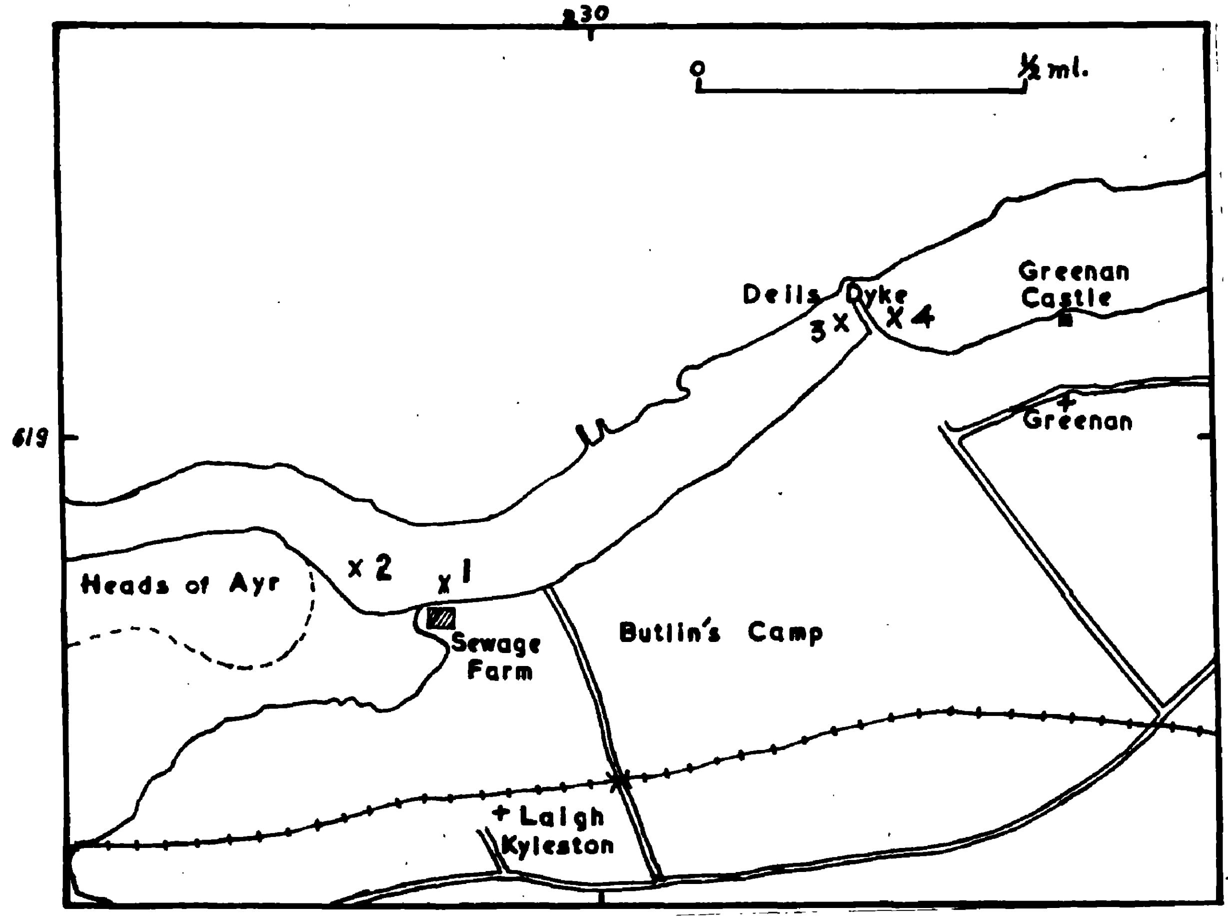


Fig. 35. Ostracod localities on shore near Heads of Ayr.

slightly posterior to the centre. It swings round by the dorsal margin and then down to the posterior margin to form an ill defined posterior sulcus. The anterior lobe is much more tumid than the posterior, thus making the test much wider anteriorly than posteriorly; the surface is coarsely reticulate.

Dimensions. Length, 0.8 - 1 mm.
Height, 0.4 - 0.6 mm.

Distribution. Cementstone Group of Scotland and N. England, the 'solenopora' sub-zone of Ravenstonedale, the Lower Limestone Shales of Forest of Dean, the Lower Limestone Shales of Cultra and Draperstown, N. Ireland.

Ostracod Faunal Lists, (Figs. 36-40).

Localities near base of Heads of Ayr section (1, 2, on Fig. 35).
(See Fig. 36).

Glyptopleura plicata Jones & Kirby.

Glyptopleura spiralis " " "

Beyrichiopsis finbriata " " "

Geisina crateriga " " "

Bythocypris sequalis " " "

Paraparchites okeni Munster.

Paraparchites okeni obliquius Jones & Kirby.

Paraparchites sq. Ulrich & Bassler.

Localities near top of Heads of Ayr section, (3, 4 on Fig. 35.) (See Fig. 36).

Glyptopleura spiralis	Jones & Kirby.
Paraparchites okeni	Münster.
Geisina crateriga	Jones & Kirby.

Patna, Locality Troquhain Wood, (378093) (See Fig. 37.)

Glyptopleura spiralis	Jones & Kirby.
Bythocypris aequalis	" " "
Paraparchites sq.	Ulrich & Bassler.

Dailly, Lindsayston Burn below Cemetary.

Glyptopleura spiralis	Jones & Kirby.
Paraparchites okeni	Münster.

Ballagan.

Glyptopleura spiralis	Jones & Kirby.
Bytho cypris aequalis	" " "
Paraparchites okeni	Münster.

Cultra, Co. Down. (Both to the east and west of the harbour). (See Fig. 38.)

Glyptopleura plicata	Jones & Kirby.
Glyptopleura spiralis	" " "
Beyrichiopsis finbriata	" " "
Geisina crateriga	" " "
Hollinella sp.	Coryell.
Paraparchites okeni	Münster.

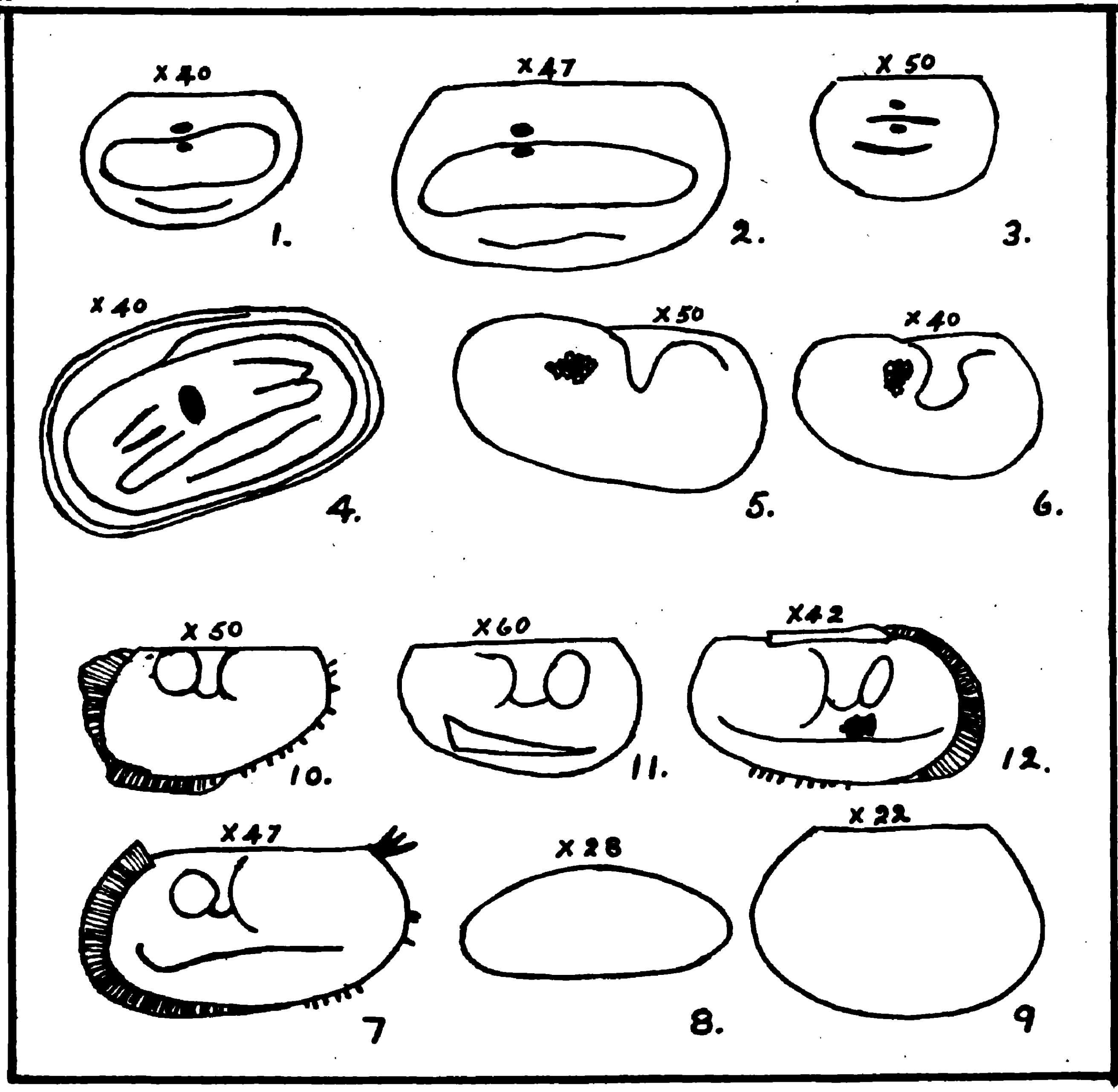


Fig. 36. Ostracod fauna from Heads of Ayr.

1 - 3, *Glyptopleura plicata.*

4. *G. spiralis.*

5 - 6 *Geisina crateriga.*

7, 10 - 12. *Beyrichiopsis fimbriata.*

8. *Bythocypris aequalis.*

9. *Paraparchites okeni.*

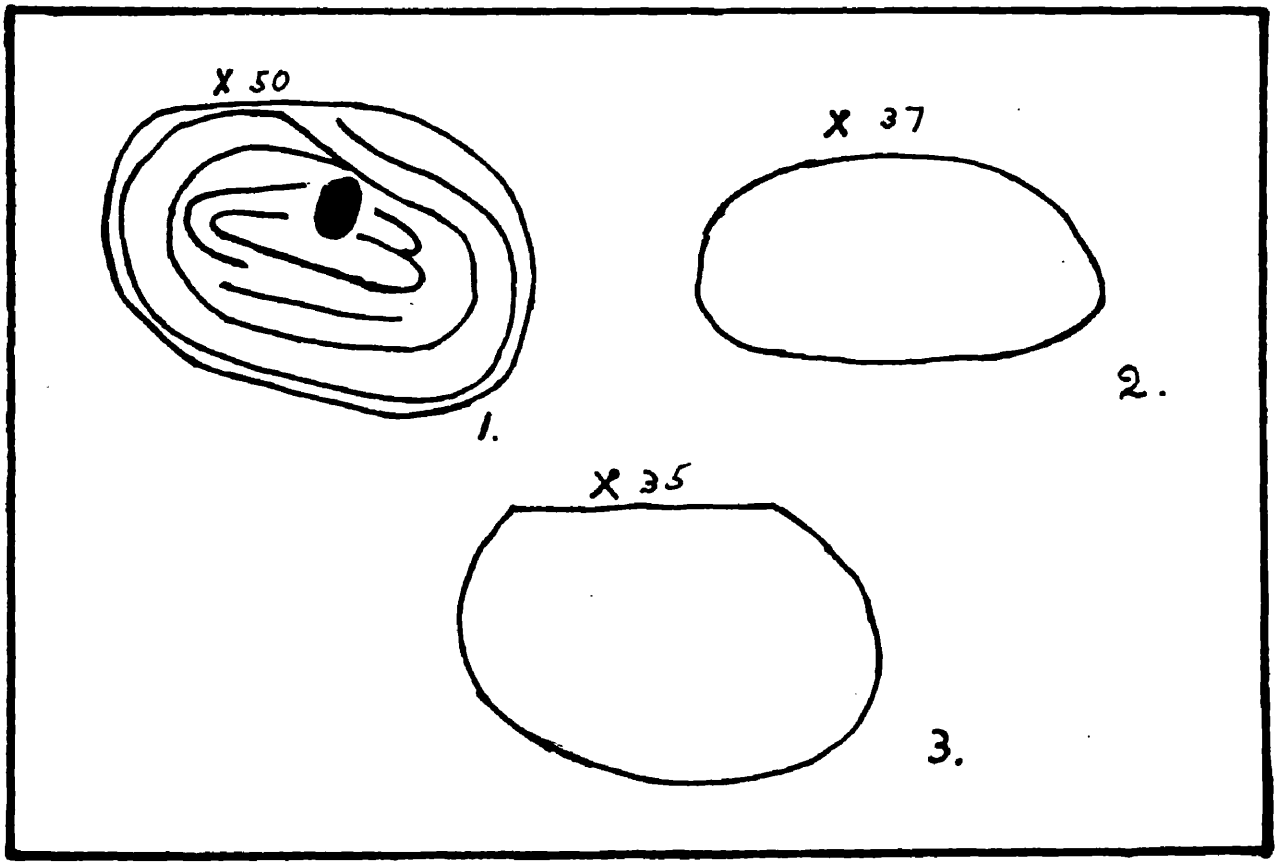


Fig. 37. Ostracod fauna from Patna.

1. *Glyptopleura spiralis.*

2. *Bythocypris aequalis.*

3. *Paraparchites okeni.*

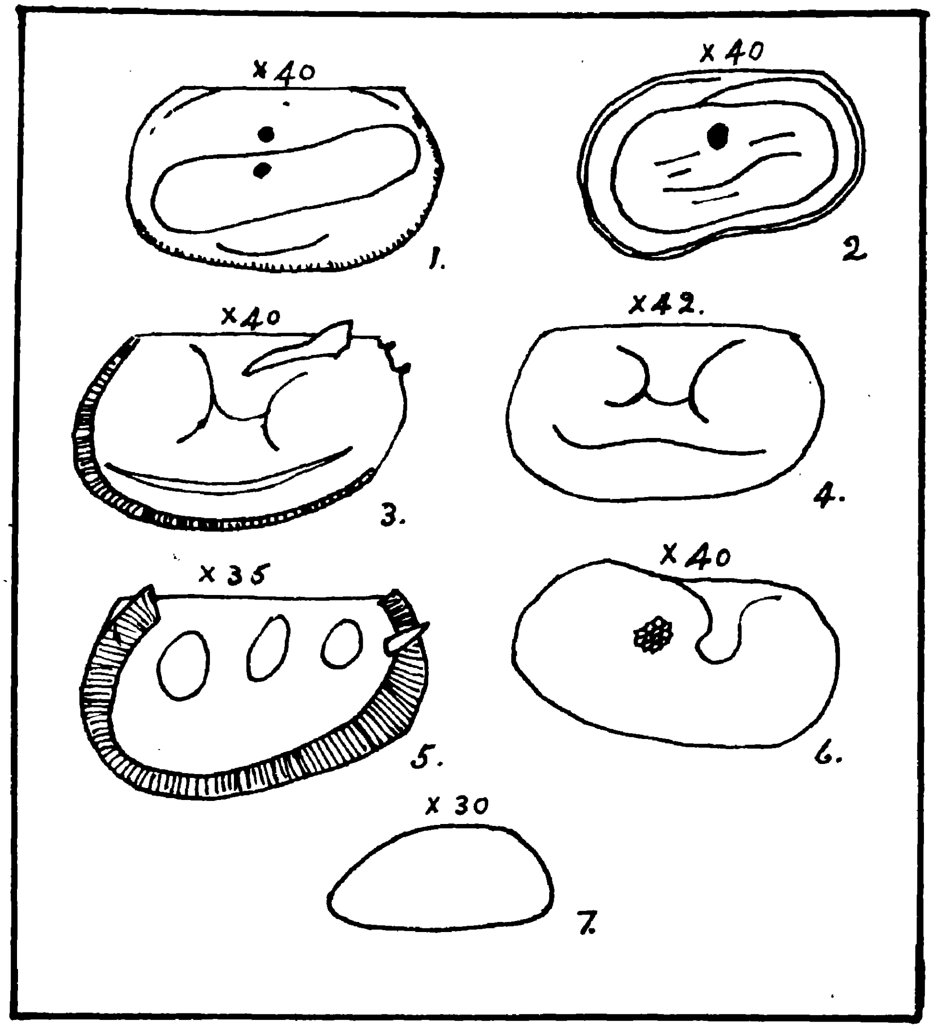


Fig. 38. Ostracod fauna from Co. Down.

1... *Glyptopleura plicata*.

2. *G. spiralis*.

3 - 4. *Beyrichiopsis fimbriata*.

5. *Hollinella sp*.

6. *Geisina crateriga*.

7. *Bythocypris sp*.

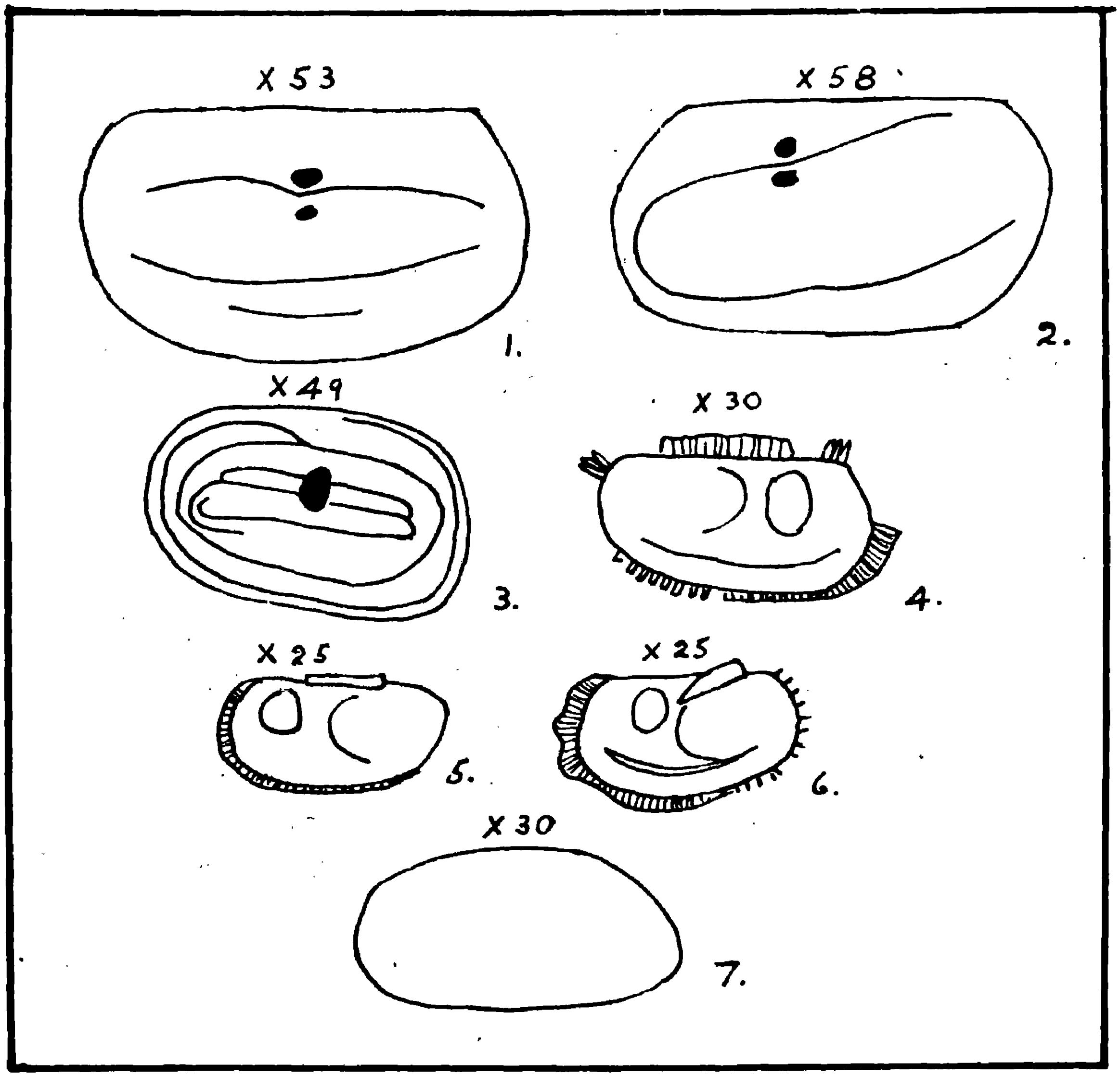


Fig. 39. Ostracod fauna from Northumberland and Liddisdale. (main Algal series and Cementstone Group).

1 - 2. <u>Glyptopleura plicata</u>.

3. <u>G. spiralis</u>.

4 - 6. <u>Beyrichiopsis fimbriata</u>.

7. <u>Bythocypris aequalis</u>.

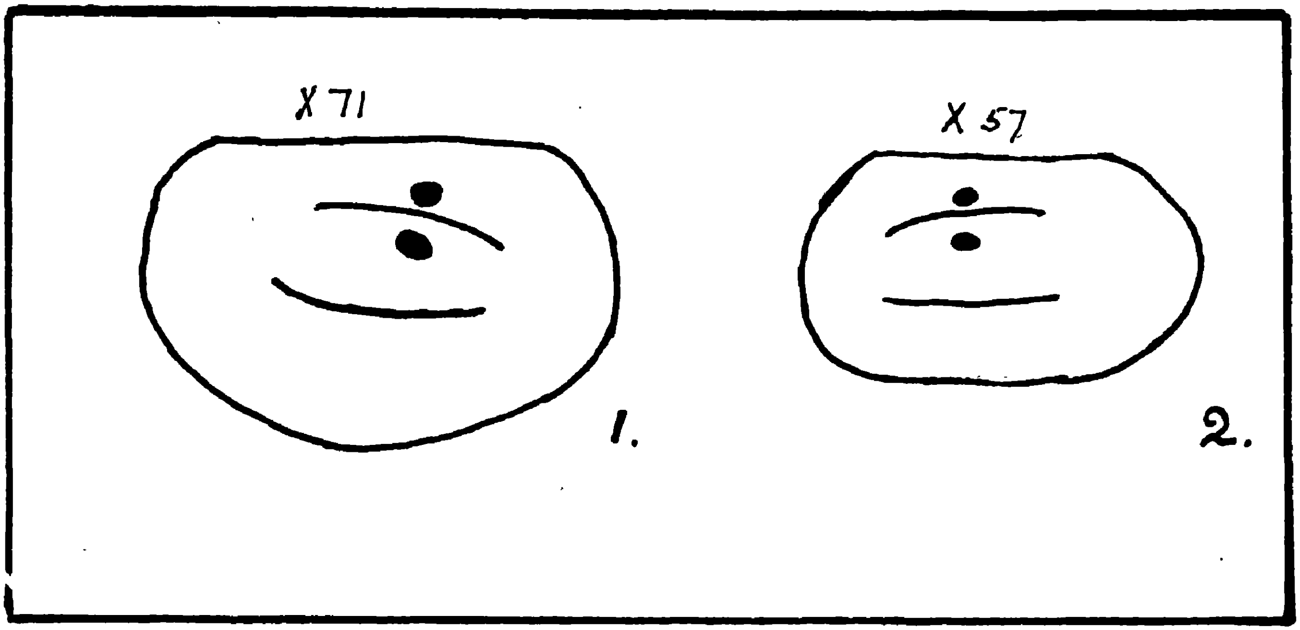


Fig. 40. Glyptopleurids from Lower Limestone shales of the Forest of Dean.

1 - 2. <u>Glyptopleura plicata</u>.

Draperstown, Co. Londonderry. (Altagoan Burn).

Glyptopleura spiralis	Jones & Kirby.
Cytherella valida	" " "

Larriston Burn, Liddisdale. (Main Algal Series and beneath). (See Fig. 39.)

Glyptopleura plicata	Jones & Kirby.
Glyptopleura spiralis	" " "
Paraparchites okeni	Münster.
Bythocypris sp.	Brady.
Cytherella sp.	Jones.

BRACHIOPODA.

FAMILY RYNCHONELLIDAE.

GENUS CAMAROTOECHIA Hall & Clarke.

Camarotoechia sp. nov. (Fig. 41)

Description. Exterior. The shell is triangular in shape, with a semicircular anterior margin. The length is slightly greater than the breadth in the pedicle valve. As all the specimens found were from a shale, and therefore crushed, any plication or sulcation was destroyed. However, from the lack of severe cracking on the surface of the valves, it is probable that any plication or sulcation is extremely small, if present at all. The ribbing varies from brachial to pedicle valve, being between 17 to 24 in number for the brachial valve, and between 13 and 19 for the pedicle valve (see Fig. 41.)

Sections of the brachial valve show a well developed crural cavity containing a median septum. The hinge

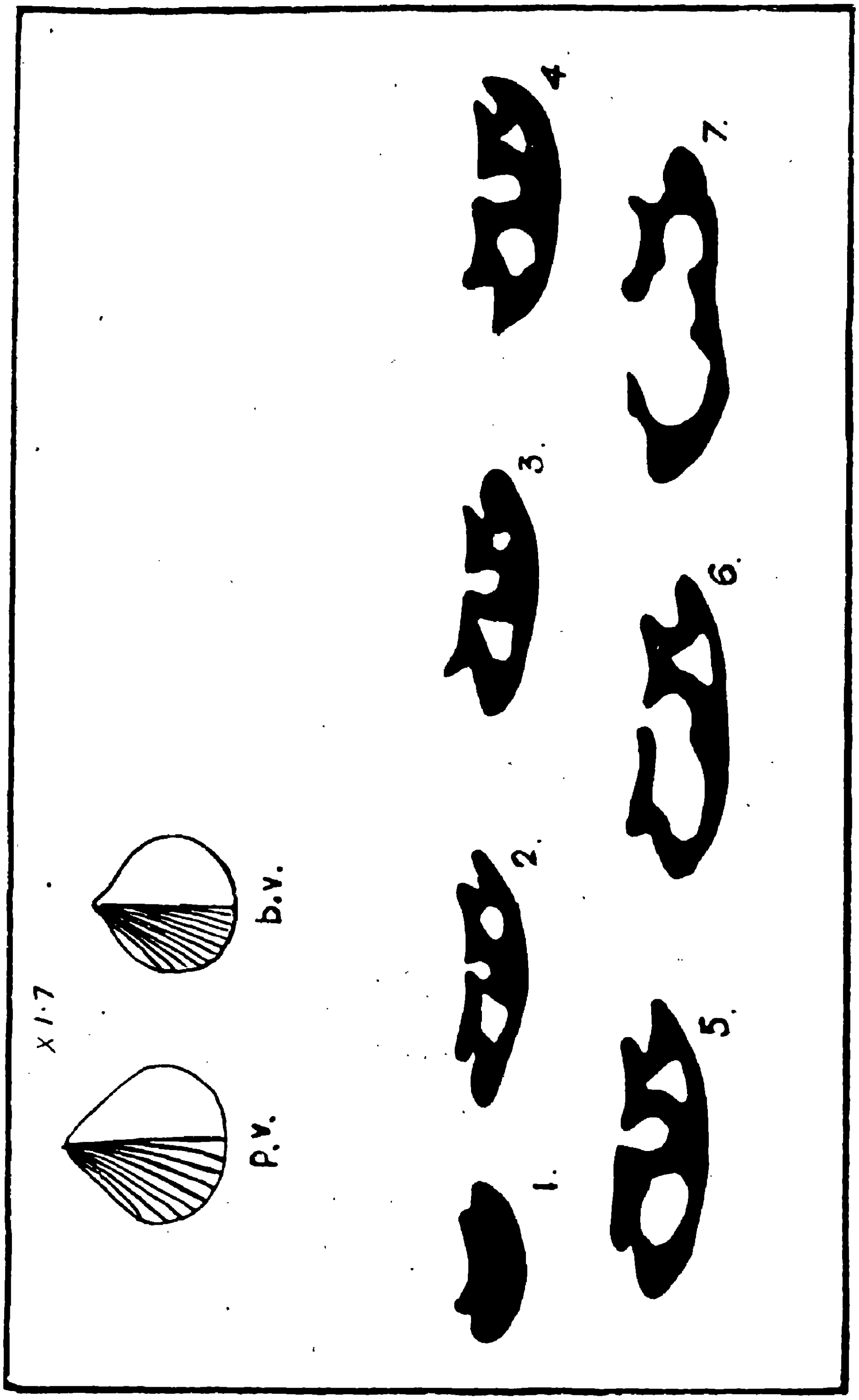


Fig. 41.

Fig. 41. Camarotoechia sp. from locality 1, Fig. 35.

1 - 7. Sections from the umbo of the

brachial valve at 0.3 mm. intervals.

plates are concave, with deep dental sockets under their outside edges; the crural processes are unknown.

Horizon and Locality. Approximately 250 feet above the base of the Cementstone Group. In dark silty ostracodal shales just below the high water mark, adjacent to the sewage farm for Butlin's Camp, Heads of Ayr.

Discussion. This species resembles the form referred to, Camarotoechia proava (Phillips) from Ravenstonedale, (Garwood, 1912, p. 567, Pl. 51, Figs. 1a-1c) in which however there is a higher length/breadth ratio of about 1.1/1, and the number of ribs in each valve is about 22-24.

The specimens of C. proava from Bolland Shales (Davidson 1858-63 p. 111, Pl. 25, Fig. 10) have an even higher length/breadth ratio 1.19/1; the number of ribs on the brachial valve is 24, and the commisure shows a slight to moderate plication.

Palaeoecology. In 3 feet of dolomitic marls, grey shales and layered cementstones (Locality 1 Fig. 35), the faunal content of which is shown in Fig. 42 along with Ca/Mg ratio and Insoluble Residue percentage the distribution of the fossils appears to show significant local concentrations. In the highly dolomitic marls below the silty grey shales, and in the layered cementstones above, there are no fossils. The low Ca/Mg ratio of both suggests a high temperature at the time of deposition (Chilingar 1953, pp. 38-47), and thus possibly a high salinity. The abundance of fossils in the shale

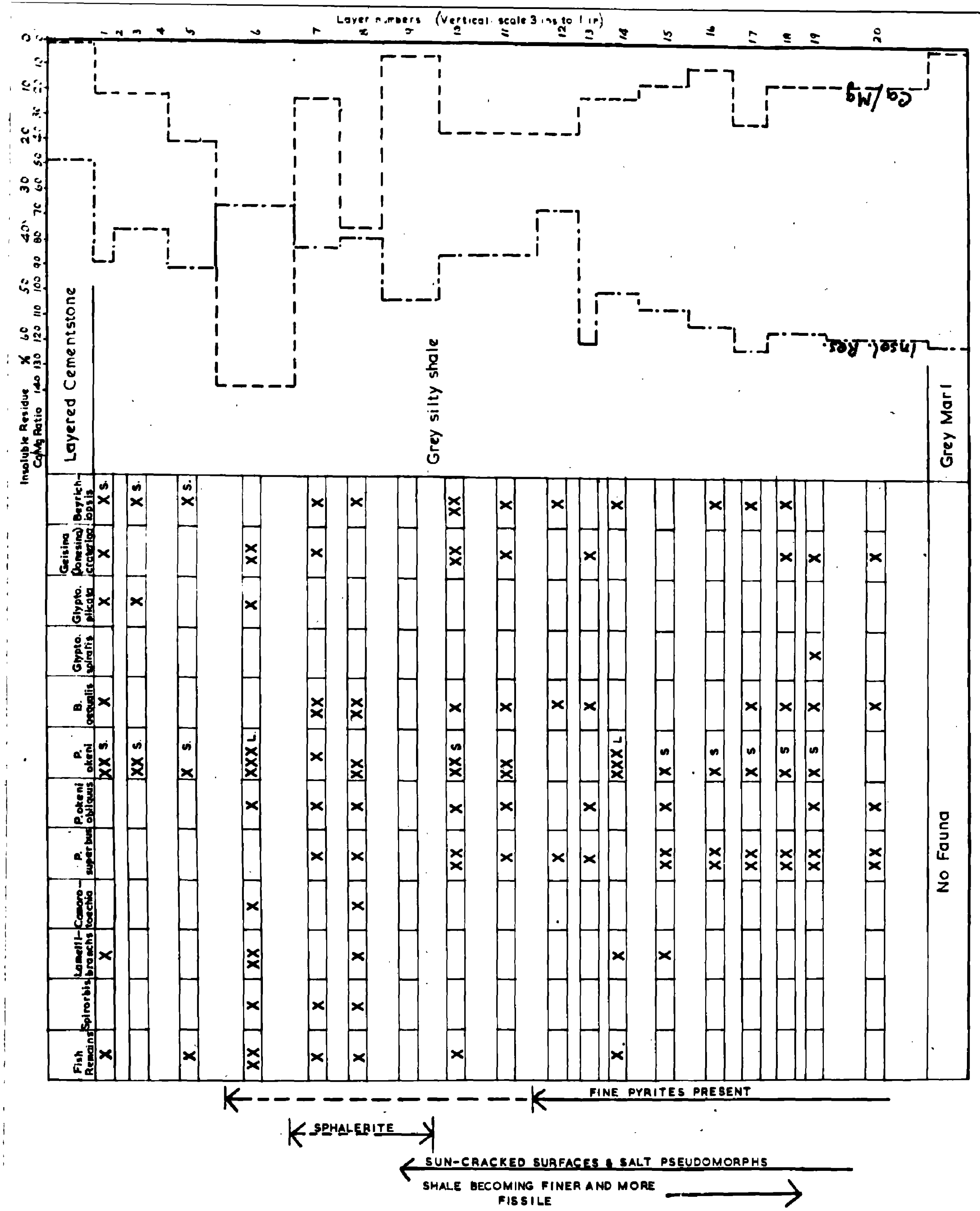


Fig. 42. To show the variation in fauna with change in chemical composition and lithology in a sequence of marl, shale and layered cementstone.

x. present. s. small.

xx. fairly abundant. l. large.

xxx. abundant.

coincides with higher Ca/Mg ratios for the carbonates in the shale, and an increase in the proportion of silt grade insoluble residues, thus inferring lower temperatures, and an increased influx of water respectively. The reduction in salinity consequent on this permitted the establishment of a fauna of estracods, lamellibranchs, and brachiopods.

Within the shale itself changes in the Ca/Mg ratio, and in the petrology, seem to be reflected in the faunal concentrations. In general, the horizons of low Ca/Mg ratio are characterised by an absence of lamellibranchs, brachiopods, spirorbis and fish, and by the dwarfing of such ostracod species that remain. This is particularly noticeable in layer 9, where there is no fauna. Layers such as number 6 are characterised by the presence of brachiopods, lamellibranchs, fish and _spirorbis_, and by large individuals of such species as _Paraparchites okeni_ and _Bythocypris aequalis_. _Beyrichiopsis_ and _Paraparchites_, from their almost continuous presence through the section, seem to be tolerant of the changes in salinity indicated indirectly by the variable Ca/Mg ratio and therefore variable temperature of the water. The suncracking and distorted salt pseudomorphs that are so common in the lower half of the shale, show that for brief periods the salinity must have risen to hypersaline. The ostracods to be found below the sun cracks are small and dwarfed _Beyrichiopsis_ and _Paraparchites_ which are finally absent just below the sun cracks. The cracks themselves contain large Paraparchites and Bythocypris, possibly brought in by the later influx of water of lower salinity. Often associated with these genera is Geisina (Jonesina) crateriga which is thought to have brackish affinities (Kremp 1956, pp. 145-168). There is a noticeable absence of such typical marine genera such as Bairdia. Beyrichiopsis and Paraparchites are commonly found in normal marine limestones, but their presence here associated with hypersaline conditions probably indicates that their salinity tolerance is high. It is therefore possible that within this section salinity conditions varied from hypersaline to brackish.

The Correlation with the North of England, the Borders, and the S. W. Province.

The ostracod faunas figured in Figs. 36-40 show the close similarity in species and varieties of species between the Cementstone Group of the Heads of Ayr, and of Northumberland, and the Main Algal Series and Cementstone Group of Liddisdale, and the Lower Limestone shales of Cultra, Co. Down. Because of this similarity, and because of the occurrence of similar cementstone type lithologies in all of these areas, it is suggested that the Cementstone Group of the Midland Valley is in part equivalent in age to these sediments.

A study of the ostracod species Glyptopleura plicata,

G. scotica Jones & Kirby, G. spinosa Jones & Kirby, and G. costata Jones & Kirby, provides some clues to the age of the Cementstone Group. In this study most of the information relating to these species was supplied by Dr. F. W. Anderson. In a personal communication, Dr. Anderson said that he had noted an evolutionary and stratigraphical sequence, Glyptopleura plicata - Glyptopleura scotica, and a similar sequence G. spinosa - G. costata. In both of these sequences the changes are in the increase in the number and complication of the costae inside the marginal costa.

Thus in the L. Tournaisian, G. plicata is the sole representative of the G. plicata - G. scotica sequence, and it is not until Lower Visean, or uppermost Tournaisian that 'scotica' types begin to appear. These continue on up to the Lower Limestone Group, along with G. plicata. The author collected a fauna of G. plicata from the basal Lower Limestone shales of the Forest of Dean (Bed 2b, Sibly 1937, p. 23). They are all of very simple type, some without the small ventral rib below the loop, and the loop is always open at both ends. These are also quoted from the Gayton boring, Northamptonshire, (Jones & Kirby 1886), and types like them were found in Layer 1, locality 1, Fig. 35, from Heads of Ayr. In the faunas from the Heads of Ayr, Liddisdale and Cultra G. plicata is again the sole representative of G. plicata - G. scotica sequence, no forms with more than a ventral and a loop costa being seen. In general the G. plicata from these last localities seem to show a greater development of the loop than those of the Forest of Dean in more definite costae, and in having the loop closed, often at both ends.

Ostracod faunas sampled by the author from the 'proava' band of Ravenstonedale showed as many examples of G. scotica as of G. plicata. It is therefore possible that the basal beds of Ravenstonedale, which are either Upper Tournaisian or Lower Visean in age are younger than the Cementstone Group of the Heads of Ayr, Cultra and Liddisdale. Dr. Anderson concurs with this suggestion. A tentatively suggested age for the Cementstones on the basis of the ostracods is K or Z zone. This assumes that G. scotica had not yet evolved from the G. plicata stock, rather than that G. scotica was absent from the Midland Valley because of adverse conditions.

A number of samples of carbonaceous limestone and shale containing spores from the Cementstone Group of Sorn and the Heads of Ayr were sent to Dr. Herbert Sullivan of Sheffield University for examination and comment. Dr. Sullivan states (in lit.) that:-

(i) The horizon is certainly below the lower spore zone of Camptotriletes vernicosus of the Coal Board classification, i.e. below S2.

(ii) The absence of Lycospora, Tripartites, and Rotaspora show that it is at least as low as Lower

Visean.

(iii) It is a rather restricted microflora consisting principally of three genera, Punctatis porites, Stenozonotriletes and Archeozonotriletes.

The Latter genus is the most useful stratigraphically, and a tentative identification of the species present show them to be all either Tournaisian or U. Devonian.

(iv) The assemblage has an U. Devonian rather than a Visean aspect.

Dr. Sullivan ends by suggesting provisionally a Middle Tournaisian age for the microflora.

Chapter 5. PALAEOGEOGRAPHY.

The Lower Cementstone Group.

(1) The Geology.

So far as residual evidence indicates, the sediments of the Lower Cementstone Group were deposited exclusively on a floor of U. Old Red Sandstone - mainly outwash-fan sediments - with a hinterland to the north of exposed Dalradian and older metamorphic rocks and Old Red Sandstone, and a hinterland to the south-east of Lower Palaeozoic greywackes and shales.

(2) The Strand Line. (See Fig. 27).

The alignment of this postulated shoreline is based on the signs of current direction, the facies variations, the positions of the residual zero isopach, and the provenance of the pebbles and heavy minerals. From the current directions, and from the heavy minerals suites, it is obvious that a north-east - south-west shoreline lay to the north-west of the Glasgow region, and south of the probable source of the abundant garnets and pink-brown tourmalines, only a few miles to the north-west of the present Highland Boundary Fault. The abundance and relative coarseness of the clastics in Arran and the Cumbrae, and to some extent in the Greenock area, strongly suggests a shoreline very close to the north-west. The sharp change in facies between Dumbarton and Helensburgh from a normal cementstone facies to sandstone and red marls with few cementstones, again indicates an approach to a shoreline.

The southern shoreline is sharply delineated along the line of the Straiton Fault, and the extension of this north-east of Cumnock. Again this shoreline is indicated by current directions, pebbles and heavy minerals, and the presence of the outwash-fan sediments. A shoreline is also indicated immediately north-west of Dailly by the facies and the current directions in the Dalrymple area, and the current directions in the Ayr area. The carbonaceous material and coal (see p.34) in this area indicate a surface varying above and below sea level in the immediate vicinity of Ayr.

North-east from Ayr towards Muirkirk and Coalburn, the basin appears to close. Certainly at Coalburn the thickness is reduced to 100 feet, and the facies indicates the proximity of a shore. Further north-east the Cementstone Group is absent, although the thinning could be due to overstep.

The current directions and facies of the Back Burn area to the north of Muirkirk are highly indicative of a shoreline immediately to the north, at least early during the deposition of the Cementstone Group. From the evidence of the heavy minerals (p.49) it has been suggested that this land mass disappeared later on in the Lower Cementstone Group. Its northern boundary is not easily identified, but ran south of the Campsies where the facies does not suggest that there is a near shoreline to the south.

(3) Geomorphology.

The coarseness of the marginal sediments (see pp.33-38) indicates a topography of low relief of the 'highland' land mass, of the land to the north and east of Muirkirk, and of the area to the south and south-west of Ayr. The extreme coarseness of the clastics in the Dailly Basin, on the contrary, suggests a strong relief of the hinterland to the south-east, with frequent rejuvenation probably caused by movement along the Southern Upland and associated faults, or along the Straiton Fault.

(4) The Environment of Sedimentation.

The sediments of the Lower Cementstone Group were deposited in a comparatively shallow restricted evaporitic basin, the salinity varying from penesaline to brackish; the same conditions occur, possibly frequently, in the marginal regions such as Ayr (p.63), and in the Kilmarnock - Muirkirk area. Brackish conditions occasionally extended to the centre of the slightly deeper basinal areas such as Ballagan, as the occurrence of carbonaceous silts, with ostracods such as *Paraparchites*, *Glyptopleura spiralis* and *Bythocypris aequalis*, indicate.

Along the south margin of the basin a wedge of outwash-fan sediments, spilled down from high ground to the south-east and stretch as far as the Dalrymple area, beyond which, however, they merge into normal sandstones sub-aqueously deposited as at Ayr.

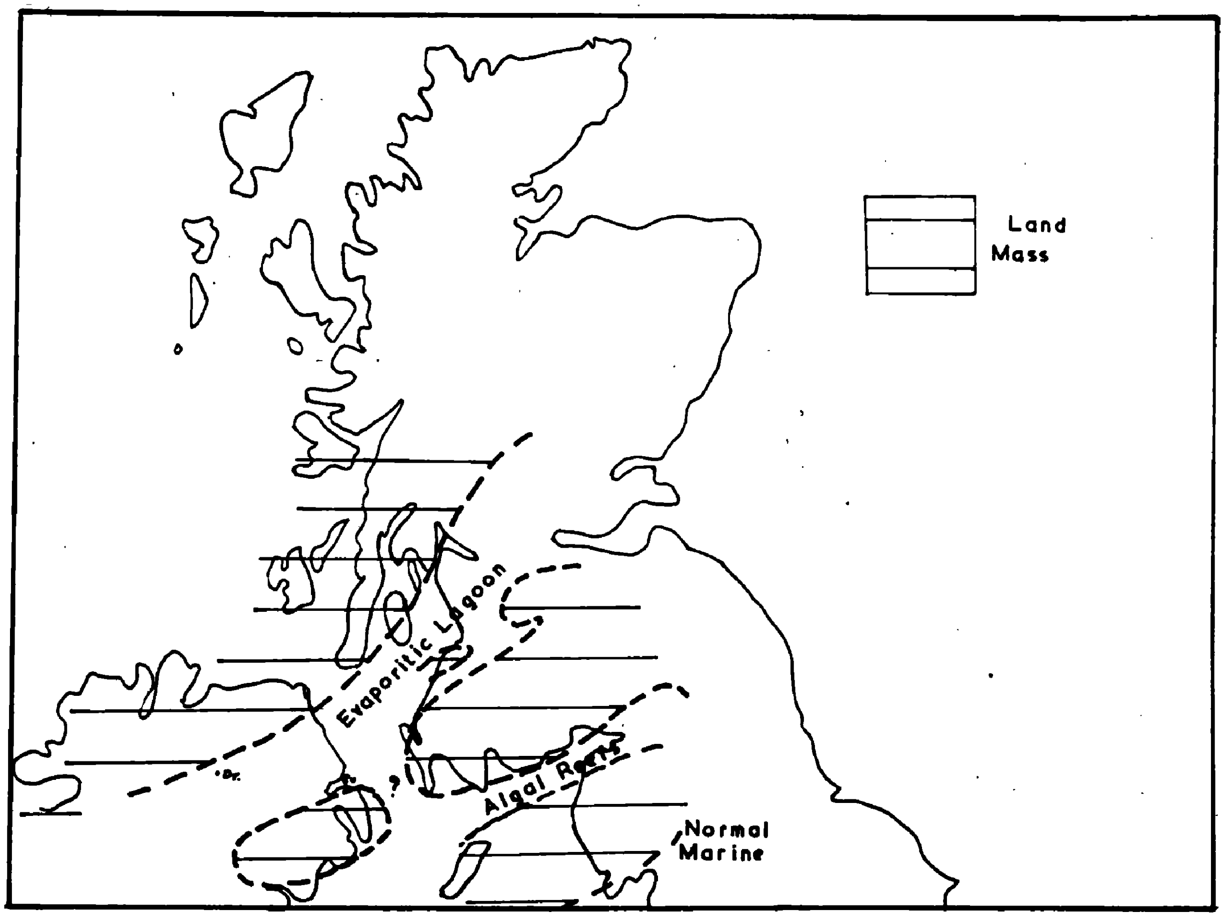


Fig. 43. To show possible palaeogeographical relations of the Midland Valley to Ireland and Northern England during deposition of the Lower Cementstone Group.

On the whole the area with the closest marine faunal affinities is Ayr, which in turn is very similar to Cultra between which it is suggested that there was a direct seaway (see Fig. 43). The connection between the main areas of marine Tournaisian sedimentation may have been either through the area to the south-west of L. Neagh, the sediments forming this connection having been removed by erosion previous to the Visean transgression, or connection may have been through the position of the present North Channel between Larne and Stranraer, and the strong similarity between the faunas of Ayr and Liddisdale suggests some connection between the two areas by this route.

(5) The Climate.

The temperature at the time of the deposition of the L. Cementstone Group was probably high, and the average rainfall low. The presence of the pedocal (cornstones) soils and outwash-fan sediments indicates that rainfall was infrequent but heavy.

The Upper Cementstone Group (Fig. 28).

The quieter sedimentation of the Lower Cementstone Group was terminated by the development of large outwash fans spreading from a rejuvenated hinterland of high relief to the north-west, and another hinterland of high relief to the south-east. The extent of the northerly outwash-fan sediments is lost under the cover of later rocks, but the thickness appears to be diminishing towards the south-east. The similar sediments in the Dailly region seem to thin to the north-west, and grade into micaceous sandstones possibly deposited in lakes existing between the northerly and southerly fans. The widespread occurrence of cornstones similar to those of the U. Old Red Sandstone (Burgess 1961) suggests a continuance of the infrequent heavy rainfall of the Lower Cementstone Group.

Deposition of the Cementstone Group was brought to a close by the tectonic movement which preceded the sub-aerial volcanic activity, and the consequent Visean transgression into the Western Midland Valley.

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ACKNOWLEDGEMENTS

The author wishes to thank Professor T. N. George for his critical reading of the manuscript, and for the invaluable assistance gained in discussion with him. Dr. R. Cummings also was of great help in the preparation of this thesis. The authors thanks are also due to Dr. F. W. Anderson of the Geological Survey for his extensive assistance with the ostracods, and to Dr. H. Sullivan of Sheffield University for his remarks on the spores.

This research was carried out during the tenure of a D.S.I.R. Research Grant.

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