

Letters to the Editors

STRATIGRAPHIC CORRELATION OF THE DALRADIAN ROCKS IN THE SOUTH-WEST HIGHLANDS OF SCOTLAND

SIRS,—I would welcome an opportunity of commenting on Dr J. L. Roberts' paper published in June 1966. In view of the importance of his proposed tentative correlation of the Loch Tay Limestone with the Leny Limestone, it is rather surprising that Dr Roberts did not enlarge on the implications of his correlations and their bearing on the stratigraphy of the Dalradian rocks.

If the correlation of the Loch Tay and Leny Limestones is correct, it follows that:

- (1) the Ben Ledi Grits are, at least in part, the equivalent of the Ben Lui Schists (Crinan Grits/Erins Quartzite),
- (2) the Upper Leny Grits and probably the younger part of the Ben Ledi Grits (those in the core of the Ben Ledi Downbend) are the equivalent of the Pitlochry Schists,
- (3) the Aberfoyle Slates (*sensu stricto*) may be part of the Ben Lawers Schists (Ardrihaig Phyllites); these have hitherto been correlated with the Pitlochry Schists (Shackleton 1958),
- (4) since the Leny Limestone has been assigned to the upper part of the Lower Cambrian (Stubblefield 1956), much if not all of the 'Ben Lui/Ben Ledi Group' must be Lower Cambrian in age, while the Pitlochry Schists must be younger than the upper part of the Lower Cambrian.

The implications (1-4) above involve such a radical change in the stratigraphy of the Dalradian rocks that it is necessary to assess the evidence, both structural and stratigraphical, on which Dr Roberts' conclusions are based.

(a) It has been suggested (p. 217) that since the Ardrishaig/Aberfoyle anticline is an isoclinal fold "it is unlikely that the horizon of the Loch Tay Limestone is folded back on itself before reaching the present level of erosion". While it may be accepted that this structure is an isoclinal fold it cannot be accepted that this implies that the formations involved do not fold back on themselves before reaching any given fortuitous level, such as the present erosion-surface. The presence of the Loch Tay Limestone in those areas where it forms part of the Flat Belt (for example in the Lochearnhead area) does not imply that the Limestone reaches across the Flat Belt to become involved with the rocks of the Southern Dalradian. It is much more likely that the Limestone folds back on itself as shown by Johnstone and Smith (1965; fig. 2A, p. 47) who based their conclusions on extensive observations in the Hydro-Electric Tunnels between Ben Lawers and Loch Earn.

(b) It was stated (p. 215) that the Loch Tay Limestone separates rocks of the graded quartzite affiliation (Crinan Grits/Erins Quartzite-Ben Lui Schists) from younger rocks of the greywacke affiliation. The Loch Tay Limestone cannot be

correlated with the Leny Limestone on this basis since the latter, in the type-locality, separates the Upper and Lower Leny Grits, both of which are of greywacke affiliation.

(c) If the sedimentary affiliations erected by Dr Roberts are to be valuable as stratigraphical indicators they must be consistent over considerable distances both parallel to and across the strike. In this respect the following comments may be relevant:

- (i) If the Leny Limestone is the equivalent of the Loch Tay Limestone the corollary that the Ben Ledi Grits (in part) are equivalent to the Ben Lui Schists (Erins Quartzite/Crinan Grits) must apply. Thus, the Erins Quartzite (graded quartzite) which forms part of the south-east limit of the Ardrishaig/Ra Chreag Anticline, and the Ben Lui Schists which occupy a similar position in respect to the Creag na h'Iolaire Anticline in Perthshire (Sturt 1961), must pass south-eastwards on the lower limb of the Tay Nappe adopting a greywacke affiliation (Ben Ledi Grits) in this direction. Having passed round the nose of the Aberfoyle Anticline (synform) the rocks 'return' north-westwards on the upper limb of the Tay Nappe and become graded quartzite (Crinan Grits) where they form the north-west flank of the Ardrishaig/Ra Chreag Anticline and the envelope of the Loch Awe Syncline.

If this state of affairs does exist, it would suggest that, in the trough of deposition, the two graded quartzites (Erins Quartzite and Crinan Grits) were separated and were the lateral equivalent of rocks of the greywacke affiliation (Ben Ledi Grits and their equivalent along the Highland Border). This in itself would suggest that affiliations could not be used as reliable stratigraphic indicators and also carries the implication that the Erins Quartzite and Crinan Grits were deposited a great distance one from the other, so that their similar affiliation on either limb of the Ardrishaig Anticline would become purely fortuitous.

- (ii) In the Southern Dalradian rocks, those members of the succession having a black slate affiliation appear to have a somewhat limited occurrence, possibly suggesting a sporadic and/or localized development of anaerobic conditions of deposition. For example, Dr Roberts indicates (p. 217) that rocks of the black shale affiliation, common in the Dunoon Phyllites, fail in the pelitic groups north-east of Loch Lomond. Furthermore, it is very likely that the Leny Limestone in the Callander area fails towards the north-west across the axis of the Aberfoyle Synform, since it is not recorded on the northwest limb of that structure. The Leny Limestone is separated by only some 3500 ft of grits from the slates in the core of the Aberfoyle Synform, and it is likely that an equivalent horizon reaches erosion-level in the steeply inclined Ben Ledi Grits to the north-west of the core-rocks.

If a band of the black slate affiliation can fail so readily in, at most, a few miles across the strike, it is unlikely to be useful as a horizon which can be correlated with a 'key horizon' such as the Loch Tay Limestone.

It must be concluded that, although the concept of sedimentary affiliation has proved useful in confirming the correlation of rocks across the axis of the Ardrishaig Anticline in the South-west Highlands, Dr Roberts' attempt to extend correlations across the Cowal Anticline/Ben Ledi Downbend is not valid. The Leny Limestone and similar horizons, such as the Margie Limestone, along the Highland Border represent deposition under anaerobic conditions at a much later stage than that which produced the Loch Tay Limestone.

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SIRS,—In a recent paper in this *Journal*, Roberts (1966) has made a most interesting contribution to the problem of Dalradian correlation across the Tay Nappe (Shackleton 1957, p. 383).

A curious aspect of this problem is that correlation should seem so much more difficult across the Cowal Antiform than across the Ardrishaig (Ra Chreag) Anticline. Ease of lithological correlations, such as have to be used in the Dalradian, should decrease with increasing distance; but it is clear from the work of Shackleton (1957, fig. 11) and Roberts (1966, fig. 2) that the successions now exposed south-east of the Cowal Antiform must, at the time of deposition, have occupied an area intermediate between those on the limbs of the Ardrishaig Anticline. The difficulty of correlation is largely due to the virtual absence of the distinctive Loch Tay Limestone in the areas south-east of the Cowal Antiform.

An examination of sedimentary affiliations has now led Roberts to suggest that that Leny Limestone and part of the Dunoon Phyllites may be the south-eastern equivalents of the Loch Tay Limestone. The Leny Limestone is thin and discontinuous, possibly due to its behaviour as a movement horizon (Stone 1957,

p. 269). It may be that the differences which now appear between the successions on either side of the Cowal Antiform are largely the result of tectonic and, perhaps metamorphic effects.

The importance of the suggested correlation is that it carries with it the late Lower Cambrian age of the Leny Limestone (Stubblefield 1956, p. 29). If the Loch Tay Limestone, at the base of the Upper Dalradian (Knill 1963, Table 1) is late Lower Cambrian, then the Lower Cambrian should extend well down into the Middle Dalradian. This is consistent with a Lower Cambrian age for the Dolomitic Group of Islay, suggested by the remarkable similarity between this group and the Lower Cambrian Pipe Rock and Fucoïd Beds of North-western Scotland (Peach and Horne 1930, pp. 213, 214). Indeed a case might be made out for taking the Portaskaig Boulder Bed (Kilburn *et al.* 1965) as the base of the Cambrian, thus including the whole of the Middle and Upper Dalradian in the Cambrian. This would be in line with Spjeldnaes' (1959) suggestion that the Moelv Tillite should be taken as the base of the Cambrian in Southern Norway.

More Dalradian fossils are needed. Attempts by the writer to extract fossil micro-plankton from Dalradian and Highland Border Series slates have so far produced no results.

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SIRS,—The tentative correlation between the Loch Tay Limestone and the Leny Limestone put forward in a recent paper (Roberts 1966) was intended, as a working hypothesis, to be simply a basis of discussion. I therefore welcome the comments of Dr A. L. Harris and Dr W. A. Cummins on this matter.

In attempting any correlation across the Cowal Antiform the first and most

important decision to be made is the structural one of whether or not the horizon of the Loch Tay Limestone is present south-east of the Cowal-Loch Tay flat belt in the Highland Border steep belt of the Southern Dalradian. Dr Harris argues that, although the Ardrishaig-Aberfoyle Anticline can be accepted as an isoclinal fold, this fact does not indicate that any given horizon such as the Loch Tay Limestone reaches a purely fortuitous level, such as the present land surface in the Highland Border steep belt, before being folded back on itself by the Aberfoyle Anticline. This argument, however, ignores not only the now well-established correlation between the Loch Tay Limestone and the Tayvallich Limestone but also the variations in thickness of the stratigraphic formations in the Dalradian, as detailed in the original paper. Thus, in the South-west Highlands it can be estimated that the Ardrishaig-Aberfoyle Anticline must gape by more than $15-20^\circ$ if the horizon of the Loch Tay Limestone is not to be folded back on itself before reaching the present level of erosion in the Southern Dalradian. However, the available evidence indicates that the Ardrishaig-Aberfoyle Anticline is a tighter fold than this since:

1. ss and s_1 are apparently parallel to one another throughout the Loch Tay Inversion.
2. There is no evidence of sufficient f_1 folding on a minor scale throughout the Loch Tay Inversion which could account for the major Aberfoyle Anticline having a gape of $15-20^\circ$ despite the parallelism of ss and s_1 on the limbs of minor f_1 folds.
3. Where the axial trace of the Aberfoyle Anticline crosses the eastern shore of Loch Long near Kilcreggan the limbs of this major fold are seen to be parallel to one another (see also Harris 1962).

Thus it would appear that the horizon of the Loch Tay Limestone does reach the present level of erosion of the Southern Dalradian. Although it is not impossible that the Leny Limestone has been removed from the succession on the north-west limb of the Aberfoyle Anticline by local sliding, as suggested by Dr Cummins, structural and metamorphic effects are very unlikely to have resulted in the marked differences shown by the successions on either limb of the Cowal Antiform, since these are essentially reflected in the non-appearance of rocks belonging to the graded quartzite affiliation in the core of the Aberfoyle Anticline.

The above arguments are very strongly supported by the fact that Clough (1897) postulated the presence of the Carrick Castle Fold in the Southern Dalradian in order to account for the marked differences in the formation thickness of the Ben Bheula Schists on either limb of the Cowal Antiform, and thus for the non-appearance of the Loch Tay Limestone in the Southern Dalradian. Since the existence of the Carrick Castle Fold has now been disproved (Shackleton 1958) it follows that the horizon of the Loch Tay Limestone must crop out in the Southern Dalradian. Alternative interpretations, which are not supported by the evidence

available, require very marked differences either in original thicknesses or in deformation intensities for the Ben Bheula Schists now on either limb of the Cowal Antiform. A further interpretation, that the f_2 folding affecting the rocks on the south-east limb of the Cowal Antiform results in a 'faltenspiegel' for the primary banding (s_0 and s_1 only) which dips too shallowly south-east for the horizon of the Loch Tay Limestone to reach the present level of erosion in the Southern Dalradian, would require more equant f_2 folds than are actually observed in these rocks.

Thus the argument put forward by Dr Harris that the Loch Tay Limestone is folded back on itself before reaching ground level in the Southern Dalradian can be rejected on structural grounds. However, Dr Harris supports this interpretation by reference to Johnstone and Smith (1965, pp. 47, fig. 2a) "who based their conclusions on extensive observations in the Hydro-Electric Tunnels between Ben Lawers and Loch Earn". On examining the figure referred to, it is rather surprising to find that the Loch Tay Limestone is shown as folded back on itself by the Aberfoyle Anticline *above* the present level of erosion. As far as I am aware, there is no actual field evidence from anywhere in the Cowal-Loch Tay flat belt to support such a subjective interpretation.

On sedimentological grounds Dr Harris argues that the Lower Leny grits of greywacke affiliation cannot be correlated with formations stratigraphically underlying the Loch Tay Limestone since the latter belong to the graded quartzite affiliation. However, this argument neglects two important facts which are closely related. Both were discussed in the original paper. Firstly, the differences between these two affiliations (greywacke and graded quartzite), appear to reflect whether or not detrital material of basic volcanic origin was available for inclusion in the turbidity currents depositing the psammitic members of the two affiliations. Thus, there are no great differences envisaged between these two affiliations and, as I pointed out in the original paper, they can be termed sub-affiliations (as related components of a general turbidite affiliation). Secondly, it is not entirely true that the Loch Tay Limestone separates older rocks of graded quartzite affiliation from younger rocks of greywacke affiliation. For example, in the South-west Highlands, members of the greywacke affiliation are locally but widely distributed within the Ardrishaig Phyllites, the Garnetiferous Mica-Schists, the Erins Quartzite and the Stonefield Schists, and in such cases are often associated with green bed material. Thus, there is evidence that rocks of the greywacke affiliation, such as the Lower Leny Grits on the proposed correlation, could have been formed before the deposition of the Loch Tay Limestone if basic volcanic detritus was available for sedimentation. That such volcanic material was available at that time is evident from the local development of green beds stratigraphically below the Loch Tay Limestone, and from the common presence of the Farragon or Transition Group lying between the Ben Lawers Schists and the Ben Lui Schists in Central Perthshire (Sturt 1961; Johnstone and Smith 1965).

However this sedimentological problem can be considered from a more general stratigraphic viewpoint since Dr Harris bases his third line of argument against the proposed correlation on the fact that "if the sedimentary affiliations . . . are to be valuable as stratigraphic indicators they must be consistent over considerable distances both parallel to and across the strike". As Dr Harris correctly points out, neither the Lower Leny Grits of greywacke affiliation nor many of the horizons in the Middle and Upper Dalradian belonging to the Black Slate affiliation satisfy this condition—the former on the proposed correlation must merge laterally with formations belonging to the graded quartzite affiliation while the latter are often seen to wedge out both along and across the strike. Dr Harris, therefore, contrasts the use of the sedimentary affiliations in stratigraphic correlation with that of 'key horizons' such as the Loch Tay Limestone. However, even the Loch Tay Limestone only preserves its lithological character along the strike in a specific structural position. Across the strike, if the now well-established correlation of this formation with the Tayvallich Group of Black Slates and Limestones is accepted, its lithological character changes considerably. Thus, 'key horizons' in the Dalradian would only be expected if there was originally an extensive and uniform area of sedimentation. From the facies changes described, not only in the paper under discussion from those Middle Dalradian rocks younger than the Easdale Slates in the South-west Highlands, but also by Harris (1962) and others from the Southern Dalradian, it is evident that this was not so. Thus it would be entirely possible for psammitic rocks belonging to the greywacke affiliation to be laid down between rocks of the graded quartzite affiliation if they were not deposited by turbidity currents flowing either in the same direction from the same source of detrital material or along the same local trough of sedimentation. Likewise, the wedging out of horizons of Black Slate affiliation can be accounted for by local warps in the sedimentation surface due to differential subsidence and sedimentation. In such a complex area of sedimentation as the Dalradian the use of 'key horizons' in stratigraphic correlation is manifestly mistaken except where such horizons can be traced in the field. In putting forward the concept of sedimentary affiliations I have attempted to place problems of stratigraphic correlation in rocks which evidently show rapid facies variations both parallel and perpendicular to the strike on a more rational foundation. It is not necessary that individual sedimentary affiliations should have a considerable lateral extent, as Dr Harris states, since by definition they must extend further than the individual members, including 'key horizons,' belonging to the affiliations. Thus, the use of sedimentary affiliations in stratigraphic correlation must be justified. Admittedly, in the present case the structural evidence outlined above raises considerable difficulties in correlation across the Cowal Antiform and these difficulties were first pointed out by Clough (1897). I have attempted to resolve these difficulties not by a structural interpretation which would be almost impossible to sustain in

the light of present knowledge but by a stratigraphic solution which is somewhat more credible and thus, perhaps, the lesser of two evils.

Finally, as Dr Harris considers that the proposed correlation " involves such a radical change in the stratigraphy of the Dalradian " I will discuss some of the stratigraphic implications that I would draw from the proposed correlation.

1. The horizon of the Leny Limestone divides the Ben Ledi Grits into upper and lower groups. From the facies changes recorded by Stone (1957), Shackleton (1958) and Harris (1962) across the axial trace of the Aberfoyle Anticline, it is unlikely that we can consider the Lower Leny Grits to be the exact equivalents of the Lower Ben Ledi Grits. Instead I would consider the Aberfoyle Slates, the Lower Leny Grits, and the Lower Ben Ledi Grits to be all parts of a single stratigraphic time-unit. This stratigraphic unit is likely to be equivalent to the Ben Lui Schists. It is unlikely that the Aberfoyle Slates can be correlated, even in part, with the Ben Lawers Schists. This is so because the latter group is older than the Farragon or Transition Group in which green beds were strongly developed for the first time in the sedimentation history of the Dalradian. It is possible that basic volcanic activity associated with this group contributed to the formation of greywackes rather than graded quartzites in the Aberfoyle Slates, the Lower Leny Grits and the Lower Ben Ledi Grits.

2. The Upper Ben Ledi Grits, i.e. that part of the Ben Ledi Grits younger than the Leny Limestone, are the stratigraphic equivalents of the Pitlochry Schists. This interpretation is supported by the structural work of Johnstone and Smith (1965) concerning the relations of the Ben Ledi Grits in the Highland Border steep belt to those rocks in the Loch Tay flat belt north-west of the axial trace of the Ben Ledi Antiform. They consider, from actual evidence obtained in the tunnels mentioned by Dr Harris, that the main horizon of green beds, a horizon which is younger than the Pitlochry Schists, either wedges out completely within a few hundred yards across the axial trace of the Ben Ledi Antiform or is downfolded by the Ben Ledi Antiform so that it does not crop out in the Highland Border steep belt. On the structural evidence which they describe, it is clear that the latter interpretation is to be preferred, unless the actual structure is more complex than at present realised. On this structural interpretation the Pitlochry Schists would be equivalent to part of the Ben Ledi Grits. On the views that I have put forward, this indicates that the Pitlochry Schists are equivalent to the Upper Ben Ledi Grits.

While the correlations discussed above do constitute a change in the interpretation in Dalradian stratigraphy it must be realised that the previously maintained correlation of the Pitlochry Schists with the Aberfoyle Slates across the Loch Tay Inversion (Shackleton 1958; and others) was never founded on very strong evidence. This has become increasingly apparent as the instances of lateral facies changes from pelitic to psammitic formations multiply in the Dalradian. Moreover, the proposed correlations only involve moving the horizon of the

Leny Limestone downwards by some 3 km as represented by the Lower Leny Grits and the Aberfoyle Slates. In view of the very great thickness of the Dalradian system as a whole, it cannot be admitted that this consists in such a radical revision of Dalradian stratigraphy as maintained by Dr Harris. Even on the correlation defended by Dr Harris, much if not all of the Upper Dalradian must be Cambrian in age. The proposed correlation only lowers the base of the Cambrian *definitely* into the Middle Dalradian. If, as Dr Cummins points out, the correlation of the Dolomite Group in the basal Middle Dalradian of Islay with the Pipe Rock and Fucoïd Beds of the basal Cambro-Ordovician sequence in the North-west Highlands is correct, then the base of the Cambrian must be near, if not at, the Lower-Middle Dalradian boundary, thus strengthening the proposed correlation between the Leny Limestone and the Loch Tay Limestone at a higher level in the Dalradian sequence. In the light of recent work on the age of Dalradian deformation and metamorphism, such a revised stratigraphy does not appear to be unreasonable.

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