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SIR,—May I thank Messrs Black, Bulman, Hey and Hughes for their most valuable comments on the paleontology of the Abereiddy Bay area. My own interest in the geology of the area was primarily structural and my fossil collecting was relatively minimal.

The quoted paleontological evidence for the age of the beds in the Porth-gain quarry prompts a modified interpretation of the structure which I cannot refute.

At Abereiddy the structural evidence was adequate to show that Cox was, at least in part, incorrect over his correlations of the *Dicranograptus* shale and the Castell Limestone. I had suspected, but, lacking adequate knowledge of the geology in adjacent areas, could not prove, that the *Dicranograptus* and Hendre Shales did not correlate, as suggested by Cox. The paleontological evidence is sufficiently conclusive.

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## Phases of deformation in North Wales

SIR,—In a recent paper, Dr B. T. D. Lynas (Geol. Mag. **107,** 1970, 505–510) proposed that the low angle slaty cleavage developed in pelitic rocks on the northern flanks of the Harlech Dome (North Wales) is a pre-Caledonian structure. He suggested that it was produced by near vertical compression stresses induced as a result of magmatic uplift of the Harlech Dome in mid-Caradocian times. I believe this hypothesis to be untenable for the following reasons.

1. Between Blaenau Ffestiniog and Dolwyddelan, in the area to the west and northwest of that described by Dr. Lynas, the low angle cleavage characteristic of the Ffestiniog Slate Belt (S1 of Lynas) gradually steepens in dip and swings in strike until it becomes axial planar to the Dolwyddelan syncline. The latter structure is considered by most authors (e.g. Williams & Bulman, 1931, 452–453; Shackleton, 1954) to be of Caledonian age. Nowhere, in open sections between Ffestiniog and Dolwyddelan, is there any evidence that the low angle slaty cleavage either dies out away from the

Harlech Dome or that it is overprinted by the Caledonian slaty cleavage of Snowdonia.

2. Dr Lynas, citing Maxwell's (1962) explanation for the development of cleavage in the Martinsburg Slate, suggested that the process by which the low angle cleavage was produced was one of '. . . rotation of clay minerals (in unconsolidated sediments) together with a subordinate component of concentric shear. . . both these processes being directly due to near vertical compressive stress . . .'. While rotation of platy minerals during dewatering may induce cleavage in clay sediments and while a 'subordinate component of concentric shear' may be invoked to account for cleavage in the margins of basic sills it fails to explain why the low angle cleavage is present in a wide variety of both extrusive and intrusive igneous rocks and in pelitic and semipelitic hornfelses which were undoubtedly thoroughly crystalline before that cleavage was imposed. For example, in the extensive contact aureole of the Tan-y-Grisiau microgranite, emplaced into Tremadocian and Upper Cambrian rocks which outcrop to the west of the area described by Dr Lynas, metamorphic spots in pelitic and semipelitic hornfelses are strongly flattened in the plane of the low angle cleavage and are elongated parallel with the cleavage dip (Bromley, 1970a, 389–90). The total volume of hornfelses around the Tan-y-Grisiau microgranite must have been many cubic kilometres and except in closest proximity to the igneous contact the hornfelses are always strongly deformed. It is difficult to envisage how such a large volume of crystalline rocks could take up cleavage by the processes outlined by Dr Lynas. Furthermore, it has been proposed by the author (Bromley, 1970a, 1970b) and Rast (1970) that the Tan-y-Grisiau microgranite and other similar intrusions in Snowdonia represent portions of the magma responsible for mid-Caradocian doming which broke through to high level immediately before the onset of surface volcanism. If Dr Lynas's hypothesis for the origin of the low angle cleavage is correct it is difficult to imagine why portions of the magma broke through to high crustal level before the low angle cleavage was generated. If on the other hand the rise of a proto-Harlech Dome was related to earlier volcanism (volcanic rocks of Arenig, Llanvirn and Lower Caradoc age are widespread on the flanks of the Harlech Dome while those of Middle-Upper Caradoc age are poorly represented) it is inconceivable that the low angle cleavage should be impressed upon Caradocian rocks above the volcanic horizons. Dr Lynas's map suggests that he has traced the low angle cleavage in rocks far above the base of the Nant Hir Shales.

Mid-Caradocian volcanic doming in central Snowdonia has been recognised with reference to the distribution of environmental volcanic facies, the distribution and magnitude of pre- and intra-volcanic unconformities and relationships between intrusive and extrusive events in addition to the discovery of more or less circular structures of undoubted pre-Caledonian age (Bromley, 1970a; Rast, 1970). While it is possible that volcanic doming may induce cleavage no such structure has been identified in Snowdonia. Beavon (1963, 506), in describing the crestal region of the Snowdonian volcanic dome noted that '. . . although the folds above and below the unconformity (at the crest of the eroded dome) are disharmonic, they appear to share the same axial planar cleavage'. The cleavage to which Beavon refers is the Caledonian slaty cleavage (S1 of Helm, Roberts & Simpson, 1963).

3. Dr Lynas equates a NNE–SSW lineation (S2 of Lynas) with the powerful slaty cleavage of Snowdonia (S1 of Helm et al). The lineation described by Lynas sometimes develops into a penetrative, vertical cleavage (for example in Tremadocian rocks immediately south of Blaenau Ffestiniog). This cleavage is axial planar to a series of northerly plunging NNE–SSW major folds developed on the northern flanks of the Harlech Dome. In the Ffestiniog area these folds affect both the low angle slaty cleavage and the great thrusts which extend from Portmadoc to the neighbourhood of Blaenau Ffestiniog (Fearnsides & Davies, 1944; Shackleton, 1954). They may perhaps be equated with the almost N–S trending periclinal folds which characterise the more central regions of the Harlech Dome (Matley & Wilson, 1946). What is certain is that they and the associated cleavage die out northwards in the ground between Ffestiniog and Dolwyddelan. The more or less N–S pillaring joints, equated by Dr Lynas with the NNE–SSW lineation, are, however, known from the slate quarries of Dolwyddelan and for that matter from the Cambrian Slate Belt as well (Morris & Fearnsides, 1926).

Neither these folds nor the associated cleavage and lineations can be equated, therefore, with the F1 folding and slaty cleavage of Snowdonia.

While it is possible to recognise polyphase deformation in lower Palaeozoic rocks in almost all parts of North Wales it has, as yet, been described in detail only from restricted and widely separated areas. The powerful slaty cleavage, however, is the most easily recognised and well-documented structure. Though its complex distribution is not completely understood there seems little doubt that it has been generated by a single, major tectonic event. Shackleton (1954, 273) notes that '. . . these structures (cleavage) really curve smoothly from one direction to the other. . . . The pattern cannot be interpreted as due to the combination of two independent sets of structures, one later than the other. . .'. Later deformations (F2, F3 of Helm et al; F2, F3, F4 of Lynas) are much less intense and are usually only recognised in relatively incompetent rocks. Moreover, they appear to be confined to somewhat restricted areas or even to particular stratigraphic units. Until much larger areas have received detailed structural examination it seems premature to attempt widespread correlation of minor deformations.

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