CORRESPONDENCE

THE LOWER CARBONIFEROUS LIMESTONE KNOLLS, CLITHEROE, DISTRICT, LANCASHIRE & YORKSHIRE

SIR,—I should like to comment on Dr. D. Parkinson's recent article (1967, pp. 372–389) in which he puts forward modified views concerning the origin of knoll limestones and reinterprets new evidence presented by Earp, Magraw, Poole, Land, & Whiteman (1961) in the Clitheroe and Nelson Memoir, and by Whiteman (1954).

(1) Recognition of reef builders : Parkinson (1967) stated that this topic was not discussed in the Memoir. This is incorrect and the reader is referred to Earp *et al.* (1961, pp. 43–48 and 50–63) where the subject is dealt with systematically.

(2) The upstanding nature of the knolls during deposition : Having demonstrated that the knoll biota did not include binding and cementing organisms, and that inter-knoll breccias are absent, we proposed in Whiteman (1954), and in the Memoir, that the knoll limestones accumulated in shoal water as loosely consolidated banks which rose only slightly above the sea bottom, and which passed laterally into the " terrigenous " facies of the Worston Shale Group.

Parkinson (1967) on the other hand postulated that some of the knolls were upstanding hundreds of feet above the sea bottom (implying initial reef rigidity), and he explained the absence of inter-knoll breccias by proposing that the knolls were built up below wave and current base. He postulated also that knoll growth was terminated by emergence (p. 379), so implying uplifts of hundreds of feet in the cases of larger knolls and the existence of faults and folds in the knoll belt to explain differential movement. No such structural associations have been demonstrated.

By analogy with modern reefs and banks (Newell *et al.* 1951, etc.) Parkinson's version appears to be an unlikely explanation. The intense biotic activity required to produce the knoll facies could not have been sustained below wave and current base. The knolls could only have accumulated in shallow, well-lit waters. The absence of inter-knoll breccias demonstrates that they were not true wave-resistant structures like modern or fossil reefs.

(3) Unconformities and differential compaction : Parkinson's version that the knolls in some cases stood hundreds of feet above the surrounding sea bottom requires the presence of large cliff-like unconformities at the sides of the knolls.

Palaeontological evidence is inconclusive here but the field evidence clearly points to a conformable and gradational relationship between the coarse grained knoll and fine grained terrigenous facies (e.g. on the Salt Hill–Bellman Knoll and between the Peach Quarry Limestone and the Knoll facies). Differential compaction, therefore, was an important factor in determining both knoll shapes and dips, and the relationship was not as Parkinson (p. 376) has assumed with calcareous muds compacting alongside " terrigenous " muds. The calcareous muds mentioned in the Memoir in reference to Terzhagi (1940) are those upon which Terzhagi experimented. Cobble-, sand-, silt- and clay-sized particles passed laterally into fine grained terrigenous facies, a point made amply clear in the Memoir.

(4) The tectonic elements in knoll formation : Parkinson (p. 376) mentions structure in the context of regional tilting and minimizes tectonic effects on the knolls. He is incorrect in stating that compressional effects were not noted along the largest knolls east of Worston Village. Limestone and shales adjacent to the upper part of Twiston Knoll (and elsewhere) are highly contorted, vertical and in places overturned.

One of the major points put forward in the Clitheroe and Nelson Memoir is that the great compressional forces of the Variscan orogeny played a large part in determining the relationships between the knolls and the country rock, and the dip variations within the knolls (Earp *et al.* 1961, p. 48).

To minimize the tectonic element as Parkinson has done is wrong, especially as the knoll belt is underlain by the Horrocksford Hall Thrust (displacement about 2,000 ft, 609 m). It is associated to the north with a series of complex compressional structures, and to the east and west with " tear " faults.

Clearly, the knoll limestones acted as competent masses within the Worston Shale Group which, together with the Bowland Shale Group, were sandwiched between the massive Chatburn Limestone Group and the Millstone Grit and were involved in large scale earth movements.

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SIR,—I wish to reply to the points raised by Professor Whiteman.

(1) Recognition of reef builders: My statement that this topic was not discussed refers to my paper and not to the Memoir.

(2) The upstanding of the knolls during deposition: I see no reason to assume, supposing knoll growth was terminated by emergence, that uplifts of hundreds of feet, accompanied by faulting and folding, were necessitated. Little more than a pause in subsidence need have occurred. Any emergence of the knoll would have involved its upper surface only.

A discussion of the knoll biota in relation to wave and current base was outside the scope of my paper. Whiteman's statement that the knolls could only have accumulated in shallow well-lit waters seems to ignore the effects of diagenesis. The known biota constitutes but a small proportion of the rock volume. However, the biotic activity would be expected to be more intense in the higher levels of the reef. The apparent absence of inter-knoll breccias at outcrop does not mean that they did not exist.

(3) Unconformities and differential compaction: I tried to show that submarine cliffs were, in fact, present at Worsaw and Twiston. but that they did not in themselves indicate unconformities. Some slight evidence of unconformity was adduced east of the knoll belt at Ings End.

As evidence of differential compaction influencing knoll shapes and dips, Whiteman refers to the relationship between the Peach Quarry limestone and the Salt Hill-Bellman Knoll. Except that this knoll is made of " reef " limestone its present shape and dips are explicable on a bank hypothesis, but this does not apply to the much thicker knolls east of Worston. As noted in the Memoir, the knoll limestones pass laterally into and are overlain by the calcareous shales of the Worston Shale Group. These large knolls are characterized by pre-tectonic dips of the order of 60 degrees. It is admitted in the Memoir that the angle of repose of the calcareous muds of the knolls may have been as high in places as 30 degrees, but no attempt is made to explain how a dip increase of 30 degrees can be caused by differential compaction. Whiteman's reference to Terzhagi's work explains nothing. Unless he can relate it to the specific problem of the Clitheroe knolls passing laterally into the Worston Shales his whole case, as I see it, falls to the ground, since it is inconceivable that dips as high as 60 degrees can be formed in unconsolidated muds.

A simple treatment can be made to a first approximation of the effects of differential compaction on a straight inclined boundary between two types of sediment, e.g. limestone and shale. The usual assumption is made that the mud in forming shale will compact more than the calcareous sediment.

In Fig. 1 the boundary A B between shale and limestone slopes at an angle B A C $= \alpha$. To the right of the perpendicular B C the limestone surface B E before compression is assumed horizontal. The line G H represents the surface after compaction.

Similarly the original shale surface D F is depressed to J K by compaction.

After compaction the limestone-shale boundary follows the line A G at an angle G A C $= \beta$.

It is evident from the diagram that the angle G K L $= \gamma$ is a measure of the dip assumed by the shales near their contact with the limestone.

It is important to note that G will occupy the same position for any position of K, which means that limestone compaction is independent of shale compaction so long as the contact slope is in the direction shown in Fig. 1. It follows that since β is always less than α compaction cannot increase the angle of slope between shale and limestone. Neither can it increase the angle of outward dip (if any) within the limestone.

In the case of a boundary slope inclined downwards towards the limestone, both the contact angle and the limestone dip will be influenced by the compaction of the shales, as will be evident from a consideration of Fig. 2. After compaction the limestone-shale contact will follow the direction A K G H and the upper surface will be along the line J K G H. The angle of shale compaction γ is now also the angle of dip of the limestone between G and K. Or if the limestone initially had a dip towards the shales this will be increased by the value of the angle γ.

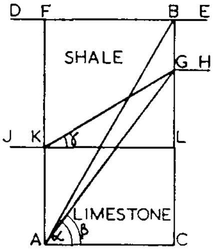

FIG. 1

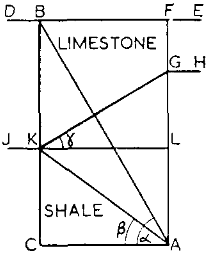

FIG. 2

If a mass of comparatively incompressible limestone (e.g. a rigid structure such as a reef) has a contact angle with the shale pointing towards the limestone it is evident that compaction of the shales will result in the warping down of the limestone near the shale boundary. But the actual volume of limestone in an ideal case will remain unchanged, and therefore the length of the boundary slope should remain constant. This is illustrated in Fig. 3, where the line A C represents the initial slope and B C the slope after compaction of the shales, the extent of which is denoted by the line A D. The triangle A B C is therefore a measure of the volume of limestone formerly occupied

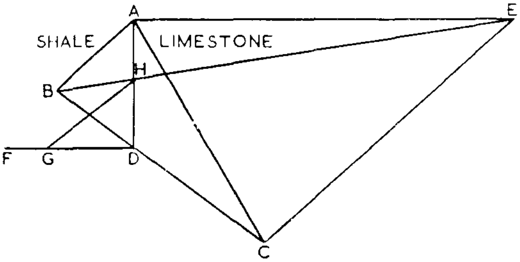

FIG. 3

by shales. If E C is drawn parallel to A B, then triangle A C E = triangle B C E in area, and angle A E B = the angle of acquired or increased dip of limestone. But since the surface of the shales is now along the horizontal line F D the limestone occupying the small triangle B D H would be expected to collapse on the shales and the final surface would follow a line approximating to F G H E and the shale-limestone contact to C D G H E. The point G is not fixed by exact geometrical reasoning.

The map (Memoir, Pl. IV, reproduced in my paper) shows that in a few places the conditions illustrated in Figs. 1 and 2 may have applied. But in general, the boundary slopes of the knolls, except near their bases, point downwards towards the shales and any effects of compaction would be to *decrease* the angles of slope and depositional dip.

(4) The tectonic element in knoll formation : I admit that my statement that compressional effects had not been observed east of Worston was not strictly correct. I ought to have said that such effects were small in comparison to those observed near the Horrocksford Hall Thrust, and can have had no appreciable influence on the dips in the knolls themselves as they had in the case of the Waddow Knoll underlying the thrust plane. As illustrated in the map (Pl. III) and text (p. 48, 54) of the Memoir the knoll limestone has been subjected to intense compressional forces, and the variations in dip direction " are better explained on a structural than a depositional basis ". East of Worston such effects of compression are rarely seen and appear to be confined to the incompetent Worston Shales near their contact with the competent knoll limestones. The best example is seen in the slightly overturned shales and cementstones adjacent to the upper part of Twiston Knoll.

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