

## Comments on Radiolarite and Ophiolite Nappes in the Iranian Zagros Mountains

Sir, In a recent paper presented in this journal (106(5), 385-394) A. J. Wells denied the existence of extensive ophiolite and radiolarite nappes as they have been described by K. W. Gray (1949) in the inner part of the Iranian Zagros mountains near Neyriz lake, East of Shiraz. Wells considers the radiolarites and accompanying formations as a special facies of the Upper Cretaceous, and the fossils, particularly the Triassic and Jurassic ones described by Gray, as reworked, and the ophiolites as a more recent intrusive body metamorphosing Cretaceous and Eocene formations.

My own observations (partly published) support the broad lines of Gray's allochthonist interpretation. The formations containing radiolarites, to which I have given the name "Pichakun formations", outcrop for the most part to the north of Neyriz lake, overlying the autochthonous Sarvak formation (Cenomano-Turonian). A cross-section of these formations shows a total thickness of sediments of over 2,000 m, constituted by the repetition of the same sequence, 400 to 700 m thick, frequently incomplete and sometimes repeated five times on the same vertical. This sequence is made up of four units, i.e. from base to top: (1) black marls; (2) siliceous, oolitic and microbreccic limestones; (3) radiolarites; (4) conglomeratic limestones. In an autochthonist interpretation this kind of repetition would involve a cyclic sedimentation of a complex and hitherto unknown type. A tectonic interpretation, in which this disposition is explained by the piling up of nappes showing the same sequence, is more appropriate and can also be proved by geometric and palaeontological considerations.

Mapping at a scale of 1/50 000 shows these nappes truncating each other and truncated along the line of contact with the underlying Sarvak formation. This disposition can be seen on a good print of the Gemini photograph accompanying Wells' article. Moreover some of these nappes change at their front into an overturned anticline whose inverted limb rests on the normally dipping lower nappe; polarity of the beds is well expressed by graded-bedding.

Fossils of different ages occur in these formations, but fossils of the same age are always in the same beds, respectively: Upper Triassic fossils in the black limestones associated with the marls of unit 1; Jurassic fossils in unit 2; middle Cretaceous fossils in unit 4. We have a stratigraphic sequence, deposited from Upper Triassic to Middle Cretaceous, then piled up in nappes, the whole having been thrust over the autochthonous Sarvak formation.

Wells referred to J. V. Harrison's opinion, but Harrison was concerned with Luristan and not Fars. Moreover his reports have never been published. The same applies to "the recently completed lithofacies studies" (p.387) which remain unpublished. Wells wrote: "a thick sequence . . . known as The Radiolarites was accumulating at the same time as the Tarbur and Gurpi formations". In my view there is no lateral change of the radiolarites into these formations; moreover, as Gray has already mentioned, one can observe the radiolarites, dipping 60 degrees, being transgressively overlaid and reworked by the horizontal Tarbur formation in the cliffs bordering the Neyriz plain to the south.

About the radiolarite formation, Wells asserted (p. 388-389): "The detritus became more frequent with time, and the age of the derived material became progressively older." Even if these formations are considered as autochthonous such an impression can be drawn only from an isolated cross-section joined with an unfortunate sampling. When these formations are seen to be piled up as nappes, it loses any meaning. Later Wells said that Gray's Triassic and Jurassic fossils come from the higher beds of the radiolarite formations, which implies that the older fossils have been reworked in the younger beds. But Gray's report (p.204 & 206) and map show that these fossils have been found in the *lower* beds, not far from the underlying Sarvak formation. Wells then quoted Gray: "were it not for the fossil evidence, the exposed section might be taken for a normal one". This sentence (Gray p.203-4) is taken out of context; it applies in fact to a single outcrop and not to the whole formation.

Wells also wrote: "The pelagic limestones interbedded with this detritus con-

tain... successive assemblages of *Globo truncana*...". This is a very important argument and one would like to know exactly where the observations were made. I myself observed this phenomenon, but it is restricted to the 250 m directly overlying the Sarvak formation and below the radiolaritic Pichakun formations. There are here fine-grained marly limestones containing gravels and boulders derived from the now overlying Pichakun series. These formations belong to the autochthonous series and follow the Sarvak formation normally. It is essential not to confuse them with the Pichakun series from which they are separated by a major thrust plane. On the other hand the younger fossils found up to now in Pichakun are Aptian.

As far as the ophiolites are concerned, Gray considered them thrust together with the radiolarites, whereas Wells considered them a distinctly younger intrusion in situ. He noted (p.391): "Isolated remnants of the roof of the intrusive are seen in at least four places; and metamorphosed contact with rocks of Cretaceous and Eocene age are numerous". As I observed myself, there are some metamorphic contacts, but never with fossiliferous or even recognizable Cretaceous or Eocene rocks.

Ophiolites are in contact with Sarvak Cretaceous east of Dalnashin and with Pichakun formations east of Pichakun Mountain. There the contacts are tectonic and marked out by a crush zone. Directly north of the eastern part of Neyriz lake they are in contact with white crystalline limestones indicated by Wells as Jahrum (Eocene) on his map. The contact is undoubtedly metamorphic, with pyroxene skarns; however the limestones are not fossiliferous and bear only a remote resemblance to the Jahrum formation. Moreover, one can see in Rushan Kuh the Jahrum limestone overlying and reworking the ophiolites. This led me to regard the ophiolites as intruded in the crystalline limestone, then thrust over the Sarvak and Pichakun formations, and at last transgressively overlain by the Eocene limestone.

In conclusion I maintain the existence in the Neyriz area of extensive nappes consisting mainly of radiolarites and ophiolites, overthrust during the upper Cretaceous period, their displacement being at least 100 km.

## REFERENCES

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Sir,

I appreciate the opportunity to reply to the foregoing letter from L.-E. Ricou, whose own work in Iran was not published until some considerable time after my paper on the Crush Zone was accepted by your magazine.

It is indeed unfortunate that most of the previous work in the area studied by Ricou remains unpublished, but the views of Harrison *et al.* which I quoted referred not only to Luristan but to the full length of the Iranian Zagros Mountains and beyond. My point in giving the quotation was that the remarks stemmed directly from Gray's interpretation of the Radiolarites in the Pichakun area, with which a number of his colleagues then disagreed.

The Radiolarites themselves, including Ricou's Pichakun Formation, are often highly disturbed. This is a common feature of such thin-bedded and relatively incompetent sequences in orogenic regions, and the Zagros is no exception. Complex isoclinal folding, with consequent overturning and repetition of sequences, certainly occurs locally, but the resulting succession does not necessitate interpretation as nappes. Cyclic sedimentation of the type often associated with flysch-like deep-water trough deposits is also present, although it is somewhat complicated in the Pichakun area by tectonic disturbance.

Ricou sees no lateral change from the bathyal Radiolarites into the neritic Tarbur and Gurpi Formations. This is indeed often the case, as I explained, because the slope separating their contrasting environments of deposition tended to become too steep for sedimentation. There are at least two localities near Ricou's area, however, where the relationship can be seen, on the flank of Kun-e Barfi (30 km north-east of Shiraz) and in a mountain pass some 40 km west of Neyriz.

Ricou claims that a good print of the Gemini photograph which accompanied my article shows the Radiolarites to be truncated along the line of contact with the underlying Sarvak Formation. Although the reproduction was certainly very poor, I regret that the excellent print from which it was made gives me no more indication of an abnormal basal contact than do the conventional air photographs or the field outcrops.

Oil Company palaeontologists have, over the years, studied the fauna of the Radiolarites from numerous localities throughout the High Zagros, from the Kermanshah area in the north-west to the Bandar Abbas hinterland in the south-east. Very detailed and painstaking work has been required to establish the upper Cretaceous pelagic zonation where virtually all the benthonic fossils were derived. In the Pichakun area the pelagic foraminifera are certainly more common in the lower part of the Radiolarites, below the coarsely detrital beds, but they are also sparingly present in favourable lithologies in the upper part of the section. I am aware of no evidence, field or otherwise, which makes it necessary to divide the series by a major thrust plane which was first devised largely as an explanation for a supposed palaeontological anomaly.

Ricou believes that the igneous rocks in the Neyriz area also form parts of extensive nappes. I have already drawn attention to the interbedded pillow lavas in the Radiolarites, and although these are of only local importance, they are sometimes reworked into the overlying Eocene beds (as is the case in a part of Rushan Kuh). These pillow lavas are quite separate from the intrusive plutonic rocks which clearly metamorphose the Radiolarites east of Kuh-e Dalnashin and Eocene rocks elsewhere, and again I know of no necessity to invoke their emplacement by complicated tectonics.

The structural pattern of the Zagros Mountains as a whole is now well known and relatively simple, and I find it preferable, where the stratigraphic evidence allows, to interpret the structure of the Pichakun area within this simple regional context.

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*Post-script by L-E. Ricou*

Mr. Ricou wishes to point out that he used the term *ophiolite* only for the pyroxenites, serpentinites, and gabbros, which are, he agrees with Dr. Wells, quite separate from the pillow lavas. In Rushan Kuh he saw that the Eocene beds had reworked the serpentinites, which are therefore older.