A MAGYAR ÁLLAMI FÖLDTANI INTÉZET ÉVKÖNYVE

ANNALES

INSTITUTI GEOLOGICI PUBLICI HUNGARICI

ЕЖЕГОДНИК ВЕНГЕРСКОГО ГЕОЛОГИЧЕСКОГО ИНСТИТУТА
ANNALES DE L'INSTITUT GÉOLOGIQUE DE HONGRIE
ANNALS OF THE HUNGARIAN GEOLOGICAL INSTITUTE
JAHRBUCH DER UNGARISCHEN GEOLOGISCHEN ANSTALT

VOL. LIV., FASC. 2.

100-YEAR CELEBRATIONS OF THE HUNGARIAN GEOLOGICAL INSTITUTE

COLLOQUE DU JURASSIQUE MÉDITERRANÉEN
Budapest, 3—8. IX., 1969

КОЛЛОКВИУМ ПО ЮРСКОЙ СИСТЕМЕ СРЕДИЗЕМНОМОРСКОЙ ОБЛАСТИ
Будапешт, 3–8. IX., 1969 г.

MŰSZAKI KÖNYVKIADÓ, BUDAPEST

1971. január

EVALUATION OF BATHYMETRIC CRITERIA FOR THE MEDITERRANEAN JURASSIC

by

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One of the outstanding problems of the Mediterranean Jurassic concerns the depth of deposition of the various facies, in both the relative and absolute sense. There is a long- and widely-held belief that certain rock formations in the Alpine fold belts of southern Europe were laid down in considerable depths of sea, of the order of several thousand metres (e.g. MERLA 1952, TRÜMPY 1960, GÉCZY 1961, MIŠÍK and RAKÚS 1964, COLOM 1967, GARRISON and FISCHER 1969). Such interpretations have an important bearing on major tectonic concepts such as TRÜMPY's "leptogeosyncline", signifying sediment starvation in deep sea basins. Now depth of deposition is a singularly elusive factor since it does not exert a direct influence on either sediments or organisms. Bathymetric inferences must accordingly be based upon the correlation of depth with other factors which do exert such an influence. Since rapid progress is now being made in our understanding of the facies in question, the time seems ripe for a brief evaluation of the major arguments involving bathymetry. It will be assumed that the reader has a general familiarity with Jurassic geology in the Mediterranean region.

Evidence favouring deep-water deposition

1. It has been suggested that the widespread absence of aragonitic fossils, or even their moulds, is related to solution of the mineral below a certain depth (in the oceans at present *pteropod ooze* does not extend below approximately 3500 m). Likewise, the radiolarian cherts which are widespread in the Middle and Upper Jurassic have been compared with Recent *radiolarian oozes,* which are found below the $CaCO_3$ compensation depth of about 4500 m.

It is abundantly clear from the study of many shallow-water deposits that aragonite is a relatively unstable polymorph of $CaCO_3$ which readily dissolves or is replaced by calcite during diagenesis. Absence of calcitic replacements or moulds of aragonitic fossils does suggest, however, relatively rapid solution of shells while still exposed on the sea floor, and such deposits as the

Upper Jurassic *Aptychus limestones*, *Maiolica*, etc. no doubt signify relatively deep water. However, simple comparisons with the present-day oceanic situation may be very misleading. As HUDSON (1967) has argued, the present $CaCO_3$ compensation depth may be controlled more by low rates of dissolution related to the low temperatures of deep oceanic waters, than to chemical undersaturation. If this is so, then the compensation depth in relatively equable periods like the Jurassic might have been much shallower than today. Ocean waters at present appear to be undersaturated with respect to $CaCO_3$ below depths of a few hundred metres.

With regard to radiolaria, maximum solution does indeed occur in shallow water, because, in contrast to calcite, solubility (as well as rate of solution) of silica is proportional to temperature (BERGER 1968). The Upper Jurassic *radiolarites* are very probably relatively deep-water deposits, but not necessarily deeper than the overlying *Aptychus limestones* of Tithonian age, as has sometimes been assumed. Electron microscopy has revealed that the latter are largely composed of coccoliths (FARINACCI 1964, FLÜGEL 1967, GARRISON 1967). The planktonic algae which produced the coccoliths underwent an evolutionary burst in the late Jurassic (NOËL 1965), suggesting that the widespread passage of *radiolarites* up into pelagic limestones might be a biological rather than a bathymetric phenomenon.

2. *Allodapic limestones*, that is, coarse-grained skeletal or pelletal limestones have been transported by submarine currents from shallower regions of the sea floor, are now widely recognised in the Mediterranean Jurassic (GARRISON 1967, BERNOULLI 1967) and appear to be characteristic of the deeper water facies. As with slide conglomerates and breccias, which also occur widely, their presence demands the former existence of a submarine slope but this need not necessarily have been steep, nor need the original difference in submarine topographic levels have been very great. It is known that turbidites can form in quite shallow water. The oldest *allodapic limestones* are recorded from *Ammonitico Rosso* deposits of Domerian—Toarcian age. This accords with the general notion of a deepening sea during the course of the Lower Jurassic.

3. Although there is no indication of anaerobic conditions, many of the so-called *pelagic limestones* and *marls* contain calcareous or siliceous plankton but very few benthonic fossils, a fact which is especially striking when the beds are compared with the adjacent "platform" deposits or with stratigraphically equivalent deposits north of the Mediterranean region. This is not merely the consequence of aragonite dissolution because calcitic fossils such as belemnites, crinoids, brachiopods and oysters are also rare in these limestones (most notably the *Aptychus limestones*). Benthonic fossils are also sparse in condensed deposits, thereby eliminating a "sedimentary dilution" factor.

To account for this phenomenon, comparison has again been made with the present-day oceans, and it has been noted how the abundance of shelly benthos declines strongly with increasing depth, but only at depths of thousands of metres does this benthos become extremely rare. Once more, it must be realised that such actualistic comparisons can be misleading unless the critical controlling factor is isolated. In this case it is almost certainly food supply, *i.e.* plankton and organic detritus. This indeed diminishes with depth but also towards the open ocean away from coastal regions into which nutrients are carried by rivers. Only where strong upwelling brings nutrients from the deep ocean to the surface does organic productivity rise to values approaching those of certain coastal regions. Much of the tropical ocean is in fact comparatively barren (RYTHER 1963).

The southward changes of Jurassic litho- and biofacies in Europe seem to reflect increasing "oceanicity" and the reduced influence of rivers rather than any striking increase of depth (HALLAM 1967a, 1969a). The reduced benthonic abundance southwards (reef deposits excepted), as opposed to increased diversity, might have been one of the consequences of rather weak water circulation in the western Tethys, which seems quite likely in view of the probable absence of polar ice caps.

4. Another actualistic comparison has frequently been made between manganiferous incrustations in condensed limestones of the calcareous *Ammonitico Rosso* type and the manganese nodules which occur in prolific quantities on the present deep-sea floor. However, manganese concentrations are dependent essentially on a combination of minimal terrigenous sedimentation and sparsity of organic matter (KRAUSKOPF 1967); it just happens that at the present day these conditions are best realised on the deep sea floor and on seamounts. Depth *per se* is clearly not a controlling factor and shallow-water manganese concentrations are known (PRICE 1967, JENKYNS 1967). JENKYNS interprets manganese nodules in the Jurassic of Sicily as having been laid down on submarine rises on which rates of carbonate sedimentation were extremely slow.

5. A further argument has been based on the fact that many beds in the Mediterranean Jurassic are extremely persistent laterally, preserving their lithological and faunal characteristics at the same stratigraphical horizon for many miles. It has been assumed that this could only occur at relatively great depths well below the zone of wave action. This view is related to the old belief that coarse-grained deposits are always laterally less persistent and deposited in shallower water than fine-grained rocks (often the statement has appeared that shales signify "deep" water, whatever that may mean). We have today a much more sophisticated appreciation of sedimentary environments and there are indeed numerous instances of fine-grained, laterally persistent beds in the Jurassic which were laid down in quite shallow water. A good example is provided by the German Toarcian *Posidonienschiefer* and its equivalents in France and England (HALLAM 1967b).

6. Several thousand metres of very shallow-water Upper Triassic carbonates in the southern and eastern Alps signify tectonic subsidence of that amount within a few million years. Subsidence at a similar rate combined with a strong reduction of sedimentation would have resulted in the development of deep oceanic troughs by late Jurassic times (GARRISON and FISCHER, 1969). This is an interesting argument but it entails a bold extrapolation which is dubiously justifiable. If the pattern of sedimentation changed so drastically from the Triassic to the Jurassic, can one reasonably assume that the tectonic pattern persisted with little modification?

Evidence favouring shallow-water deposition

1. The existence of hardgrounds, signifying early lithification of limestone followed by corrosion and perhaps incrustation and boring by organisms, has sometimes been accepted as evidence of emergence above sea level. However, many if not most hardgrounds appear to have formed subaqueously so that they cannot be considered as conclusive evidence of emergence (HOLLMANN 1964, BERNOULLI 1967). Submarine lithification has been recorded from the present ocean (GERVIRTZ and FRIEDMAN 1966, FISCHER and GARRISON 1967) but so far no indubitable evidence of submarine corrosion has been recognized (this indeed poses one of the major problems of carbonate sedimentology).

On the other hand, one occasionally finds "pelagic" Jurassic deposits resting directly upon what appears to be an ancient karst land surface, eroded in Triassic or basal Jurassic carbonates. A good example is provided by the *Liassic Adneterkalk* in its type area near Salzburg (HALLAM 1967a). This throws into question the common assumption that the *Adneterkalk* represents moderately deep-water facies.

2. Another traditional argument favouring shallow-water deposition is the occurrence of thick beds of breccia or conglomerate intercalated in a "pelagic" sequence. These are now widely regarded as submarine slide deposits related to contemporaneous faulting and the existence of bottom slopes, and as such may represent any depth.

3. *Bauxites*, such as occur in the Jurassic of Greece (CONLEY 1968) are unequivocal indicators of emergence, but unfortunately are too restricted in time and space to be of much assistance to the paleogeographer.

4. *Stromatolites* have been widely interpreted as signifing intertidal conditions but they have recently been discovered down to 11 m below low tide level off Bermuda (GEBELEIN 1969). The laminae appear to be diurnal but are evidently not necessarily related to periodic exposure as formerly thought. They at least signify deposition within the photic zone, which at present extends to a maximum of 150 m in clear oceanic waters of low latitudes (JOHNSON 1957). Almost certainly, abundant stromatolites signify much shallower water than this.

It is now apparent that *stromatolites* are widespread in many massive limestone—dolomite sequences, characteristic especially of the basal Jurassic of the Mediterranean region, *e.g.* Greece (CONLEY 1968), the souther Apennines of Italy (D'ARGENIO and VALLARIO 1967) and Morocco (personal observations). Their discovery is not especially surprising because the deposits, frequently associated with beds containing abundant shelly benthos, have generally been considered to have been laid down in shallow water. The recognition of *stromatolites* in condensed red limestones of Middle Jurassic age in western Sicily (JENKYNS and TORRENS, this symposium) is much more intriguing because the other features of these limestones, such as manganese concentrations, sparsity of benthos, lack of organic matter, and nodularity are characteristic of deposits of calcareous *Ammonitico Rosso* type which have been attributed to moderately deep-water deposition.

5. Another important discovery which has followed from FISCHER's (1965) work on the Alpine Triassic is that of *"birdseye"-limestones* or *loferites* (to use

FISCHER's term), which are fine-grained limestones containing calcite- or dolomite-filled sheet cracks and shrinkage pores. Such beds, which are generally associated but not necessarily coincident with *stromatolites*, are known to occur in Greece (CONLEY 1968), the southern Appenines (D'ARGENIO and VALLARIO 1967) and the eastern High Atlas of Morocco (personal observations) and are no doubt more widespread. The key to their interpretation is given by SHINN's (1968) description of such structures in Florida. Both here and in the Persian Gulf, they are mainly supratidal, sometimes intertidal and never subtidal. As such, they are apparently the best evidence available of the former position of sea level.

Conclusions

It seems to me that a sound case for the existence of "oceanic" depths of several thousand metres in the troughs or basins of the so-called Mediterranean geosyncline has not been made. Actualistic comparisons have generally suffered from an inadequate understanding of the fundamental factors controlling sedimentation and organic activity and I see no compelling reasons for invoking depths at any time of more than a few hundred metres. This is not to say, of course, that substantially greater depths were never attained, but such claims should be treated with scepticism.

On the other hand, a high measure of agreement on *relative* depths may be attainable. Massive carbonate sequences with *stromatolitic beds* and *loferites* alternating with deposits containing, among other fossils, thick-shelled bivalves, hermatypic corals and dasycladacean algae, are clearly shallow-water, periodically emergent, platform deposits while the adjacent troughs or basins are signified by fine-grained "pelagic" limestones and marls containing calcareous microplankton but only rare benthonic fossils, with intercalated bands of *allodapic limestones* derived from the platforms, and *radiolarian cherts* (cf. BERNOULLI 1967). Within the deeper water facies, thick grey white siliceous, marly limestone sequences pass laterally into thin red nodular manganiferous limestones with corrosion surfaces. The latter almost certainly signify slow sedimentation on topographic highs within the basins. This accords with the known relationship of sedimentation to topographic relief on the present ocean floor and with the greater concentration of organic matter (HALLAM 1967a), and silica (LISITSYN 1967) in sediments of the basins.

Viewed as a whole, there appears to have been a more or less progressive deepening of the sea in the Mediterranean area during the course of the Jurassic, although some regions persisted as platforms and there were local regressions, as in Morocco. No doubt much of this regional deepening is associated with the failure of sedimentation to keep pace with epeirogenic subsidence of the basins (which poses a very interesting problem). It should be recognized, however, that there was very probably in addition an eustatic component, because sea level tended to rise on a world-wide scale during most of the Jurassic (HALLAM 1969b).

I wish to thank Dr. H. S. JENKYNS and Dr. J. D. HUDSON for helpful comments.

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