Mitt. Bayer. Staatsslg. Paläont. hist. Geol.	25	195–208	München, 31. 12. 1985

Facies relationships in the Jurassic and Lower Cretaceous pelagic limestones of the Monte Nerone Area, Province of Marche, Italy. – Sedimentation on a submarine high

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With 8 text figures

Abstract

Detailed mapping and outcrop studies of Jurassic and Lower Cretaceous pelagic limestones in the Monte Nerone area has allowed the identification of four different sequence types (facies). Their characteristics and spatial and chronological relationships to each other are due to drape and onlap deposition on a subsiding submarine basin and swell topography induced by extensional tectonics (block-faulting).

The four sequence types are:

1) Swell facies,
2) Upper Slope facies,
3) Lower Slope facies,
4) Basin facies.

Sedimentary features attributable to submarine current action have been observed, but no indications of shallow water deposition or subaerial exposure were detected.

Resumée

Une étude détaillée des affleurements de calcaires pélagiques du Jurassique et Crétacé inférieur dans la région du Monte Nerone a permis d'identifier quatre différents types de faciès sédimentaires. Ces calcaires ont été déposés dans un bassin sous-marin où existait une succession de reliefs locaux associés à des mouvements tectoniques extensionnels. La présence de ces reliefs explique les caractèristiques et les relations temporelles et spatiales des différents faciès les uns par rapport aux autres.

Les quatre faciès sédimentaires décrits sont:

1) Faciès associé aux reliefs locaux,
2) Faciès de pente supérieure,
3) Faciès, de pente inférieure,
4) Faciès profond.

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Des figures sédimentaires résultant de l'action de courants sous-marins ont été observées, mais il n'y a pas d'indications de figures sédimentaires associées à des dépôts de faible profondeur ou supratidaux.

Kurzfassung

Durch Detailkartierung und Profilaufnahme in den pelagischen Jura- und Unterkreidekalken des Monte-Nerone-Gebietes konnten vier verschiedene Schichtfolgetypen identifiziert werden. Ihre Kennzeichen sowie ihre räumlichen und zeitlichen Beziehungen zueinander sind bedingt durch Sedimentation auf einer absinkenden, untermeerischen Becken- und Schwellenmorphologie, die durch Dehnungstektonik entstanden ist.

Die vier Schichtfolgetypen sind:

1. die Schwellenfazies,
2. die Hangfazies,
3. die Hangfußfazies,
4. die Beckenfazies.

Sedimentstrukturen, die auf untermeerische Strömungsaktivität hindeuten, wurden beobachtet, jedoch keine Hinweise auf Flachwasserablagerung oder gar Auftauchperioden.

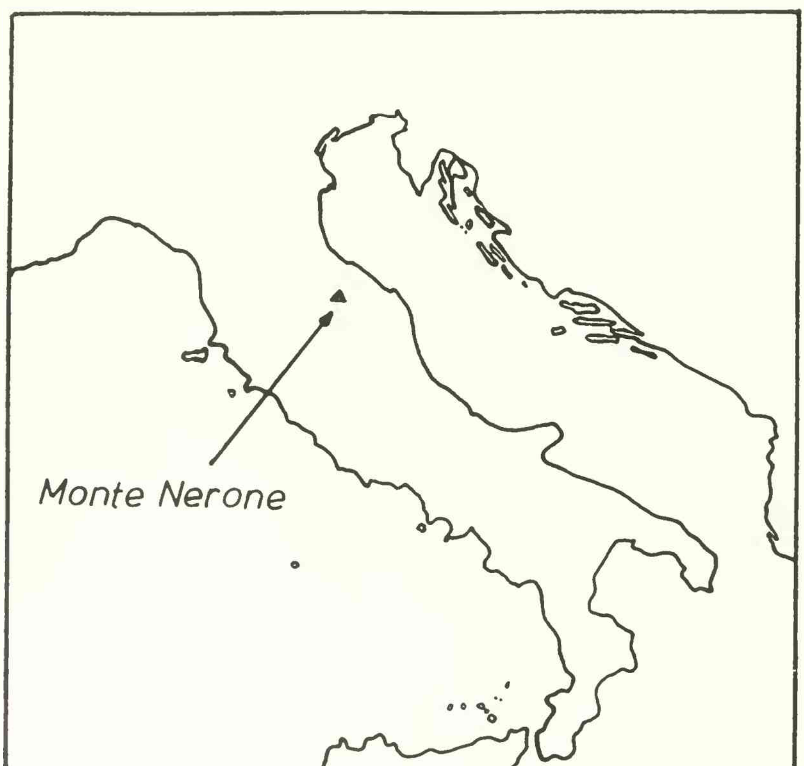

Fig. 1: Location map.

Introduction

The Monte Nerone is situated in the eastern part of the Appennine Mountains in the province of Marche, Italy (see fig. 1). Unlike the intensely deformed western part of the Appennines, this eastern part is characterized by comparatively smooth – though sometimes overturned – NW-SE to N-S striking folds.

Mesozoic carbonates deposited in the ancient Tethyan Sea are exposed in the cores of the anticlines. One of the most northerly ones is the Monte Nerone anticline, where the working area is located.

For the position of the Monte Nerone carbonates in a more regional context of the tectonicly rather complicated Alpine-Mediterranean system reference is made to the literature (e. g.: BERNOULLI, 1972). After early Jurassic times they have been deposited in a deeper marine environment compared to the more shallow marine carbonates exposed in the southern Appennines.

Stratigraphy

1. General

The oldest exposed formation is the "Calcare massiccio"; a sequence of Bahamian-type platform carbonates of Rhaetian to Sinemurian/Pliensbachian age up to several hundred metres thick. Subsidence and block-faulting of these platform carbonates gave a pronounced submarine relief, upon which pelagic limestones were deposited during the Jurassic. There are considerable variations of thickness and facies over short distances between condensed sequences deposited on highs (swell facies) and complete sequences in the basin (basin facies) (see fig. 2).

In Lower Cretaceous times (Upper Tithonian to Aptian) a very clean, fine-grained, pelagic limestone, the "Maiolica", was deposited. This filled in the Jurassic relief and, therefore, still shows considerable thickness – and in its basal parts facies – variations.

The whole Rhaetian to Lower Cretaceous sequence consists predominantly of limestones with some cherts in the pelagic sequence. The only clastic sediments are fine-grained, pelagic mudstones occasionally intercalated with the limestones.

In the following a description is given of the different sequence types as they are developed in various settings associated with the Jurassic submarine topography in the Monte Nerone area. Field observations and the results of a detailed examination of a number of outcrop sections have been assembled into two schematic cross sections (fig. 3) and a facies distribution map (fig. 4), which illustrate the paleogeographic development of the area in the Jurassic and Lower Cretaceous. Biostratigraphic subdivision of the outcrop sections examined has been achieved by the identification of a series of microfaunal associations as described in CENTAMORE et al., 1971.

2. Calcare massiccio
(Rhaetian – Sinemurian/Pliensbachian)

COLACICCHI et al. (1975) distinguish three main sedimentary environments in the Calcare massiccio:

1) offshore bar (at the Italian west coast near the island of Elba),
2) low energy lagoon (east of 1; in the province of Toscana and in the western part of Umbria),
3) tidal platform (in the eastern part of Umbria and in Marche).

<table>
<tr><th>AGE</th><th>BASIN FACIES</th><th>SWELL FACIES</th></tr>
<tr><td>Upper Tithonian to Aptian</td><td>Maiolica (up to 400 m)</td><td>Maiolica (ca. 60 m)</td></tr>
<tr><td>Callovian to Lower Tithonian</td><td>Calcari diasprini (60 - 100 m)</td><td rowspan="4">condensed sequence (40 - 60 m)</td></tr>
<tr><td>Aalenian to Bathonian</td><td>Posidonia Limestones (20 - 35 m)</td></tr>
<tr><td>Toarcian</td><td>Ammonitico rosso (14 - 23 m)</td></tr>
<tr><td>Pliensbachian</td><td rowspan="2">Corniola (170 - 180 m)</td></tr>
<tr><td>Sinemurian</td><td>Calcare massiccio A</td></tr>
<tr><td>Rhaetian to Hettangian</td><td colspan="2">Calcare massiccio C (several hundred metres)</td></tr>
</table>

Fig. 2: Stratigraphic correlation chart (schematic).

The Monte Nerone carbonates were deposited on the tidal platform, but close to the low energy lagoon.

In the tidal platform area Centamore et al. (1971) distinguish a Calcare massiccio C from a Calcare massiccio A, the former being deposited in shallow, subtidal areas similar to the lagoonal facies, whilst the latter is a pure intertidal sediment.

In general subsequently deposited basinal sequences are underlain by the Calcare massiccio C, while sequences deposited on highs are underlain by the Calcare massiccio A. This suggests that the later basin and swell topography had already some expression in the lowermost Jurassic. The top of the Calcare massiccio is strongly diachronous. In basinal areas shallow water deposition ceased in the Upper Sinemurian, but continued on the highs until the Upper Pliensbachian. Accordingly the uppermost part of the Calcare massiccio on the highs is time equivalent to the lowest member of the basinal sequence, the Corniola (see fig. 2).

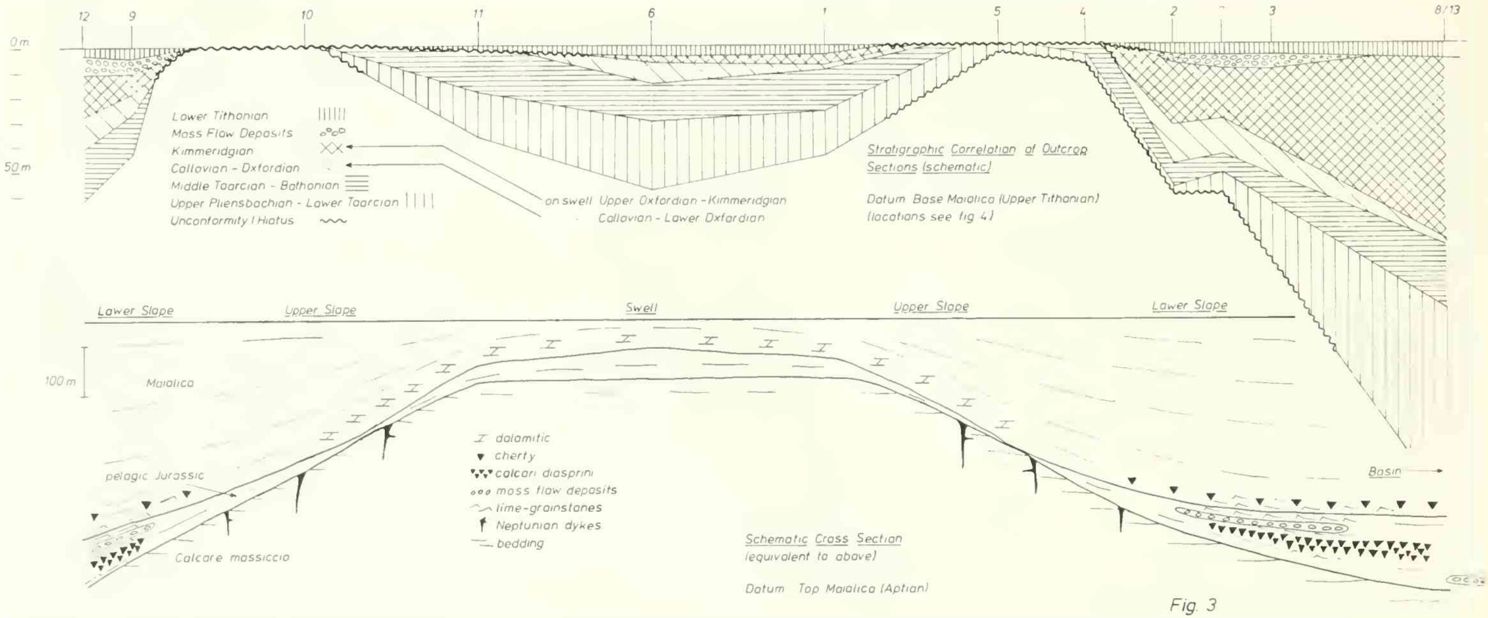

Fig. 3: Stratigraphic correlation of outcrop sections (schematic) and schematic cross sections.

3. The Jurassic, Pelagic Limestones (Sinemurian/Pliensbachian – Tithonian)

a) General

Due to deposition on a pronounced submarine relief, thickness and facies variations of the Jurassic, pelagic limestones are considerable. Four different sequence types have been identified, which are termed Basin Facies, Swell Facies, Upper Slope Facies, and Lower Slope Facies, in accordance with their position in the Jurassic paleotopography.

A basin sequence sensu CENTAMORE et al. (1971) is only exposed in the northernmost corner of the working area. Elements of it – although in reduced thicknesses – are, however, recognized elsewhere, too.

b) Basin Facies

Overlying the Calcare massiccio is the Corniola, a grey, micritic limestone, containing pelagic faunas, of 170–180 m thickness, and of Upper Sinemurian to Upper Pliensbachian age. It is well bedded on a dm-scale, has thin marly interlayers, and contains frequently siliceous bands or nodules within the limestone beds.

Up to several metres thick mass flows, derived from the Calcare massiccio occur – often associated with slumping structures.

Overlying the Corniola is the Ammonitico rosso, a red, marly, nodular limestone, rich in ammonites, 14–23 m thick, and of Toarcian age.

It is overlain by the 20–25 m thick, Aalenian to Bathonian *Posidonia* limestones. These are thinly bedded, yellowish brown, marly, micritic limestones with a striking abundance of the thin shells of the pelagic lamellibranch *Posidonomya?* or *Bositra*. Due to resulting textural characteristics, they may also be referred to as filament limestones.

The Posidonia limestones grade into the 60–100 m thick Calcari diasprini, cherty limestones of Callovian to Lower Tithonian age. These thinly bedded, greenish to brownish grey, marly limestones contain abundant darkgrey to black chert layers and nodules, which can – especially in the middle part of the formation – almost completely replace the carbonate. The silica is derived from abundant, rock forming radiolaria, which were blooming at that time.

c) Swell Facies

Unlike the basinal sequence, the Pliensbachian to Tithonian sediments on the highs are much more uniform. They are essentially brownish to greenish grey, fossiliferous, micritic limestones – well bedded on a dm-scale with thin marly interbeds.

They overlie the Calcare massiccio conformably and reach typical thicknesses of 40–60 m, with the thicknesses increasing from the margins to the centre of the high. The transition from the typical Calcare massiccio to the pelagic limestones is gradational over a few metres. The lowermost 3–5 m of the swell sequence is still dominated by a benthonic fauna (pelecypods, gastropods, and echinoderms), but pelagic fauna – such as cephalopods and pelagic mircoplankton – rapidly becomes more abundant.

Bioturbation is another characteristic feature of the entire Jurassic swell sequence (see fig. 5). The burrows are the preferred site for the diagenetic formation of pyrite and dolomite in parts of the sequence. In more marly layers and especially in the weathered state this leads to a colouration and nodular appearance of the rocks. No hard grounds, shallow water fossils, or sedimentary features indicative of subaerial exposure have been observed. There is, however, a constant

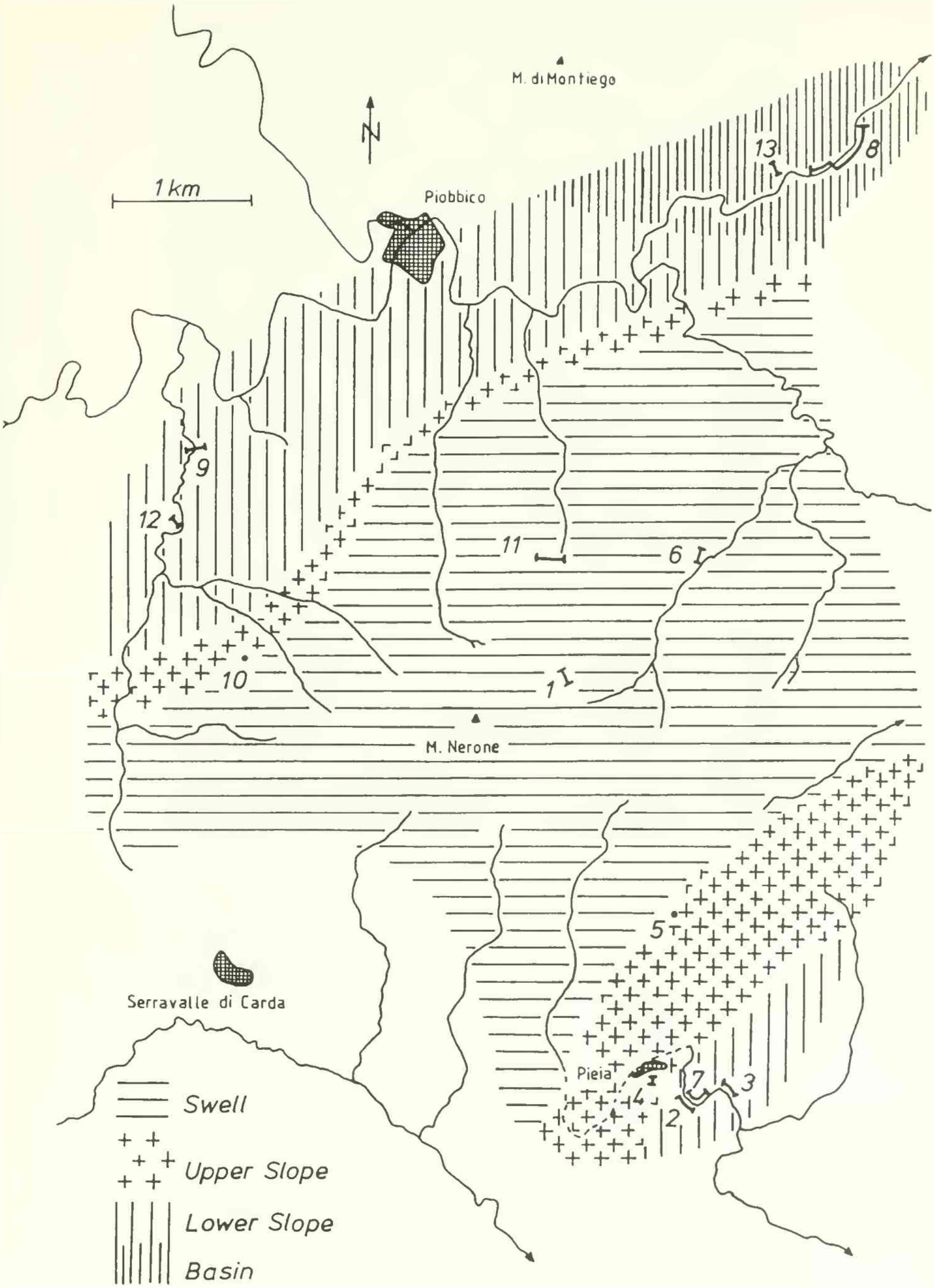

Fig. 4: Facies map (with locations of outcrop sections in figure 3).

Fig. 5: Lower Jurassic, fossiliferous, pelagic limestone of the swell facies showing intense bioturbation; polished surface, original size.

decrease in sedimentation rates throughout the Jurassic as evidenced by hiatusses in the Upper Jurassic, while Lower and Middle Jurassic are always present and comparatively thick (see fig. 3). This trend continues into the Lower Cretaceous Maiolica.

d) Upper Slope Facies

The upper slope facies typically shows (see fig. 3):

1) an increased frequency of sediment filled fractures (Neptunian dykes) in the underlying Calcare massiccio,
2) an angular unconformity between the Calcare massiccio and the overlying pelagic limestones,
3) a very variable, but always very thin (less than 10 m) thickness of the Jurassic, pelagic limestones. Locally they can be completely absent.

The localized occurrence of angular unconformities, which do not characterize either the basin or the swell facies, indicates this to be a zone of tectonic activity. This assumption is supported by the Neptunian dykes in the Calcare massiccio. The thin to missing thicknesses of the Jurassic, pelagic limestones are explained by here being the source area for the abundant mass flow deposits occurring in the lower slope facies.

The overlying Maiolica does not show the same characteristics any more.

e) Lower Slope Facies

The lower slope facies (see fig. 3) is characterized by:

1) onlapping sediments of the basinal facies in reduced thicknesses, whith an angular unconformity to the underlying Calcare massiccio,
2) mass flow deposits of different types, derived from the swell/upper slope,
3) frequent layers of well sorted lime-grainstones in sediments from the Middle Jurassic Posidonia limestones onwards, indicative of current action.

The basin-type sediments observed in the lower slope facies show a typical onlap pattern. Lower Jurassic, pelagic limestones are thin and resemble more their swell equivalents than the Corniola, although their macrofossil content is lower. They still overly the Calcare massiccio unconformably. In one case the unconformity is marked by a bored hardground. The Middle Jurassic Posidonia limestones are already quite like their basinal equivalents, – as are the Upper Jurassic cherts, which can reach substantial thicknesses and extend higher up the paleo-slope. This increasing basinal influence leads to increasing sedimentation rates throughout the Jurassic – a trend which continues into the Lower Cretaceous Maiolica. This development is quite opposite to the one observed on the swell, where sedimentation rates decrease.

Mass flow deposits characterize the lower slope facies particularly in the Upper Kimmeridgian and Lower Tithonian. Different types showing a variety of transitions were deposited. There are several metres thick slide complexes with angular components showing grain-to-grain contacts. They must have been highly viscous and were obsiously not transported very far. Slumping structures are also common. There are dm-thick mudflows with rounded components of different sizes floating in a fine-grained, muddy matrix (see fig. 6). Thin (up to 20 cm thick) carbonate turbidites of reasonably sorted, sand-sized carbonate particles, also occur.

Fig. 6: Mudflow from the Upper Kimmeridgian/Lower Tithonian of the lower slope facies; rounded components floating in muddy matrix showing diagenetic pressure solution features; polished surface, original size.

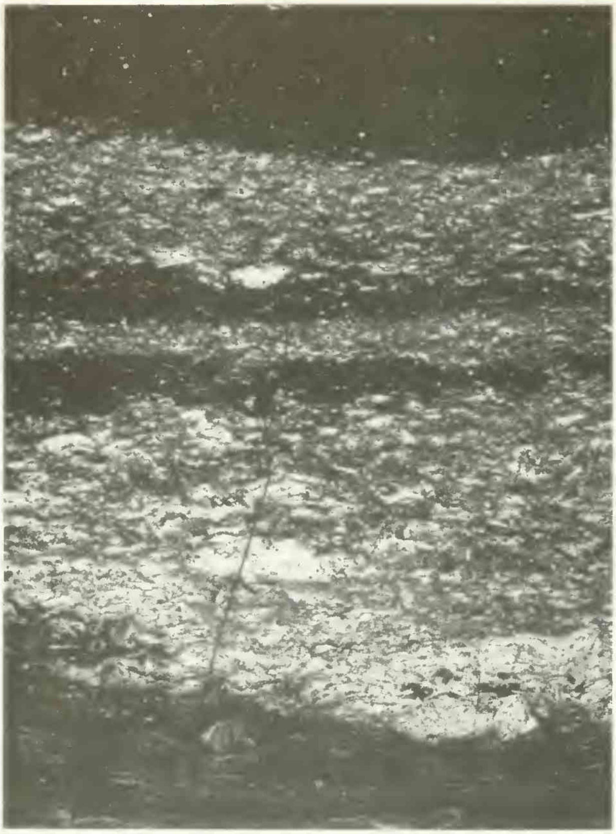

Fig. 7: Transition of Posidonia limemudstones and grainstones into radiolaria bearing mudstones/wackestones. The winnowed layers, which appear light, are silicified. Thin section. 6×.

Another sediment type characteristic for the lower slope facies are lime-grainstones, which appear for the first time in the Middle Jurassic Posidonia limestones and are still observed in the lowermost Maiolica (Upper Tithonian). They are composed of whatever coarser grained particles were available (*Posidonia* shells in the Middle Jurassic, other fossil debris and carbonate particles in the Upper Jurassic). They are well sorted and do not or hardly contain any muddy matrix. The interstitial pore spaces are filled with sparry calcite or occasionally silica.

In the Posidonia limestones the large, thin shells can be layered evenly, as if the current energy had just been sufficient to winnow away the fine-grained particles, but also chaotic – indicating at times a higher energy environment capable of reworking the shells themselves, too (see fig. 7). The grainstones are often intercalated with their equivalent mud/wackestones on a cm-scale. Several cm thick carbonate sand layers composed of coarse-grained fossil debris are observed in the Kimmeridgian and the lowermost Maiolica (Upper Tithonian). Sedimentary features such as ripples, small-scale cross-bedding, and graded bedding are occasionally seen (see fig. 8). The above mentioned carbonate turbidites also provide a source of coarser grained material. They are easily reworked by the currents, so that it can be difficult to recognize their original turbiditic nature.

Fig. 8: Upper Tithonian carbonate sand layer of the lower slope facies: Mud ripples at the base are overlain by a 1 cm thick, coarse-grained carbonate sand layer with graded bedding. The finer grained, partly silicified unit on top shows weak cross-bedding. Possibly thin, reworked turbidite. Polished surface, original size.

It is possible that similar features occur in the Upper Jurassic cherts, but their strong diagenetic deformation makes it difficult to recognize them.

Equivalent higher energy deposits have not been observed in the swell and upper slope facies and are not reported from the basin facies proper.

4. Maiolica
(Upper Tithonian – Aptian)

The typical Maiolica is a white, clean, pelagic limemudstone, which is almost exclusively made up of nannoplankton remains with very scarce marcrofossils. The age is Upper Tithonian to Aptian. It is well bedded on a dm-scale with thin, marly laminae separating the limestone beds. Dark chert layers and nodules are frequent – especially in the more basinal parts, while the basal parts of the Maiolica overlying the swell typically contain diagenetic, idiomorphic dolomite.

Variations in thickness are quite substantial. The Maiolica may be up to 400 m thick in the basin proper, but can thin to 60 m over the Jurassic high.

The basal (mainly Upper Tithonian) parts of the Maiolica still display similar facies variations as the underlying Jurassic sediments. On the swell the basal Maiolica is still condensed and has accordingly an untypically high macrofossil content. An upper slope facies can not be recognized in the Maiolica. In the lower slope facies area, however, it shows the same characteristics as described for the Jurassic – namely:

1) continuation of the onlap pattern,
2) intercalated mudflows and carbonate turbidites,
3) thin grainstone layers indicative of current action.

At the end of the Maiolica deposition uniform conditions for the whole area were established, with any possibly remaining relief not causing any significant differences in facies development any more.

Discussion of the Sedimentary Environment

The occurrence of facies variations in the Tethyan Jurassic, pelagic limestones – with thin, condensed sequences deposited on paleo-highs and thick, complete sequences in the lows – has long been recognized. For the basinal settings deposition in relatively deep, quiet water has always readily been accepted. Interpretation of the depositional environment of the highs has been more controversial. It is probably fair to assume that each of those highs has had a history of its own. Therefore, the following considerations are meant to apply only for the working area, although parallels to other areas may exist.

Colacicchi et al. (1970) postulated deposition of the swell facies of the Monte Nerone area in an enclosed lagoon, separated from the open ocean by a kind of atoll. The winnowed grainstones of the lower slope facies would then have represented the beach facies of that atoll. A tempting hypothesis – indeed – looking at a schematic cross section of outcrop sections with base Maiolica as datum (fig. 3). However, no other positive evidence for this model can be detected.

In the area of the postulated atoll no shallow water fossils or even sedimentary features indicating subaerial exposure have been observed. Neither does the swell facies display characteristic lagoonal features. The amounts of pyrite and dolomite present are insignificant to account for a reducing or hypersaline environment assumed by Colacicchi et al. and are probably of a pure diagenetic origin. The abundant bioturbation also contradicts their model, as does the almost exclusively pelagic character of the rich fauna.

A more attractive model is presented by a schematic cross section with datum top Maiolica (fig. 3). It shows a Calcare massiccio high, which is draped and onlapped by subsequent pelagic sedimentation, and from which material is shed into the basin as mudflows etc. All processes occurred in the open ocean at a depth not influenced by shallow marine processes. The following features, however, still require explanation:

1) the rather localized – though typical – occurrence of higher energy sediments at the lower slope from the Middle Jurassic onwards, coinciding with
2) a decrease in sedimentation rates on the high, which is
3) more pronounced at the margins of the high, leading to relatively thicker sequences in the centre.

In the assumed depositional setting, the only process, which can account for these features simultaneously, are contour currents. The highest energy conditions occurred at the depth, where the lower slope was located, causing the deposition of the winnowed grainstones in Middle and Upper Jurassic times. The upper slope is so much characterized by hiatusses, that not much evidence for current action can be found. In the swell sediments no sedimentary structures indicative of water movement are observed. However, the reduction in sedimentation rates could be explained by the weak, but constant winnowing action of the same currents, this being all the fading energy could achieve at this depth. This concept is confirmed by the relatively higher thicknesses of the swell sediments in the centre, which was probably somewhat shielded from currents having their energy maximum at the lower slope.

Conclusions

On the basis of the field work done, the Jurassic high of the Monte Nerone area emerges as a 3–4 km wide, SW–NE striking feature (about perpendicular to the present, NW–SE striking anticlinal axis), the length of which is not exposed. Coming into existence at the latest in Lower Jurassic, Sinemurian times, it can still be recognized in the Lower Cretaceous, and must – at least temporarily – have had a relief of several hundred metres (see figures 3 and 4).

No shallow water deposits are present on the high, which must have been at all times in rather deep water. However, as can be expected from such a pronounced seabottom relief, mass flow deposits are characteristic for the lower slope facies. They have clearly a maximum development in the Upper Jurassic, possibly indicating a period of increased tectonic activity. From Middle Jurassic times on indications exist of contour currents sweeping this submarine topographic feature.

Acknowledgements

This paper is abstracted from a detailed data base, included in the theses of the author and two fellow students, HANSMARTIN HÜSSNER and EUGEN ANGSTER. The thesis formed part of studies leading to a degree in Geology at the University of Munich. The field work was carried out in summer 1978 and spring 1979.

I wish to thank HANSMARTIN HÜSSNER and EUGEN ANGSTER for their cooperation during the fieldwork and the compilation of the thesis and Prof. Dr. F. T. FÜRSICH and Prof. Dr. D. HERM, Munich, for fruitful discussions and experienced advice during that time.

The fieldwork was supported by a grant from the Deutsche Akademische Austauschdienst.

Special thanks go to the mayor and the inhabitants of the township of Piobbico, Italy, for their most generous hospitality during the fieldwork.

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Zeitschrift/Journal: Mitteilungen der Bayerischen Staatssammlung für Paläontologie und Histor. Geologie

Jahr/Year: 1985

Band/Volume: 25

Autor(en)/Author(s): Immerz Peter

Artikel/Article: Facies relationships in the Jurassic and Lower Cretaceous pelagic limestones of the Monte Nerone Area, Province of Marche, Italy. - Sedimentation on a submarine high 195-208