Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 74 (1981)

Heft: 2

Artikel: Depositional processes in an ancient pelagic environment : the Lower Cretaceous Maiolica of the Southern Alps

Autor: Weissert, Helmut

DOI: https://doi.org/10.5169/seals-165109

Eclogae geol. Helv.	Vol. 74/2	Pages 339-352	6 figures in the text	Basle, July 1981

Depositional processes in an ancient pelagic environment: the Lower Cretaceous Maiolica of the Southern Alps[1])

By HELMUT WEISSERT[2])

ABSTRACT

The facies pattern of the pelagic Maiolica Formation (Early Cretaceous, Southern Alps) was not only controlled by paleoceanography but significantly modified by local processes of sediment redeposition. As a main redistribution process acted subaqueous mass flows related to the basin and swell morphology, typical for wide parts of the continental margins of the Mesozoic Tethys Ocean. In the Maiolica Formation the deposits related to subaqueous mass flows can be grouped in four categories: 1. rotated beds, 2. slumps with syngenetic folds, 3. slumps with chaotic internal structure and 4. coarse-grained beds and turbidites. These four categories represent different stages of subaqueous mass flows. Bottom currents acted as a second significant redeposition process. Sedimentary structures in chert layers, intercalated between the limestone sequence, indicate that radiolaria were periodically reworked by currents.

ZUSAMMENFASSUNG

Das Faziesbild der pelagischen Maiolica-Formation aus der südalpinen Unterkreide wurde nicht nur durch paläozeanographische Prozesse geprägt, Sedimentumlagerungsprozesse modifizierten das Sedimentbild zum Teil beträchtlich. Subaquatische Rutschungen waren in erster Linie verantwortlich für die beobachtete Umverteilung der pelagischen Sedimente. Diese Rutschungen standen in enger Beziehung zur südalpinen Becken- und Schwellenmorphologie. Die Ablagerungen, die auf submarine Rutschungen zurückzuführen sind, können in vier Kategorien gruppiert werden: 1. rotierte Schichtpakete, 2. submarine Rutschungen mit syngenetischen Falten, 3. submarine Rutschungen mit chaotischer Struktur, 4. Konglomerate und Turbidite. Diese vier Kategorien widerspiegeln vier verschiedene Phasen in submarinen Rutschungsprozessen. Neben submarinen Rutschungen waren es hauptsächlich Bodenstömungen, die das ursprüngliche pelagische Sedimentbild veränderten. Sedimentstrukturen in Silexlagen deuten darauf hin, dass Radiolarien wiederholt durch Bodenströmungen umgelagert wurden.

Introduction

At the beginning of this century, the German geologist STEINMANN (1905, 1925) interpreted fine-grained and homogeneous limestones from the Southern Alps (North Italy) and elsewhere in the Mediterranean area as remnants of a deep Mesozoic Tethys Ocean and initiated a long lasting controversy among geologists on the absolute depth of ancient "geosynclines". Steinmann's argument, that deep-sea sediments could indeed be found in mountain belts, was based on a comparison of

---

[1]) International Geological Correlation Programme, Project 105, Contribution No. 29.
[2]) Geologisches Institut der Universität, Bernoullistr. 32, CH-4056 Basel.

the Southern Alpine Maiolica limestone with modern deep-sea sediments recovered by the famous *Challenger* expedition (1872-76, MURRAY & RENARD 1891). Half a century after Steinmann's impressive analysis, new discoveries in oceanography and marine geology stimulated alpine geologists to reexamine their classic sequences in the Southern Alps. The new analysis no longer concentrated on the problem of absolute depth of deposition. The interpretation of fine-grained, pelagic sediments in the light of modern oceanography, or, in other words, the reconstruction of fertility, circulation and chemistry of the Mesozoic Tethys became a central theme of these studies (HSÜ 1976, WEISSERT 1979).

A reconstruction of oceanic history from pelagic sediments is generally made using the assumption that the studied sequences are continuous and interruptions resulting from redeposition processes are negligible. However, reexamination of Steinmann's Maiolica sequences in the Southern Alps showed that the pelagic facies pattern is not only controlled by oceanographic processes but that various redeposition processes have significantly modified the original sedimentary distribution. Paleoceanographic studies, therefore, should include a detailed examination of potential redeposition processes in the area of study. In this paper, I will present examples of redeposited sediments in the pelagic limestones of the Lower Cretaceous Southern Alpine Maiolica Formation. This study is based on an analysis of 18 sections, situated between Lago Maggiore and the Italian-Yugoslavian border (Fig. 1). Special emphasis will be placed on a discusssion of sediment redistribution by subaqueous sliding and slumping and by periodic bottom currents. Only an understanding of the effect of these processes upon the sedimentary facies pattern will allow an evaluation of the oceanographic processes influencing the composition of ancient pelagic deposits such as the Maiolica limestone.

The Southern Alps in the Early Cretaceous

During the Mesozoic, the Southern Alps were part of the southern continental margin of the western Tethys Ocean. After the breakup of the Eurasian-African continent in Late Triassic-Early Jurassic times, large parts of this southern continental margin were submerged and pelagic sediments were deposited over these areas of the Late Jurassic-Early Cretaceous Tethyan margins (BERNOULLI & JENKYNS 1974). Distinct variations in the facies pattern of the Jurassic pelagic sediments indicate that a complex basin and swell configuration had already developed by Late Triassic times and persisted throughout the Jurassic. In the Southern Alps, two basins - the Lombardian Basin and the Belluno Basin - were separated by a submarine high, the Trento Swell (AUBOUIN 1960). To the east, a shallow-water platform, the Friuli Platform, bordered the Belluno Basin. Facies differences between basins and plateaus became less pronounced with the deposition of a white to gray nannofossil ooze during the Early Cretaceous (Fig. 1, 2B).

In the Lombardian Basin, the sequence of these nannofossil limestones, defined as Lombardian Maiolica Formation (WEISSERT 1979), overlies radiolarites and radiolarian limestones. The formation is of Late Tithonian to Barremian age. In the lower part of the up to 150 m thick formation, white lutitic limestones with irregular-

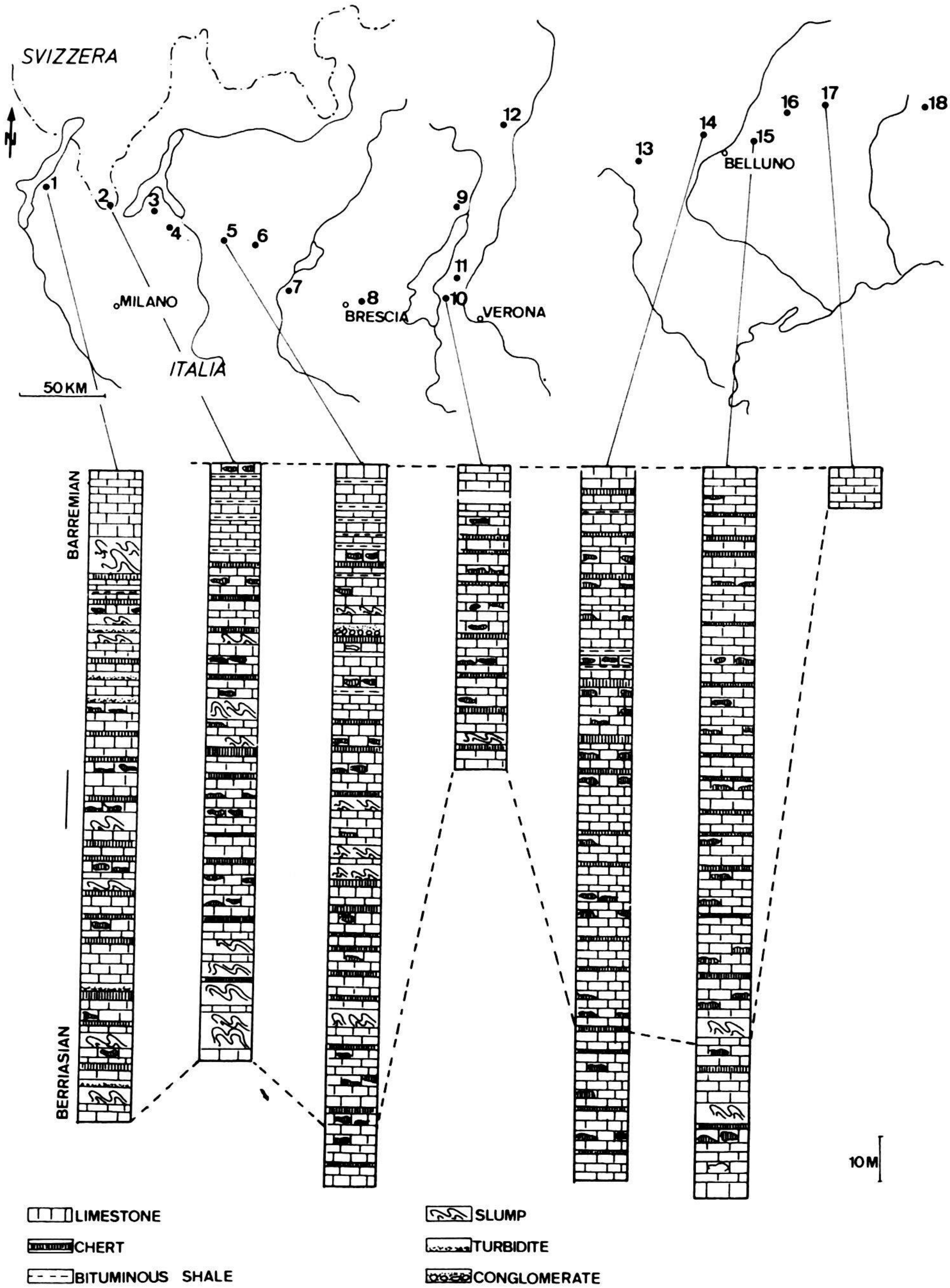

Fig. 1. Typical stratigraphic profiles of the Lower Cretaceous Maiolica and Biancone Formation in the Southern Alps. The locations of the studied sections are: 1 = Cittiglio, 2 = Breggia, 3 = Suello, 4 = M. Barro, 5 = Torre de Busi, 6 = Nese, 7 = Capriolo, 8 = Brescia, 9 = Ballino, 10 = Spiazzi, 11 = V. Aviana, 12 = Mezzolombardo, 13 = Fonzaso-Cismon, 14 = Valle del Mis, 15 = Soccher, 16 = Casso, 17 = Claut, 18 = Gemona.

ly intercalated chert layers and nodules dominate. The upper part of the section comprises gray lutitic limestones with chert layers and nodules. Black, bituminous shales are intercalated between the Barremian limestones. In the Aptian, the Lombardian Maiolica Formation is replaced by a sequence of red, green and black marls, the Scaglia variegata. The Venetian Biancone Formation, overlying nodular limestones in Rosso Ammonitico facies of the Trento Swell, is of Berriasian to Aptian age (CITA 1964, GRANDESSO 1979). White lutitic limestones are infrequently interrupted by a layer of chert. Black shale intercalations are missing. In the Aptian, marly limestones mark the base of the Scaglia variegata. In the eastern Belluno Basin, gray Lower Cretaceous limestones form part of the Calcare di Soccher (GNACCOLINI 1968). These limestones are comparable with the ones in the upper part of the Lombardian Maiolica Formation. Whereas chert intercalations are common, black-shale intercalations comparable to those from the Lombardian Basin are missing.

The lutitic limestones, described by STEINMANN (1925) as deep, pelagic deposits, consist of 80–95% $CaCO_3$. The main calcareous constituents are nannofossils cemented by diagenetic calcite. Notable is the monotonous floral composition of the limestones. Resistant and long living forms, such as *Watznaueria barnesae* or *Nannoconus*, dominate the floral association. Dissolution features and syntaxial overgrowth observed on *Watznaueria* are probably related to dissolution-reprecipitation processes during diagenesis. Calpionellids, calcispheres and radiolaria, the latter mainly preserved as calcite-filled moulds, complete the microfossil assemblage in the Maiolica limestone. Rare macrofossils such as aptychi, belemnites or bivalves are preserved in the limestone sequence. Besides calcite, illite, diagenetic quartz and accessory pyrite are the most important mineralogical constituents. A slightly higher percentage (15–25%) of residual material is measured in the gray Maiolica limestone, giving a dark color which contrasts with the white limestone. This contrast enhances the visibility of burrows. While the white limestones appear completely homogenized, *Planolites*, *Chondrites*, *Zoophycos* and rare *Teichichnus* burrows can be recognized in the gray limestone.

Two oceanographic events are recorded in the uppermost Jurassic-Lower Cretaceous pelagic sediments of the Southern Alps. With the onset of the nannofossil ooze deposition at the end of the Jurassic a drastic change in the planktonic association of the western Tethys took place. Radiolarian chert of Late Jurassic age, deposited below and near the carbonate compensation depth, is interpreted as a mirror of high fertility conditions in the Tethys surface water (HSÜ 1976). A decrease in productivity caused a drastic decrease in the radiolarian population and a coccolith flora, more tolerant to a low nutrient level could develop rapidly (WEISSERT 1979). The monotonous floral composition as well as a low sedimentation rate of 6 mm/1000 y (a value not corrected for compaction) reflect low fertility conditions in the surface waters of the southwestern part of the Tethys (WEISSERT 1979). In the Maiolica Formation of the Lombardian Basin, interpreted as being deposited in a depth of several thousand meters (BOSELLINI & WINTERER 1975) another significant change in paleoceanographic conditions is recorded in the Barremian. A series of bituminous shales alternating with nannofossil limestone is related to periodic anoxic events in the deep water of the Tethys Ocean (WEISSERT et al. 1979).

These anoxic events may be connected with similar events observed in all major oceans in Early to mid-Cretaceous times (JENKYNS 1980, WEISSERT 1981).

Superimposed on these sedimentation processes controlled by the paleoceanography are a series of redeposition processes related to the local paleogeographic conditions.

Sliding and slumping

Significant variations in the thickness of the Neocomian Maiolica Formation provide testimony for extensive mechanical erosion and accumulation processes which are related to the preexisting basin and swell morphology (Fig. 2). In the Lombardian Basin, the Maiolica Formation has a thickness of up to 150 m. The Garda escarpment (CASTELLARIN 1972) separates the Lombardian Basin from the Trento Swell where Lower Cretaceous sediments may be completely missing, or outcrop in sequences of up to 70 m thickness. The transition from the Trento Plateau to the Belluno Basin is gradational during the Early Cretaceous. In the eastern Belluno Basin, up to 200 m of carbonate ooze accumulated during the Berriasian-Barremian interval.

Subaqueous sliding and slumping were the main mechanisms of sediment redistribution in the Early Cretaceous of the Southern Alps. Slide and slump deposits were intercalated into basinal sequences of the Lombardian and Belluno troughs and the accretional series of the eastern Trento Swell. They are grouped into four types (Fig. 3):

1. *Rotated beds* (Fig. 4A): A characteristic example of this type of slide deposit is found in the Suello section of the Lombardian Basin. A regular bedded sequence of nannofossil limestone is interrupted by a 4-m-thick rotated unit of limestone and chert. The angle between the bedding in the slide and the dip of the undisturbed beds is around 30°. A distinct shear plane separates the underlying white limestones from the gray limestone in the slide. 50 cm beneath the shear plane a chert layer is ruptured, indicating that the sediment originally present at the site of later chert formation was deformed during the deposition of the slide mass. Within the slide, the bedding remained undisturbed. An irregular surface separates the slide from the overlying gray limestone.

2. *Slumps with syngenetic folds* (Fig. 4B): Sandwiched between undeformed sediments of the Lombardian Maiolica Formation in the sections Cittiglio, Breggia, Torre de Busi and of the Calcare di Soccher in Soccher are intensely folded deposits, up to several meters thick. Box folds, recumbent folds and isoclinal folds were formed during displacement of pelagic nannofossil ooze. Horizons, originally enriched in siliceous microfossils, were integrated into some of the slump deposits. These layers became selectively silicified during diagenesis. Slump folds, often difficult to recognize if both fold and surrounding matrix are composed of lutitic limestone, are accentuated by these silicified beds.

3. *Slumps with chaotic internal structure* (Fig. 4C): Redeposited beds with a chaotic structure outcrop in the sections Cittiglio and Breggia. Cobbles and pebbles of nannofossil limestone and chert are embedded in a matrix of homogenized

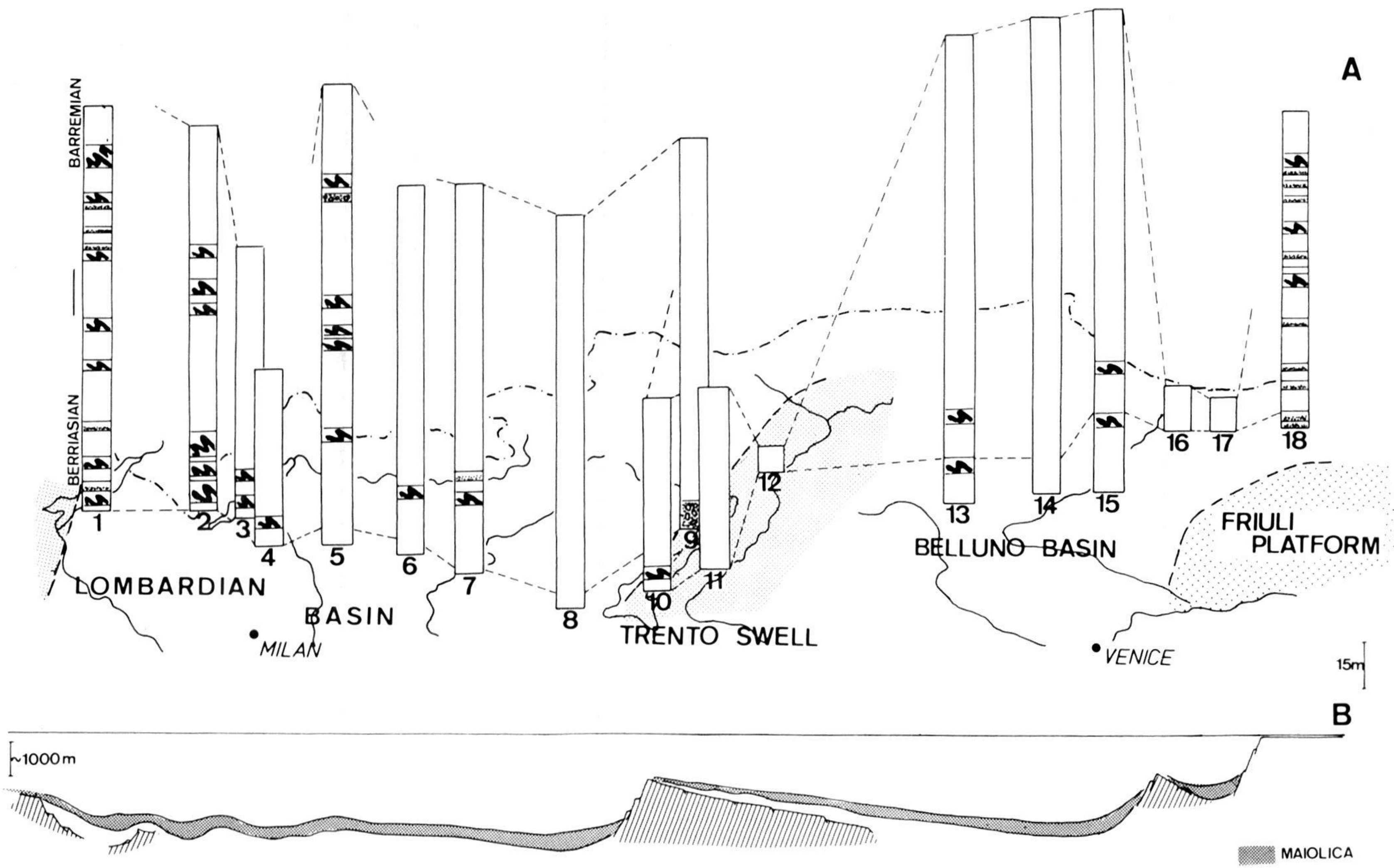

Fig. 2. A: The thickness variation and the distribution of slide and slump deposits in the Early Cretaceous nannofossil limestone sequence of the Southern Alps (sections plotted on perspectivic map, localities see Fig. 1). B: Palinspastic cross section of the Southern Alps during Early Cretaceous times.

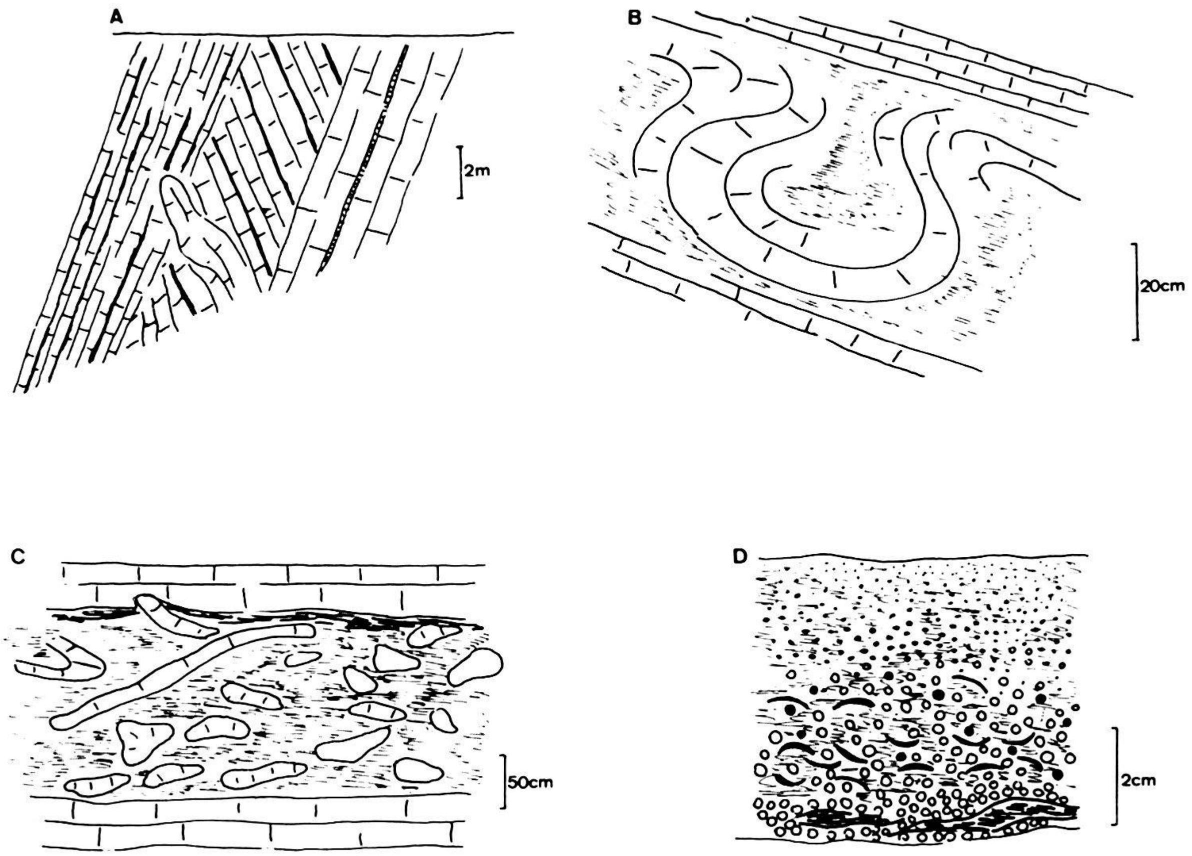

Fig. 3. Four types of redeposited beds, related to subaqueous mass movement: A = rotated beds, B = slumps with syngenetic folds, C = slumps with chaotic internal structure, D = coarse-grained beds and turbidites.

nannofossil ooze. Relicts of disruptured beds and syngenetic folds, as well as imbricated clasts, are prominent in a 60-cm-thick deposit in the Cittiglio section (Fig. 4C). The lower contact is erosional, the upper surface of the slump is irregular with large clasts projecting above the bed level.

4. *Coarse-grained beds and turbidites* (Fig. 4D): Beds, up to 50 cm thick with a conglomeratic texture, are intercalated between the nannofossil limestones at Cittiglio and Capriolo. Unsorted pebbles of nannofossil limestone and chert are supported by a matrix of nannofossil limestone or chert. Rapid lateral thinning of a coarse-grained bed in the Capriolo section indicates that small erosional channels were filled with redeposited pelagic material. Load casts and flame structures at the base of a coarse-grained bed in the section Cittiglio suggest strong erosional activity of subaqueous mass flows. Slump and slide deposits, as well as conglomeratic beds, are locally overlain by a graded bed. An example of a centimeter-thick turbidite horizon covering a sheet of slumped nannofossil ooze is shown in Figure 5A. Aptychi and limestone and chert grains form the graded part of the bed. An intensely silicified layer of radiolarian sand without recognizable sedimentary structures overlies the graded unit.

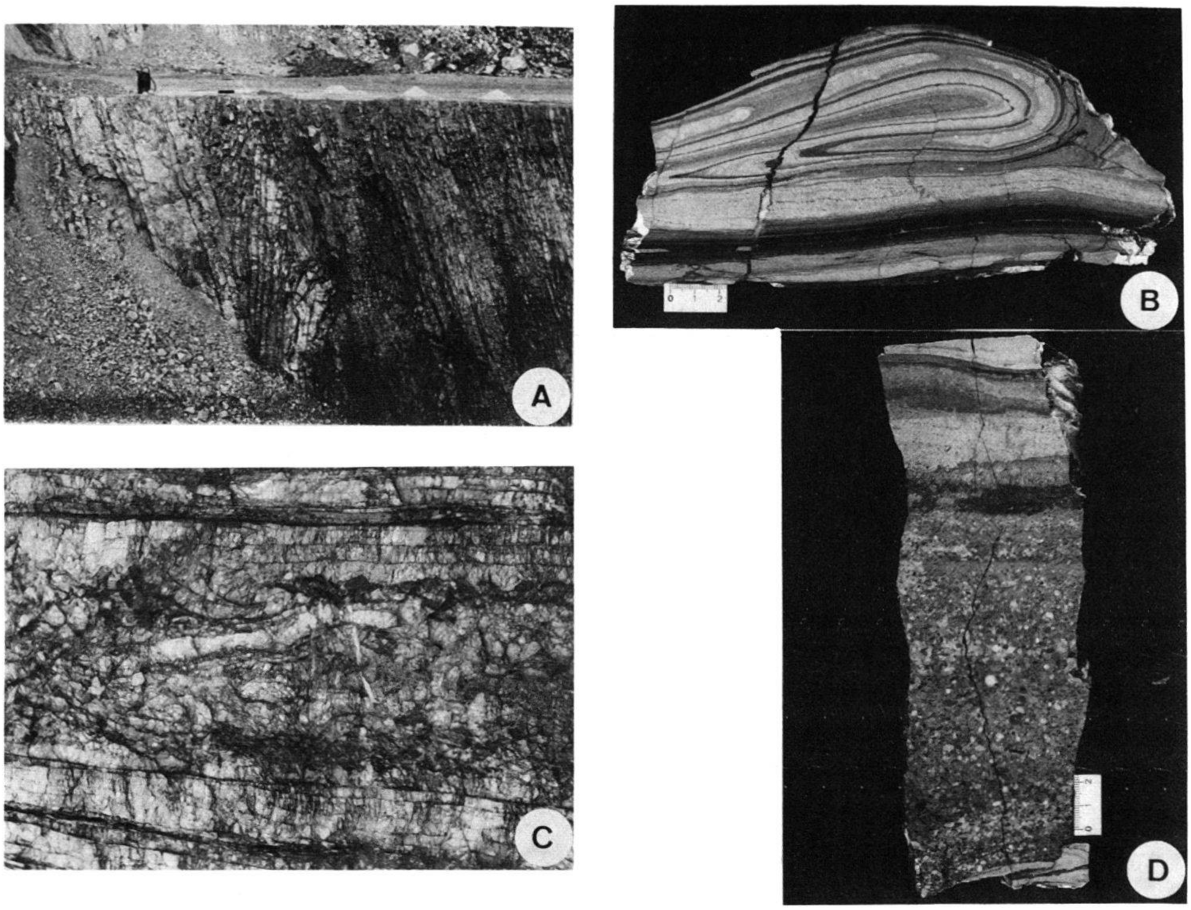

Fig. 4. A: Rotated beds, sandwiched between a sequence of undisturbed nannofossil limestone of the Suello section. Thickness of the slide: 4 m. B: Refolded isoclinal fold from a slump in the Cittiglio section (scale in cm). C: Slump with a chaotic internal structure (locality: Cittiglio). Clasts project above bed level. Thickness of the slump: 60 cm. D: Coarse-grained bed overlain by a series of turbidites. Nannofossil limestone (white) and chert (gray and black) are recognized as main components. The dark areas in the upper part of the bed are intensely silicified (scale in cm). Locality: Cittiglio.

Slides and slumps: mechanism of transport and deposition

The reconstruction of the transport and depositional mechanism for a resedimented unit on the basis of depositional structures is a difficult task. The observed structures often only reflect the last of a series of transport mechanisms. Slides, slumps and fluidal flows form a continuum of mass movement processes along a slope (DOTT 1963, MORGENSTERN 1967, NARDIN et al. 1979). Different depositional structures commonly record changes in the mechanical behavior of a flow. For example, elastic deformation is typical in slides, whereas slumps are characterized by plastic internal deformation. A fluidal flow can result when a slump mass is increasingly mobilized by an admixture of water (MIDDLETON & HAMPTON 1972, CARTER 1975). Depositional features reflecting different stages of a gravity-controlled subaqueous mass flow have been observed in various modern depositional environments (EMBLEY 1976, HANER & GORSLINE 1978, NARDIN et al. 1979, KELTS & HSÜ 1980). Comparison of the redeposited beds observed in the Southern Alps with recent slide and slump beds offers convincing evidence that the above four depositional types reflect different stages of subaqueous mass movements. A slide, consisting of a package of rotated beds, can evolve into a slump with syngenetic folds, as described in type 2. Increasing plastic deformation within the slump causes disruption of folds and beds and a chaotic structure with variable-sized clasts embedded in a homogenized matrix results. Through the integration of water, parts of the slump may be completely mobilized. This stage of subaqueous mass flow is recorded in deposits of type 4.

In the Southern Alps, the slides and slumps are commonly associated with lithological boundaries. An increased number of slumping features is registered at the contact between Maiolica Formation and the underlying Rosso ad Aptici Formation. Another group of slumps occurs at the transition from the white to the gray Maiolica. Along these lithological boundaries, the shear strength of the sediments may have been reduced because of permeability and pore pressure changes. This reduced shear strength made these horizons preferred zones of mechanical failure.

The paleomorphology or, in other words, the inclination of the slopes acts as another controlling factor on the stability of sediments. The large number of slump deposits in the section Cittiglio of the western Lombardian Basin suggests that a Jurassic high - the Gozzano Swell (KÄLIN & TRÜMPY 1977) - was still present in Early Cretaceous times, although the orientation of slump folds gives no conclusive evidence on the orientation of the ancient slope. Slump deposits in the Breggia section originated from another submarine high - the Arbostora Swell (BERNOULLI 1964) - which had persisted from Early Jurassic times. Decimeter-sized phacoids (VOIGT 1962), covering an erosional surface underneath the basal slump of the Maiolica Formation, face towards southeast. Their orientation suggests that the Breggia section was situated along the southeastern slope of the Arbostora High. Slump and slide deposits distributed throughout the Cretaceous of the central part of the Lombardian Basin document an uneven topography inherited from its Jurassic precursor (GAETANI 1975). The Lombardian Basin was separated from the Trento Swell by a steep escarpment causing the formation of slide and slump deposits and conglomerates (CASTELLARIN 1972). In the sequences of the gently inclined eastern slope of the Trento Plateau only a few slide and slump deposits could be recognized. More pronounced morphological differences characterize again the easternmost part of the Southern Alps. Periodic turbidity currents transported shallow-water debris from the Friuli Platform into the eastern Belluno Basin (GNACCOLINI & MARTINIS 1974).

Layered chert - an indicator for bottom-current activity

Chert nodules and layers are associated with the nannofossil limestones of the Southern Alps. Chert nodules rarely contain information on the type and structure of the sediments originally present but various sedimentary structures, not masked by diagenetic silicification, indicate depositional processes related to the siliceous layers. Texturally the Maiolica chert can be classified into two groups:

1. Dense chert with conchoidal fracturing is classified as vitreous chert (cf. ROBERTSON 1977) (Fig. 5B). X-ray diffraction analysis of 12 characteristic samples from the Breggia and Torre de Busi sections indicates that quartz is the only existing SiO_2 phase. In thin section, rare radiolarian moulds can be recognized in a chalcedonic matrix.

2. Limestone with a granular texture, incompletely silicified, is classified as granular chert (cf. ROBERTSON 1977). Quartz is again the only silica phase. In thin section up to 40% radiolarian moulds are seen densely packed in a partially silicified matrix of nannofossil limestone. The radiolaria are either completely silicified or occur as calcitic or pyritic moulds.

Vitreous chert layers reach a thickness of up to 20 cm. Primary structures are rarely preserved. Aptychi, enriched at the base of one of these horizons (Fig. 5B), indicate modification of the sediment by current action. Sharp contacts separate the

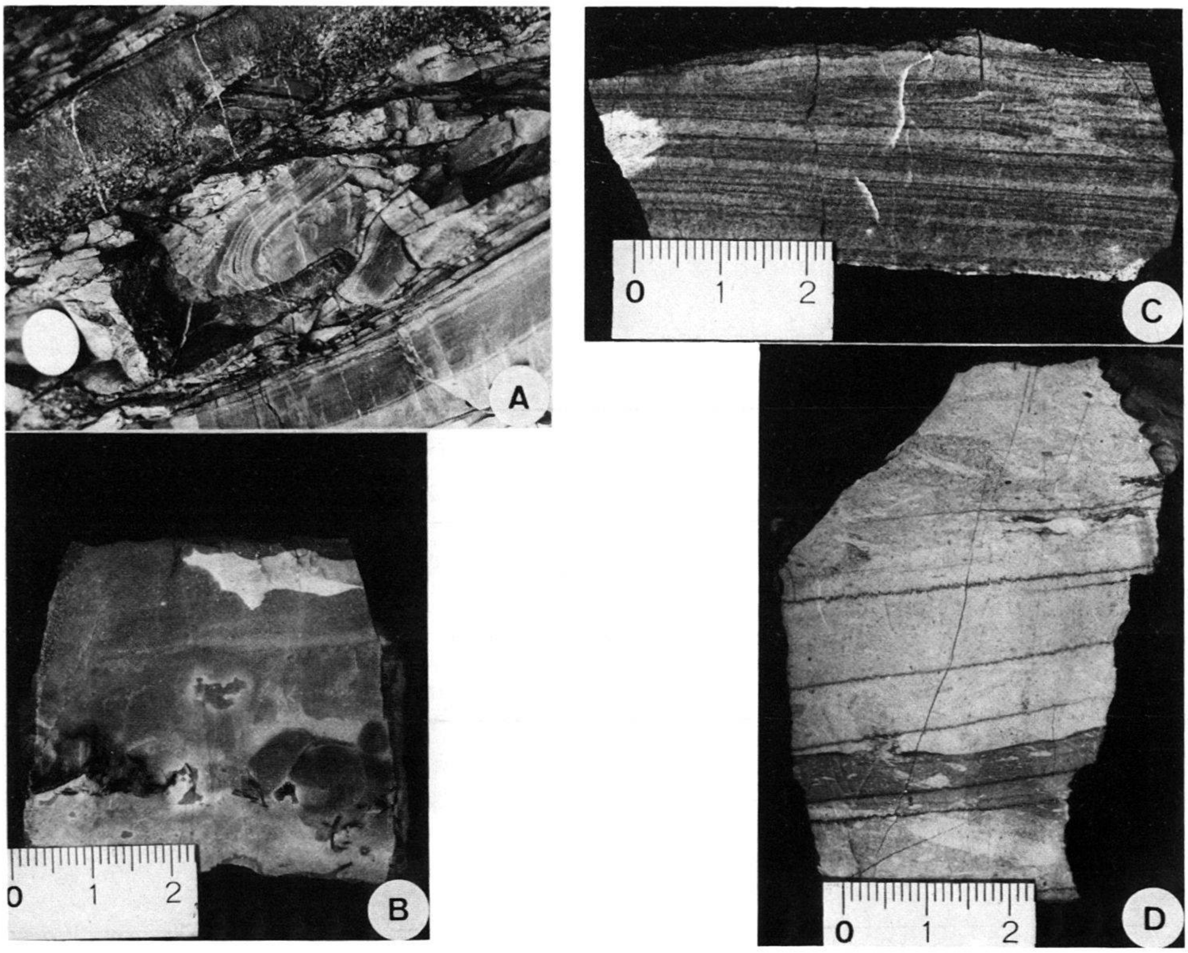

Fig. 5. A: A radiolarian turbidite overlying a slumped sheet in the Cittiglio section, the turbidite is intensely silicified. Diameter of the coin is 2 cm. B: Vitreous chert layer from the Nese section with aptychi enriched in the lower part of the bed (scale in cm). C: Granular chert layer from the Nese section with winnowing features in the upper part of the bed (scale in cm). D: Redeposited nannofossil limestone. Bioturbation features are restricted to the sediments underneath and above the reworked layer. An escape burrow ends within the redeposited bed (left part of the photograph). Scale in cm.

vitreous chert layers from the adjacent nannofossil limestone or granular chert. The granular chert layers contain more evidence on the environment of deposition. Sedimentary structures such as parallel lamination, small scale cross-bedding and winnowing suggest current activity was envolved in the formation of the beds (Fig. 5C). Another common feature of granular chert is size grading of radiolaria. In the granular chert and to a lesser extent, in the vitreous chert, the enrichment of radiolarian tests suggest that the silicification occurred preferentially at sites of silica concentration. This observation is in agreement with various descriptions of chert recovered by the Deep Sea Drilling Project (i.e. VON RAD & ROESCH 1974, KEENE 1976).

In the study of the Tethyan paleoceanography a central question is whether the silica concentration necessary for the subsequent chert formation was produced by productivity changes in the Early Cretaceous Tethys Ocean or whether it was the result of episodic hydrodynamic processes such as bottom currents or turbidity currents. The distribution of chert layers within the Lombardian Maiolica is irregular and their number varies significantly among the examined stratigraphic sections (Fig. 6). Positive indications for episodic radiolarian blooms due to fertility changes cannot be found. On the other hand the observed sedimentary structures argue in favor of hydrodynamic processes. The enhancement of radiolarian concentrations could be produced by two processes: either coccoliths are winnowed out by currents and the remaining radiolaria form a lag deposit, or radiolaria are reworked and redeposited by bottom currents or low-density turbidity currents. The development of lag deposits by current activity has been observed by various authors in the pelagic realm of modern oceans (i.e. HEEZEN & HOLLISTER 1964, PRELL 1977). PRELL (1977) studied the sediment-size distribution in the present-day Columbia Basin and observed a significant increase in the sorting coefficient as a result of bottom current activity. He found evidence for redeposition of coccolith ooze. Foraminifera were not eroded but formed a well-sorted lag deposit. Whether the coccoliths actually were winnowed or removed prior to deposition remains an important but unanswered question. Evidence for reworked coccolith debris in the Maiolica Formation is rarely found but abrupt changes in the intensity of bioturbation in some limestone beds provides the best argument for redeposition of Early Cretaceous carbonate ooze (Fig. 5D).

Enrichment of radiolaria by bottom currents or low-density turbidity currents was proposed by various authors studying ancient chert deposits (BERGER & VON RAD 1972, NISBET & PRICE 1974, GARRISON 1974, ROBERTSON 1977). Yet current-concentrated radiolarian sands have not been described from present-day oceans. Experimental data on threshold velocities of radiolarians are also unavailable. In a sediment with grains of different bulk density, specific threshold velocities have to be calculated for each grain type (MILLER & KOMAR 1977). In their experiments, MILLER & KOMAR have demonstrated that the threshold velocity for foraminifera is significantly lower than for coccoliths because of their lower bulk density. Bottom currents with velocities of 5-15 cm/s may erode foraminifera while currents of 15-30 cm/s are required to winnow coccoliths (SOUTHARD et al. 1971). Radiolaria have a considerably lower bulk density than coccoliths and foraminifera (KEENE 1976). Therefore, one might expect lower threshold velocities for radiolarians than

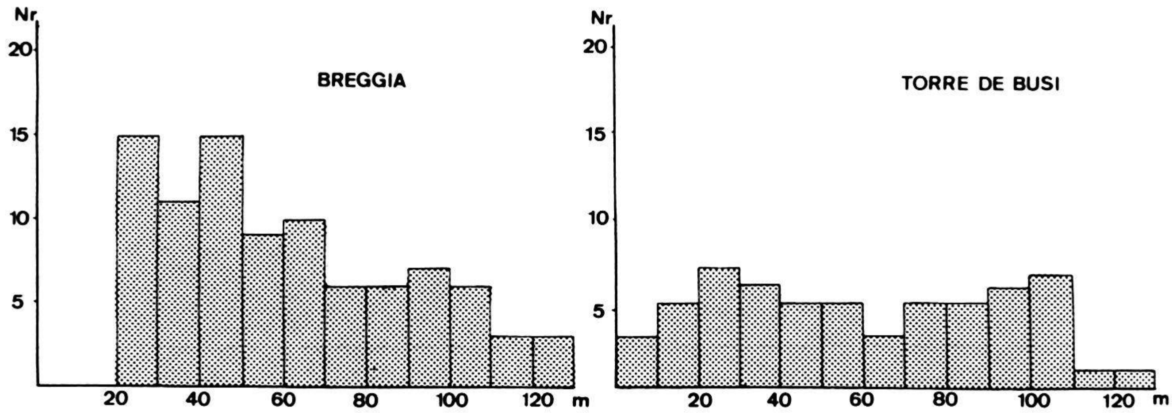

Fig. 6. The distribution of chert layers in the Breggia and Torre de Busi sections from the Lombardian Basin. Nr. = number of chert layers per 10 m of section. Abscissa: thickness of the formations.

for coccoliths or even foraminifera. This would imply that horizons enriched with siliceous material were not lag deposits but were formed by redeposition due to current activity. The estimated velocities of 5–15 cm/s required for erosion of radiolarians are within the range of reported velocities for periodic bottom currents in present-day oceans (LONSDALE & MALFAIT 1974).

Assuming that most of the chert layers in the Maiolica Formation resulted from bottom current activity, the vertical distribution of chert layers in the sequence reflects the frequency of episodic currents influencing the depositional environment. A significant decrease in the number of chert layers is registered in the Barremian Maiolica Formation of the Lombardian Basin (Fig. 6). This decrease coincides with the beginning of cyclic anoxic events in the Early Cretaceous Tethys (WEISSERT et al. 1979). The reduced number of chert layers may be additional evidence that the Lombardian Basin was characterized by sluggish bottom water conditions during the Barremian.

Summary

The Early Cretaceous pelagic sediments of the Southern Alps reflect the general paleoceanographic conditions of the southwestern Tethys Ocean (WEISSERT 1979). Superimposed on sedimentation processes controlled by the paleoceanography are sediment redistribution processes related to the paleogeography and local paleoceanography. In the Southern Alps, the basin and swell pattern, typical for the Mesozoic continental margin of the southwestern Tethys had a considerable effect upon the distribution pattern of the pelagic sediments. The erosional environments of the plateaus and the adjacent escarpments were represented by formations with reduced thickness, while accretional environments of the basins were characterized by thicker sequences. Subaqueous mass flows acted as a main sediment transport mechanism. The deposits related to mass flows can be classified in four groups: 1. rotated beds, 2. slumps with syngenetic folds, 3. slumps with chaotic internal bedding and 4. coarse-grained beds and turbidites. These four groups represent different stages in subaqueous mass flows. Bottom currents acted as a second mechanism of sediment redistribution. Radiolaria were periodically reworked by the

currents and accumulated in distinct horizons. These beds became preferred sites of chert formation during diagenesis.

An understanding of these depositional processes modifying the original facies pattern is not only essential for the reconstruction of the regional paleoenvironment. It is also of importance for paleoceanographic studies. A detailed reconstruction of the circulation history, the fertility changes or the paleotemperature development in the Early Cretaceous Tethys Ocean requires the application of precision stratigraphy using new methods as stable-isotope stratigraphy or magnetostratigraphy (CHANNELL et al. 1979, WEISSERT et al. 1979). Any interpretation of these data has to include the possibility that the pelagic sequences are not continuous but disruptured by local sediment distribution processes.

Acknowledgments

Helpful discussions with K. Hsü and K. Kelts are gratefully acknowledged. I thank J.A. McKenzie, H. Jenkyns and D. Bernoulli for critical comments which improved the manuscript. I also thank U. Gerber for his photographic work. Funds made available by Cementia Engineering and Consulting Ltd. (Zürich) and S.A. Cementi Balerna (Morbio Inferiore) for the publication of this paper are gratefully acknowledged.

REFERENCES

AUBOUIN, J. (1960): *Essai sur l'ensemble italo-dinarique et ses rapports avec l'arc alpin.* - Bull. Soc. géol. France (7), *2*, 487-526.

BERGER, W.H., & VON RAD, U. (1972): *Cretaceous and Cenozoic sediments from the Atlantic Ocean.* In: HAYES, D.E., PIMM, A., et al.: Init. Rep. Deep Sea Drill. Proj. (*14*, p.787-913). - U.S. Govt, Printing Office, Washington.

BERNOULLI, D. (1964): *Zur Geologie des Monte Generoso (Lombardische Alpen).* - Mater. Carta geol. Svizz.

BERNOULLI, D., & JENKYNS, H.C. (1974): *Alpine, Mediterranean and Central Atlantic Mesozoic facies in relation to the early evolution of the Tethys.* - Spec. Publ. Soc. econ. Paleont. Mineral. *19*, 129-160.

BOSELLINI, A., & WINTERER, E. (1975): *Pelagic limestone and radiolarite: A genetic model.* - Geology *3*, 279-282.

CARTER, R.M. (1975): *A discussion and classification of subaqueous mass-transport with particular application to grain-flow, slurry flow and fluxoturbidites.* - Earth-Sci. Rev. *11*, 145-177.

CASTELLARIN, A. (1972): *Evoluzione paleotettonica sinsedimentaria del limite tra «piattaforma veneta» e «bacino lombardo» a nord di Riva del Garda.* - G. Geol. *(2)*, 38, 11-212.

CHANNELL, J., LOWRIE, W.F., & MEDIZZA, F. (1979): *Middle and Early Cretaceous magnetic stratigraphy from the Cismon section, N. Italy.* - Earth planet. Sci. Lett. *42*, 153-166.

CITA, M.B. (1964): *Ricerche micropaleontologiche e stratigrafiche sui sedimenti pelagici del Giurassico superiore e del Cretacico inferiore nella catena del M. Baldo.* - Mem. Riv. ital. Paleont. (Stratigr.) *10*.

DOTT, R.H. (1963): *Dynamics of subaqueous gravity depositional processes.* - Bull. amer. Assoc. Petroleum Geol. *47*, 104-128.

EMBLEY, R.W. (1976): *New evidence for occurrence of debris flow deposits in the deep-sea.* - Geology *4*, 371-374.

GAETANI, M. (1975): *Jurassic stratigraphy of the Southern Alps: A review.* In: SQUIRES, L. (Ed.): *Geology of Italy* (p.377-402). - Earth-Sci. Soc. Libyan Arab. Republic, Tripoli.

GARRISON, R.E. (1974): *Radiolarian cherts, pelagic limestones and igneous rocks in eugeosynclinal assemblages.* In: HSÜ, K.J., & JENKYNS, H.C. (Ed.): *Pelagic sediments on land and under the sea* (p.367-399). - Spec. Publ. int. Assoc. Sedimentol. *1*.

GNACCOLINI, M., & MARTINIS, B. (1974): *Nuove ricerche sulle formazioni calcaree giurassico-cretaciche della regione compresa tra le valli del Natisone e del Piave.* - Mem. Riv. ital. Paleont. (Stratigr.) *14*, 5-109.

GRANDESSO, P. (1979): *Gli strati a precalpionellidi del Titoniano e i loro rapporti con il Rosso Ammonitico veneto.* - Mem. Ist. geol. Univ. Padova *32.*

HANER, B., & GORSLINE, D.S. (1978): *Processes and morphology of continental slope between Santa Monica and Dume submarine canyons, Southern California.* - Marine Geol. *28,* 77-87.

HEEZEN, B.C., & HOLLISTER, C. (1964): *Deep-sea current evidence from abyssal sediments.* - Marine Geol. *1,* 141-174.

HSÜ, K.J. (1976): *Paleoceanography of the Mesozoic Alpine Tethys.* - Spec. Pap. geol. Soc. Amer. *170.*

JENKYNS, H.C. (1980): *Cretaceous anoxic events: from continents to oceans.* - J. geol. Soc. (London) *137,* 171-188.

KÄLIN, O., & TRÜMPY, D. (1977): *Sedimentation und Paläotektonik in den westlichen Südalpen: Zur triasisch-jurassischen Geschichte des Monte Nudo-Beckens.* - Eclogae geol. Helv. *70,* 295-350.

KEENE, J.B. (1976): *The distribution, mineralogy, and petrography of biogenic and authigenic silica from the Pacific basin.* - Diss. Univ. Calif., San Diego.

KELTS, K., & HSÜ, K.J. (1980): *Resedimented facies of 1875 Horgen slumps in Lake Zurich and a process model of longitudinal transport of turbidity currents.* - Eclogae geol. Helv. *73,* 271-281.

LONSDALE, P., & MALFAIT, B. (1974): *Abyssal dunes of foraminiferal sand on the Carnegie Ridge.* - Bull. geol. Soc. Amer. *85,* 1697-1712.

MIDDLETON, G.V., & HAMPTON, M.A. (1976): *Subaqueous sediment transport and deposition by gravity flows.* In: STANLEY, D.J., & SWIFT, D.P. (Ed.): *Marine sediment transport and environmental management* (p. 197-218). - Wiley, New York.

MILLER, M.C., & KOMAR, P.D. (1977): *The development of sediment threshold curves for unusual environments (Mars) and for inadequately studied materials (foram sands).* - Sedimentology *24,* 709-721.

MORGENSTERN, N.R. (1967): *Submarine slumping and the initiation of turbidity currents.* In: RICHARDS, A.F. (Ed.): *Marine Geotechnique* (p. 189-220). - Univ. Illinois Press, Urbana, Ill.

MURRAY, J., & RENARD, A.F. (1891): *Report on deep-sea deposits based on the specimens collected during the voyage of H. M. S. Challenger, in the years 1872-1876,* - Eyre & Spottiwoods, London.

NARDIN, T.R., HEIN, F.J., GORSLINE, D.S., & EDWARDS, B.D. (1979): *A review of mass movement processes, sediment and acoustic characteristics, and contrasts in slope and base-of-slope systems versus canyon-fan-basin floor systems.* - Spec. Publ. Soc. econ. Paleont. Mineral. *27,* 61-73.

NISBET, E.G., & PRICE, I. (1974): *Siliceous turbidites: bedded cherts as redeposited ocean-ridge derived sediments.* In: HSÜ, K.J., & JENKYNS, H.C. (Ed.): *Pelagic sediments on land and under the sea* (p. 367-399). - Spec. Publ. int. Assoc. Sedimentol. *1.*

PRELL, W.L. (1977): *Winnowing of recent and late Quaternary deep sea sediments, Colombia Basin, Carribbean Sea.* - J. sediment. Petrol. *47,* 1583-1592.

ROBERTSON, A.H.F. (1977): *The origin and diagenesis of cherts from Cyprus.* - Sedimentology *24,* 11-30.

ROBERTSON, A.H. F., & HUDSON, J.D. (1974): *Pelagic sediments in the Cretaceous and Tertiary history of the Troodos Massiv, Cyprus.* In: HSÜ, K.J., & JENKYNS, H.C. (Ed.): *Pelagic sediments on land and under the sea* (p. 403-436). - Spec. Publ. int. Assoc. Sedimentol. *1.*

SOUTHARD, J.B., YOUNG, R.A., & HOLLISTER, D. (1971): *Experimental erosion of calcareous ooze.* - J. geophys. Res. *76,* 5903-5909.

STEINMANN, G. (1905): *Die SCHARDTsche Überfaltungstheorie und die geologische Bedeutung der Tiefsee-Absätze und der ophiolithischen Massengesteine.* - Ber. natf. Ges. Freiburg i. Br. *16,* 44-65.

— (1925): *Gibt es fossile Tiefseeablagerungen von erdgeschichtlicher Bedeutung?* - Geol. Rdsch. *16,* 435-468.

VOIGT, E. (1962): *Frühdiagenetische Deformation der turonen Plänerkalke bei Halle/Westfalen als Folge einer Grossgleitung unter besonderer Berücksichtigung des Phacoidproblems.* - Mitt. geol. Staatsinst. Hamburg *31,* 57-145.

VON RAD, U., & ROESCH, H. (1974): *Petrography and diagenesis of deep-sea cherts from the central Atlantic.* In: HSÜ, K.J., & JENKYNS, H.C. (Ed.): *Pelagic sediments on land and under the sea* (p. 327-348). - Spec. Publ. int. Assoc. Sedimentol. *1.*

WEISSERT, H. (1979): *Die Paläozeanographie der südwestlichen Tethys in der Unterkreide.* - Mitt. geol. Inst. ETH u. Univ. Zürich *226.*

— (1981) *The environment of deposition of black shales in the Early Cretaceous: An ongoing controversy.* - Spec. Publ. Soc. econ. Paleont. Mineral. *32.*

WEISSERT, H., MCKENZIE, J.A., & HOCHULI, P. (1979): *Cyclic anoxic events in the Lower Cretaceous Tethys Ocean.* - Geology *7,* 147-151.