56. LITHOLOGIC FINDINGS OF DSDP LEG 42A, MEDITERRANEAN SEA

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ABSTRACT

This contribution records the most striking sedimentological findings of Leg 42A and outlines the scope for further research on recovered core materials. It emphasizes the use of comparative sedimentology as a tool in environmental interpretation and derives support for these interpretations from other lines of evidence, in particular faunal analyses and geophysical studies.

Sedimentological analyses of the pre-Messinian sequences, extensively drilled for the first time during this cruise, show that they are typically of a basinal facies: pelagic to hemipelagic sediments with turbidites. Pre-Messinian water depths derived from analyses of benthic foraminifers and ostracodes confirm these findings. The sites, however, occupy substantially different tectonic settings at the present day.

All of the depositional sequences drilled from the upper part of the Mediterranean evaporite formation, of Messinian age, can confidently be referred to subaerial or shallow subaqueous environments, although in the Ionian and Antalya basins these were replaced in the late Messinian by an oligohaline "Lago Mare" facies.

Post-Messinian sequences are again typically basinal, hemipelagic, and frequently turbiditic and are similar to those recovered in piston cores of Holocene and Pleistocene sediments. Sediments of this facies date from the Miocene/Pliocene boundary and faunal analyses show that early Pliocene water depths were at least 1000-1500 meters.

A review of the clay mineralogical results shows the primary influence of terrigenous sources and records the possible genesis of certain clay minerals in the desiccated environments of the Messinian. Sapropel layers are recognized to be more numerous than previously thought and are shown to date back as far as the middle Miocene. Conversely, tephra layers are, somewhat unexpectedly, poorly represented in the recovered material. Considerable scope remains for studies on both sapropel and tephra chronology. A complex history of sedimentation upon a volcanic Tyrrhenian seamount has been established and isotopic estimates of breccia cementation temperatures confirm that the seamount was in a deep water environment in the early Pliocene.

Four of the authors (R.B.K., D.B., R.E.G., F.M.) feel that the nature of the Messinian evaporites—shallow subaqueous to subaerial deposits, sandwiched between typically basinal, hemipelagic, Burdigalian to Tortonian and Pliocene to Holocene sequences—together with corroborative evidence from geophysical studies, strongly supports the deep-basin desiccation hypothesis for the Mediterranean during the late Miocene.

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INTRODUCTION

Glomar Challenger returned to the Mediterranean Sea in April and May of 1975 for Deep Sea Drilling Project Leg 42A, and drilled 10 holes at eight separate sites. Five years earlier, during Leg 13, 28 holes had been drilled at 15 site locations (Figure 1). From the shipboard participants evolved a late Neogene and Quaternary stratigraphy for the Mediterranean deep-sea areas (Ryan, Hsü, et al., 1973). This immediately provoked considerable debate concerning its paleoenvironmental significance, because a Pliocene-Quaternary sedimentary sequence, similar in all respects to sediments being deposited in modern deep-sea basins, directly overlies late Miocene (Messinian) evaporite rocks, which were comparable with those forming in the subaerial and shallow water environments of the present-day Persian Gulf.

Two of the prime objectives of this second cruise were to extend the stratigraphy of the deep basins to before the Messinian in order to establish paleoenvironments prior to the evaporite deposition; and by increased core recovery, to study in more detail environments during and after deposition of the evaporite.

Generalized sediment sequences drilled by Leg 42A are shown in Figure 2. Site 372 on the Menorca margin and the composite section resulting from Sites 375 and 376 on the Florence Rise are especially significant in that we recovered material from the overlying Pliocene sediments, through the Messinian evaporite and into the underlying pre-Messinian sediments.

The purpose of this contribution is to draw together the more significant lithologic findings contributed by drilling during Leg 42A. Discussion of the tectonic history of the Mediterranean basins and of the genesis of the Messinian evaporite formation appear in the main synthesis chapter of this volume (Hsü et al., this volume). We record here the sedimentological findings that are detailed in the contributions to Part II of this volume. We stress some especially significant features and outline possible further research studies on the sediments. The Leg 42A cores are now stored at the DSDP East Coast Repository at Lamont-Doherty Geological Observatory, New York.

When drilled sections are calibrated to seismic profiles, a three-dimensional picture of the stratigraphy of a basin emerges. For the finer scale, however, scientists rely heavily upon comparative sedimentology as a tool in interpreting the lithologies encountered. Sedimentologists aboard *Glomar Challenger* study cores up to 9.5 meters long, but these cores are not always taken continuously (only 79 of the 150 Leg 42A cores are part of continuously cored sequences), and they are only 6.5 cm in diameter. In order to build a detailed three-dimensional picture we rely heavily, therefore, upon comparison with land sections and sediments being deposited at the present time. Our descriptive terminology reflects this process. For example, the term "pelagic" when used for carbonate sediments means a fairly pure biogenic ooze which is similar to those deposited in certain open sea regions at the present time, "hemipelagic" sediments signifies those which have received a significant contribution of land-derived sand, silt, and clay material. Because of the geography of the present-day Mediterranean sediments of the latter type are particularly important. Neither term, however, is specific with respect to water depth at the site of deposition. We thus rely upon estimates of water depths from faunal assemblages for confirmation, or otherwise, of environmental interpretations on the basis of comparative sedimentology.

We discuss the pre-Messinian, Messinian, and post-Messinian sediment sequences separately, and we employ comparative sedimentology for environmental analysis and examine the faunal evidence in each case. We deal with the pre-Messinian sediments site by site and in greatest detail, because no specific chapters are devoted to them in this volume. The results of studies of clay mineral assemblages is presented in a later section, with emphasis placed on the sources of the fine sediment fractions. Intercalations in the sediment sequences, representing specific events in the history of deposition, are considered in succeeding sections devoted to sapropel and tephra layers. Finally, we consider the effects of submarine volcanic activity on sea floor sediments, which resulted in the basaltic breccia sequence of Hole 373A on one of the Tyrrhenian seamounts.

PRE-MESSINIAN SEDIMENTS

Prior to the Leg 42A, hemipelagic and turbiditic sediments, interpreted as deep water sequences, were known to underlie the Mediterranean Evaporite Formation at many places on land. However, these deposits were in part violently folded during the Pliocene and the Quaternary, and even though the evaporites are often sandwiched between hemipelagic and pelagic deposits, the evidence for a deep basin in which desiccation occurred during the late Miocene was not accepted as unequivocal (cf. Drooger, 1973). Thus the recovery of pre-evaporitic sediments in a postorogenic, extensional, and subsiding setting was of prime importance for the establishment of the tectonic and depositional environment in which the evaporite deposition occurred.

Pre-evaporitic sediments had been drilled during DSDP Leg 13 at Sites 121 and 126. At Site 121 in the Alboran Basin, 178 meters of hemipelagic marls, of Tortonian (Ryan, Hsü, et al., 1973) or pre-evaporitic Messinian (Montenat et al., 1975) age, with turbiditic sandstones, were encountered below a Miocene-Pliocene unconformity. At Site 126, only a few meters of Serravallian marls were recovered from a cleft in the Mediterranean Ridge (Ryan, Hsü, et al, 1973). During Leg 42A pelagic, hemipelagic and turbiditic, pre-evaporitic, early to middle and late Miocene sediments were recovered at Sites 372, 375, and 377.

The Messinian evaporites and their underlying sediments today occur in different tectonic settings. The sequence drilled at Site 372 on the Menorca Rise was deposited along a rifted and down-faulted margin (Mauffret et al., 1973) which came into existence

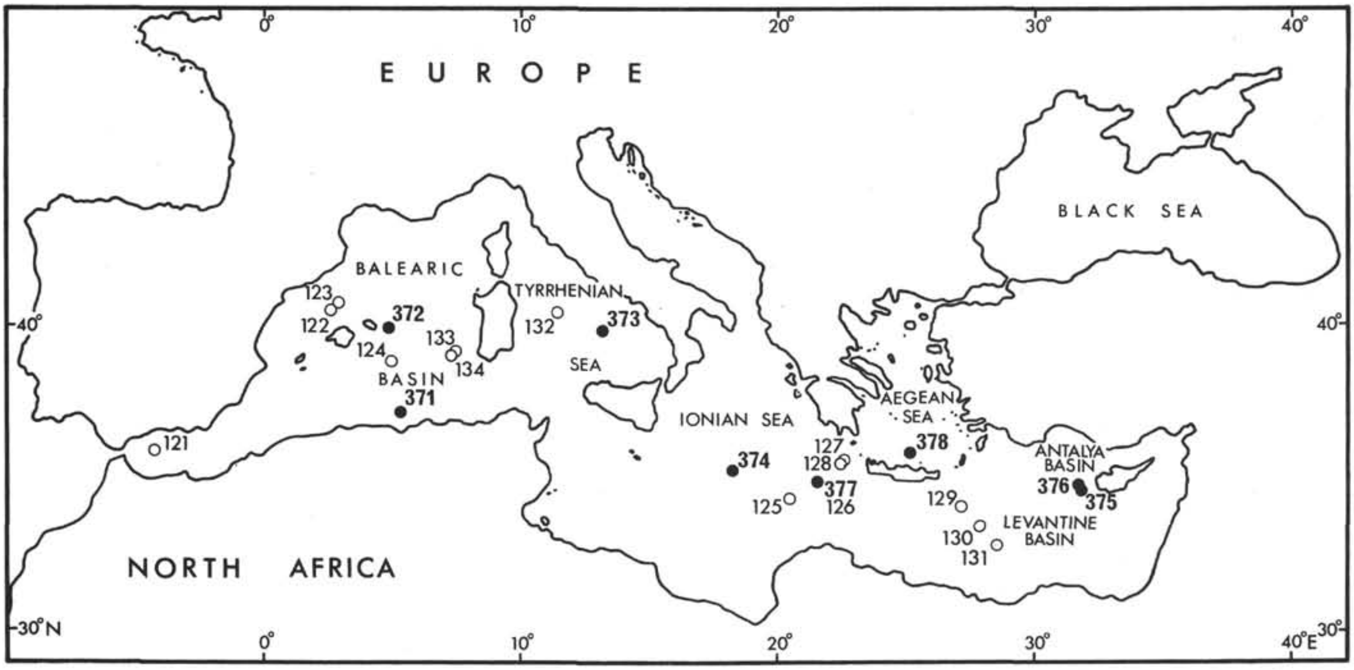

Figure 1. *Index map showing Leg 42A sites in relation to those of Leg 13.*

during the Oligocene and which has been subsiding ever since (Biju-Duval et al., this volume; Wright, this volume). Sites 375-376 are on the Florence Rise, a young Pliocene-Pleistocene compressional belt (Biju-Duval et al., 1974). Finally, at Site 377 we redrilled a larger section of pre-evaporitic sediments near Site 126 in the Mediterranean Ridge.

At all these three sites, the Mediterranean evaporite formation overlies, either directly or unconformably, typical basinal, hemipelagic, pelagic, and turbiditic sediments. Two major *facies* were encountered: at Site 372 there are homogeneous, intensely burrowed marls and marlstones overlying dark colored marlstones to mudstones. At Site 375 a cyclic sequence of terrigenous turbidites was found overlying pelagic and hemipelagic marls and limestones with minor intercalations of redeposited pelagic carbonates. At Site 377, recovery was very poor: here the middle to early Miocene consists of gray nannofossil marlstones underlain by dark gray flysch-like mudstones, siltstones, and sandstones.

Facies and General Lithology

Site 372

Near Menorca, pre-Messinian sediments, extending from below the evaporites of the Balearic Abyssal Plain, directly underlie Pliocene-Quaternary sediments or even outcrop. At Site 372, these sediments occur below a thin sequence of the upper evaporitic member which pinches out towards the margin. They are separated from the evaporites by an unconformity which represents a hiatus of 6 m.y. (see Site 372 Report, this volume). The upper part of the sequence (lithologic Unit III, 199.5-468 m sub-bottom and late Burdigalian to Serravallian in age) consists of light bluish gray to greenish gray homogeneous nannofossil marls, which gradually pass into more lithified limestones below. The sediment is intensely burrowed throughout, with *Planolites*- (Figure 3), *Zoophycos*- and *Chondrites*-type burrows, which generally are typically associated with fine-grained sediments of deeper waters (Ekdale, this volume). Resedimentation does not occur in these hemipelagic deposits, except for highly contorted intervals (Cores 24-26) which might represent submarine slumping. At about 470 meters sub-bottom, a pronounced break in sedimentation occurs which corresponds to a seismic reflector. From lithologic Unit III to Unit IV (468-885 m sub-bottom, Burdigalian), the carbonate content drops from 65% to 30% with a corresponding increase in detrital minerals. Near the base of Unit IV (Cores 44-46) a few intercalations of graded and laminated quartzose sandstone to siltstone, lithic sandstone and silty limestone are present.

In both units, quartz, mica (illite), and chlorite correlate well with one another indicating a terrigenous origin for the non-carbonate fraction. Only near the base of Unit III does an increase in the smectite content and the presence of neomorphic clinoptilolite (Figure 4) suggest derivation from volcanic material. Moreover, in this interval considerable volcanic material is found in the heavy mineral fraction. In Unit IV, appreciable amounts of Opal-CT (Jones and Segnit, 1971, a disordered interstratification of α -cristobalite and α -tridymite) is present. This is obviously derived from biogenic silica, as it occurs as lepispheres lining molds of radiolarians (Figure 5).

The pre-Messinian hemipelagic sediments of Site 372 are similar to those deposited there today. Planktonic and benthic fauna and flora are fully open marine and trace fossils are those typical for fine-grained sediments of deeper waters. Quantitative analysis of the benthic communities by Wright (this volume) shows an increase in water depth from approximately 900 meters in the early Burdigalian to 1500 meters at the end of the Serravallian.

These depths concur well with the depth ranges that can be inferred from the general lithology. A marked change in depositional environment and rate of sedimentation obviously occurred between Units III and IV during the late Burdigalian. Geophysical profiles show that the Unit IV sediments were ponded between basement horsts towards the end of the early foundering stage of the margin, whereas Unit III sediments occur as a wedge burying the pre-existing relief.

Site 375

At Site 375, the pre-evaporitic Neogene sediments show a typically cyclic development. They comprise 400 meters of dark gray, flysch-like sediments of Tortonian age (Unit IV), overlying over 200 meters of variegated marlstone and claystone, which are interpreted as distal turbidites, alternating with pelagic marlstone to limestone and turbidites composed of pelagic material only (Units VIII through XI, Burdigalian to Serravallian).

In Unit VII of this site the thickness of individual cycles varies from 10 cm to more than 1 meter. The cycles typically start with fine terrigenous arenite to siltite and have sharp lower boundaries (Figure 6). This grades upwards into homogeneous and structureless marlstone overlain in turn by marlstone with sparse burrowing. The sandstones and siltstones are interpreted as the "a-d" intervals of Bouma cycles (Bouma, 1962): the homogeneous marlstone as the finest fraction transported by the turbidity current and the burrowed marlstones as the top of the turbiditic marlstone and/or the "normal" hemipelagic interval. Organic carbon-rich nannofossil marlstones ("sapropels") which occur, may also be partly redeposited, as is shown by distinctly graded and cross-laminated examples.

In Units VIII through XI, intercalations of graded and laminated siltites occur only rarely. Here the cycle starts with variegated or gray marlstones to claystones with a sharp lower boundary. These grade upwards into light colored, more calcareous and foram-rich marlstones and limestones. Typically the tops of the darker layers are intensely burrowed from the top with lighter sediment piped down and older burrows burrowed again by younger and usually smaller ones (Figures 7 and 8). We interpret these cm- to dm-thick cycles as distal turbidites of terrigenous and hemipelagic material overlain by "normal" pelagic to hemipelagic sediment. In Unit X (Langhian), still another type of resedimented layer has been observed. This comprises light gray to bluish white, hard, cemented limestones which are composed entirely of tests of planktonic foraminifers and which often show pronounced size grading and low-angle current laminations (see fig. 13 in Site 375/376 Report, this volume). The sedimentary structures of these pelagic turbidites

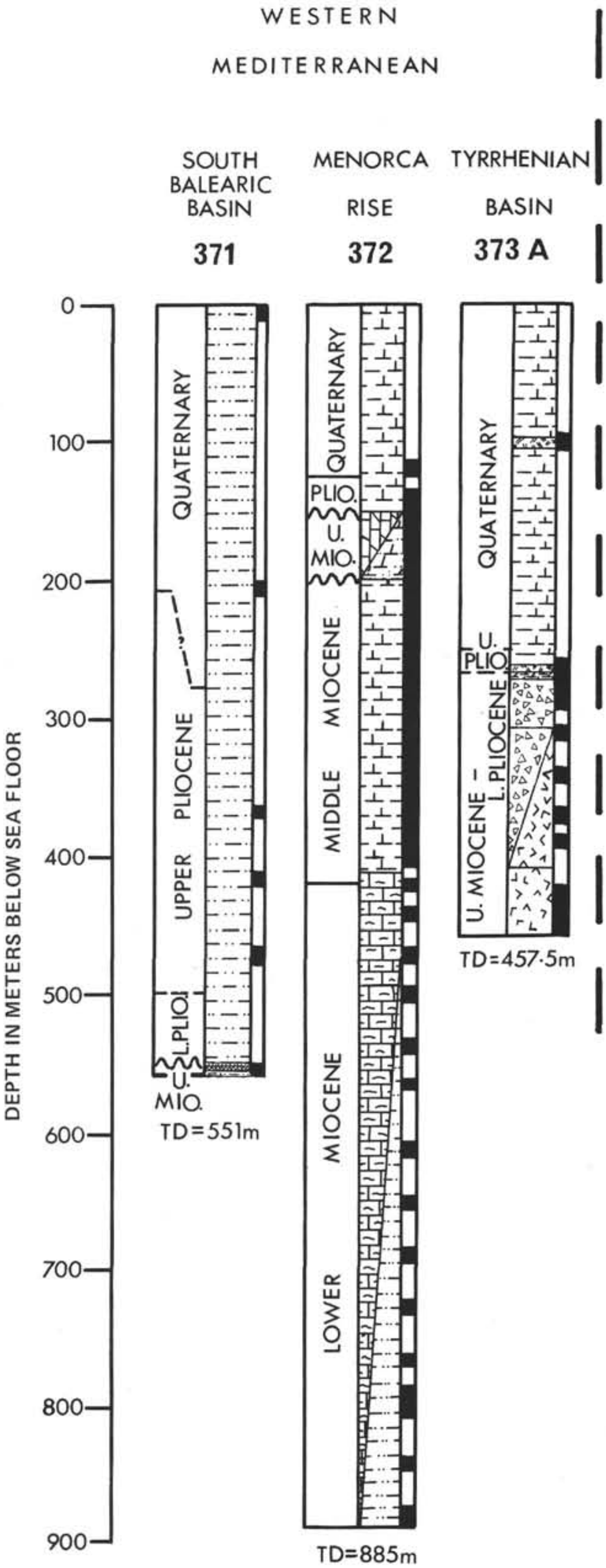

Figure 2. *Generalized lithologies drilled at Leg 42A, Sites 371 through 378.*

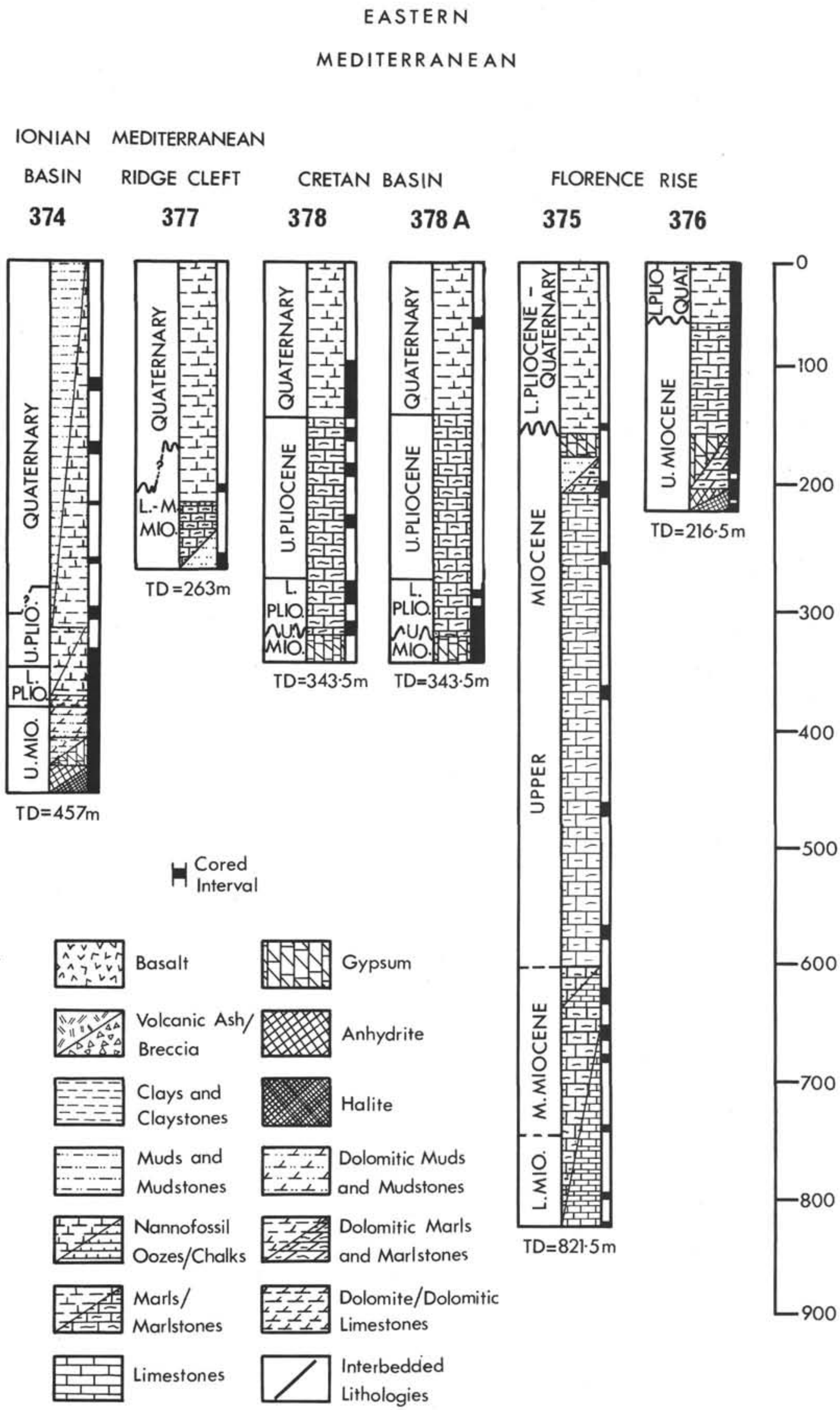

Figure 2. *(Continued).*

Figure 3. *Homogeneous greenish gray marlstone with small* Chondrites-*type and large* Planolites-*type burrows. Lithologic Unit III, Langhian, Sample 372, 28-3, 30-40 cm. Scale bar: 2 cm.*

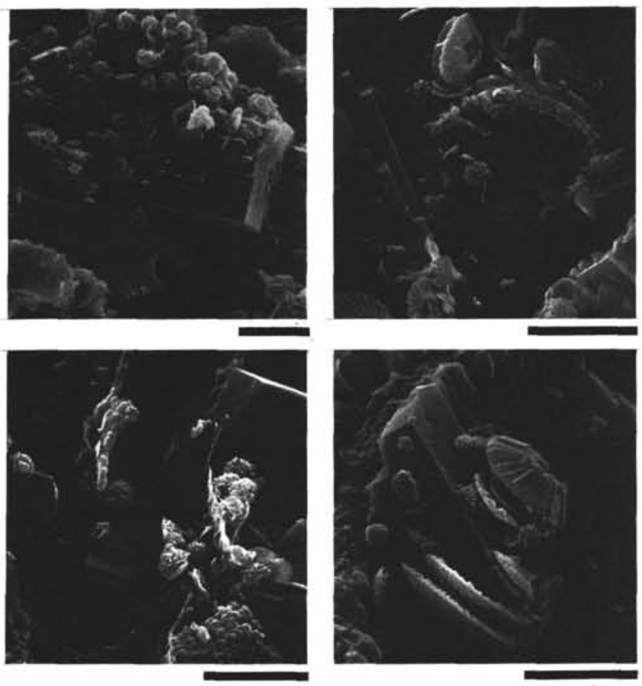

Figure 4. *Neomorphically formed clinoptilolite crystals in foraminiferal shells. Unit III, late Burdigalian, Sample 372-33-3, 33 cm. SEM-micrographs. Scale bars: 5 µm.*

are similar to those described from other deep-sea sequences (Bernoulli, 1972; Cook et al., 1976; Hesse, 1975).

The very close correlation between the pre-Messinian Neogene sediments at Site 375 and the Kythrea Group of northern Cyprus leaves no doubt that both sequences have been deposited in the same depositional basin (Baroz et al., this volume). On Cyprus the thicknesses of the individual formations of the Kythrea Group and the amount of terrigenous material decrease from east to west, and hence toward Site 375. This is consistent with current directions during deposition of this group in which the terrigenous clastics indicate sediment transport from east to west (Weiler, 1963). It appears that the Kythrea Group and its equivalents at Site 375 were deposited in a narrow deep east-northeast-trending trough between the Taurus Mountain to the north and the Troodos High to the south (cf. Weiler, 1970). Much of the terrigenous material was derived from ophiolitic and volcanic terrains and apparently was brought into the basin by large rivers (the ancestral Çeyhan and Seyhan rivers) which drained large ophiolitic areas of the Bitlis-Misis belts. Terrigenous sandstones and siltstones contain lithic fragments of mafic volcanics and some metamorphic and carbonate rocks, mainly dolomite, quartz, plagioclase, amphibole, and biotite. Smectites are the dominant clay minerals, followed by chlorite and attapulgite with traces of illite and kaolinite. Other sources of sediments apparently were the ancestral, Oligocene-Miocene Pentadaktylos (Kyrenia) Range of Cyprus, from the flanks of which the turbidites containing shallow water organisms of the Kythrea Group were derived, and the Troodos High, from which issued turbidity currents that transported pelagic material only (Panagra Marls and Unit X Site 375, cf. Baroz et al., this volume).

The Kythrea Group and the Neogene sequence of Site 375 coarsen upwards, but, during the Tortonian, water depth was still in excess of 1000 meters as shown by benthic foraminifers (Wright, this volume). Deposition took place in a basin that was semireducing and episodically was even stagnant, as is suggested by the abundance of organic matter and by the generally poor benthic assemblages.

Site 377

At Site 377 recovery was very poor. However, the presence of middle to early Miocene nannofossil marlstones and flysch-like lithic arenites indicates that this site was already in a basin prior to the salinity crisis and the deformation of the Mediterranean Ridge.

Diagenesis

At Site 372 the pre-evaporitic sediments show a general increase in induration and lithification with depth. Seismic reflection data indicate a progressive increase in the density of the sediments downhole, and the parallel decrease in water content represents a decrease in porosity. Compaction in the mudstone of Unit IV is indicated by flattened burrows. In Unit III, SEM-micrographs show a gradual increase in overgrowth on discoasters and on the distal shields of placoliths with depth. The results of preliminary isotope studies (McKenzie et al., this volume) indicate a

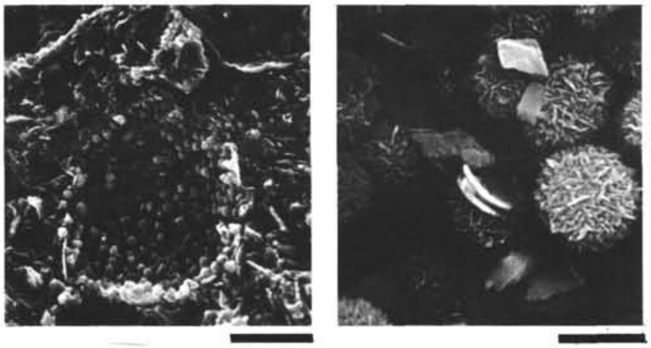

Figure 5. *Radiolarian mold lined by lepispheres of opal-CT. Unit IV, Burdigalian, Sample 372-36-5, 48-54 cm. SE-Micrographs. Scale bars: left 20 μm, right 2 μm.*

down-hole depletion in the oxygen-18 content of the bulk carbonate, which is directly associated with the progressive lithification of the sediment. This O^{18} shift results from the isotopic re-equilibration of the carbonate ions during cementation and recrystallization at

Further research on these pre-Messinian deep-sea sediments should be directed toward analyses of their lithification history through further SEM and isotope studies. Identification of the sources of heavy and clay minerals would also be a fruitful line to follow, but we stress that increased knowledge of related land sections higher temperatures, whereby the O^{18} value of the bulk carbonate becomes progressively more negative with increased burial depth while the pore waters take up the released O^{18} (McKenzie et al., this volume).

At Site 375 a similar increase of induration and lithification with depth was observed; this is also paralleled by an increase in sonic velocity. As at Site 372, the calcareous nannoplankton shows progressive overgrowth by syntaxial calcite with depth. As well as detrital (stoichiometric) dolomite, small neomorphically formed (calcian) dolomite rhombs are present. In Unit X, hard limestone layers consisting exclusively of redeposited planktonic foraminifers occur. These have been tightly cemented by syntaxial and blocky, usually ferroan, calcite cements (Figure 9); rarely occurring coccoliths in these layers show extensive overgrowth by syntaxial calcite. Some of the hard cemented limestones in Unit X have faint, closely spaced solution seams parallel to bedding which may represent the earliest stages of flaser-development. They also have stylolites which are oblique and perpendicular to bedding.

Conclusions and Further Research

Sedimentological analyses of the pre-Messinian sequences at Sites 372, 375, and 377 suggest that they are typically of a basinal facies: pelagic to hemipelagic sediments with turbidites, although they occupy substantially different tectonic settings at the present day. Faunal analyses of benthic foraminifers (Wright, this volume), ostracodes (Benson, this volume), and trace fossils (Eckdale, this volume), confirm the lithologic interpretations throughout. More specifically, they show that water depths at Site 375 prior to the salinity

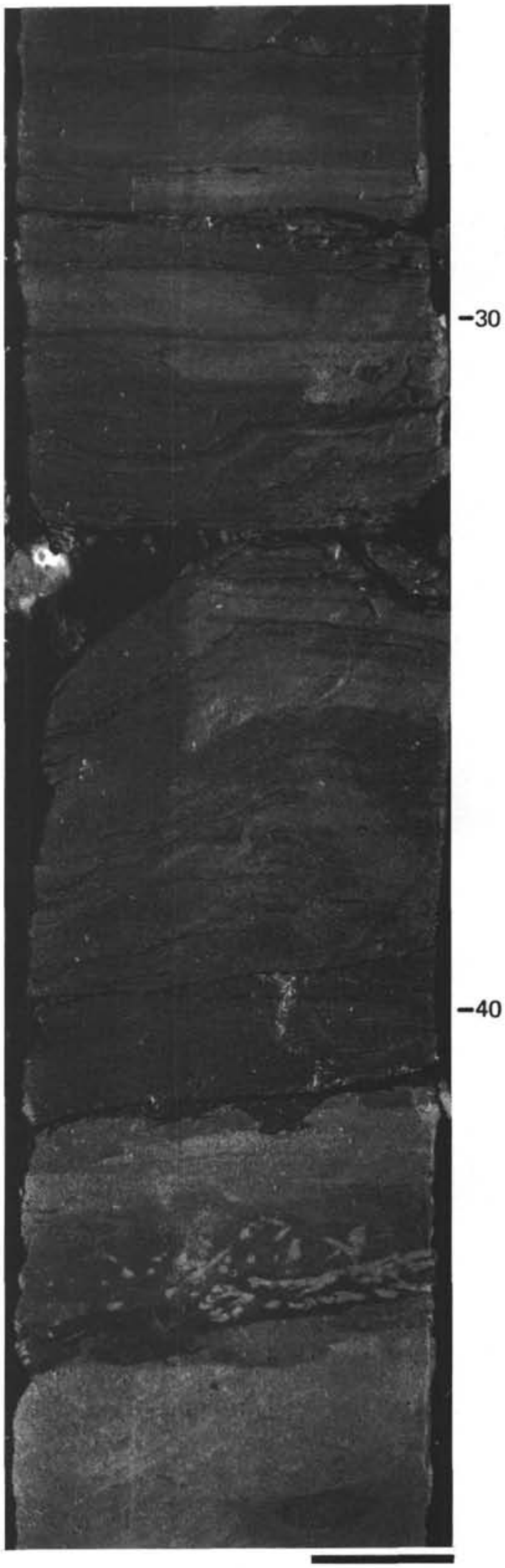

Figure 6. *Terrigenous turbidite, overlying burrowed hemipelagic marlstone with a sharp erosional contact. Turbidite is graded and laminated fine lithic arenite to siltite which passes upwards into homogeneous, dark gray turbiditic marl. Unit VII, Tortonian, Site 375, Section 4-3, Scale bar: 2 cm.*

Figure 7. *Characteristic cycle in Lithologic Unit IX, Site 375. Dark gray turbiditic mudstone passes upwards into light gray pelagic to hemipelagic marlstone, rich in planktonic foraminifers. The contact between the dark turbiditic and the light pelagic sediment is strongly modified by* Zoophycos-*type burrows which are filled with light sediment from above. At 31 to 32 cm, a thin intercalation of dark mudstone is present which is partly replaced by light sediment infilling small* Zoophycos-*type burrows. The light pelagic sediment above appears to be completely homogenized by burrowing. Unit IX, Serravallian, Site 375, Section 9-3. Scale bar: 2 cm.*

crisis (in the Tortonian) were at least 1000 meters while, despite a 6-m.y. hiatus, below the evaporites, Site 372 subsided to at least 1500 meters by Serravallian time (Wright, this volume).

would be required. In fact we urge that further regional sedimentary studies, especially on Menorca and Cyprus, be instigated in order to examine some of the more important tectonic implications raised by the

Figure 8. *Typical example of distal pelagic turbidite, Unit X, Site 375. Laminae of light gray, calcisiltite composed of small, size-sorted planktonic foraminifers, alternating with and grading into red marlstone; burrows are filled with calcisiltite and larger planktonic foraminifers and are partly reburrowed. In the turbiditic marlstone (upper part of photograph) larger planktonic foraminifers were introduced from the overlying limestone by burrowing. Unit X, Langhian, Sample 375-10-2, 93-98 cm, negative print from thin section. Scale bar: 5 cm.*

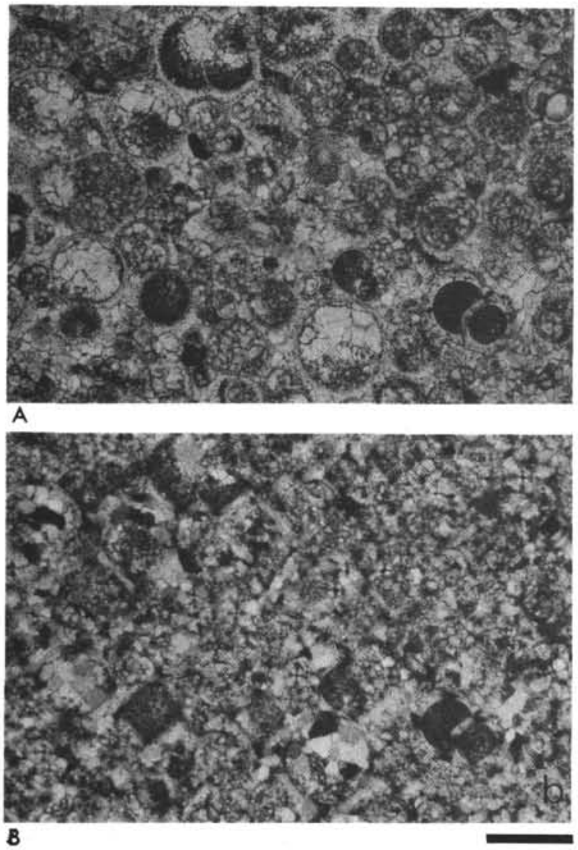

Figure 9. *Foraminiferal lime grainstone (pelagic turbidite), composed entirely of planktonic foraminifers, partly with geopetal infill of micrite and cemented by syntaxial calcite. Unit X, Langhian, Sample 375-11-1, 125-130 cm, thin section, (A) parallel nicols, (B) crossed nicols. Scale bar: 0.5 mm.*

results from these drilled sections (see Hsü et al, this volume).

MESSINIAN EVAPORITES

Leg 42A recovered Messinian evaporitic rocks and sediments at eight locations: Sites 371, 372, 374, 375, 376, and 378 (Figure 1). Bear in mind, however, that, from comparison with seismic profiles, sediments were recovered only from the upper part of the Mediterranean evaporite formation. They only sample the upper 70 or so meters of a formation which can be up to 2 km thick. We continuously cored over 278 meters but, as is usual in such rocks, recovery was fragmentary and averaged 34% in the individual cores. This recovery, however, is significantly better than on Leg 13 where the Messinian evaporites were sampled at seven sites, 201 meters were continuously cored and recovery was 24%.

Apart from fragmentary recovery, sedimentological analysis is here even more seriously handicapped by the small diameter of the cores than is the case for other rock types. Assessment of lateral continuity is particularly important in the interpretation of evaporite sequences (Dean et al., 1975; Von der Haar, 1976). Thus we relied heavily for comparison upon our examination of the late Miocene evaporites of Sicily and Spain, and upon the observations of other workers in these areas and elsewhere in the Mediterranean. These sequences are, for the most part, barren of microfossils which further limit our ability to check the paleoenvironmental interpretations. On the other hand, considerable information can be gleaned from comparisons made with modern analogues (Schreiber, 1974; Schreiber and Friedman, 1976) and this approach has allowed us to identify paleoenvironments, at least tentatively, for all the rock types recovered. These studies are reported fully in Garrison et al., this volume).

Facies and General Lithology

The evaporite sequences are extremely diverse in the drilled sections. Each site had a somewhat different succession of rock types.

Site 371 has nodular anhydrite overlying dolomitic mudstone and is interpreted as part of a prograding sabkha cycle. Laminated gypsum, containing cross-bedding, ripple marls, and other indications of current deposition dominates at Site 372. This suggests that this gypsum may have been deposited on a very shallow water evaporite flat that was periodically exposed. The sequence contrasts markedly with the coarse selenitic gypsum at the bases of the holes drilled at Site 378. The latter was probably precipitated in a shallow body of water into which there were influxes of less saline water that caused the dissolution and reworking effects observed. A halite to marlstone sequence occurs at Site 374, and the upper part of this sequence contains several gypsum-dolomitic mudstone cycles. Coring at Sites 375 and 376 recovered a somewhat similar Messinian sequence with halite at the base, but rather thick dolomitic marlstone and clastic gypsum deposits dominate the upper part of this succession and indicate considerable reworking of evaporites as well as probable deepening of the water.

The last Messinian sediments at Sites 374, 375, and 376 are dolomitic marls and marlstones sometimes interbedded with turbiditic arenite and siltites. These are the deposits of a standing body of water, markedly less saline and possibly of considerable depth (the "Lago Mare" of Hsü et al., this volume).

The variability between sites summarized above reflects the variability and complexity of depositional environments in the Mediterranean region during Messinian time. The *evaporites* at all the sites, however, share in common indications of deposition and diagenesis in very shallow subaqueous to subaerial environments.

Gypsum-Mudstone Cycles

Drilling at Site 374 recovered five cores which penetrated an apparently cyclically bedded sequence of mudstones and gypsum, between sub-bottom depths 406.5 and 425.5 meters (Figure 10). Despite only partial recovery, we were able to construct an idealized three-member cycle and to examine in detail each member (cf. fig. 17 of Garrison et al., this volume). The cycles appear to record slight changes in water level that caused periodic fluctuations between subaqueous and subaerial sedimentation. This site, in one of the deepest parts of the present Mediterranean, also contains algal stromatolites and algal filaments, which, because of the light dependence of these organisms, confirms our interpretations regarding water depths during this part of the Messinian (Awramik, this volume).

Laminated Gypsum

Laminated gypsum is conspicuous at Sites 372, 374, 375, and 376 and appears to have several different origins. One variety formed through periodic redeposition of clastic gypsum grains by currents. In another type, recrystallization of the redeposited gypsum grains occurred during early diagenesis and acted to accentuate inverse size grading of particles within the laminae. A third variant originated when vertical growth of small selenite crystals up from the sediment-water interface was periodically interrupted by deposition of clastic gypsum particles or carbonates (Figure 11).

Conclusions and Further Research

Although lack of fossils and incomplete core recovery present problems of precise correlation between evaporite sections, we are able to demonstrate that, through comparative sedimentology, all these depositional sequences from the upper part of the Mediterranean evaporite formation can confidently be referred to subaerial to shallow subaqueous environments. In the Ionian and Antalya basins such conditions were succeeded by the late Messinian oligohaline "Lago Mare."

The Leg 42A evaporites contain a number of features worthy of further investigation. Among these are laminated gypsum, coarse recrystallization fabrics, of diagenetic or metamorphic origin at Sites 374 and 376, clastic gypsum at Site 376, and selenitic gypsum and gypsum dissolution breccias at Site 378.

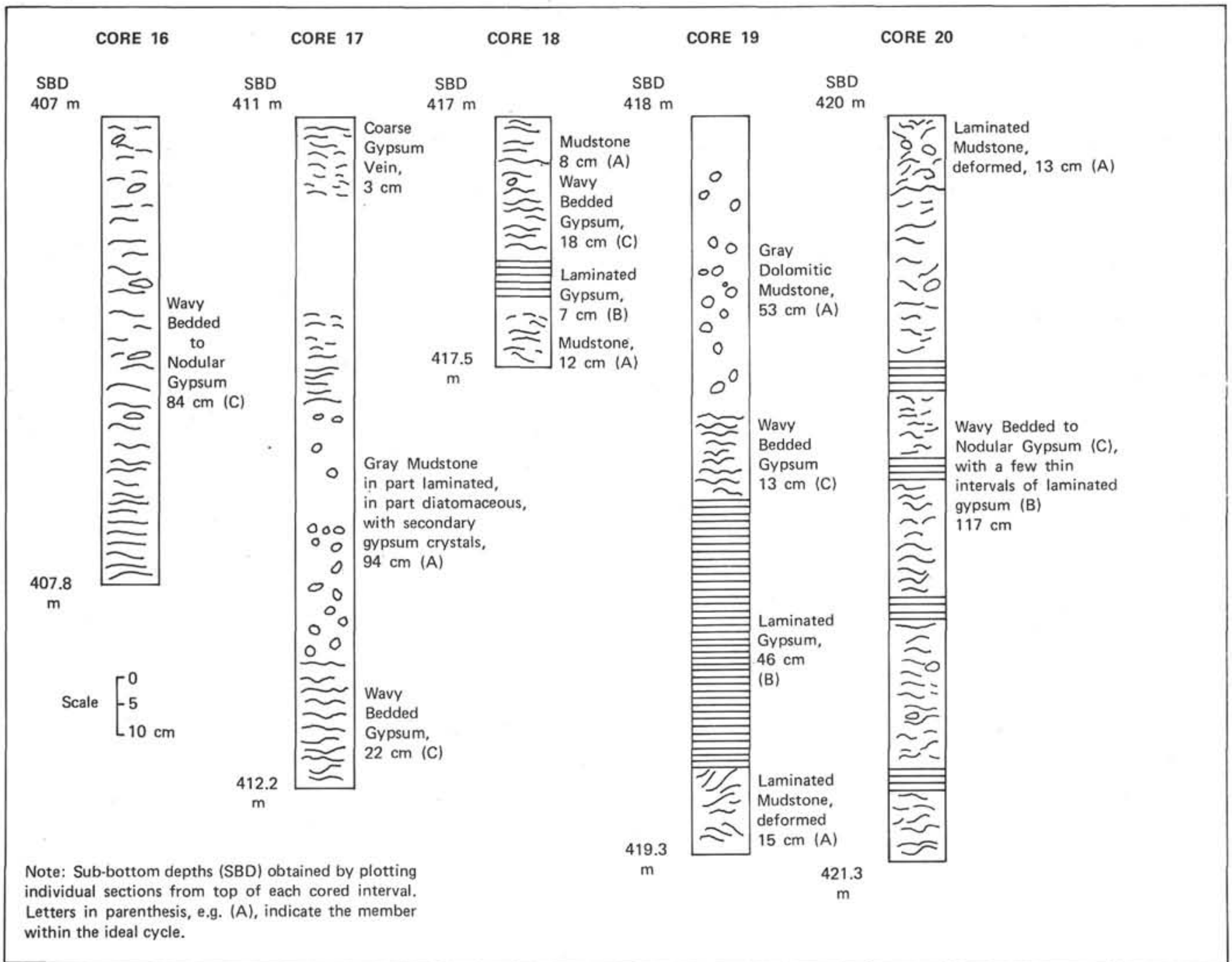

Figure 10. *Gypsum-mudstone cycles recovered at Site 374 (SBD refers to sub-bottom depths).*

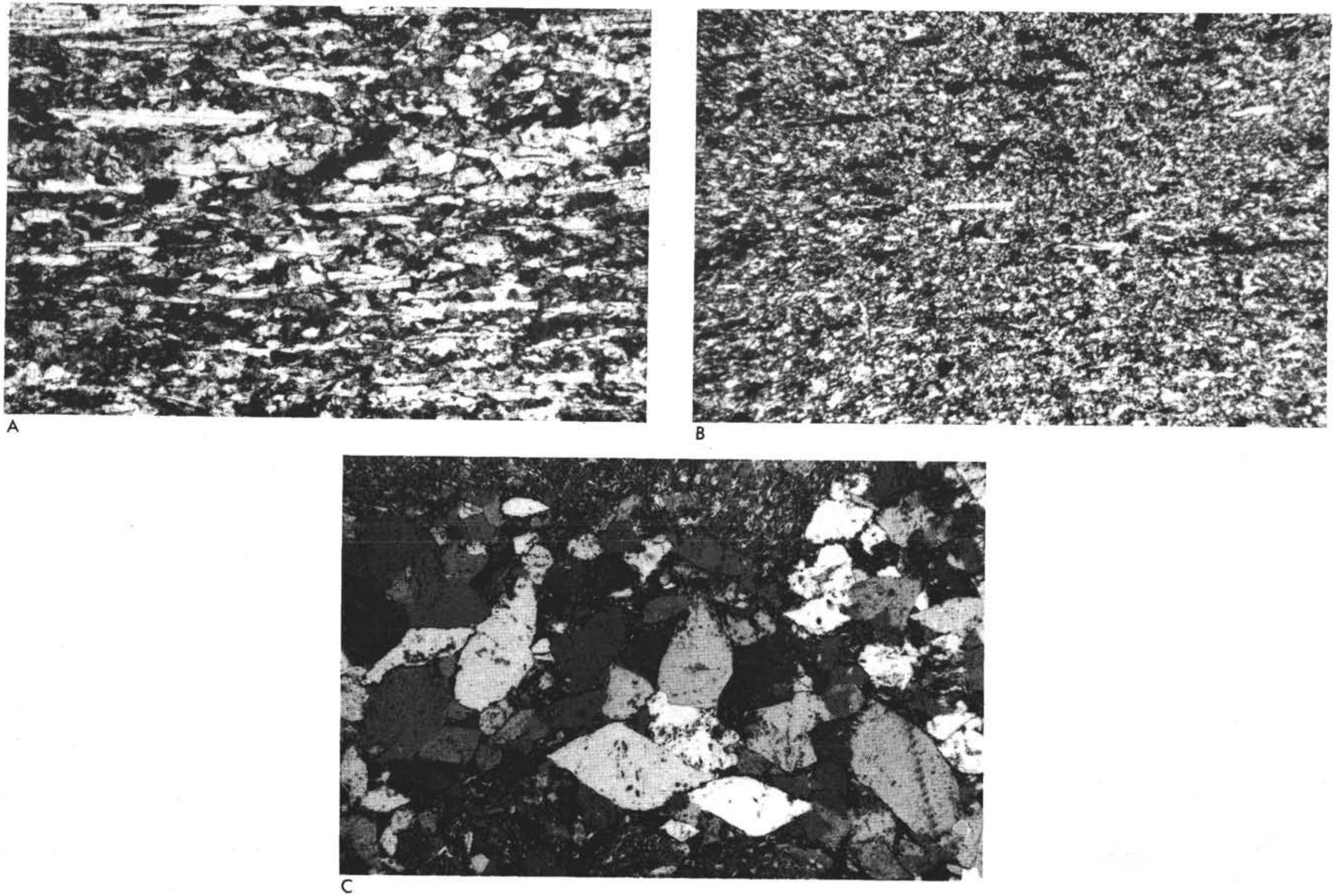

Figure 11. *Photographs of laminated gypsum from Site 376 and from the Lapatza Formation, Cyprus (crossed nicols, scale bars: 500 µm). (A) Laminated gypsum from the Lapatza Formation; elongated gypsum crystals were apparently reworked and redeposited by currents; many crystals are twinned and have irregular grain boundaries as a result of diagnetic overgrowth. (B) Laminated gypsum from Site 376; somewhat like (A), but finer grained and containing fewer elongated crystals (376-20-1, 71-74 cm). (C) Laminated gypsum from Site 376; alternations of coarse- and fine-grained gypsum. Here a coarse layer made up of small euhedral selenite crystals was partly reworked so that the crystals now lie with their long axes more or less parallel to bedding, instead of the upright position characteristic of* in situ *growth (376-20-1, 61-64 cm).*

POST-MESSINIAN SEDIMENTS

As was the case with Leg 13, most of the Pliocene-Quaternary sections drilled during Leg 42A were "spot-cored." Again, only one post-Messinian sequence was continuously cored. The 55 meters of nannofossil marls with interbedded tephra and sapropel horizons at Site 376 now complement the 182-meter western Mediterranean section drilled at Site 132. From comparison of these, together with the "spot-cores" from other sites, we conclude that we now have representative sampling of most of sediment types present in the post-Messinian deep-sea sections.

Facies and General Lithology

The post-Messinian sediments are nannofossil marl to marlstone which sometimes contain a greater terrigenous content (calcareous muds) and are sometimes more pure carbonates (tending towards calcareous oozes). Graded (and non-graded) sandy and silty beds and laminae, volcanic tephra horizons, and sapropel layers are intercalated in these sediments.

Most of the sediments contain a moderate to high percentage of calcium carbonate. The majority of the calcite present is of organic origin derived from foraminifers and coccoliths. Aragonite is generally rare, except within the turbiditic sequences at Site 374 where aragonite, together with magnesium calcite, was probably derived from shelf areas (Müller et al., this volume). In general, the dolomite content is low and, where it occurs, is probably of continental origin.

Sediments range in color from almost black, where sapropel layers are intercalated, to shades of blue-gray to olive-gray. Bright beige to brown and reddish-colored intervals are intercalated in, or even dominate, the Quaternary sediments. These reddish hues indicate a high state of oxygenation of the sediment, and at the other extreme, the grayish and black colors suggest a less intense to total absence of oxygen, respectively (Sigl et al., this volume).

Bioturbation is common and has destroyed most of the primary sedimentary features, including stratification.

Turbidites

Intercalations of sand and coarse silt within the above sediments have mineralogical and faunal compositions which identify them as material displaced from shallower water areas. Most of the beds are graded and can be linked to Bouma cycles (Bouma, 1962) and are thus interpreted as turbidites. On the other hand, a significant number, especially at Site 371, which is on a basement knoll, are cross-laminated but not graded. These are interpreted as turbiditic-type material which has been redeposited by bottom currents linked to deep water circulation.

Turbiditic sequences are confined to the Quaternary part of the central Ionian Sea sequence (Site 374). The underlying reason for this is variously interpreted as:

1) the expression of the geologically recent uplift of the Sicilian and Calabrian landmasses (K. J. Hsü, personal communication); see later section for an interpretation that would explain the observed clay mineral assemblages.

2) the result of a significant steepening of the slopes of the basins since the beginning of the Quaternary (Müller et al., this volume, who link the coarse turbidite material to a source on the African Shelf).

3) an indication that only after the Pliocene were the marginal basins sufficiently filled to allow bypass of land-derived sediments into the central areas of the major basins (Cita et al., this volume, who examined the geodynamic significance of Neogene sedimentation rates as determined by drilling on both Legs 13 and 42A).

Pliocene-Pleistocene Discontinuities

Lithologic evidence of local and minor stratigraphic gaps was frequently found in the Pliocene-Quaternary sequences in the form of erosional surfaces, "hardgrounds" and omission surfaces. These reduced stratigraphic sections, which often include horizons with iron- and manganese-rich crusts and/or winnowed debris, substantially lower the calculated sedimentation rates (Figure 12). Some, but not all, can be demonstrated paleontologically as hiatuses in deposition. Condensed sequences were identified at Site 373, where four of the six Pliocene foraminiferal zones occurred in a 1-meter interval; at Site 372 where the Pliocene sequence is again condensed near its base; and at the continuously cored Site 376, where both the Quaternary and Pliocene are highly condensed. The location of these reduced sections on topographic rises suggests that they resulted from the impingement of circulating water masses against upstanding features.

Conclusions and Further Research

The post-Messinian sequences drilled during Leg 42A are stikingly similar in lithology to open marine deep basinal sections drilled elsewhere by *Glomar Challenger.* They are hemipelagic and frequently turbiditic, as is the case for sediments cored in the modern Mediterranean basins. Support for the view that the whole Pliocene-Quaternary sequence was deposited in basins comparable to those of the present day comes from analyses of water depths at which the open marine benthic foraminifers and ostracodes lived. Both Wright (this volume) and Benson (this volume) conclude that sediments above the Miocene-Pliocene contact were deposited in water depths of at least 1000 to 1500 meters. They note however that below 1500 meters faunal differences can rarely be distinguished. On the other hand, seismic evidence (Biju-Duval et al., this volume) and sedimentological studies on land sections (Fabricius et al., this volume) demonstrate considerable Pliocene-Quaternary subsidence, and this would be compatible with present depths in these basins, often in excess of 3000 meters. Because of the fragmentary record of the drilled Pliocene-Quaternary sediments, we suggest that further sedimentologic research be tied closely to studies on gravity and piston cored material. The lithology of the Mediterranean

Figure 12. *Early Pliocene pelagic ooze with omission surfaces (arrowed) from the Antalya Basin (Site 376, Section 5-5). Three biozones (MPL-2 to MPL-4) spanning approximately 2 m.y. are represented in 1.5 meters of core. Sedimentation rates are thus as low as 0.1 cm/1000 yr.*

sequences is more influenced by the recent geological history and climate of this inland sea than is the lithology of open ocean sequences. Consequently, the effects of small-scale events should be more easily identifiable. We suggest that (1) a more accurate picture of the small-scale geodynamic evolution of the Mediterranean would emerge through further comparison between the lithostratigraphy of cored and drilled sequences, (2) detailed studies of heavy and clay mineral assemblages to identify sources, (3) increased analysis of the effects on Mediterranean sediment distribution of its water mass exchanges, and (4) investigations of intercalated sapropel and tephra layers (see below).

CLAY MINERALOGY

We made a concerted effort during Leg 42A to extensively sample for clay mineral analyses. Initially this was done to provide more detailed lithologic interpretations, and ultimately produced considerable results (see Mélières et al., Chamley et al., Chamley and Giroud d'Argoud, all this volume) and the following represents an overview.

Balearic Basin

At Site 372 the clay mineralogy is dominated, from the lower Burdigalian (bottom of the hole) upwards by the association of illite with chlorite; the relative proportions of these minerals is constant throughout the penetrated section. This suggests their probable origin in the Alpine orogenic belt. Poorly crystallized smectite appears in the uppermost Burdigalian and is interpreted as characterizing calm sedimentary conditions (see below) during the Langhian and Serravallian. This smectite is probably derived, in part, from illite. The clay mineralogy of the Messinian sediments is very similar to that of the pre-Messinian sediments, suggesting either that the former could be derived from the latter by reworking during the Messinian regression, or that distant sources were still active during this regression. Because the Messinian physiography is interpreted as shallow subaqueous to subaerial, the first hypothesis appears more probable. The Pliocene-Quaternary sediments are characteristically devoid of smectite, which suggests either a change in the nature of the terrigenous sources, or more likely, the existence of rather active water circulation in the basin, which prohibited the finest particles (the smectites) from settling out. The total lack of smectite in the Pliocene-Quaternary sediments at Site 371 seems to support this conclusion. At both Balearic Basin sites no trace of attapulgite was found.

At Site 371, kaolinite constitutes 20% of the clay mineral assemblage in the Pliocene-Quaternary sediments, whereas at Site 372 this mineral appears only as traces. This reflects the North African contribution to the sediments in the southern part of the Balearic Basin since kaolinite is preferentially generated in warm climates. The inability of kaolinite to reach the central part of the basin in significant amounts seems to confirm the suggestion above of rather active water circulation during the Pliocene-Quaternary.

Ionian Basin

The clay mineralogy of the sediments drilled in the central part of the Ionian Basin is partly influenced, during the Pliocene, by attapulgite which is derived from the North African platform (Chamley, 1971). This influence is not apparent (a) in the upper Messinian sediments, suggesting that the North African attapulgite was unable to reach the site because of the physiography of the basin at this time, and (b) in the Quaternary sediments because the uplifted northern landmasses of Sicily and Calabria began to supply considerable amounts of terrigenous material devoid of attapulgite during Quaternary time.

Levantine Basin

At Sites 375 and 376 (about 40 km west of Cyprus) the clay mineralogy is strongly dominated by smectite. These are thought to be derived from the ophiolites of southern Turkey rather than from those of Cyprus, on the basis of paleocurrent evidence (Weiler, 1963) and the fact that the Troodos ophiolites are associated with a Neogene pelagic limestone sequence (Robertson and Hudson, 1974). The prominence of smectite is sustained throughout the sedimentary column (Burdigalian to present), with an acme during the upper Messinian. This indicates that the clay mineral assemblage is mostly derived from continental sources. The considerable amount of smectite in the upper Messinian suggests that this mineral possibly developed partly in the poorly drained soils of the Messinian landscape.

The above comparison between the three Mediterranean basins shows the primary influence of terrigenous sources on the clay mineralogy of the sediments.

At Sites 374 and 376, the mineralogy of the upper Messinian sediments is characterized by a higher chlorite content than is present elsewhere in the sedimentary sequences. From this we propose that the genesis of this magnesium-rich mineral may be the result of its development, or at least its aggradation, in the magnesium-rich environments of the Messinian (Chamley et al., this volume). The occurrence of attapulgite associated with chlorite in the upper Messinian at Site 376 seems to support this hypothesis, especially because the attapulgite, also a magnesium-rich mineral, occurs in long and well-crystallized fibers. This suggestion, we think, warrants further investigation, as does extended research on other drilled sequences and on Neogene and Quaternary land sections throughout the Mediterranean to identify sources from clay mineralogy.

SAPROPEL LAYERS

Prior to Leg 42A drilling, large numbers of discrete dark colored layers of organic carbon-rich sediment had been identified in Quaternary eastern Mediterranean piston cores (Ryan, 1972; McCoy, 1974). These were correlatable and were thought to be the sedimentary expression of periods of bottom water stagnation linked to glacial phenomena. Leg 13 drilling penetrated some of these Pleistocene sapropel layers, but also recovered one of late Pliocene age. Leg 42A recovered over 150 separate layers and proved their existence dating back to the middle Miocene (Kidd et al., this volume).

On the basis of a definition which recognizes a sapropel as a "discrete layer, greater than 1 cm in thickness, set in open marine pelagic sediment and containing greater than 2.0% organic carbon" (Kidd, et al., this volume), about two-thirds of the layers in the Leg 42A cores were true sapropels, while the remainder were "sapropelic layers" (0.5% to 2.0% organic carbon). Detailed studies of individual layers (Sigl et al., this volume) reveal that organic carbon contents can reach 16% (Section 374-5-3), that their intensity of color is primarily the result of monosulfide formation, which is itself linked to the percentage of finely dispersed organic matter, and that total carbonate content varies widely from nearly zero to 78%.

The extension of the record of Mediterranean sapropel stratigraphy back to the middle Miocene and, while recognizing the incompleteness of our drilling record in both space and time, the development of tentative correlations back to the early Pliocene (Kidd et al., this volume) lead us to conclude that these stagnation events cannot merely be linked to Pleistocene glacial phenomena. On the other hand, their apparent widespread distribution and wide range of depths involved, argue against the presence of an oxygen-minimum layer (Arthur, 1976). Intermittent stagnation, resulting from stratification of the water column, appears to have been caused by a number of interacting environmental factors. During the Pleistocene, the most significant factors were indeed the glacial expansions but similar prime factors are as yet unidentified for the Pliocene and middle Miocene epochs.

The scope for further research on the sapropels recovered through drilling is considerable. Most important would be studies aimed at their correlation, as many of the large number of individual layers have not so far been sampled for detailed faunal and mineralogical analysis. Other studies aimed at identification of the environmental parameters that may have brought about the pre-Pleistocene stagnations are needed. In particular, substantially more information in isotopic, organic, and trace element geochemistry is desirable.

TEPHRA LAYERS

A number of volcanic ash (tephra) layers were encountered during the Leg 42A drilling. Their incidence was surprisingly low in view of the large numbers of tephra layers recognized from coring Quaternary sediments. This is, of course, partly a result of the intermittent coring of the post-Messinian sequence. Tephra layers were naturally well represented in the Pliocene-Pleistocene sediments at Site 373, which was drilled on a Tyrrhenian volcanic seamount. They were also present in the Pleistocene at Site 376 and of Site 378. To date no detailed petrological or geochemical investigations of their volcanic glass or other minerals have been attempted to link these to the tephra chronology established for sediment cores. Thus links to terrestrial volcanic activity are impossible at present. One layer at Site 376 does however appear correlatable to a tephra at Site 125 (DSDP Leg 13) (Kidd et al., this volume).

One problem which merits further study in DSDP materials is that of clay mineral diagenesis from volcanic material. In spite of thorough investigation of the Leg 42A sequences, Chamley and Giroud d'Argoud (this volume) were unable to find any evidence of transformation of volcanic glass into clay minerals. This is important because transformation of volcanic glass into smectites in subaqueous environments is still widely held to have occurred, despite the finding of completely unweathered volcanic glass up to 3.8 m.y. old in sediments of the north-east Pacific (Scheidegger, 1973) and experimental evidence on the solubility of volcanic glass reported in Heath (1974).

VOLCANIC BRECCIAS

Coring at Hole 373A penetrated the flank of a seamount in the Tyrrhenian Basin. The upper part of the basaltic sequence cored there included carbonate-cemented basaltic breccias with a complex history. A detailed analysis of these breccias (Bernoulli et al., this volume) identifies the interclast carbonates as being of three types: pelagic limestones, diagenetic limestones, and void-filling sparry calcite cement. Each of these components is represented by two or more different generations. The pelagic limestones are interpreted as sediments that filtered down into interclast crevices from the sea floor.

The diagenetic limestones apparently originated through precipitation of small calcium carbonate crystals within the breccia, followed by current-induced redeposition, most prominently within late-stage open fractures. Stable isotope compositions indicate that the cementation of these breccias and limestones occurred at low temperatures (6°C to 8°C) which would be characteristic of the *deep* sea floor. This shows that water depths above this volcanic seamount were already considerable in early Pliocene time.

SUMMARY

The pre-evaporitic sediments drilled at Sites 372, 375, and 377 are typically *basinal,* pelagic to hemipelagic and turbiditic sediments, although today they occur in different tectonic settings: along a rifted and down-faulted margin which began subsiding in the Oligocene or early Miocene (Menorca Rise, Site 372); or in young compressional belts (the Florence Rise, Site 375, and the Mediterranean Ridge, Site 377). Faunal analyses also show that at Sites 375 and 372 water depths prior to the Messinian evaporite deposition exceeded 1000 to 1500 meters[6]. The sediments deposited during the pre-Messinian Miocene at the sites are also similar in facies to the corresponding Pleistocene to Recent deposits. Again, for the post-Messinian sediments, faunal analyses require the existence of water depths in excess of 1000 to 1500 meters even in the early Pliocene, and data from seismic profiling and information derived from land sections give evidence of further deepening through the Plio-cene-Quaternary, to the present-day depths.

Equilibrium conditions of deposition in these basins, both prior to and after the Messinian event, must have been roughly the same as at the present day. Periods of near-oceanic conditions when almost pure biogenic oozes were deposited occurred only after the early Pliocene flooding of the Mediterranean Basins (Cita et al., this volume) and, to a minor extent, following the Langhian transgression in the eastern Mediterranean (Panagra Marls, Cyprus, and Site 375, lithologic Unit 10).

The drilled Messinian evaporite sequences, which are interpreted as having developed in shallow subaqueous and subaerial environments, are consequently sandwiched between deep water marine sedimentary series. A slightly different succession was developed in the Ionian and Antalya basins where the "Lago Mare" environment was in existence in the latest Messinian. Here the dolomitic sediments deposited in this oligohaline body of water are in apparent sedimentological continuity with the open marine sediments of the Pliocene above. The faunal evidence, on the other hand, is again of a vital change in ecological conditions at the Miocene/Pliocene contact.

We conclude, on the basis of sedimentological and environmental analyses, that the Mediterranean salinity crisis affected a series of individual basins which varied in their pre- and post-Messinian evolution. Some of these basins have obviously been deep since the early Miocene. Geophysical evidence confirms this and shows that they have also been subsiding ever since that time (Biju-Duval et al., this volume; Ryan, 1976). In some of the young compressional belts on land (Apennines, Calabria, Sicily, Crete) the evaporites again occur sandwiched between deep-water deposits and have been violently folded and uplifted during subsequent Pliocene to Recent orogenic movements. The Messinian event is recognized as having been imposed upon deep basin topography and thus the lithologic findings of Leg 42A uphold the hypothesis (Ryan et al., 1973) of a late Miocene deep basin desiccation of the Mediterranean[7]. However, as noted by Hsü et al. (synthesis chapter, this volume), the original concept proposed after Leg 13 must be refined on the basis of the Leg 42A results. In addition,

[6]One of our number (F. Fabricius) disputes the evidence for deep basins *immediately* prior to the late Miocene salinity crisis. He emphasizes that only in the discontinuously cored Hole 375 were the deep marine sediments below the Messinian of Tortonian age and that the evaporites unconformably overlie Serravallian sediments at Sites 372 and 377. He believes that the hiatuses could leave room for other interpretations of the tectonic history of the Mediterranean (Fabricius et al., this volume).

[7]F. Fabricius favors shallow environments for the Messinian but within basins that continually subsided and, linking his arguments to observations on land in the Ionian Islands, he sees the Pliocene-Quaternary record as one of sedimentation in "starving basins" which sank at an average rate of 1 meter per thousand years (Fabricius et al., 1977). The other four authors consider that the weight of geophysical, geochemical, and biological evidence (Hsü et al., 1977) is overwhelmingly in support of their conclusion that deep basins existed immediately prior to the salinity crisis.

because of the numerous implications that this interpretation of the genesis of the Mediterranean evaporite formation has for analogs present elsewhere in the geologic record, we stress, throughout this contribution, areas where further research is of utmost importance.

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REFERENCES

Arthur, M. A., 1976. The oxygen minimum: expansion, intensification and relation to climate Abstract: Joint International Oceanographic Assembly, Edinburgh, Scotland, September 1976.

Bernoulli, D., 1972. North Atlantic and Mediterranean Mesozoic facies, a comparison. *In* Hollister, C. D., Ewing, J. I., et al., Initial Reports of the Deep Sea Drilling Project, Volume 11: Washington (U. S. Government Printing Office), p. 801-871.

Biju-Duval, B., Letouzey, J., Montadert, L., Courrier, P., Mugniot, J. F., and Sancho, J., 1974. Geology of the Mediterranean Sea basins. *In* Burk, C. A. and Drake, C. L. (Eds.), The geology of continental margins: New York (Springer-Verlag), p. 695-721.

Bouma, A. H., 1962. Sedimentology of some flysch deposits: Amsterdam (Elsevier).

Chamley, H., 1971. Réchèrches sur la sédimentation argileuse en Méditerranée: Sci. Géol. Strasbourg, Mem. 35.

Cook, H. E., Jenkyns, H. C., and Kelts, K. R., 1976. Redeposited sediments along the Line Islands, equatorial Pacific. *In* Schlanger, S. O., Jackson, E. D., et al., Initial Reports of the Deep Sea Drilling Project, Volume 33: Washington (U. S. Government Printing Office), p. 837-847.

Dean, W. E., Davies, G. R., and Anderson, R. Y., 1975. Sedimentological significance of nodular and laminated anhydrite: Geology, v. 3, p. 367-372.

Drooger, C. W. (Ed.), 1973. Messinian events in the Mediterranean: Koninkl. Nederl. Akad. Wetensch., Amsterdam.

Garrison, R. E., Schreiber, B. C., Bernouilli, D., Fabricius, F., Kidd, R. B., and Mélières, F., 1977. Sedimentary petrology and structures of Messinian Evaporites in the Mediterranean Sea, Leg 42A Deep Sea Drilling Project: this volume.

Heath, G. R., 1974. Dissolved silica and deep-sea sediments. *In* Hay, W. W. (Ed.), Studies in paleo-oceanography: Spec. Publ. Soc. Econ. Paleon-Miner. Tulsa, v. 20, p. 77-93.

Hesse, R., 1975. Turbiditic and non-turbiditic mudstones of Cretaceous flysch sections of the East Alps and other basins: Sedimentology, v. 22, p. 387-416.

Jones, J. B. and Segnit, E. R., 1971. The nature of opal. I. Nomenclature and constituent phases: J. Geol. Soc. Australia, v. 18, p. 57.

Mauffret, A., Fail, J. P., Montadert, L., Sancho, J., and Winnock, E., 1973. North-western Mediterranean sedimentary basin from seismic reflection profile: Am. Assoc. Petrol. Geol. Bull., v. 57, p. 2245-2262.

McCoy, F. W., Jr., 1974. Late Quaternary sedimentation in the eastern Mediterranean Sea: Unpublished Ph.D. thesis, Harvard University, p. 149-170.

McKenzie, J., Bernoulli, D., and Garrison, R. E., 1977. Lithification of pelagic-hemipelagic sediments at Site 372: oxygen isotope alteration with diagenesis: this volume.

Montenat, C., Bizon, G., and Bizon, J. J., 1975. Rémarques sur le Néogène du forage JOIDES 121 en mer d'Alboran (Méditerranée occidentale): Soc. Geol. France Bull., v. 17, p. 45-51.

Robertson, A. H. F. and Hudson, J. D., 1974. Pelagic sediments in the Cretaceous and Tertiary history of the Troodos Massif, Cyprus. *In* Hsü, K. J., Jenkyns, H. C. (Eds.), Pelagic sediments: on land and under the sea: Spec. Publ. Int. Assoc. Sediment., v. 1, p. 403-436.

Ryan, W. B. F., 1972. Stratigraphy of late Quaternary sediments in the Eastern Mediterranean. *In* Stanley, D. J. (Ed.), The Mediterranean Sea: Strasbourg, Virginia (Dowder, Hutchinson and Ross).

———, 1976. Quantitative evaluation of the depth of the western Mediterranean before, during and after the late Miocene Salinity Crisis: Sedimentology, v. 23, no. 6.

Ryan, W. B. F., Hsü, K. J., et al., 1973. Initial Reports of the Deep Sea Drilling Project, Volume 13: Washington (U. S. Government Printing Office).

Scheidegger, K. F., 1973. Volcanic ash layers in deep-sea sediments and their petrological significance: Earth Planet. Sci. Lett., v. 17, p. 397-407.

Schreiber, B. C., 1974. Upper Miocene (Messinian) evaporite deposits of the Mediterranean and their depositional environments: Ph.D. Thesis, Rensselaer Polytechnic Institute.

Schreiber, B. C. and Friedman, G. M., 1976. Depositional environments of Upper Miocene (Messinian) evaporites of Sicily as determined from analysis of intercalated carbonates: Sedimentology, v. 23, p. 729-760.

Von der Haar, S., 1976. Gypsum in sediments. *In* Fairbridge, R. W. (Ed.), Encyclopedia of sedimentology: New York (Reinhold Publishing Co.).

Weiler, Y., 1963. Some remarks on the Kythrea Flysch: Ann. Rept. Geol. Survey Cyprus, p. 53-56.

———, 1970. Mode of occurrence of pelites in the Kythrea Flysch Basin (Cyprus): J. Sediment Petrol. v. 40, p. 1255-1261.