# 42. PALEOENVIRONMENT OF UPPERMOST MESSINIAN SEQUENCES IN THE WESTERN MEDITERRANEAN (SITES 974, 975, AND 978)[1]

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**ABSTRACT**

The uppermost Messinian sediments show different patterns in Holes 974B, 975B, and 978A. Hole 974B from the central Tyrrhenian Sea is characterized by rhythmically bedded claystone that is dominantly brownish and almost barren of fossil content. A transitional interval a few decimeters thick has been recorded at the top of the Lago Mare sequence at Hole 975B from the Balearic Basin. The interval is characterized by whitish-gray, finely laminated micrite and micritic silty clay yielding a *Loxochonca djaffarovi* (ostracode) assemblage typical of the Paratethys**,** interbedded with planktonic foraminifers. This transitional interval might indicate temporary incursions of marine waters.

The Messinian sequence retrieved at Hole 978A from the Alboran Sea is characterized by sandy turbidites interbedded with fine-laminated sediments.The fossil content (foraminifers, calcareous nannofossils, and ostracodes) is contradictory, because both marine and lacustrine forms occur. According to the model proposed here, the sequence was deposited in a basin fed by continental waters. Temporary incursions from the Atlantic Ocean are not documented in any part of the cores investigated.

## INTRODUCTION

A prerequisite of the deep basin dessication model of Hsü et al. (1973) is that the Miocene/Pliocene (M/P) boundary corresponds to a sudden change from continental to open-marine paleoceanographic conditions. In this paper, special attention is paid to the late stage of the Messinian salinity crisis during which the Mediterranean region experienced freshwater invasion from the Paratethys, related to tectonics and climatic variations that changed the drainage. Evidence of such a Paratethyan influence is numerous in land sections from Cyprus (Orszag-Sperber and Rouchy, 1979), eastern Mediterranean (Spezzaferri et al., 1998), northern Italy (Iaccarino and Papani, 1980; Casati et al., 1976; Rizzini and Dondi, 1980; Bossio et al., 1993), southern Italy (Ruggieri and Sprovieri, 1974, 1976, 1978; Sprovieri, 1975), and southern Spain (Backman, 1978; Cita et al., 1980), where brackish to lacustrine sediments well known as Lago Mare facies (bio- and lithofacies), are recorded. The fossil content in these sediments consists mainly of *Ammonia tepida* (foraminifer), *Cyprideis* and *Candona* (ostracodes), and small *Dreissena, Melanopsis,* and *Neritina* (molluscs).

On the contrary, records from deep-sea sequences are few and not well documented. At Site 372, laminites very similar to the Lago Mare facies were retrieved below and above the evaporites. According to Cita et al. (1978), the rich populations of *Ammonia beccarii* recorded in the laminites are autochthonous and indicate shallow, hypersaline conditions while the ecological significance of dwarfed planktonic faunas commonly preserved in the interbedded marls is not well understood.

Some scientists, both in the past and present, have provided a different interpretation of the paleoenvironmental changes at the M/P boundary. Ogniben (1957) considered the Sicilian Arenazzolo Formation, which is the topmost unit of the "Gessoso solfifera", as a sediment deposited in a shallow or marginal marine environment in which normal and marine conditions were gradually introduced. Only lately the terrigenous supply decreased and the biogenic sedimentation of the Pliocene Trubi Formation started. Brolsma (1975, 1978) agreed with the interpretation of Ogniben (1957), and distinguished at Eraclea Minoa (Sicily) a "transitional interval," 40 cm thick, in which a thin intercalation of Trubi limestone was suggested to indicate that the change from the Arenazzolo to the Trubi was a gradual process. The explanation given by Brolsma (1978) is that the fine, terrigenous supply decreased, which permitted the biogenic sedimentation.

Hsü et al. (1978) wrote that "the eastern and probably some western Mediterranean basins were inundated in latest Messinian, by continental waters presumably drained from the Paratethys. At the very end of the Messinian the Balearic and Tyrrhenian Basins began to receive marine waters from the Atlantic, but the environment was not completely open marine."

More recently, Robertson et al. (1990) suggested that the Lago Mare sediments at Site 652 (Tyrrhenian Sea) have accumulated in a close, freshwater lake that periodically became saline and may have experienced marine incursions. Cita et al. (1990) included in the Messinian sequence an additional unit 40 cm thick, consisting of alternating decimetric layers of red marls and of fine-grained, pale green–gray silty muds containing only rare planktonic foraminifers and representing the transition from the terrigenous/evaporitic Messinian to the Pliocene pelagic facies. Finally, Spezzaferri et al. (1997) consider problematic the occurrence of planktonic foraminifers in Lago Mare sediments of the eastern Mediterranean and suggest either reworking, contamination or a transitional phase between full Lago Mare and full marine conditions.

Two main hypotheses are still argued for the Miocene/Pliocene boundary: is the boundary gradual or abrupt? The late stage of the salinity crisis is not yet completely understood, and the evidence is not irrefutable. However, according to the previous data, evidence of a well-developed Lago Mare facies seems to be more consistent in the eastern than in the western Mediterranean.

During Ocean Drilling Program (ODP) Leg 161, late Messinian sequences were drilled at Sites 974 (Tyrrhenian Sea), 975 (Balearic Basin), and 976 and 978 (Alboran Sea; Fig. 1). These sequences offer the potential to find new evidence to substantiate one of the two hypotheses and to recognize the paleoenvironmental setting of the latest Messinian across this east-to-west transect. The sediments overlying

[1]Zahn, R., Comas, M.C., and Klaus, A. (Eds.), 1999. *Proc. ODP, Sci. Results,* 161: College Station, TX (Ocean Drilling Program).

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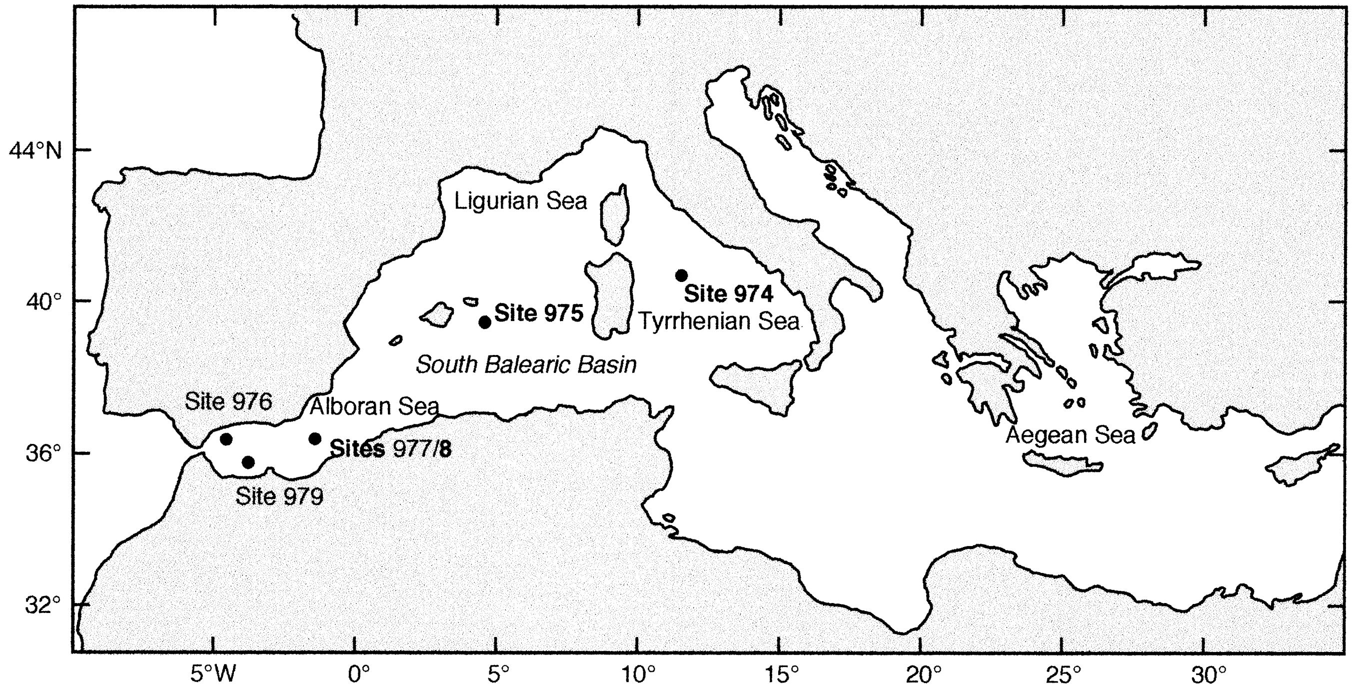


Figure 1. Location map of investigated Sites 974, 975, and 978.

the evaporites up to the M/P boundary are almost unanimously attributed to the Lago Mare environment. This attribution is well founded for the sites located in the Tyrrhenian Sea and Balearic Basin where the evaporites were retrieved below the Lago Mare deposits, but is questionable for Site 978 where no evaporites were recorded. Site 976 is excluded from this study because the Messinian interval is represented only by marine deposits (Comas, Zahn, Klaus, et al.,1996)

To achieve a paleoenvironmental understanding of the Lago Mare deposits, different groups of fossils, such as foraminifers, ostracodes (very useful for the paleoenvironmental interpretation), and calcareous nannofossils, were studied, as well as the lithology and carbonate content.

## MATERIAL AND METHODS

The material on which the present study is based consists of samples collected on board ship during Leg 161 and later at the Bremen Core Repository (Table 1). The samples (10 $cm^3$) were washed with a 63-µm sieve. The foraminifer and ostracode analyses were made mostly on the entire residue for the following different reasons: (1) absence of the >125 µm fraction, which is the fraction commonly used for the foraminiferal analysis; (2) dilution of fossils in sandy residues; and (3) very small amount of residue. The random occurrence of foraminifers and ostracodes prevented a construction of a range chart for the Messinian interval. Therefore, the planktonic foraminifers of Hole 974B and 975B were plotted in the Pliocene range chart (Iaccarino et al., Chap. 15, this volume), while for Hole 978 only the major paleontological features were plotted.

### Hole 974B

This hole is located at the northern edge of the central deep basin of the Tyrrhenian Sea (40°21.362′N, 12° 8.516′E) at a water depth of 3459 mbsl, very close to ODP Leg 107 Site 652 (Fig.1). The Miocene interval has been assigned to Unit III. Like the equivalent section at Site 652, the sediments of Unit III contain sedimentary structures consistent with lacustrine sedimentation (Comas, Zahn, Klaus, et al., 1996) and consist mainly of variegated brownish-gray to blackish-red, silty clay with calcareous, light to dark greenish gray intercalations and millimeter-scale lamination. A detailed mineralogical description of these sediments is given in Comas, Zahn, Klaus, et al. (1996).

The interval investigated, 352 cm thick, includes the topmost Miocene sediments extending from 200.80 mbsf (interval 161-974B-22X-4, 72 cm), the base of the Pliocene sequence (Iaccarino et al., Chap. 15, this volume), down to the bottom of the hole at 203.7 mbsf (interval 161-974B-22X-6-CC).

Different sedimentary and color features recorded from this interval are described as follows from top to bottom:

1. From 161-974B-22X-4, 92 cm, to 22X-5, 40 cm (Fig. 2) the sedimentation is characterized by rhythmically repeated ~1-cm alternating calcareous silty clays and light-gray micrites, interbedded with dark-gray to reddish-black laminated clays. The color in the upper part of the interval is more brownish. All lithologies were barren of ostracodes and yielded only a few, very small-sized foraminifers and calcareous nannofossils (Comas, Zahn, Klaus, et al.,1996); and
2. From 161-974B-22X-5, 40 cm, to 22X-6-CC, the sedimentation is more homogeneous and characterized by silty and sandy clays. Ripple–cross-laminated fine sands occur at Section 22X-5. Most of this interval is barren of fossil content; only toward the base are planktonic foraminifers present (Sample 161-974B-22X-5, 83-85 cm, downward; see table 2 in Iaccarino et al., Chap. 15, this volume). Their preservation and their dominantly small and equal size are indicative of an allochthonous assemblage. In Sample 974B-22X-6, 66-68 cm, a few specimens of *Candona* sp. and *Cyprideis* sp. are recorded (Pl.1, figs. 2, 3).

The sediments of Unit III do not contain elements that prove their stratigraphic attribution. However, the position between the underlying evaporites recorded at Site 652 and the overlying Zanclean pelagic oozes allows the attribution of these sediments to the Messinian. The sedimentary features, the absence of autochthonous fossil record, and the low value of the carbonate content (see fig. 2 in Iac-

**Table 1. Samples investigated from Holes 974B, 975B, and 978A.**

| Core, section, interval (cm) | Depth (mbsf) |
|---|---|
| 161-974B- | |
| 22X-4, 77-79 | 199.37 |
| 22X-4, 82-84 | 199.42 |
| 22X-4, 90-92 | 199.50 |
| 22X-4, 93-95 | 199.53 |
| 22X-4, 103-105 | 199.63 |
| 22X-4, 114-116 | 199.74 |
| 22X-4, 120-122 | 199.80 |
| 22X-4, 127-129 | 199.87 |
| 22X-4, 133-135 | 199.93 |
| 22X-4, 148-150 | 200.08 |
| 22X-5, 6-8 | 200.16 |
| 22X-5, 13-15 | 200.23 |
| 22X-5, 18-20 | 200.28 |
| 22X-5, 28-30 | 200.38 |
| 22X-5, 32-34 | 200.42 |
| 22X-5, 44-46 | 200.54 |
| 22X-5, 48-49 | 200.58 |
| 22X-5, 60-62 | 200.70 |
| 22X-5, 70-72 | 200.80 |
| 22X-5, 80-82 | 200.90 |
| 22X-5, 90-92 | 201.00 |
| 22X-5, 100-102 | 201.10 |
| 22X-5, 110-112 | 201.20 |
| 22X-5, 118-120 | 201.28 |
| 22X-5, 125-127 | 201.35 |
| 22X-5, 143-145 | 201.53 |
| 22X-6, 2-4 | 201.60 |
| 22X-6, 13-15 | 201.73 |
| 22X-6, 16-18 | 201.76 |
| 22X-6, 50-52 | 202.10 |
| 22X-6, 66-68 | 202.26 |
| 22X-6, 83-85 | 202.43 |
| 22X-CC,13-15 | 203.13 |
| 161-975B- | |
| 33X-2, 132-134 | 305.22 |
| 33X-2, 135-137 | 305.25 |
| 33X-2, 139-141 | 305.29 |
| 33X-3, 2-4 | 305.42 |
| 33X-3, 6-8 | 305.46 |
| 33X-3, 11-14 | 305.41 |
| 33X-3, 27-29 | 305.67 |
| 33X-3, 33-35 | 305.73 |
| 33X-3, 35-37* | 305.75 |
| 33X-3, 39-41 | 305.79 |
| 33X-3, 44-46 | 305.84 |
| 33X-3, 47-49* | 305.87 |
| 33X-3, 58-60 | 505.98 |
| 33X-3, 61-63* | 306.01 |
| 33X-3, 70-72 | 306.10 |
| 33X-3, 72-74 | 306.12 |
| 33X-3, 82-83 | 306.22 |
| 33X-3, 83-85* | 306.23 |
| 33X-3, 90-92 | 306.30 |
| 33X-3, 94-96 | 306.34 |
| 33X-3, 97-99 | 306.37 |
| 33X-3, 112-114 | 306.62 |
| 33X-3, 125-127 | 306.65 |
| 33X-3, 137-139 | 306.77 |
| 33X-CC, 6-8 | 310.08 |
| 161-978A- | |
| 45R-CC | 620.91 |
| 47R-1, 7-9 | 630.67 |
| 47R-1, 5-28 | 630.85 |
| 47R-1, 78-80 | 631.38 |
| 47R-1, 121-123 | 631.81 |
| 47R-2, 7-9 | 632.17 |
| 47R-2, 49-51 | 632.59 |
| 47R-2, 87-89 | 632.97 |
| 47R-2, 101-103 | 633.11 |
| 47R-2, 147-149 | 633.57 |
| 47R-3, 54-56 | 634.14 |
| 47R-3, 107-109 | 634.67 |
| 48R-1, 97-99* | 641.27 |
| 48R-4, 98-100 | 645.78 |
| 48R-6, 32-34 | 648.12 |
| 48R-6, 59-61* | 648.39 |
| 48R-CC | 649.93 |
| 49R-3, 49-51 | 653.39 |
| 49R-7, 6-8 | 658.96 |
| 49R-CC, * | 659.63 |
| 50R-1, 113-115 | 660.73 |
| 50R-3, 28-30* | 662.88 |
| 50R-3, 56-58 | 663.16 |
| 50R-4, 122-124 | 665.32 |
| 50R-CC | 669.23 |
| 51R-2, 11-12 | 670.80 |
| 51R-CC, * | 678.02 |
| 52R-1, 13-15 | 678.93 |
| 52R-2, 97-99 | 681.27 |
| 52R-CC, * | 688.42 |
| 53R-1, 38-40 | 688.78 |
| 53R-1, 103-105 | 689.43 |
| 53R-2, 16-18* | 690.06 |
| 53R-2, 78-80 | 690.68 |
| 53R-2, 128-130* | 691.18 |
| 53R-2, 145-147 | 691.35 |
| 53R-3, 1-3* | 691.41 |
| 53R-3, 100-102 | 692.40 |
| 53R-4, 1-3 | 692.91 |
| 53R-4, 6-8 | 692.96 |

Note: * = samples yielding ostracodes.

carino et al., Chap. 15, this volume) are typical elements of the Lago Mare environment. Therefore, the uppermost part of the Messinian sequence could correspond to the transitional unit described by Cita et al. (1990) at Site 652, about 300 m from Hole 974B.

## Hole 975B

This hole is located in the Balearic Basin near the foot of the Menorca Rise (38°53.786′N, 4°30.596′E), at a water depth of 2415 mbsl, close to DSDP Leg 42 Site 372 (Fig. 1).

The interval investigated, 273 cm thick, extends from the base of the Zanclean sediments (161-975B-33X-3, 132 cm) (Iaccarino et al., Chap. 15, this volume) down to the top of the evaporites (161-975B-33X-4, 15 cm), and was distinguished as Unit II (Comas, Zahn, Klaus, et al.,1996). From the top, we subdivided Unit II as follows:

1. The 6-cm interval 161-975B-33X-3, 132–138 cm (Fig. 3), consisting of 2-cm whitish micrites and 4-cm gray-and-whitish, weakly laminated clays. These clays yield a very oligotypical benthic foraminiferal assemblage consisting of *Bolivina* cf. *paralica* (Pl. 1, figs. 1a, b), a common inhabitant of brackish environments, associated with a few planktonic foraminifers (mostly small globigerinids);
2. The 54-cm interval 161-975B-33X-2, 138 cm, to 33X-3, 42 cm (Fig. 4), consisting of submillimeter-scale, white-and-gray laminated micrites and micritic silty clays, yielding common planktonic foraminiferal assemblages, few benthic foraminifers, and rare freshwater ostracodes;
3. The 68-cm interval 161-975B-33X-3, 42–110 cm (Fig. 5), consisting of centimeter-scale, white-and-gray interbedded micritic and micritic silty clays. The white interbeds yield only freshwater ostracodes (Pl. 1, figs. 4–6), whereas in the gray beds are commonly found predominantly small planktonic foraminifers, all of equal size;
4. The 30-cm interval 161-975B-33X-3, 110–140 cm (Fig. 6), consisting of light gray micritic clays that look similar to the clays of the second interval. However, the lamination is less evident, except for red laminae, and the fossil content consists of small, equal-sized, but not well-preserved, planktonic foraminifers; and
5. The 25-cm interval 161-975B-33X-3, 140 cm, to 33X-4, 15 cm characterized by gray, sandy sediments that were completely barren.

The planktonic foraminiferal assemblages show the following features:

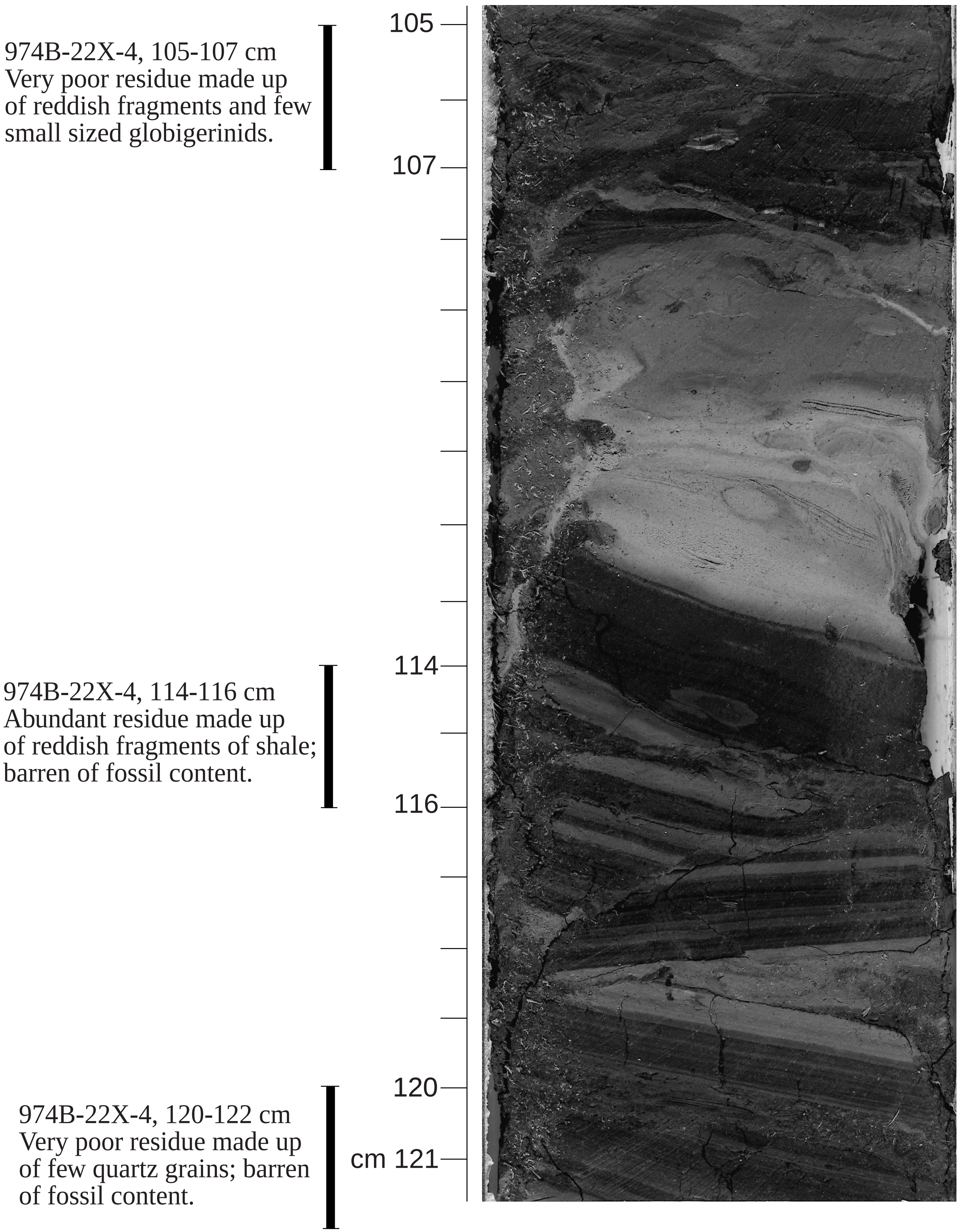


Figure 2. Major features of sample residues from interval 161-974B-22X-4, 105–121 cm.

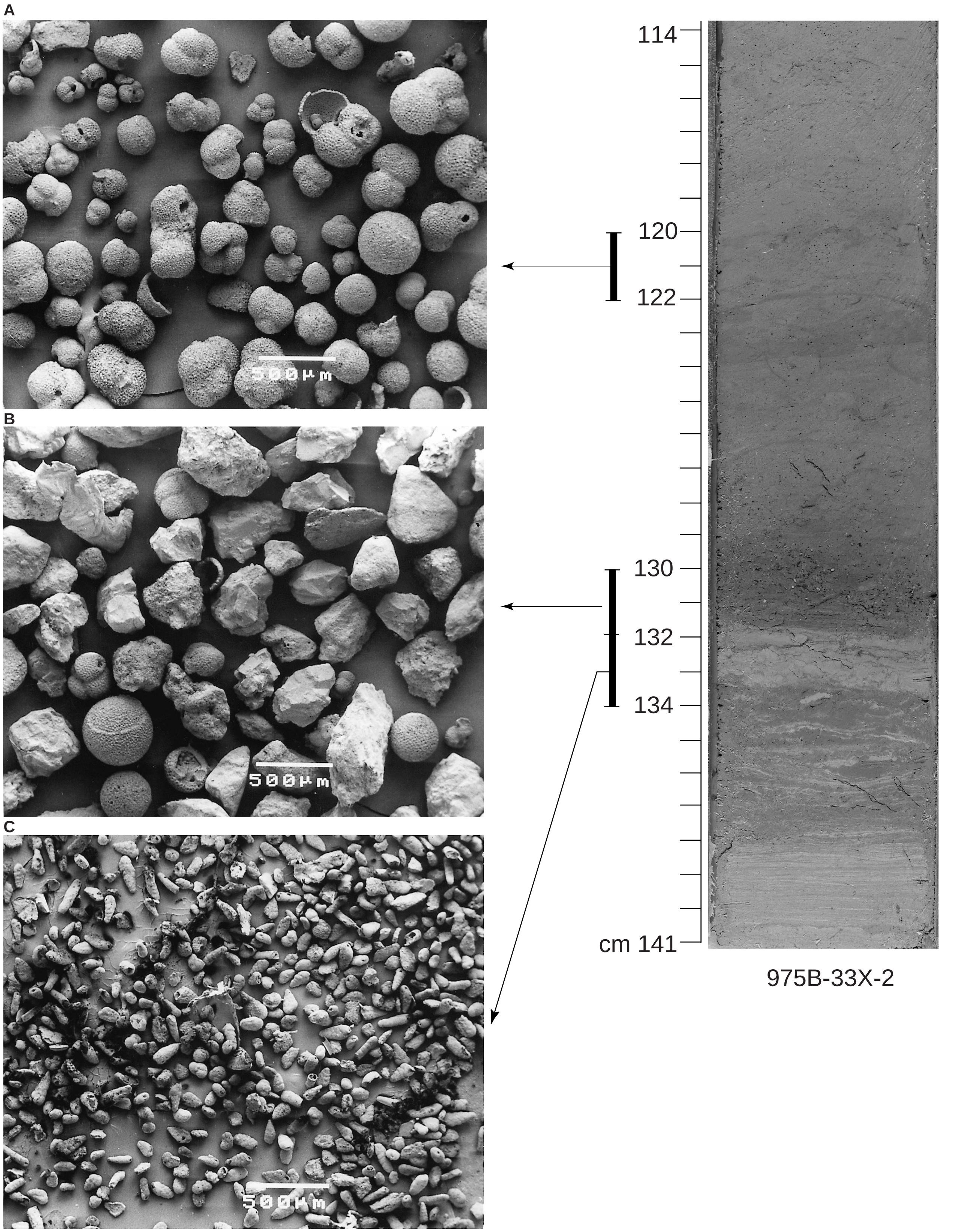


Figure 3. Residues from interval 161-975B-33X-2, 105–141 cm. **A.** Sample 161-975B-33X-2, 120–122 cm, fraction >125 µm. Planktonic foraminiferal assemblage. **B.** Sample 161-975B-33X-2, 130–132 cm, fraction >125 µm. At the very base of the Pliocene small clasts are present in the matrix. **C.** Sample 161-975B-33X-2, 132–134 cm, fraction <125 µm. Very abundant benthic foraminiferal assemblage (mainly *Bolivina* cf. *paralica* and *Ammonia tepida*).

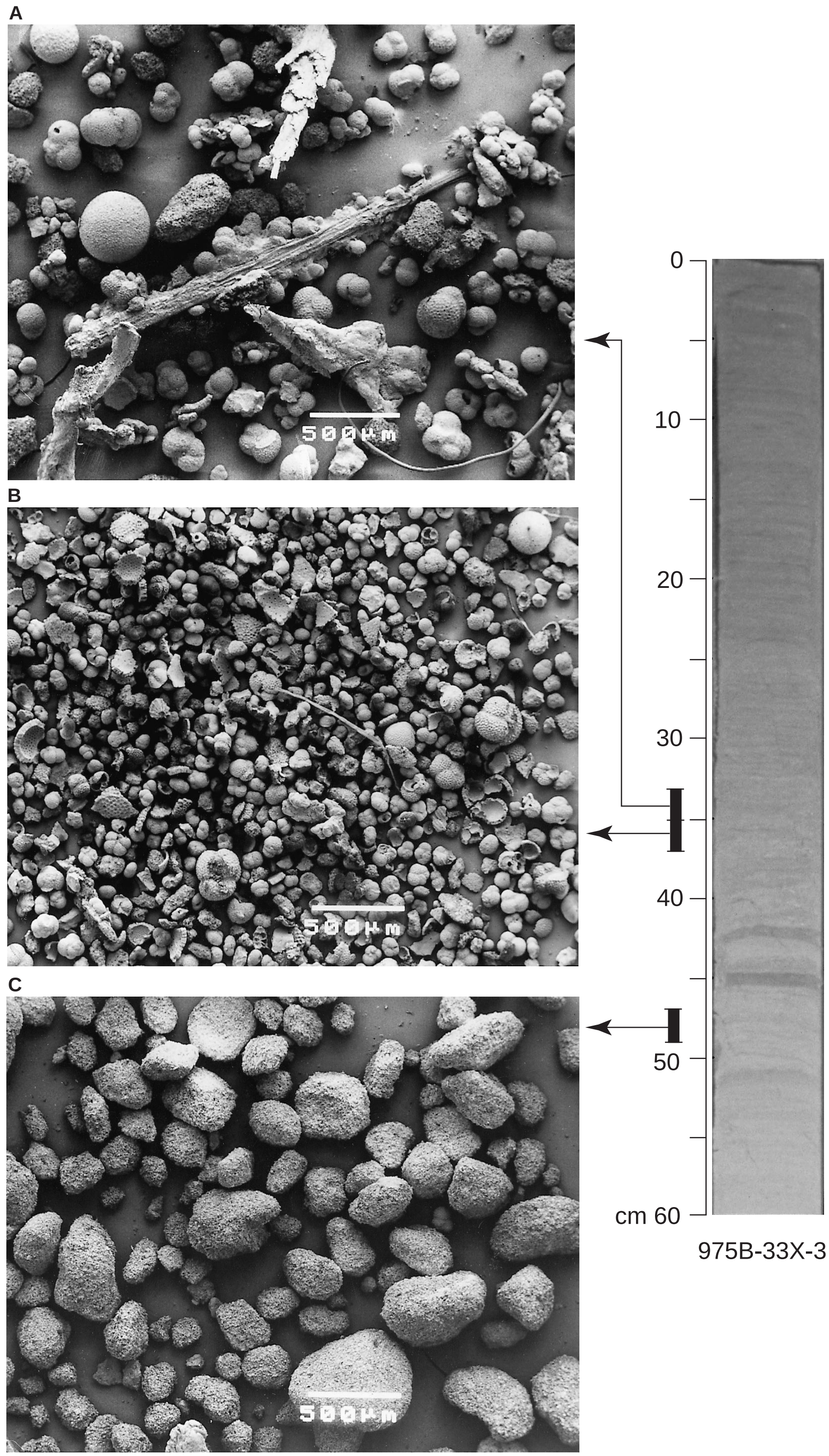


Figure 4. Residues from interval 161-975B-33X-3, 0–60 cm. **A.** Sample 161-975B-33X-3, 33–35 cm, fraction >125 µm. Foraminiferal assemblage mainly composed of planktonic forms. **B.** Sample 161-975B-33X-3, 35–37 cm, fraction >125 µm. Rich, small-sized planktonic foraminiferal assemblage; the larger specimens are below the average size (see the size of the Pliocene Sample 161-975B-33X-2, 120–122 cm, fraction >125 µm). **C.** Sample 161-975B-33X-3, 47–49 cm, fraction >63 µm: barren residue.

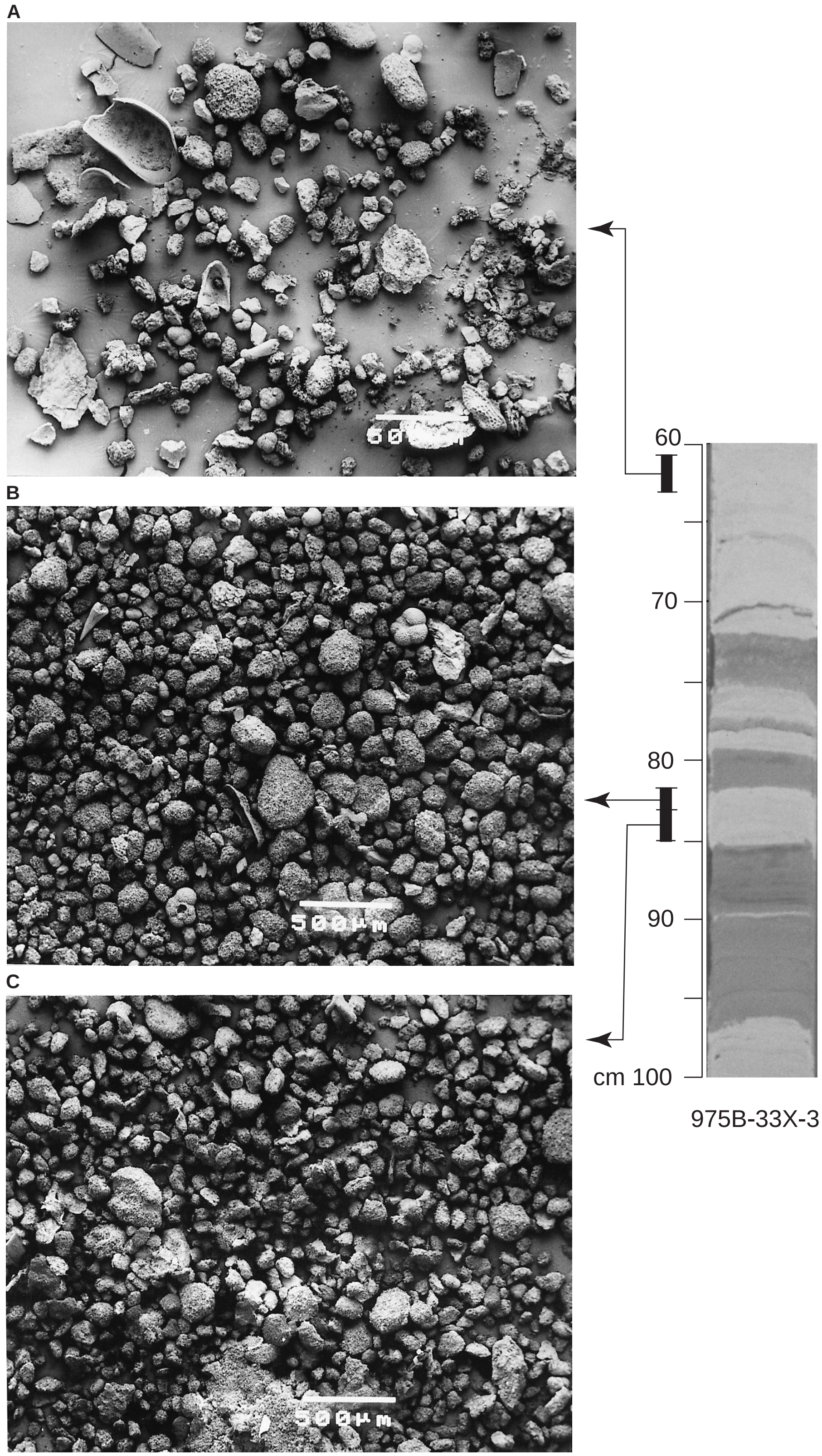


Figure 5. Residues from interval 161-975B-33X-3, 60–100 cm. **A.** Sample 161-975B-33X, 61–63 cm, fraction >125 µm. Small-sized planktonic foraminifers associated with common ostracodes from white interval. **B.** Sample 161-975B-33X-3, 82–83 cm, fraction >63 µm. Very few small-sized foraminifers from white interval. **C.** Sample 161-975B-33X-3, 83–85 cm, fraction >63 µm. Barren residue from same white interval.

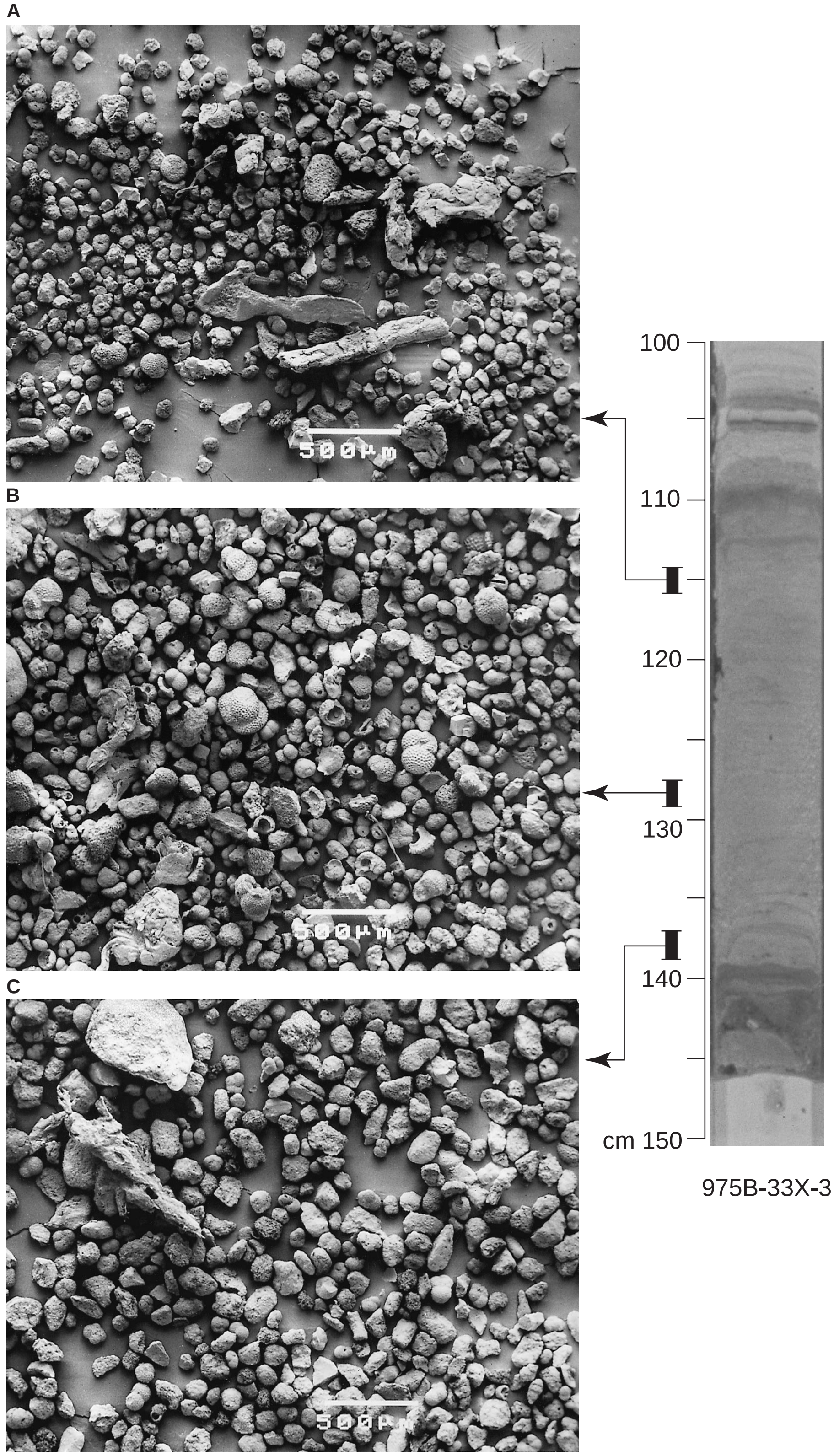


Figure 6. Residues from interval 161-975B-33X-3, 100–150 cm. **A.** Sample 161-975B-33X-3, 114–116 cm, fraction >63 µm. Very fine residue with very poorly preserved foraminifers. **B.** Sample 161-975B-33X-3, 127–129 cm, fraction >63 µm. Rich, small-sized planktonic foraminiferal assemblage with larger specimens below the average size. **C.** Sample 161-975B-33X-3, 137–139 cm, fraction >63 µm. Common small-sized planktonic foraminifers.

1. The general size of the individuals is well below average. Even the largest specimens are small, if compared to a normal marine population;
2. The assemblage is generally composed of small globigerinids, not easily recognizable, and a few larger specimens of which *Orbulina, Globigerinoides, Globorotalia menardii* gr., *G.* gr. *miotumida*, and *Sphaeroidinellopsis* were recognized;
3. The preservation is rather poor and shows dissolution traces and recrystallization; some specimens are broken; and
4. The assemblage does not yield specific Pliocene forms; on the contrary, Miocene forms are present (i.e., *G.* gr. *miotumida*).

The benthic foraminifers are very rare throughout the entire Messinian sequence except for interval 161-975B-33X-3, 132-138 cm in which the fraction <125 µm is made up almost exclusively of *Bolivina* cf. *paralica* (it constitutes the greatest part of the assemblage also in the fraction >125 µm). This taxon is common in brackish environments as recorded by Bossio et al. (1978). Associated with *B.* cf. *paralica,* numerous specimens of *Ammonia tepida* and *Rosalina* sp. occur. Sporadic specimens of *B.* cf. *paralica* occur also in other samples (161-975B-33X-3, 83-85 cm, and 33X-3, 127-129 cm). A few specimens, including *Orthomorphina* spp., *Gyroidinoides soldanii,* and *Oridorsalis stellatus* are also present in Sample 975B-33X-3, 33-35 cm (six specimens), and in Sample 975B-33X-3, 35-37 cm (three specimens).

The ostracodes are generally rare and are present only in the white intervals (Table 1). It is very surprising that such a small quantity of sediments (10 $cm^3$) contain ostracodes because, in general, studying these organisms requires much more material. The most recurrent taxa are typical of a freshwater or brackish environment. The following forms have been recognized: *Loxochonca djaffarovi* (Pl. 1, figs. 4–5), *Candona* sp., and *Cyprideis* sp. (Pl. 1, fig. 6). The richest levels are recorded from Core 161-975B-33X-3, 50-85 cm. It is worth mentioning that in the equivalent interval of Hole 975C (Core 33X-4 to 33X-CC) the following ostracodes, typical of the Paratethys, were observed: *Euxinocythere praebaquana, Amnicythere idonea,* and *Leptocythere limbata*.

Based on the previous considerations, it is inferred that the autochthonous assemblage is made up of ostracodes, while the small, equal-sized planktonic foraminifers are reworked from older sediments (early Messinian and pre-Messinian Miocene sediments). The oligotypic assemblage of *Bolivina* cf. *paralica, Rosalina* sp., and *Ammonia tepida* strongly supports this interpretation.

From the paleoenvironmental point of view, we suggest that the whitish interval containing lacustrine or brackish ostracodes should indicate the normal sedimentation of the Lago Mare environment, while the gray intervals are interpreted as episodes of resedimentation during periods of increased runoff, which led to greater erosion of terrestrially exposed marine sediments on the subaerial margins of the basin.

The whitish and gray, thinly laminated sediments represent a similar depositional setting to the white-and-gray centimetric intervals previously described; the whitish horizons represent the authocthonous sedimentation and the gray ones are resedimented.

However, the uppermost 50-cm-thick interval (161-975B-33X-2, 132 cm to 33X-3, 40 cm) containing a rich population of *Bolivina* cf. *paralica* and abundant planktonic foraminifers (Figs. 3, 4), might be the paleontological expression of the first arrival of Atlantic water masses before the complete opening of the Gibraltar Strait.

## Hole 978A

Site 978 is located in the Eastern Alboran Sea to the south of Cabo de Gata (36°13.867′N, 2°3.424′W) at a water depth of 1929 mbsl (Fig. 1). The Miocene sequence consists of a ~10-m-thick, gravel-bearing interval (Unit II) containing pebbles of volcanic rocks, which is above Unit III, 68 m thick, and composed predominantly of terrigenous silt- and sand-sized material. An unconformity separates Unit II from the overlying Pliocene–Pleistocene Unit I. The interval investigated extends from Core 161-978A-46R down to Core 53R. However, Core 46R was not considered because the recovery consists of only three volcanic pebbles.

The environmental interpretation of the Miocene sequence drilled in Hole 978A was debated among the scientists during the cruise: is it a “Lago Mare” sequence or a marine sequence? According to the sedimentary structures, Unit III (corresponding to the Miocene interval) was interpreted as a submarine fan lobe deposit in which the presence of inverse grading at the base of a normally graded sequence could be attributed to traction carpets produced by turbidity currents. Sparse ichnofacies and varve-like laminations restricted to some intervals were interpreted as signals of anoxic marine bottom-water conditions. The paleontological content of this sequence was interpreted differently.

### *Calcareous Nannofossils*

The calcareous nannofossils (Fig. 7) are present continuously from Core 47R down to Core 53R. The preservation is quite good and the number of specimens sufficient to make a quantitative study. Cretaceous and Tertiary reworked forms are present consistently throughout (Tazzi, 1996). Counting 300 specimens from the base to the top of the investigated sequence allowed us to recognize the occurrence of *Reticulofenestra rotaria* whose First Occurrence (FO) and Last Occurrence (LO) define the *R. rotaria* Zone of Theodoridis (1984), associated with randomly distributed specimens of *A. delicatus* and *A. primus.* According to Theodoridis (1984) and Negri et al. (1997) the *R. rotaria* Zone characterizes the lower part (that is, the pre-evaporitic interval) of the Messinian, and, therefore, the calcareous nannofossils of the Miocene sequence at Site 978 suggest an early Messinian age.

### *Foraminifers*

Most of the examined samples, listed in Table 1 and shown in Figure 7, contain rare and poorly preserved foraminiferal assemblage, and some samples did not provide any residue (fraction >63 µm). Only a few samples yield common, small-sized planktonic foraminifers among which a few specimens of *Globorotalia conomiozea* occur; other Miocene keeled globorotalids are present at intervals. Benthic foraminifers are always rare. However, a few specimens of *Brizalina dentellata* and *Bulimina echinata*, typical taxa of the marine pre-evaporitic Messinian marls (Colalongo et al. 1979), were observed associated with *Ammonia tepida* and *Protelphidium granosum*, typical of a brackish environment.

Therefore, the foraminiferal assemblage supports the Messinian age of the sediments, but it does not clearly define the environment because normal marine and non-marine taxa co-occur. Marine forms could be reworked into a lacustrine setting or vice versa. The indications provided by the sedimentary structures support both the possibilities. In any case, if the brackish fauna is displaced, it then must have been transported during the early Messinian into a marine environment from coeval brackish waters. In the second hypothesis, the marine foraminifers are reworked from the early Messinian during the late Messinian Lago Mare sedimentation, when most of the Mediterranean area was invaded by freshwater from the Paratethys and its earlier deposited marls were exposed to erosion on its subaerial margins.

### *Ostracodes*

In order to have more unequivocal evidence of the depositional environment of Unit III, the ostracodes, which are very useful in recognizing the sedimentary environment and largely used by Mediterranean Messinian stratigraphers, were analyzed (Fig. 7; Pl. 1, figs. 7–12). They are always rare and randomly distributed; in Cores 48R and 47R, they are missing. However, the most represented taxa are *Candona* sp., *Loxoconcha mülleri*, and *Cyprideis* sp., that are recorded with different stages of instars (Pl. 1, figs. 8–11). The instars have very delicate and fragile tests, and, therefore, cannot be displaced (i.e., become allochthonous) without being broken.

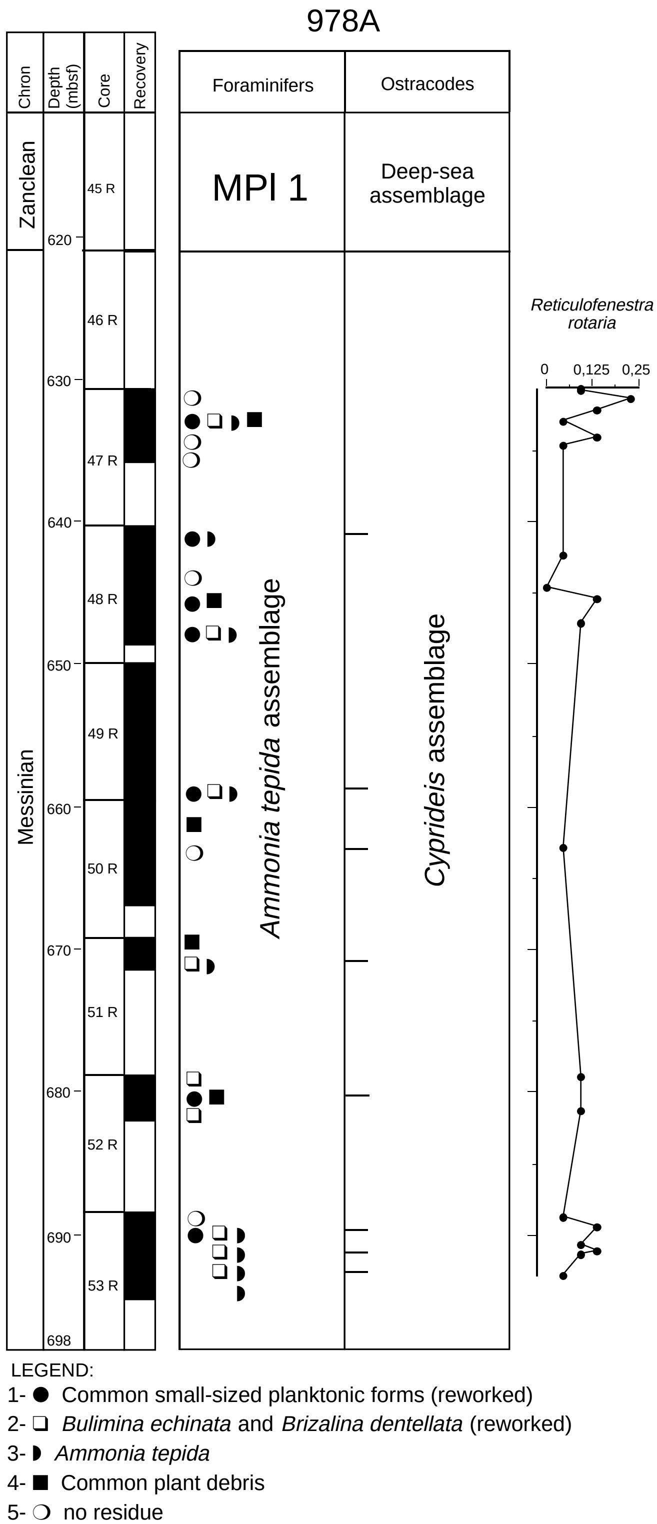


Figure 7. Major paleontological features of Messinian sequence at Hole 978A.

Numerous previous studies made on both land and deep-sea sections of both the eastern and western Mediterranean revealed that such an assemblage is typical of the uppermost part of the Messinian and is characterized by a brackish or freshwater environment.

Additional evidence of the environmental interpretation is the $CaCO_3$ content, which sharply decreases below the marl ooze of Unit I (fig. 40 in Comas, Zahn, Klaus, et al.,1996).

## Comparison

The results of the micropaleontological study of Holes 974B, 975B, and 978A show them to be comparable and consistent with those obtained by other workers in land sections of different parts of the Mediterranean area. In the Tyrrhenian Sea, the barren sediments have strong analogies with those encountered in most of the Lago Mare Italian land sections. The transitional interval, as described by Brolsma (1978) in Sicily at the top of the Arenazzolo, and that described by Cita et al. (1990) at Site 652, could be equivalent to the uppermost part of the Miocene sequence. In fact, the brown- to white-laminated intervals are almost barren and contain only rare, small-sized planktonic foraminifers. Few lacustrine ostracodes were recorded from the lowest part of the Messinian sequence. In the Balearic Sea, the terminal Messinian show a different pattern. The presence of typical Paratethys ostracodes (*Loxoconcha djaffarovi* and *L. mülleri*) makes the sequence comparable with that of the Vera basin in southern Spain (Cita et al., 1980), the Tuscany area (Bossio et al., 1978, 1981, 1996), and the Emilia-Romagna area (Iaccarino and Papani, 1980; Casati et al. 1976) in Italy, where identical ostracode faunas were recorded in the topmost part of the Messinian (Fig. 8). The entire Messinian sequence in Hole 978A shows sedimentary feature similar to those recorded in the Flysch della Laga (Periadriatic Trough) which was deposited in a Lago Mare environment.

The seismic reflector at the Miocene/Pliocene boundary at Site 978, in the Alboran Sea (Fig. 9) and interpreted as equivalent to "M" reflector, can be correlated with the erosional unconformity observed by Bernet Rolland et al. (1979) at the Cuevas del Almanzora section where they observed, at the base of the Pliocene succession, an ero-

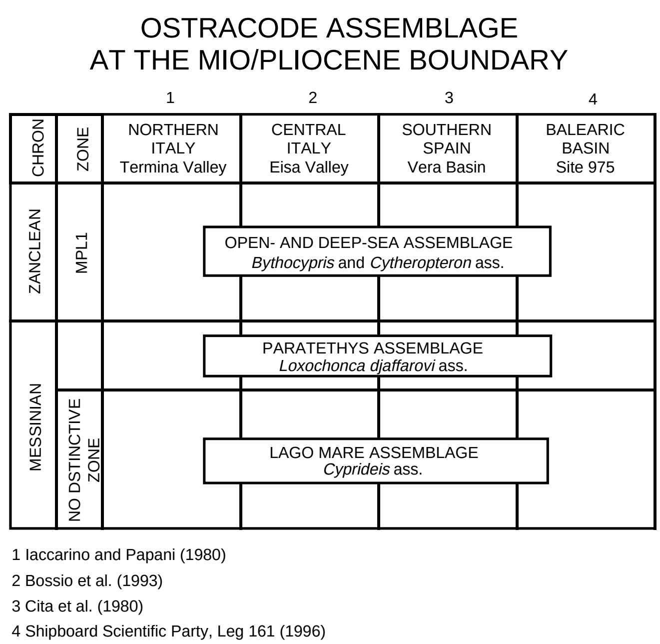


Figure 8. Occurrence of the ostracode Paratethys assemblage in different Mediterranean localities.

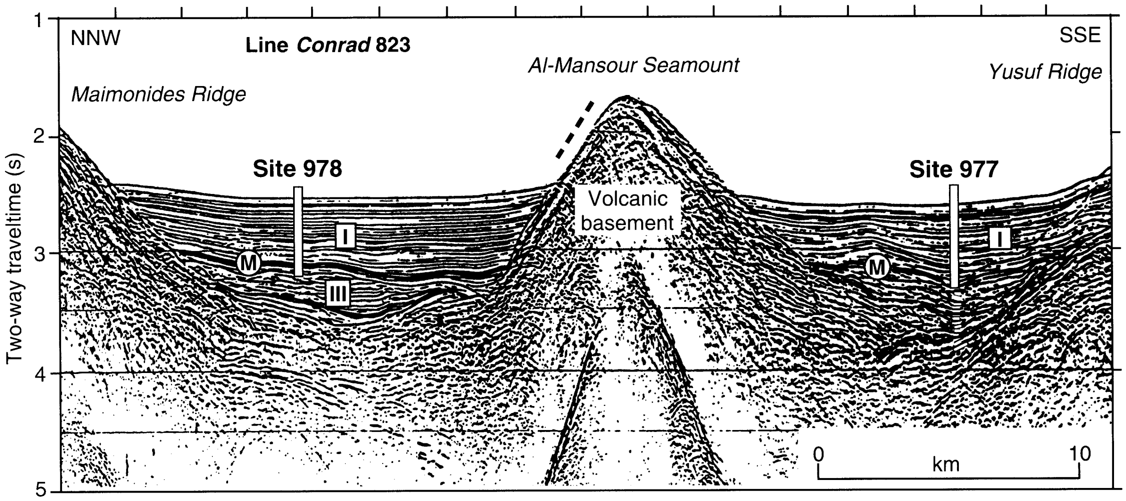


Figure 9. Site 978. Interpreted profile based on seismic frequency analysis and stratigraphic subdivision proposed by Comas et al. (1992). I and III = lithoseismic units from Comas et al. (1992); M = "M" reflector.

sional surface in which volcanic pebbles are strewn as in Hole 978A. The deeper seismic reflector (Fig. 9), which was not reached by the drilling, could correspond to the discontinuity observed in the Vera Basin between the early and late Messinian (Cita et al, 1980). The hiatus could correlate with an inferred erosional period most likely corresponding to a time of lowered sea level and evaporite deposition elsewhere in the Mediterranean Basin as suggested by Geerlings et al. (1980). At that time the area of Site 978 would have been occupied by an alluvial fan, which was drowned and subsequently covered directly by marl ooze with typical planktonic marine fauna of the early Pliocene Trubi.

## CONCLUSION

The Miocene sequence of the three Holes 974B, 975B, and 978A is referred to the Messinian Lago Mare environment. We can say that the Lago Mare sediments are surely present in the Tyrrhenian Basin, the Balearic Basin, and are suggested to be present in the Alboran Sea, as documented by the presence of ostracodes typical of the Paratethys, which generally are recorded from the terminal part of the Lago Mare sediments (Carbonnel, 1977; Casati, et al., 1980; Bossio et al., 1978, 1981, 1996; Iaccarino and Papani, 1980). However, in Hole 975B it cannot be entirely ruled out that at the end of the Messinian, marine incursions from the Atlantic could have arrived and been mixed with the lacustrine waters. The deep-water facies of the basal Pliocene, the absence of dessication structures, and paleosoils suggest the invasion of the Atlantic water masses into the Mediterranean to form a "water on water" change from a continental to an open-marine environment (Bossio et al., 1978, 1981; Cita et al., 1980). This hypothesis could explain the presence of planktonic foraminifer-rich layers interbedded with Paratethys ostracode-bearing layers.

However, the presence of occasional incursions of marine waters in some parts of the Western Mediterranean Basins does not contradict the abrupt paleoceanographic change created by the re-establishment of an open-marine environment in the earliest Pliocene. As concerns Hole 978A, we are convinced that, on the basis of the ostracode content, both foraminifers and calcareous nannofossils are reworked from the early marine Messinian, while the ostracode fauna reflects the original paleoenvironment.

The physiography of the Mediterranean at the end of the Messinian was differentiated in deeper central and shallower marginal basins, often with intervening sills like the present peri-Tyrrhenian basins. The shallower basins would have received fresh water during the entire duration of the Paratethys drainage. The level of the lake surfaces could have stood at higher elevations than those of deeper central basins. The rich, brackish assemblages in the land sections of most areas of the Mediterranean area and the absence of a transitional unit support this interpretation. The deeper basins, where the brackish assemblages are less abundant or absent, might have been invaded directly by incursions of marine water from the Atlantic in the very first stages of the opening of the Gibraltar Strait.

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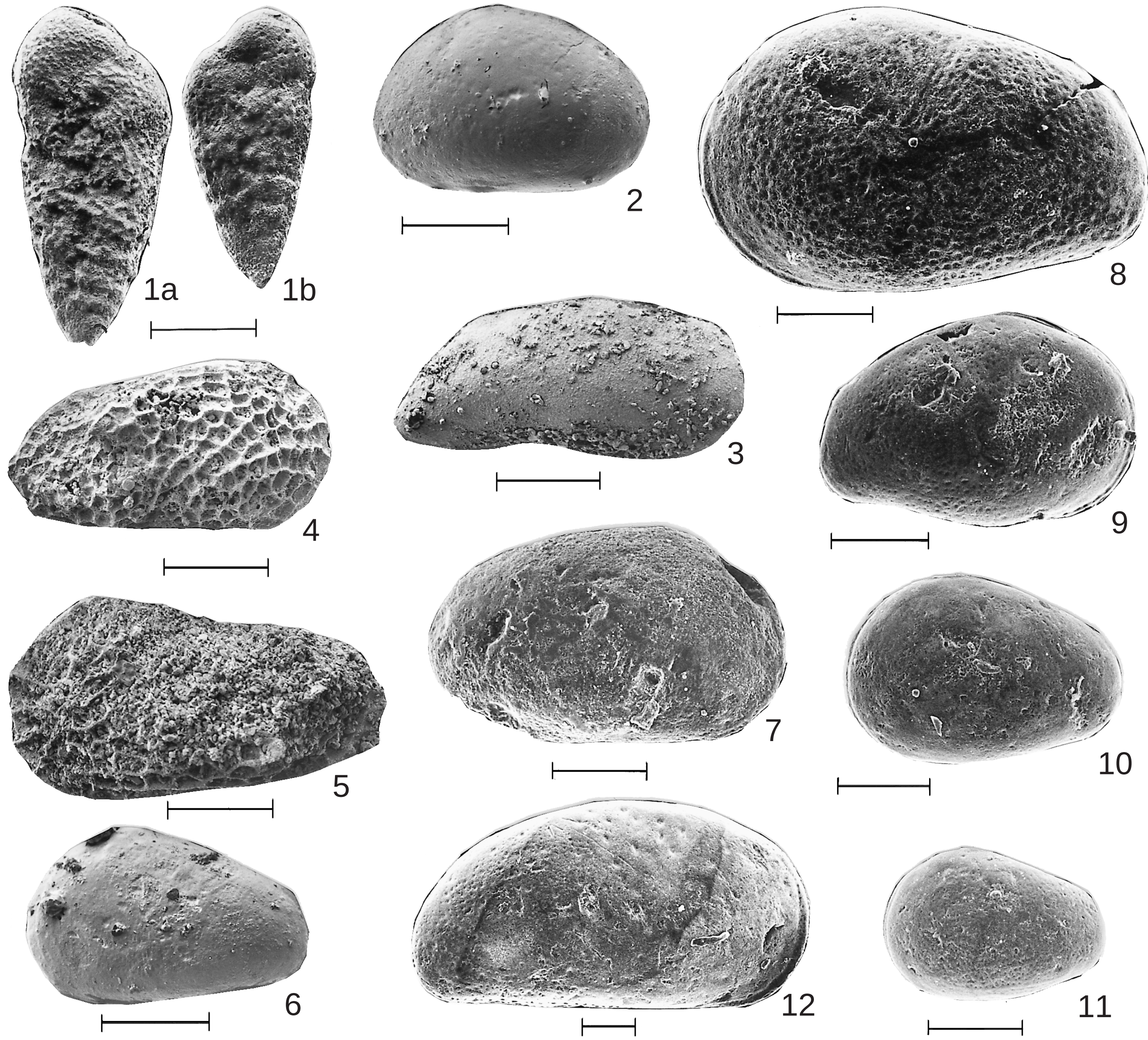


Plate 1. **1a, b.** *Bolivina* cf. *paralica* Perconig (Sample 161-975B-33X-2, 132–134 cm). **2.** *Cyprideis* sp. v.sx (Sample 161-974B-22X-6, 66–68 cm). **3.** *Candona* sp v.dx (Sample 161-974B-22X-6, 66–68 cm). **4, 5.** *Loxoconcha djaffarovi* Schnei-der v.sx (Sample 161-975B-33X-3, 83–85 cm). **6.** *Cyprideis* sp. v.sx instar (Sample161-975B-33X-3, 83–85 cm). **7.** *Loxoconcha mülleri* (Mehes) v.dx (Sample 161-978A-53R-2, 16–18 cm). **8–11.** *Cyprideis* spp. (Sample 161-978A-53R-2, 16–18 cm); 8 = v.dx instar; 9 = v.sx; 10 = v.sx instar; 11 = v.sx instar. **12.** *Cyprideis* sp. v.dx (Sample 161-78A-53R-2, 128–130 cm).