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6. ENVIRONMENTAL SIGNIFICANCE OF AN UPPERMOST PLIOCENE CARBONATE DEBRIS FLOW AT SITE 978[1]

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ABSTRACT

A single, coarse-grained, carbonate layer was recovered at Ocean Drilling Program Leg 161 Site 978, within the uppermost Pliocene sediments of the Eastern Alboran Basin. We interpret this layer as a debris-flow deposit, primarily produced by hyperconcentrate to high-density gravity flows. Gravel-sized bioclasts consist mainly of coralline algae, bivalves, and bryozoans. This skeletal-grain association and the occurrence of branch fragments of the coralline algae *Lithothamnion* and *Phymatolithon,* as well as the serpulid *Ditrupa* and the brachiopods *Mergelia* and *Megathiris,* indicate that the source area for the carbonate particles was a temperate outer platform. Regional data on late Pliocene to Holocene paleogeography suggest that a platform located ~25 km to the north of Site 978, just south of Cabo de Gata, was the source area for the debris-low layer. We consider the gravity-flow event as having been triggered by earthquake activity ~2.1 Ma, thus representing a proximal "seismite" layer intercalated with low-density, distal-turbidite sequences.

INTRODUCTION

Ocean Drilling Program Leg 161 drilled the Eastern Alboran Basin (EAB) to determine the nature and age of the sedimentary cover and to yield information on the subsidence history and tectonic evolution of this region. Site 978 (1942.4 meters below sea level [mbsl] water depth) lies in an east-west–trending, 35-km-wide sedimentary depocenter, which is limited to the south by the volcanic Al-Mansour Seamount and to the north by the southeastern prolongation of the Maimonides Ridge, and which widens toward the South Balearic Basin to the east (Fig. 1).

The Pliocene–Pleistocene sequences in the EAB are known from coring at Sites 977 and 978 (Comas, Zahn, Klaus, et al., 1996). Below, the Messinian deposits of the Alboran Basin (seismic Unit II; Jurado and Comas, 1992) are formed of marine facies containing minor gypsum and anhydrite intervals, although no substantial evaporite or salt layers exist. Salt diapirs, associated with the "upper evaporite" Messinian sequence (Ryan, Hsü, et al., 1973), occur just to the east of Sites 977 and 978 at the transition from the EAB to the South Balearic Basin under seafloor deeper than 2400 m (Fig. 1). Older sediments are depicted on seismic lines as filling discrete grabens or half grabens overlying basement, and are interpreted as corresponding to the Miocene synrift sequence. The sedimentary cover of the EAB is affected by folding and strike-slip faulting as a result of late Miocene to Pleistocene compressional tectonics. At places, very recent folding and faulting deform the present seafloor (Comas et al., 1992, 1995; Mauffret et al., 1987, 1992; Watts et al., 1993; Woodside and Maldonado, 1992).

This paper outlines the character and environmental significance of a single, coarse-grained, carbonate debris-flow interval recovered at Site 978 within the upper Pliocene sequence of the EAB. Biogenic components and nature of this layer point to the occurrence of temperate carbonate platforms at the northern margin of the Alboran Basin during the late Pliocene.

SUMMARY OF SEDIMENTS RECOVERED AT SITE 978

Coring of the upper Pleistocene sediments was intermittent down to 213 meters below seafloor (mbsf) at Site 978; however, drilling penetrated and sampled a continuous sequence of 485 m (from 213 to 698 mbsf) from upper Miocene to lower Pleistocene sediments in a single hole. Three lithologic units were recognized in sediments cored in Hole 978A. In reverse stratigraphic order (from top to bottom), the character of the lithologic divisions is summarized as follows (Shipboard Scientific Party, 1996):

1. Unit I (213.0-620.9 mbsf), early Pleistocene to late Pliocene in age, is mainly formed of greenish gray bioturbated nannofossil clay to claystone, with foraminifers and shell fragments dispersed throughout, and occasional laminated layers of foraminifer-rich sands and silts. On the basis of variations in color, composition, and sedimentary structures, pelagic/hemipelagic and turbidite facies associations, and scarce contourite, debris-flow and slump beds have been identified within Unit I. These facies associations are interpreted as being deposited in a deep, open-marine environment. The studied debris-flow layer occurs in this unit, within planktonic foraminifer zone MPL6 (i.e., in the upper Pliocene part of the unit).
2. Unit II (620.9–630.67 mbsf) corresponds to a lower Pliocene–upper Miocene(?) gravel-bearing interval containing pebbles of volcanic and sedimentary rocks. A similar gravel unit was sampled at 598.5 mbsf in Hole 977A (24 km to the south; Fig. 1), which suggests that the gravel interval is ubiquitous in the EAB and may have resulted from a strong erosional event that occurred by the end of the Messinian, represented by the M-unconformity (M-reflector) in the Eastern Alboran Basin (Comas et al., 1995).
3. Unit III (630.67–694.3 mbsf), of late Miocene (Messinian) age, is formed of bioturbated claystones, laminated and sandy siltstones, and graded sandstone beds. Thin and fine-grain–sized siliciclastic turbidite layers, in situ brecciation and clastic dikes are common throughout Unit III.

Using combined nannofossil and planktonic foraminifer appearance events and magnetostratigraphic chrons, the average sedimentation rates at Site 978 are: 127 m/m.y. for the Pleistocene, 111 m/m.y.

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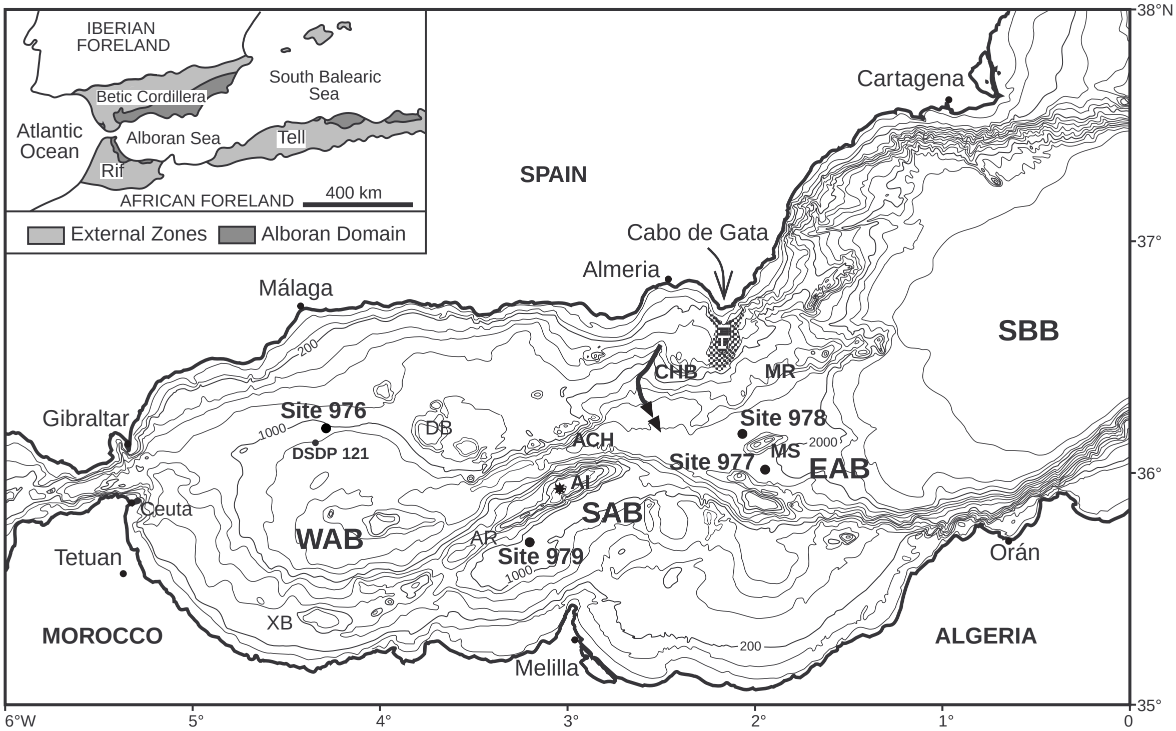

Figure 1. Bathymetric map of the Alboran Sea showing the location of Leg 161 sites and the proposed source area for the carbonate debris-flow bed. Note the location of the Holocene temperate-carbonate platform (black squares) and the fringing talus (stippled) at the offshore prolongation of Cabo de Gata. The two-arrowed line marks the path of the Andarax Canyon turbidite system. Bathymetric contour lines are every 200 m. ACH = Alboran Channel, AI = Alboran Island, AR = Alboran Ridge, CHB = Chella Bank, DB = Djibouti Bank, EAB = Eastern Alboran Basin, MR = Maimonides Ridge, MS = Al-Mansour Seamount, SAB = South Alboran Basin, SBB = South Balearic Basin, WAB = West Alboran Basin, and XB = Xauen Bank. The inset map shows the location of the Alboran Sea between the Betic and Rif Cordilleras, and general tectonic subdivisions.

for the upper Pliocene, 120 m/m.y. for the lower Pliocene, and 156 m/m.y. for the upper Miocene (Shipboard Scientific Party, 1996).

THE COARSE-GRAINED LAYER

Sedimentary Facies

A single coarse-grained layer was recovered at Site 978 from 262.12 to 262.50 mbsf (interval 987A-8R-5, 59–97 cm; Fig. 2). The layer has sharp upper and lower boundaries, and from bottom to top consists of three beds, or depositional divisions, as follows:

1. A basal bed, 23 cm thick, formed of chaotic mud-supported gravel. Angular-to-rounded clasts are coarse sand to pebble in size (up to 10 mm) and consist of white bioclasts (see below) and dark greenish mudstone intraclasts. The matrix is formed of dark greenish gray, nannofossil-rich clay to silty clay. Coarser clasts show a slight tendency to concentrate in the lower part of the bed.
2. A 6-cm-thick bed formed of roughly reverse-to-normal graded, coarse-sand–sized, pebbly packstone. Grains and matrix are similar in composition to those in the underlying bed.
3. An uppermost 9-cm-thick bed of structureless packstone, including some outsized clasts at its base. Grain composition is also similar to that in the underlying beds.

We interpret this layer as the product of a cohesive debris flow (basal bed), in which the clasts were supported by matrix strength and density, passing upward to facies deposited from high-density turbidite currents (upper beds; Lowe, 1982). The vertical track of the three depositional divisions (beds) in the layer indicates flow transformation during the downslope motion from a dense, cohesive flow to a more fluidized gravity flow.

Following the turbidite facies definition of Mutti (1994), we consider the basal bed in the layer (Fig. 2) as an F2 deposit produced from hyperconcentrate flows, in which mudstone clasts are rip-up fragments derived from erosion by the gravity flow on the underlying mudstone substratum (Fig. 3). The F2 deposit changes upward into a clast-supported, crudely reverse-to-normal organized bed (F3 bed), which probably resulted from clast segregation from the hyperconcentrate flow. The structureless, coarse-sand–sized packstone at the top of the layer, which includes large (up to 1 cm) clasts (i.e., at 32 cm in Fig. 2) is considered an F4 deposit (the traction carpet division of Lowe, 1982), caused by deposition from a gravelly high-density turbidite current.

This is the only debris-flow layer intercalated between the classical distal turbidite facies (deposit F9a of Mutti, 1994) caused by low-density turbidite currents (Fig. 2) that formed the entire upper Pliocene sequence recovered in Hole 978A (Shipboard Scientific Party, 1996).

Carbonate Biogenic Components

The lowest 23-cm (interval 161-978A-8R-5, 74–97 cm) contain gravel-sized (up to 10 mm), poorly sorted fragments of coralline red algae, bivalves, echinoids, bryozoans, gastropods, barnacles, serpulids (*Ditrupa* sp. among others), brachiopods (*Mergelia* sp. and *Megathiris* sp.), crabs, ostracodes, and planktonic and benthic foraminifers (Fig. 3). Among the latter, *Elphidium* spp., *Lenticulina* spp., *Cassidulina* sp., *Hoeglundina* sp., and *Epistominella* sp. can be recognized, together with some miliolids and textulariids. The coralline algal association consists of branch fragments of *Lithothamnion* in-

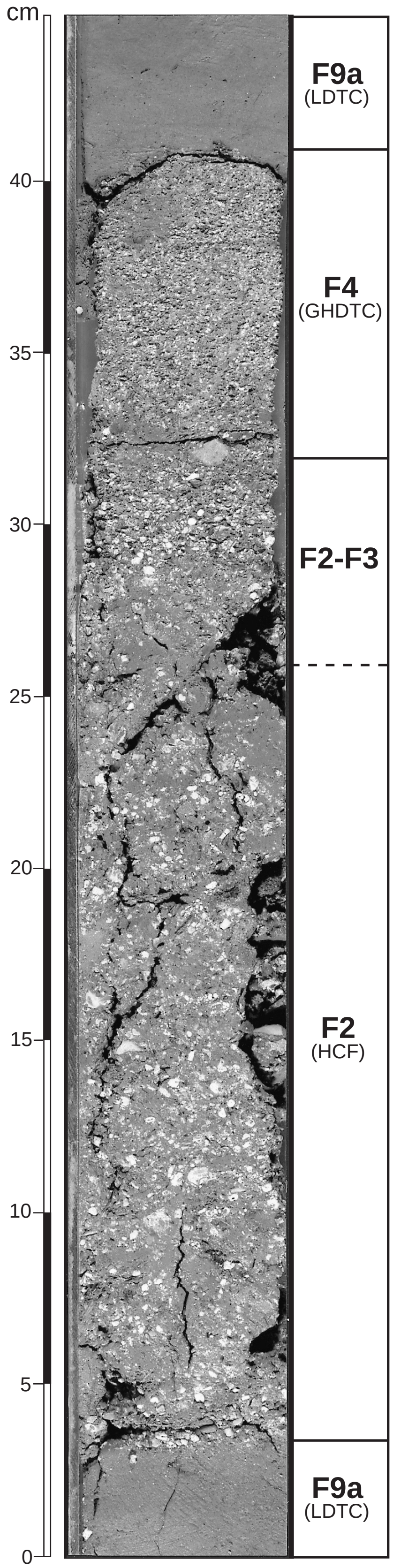

Figure 2. The carbonate gravel layer (interval 161-978A-8R-5, 59–97 cm). Debris-flow facies are depicted on the right side of the photograph. LDTC = low-density turbidite current, GHDTC = gravelly high-density turbidite current, HCF = hyperconcentrate flow. See text for explanation.

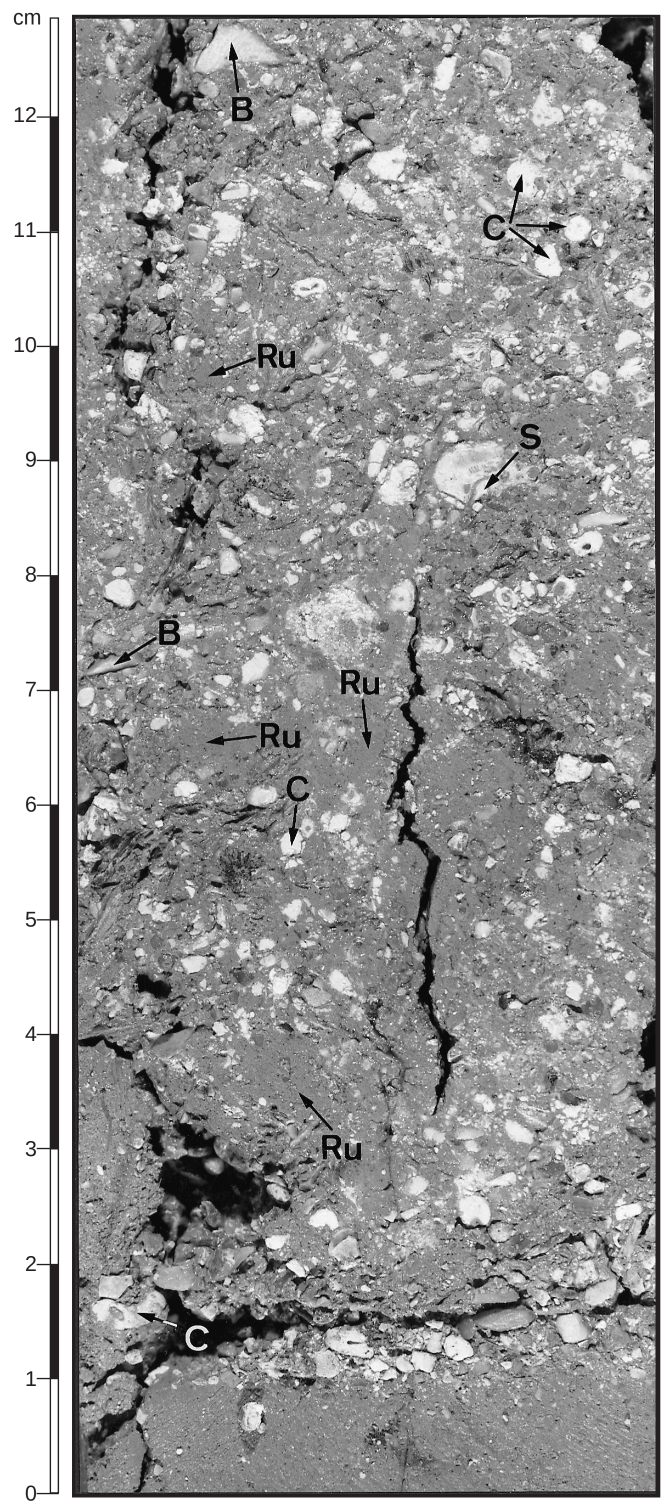

Figure 3. Close up of the base of Figure 2 (interval 161-978A-8R-5, 85–97 cm). Note the poor sorting and mudstone rip-up intraclasts (Ru) mixed with carbonate gravel-sized bioclasts. C = coralline algae, B = bivalves, and S = serpulid worms.

cluding *Lithothamnion corallioides* (P. and H. Crouan), and *Phymatolithon* (mostly *Phymatolithon calcareum* [Pallas]) (Adey and McKibbin). Unidentifiable coralline fragments may belong to other melobesioid species. Identifiable bivalve clasts belong to pectinids, ostreids, nuculids, and venerids.

Bioclast size is smaller and sand sized in the uppermost 15 cm (interval 161-978A-8R-5, 59–74 cm). In this interval, the general composition of the fossil assemblage is similar to that underneath, although both the proportion of invertebrates in relation to coralline algae and the number of unidentifiable fragments increase.

DISCUSSION AND CONCLUSIONS

Components of the fossil assemblages in the reported layer are characteristic of temperate outer-shelf settings in the Mediterranean late Cenozoic. The general composition of the fossil assemblages is distinctive of warm temperate carbonates in the Neogene from southeast Spain (Martín et al., 1996; Brachert et al., 1996; Braga et al., 1996), which are made up of various proportions of bryozoans, bivalves, and coralline red algae, together with echinoids, barnacles, and benthic foraminifers. These are also the main components of skeletal gravels in the present-day Mediterranean platforms (Pérès and Picard, 1964; Zamarreño et al., 1983; Carannante and Simone, 1988; Carannante et al., 1988). Branching growths of the recorded coralline algal species (*L. corallioides* and *P. calcareum*) are typical of the deepest areas of the platform around Cabrera Island (Balearic Islands), where they dominate the algal associations below 90 m (J.C. Braga, unpubl. data). Coralline associations dominated by melobesioids are characteristic of relatively deep-water settings both in modern and ancient examples (Adey and McIntyre, 1973; Minnery, 1990; Perrin et al., 1995). *Lithothamnion* and *Phymatolithon* are also the main components in the algal assemblages from the lower Pliocene outer platform sediments cropping out in southern Spain (Aguirre, 1995). *Ditrupa* sp., as well as the brachiopod genera *Mergelia* and *Megathiris*, are common although not exclusive of the latter deposits (Aguirre, 1995; Aguirre et al., 1996).

Regional geologic data suggest that no major changes in paleogeography occurred from the latest Pliocene to the present in the EAB (Comas et al., 1992). Therefore, the organization and composition of Holocene sediments on the Almería platform may provide a modern analog to the distribution of the uppermost Pliocene sedimentary environments north of Site 978. Siliciclastic sediments from the Andarax river cover most of Almería Bay and feed Andarax Canyon. However, on shelf areas at the offshore prolongation of Cabo de Gata, a 20-km-wide platform with carbonate or mixed terrigenous-carbonate sediment types has developed (Fig. 1). Carbonate sediments consist of skeletal gravels mainly made up of coralline algae, bryozoans, and bivalves. Some of these gravels have been interpreted as relics from Pleistocene or older times carbonates (Baena et al., 1982; Maldonado and Zamarreño, 1983; Zamarreño et al., 1983). We propose an outer part of this platform, which probably developed with a similar character and in a similar position from the latest Pliocene, as the source area of the carbonate bioclasts in the debris-flow layer.

The coeval upper Pliocene–lower Pleistocene deposits that crop out inland east of the city of Almería largely consist of beach, shallow-bay, and fan-delta sediments (Aguirre, 1995). Therefore, presently emerged areas in southern Spain must be discarded as a source for bioclasts in the reported layer.

Sedimentary facies recognized in the carbonate gravel layer are consistent with a source area as proposed above. The single gravity flow was probably generated from a sediment failure or collapse event on a relatively steep submarine slope, as emphasized for similar isolate or distinct debris-flow layers in other sedimentary realms (e.g., Einsele, 1992). Relatively steep slopes may have occurred at the shelf break of the Almería platform either because of differences in lithification between the weakly early cemented carbonate shelf and the muddy talus or because of a fault scarp. Considering that an intensive Pliocene–Holocene faulting is well recorded in this region (Comas et al., 1992), we favor a coeval fault scarp as the probable source area for the gravity flow. As no major changes in paleogeography occurred from the latest Pliocene to the present, the modern position of the outer break of the Almería platform, which is located ~25 km to the north of Site 978, provides us with an estimate of the travel distance for the redeposited material in the debris flow.

The Pliocene sedimentary sequences recovered at Sites 978 and 977 are equivalent, and the lithologic units recognized in both sites can be well correlated (Shipboard Scientific Party, 1996). Low-density, muddy, turbidite deposits, which make up most of the sequences at both sites, are considered to be supplied by dilute gravity flows from the Andarax depositional system (the Andarax Canyon and the Andarax deep-sea fan; Fig. 1). Turbidite flows passed toward the South Balearic Basin along the eastern prolongation of the Alboran Trough, as demonstrated by the existence of distal depositional lobes of the Andarax deep-sea fan observed in seismic profiles (Alonso and Maldonado, 1992). The similarity between the Pliocene sequences recovered at Sites 978 and 977, located to the north and to the south of the Al-Mansour Seamount, respectively (Fig. 1), suggests a common western distal source area for the low-density turbidite deposits. Notwithstanding, the reported debris-flow layer only occurs at Site 978, but not within the sequence recovered at Site 977 (Comas, Zahn, Klaus, et al., 1996), which can be explained by considering a different and supposedly northern proximal source area for the debris flow. A gravity flow coming downslope from a northern platform, located ~25 km away, may have arrived at Site 978, but was probably not able to bypass the Al-Mansour Seamount and reach Site 977 located to the south (Fig. 1).

The fact that the reported carbonate debris-flow bed is the only one in all of the Pliocene sequences drilled in the EAB indicates that an episodic and isolated event caused the gravity flow. This suggests that an earthquake triggered the gravity flow, while probably discarding an origin caused by a sea-level fall. We therefore interpret the debris-flow layer as a “seismite.” A coeval sea-level fall would most likely have conditioned a sedimentary sequence with multiple, or cyclic, debris-flow beds intercalated in the host deposits, which is not the case for the upper Pliocene sequence sampled at Site 978. Furthermore, a tectonic origin for the carbonate debris-flow layer is supported by the existence of Pliocene–Holocene strong tectonic activity in the Almería-Cabo de Gata region, as documented from multiple offshore and onshore geologic data and Leg 161 results in the EAB (Comas, Zahn, Klaus, et al., 1996; Alvarez-Marron, Chap. 26, this volume). Ages and sedimentary rates reported from Pleistocene–latest Pliocene cores recovered at Site 978 (Shipboard Scientific Party, 1996) suggest that the debris-flow event occurred ~2.15 Ma.

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