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Geologia. — *Prehistoric mega-tsunami in the eastern Mediterranean and its sedimentary response.* Nota di Maria Bianca Cita Sironi e Bianca Rimoldi, presentata (*) dal Socio M.B. Cita Sironi.

Abstract. — The volcanic island of Santorini that belongs to the trench-arc-backarc Aegean system of the eastern Mediterranean underwent a catastrophic eruption in the Bronze age (circa 3500 y BP), with caldera collapse and creation of a tsunami wave that was funnelled westward. The sedimentary response to this exceptional event in the deep sea was the deposition of resediments called Homogenites. The data set available after almost thirty years of active research consists of 60 sediment cores, including several giant piston cores up to 30 meters long, raised from water depths ranging from 4100 to 2500 m in discrete parts of the Ionian Sea. Two types of Homogenite are recognized. Type A Homogenite consists of pelagic turbidites typically recorded in the Calabrian Ridge and in the western Mediterranean Ridge accretionary prisms, characterized by the «cobblestone topography», only in lows or basinal settings. Their stratigraphic position consistently above the Holocene sapropel S-1 and the depositional base are interpreted as the result of liquefaction of the unconsolidated pelagic sediments draping the nearby slopes caused by the tsunami waves, followed by downslope movement and settling. Type B Homogenite is a megaturbidite of African provenance that expanded throughout the Messina and Sirte abyssal plains originating an up to 24 m thick surficial acoustically-transparent layer calibrated by coring. Type B Homogenite has a coarse and thick sandy base consisting of bioclasts deriving from the continental shelf of North Africa and is interpreted as triggered by the tsunami wave reaching the Sirte Gulf. The Dec. 26, 2004 megatsunami that hit the coastlines of SE Asia provides a real world example of how sediment dispersal can be triggered by a series of gigantic waves. Megaturbidites similar in thickness to Type B Homogenite have been recorded in all the abyssal plains of the Mediterranean, both west and east of the Ionian basin, but their age is older (late Pleistocene) and their emplacement occurred during low sea-level stands corresponding to the last glaciation. The occurrence of a Holocene megabed, postdating the Climatic Optimum, is a paradox in a paleoclimatic scenario. An exceptional event, as the megatsunami originated by the collapse of the Santorini caldera is required.

Key words: Santorini; Tsunami; Megaturbidite; Holocene.

Riassunto. — *Un megatsunami preistorico nel Mediterraneo orientale e la sua risposta sedimentaria*. L'isola vulcanica di Santorini, che fa parte del sistema arco-fossa-bacino di retroarco del Mare Egeo, ha subito una eruzione devastante nell'età del Bronzo (circa 3500 anni fa) con collasso della caldera e creazione di un'onda di tsunami che è stata convogliata in prevalenza verso ovest. La risposta sedimentaria a questo evento eccezionale in mare profondo è stata la mobilizzazione e la rideposizione di sedimenti, chiamati Omogeniti. Dopo quasi trent'anni di ricerca attiva, il data set consiste di 60 carote di mare profondo, comprese diverse carote giganti lunghe fino a 30 metri, raccolte da profondità comprese fra 4100 e 2500 m. Vengono distinti due tipi di Omogeniti. L'Omogenite di Tipo A è costituita da torbiditi pelagiche di provenienza locale che si trovano nelle depressioni dei prismi di accrezione della Dorsale Calabra e della Dorsale Mediterranea caratterizzati dalla cosiddetta «Topografia a Cobblestone». La posizione stratigrafica a tetto del sapropel S-1 olocenico e la base deposizionale sono interpretate come il risultato della liquefazione dei sedimenti pelagici che ricoprivano i pendii circostanti causata dal passaggio dell'onda di tsunami seguita dalla deposizione al fondo dei piccoli bacini sospesi. L'Omogenite di Tipo B è invece una megatorbidite di provenienza africana che si è espansa al fondo delle ampie piane abissali di Messina e della Sirte dando origine a uno strato trasparente superficiale, spesso fino a 24 m, calibrato dai carotaggi. L'Omogenite di Tipo B ha una base spessa e grossolana, costituita da bioclasti provenienti dalla piattaforma continentale nordafricana, ed è interpretata come provocata dalle onde superficiali dello tsunami che hanno raggiunto il golfo della Sirte. Il megatsunami del 26 dicembre 2004, che ha colpito le

(*) Nella seduta dell'11 marzo 2005.

coste del SE asiatico, fornisce un esempio reale di come la dispersione dei sedimenti possa essere influenzata da onde gigantesche. Megatorbiditi di spessore simile a quello dell'Omogenite di Tipo B sono state documentate in tutte le piane abissali del Mediterraneo, sia a ovest che a est del Mare Ionio, ma la loro età è più antica (Pleistocene superiore) e la loro messa in posto è avvenuta durante stazionamenti bassi del livello del mare, corrispondenti all'ultima glaciazione. La presenza di una megatorbidite nell'Olocene, in un periodo di alto livello del mare, è un paradosso in uno scenario paleoclimatico: occorre un evento eccezionale come il megatsunami provocato dal collasso della caldera di Santorini per spiegarne l'esistenza.

Introduction

Geodynamic foreward.

The Mediterranean is a small ocean basin with a complex geodynamic setting and is characterized by an articulated physiographic configuration. The volcanic island of Santorini is part of the volcanic front in the Aegean back-arc basin within a convergent plate boundary developed in the eastern Mediterranean since Miocene times (Hsü *et al.*, 1977; Ferrara *et al.*, 1980; Fytikas *et al.*, 1984).

The Mediterranean Ridge (MR) is an accretionary prism developed above the subduction plane of the African oceanic crust (Le Pichon *et al.*, 1979; Cita and Camerlenghi, 1990; Westbrook and Reston, 2002, *inter alias*).

The Messina, Sirte and Herodotus abyssal plains are foredeeps or «trenches», although they are less deep than the Hellenic Trench located on the northern side of the ridge, on top of a continental crust (Aegean backstop) as proved by deep seismic exploration carried out recently by the MEDRIFF and IMERSE Projects (Westbrook and Reston, 2002; Reston *et al.*, 2002) along the so-called MEDRIFF CORRIDOR corresponding to seismic line MS33 of Finetti and Morelli (1972). As a consequence, when discussing the depositional processes induced by the tsunami event originated by the collapse of the Santorini caldera, we have to bear in mind that the bottom configuration is far from being simple in this part of the world, and that sills, trenches and submarine mountain ridges play a fundamental role in controlling sediment dispersal.

In other words, it is not sufficient to investigate the sedimentological characters of inferred tsunamiites to prove or disprove their origin, but it is essential to consider the geodynamic setting of the sites, the possible source area of the redeposited bioclasts, the active versus passive nature of the adjacent continental margins, the seismic versus aseismic nature of the potential source areas, the presence of big depressions acting as sediment traps and eventually preventing sediment dispersal.

Last but not least, the stratigraphic position of the Santorini tsunamiite is unique and well controlled, in the middle of the Holocene, that is in post-glacial times characterized by high sea-level stand (Holocene Climatic Optimum 9.2/8.5 ky BP in the Aegean Sea – Wezel, 2004), when large turbidites never occur anywhere in the world. The ubiquitous presence of the post-glacial sapropel S-1 in the pelagic settings investigated from the Calabrian and Mediterranean Ridges (Type A Homogenite) and the surficial, near-bottom occurrence of the Holocene megabed in basinal settings (Type B Homogenite) as the Messina and Sirte abyssal plains are very strong arguments that cannot be ignored any more (Cita *et al.*, 1984*b*; Cita and Camerlenghi, 1985).

Santorini collapse and tsunami wave dispersal: databases.

The collapse of the Santorini volcano after the devastating Bronze-age multiphase eruption is well documented (Marinos and Melidonis, 1971; McCoy, 1974; Friedrich and Pichler, 1976; Bond and Sparks, 1976; Keller *et al.*, 1978; Yokoyama, 1978; Watkins *et al.*, 1978; McCoy, 1980; Pichler and Friedrich, 1980; Keller, 1981; Heiken and McCoy, 1984; Friedrich, 1999).

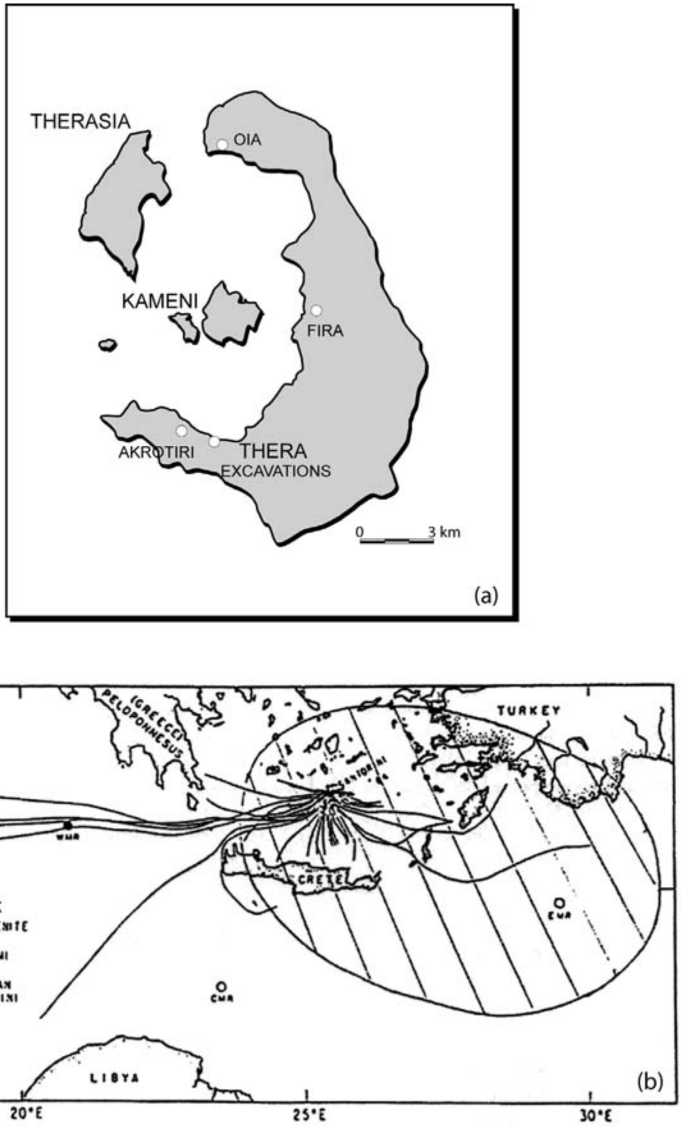

Fig. 1. – *a)* Map of the volcanic island of Santorini in the Aegean Sea: the rim of the collapsed caldera is interrupted to the west. *b*) Ray paths of the tsunami wave radiating from the source island, eastern Mediterranean (after Kastens and Cita, 1981).

The shape of the remaining caldera rim is such that the largest part of the energy originated by the collapse was funnelled westward (see fig. 1*a*). The distribution of the tsunami-induced sediment transport was consequently limited to the western part of the eastern Mediterranean (*i.e.* Ionian Basin) with exclusion of its eastern part (*i.e.* Levantine Basin), see fig. 2.

The first recognition of an unusual type of pelagic turbidite in small depressed basins of the southern Calabrian Ridge (CR) (Cobblestone Area 4, see fig. 2) and of the western MR (Cobblestone Area 3) occurred in 1978, during the at-sea operations of the «Cobblestone» (1978-1980) bilateral project funded by the National Science Foundation of U.S.A. and by the Italian CNR (Consiglio Nazionale delle Ricerche). The project aimed at elucidating the causing mechanism of the extremely irregular so-called «cobblestone topography» (of Hersey, 1965). By means of sophisticated geophysical investigations, the bottom configuration was mapped, and subbottom high resolution seismic profiling was carried out with precision navigation (transponder-navigation) of selected areas (Melville Cruise, July 1978). Phase two followed, that is a geological ground-truthing expedition with precision coring in the same areas (Eastward Cruises, August-September, 1978). The sediment cores were opened, visually described, dated by means of calcareous plankton biostratigraphy and correlated on the ship. The numerical model proposed by Kastens and Cita (1981) was based on bathymetry and a limited data base of deep-sea sediment cores: 3 from Cobblestone Area 3 (~500 km from Santorini) and 8 from Area 4 (~800 km from Santorini).

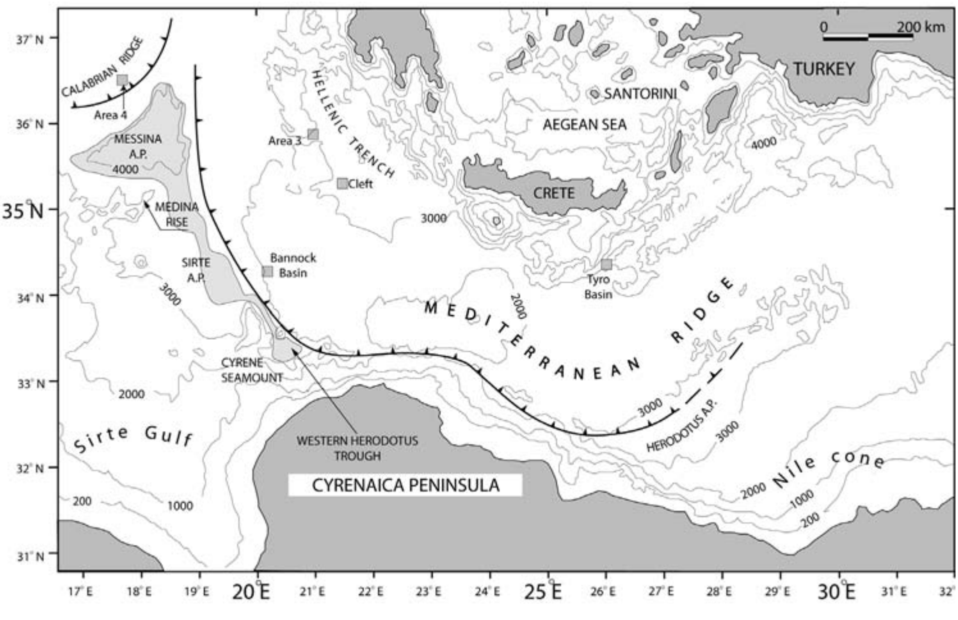

Fig. 2. – Map of the eastern Mediterranean showing the main physiographic features, the outer deformation front of the Calabrian and Mediterranean Ridges, and the location of the areas where the Holocene Homogenite has been identified. Type A in Cobblestone Area 4 (southern Calabrian Ridge); Bannock Basin, Cobblestone Area 3, Cleft and Tyro Basin in the Mediterranean Ridge. Type B (megabed) in Messina Abyssal Plain, Sirte Abyssal Plain and western Herodotus Trough.

Nowadays, the database consists of 60 deep-sea cores, including several giant cores up to 30 m long (see Cita and Rimoldi, 1997; Cita *et al.*, 1996) raised from water depths ranging from 4100 to 2500 m, most of them within the range of 3000-4000 m.

Results

Deep-sea Homogenites.

The name Homogenite was used shipboard in 1978 to identify the homogenous, very fine-grained, structureless sediment that characterized exclusively the basinal settings of the cobblestone topography, differing from the hemipelagic sediments recovered from the basin flanks or from the plateaus, that consist of coarse-grained marls alternating with sapropels and tephra layers that create a well constrained lithostratigraphic framework (Ryan, 1972; Cita *et al.*, 1982*b*; Emeis *et al.*, 1996 *inter alias*) for the eastern Mediterranean deep-sea record.

The name Homogenite has a descriptive connotation, although it is related to a definite exceptional event. Two basic types are now recognized that strongly differ in terms of sedimentary processes involved.

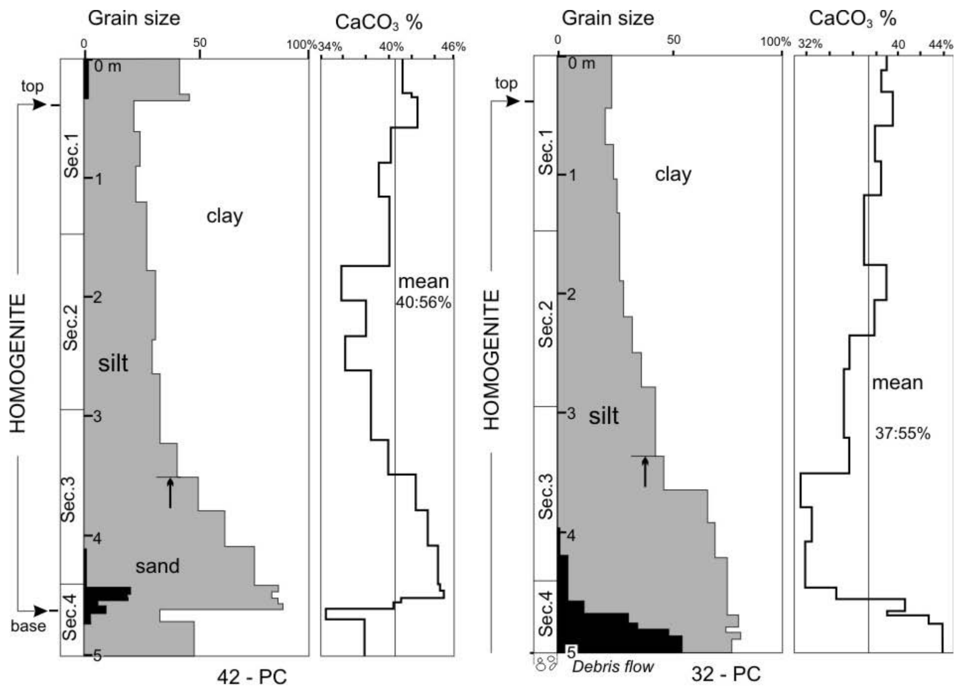

Fig. 3. – Grain-size distribution and carbonate content measured in two piston cores where Homogenite has a comparable thickness, *i.e.* Eastward Core 42 from the Calabrian Ridge and Eastward Core 32 from the western Mediterranean Ridge. Arrows indicate the highest occurrence of coarse silt in the Homogenite.

Type A Homogenite.

What we call now Type A Homogenite (following Cita *et al.*, 1984*b*; Cita and Camerlenghi, 1985, and later papers) was the only typology known in the first published reports (Kastens and Cita, 1981; Cita *et al.*, 1982*c*; Blechschmidt *et al.*, 1982). It is a pelagic turbidite that does not contain any material reworked or indicative of a provenance from a shallow, near-shore source area. The carbonate content increases at the base of the unit (see fig. 3). The sand fraction entirely consists of planktonic foraminifers, size-selected, and of fragments of pteropods. Due to the presence of abyssal plains to the south, and of the Hellenic Trench to the north of the sites investigated, no distant source area is conceivable.

Thickness of the Homogenite is up to more than seven meters, that is one order of magnitude greater than other Quaternary turbidites recovered from the same location, in the same sediment cores and related to seismic shocks in an active margin setting (Kastens, 1984).

The unit, that conformably overlies a few cm thick hemipelagic interval followed by the ubiquitous sapropel S-1, post-glacial in age and correlated to isotopic substage 1 (Cita *et al.*, 1977; Vergnaud-Grazzini *et al.*, 1977; Emeis *et al.*, 1996 *inter alias*), see fig. 4*a*, can be correlated from core to core.

The topmost part of the cores raised from the basin slopes, controlled on the trigger cores, is consistently formed by a top layer of sub-recent brownish Pteropod ooze unconformably overlying mid Pleistocene, or early Pleistocene, or even Pliocene pelagic oozes (see fig. 4*b*). Note that the vertical relief of the «cobblestone» is of the order of 100-200 meters in the CR, slightly more in the western MR.

No distinct grading is observed in the Homogenite, except for the basal part of the unit. No laminations, either parallel or convolute, no distinction possible of the Bouma sequences. X-ray observations by Cita *et al.* (1982*c*), Hieke (1984) and Troelstra (1987) confirmed the structurless nature of the Homogenite.

Grain-size analysis carried out on Homogenite samples from two cores where the unit is approximately 500 cm thick support the theoretical calculations that a higher energy was available in the western MR Site 3 (~500 km from Santorini) than in the southern CR Site 4 (~800 km from Santorini), see fig. 3.

The model proposed by Kastens and Cita (1981) hypothesizes a liquefaction of the deep-sea oozes draping the flanks of the rugged cobblestone relief caused by excess pressure of pore water versus ambient sea water during the depression phase(s) of the pression/depression cycles created by the tsunami waves. The cartoon of fig. 5 depicts the paths followed by the numerous, but limited small turbidity currents that fell down from the various slopes of the cobblestone topography as a result of temporary slope instability caused by «explosion» of the unconsolidated, soupy surficial hemipelagic sediments. Due to the low sedimentation rate characteristic of the eastern Mediterranean deep-sea record (Kidd *et al.*, 1978; Cita *et al.*, 1982*b*; Emeis *et al.*, 1996) the total thickness of the sediments removed by the local turbidity currents is limited, of the order of a few tens of meters. No important erosional scars are expected, due to the local source of the removed sediments, and the limited vertical relief of the slopes.

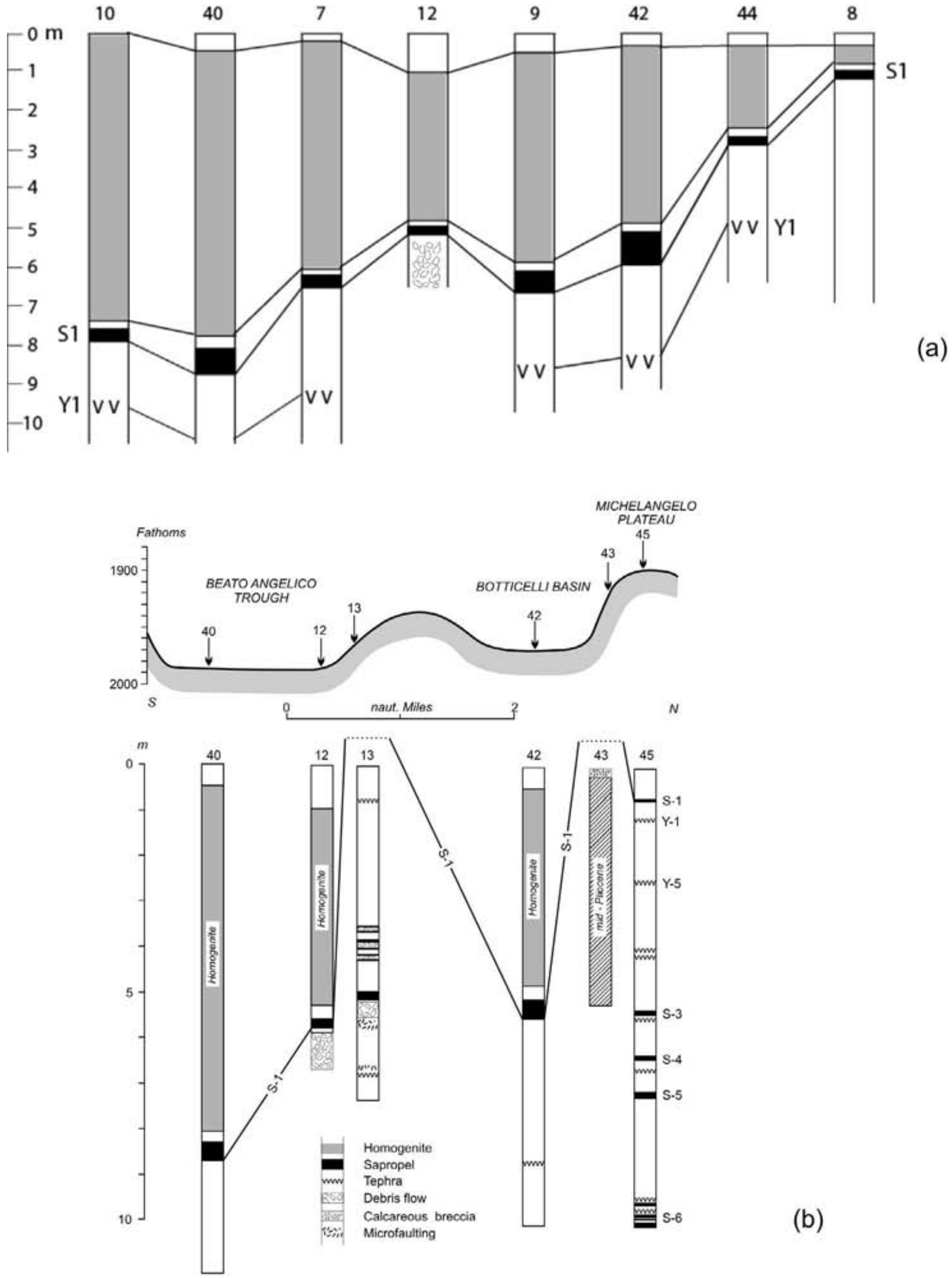

Fig. 4. – *a*) Correlation of Homogenite, and of other isochronous lithologies (*i.e.* sapropel S-1 and Tephra Y-1) in eight piston cores raised by R/V. EASTWARD in the southern Calabrian Ridge (Cobblestone Area 4). *b*) Stratigraphic correlation of deep-sea cores along a N-S transect crossing basins, slopes and plateaus of the same area.

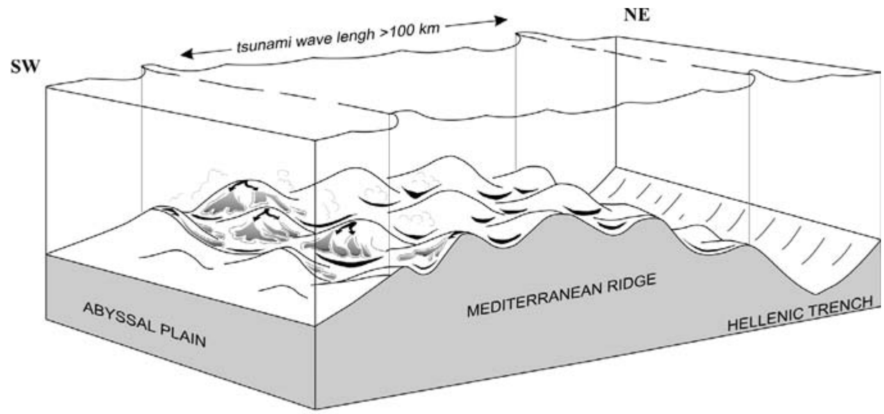

Fig. 5. – Cartoon depicting the depositional model of the Type A Homogenite as recorded from the southern Calabrian Ridge and from the western Mediterranean Ridge characterized by cobblestone relief.

Additional evidence for the occurrence of Holocene pelagic turbidites in basinal settings from the «cobblestone» relief of the MR, correlatable with the Homogenite both for its stratigraphic position (*i.e.* overlying sapropel S-1) and for its (hemi)pelagic nature (*i.e.* consisting of pelagic bioclasts without any evidence of a near-shore, shelf source area) was recorded in the following years, in various cruises postdating the Cobblestone Project of 1978-80, carried out with research vessels Bannock and Tyro (Cita *et al.*, 1982*a*; Troelstra, 1987; Rimoldi, 1989; Erba, 1991) and, more recently, Discovery and Atalante (Fusi *et al.*, 1996). The areas Bannock Basin, Cleft and Tyro Basin (see fig. 2) listed from west to east, fall in this category.

A distinction between «closed cobblestone» and «open cobblestone» was made by Cita *et al.* (1996). The former corresponds to what we discussed so far. The latter will be discussed later since it belongs to Type B Homogenite.

A special subtype of the «closed cobblestone» Type A Homogenite refers to sediment cores raised from anoxic basins as Bannock Basin or Tyro Basin (see location in fig. 2). The first is close to the deformation front of the ridge and contains an over 500 m thick dense (over 20% denser than normal sea-water), entirely anoxic brine originated by the subaqueous dissolution of Messinian evaporites (Scientific Staff Bannock 1984-12, 1985; Cita *et al.*, 1988, Camerlenghi and McCoy, 1990). The second is located in the western Strabo Trench south of Crete, and contains deep-seated brines of similar origin (Jongsma *et al.*, 1983). Homogenite has been recorded in both locations (Cita *et al.*, 1988; Troelstra, 1987; Erba, 1991) even in long cores raised in 1991 and 1995 by the French research vessel Marion Dufresne (Rimoldi, 1993; Cita and Rimoldi, 1997). The only difference versus the normal type is that the sediment are dark grey to black, due to the abundance of organic matter which is one order of magnitude greater than in normal eastern Mediterranean hemipelagic sediments. The thickness of the basal sandy layer versus the total thickness of

Homogenite in other non-anoxic basins (see fig. 4 of Cita and Rimoldi, 1997) is accounted to the peculiar environmental conditions where the turbid flow, coming from upslope, splits when reaching the strong pychnocline separating normal sea water from anoxic brines, as hypothesized by Corselli and McCoy (1989) and by Erba (1991) and proven by experiments carried out by Rimoldi *et al.* (1996), and the settling velocity is strongly reduced.

In summary, 1) pelagic nature of the re-sediment, 2) local provenance from submarine highs, 3) conformable basal contact and 4) well defined and isochronous stratigraphic position (above sapropel S-1) are the basic criteria for recognizing Type A Homogenite.

Type B Homogenite.

The first identification of this type coincides with the finding of very thick, fine-grained homogenites in the Messina and Sirte abyssal plains, similar to those recovered from the «cobblestone» deformed areas, but lacking the basal contact because the thickness of the layer exceeds the length of the piston corer. The research plan of the 1984 Bannock cruise was to investigate geophysically and geologically a few radial transects across the deformation front by recording a PDR profile and raising a number of (traditional) piston cores from the abyssal plain, to the first hills of the «cobblestone» terrain – see Ionian, Sirte, Katia transects discussed by Cita and Aloisi (2000: pp. 186-191). Transects were 30 km long or more, covering a vertical relief of several hundred meters (see Cita and Aloisi, 2000: figs. 4-6). The cores recovered in the abyssal plains contained Homogenite, but not its base. Cores from the lowermost end

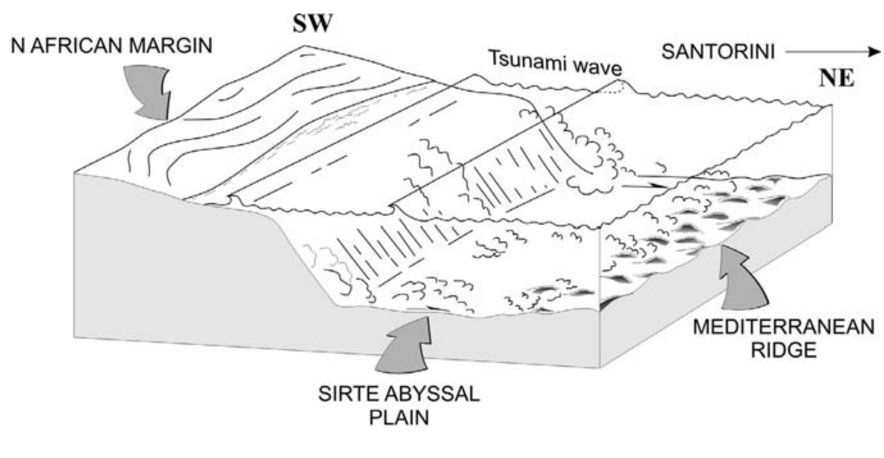

Fig. 6. – Cartoon depicting the depositional model of Type B Homogenite, as recorded in the Messina and Sirte abyssal plains, in the western Herodotus Trough and on the lowermost part of the deformation front of the Mediterranean Ridge.

of the transect, although raised from the Cobblestone topography itself, contained a Homogenite that differed from the originally described one because of the northern African provenance, from shallow depth, as proven by the composition of the coarse-grained sandy base.

Purpose of the radial transect experiment was to document the change in depositional regime, from a basinal setting with turbidites to a ridge setting with (hemi)pelagic sedimentation, and to date this change in order to precisely reconstruct the history of the deformation front. But the experiment failed, due to the recorded occurrence of «upslope turbidites» originating from the African margin (Cita *et al.*, 1984*a, b*; Chinigò, 1987; Rimoldi, 1989; Lucchi and Camerlenghi, 1993) and the insufficient penetration of the traditional piston cores.

When the base of the surficial transparent layer (see Cita and Aloisi, 2000: figs. 4, 6) was reached near the toe of the MR, where it thins out markedly, the coarse-grained basal part of the turbidite proved to be formed by bioclasts consisting of larger benthic foraminifers, gastropods, calcareous algae and fragments of bryozoans (see Cita and Aloisi, 2000: Plate 1) indicative of a source area from the north African shelf. Indeed, no other source areas can be hypothesized, because the European continental margin to the north is separated by the deep Hellenic Trench that behaves as a sediment trap, and the MR crestal area is some 2000 m deep.

A depositional model was developed (see cartoon of fig. 6) that involves the gigantic tsunami wave originated by the collapse of the Santorini caldera, following the Bronze-age eruption as trigger for the megabed. The sudden and repeated retreat of the sea should have mobilized the loose, coarse-grained sediments deposited on the continental shelf of the Sirte Gulf.

It is pointed out that:

1) no «explosion» or liquefaction of the bottom sediments is foreseen, but just the effects of the surficial tsunami waves on the shallow continental shelf;

2) the gigantic turbidity currents reached the abyssal plains (Messina A.P. is approximately 4000 m deep; Sirte A.P. ranges from circa 3800 to circa 3400 m) after crossing the continental shelf, slope and rise of the north African margin covering a distance of hundreds km and a vertical relief of several km, that is one to two orders of magnitude greater than the horizontal distance and vertical relief covered by the (local) pelagic turbidites of the «cobblestone» accretionary prism;

3) in all the cores investigated the base of Homogenite is erosional, not depositional, unlike in Type A, and the stratigraphic levels corresponding to sapropel S-1 and post-sapropel S-1 are missing;

4) it is highly probable that important erosional scars are present on the Sirte continental slope, but there is no direct evidence supporting this assumption, due to the poor documentation on bottom physiography and the political situation preventing at-sea operations in Libyan territorial waters;

5) the size of Type B Homogenite is such (as discussed in Cita and Aloisi, 2000 and Hieke and Werner, 2000) that it can be considered a megaturbidite (Mutti *et al.*, 1984). Such megaturbidites are typically associated to low sea-level stands (Rothwell *et al.*, 1998).

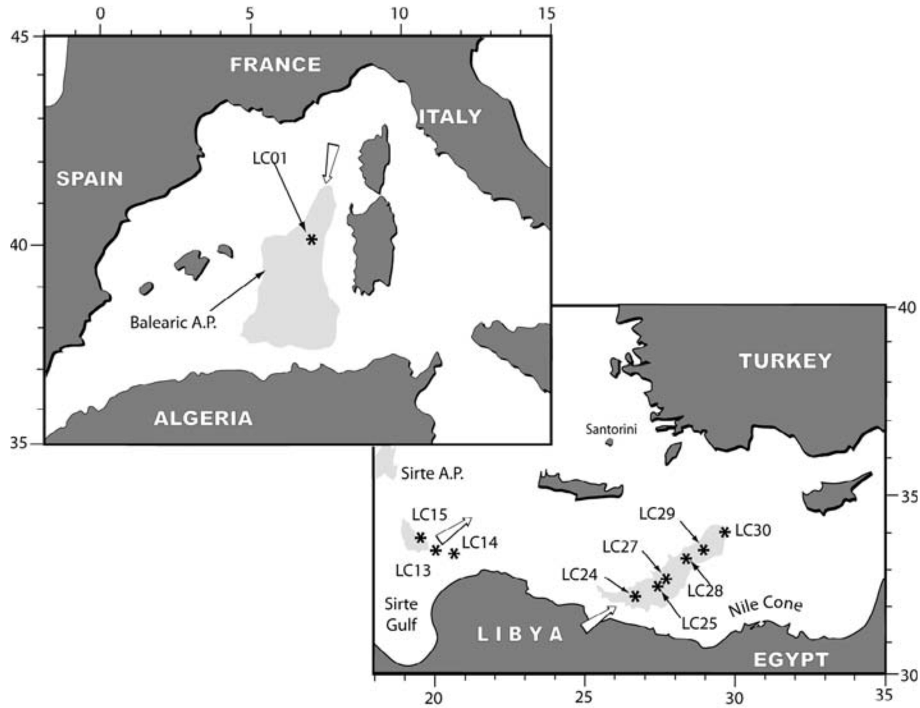

Fig. 7. – Location map of several long cores raised in the Mediterranean abyssal plains in 1995 (after Rothwell *et al.*, 2000, modified). The arrows point to the direction of the high resolution seismic profiles illustrated in fig. 8.

Discussion

A fundamental step forward in the understanding of the two discrete types of Homogenite after the original findings and interpretation (Cita *et al.*, 1984*b*) was provided by the transects of long cores raised from the various Mediterranean abyssal plains (Reeder *et al.*, 1998; Rothwell *et al.*, 1998, 2000), see fig. 7. The map shows the approximate location (indicated by arrows) of the high resolution seismic profiles (3.5 kHz) recorded in the Balearic (fig. 8A), Sirte (fig. 8B) and Herodotus (fig. 8C) abyssal plains. The seismic profiles have been calibrated by long cores. Each of the profiles contains a thick transparent layer (megabed). In the Balearic abyssal plain the megabed source area is in the European passive margin, and is late Pleistocene in age (see radiometric calibration in Rothwell *et al.*, 1998). In the Sirte A.P. and Herodotus A.P. the source areas are in the north African passive continental margin. The striking difference is that in the Sirte A.P. the surficial megabed is Holocene in age, and has no counterpart or correlative layer in either the western Mediterranean or in the Herodotus abyssal plain. A causative mechanism entirely different from the Last Glacial Maximum low sea-level stand and inferred gas hydrate release has to be invoqued.

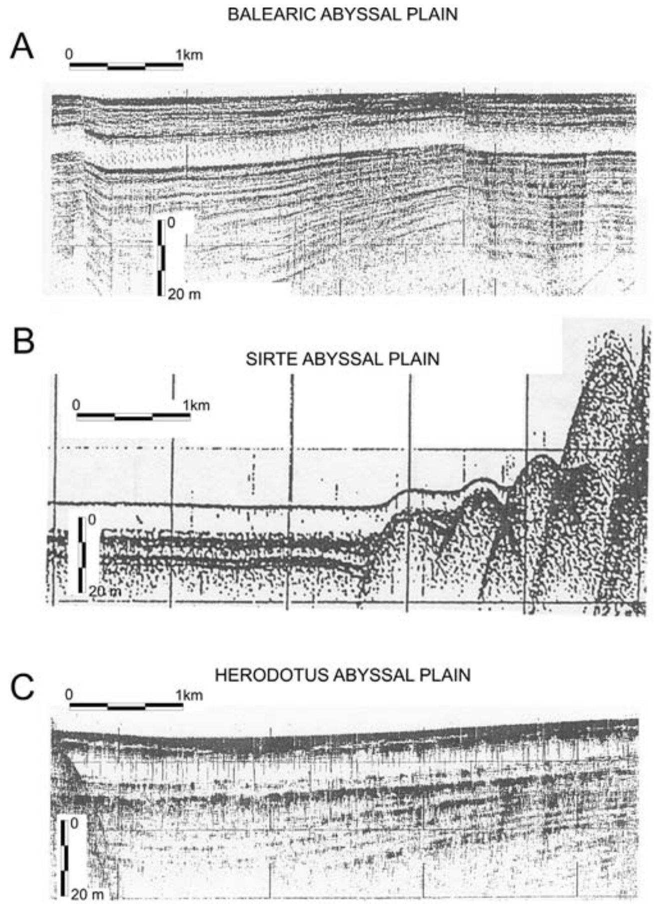

Fig. 8. – High resolution (3.5 kHz) seismic reflection profiles recorded in the Balearic (A), Sirte (B) and Herodotus (C) abyssal plains. Each profile documents the existence of a megabed (after Rothwell *et al.*, 2000 and Cita and Aloisi, 2000).

Figure 9 shows the stratigraphic correlation of eight long cores raised in the Messina, Sirte and Herodotus abyssal plains and in the western Herodotus Trough, a small depression sandwiched between the Cyrene Seamount, consisting of Mesozoic carbonates (see Groupe Escarmed, 1982; Bosellini, 2002), and the area north of the Cyrenaica promontory, where the MR collides with the African continental margin.

The grain-size distribution of the only core raised from this narrow depression (see fig. 10) is suggestive of obstacle effects by the Cyrene Seamount and of rebound effects against the MR deformation front.

The attempt to raise long cores from the Messina abyssal plain from the French research vessel Marion Dufresne was frustrated twice (in 1991 and in 1995) with loss of the heavy coring equipment, thus suggesting a great thickness of the megabed, and of its

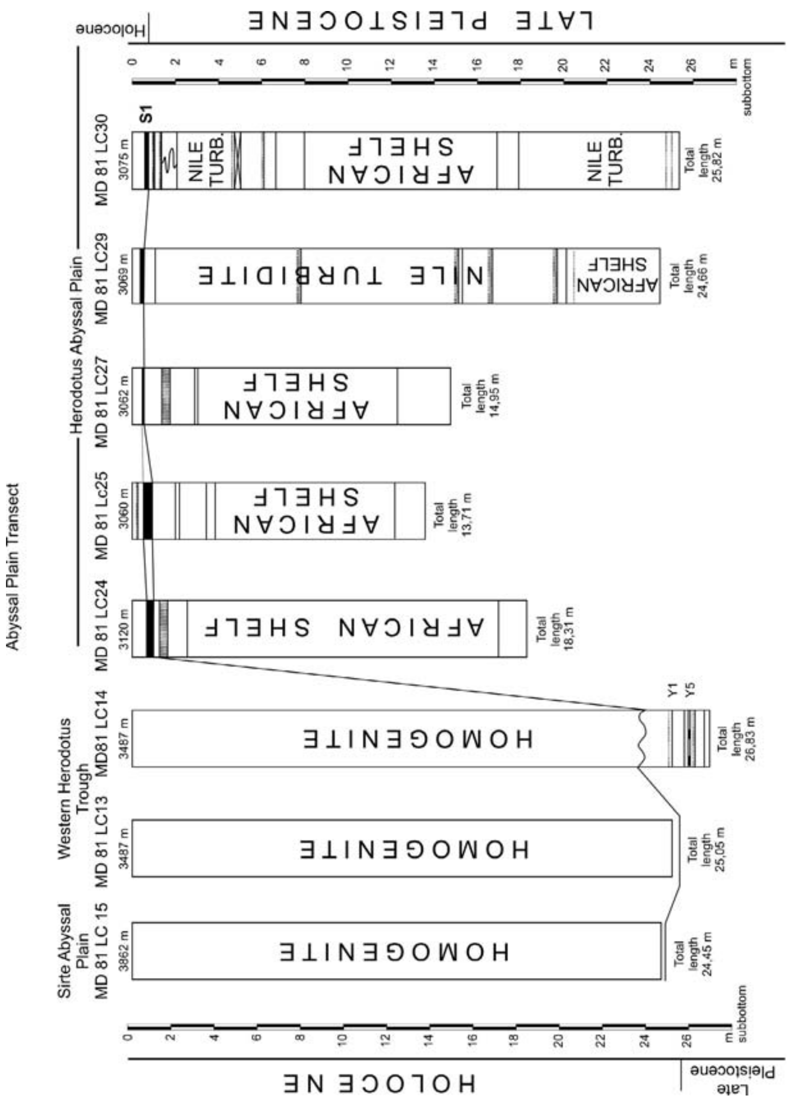

Fig. 9. – Stratigraphic correlation of eight long cores raised from the eastern Mediterranean abyssal plains (after Cita and Aloisi, 2000 and Rothwell *et al.*, 2000, slightly modified). The location of the long cores is indicated in figs. 7 and 11.

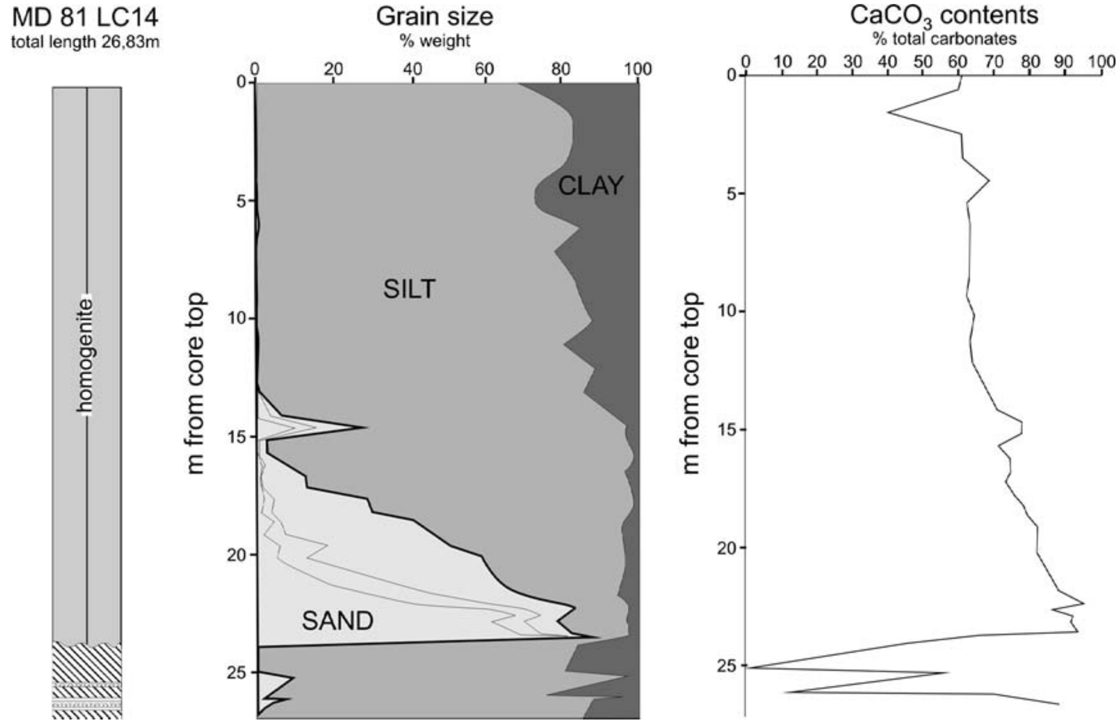

Fig. 10. – Grain-size distribution and carbonate content measured in the Homogenite recovered in long core 14 from the western Herodotus Trough (after Cita and Aloisi, 2000, slightly modified), see text for discussion.

coarse sandy base. Other megabeds, of probable late Pleistocene age, presumably correlatable with those recovered from the Balearic and Herodotus abyssal plains, and underlying the Holocene Homogenite, have been detected by high resolution seismic profiling (Hieke and Werner, 2000; Della Vedova *et al.*, 1998; Rebesco *et al.*, 2000) but have not been calibrated by coring so far.

Finally, figure 11 shows the inferred provenance of the megaturbidites recorded from the eastern Mediterranean abyssal plains, as resulting from sedimentological studies.

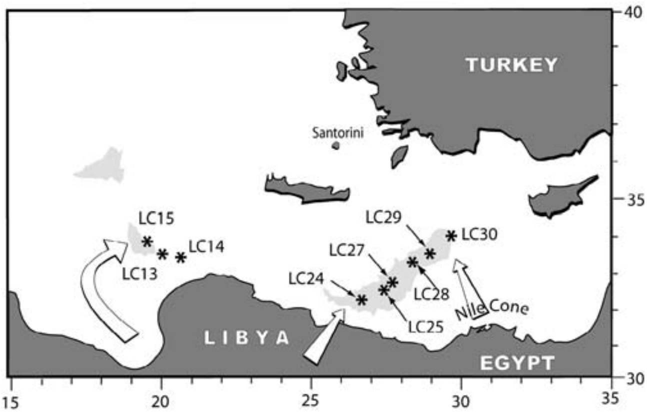

Fig. 11. – Location map of the long cores investigated that contain turbiditic megabeds. The arrows indicate the source areas as inferred from the analytical data, *i.e.* Sirte Gulf for Cores LC 13, 14 and 15; African shelf for Cores LC 24-27; Nile Cone for Cores LC 29 and 30.

Images from the present

The great earthquake (M 9 Richter) occurred off the West Coast of Northern Sumatra (Indonesia) on 26th December 2004 (UTC h 00.58.53) triggered giant tsunamis that devastated the coastal regions of Indonesia, Malaysia, Thailand, Sri Lanka, India and Maldives and affected even the coast of East Africa.

Media extensive coverage of the dramatic events and detailed satellite images put under everybody eyes the destructive power of this singular type of waves.

Tsunami effects directly observed and the interviews with the residents in the Andaman and Nicobar Islands allowed scientists and officers from the Geological Survey of India (2005) to reconstruct the events of 26th December 2004.

In the low-lying coastal regions of Andaman-Nicobar Islands the sea rose 2.5 m above the high tide line and entered inhabited area with great velocity (www.gsi.gov.in).

From the general observations 15 to 20 minutes after the main earthquake shock the first influx of sea waves approached the shores. The water level rose to above the high tide level. After some time the second influx came in, and the water level increased still further and then receded. The recession in water level was so much that the seabed became visible for quite a distance. The velocity of waves in the two influxes was slightly above normal. At around 8:30 (the first shock was at 6:35 AM local time) the third influx came to the shore with such a velocity that everybody was caught unaware. The water level rose to the maximum, in some cases to over 2.5 m above the high tide level.

After the tsunami the sea has remained at a higher level than normal and the difference between the high tide and the low tide levels seems to have been reduced.

On the coast of Andra Pradesh, the same day S.H. Gaitan Vaz (see Gaitan Vaz, 2004), geologist from GSI (www.gsi.gov.in), directly eyewitnessed the incoming of the tsunami waves. The first overflow of the sea water in the fishing harbour of Visakhapatnam has been reported by the residents at 9:30 (approximately 3 m above msl). Then, he witnessed the second cycle of water level rise, with no overflow on the jetty like the first time. Within 10 minutes the water level reached the record lower level of 2.5 m below msl (a research vessel in the harbour touched the ground). This was at around 11:00 am. Immediately after, 1 m-high wall of water gushed into the fishing harbour and raised the water level to about 2.5 m. Until 11:30 similar rise and fall of water level were observed three times.

The tidal gauges in the port recorded 7 fluctuation at 10-15 minute intervals between the maximum level of 2.3 m above msl at 9:25 and the minimum level of 2.7 m below msl at 11:30. The tidal wave again reached a maximum level of 2.06 m at 12:00 and a minimum level of 2.9 m at 12:15 (from the site of Geological Survey of India, www.gsi.gov.in, 2005). The first earthquake shock was experienced around 6:30 local time.

QuickBird Natural Color Images on the Web (by DigitalGlobe http://www.digitalglobe.com, 2005) captured the arrival of the third, most destructive wave at 11:20 on the coastline of Kalutara (Sri Lanka), showing the ocean receding nearly 300-400 meters, exposing reefs and rock structures.

Other images (Kalutara Beach and Banda Aceh areas) show massive whirlpools and rip currents created by the muddy waters (loaded with terrestrial debris) draining back to ocean.

Hydrodynamic features of this kind can be responsible of extensive mass re-mobilizing of the sediments deposited under the normal conditions on the continental shelf, ready to be further funnelled down over the edge of the continental scarp.

The rapid sea level fall before the arrival of the higher wave could have been a powerful trigger for simultaneous multiple turbidity currents, initiating at the shelf break where unconsolidated sediments lie in unstable piles.

Conclusions

Homogenites recorded in the Ionian Basin are the only deep-sea tsunamiites known so far.

The distinction between Type A Homogenite (pelagic turbidites of local, submarine origin, deposited in basinal settings within the highly deformed accretionary prism(s), deriving from liquefaction and downslope displacement of loose sediments) and Type B Homogenite (megaturbidite deriving from the north African continental shelf, triggered by the surficial tsunami wave hitting the shoreline of the Sirte Gulf) is more and more clearcut, and better understood (table I).

TABLE I. – *Comparison between Type A and Type B Homogenite.*

	TYPE A	TYPE B
Source area for turbidity currents	Proximal Active margin: Mediterranean Ridge	Distal Passive Margin: North African shelf
Distance from the origin of the tsunami	Hundreds of km (500 km Area 3, 800 km Area 4)	1000 km or more
Distance from sediment source area	Few km	Hundreds of km
Depositional setting	Closed Cobblestone, Anoxic Basins	Abyssal Plain, Open Cobblestone
Depositional model	Intrabasinal, local turbidity currents	Extrabasinal turbidity currents coming from African shelf and slope; upslope currents
Sedimentary process	Settling of pelagic drape liquefied	High-density turbidity current
Sedimentary features	Absent (structurless mud); direct grading from the sandy base	Absent (structurless mud); graded sandy base (7 m-thick or more)
Basal contact	Conformable	Erosional (base not reached in abyssal plain cores)
Thickness	Up to 7 m (in anoxic basins: up to 13 m)	> 24 m in the abyssal plain (up to 30 m according to acoustic data); up to 1 m upslope
Compositional data	Planktonic foraminifers and pteropod fragments (sandy base), pelagic calcareous mud; gelatinous mat fragments, siliceous plankton and gypsum crystals in anoxic basins	Abundant shallow-water benthic fauna and flora (bryozoans, larger foraminifers, calcareous algae) in the basal sand

The transect of long cores raised from basinal settings across the entire Mediterranean highlights the fundamental difference in stratigraphic position and geodynamic significance of the megabeds acoustically identified in the subbottom, and calibrated by coring, recorded in the abyssal plains respectively west and east of the collisional zone, where the MR overrides the passive African margin. Late Quaternary megabeds are related to low sea-level stands, and a prominent one is related to the Last Glacial Maximum. The Holocene megabed, recorded in the Ionian basin, deposited in a time of rising sea-level, following the Climatic Optimum, is a paradox in terms of paleoclimatic evolution and climatically-modulated deep-sea sedimentation.

Its anomalous occurrence derives from an exceptional event: the Santorini eruption and subsequent mega-tsunami.

The December 26th 2004 megatsunami that hit SE Asia with catastrophic effects and the unprecedented record of images on the behaviour of the anomalous waves on the coastline strongly support the conceptual model proposed for Type B Homogenite as triggered by the tsunami itself.

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