The Sicilian gateway: anatomy of the deep-water connection between East and West Mediterranean basins

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Abstract: The Sicilian gateway is a narrow, deep, interconnected series of basins, sill valleys and passageways that cuts across the broad, shallow Sicilian–Tunisian Platform in the Central Mediterranean. This deep connection allows dense Levantine Intermediate Water (LIW) formed in the Eastern Mediterranean to flow in a westerly direction through the gateway and exit into the Tyrrhenian and Balearic basins of the Western Mediterranean. LIW is replaced by a strong surface flow of Modified Atlantic Water (MAW). A complex and still active tectonic regime has been an important control on the development of physiography and on the style and distribution of sediments across the Platform.

Within the deep gateway basins, turbidites, debrites and megabeds are intercalated with a background of predominantly muddy and calcareous, hemipelagic and contourite sediments. Evidence for the influence of bottom currents on sedimentation is seen in the construction of small mounded drifts and irregular patch drifts, in zones of scouring and non-deposition, in local photographic evidence of a current-smoothed or rippled seafloor, and as a subtle combination of features present in the background sediments. These include: extensively reworked microfossil assemblages, rare diffuse lamination, coarse lenses of mixed composition within a pervasively bioturbated sediment, and relatively high rates of accumulation.

Between longitudes 10° and 16° E, the Mediterranean Sea shallows to a broad, silled platform known as the Strait of Sicily or the Sicilian–Tunisian Platform (Fig. 1). This broad shallow-water platform covers an area of approximately 250 000 km^2 between the landmasses of Sicily bordering to the north and Tunisia to the south, with a minimum separation distance of just 70 km (Marsala, Sicily to Cap Bon, Tunisia) and a maximum separation of over 440 km between SE Sicily and the Gulf of Sirte on the North African margin. It is cut through by an interconnected series of narrow elongate basins and deep sills that together form the Sicilian gateway. This gateway allows for the exchange of water masses between the east and west Mediterranean basins and has therefore played an important role in the sedimentation and oceanography of the Central Mediterranean region.

This paper presents an overview of the geological and oceanographic setting of the Sicilian gateway, and examines both seismic and sedimentary evidence for the role of bottom currents in the deposition and erosion of sediments across the region. In fact, the bottom current signature is not everywhere very evident and in many cases appears to be masked by interbedded turbidite/debrite and pelagic/hemipelagic facies. A summary of the principal characteristics of the Sicilian gateway is given in Table 1.

We have drawn together work on the sedimentary system carried out during the 1970's and early 1980's, as well as more recent oceanographic data. More detailed examination has been made of four giant piston cores and high-resolution 3.5 kHz seismic profiles collected during the 1995 *Marion Dufresne* expedition (*MD81*). This latter work is reported in more detail in a PhD thesis by the senior author (Reeder 2000) and by Reeder *et al.* (in press).

Geological and oceanographic setting

Geological framework

The Central Mediterranean region has a complex tectonic framework (Fig. 2) that is not yet fully understood and subject to several contrasting interpretations (e.g. Illies 1981; Winnock 1981; Finetti 1984; Cello *et al.* 1985; Jongsma *et al.* 1985; Boccaletti *et al.* 1987; Cello 1987; Catalono *et al.* 1995). The most significant result

Table 1. *Principal characteristics of the Sicilian gateway*

Table 1	Principal characteristics of the Sicilian gateway
Location	Central Mediterranean, separating the east and west Mediterranean basins
Setting	Series of fault-bound deep interconnected basins and valleys cutting across the shallow Sicilian–Tunisian Platform; basins > 1000 m, sill valleys around 400 m water depth
Age	Gateway assumed approximately present form in early Pliocene and has allowed water mass exchange since that time
Drift types	Small elongate mounded drifts and patch drifts in parts; more commonly contourites intercalated with downslope facies (sheet drift or mixed drift systems)
Dimensions	Gateway: 600 km long, 65 km wide (maximum) Basins: 50–100 km long, 15–25 km wide Sill valleys: 25–50 km long, 10–25 km wide Drifts: small mounds 5 × 20 km maximum, basinwide sheets
Seismic facies	Moderate-high amplitude sub-parallel reflectors, close to more widely spaced; downslope seismic facies intercalated with basinal seismic facies
Sediment facies	Interbedded turbidite, debrite, megabed and hemipelagite/contourite facies; subtle indications of contourite influence on background sediment.

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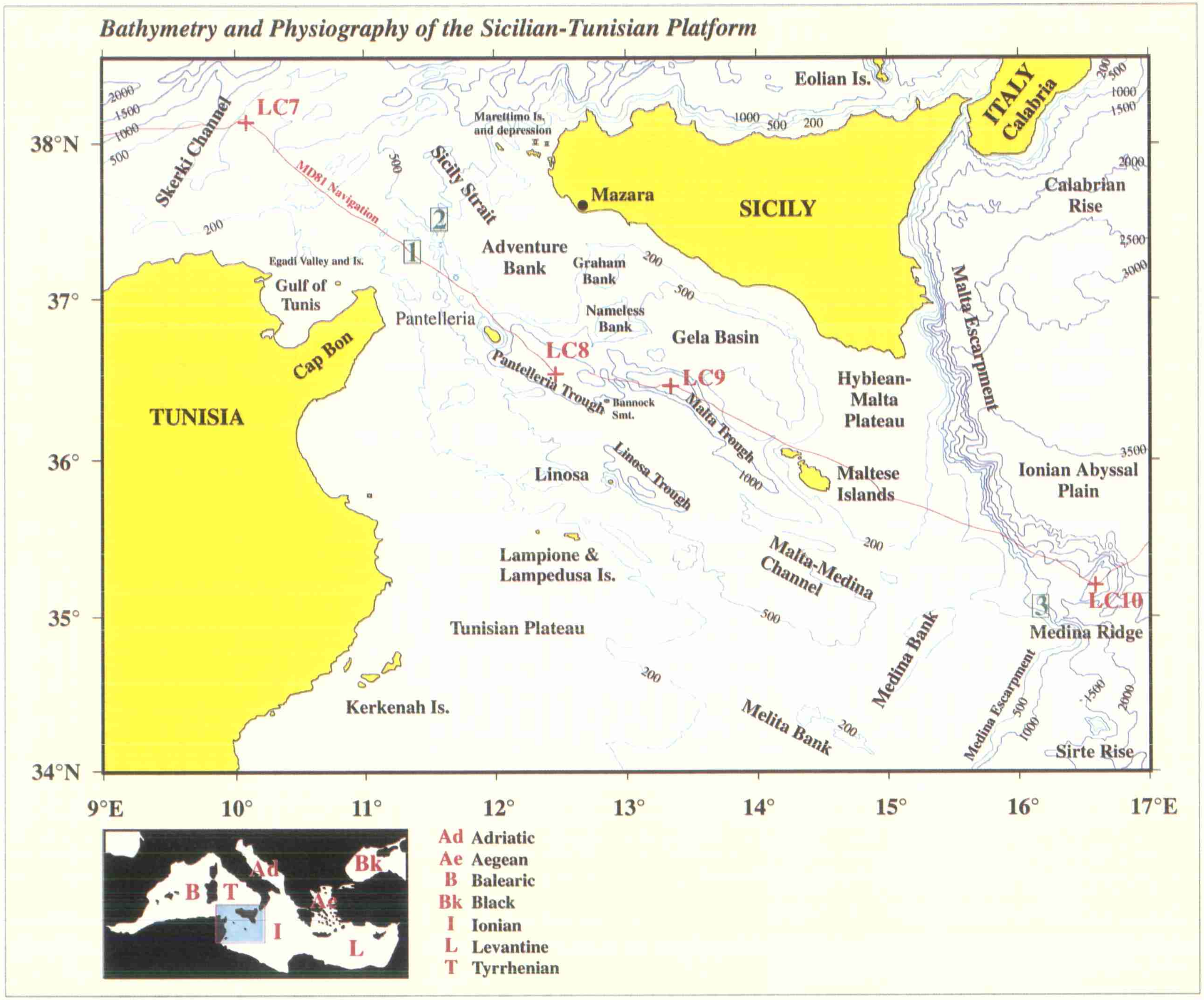


Fig. 1. General location, physiography and bathymetry of the Sicilian–Tunisian Platform. The map also shows the course of the Marion Dufresne 81 expedition (red line), giant piston core sites (red crosses), and the location of narrow valleys across the Sicily (1, 2) and Malta (3) sills.

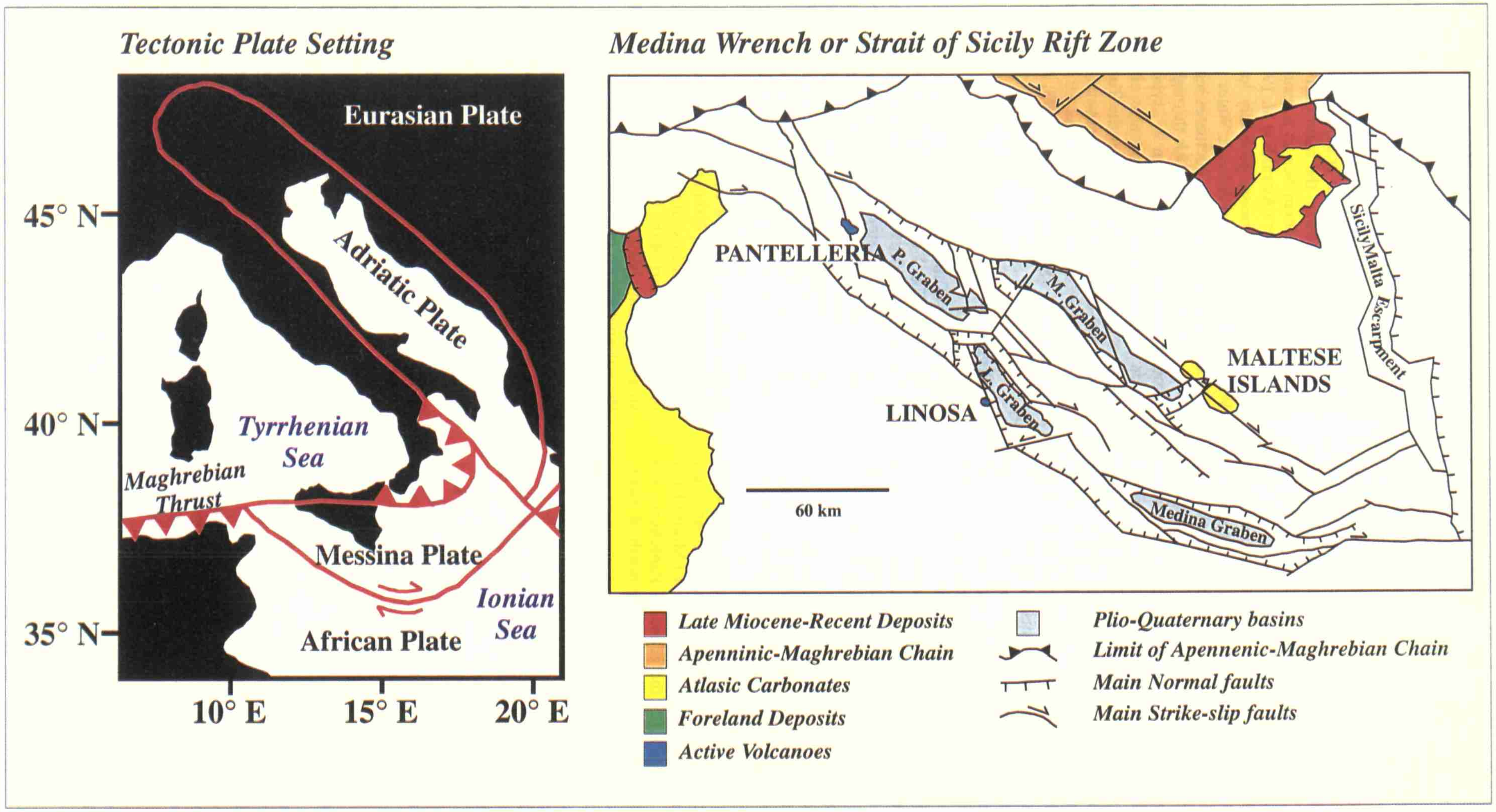


Fig. 2. Geological setting of the Sicilian gateway, showing the complex interaction of the Eurasian and African tectonic plates leading to creation of the Messina and Adriatic microplates (after Jongsma *et al.* 1985). The Messina microplate has been rotated creating a region of extensive dextral strike-slip faulting across the Sicilian–Tunisian platform known as the Medina Wrench Zone (after Cello 1987). This zone with its deep troughs and sill valleys is known as the Sicilian gateway.

of these complex tectonic movements, as far as the study area is concerned, was the creation of deep, transtensional grabens and associated transpressional horsts within the Sicilian–Tunisian Platform, and the two bounding sills/escarpments of the eastern and western platform margins. The most widely accepted tectonic history of the region is summarized below.

During early Tertiary time, the northern edge of the African Foreland collided with the southern edge of the Eurasian plate. This resulted in partial subduction of the African Foreland beneath the Eurasian plate and southwards thrusting of the Maghrebian Arc across central Sicily during the Oligocene–Miocene period. As collision continued, the Ionian Abyssal Plain to the east was subducted beneath the Calabrian Foreland forming the steep Malta and Medina Escarpments with a total vertical displacement of between 2 and 3 km to the east. Major NW–SE trending faults were created during this time across the Sicilian–Tunisian Platform together with a conjugate series of secondary faults oriented approximately WSW–ENE.

Resistance to subduction by the continental crust of the Hyblean–Malta Plateau led to small NW–SE faulted blocks being rotated anti-clockwise by 15°, giving a wide variety of fault fabrics and structural styles across the Sicilian–Tunisian Platform. This rotation created a shear zone, named the Medina Wrench Zone (also known as the Strait of Sicily Rift Zone), showing an overall dextral movement. The zone extends at least 800 km from the NW extremity of the Sicily Strait to the eastern end of the Medina Ridge, and is characterized by a series of deep en-echelon troughs. The Messina micro-plate has been formed from African continental crust and has the subduction zone of the Calabrian Arc to the North and the dextral strike-slip Medina Wrench Zone to the south (Cello 1987; Jongsma *et al.* 1987).

There are five main centres of volcanism in the region that are believed to be related to the extension and thinning of continental crust in the Medina Wrench Zone and to subduction of the African plate beneath the Eurasian plate (Di Paolo 1973; Grandjacquet & Mascle 1978; Boccaletti *et al.* 1984; Jongsma *et al.* 1985; Calanchi *et al.* 1989; Argnani 1993; Colantoni *et al.* 1993, amongst others). The five centres are: (1) the major volcano of Mount Etna on the eastern margin of Sicily, (2) the island of Pantelleria, (3) the island of Linosa, (4) the Eolian islands to the north of Sicily, and (5) localized submarine activity.

Seismic activity, though relatively less than in the eastern Mediterranean at present, occurs in relation to wrench and subduction tectonics and as a result of volcanic activity. On the basis of high-resolution seismic records, there has been much active faulting of recent and/or subrecent origin throughout the platform area. Vertical displacement along faults is commonly in excess of mean sedimentation rates, i.e. greater than 20 cm ka^{-1} (Maldonado & Stanley 1976). Locally, there is intense folding and distortion of near-surface reflectors, indicative of compression; elsewhere, the faulting is apparently normal and extensional.

Oceanographic setting

The present-day circulation over the Sicilian–Tunisian Platform is thermohaline in nature, essentially driven by the formation and sinking of dense water in the Eastern Mediterranean (Fig. 3). This deep saline water mass, known as Levantine Sea Intermediate Water (LIW), flows from east to west through the Sicily gateway and is replaced by less dense surface water (Modified Atlantic Water, MAW) passing over the platform and into the Eastern Mediterranean Sea.

LIW has an average salinity of 38.7‰ and a temperature of approximately 14°C (Stanley *et al.* 1975; Moretti *et al.* 1993) and sinks in the Levantine Basin forming an anticlockwise gyre. This deep current flows in a westerly direction towards the Sicilian–Tunisian platform, through which its direction is controlled by the gateway bathymetry. At the Sicily Channel the current is split in two by a small central ridge between two narrow pathways, one shallowing to 365 m on the Tunisian side and the other to 430 m deep on the Sicilian side (Astraldi *et al.* 1996). The annual mean high velocity on exit through the eastern passage is greater than 35 cm s^{-1}, whereas a value of only 10 cm s^{-1} has been measured in the western passage. Bottom water velocities recorded over the main platform region are 15 cm s^{-1} (winter) and 5 cm s^{-1} (summer) (Marani *et al.* 1993; Astraldi *et al.* 1996). On exiting the Sicily gateway, the main part of the LIW flows northwards into the Tyrrhenian Sea as a result of bottom topography and the Coriolis Effect (Astraldi *et al.* 1996).

The surface water mass, generally known either as Atlantic Water (AW) or Modified Atlantic Water (MAW), has a salinity of 37.4‰ and temperature that fluctuates seasonally between 13° and 23°C. It flows generally eastwards through the gateway region at a velocity between 10 and 25 cm s^{-1}, typically, and >30 cm s^{-1} at times, although large eddies are also observed and one distinct strand of the current flows nearer the Tunisian coast. MAW has a base at 100–200 m, with mixing between LIW and AW occurring up to a water depth as shallow as 60 m (Stanley *et al.* 1975; Manzella *et al.* 1990; Moretti *et al.* 1993; Astraldi *et al.* 1996).

Bathymetry

The Sicilian–Tunisian platform has an irregular and varied bathymetry (Figs 1 & 4). At its western extremity it slopes down towards the Balearic Abyssal Plain and the islands of Sardinia and Corsica of the Western Mediterranean. Its eastern margin is denoted by the Malta Sill and the steep, approximately N–S-trending Medina and Sicily–Malta Escarpments which fall sharply to the Ionian Abyssal Plain and Sirte Rise of the Eastern Mediterranean Basin. Between these, approximately 47% of the platform area has a water depth shallower than 200 m, comprising broad flat shelves and banks along the Tunisian and Sicilian margins. A further 50% of the area comprises an irregular, typically gently sloping zone between 200 m and 600 m water depth, including the Gela foredeep basin south of Sicily. Several islands are emergent in the central part of the Sicilian–Tunisian Platform, including the small carbonate islands of Malta, Lampedusa and Lampione, and the volcanic islands of Pantelleria and Linosa.

The Sicily gateway itself is the 3% of the region deeper than 600 m through which deep LIW flows. It comprises three deep fault-bounded en-echelon troughs, the Pantelleria, Malta and Linosa Troughs, the broad Malta–Medina Channel and the narrow gaps or passageways across the Sicily and Malta sills. Together, these trend in a NW–SE orientation and incise the central part of the Sicilian–Tunisian Platform.

The Pantelleria Trough is the most westerly of the three grabens and is approximately 80 km in length and 30 km in width, with a relatively flat floor in excess of 1300 m water depth. The island of Pantelleria is to the NW of the trough, and is bounded by high, irregular slopes of 5–30° on the NE flank and 6–11° on the south-western flank. The southeastern end is closed by the Bannock Seamount. *The Malta Trough* lies to the NW of the carbonate horst supporting the islands of Malta, Gozo and Comino and forms a narrow (18 km wide) elongate (150 km long) that reaches a depth of over 1700 m (1721 in at core site LC9). *The Linosa Trough* is located to the north of the volcanic island of Linosa. It is 75 km long, 15 km wide and over 1600 m deep. It opens to the southeast into the broader, shallower *Malta–Medina Channel*. The depths of the three sills (as numbered on Fig. 1) are 365 m, 430 m and 370 m respectively.

Stratigraphic context

During latest Eocene time, there existed a 300 km wide slab of Neotethyan oceanic crust between southern Europe (Corsica,

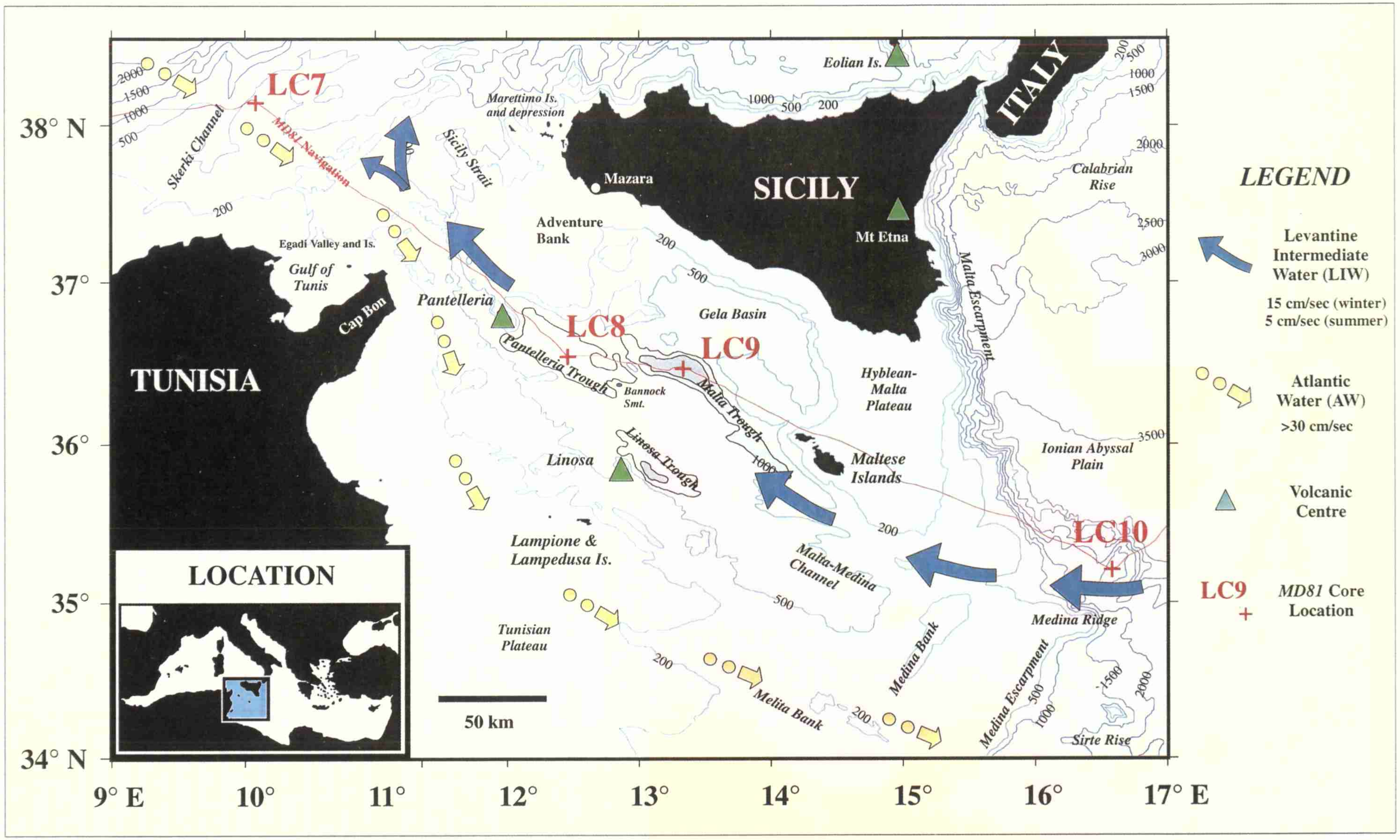


Fig. 3. Oceanographic setting and water mass exchange through the Sicilian gateway. Deep westward flowing LIW is contained within the deep troughs and sill valleys; shallow MAW follows the North African coastline (modified from Manzella *et al.* 1990; Moretti *et al.* 1993; Astraldi *et al.* 1996).

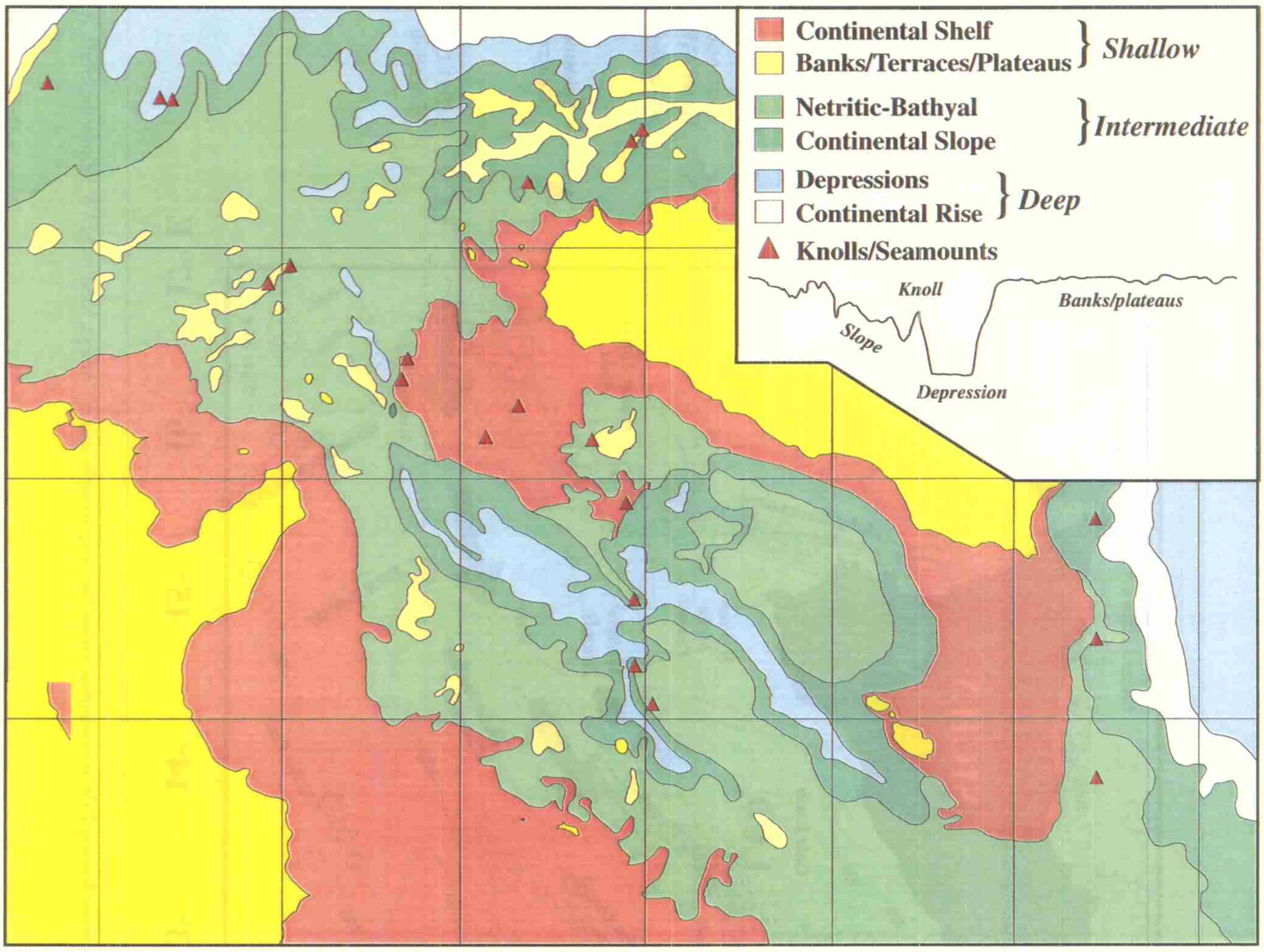


Fig. 4. Physiographic regions of the Sicilian–Tunisian Platform determined from bathymetry and topographic features (modified from Maldonado & Stanley 1976, 1977).

Sardinia and the Ballearic islands) and northern Africa (Tunisia and including most of Sicily). Complex closure together with repositioning of plate boundaries took place through the Oligocene and most of the Miocene (Dewey *et al.* 1989), so that the present day tectonic configuration did not exist before the latest Miocene to early Pliocene.

Although there is an absence of well control through the sedimentary successions of the gateway region, the top-Messinian horizon is readily identified on Sparker profiles, so that the thickness of the Plio-Quaternary section can be estimated (using a sonic velocity of 1800 m s^{-1} through these relatively unconsolidated sediments). This varies markedly in both the shallow and intermediate depth areas, from 0–225 m (0–0.25 s TWT) on the platform, and from 0–720 m (0–0.8 s TWT) in the intermediate region. The deeper basins have a more uniform, thicker Plio–Quaternary section, in some cases up to 1260 m thick (1.4 s TWT).

The cores available for this study reach a maximum length of just over 31 m, and therefore provide a high-resolution record of part of the Pleistocene–Holocene succession only. This part of the sequence can be well dated by a combination of micropalaeontological analysis, oxygen–isotope stratigraphy, tephra chronology and, for core LC10 only, sapropel chronology from the eastern Mediterranean basin (Fig. 5, see Reeder 2000). The sill region successions (LC7 and LC10) are the most slowly accumulated, extending back to about 700 ka and 550 ka respectively. The trough sequences (LC8 and LC9), by contrast, were deposited much more rapidly, each within the last 60 ka. Radiocarbon dating of the shorter cores (maximum around 8 m long) recovered during earlier cruises yielded basal ages < 50 ka.

Seismic characteristics

This study had access to a limited number of medium (Sparker) and high-resolution (3.5 kHz) seismic profiles across the Sicilian–Tunisian platform area, sufficient, however, to illustrate the complexity and variability of sedimentation in the region (Figs 6–8). For the purposes of this study, tectonic basement is generally visible either as a more or less deformed (folded, faulted, thrust-faulted) pre-Messinian seismic unit or, locally, as a distinctive and irregular post-Messinian volcanic complex.

Overlying this basement, the shallow platform regions (continental shelves, banks) show a reduced Plio–Quaternary section, generally less than 0.1 s but locally up to 0.25 s (TWT) or about 225 m in thickness. The intermediate regions vary from a thin regular to thicker irregular Plio–Quaternary cover, averaging around 0.4 s (TWT, 360 m). The Gela Foredeep, for example, shows a heavily faulted clastic sediment fill of a foreland basin, at least 0.5 s thick (TWT, 450 m) in parts, but with pinchouts over fault highs as well as thickening on the downthrown side.

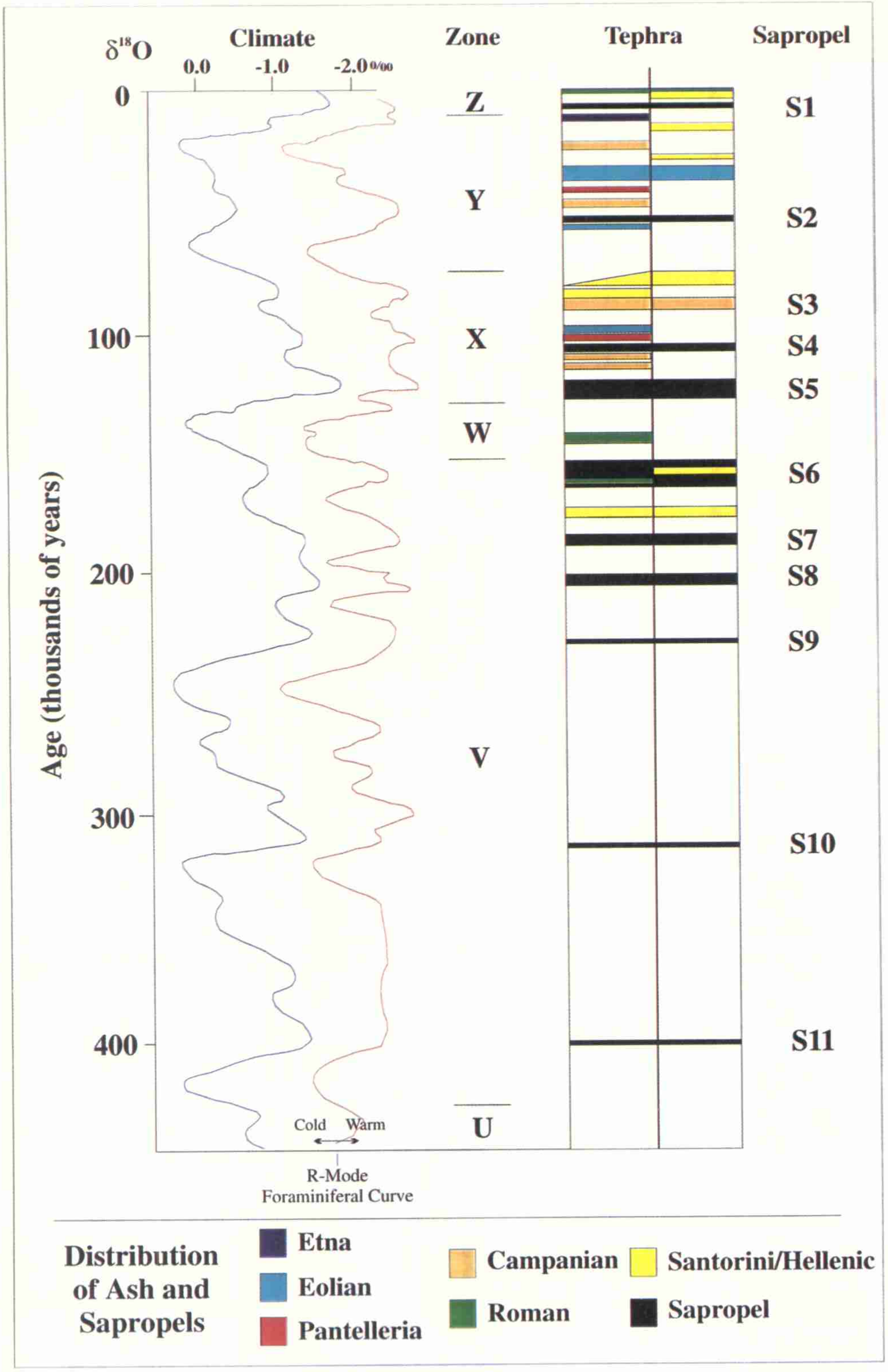


Fig. 5. Stratigraphic framework for the Pleistocene–Holocene section recovered in giant piston cores from the Sicilian gateway region, showing climatic zones based on oxygen isotopes, tephra and sapropel layers (modified after Keller *et al.* 1978).

The deep narrow basins and channels as well as the Malta escarpment show steep, faulted margins with irregular sediment cover and extensive slide-slump seismic facies evident in parts. The basin fills comprise regular parallel to sub-parallel, moderate amplitude reflectors, over 1.4 s thick (TWT, 1260 m) in places. The dominant thin, closely-spaced reflectors on 3.5 kHz profiles are interspersed with thick parallel-sided acoustically transparent layers, especially in the Pantelleria Trough and the deeper part of the Malta Trough. From direct correlation with cores, these are shown to be debrite-turbidite megabeds (Reeder *et al.* 2000).

Within the narrow Sicily Channel that forms the northern part of the Sicily gateway, there is a small elongate mounded drift flanked on either side by erosive/non-depositional moats. This forms the upper 0.25 s (TWT) or at least 200 m of section. Smaller patch drifts and localised scour, including the exposure of bedrock on the seafloor, are also evident (Marani *et al.* 1993; Bowles *et al.* 1993).

Sediment characteristics

Physiographic regions and facies

Early work by D. J. Stanley and co-authors (Stanley *et al.* 1975; Maldonado & Stanley 1976, 1977), based on the analysis of

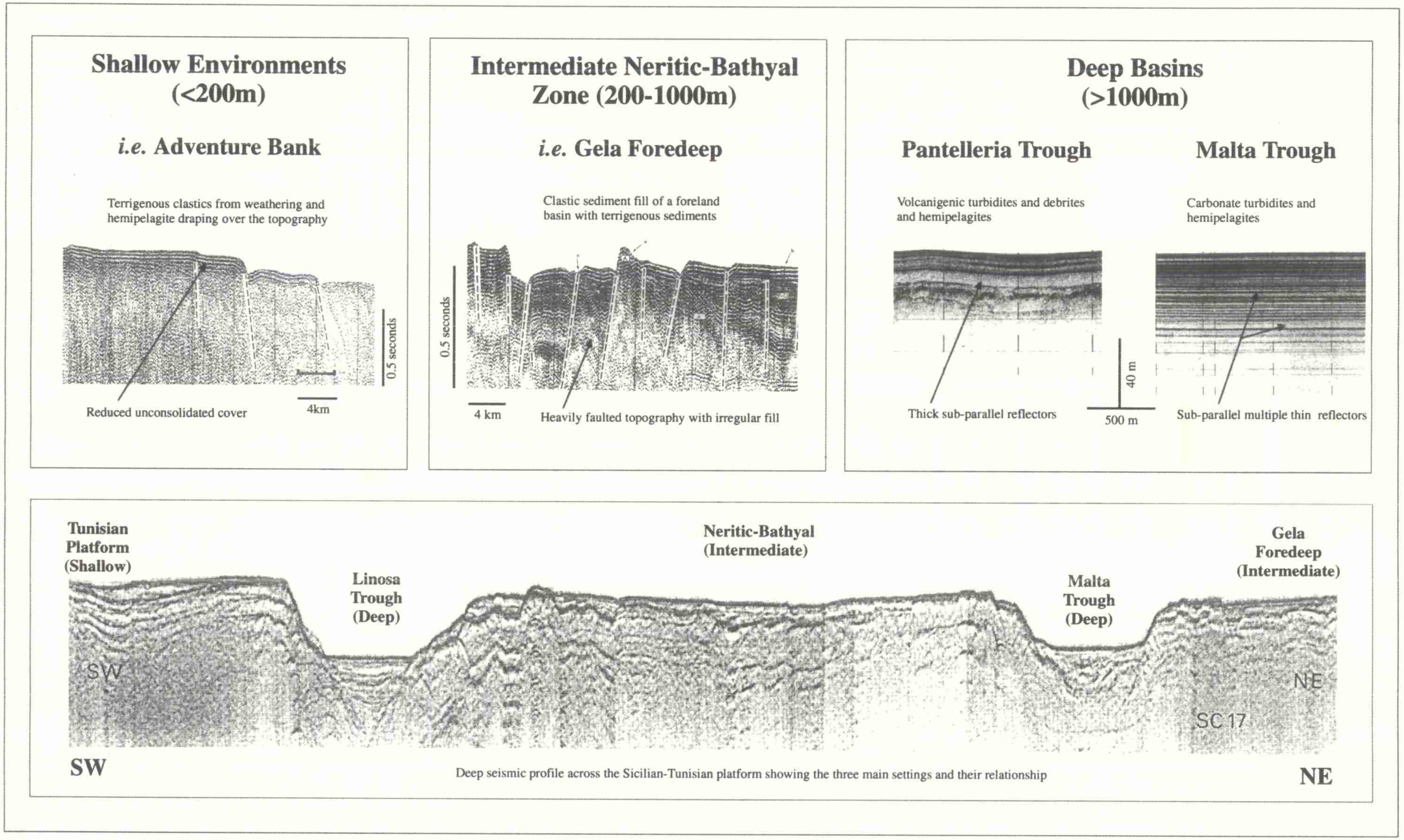


Fig. 6. Seismic images of the three main physiographic regions of the Sicilian–Tunisian Platform. (**a**) The shallow environment characterized on the Adventure Bank (Sicilian margin) by terrigenous sediments and on the Tunisian margin by platform carbonates (section after Maldonado & Stanley 1976). The physiographic region forms approximately 47% of the Sicilian–Tunisian Platform area. (**b**) The heavily-faulted horst and graben topography of the neritic-bathyal intermediate environment, forming approximately half of the regional physiographic area (after Maldonado & Stanley 1976). (**c**) Sub-parallel reflectors characterizing the sub-surface of flat, deep troughs (3% of area), the fill of which is dominated by sediments from the local islands and pelagic settlings (from the MD81 cruise). (**d**) The relationship between the three physiographic regions (after Calanchi *et al.* 1989).

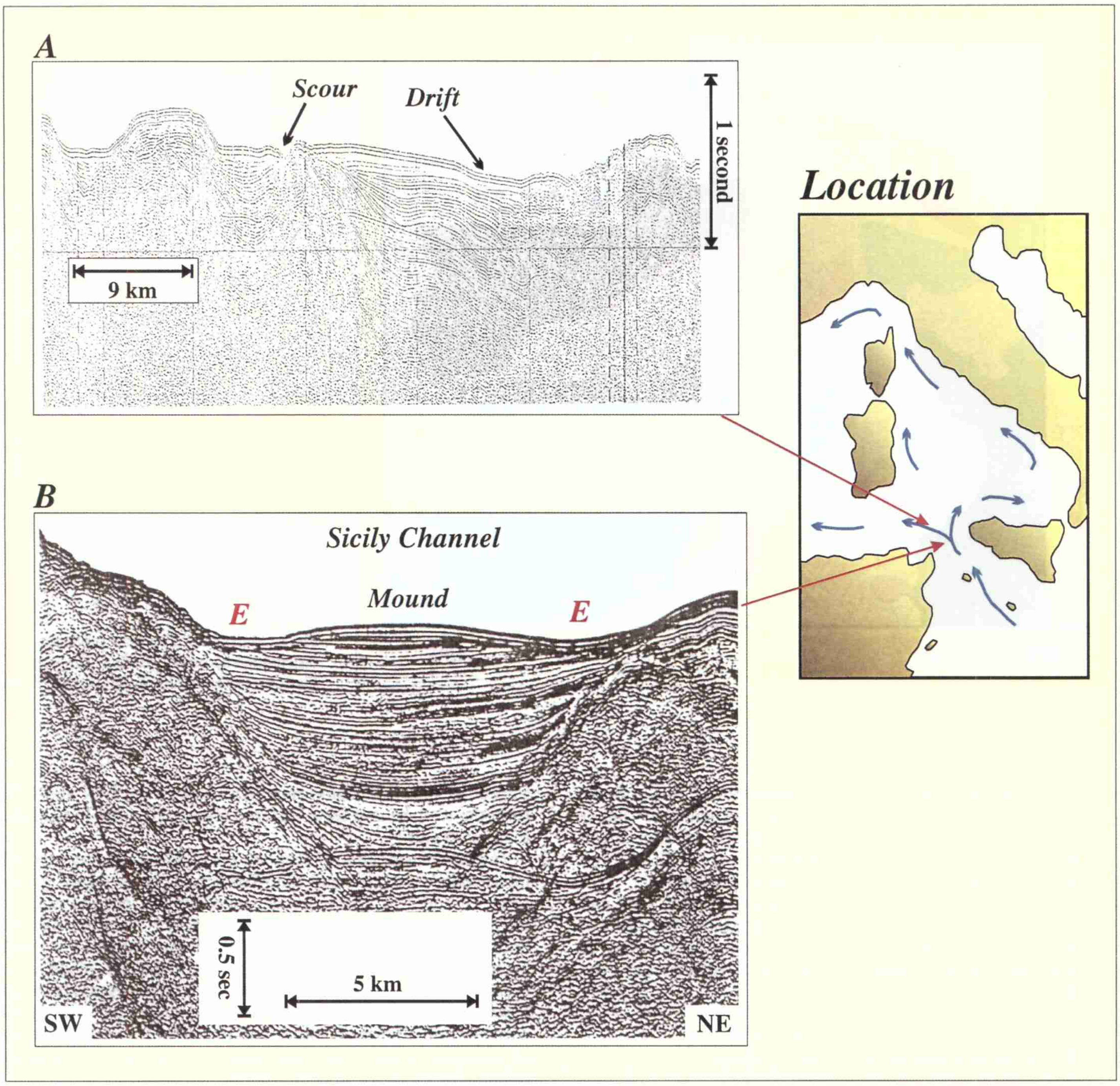


Fig. 7. Seismic evidence for erosion and deposition by bottom currents in the Sicilian gateway region, after Bowles *et al.* (1993) (A) and Marani *et al.* (1993) (B).

seafloor photographs, 3.5 kHz and Sparker seismic profiles and some 32 piston cores, provided the first good overview of sedimentation across the whole platform region. The principal physiographic regions they identify are the shallow banks (with local topographic highs), the intermediate depth platform (including neritic-bathyal, canyon and slope), and the deep basins (Fig. 4, Section 3), each with their own distinctive sediment facies and faunas. Subsequent work by Colantoni *et al.* (1993), and Reeder (2000, Reeder *et al.* in press) focused on sedimentation in the deeper basins and in the eastern and western sill slope regions.

The principal facies found across the whole region are listed below, and their distribution illustrated in Figure 9.

(1) Rock and gravel – including exposed bedrock on the seafloor and coarse gravel lag deposits, mainly siliciclastic, mixed with some bioclastic; typically found along rocky coastlines, on volcanic banks and outer shelf highs.
(2) Coarse calcareous sands – containing high proportions of bioclastic detritus, found mainly on the shallow platforms; typically concentrated by current winnowing.
(3) Sands and silts – generally bioclastic or volcanigenic, distributed on both the shallow platforms and in the deep basins, resulting from airfall tephra and turbidity currents.
(4) Muds – comprising the most abundant of the platform facies, more or less calcareous biogenic in nature, deposited by hemipelagic, contourite and turbidite processes.

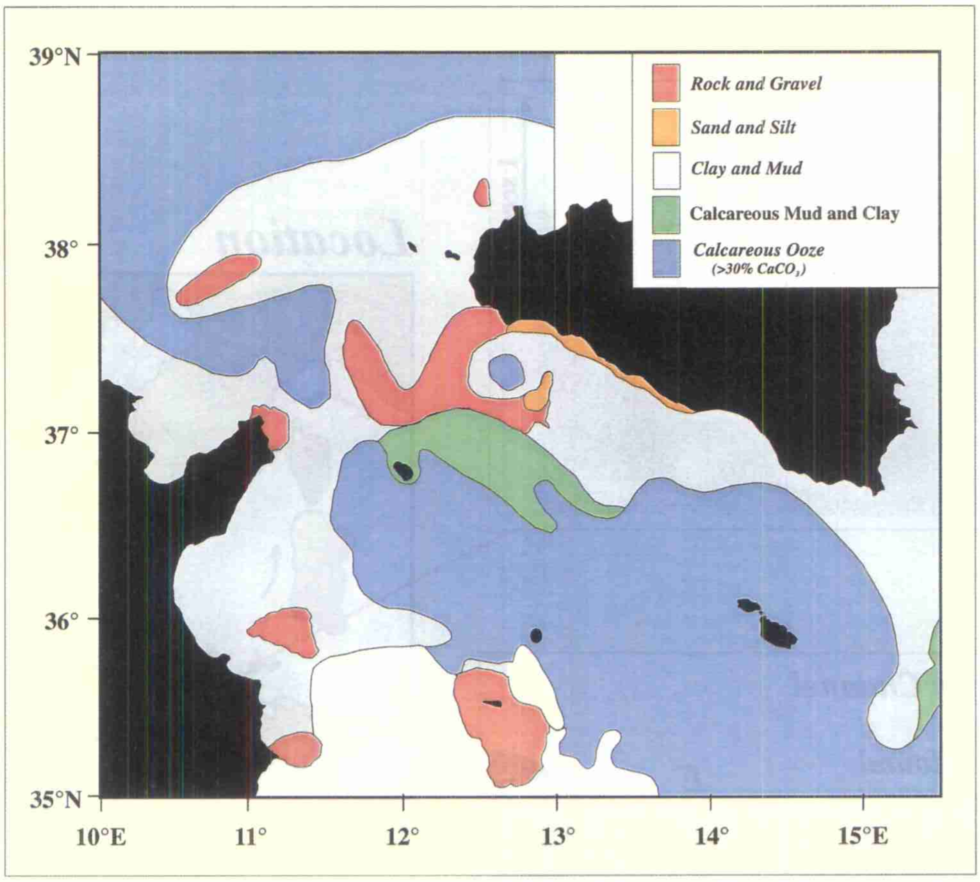


Fig. 8. Map showing surficial sediment distribution across the Sicilian–Tunisian Platform (after Stanley & Maldonado 1976).

(5) Sapropels and organic oozes – dark-coloured, fine-grained, organic-carbon rich sediments that accumulated under periodic anoxic conditions in the eastern Mediterranean Basin; present only in the easternmost sill region (LC10), and as a dark hemipelagic mud in the Linosa Trough.
(6) Volcanic ash – occurring as graded layers of mud, sand and gravel size, present across the whole platform, but particularly preserved as primary air-fall tephra layers and as secondary, mixed bioclastic-volcaniclastic turbidites on the deep basin floors.

Facies associations and depositional processes

Distinctive facies associations and depositional processes characterise each of the principal environments.

The shallow platform area is the most varied, typified locally by exposed bedrock, gravel substrate and volcanic ashfall deposits, and more generally by a complex mosaic of coarse calcareous sands, mixed composition sands and silts, and bioturbated muds. Sediments are supplied from coastal erosion, river drainage, direct volcanic fall, benthic macrofauna and planktonic microfauna. They are distributed by the normal range of shelf processes, including waves, tides and shelf currents, as well as hemipelagic accumulation in more protected regions. Winnowing by strong, shallow water, bottom currents is responsible for pockets of coarse bioclastic and mixed sand facies.

The intermediate zone is dominated by homogeneous, bioturbated, calcareous mud-rich facies, resulting mainly from slow hemipelagic accumulation. Locally, there are different facies, including turbidite sands and silts, mostly in slope channels, sapropel layers on the eastern slope towards the Ionian Basin and Sirte Rise, and thin airfall volcaniclastic horizons interbedded throughout the region. On steeper slopes the sediments are subject to slide and slump remobilization. Cores LC7 and LC10 from the western and eastern slopes respectively are illustrated in Figures 10 and 11.

The deep basins and sill channels are characterized by regularly interbedded sand, silt and mud facies and, more rarely, gravels (Figs 12 and 13). These are deposited by the normal range of deep-water processes including debris flows, turbidity currents, bottom currents and hemipelagic fall. Slump deposits are locally present around basin margins, whereas megabeds made up of debrite-turbidite couplets are known to extend across the whole basin floor. Turbidites in the Pantelleria Trough are mostly derived from a volcanic source and mixed with variable amounts of bioclastic debris. Those recovered from the Malta Trough are dominantly bioclastic in composition.

Sedimentary evidence for the influence of bottom currents on both the mud and some of the sandy horizons is generally very subtle, based on the following aspects.

- Whereas much of the western slope core (LC7) can be interpreted as being of hemipelagic origin, bottom current influence in parts is indicated by pervasive bioturbation coupled with rare diffuse lamination, mixed composition, broken bioclastic debris, and a distinctive oscillation in mean grain size.
- The local concentration of bioclastic sandy horizons with sharp tops and an absence of turbidite mud caps (in the Strait Narrows channel and in core LC7), suggests the introduction of material by turbidity currents and its subsequent winnowing by bottom currents.
- The presence of partially reworked microfossil assemblages in slope cores LC7 and LC10, as well as highly reworked assemblages in basin cores (LC8 and LC9), suggests bottom current reworking.
- The calcareous muddy intervals between turbidite layers in

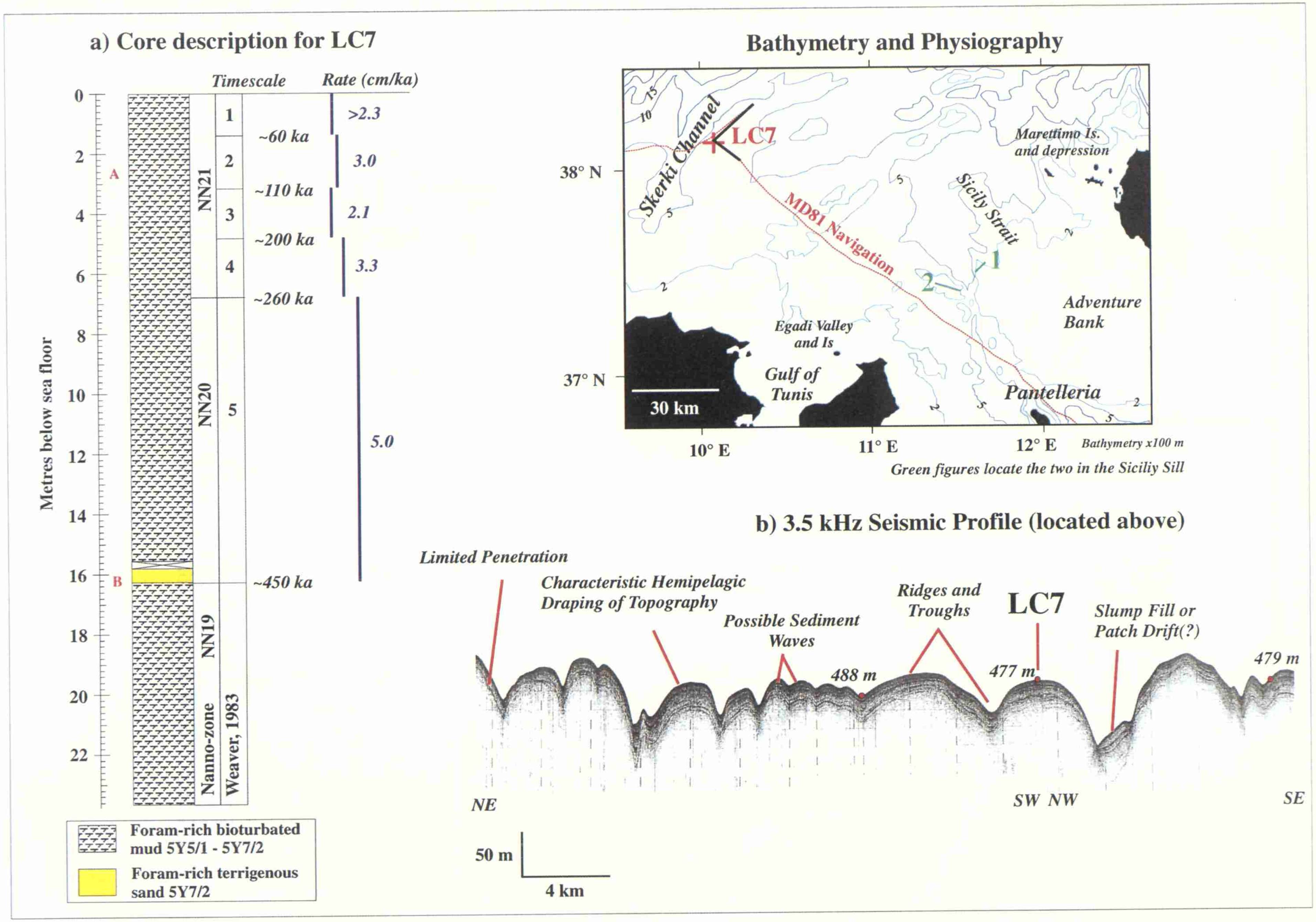


Fig. 9. Sediment and 3.5 kHz seismic characteristics of the western Sicilian–Tunisian Platform, on the slope west of the Sicily sill. (**a**) LC7 core log – A and B show the location of core photographs in Figure 13. (**b**) 3.5 kHz seismic profile passing through the core site, shown by dark line on the location map above.

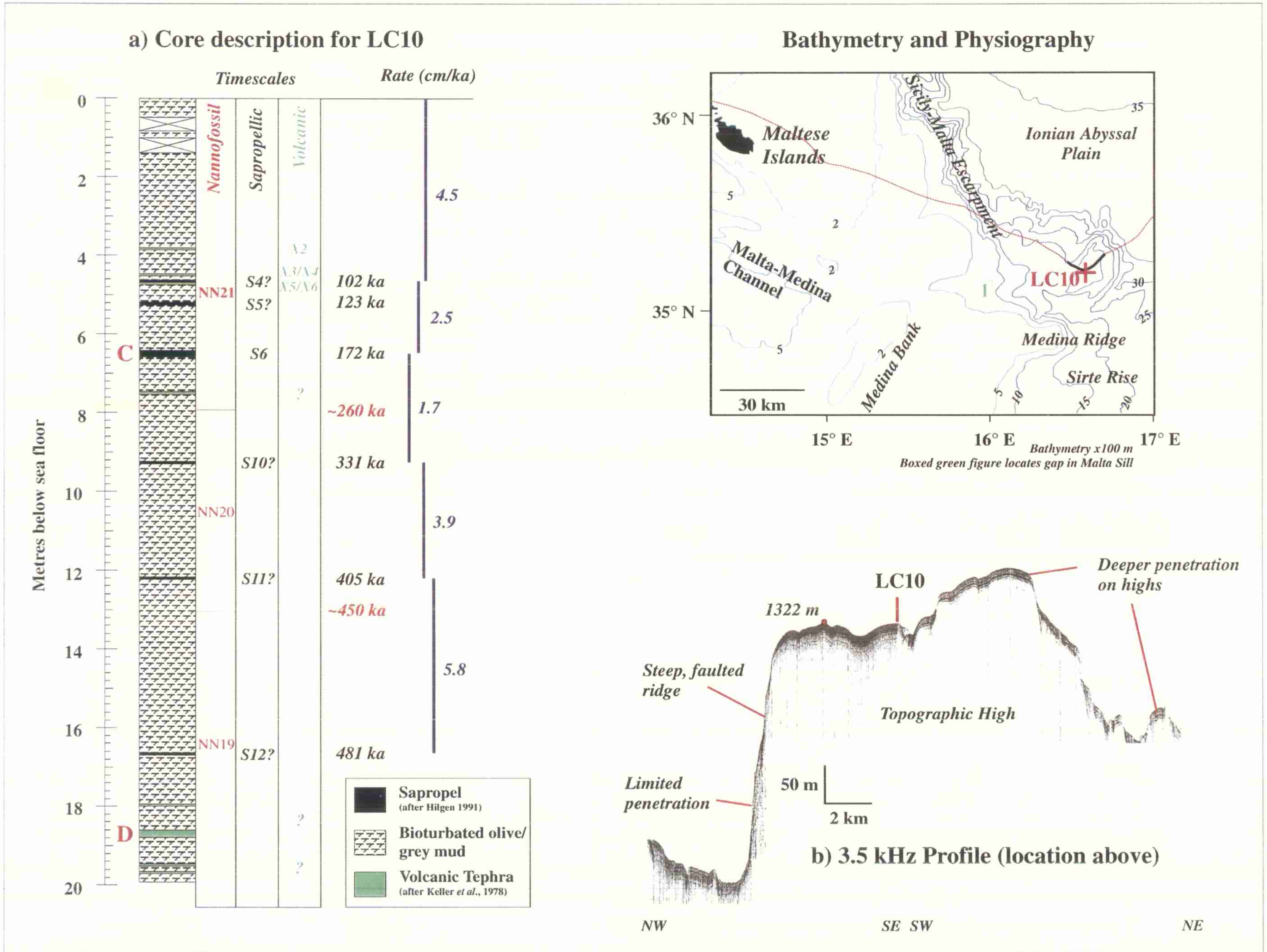


Fig. 10. Sediment and 3.5 kHz seismic characteristics of the eastern Sicilian–Tunisian Platform, on the slope east of the Malta sill. (**a**) LC10 core log – C and D show the location of core photographs in Figure 13. (**b**) 3.5 kHz seismic profile passing through the core site, shown by dark line on the location map above.

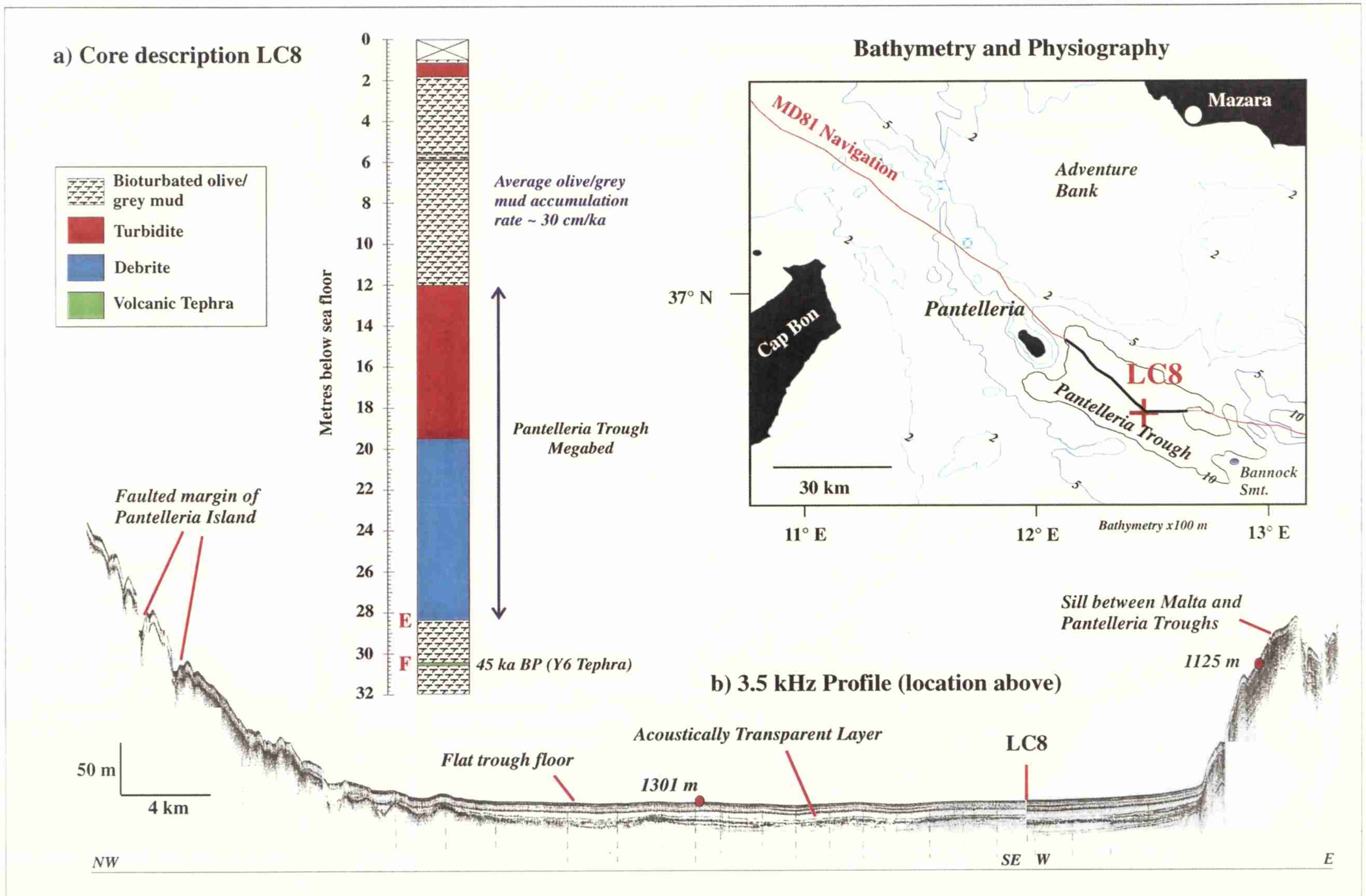


Fig. 11. Sediment and 3.5 kHz seismic characteristics of the Pantelleria Trough in the central Sicilian–Tunisian Platform. (**a**) LC8 core log – E and F show the location of core photographs in Figure 13. (**b**) 3.5 kHz seismic profile passing through the core site, shown by dark line on the location map above.

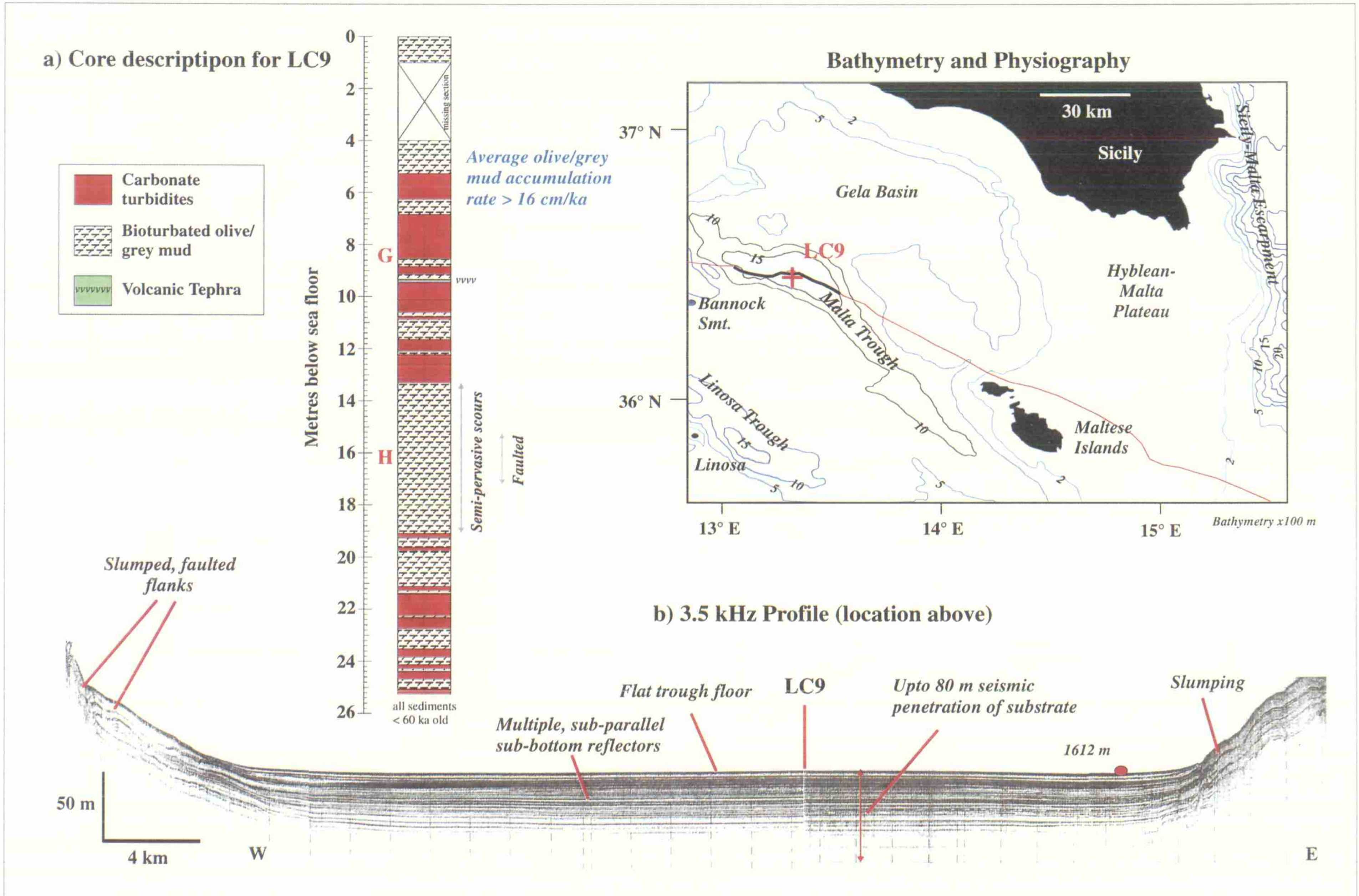


Fig. 12. Sediment and 3.5 kHz seismic characteristics of the Malta Trough in the central Sicilian–Tunisian Platform. (**a**) LC9 core log – G and H show the location of core photographs in Figure 13. (**b**) 3.5 kHz seismic profile passing through the core site, shown by dark line on the location map above.

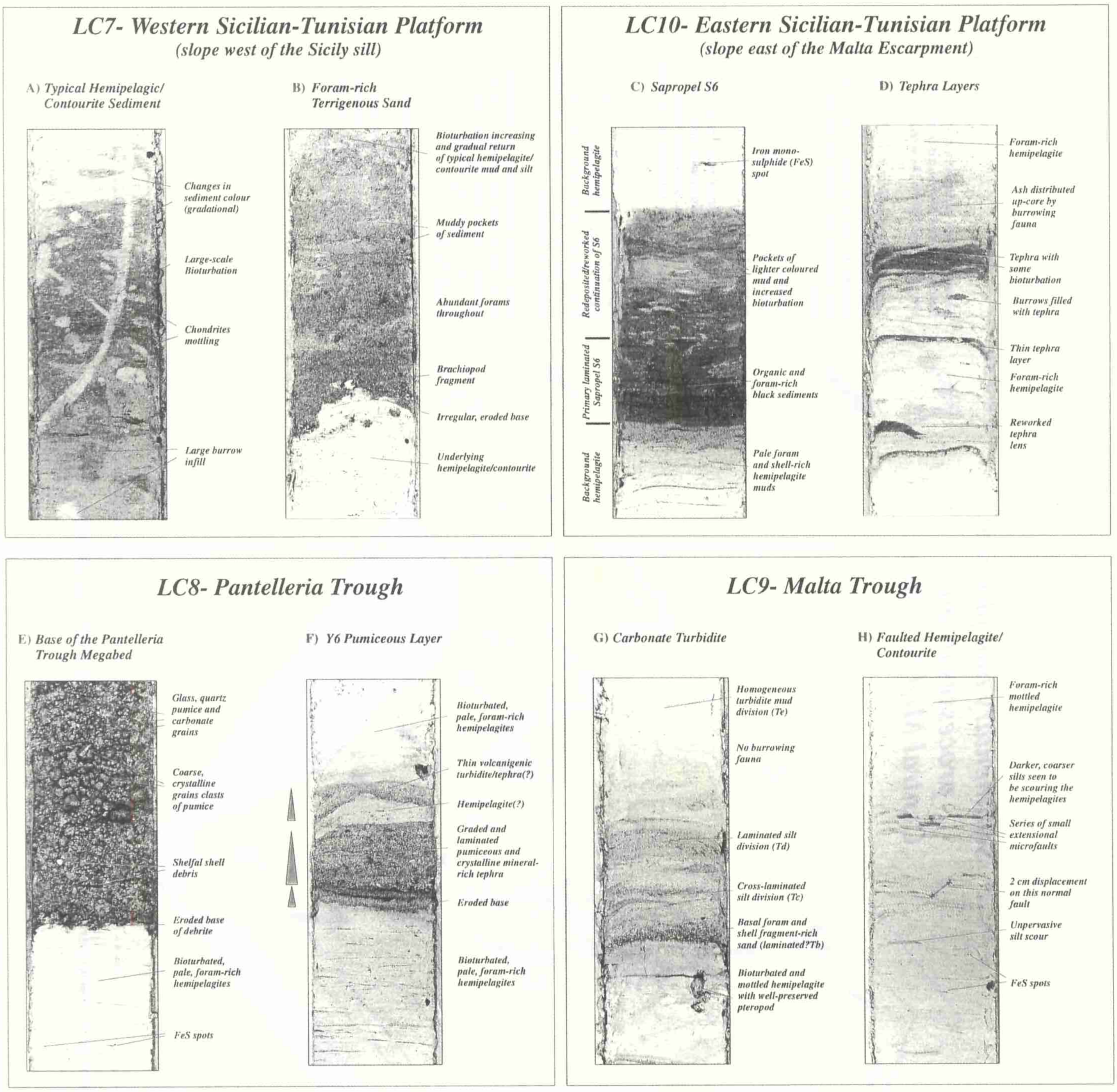


Fig. 13. Detailed core photographs from cores LC7 (**a**, **b**), LC10 (**c**, **d**), LC8 (**e**, **f**) and LC9 (**g**, **h**). Located on Figures 9–12.

the basin cores, especially core LC9 (i.e. background sediments), display variable amounts of bioturbation, scoured discontinuous lamination and lenses of foraminiferal and fragmented shell-rich silts and sands, all suggestive of bottom current influence.

- Reeder *et al.* (in press) further argue that the relatively high rates of background sedimentation found in basin cores (> 16–30 cm ka^{-1}) suggest that the regional hemipelagic sedimentation has been augmented by bottom currents. They invoke a process of bottom-current flow lofting to help trap the contourite sediments in the basins.
- Whereas most of the seafloor photographs reported by Maldonado & Stanley (1976) show little evidence of current activity in the deep basins, they do record probable bottom current smoothing of an otherwise bioturbated surface within the Malta Trough. The shallow platform regions, by contrast, show considerable evidence for shallow bottom current winnowing and concentration of coarse bioclastic debris.

Sedimentation rates and hiatuses

Based on seismic records, the average rates of sedimentation for the Plio-Quaternary section vary from < 4 cm ka^{-1} on the shallow platform, around 6–8 cm ka^{-1} in the intermediate zone and from 16–25 cm ka^{-1} in the deeper basins. However, the shelf region, in particular, would have been subject to episodic emergence and erosion during glacial sealevel lowstands, so that any sedimentary sequence will be full of hiatuses and condensed sections.

Data from cored sections (Maldonado & Stanley 1976; Reeder

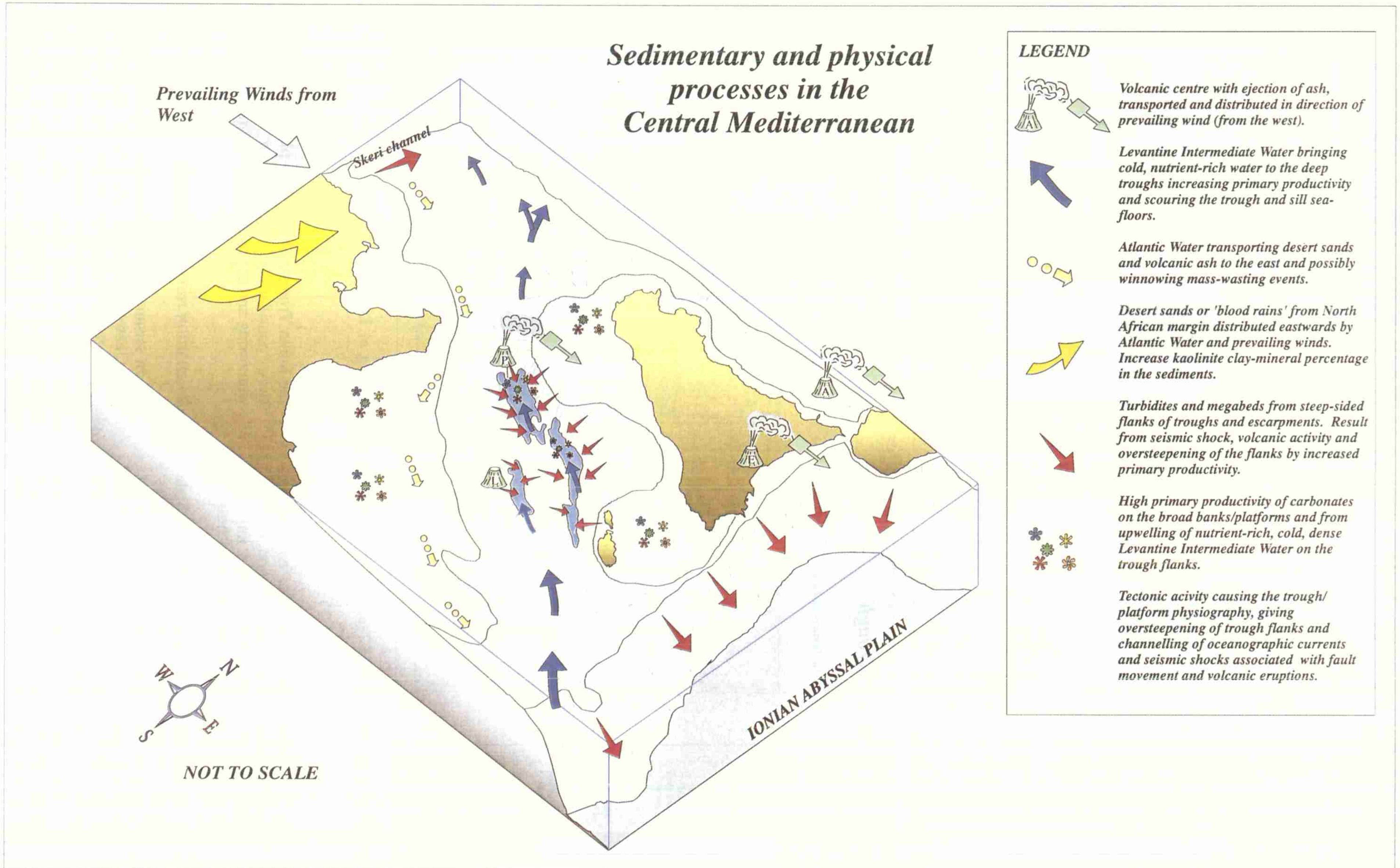


Fig. 14. Schematic representation of the sedimentary and physical processes operating in the Sicilian gateway, Central Mediterranean region.

SYNTHESIS OF SEDIMENTARY AND GEOLOGICAL PROCESS ACROSS THE SICILIAN-TUNISIAN PLATFORM DURING THE LATE QUATERNARY

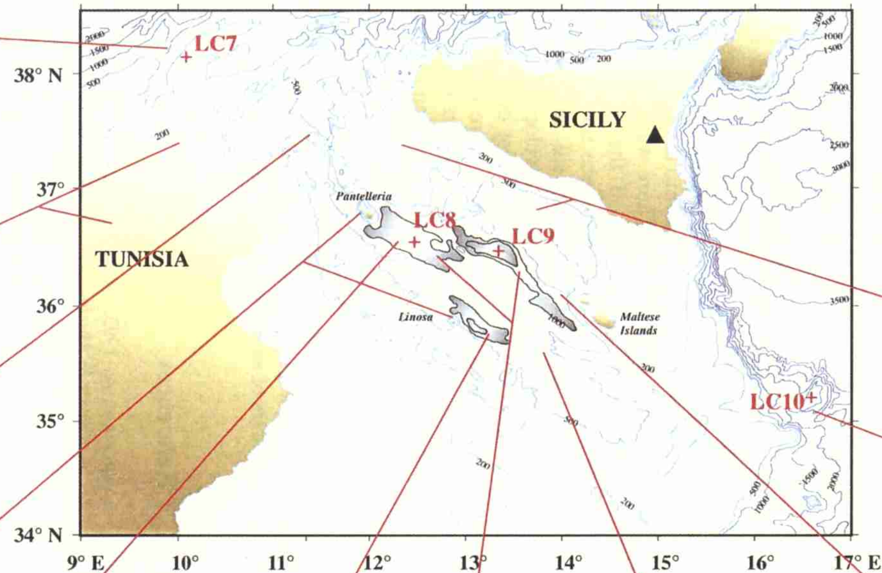
Sicily Sill and Narrows
The western margins of the Sicilian-Tunisian Platform are characterised by a gentle slope, dipping NW to the Sardinian Rise and Ballearic Abyssal Plain. Sedimenary processes are dominated by hemipelagic settling, current induced scouring and occassional gravity flows from the Tunisian margin. Interaction between downslope and alongslope processes may be interpreted in core LC7.

Eastward transportation
The prevailing winds from the east transport desert sands from the North African continent, together with eastwards flow of the Atlantic Water current across the platform (upto 30 cm/sec).

Sicily Strait
The narrowest part of the paltform, characterised by the scouring caused by deep westward flow of the dense, cooler Levantine Intermediate Water (5-10 cm/sec).

Volcanism
The volcanic islands of Pantelleria and Linosa create ash layers in the Central and Eastern Mediterranean and influence local basin sedimentology.

Pantelleria Trough Megabed
An Acoustically Transprent Layer on the 3.5 kHz seismic profiles denotes the presence of a large-scale gravity event. The sediment core LC8 shows the presence of a bi-partite megaturbidite, with a volume estimated in the oder of 30 km3. The 16.4 m thick unit (8.9 m thick debrite and 7.5 m thick turbidite) is related to volcanism on the nearby island and includes some redeposited material from the dated 45 kaBP 'green-tuff' pumiceous volcanics. The basal debrite contains pumice and carbonate clasts in a dark-grey mud that correlate with pumiceous tephra on Pantelleria dated at around 35 kaBP. The triggering of the Megabed is thought to relate to the subsequent phase of volcanism on Pantelleria, during the eruption of the Montagne Grande complex.



Complex tectonic framework
Collison of the Eurasian and African plates has uplifted this region, forming a broad, shallow platform. Rotation of the platform under the compressive regime has created the Messina microplate and a series of en-echelon, strike-slip, pull-apart troughs. The steep-sided flanks of the Pantelleria, Malta and Linosa troughs form the main sources for basin fill.

Water mass exchange
The exchange of the Atlantic and Levantine Intermediate Waters across the platform has a far reaching effect on the Mediterranean, particulalry with the transportation of sediments to the Western Mediterranean. Seismic profiles have shown that these sediments are plastered against the eastern slopes of Sardinia and Elba and northern Sicily.

Heightened sedimentation rates
The hemipelagic sediments of the Pantelleria and Malta Troughs have contrasting characteristics to those seen on the flanks. Alternation in sediment colours and an abundance of burrowing fauna are commonly present but the trough sediments contain small-scale, semi-pervasive scours and high-sedimentaton rates. These sediments are distinct from homogeneous mud turbidites seen in the cores and show accumulation rates in the order of 30 cm/ka. This high rate is suggested to be due to lofting of sediments transported by the Levantine Intermediate Water and from higher primary productivity rates caused by nutrients supplied in this cold, denser water mass.

Malta Trough
The deepest bathymetries across the platform are seen in the Matla Trough at over 1700 m. The sedimentary fill of this narrow trough is characterised by thin, basin-wide, carbonate-rich turbidites. The seismic profiles show multiple, sub-parallel reflectors, suggesting that most gravity flows from the steep carbonate flanks result in extensive transport of sediment.

Sicilian Margin
Sediments from the island of Sicily are entrapped in the Gela foredeep and the Adventure Bank and are prevented from reaching the trough complex. The bathymetry of this intermediate region is characterised by many sub-vertical fault-blocks, in which the continental sediments are ponded.

Western Sicily-Malta Sill
The eastern margin of the Sicilian-Tunisian Platform is delineated by the steep-faulted Sicily-Malta Escarpment. Gravity flows from this margin are noted on the Ionian Abyssal Plain, but core site LC10 shows a low amount of resedimentation. Its location on a small knoll on the flank of the escarpment has recorded the 'background' sedimentology for the past approximately 500,000 years. Characterised by hemipelagic settling, the accumulation rates of 2-5 cm/ka include dateable horizons such as volcanic tephra, micropalaeontological events and sapropels. The 6 Saproples record periods of water column stratification and are only seen in this core, suggesting that this bathymetry and location form the approximate eastern-most extent of Eastern Mediterranean anoxia.

Sicilian Margin
Mass-movements on the steep slopes of the troughs are noted on seismic sections and are interpreted as slumps and slides. Core evidence suggests that allochthonous sedimentation showing little disaggregation is present in core LC9, with the presence of a 1.9 m thick unit that contains small-scale, extensional faulting.

Fig. 15. General synthesis of the geological, sedimentary and physical processes operating in the Sicilian gateway, Central Mediterranean region.

et al. 2000), present a somewhat different picture through part of the Pleistocene and Holocene interval. The shallow platform cores show some of the highest rates (52 cm ka^{-1}) between about 17 and 25 ka, and then a truncation at the top of the core in some cases. However, part of this apparent hiatus may be due to sediment loss during the coring process. The intermediate depth zone also shows relatively high rates (16–40 cm ka^{-1}, average 25 cm ka^{-1}) across the main part of the platform, but much lower rates for the mainly hemipelagic sections in slope cores LC7 and LC10 (2–6 cm ka^{-1}). The deeper basin cores are quite variable, mostly averaging 20–25 cm ka^{-1}, but with values of 50, 64 and 128 cm ka^{-1} through intervals with many and thick turbidites. As mentioned above, the rates of background sedimentation calculated for cores LC8 and LC9 are > 16 cm ka^{-1} and 30 cm ka^{-1} respectively.

Discussion and conclusions

The different oceanic gateways around the world that currently serve both to compartmentalise and to connect various parts of the ocean basins and marginal seas, each present their own unique geological, oceanographic and sedimentary record (Stow & Morri 2000). Equally, however, they display many common attributes, chief amongst which appear to be their physiographic and geological complexity and the resulting variety of depositional processes and facies that occur.

The Sicilian Platform currently acts as a partial topographic barrier between the eastern and western Mediterranean basins, having taken on approximately its present form following the Messinian salinity crisis at the end of the Miocene. Most of the area is either shallow water (< 200 m) platform or of intermediate depth (200–600 m approximately). Both these physiographic provinces display highly irregular topography as a result of much neotectonic activity. They are cut through by a series of deep (> 1000 m), interconnected, fault-bound troughs that are linked with valleys incised into the shallow Malta and Sicily sills at either end of the platform.

We refer to this narrow passageway as the *Sicilian Gateway* (Figs 14 and 15) as it controls the exchange of water masses between the eastern and western basins. Levantine Sea Intermediate Water, formed by evaporation and sinking in the Levantine Sea, is channelled through the deep troughs, and is replaced by a surface flow of Modified Atlantic Water. Flow velocity of the bottom current is enhanced by the restricted topography, especially through the sill valleys, while interaction with local topographic barriers leads to flow disturbance and increased mixing with the overlying water mass. Upward mixing of the bottom nepheloid layer thereby occurs in a process known as *bottom current flow lofting* (Reeder *et al.* in press).

Sedimentation across the shallow platform is influenced by several different material sources and by a complex range of shallow-water processes that have resulted in a mosaic of coarse to fine-grained facies of biogenic, siliciclastic and volcaniclastic derivation. Strong bottom currents related to Modified Atlantic Water inflow, as well as to tides and waves, are responsible for the patchy distribution of relatively coarse-grained, mixed composition sands and gravels. Deposits of the intermediate depth zone are dominated by bioturbated hemipelagic muds. The slope sites to the east and west, respectively, of the Malta and Sicily sills show mainly slow (2–5 cm ka^{-1}) hemipelagic sedimentation, being influenced by bottom currents in the west and by basin stagnation and associated sapropel formation in the east. Airborne volcanic tephra as well as Saharan dust are dispersed towards the east by the prevailing winds.

Sedimentation in the Sicilian Gateway troughs and sill valleys is characterized by downslope gravity flows, resulting from frequent volcanic and seismic activity on their flanks that displace platform carbonates and/or volcanic debris, and by high rates of hemipelgic/contourite accumulation (16–30 cm ka^{-1}). These rates are augmented by the lofting process described above.

The interpretation of contourite deposition is more subtle and equivocal than for turbidites (Stow 1994; Stow *et al.* 1996). The principal lines of evidence for gateway contourites are recognized at three scales of study.

(1) At the large scale, oceanographic data clearly demonstrate bottom current flow from east to west through the Sicilian gateway. (2) At the medium scale, seismic data show mounded drift development in the narrow valley across the Sicily sill, as well as other areas with bottom current scoured gullies, mounds and bedforms. Contourite accumulation in the main gateway troughs is intercalated (as thin sheet or mixed drifts) with the downslope facies. (3) At the small scale, core analysis reveals extensive reworking of microfossil assemblages, minor scours, diffuse and lenticular lamination, and cyclic grain size profiles within the background bioturbated calcareous mud facies. To what extent these are hemipelagic versus contourite muds is uncertain. Bottom current winnowing of coarse bioclastic sands introduced by turbidity currents is also evident.

This complex sedimentation pattern has been influenced by the interaction of volcanic, seismic, topographic, sea-level and climatic controls (Fig. 15). During its Pleistocene history the Sicilian Gateway has periodically acted as a barrier to water exchange, principally during times of lowered sea-level. This has led to erosion and reworking of exposed platform regions and to increased downslope input into the deep basins, including some of the megabeds observed. There was also progressive starvation of oxygen from the bottom of the water column in the eastern Mediterranean basin and hence the accumulation of a series of sapropel layers. The Malta sill represents approximately the western cut-off point for the development of bottom water anoxia and sapropel deposition. The rest of the gateway remained sufficiently well ventilated, via a more open Sicily sill, to preclude stagnation but, presumably also, to restrict contourite accumulation to highstand system tracts when through-flow resumed.

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