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Deep-sea depositional systems of the Tyrrhenian basin
Sistemi deposizionali di mare profondo del bacino Tirrenico

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ABSTRACT - The multibeam and seismic data acquired during 1996 and 1999 by the Institute for Marine Geology of Bologna tied with the already available seismic lines have been interpreted for the understanding of the present-day depositional systems of the Tyrrhenian Sea. A variety of sedimentary processes and related depositional environments characterizes the different portions of the Tyrrhenian Sea. Major differences are evident between the intraslope basins stretching along the Latium-Campanian, Calabrian and Sicilian active margins and those of the Sardinian passive one. In addition, a high variability of active sedimentary processes emerges also for adjacent sectors of single intraslope basins.

KEY WORDS: sedimentary processes, intraslope basins, depositional system distribution, Tyrrhenian Sea

RIASSUNTO - I dati sismici e batimetrici di dettaglio acquisiti nel 1996 e 1999 dall'Istituto per la Geologia Marina di Bologna sono stati interpretati allo scopo di ricostruire la distribuzione e le caratteristiche dei sistemi deposizionali di mare profondo del Mar Tirreno. Una grande variabilità caratterizza i processi sedimentari e gli ambienti deposizionali del bacino. Differenze sostanziali sono state evidenziate tra i bacini di intrascarpata dei margini attivi Laziale-Campano, Calabro e Siciliano e quelli sviluppati lungo il margine passivo Sardo. Inoltre, una grande variabilità dei processi sedimentari attivi è stata rilevata anche in settori adiacenti dei singoli bacini di intrascarpata.

PAROLE CHIAVE: processi sedimentari, bacini di intrascarpata, distribuzione sistemi deposizionali, Mar Tirreno

1. - INTRODUCTION

The significant increase in the exploration of deep-water reservoirs has recently led to a renewed interest in the study of deep-sea depositional systems (WEIMER *et alii* 2000). Moreover, the growing development of seafloor communication networks, the need for a safe development of deep-sea oilfields and the strong exploitment of coastal areas has stimulated the studies of sedimentary processes capable of marine geohazards (STOCKER *et alii* 1998; LOCAT & MEINERT 2003). As a consequence, an intense worldwide seafloor and sub-seafloor mapping effort is underway that, also thanks to the always expanding resolution potential of the techniques of marine investigations, has led to the formulation of new concepts about the deep-sea sedimentary environment. In particular, the analysis of the deep-sea depositional systems is focused in recognizing, interpreting and delineating the process-oriented submarine geomorphic elements (GALLOWAY 1998) that are conveniently imaged by a detailed bathymetric coverage of the seafloor. Multibeam bathymetric mapping with the capacity of providing an unprecedented resolution of morphosedimentary features, is therefore one of the tools that has been recently extensively used in the study of present-day deep-sea depositional systems. In addition, the integration of seismic stratigraphy and seismic geomorphology in the interpretation of

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seismic lines, have led to new details about the processes that govern the evolution and the history of deep-sea depositional systems (POSAMENTIER 2003; POSAMENTIER & KOLLA 2003).

The last comprehensive researches regarding the Tyrrhenian deep-sea depositional environments date back to the 70's and 80's when, in the frame of the project "Oceanografia e Fondi Oceanici" launched by the Consiglio Nazionale delle Ricerche, seismic lines and seafloor samples were extensively collected over the basin. The acquired data led to the individuation of the single basins and of the main geomorphic elements that characterize the different portions of the Tyrrhenian Sea. In particular, the numerous intraslope basins that stretch along the Italian, Sicilian and Sardinian margins and the Marsili and Vavilov abyssal plains that centre the basin were evidenced. (WEZEL *et alii* 1981; NICOLICH 1986). Following studies have only dealt with specific research themes in particular sectors of the Tyrrhenian Sea.

The multibeam and seismic data acquired during 1996 and 1999 by the Institute for Marine Geology of Bologna tied with the already available seismic lines and seafloor samples offer therefore the possibility of advancing the understanding of the present-day depositional systems and of their temporal evolution in the Tyrrhenian Sea in the light of the new ideas about the deep-sea environment. A brief review of this issue is presented in this paper through the integrated interpretation of the recently acquired multibeam and seismic data in the different sectors of the basin (fig. 1, Plates 1,2).

2. - LATIUM-CAMPANIAN MARGIN

This margin is characterized by a complex slope sector that flanks to the east the 3500 m deep Vavilov abyssal plain and constantly widens southward from the area of the Pontine islands, where it is only 20 km large, to the area of the Palinuro volcanic complex, where it reaches a width of 150 km (fig. 2). To the

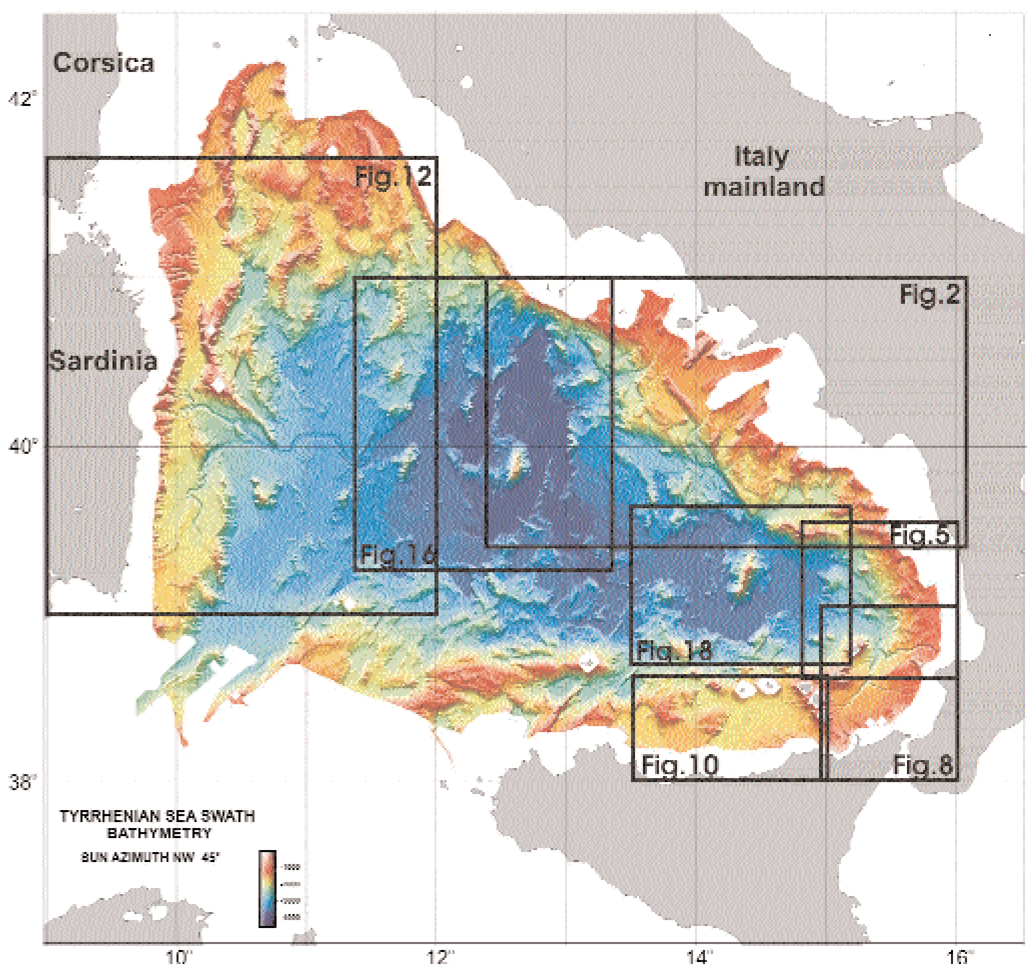

Fig. 1. – *Colour-shaded bathymetric map of the Tyrrhenian Sea from multibem data. Boxes correspond to the detailed maps of the distinct basin sectors presented in this paper. Colour depth intervals are shown in the left corner of figure.*

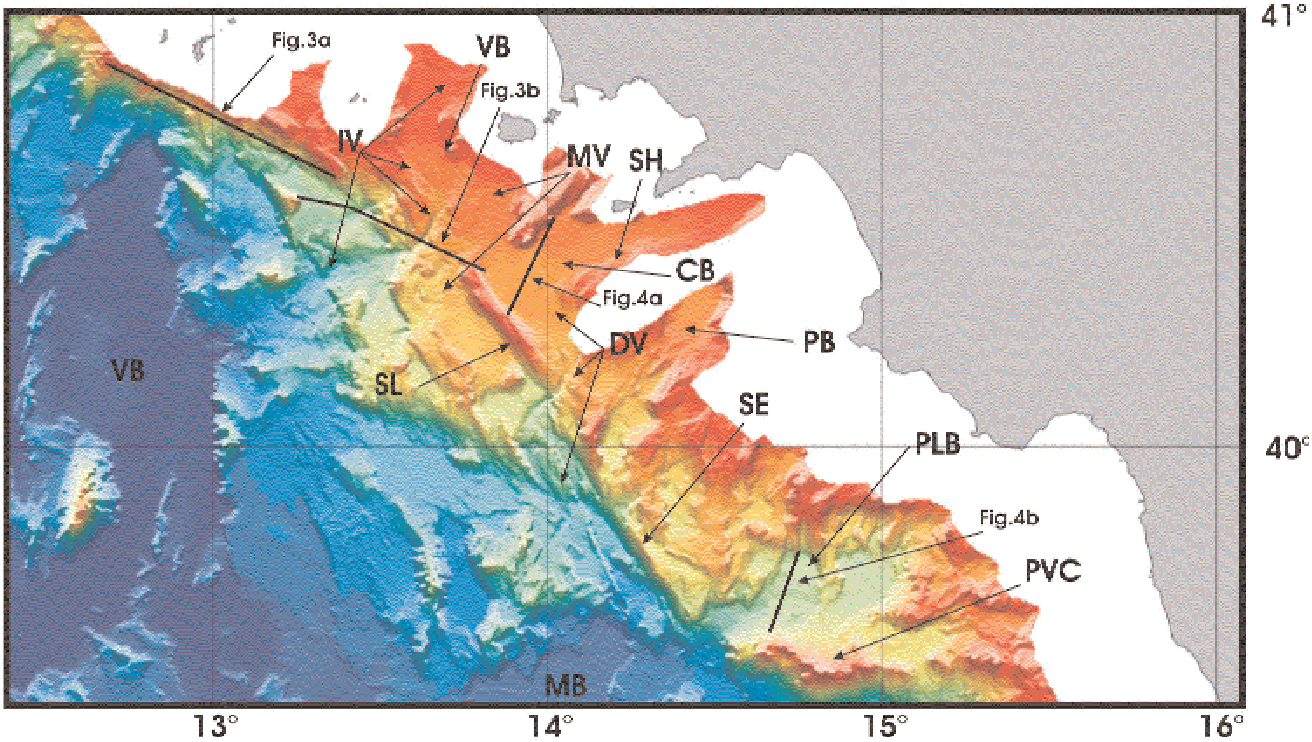

Fig. 2. - *Colour-shaded bathymetric map of the Latium-Campanian margin (IV = Ischia valley; VB= Ventotene intraslope basin; MV = Magnaghi valley; SL = Sirene lineament; SH = Sele high; CB = Capri intraslope basin; DV = Dhorn valley; PB = Paestum intraslope basin; SE = Sartori escarpment; PLB = Palinuro intraslope basin; PVC = Palinuro volcanic complex; VB = Vavilov basin; MB = Marsili basin).*

north, a single slope sector is responsible for the deepening of the margin from the platform surrounding the volcanic island of Ponza to the 3500 m deep Vavilov basin (fig. 2); here, due to the high slope gradient, canyons and associated slump scars dominate and originate a dendritic pattern of slope erosion (fig 3a) as also imaged with deep-towed sidescan sonar data by CHIOCCI *et alii* 2003.

An array of closely spaced extensional faults and fault-bounded basement highs, mainly oriented in a NNW-SSE direction, characterizes the area between Ponza Island and the Sele high and results in a down-to-the-west stepping margin morphology (fig. 2). The recent age of the tectonics that originated the basement highs has not allowed their mantling by slope sediments; as a consequence, the main loci of deposition are intraslope basins developed over the basement depressions. The intraslope basins are mainly narrow, NNW-SSE elongated troughs; apart from the Ventotene and the Capri basins, in fact, the close spacing of the fault-bounded highs does not allow the formation of large intraslope basins (fig. 2). Some portions of the intraslope basins are completely isolated from the upslope sectors; hemipelagite drapings and mounded bodies with a transparent seismic facies resulting from mass-wasting degradation of the adjacent highs, prevail (fig. 3b). Other portions of the intraslope basins are on the contrary characterized by complex submarine drainage networks that connect successive deeper intraslope basins. Some of the drainage networks originate in the upper slope portion and, crossing the entire slope, represent throughgoing sedimentary pathways that link the upper margin with the deep abyssal plain. The course, the morphology, and the depositional or erosional character of the different trunks of the submarine drainage networks are strongly influenced by the distribution of the intraslope highs. The range of the downslope variations in the character of a drainage network as a function of the margin morphology and of the changing slope gradient, in turn controlled by the tectonic structures, is illustrated by the Ischia valley (fig. 2). It starts as gullies in the upper slope north of Ischia Island and then evolves into small scale depositional channels running in a low-relief valley in the eastern portion of the Ventotene basin. It then turns parallel to and finally breaches the edge of the Sirene fault-block becoming a narrow, around 1 km wide, v-shaped deeply incised canyon. (fig. 3b). Downslope of the Sirene lineament, the Ischia valley is again very large attaining a width of 12 km (fig. 2); beside sediments fed from the upslope segment of the drainage network, it receives the sedimentary contribution from the undercutting of the margins of the valley itself, where frequent mass wasting scars are present. Finally the Ischia valley enters the eastern portion of the Vavilov basin where a small fan with a radius of around 5 km is developed. South of Ischia valley another system of gullies is present in the slope of the Ischia Island originating the Magnaghi valley that evolves to a depositional channel in the eastern portion of the Ventotene basin (fig. 3b) and joins the Ischia valley further downslope of the Sirene lineament (fig. 2).

The Dhorn canyon is another drainage system that crosses the entire slope and reaches the deep Tyrrhenian basin plain, in this case the Marsili basin (fig. 2). The bathymetric coverage, starting in the Capri intraslope basin does not image its upper reaches that consists of two single canyons that connect north of Capri Island (MILIA & TORRENTE 1999); in the Capri intraslope basin however, a very narrow and shallow depositional channel associated with a fan is evident (fig. 4a). The Dohrn canyon becomes again strongly erosive as it crosses the southern tip of the Sirene high. It is then structurally forced to run in the area east of the Sartori escarpment (CURZI *et alii* 2003)

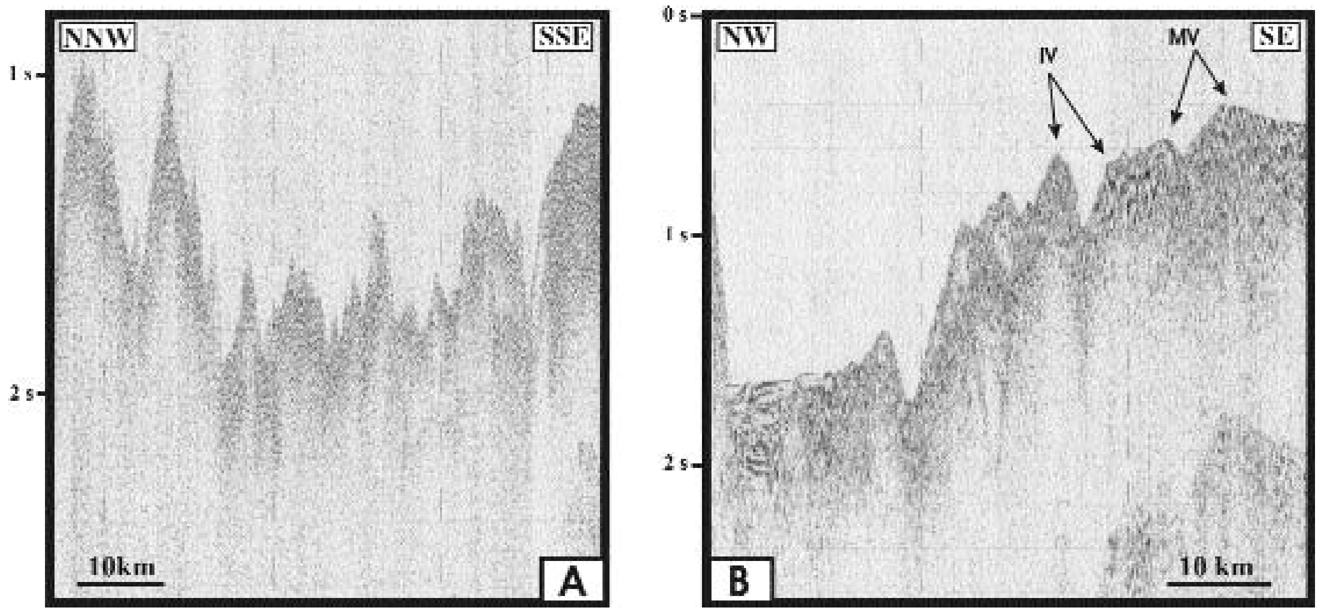

Fig.3. – *a) Seismic line T9964 crossing the Latial slope offshore Ponza island. The upper slope portion (left in figure) is characterized by narrow and deep canyons that evolve downslope into larger areas of seafloor erosion originating a dendritic pattern of slope erosion. b) Seismic line T9962 crossing the Ischia (IV) and Magnaghi (MV) sea valleys. Note the mainly erosional segment of the Ischia valley in the crossing of the Sirene lineament at variance with the depositional segment of the Magnaghi Sea valley in the eastern portion of the Ventotene basin. At the base of the Sirene lineament a further erosional fairway is evident. The filling of the intraslope basin at the foot of the Sirene lineament mainly consists of hemipelagites; however, thin transparent mounded bodies due to mass-wasting processes affecting the adjacent highs are evident.*

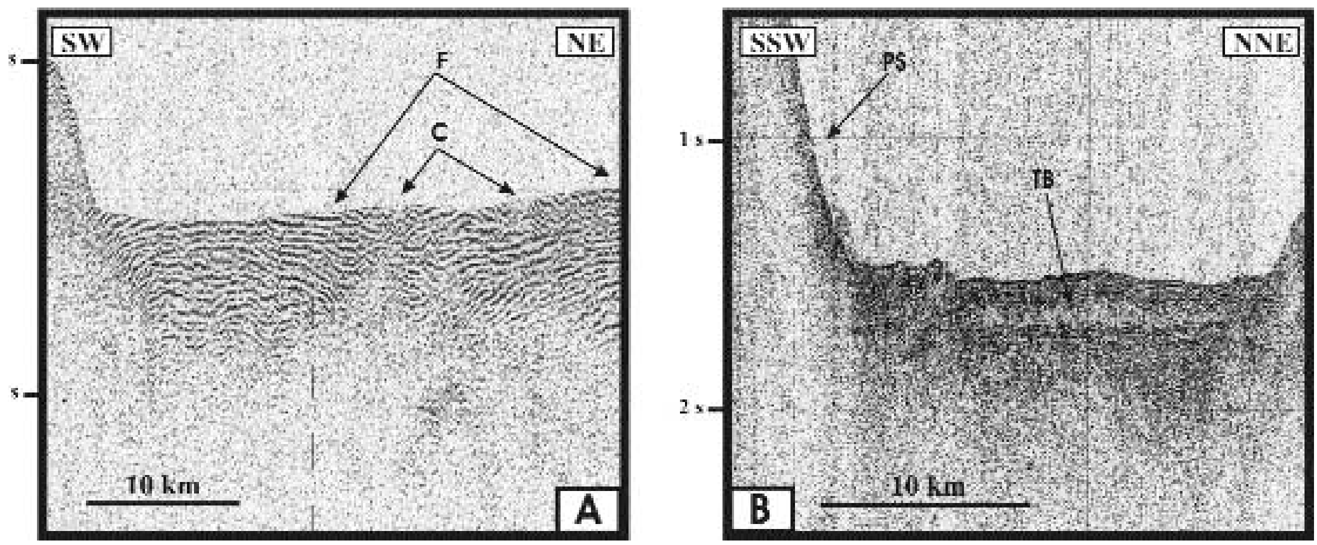

Fig. 4. – *a) Seismic line T96186 crossing the Capri intraslope basin. A fan (F) characterized by highly discontinuos reflections and mounded geometry makes up the recentmost basin infill; very low-relief channels (C) represent the fan-feeding elements. b) Seismic line T9681 over the western portion of the Palinuro basin. A transparent body (TB) with a thickness of around 100 m is imaged in the basin infill at the base of the Palinuro volcanic complex (PS) (see text for further details).*

where it branches into a series of canyons running in a SSE direction within a graben; the structural control results in its distal course being parallel to the margin for a length of 70 km entering the Marsili basin 150 km south of its initiation in the Naples Gulf (fig. 2).

South of the Sele high, both NNW-SSE and NE-SW trending extensional faults result in a complex margin morphology and in mainly completely confined small intraslope basins; the Paestum and the Palinuro basins are the only intraslope basins that have a considerable areal extent (fig. 2). Predominantly erosional processes in the form of dendritic submarine drainage systems are evident in the slope surrounding the Paestum and the Palinuro basins. Mass-wasting deposits over the western portion of the Palinuro basin (fig. 4b) can be the result of instability of the surrounding slopes or alternatively they could be a record of the evolution of the nearby Palinuro volcanic complex.

3. - NORTHERN CALABRIAN MARGIN

South of the Palinuro volcanic complex and north of the submarine extension of Capo Vaticano, the Calabrian margin consists of the upper slope, the

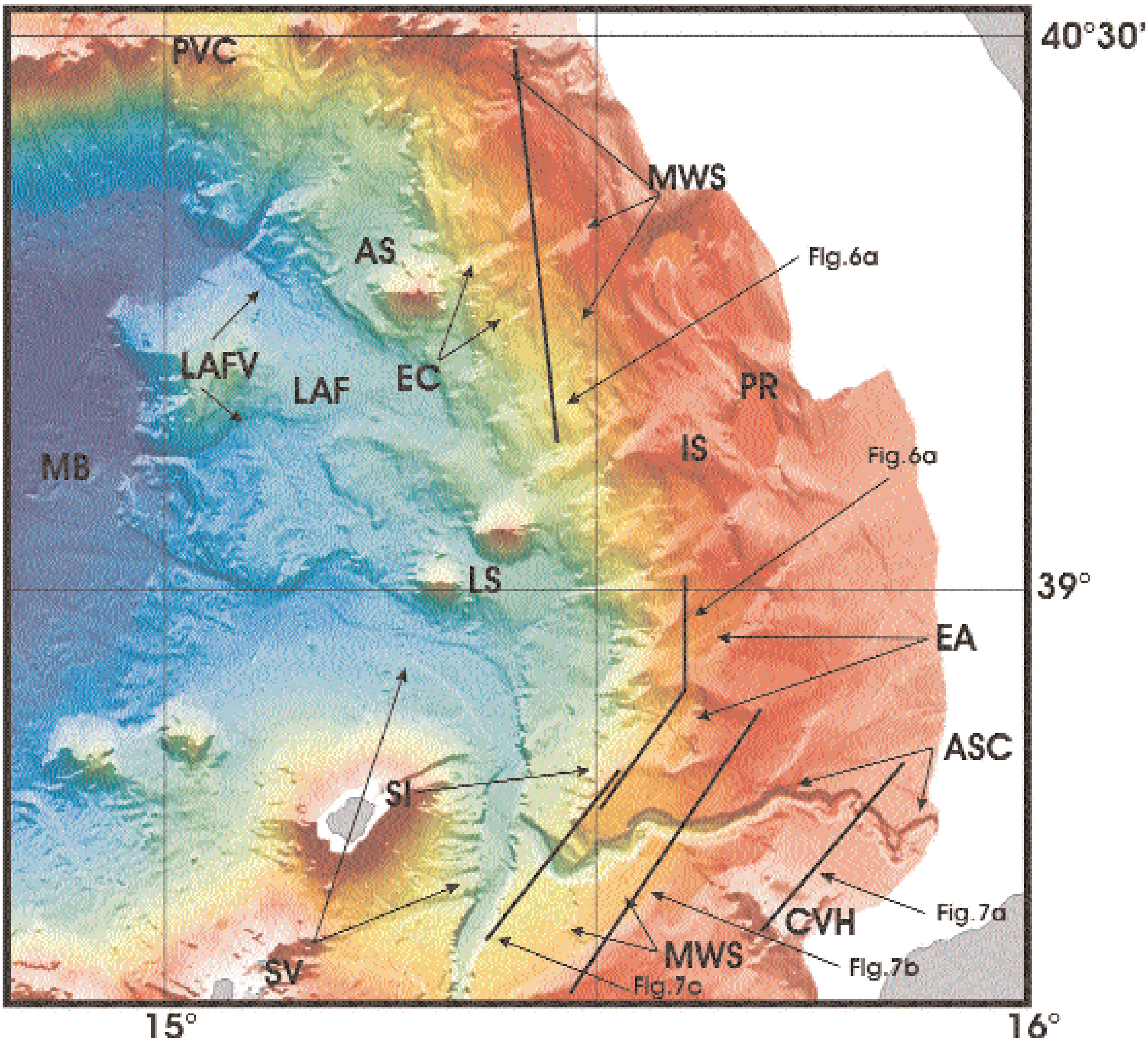

Fig. 5. – *Colour-shaded map of the Calabrian margin (PVC = Palinuro volcanic complex; MWS = mass-wasting scars; AS = Alcione Seamount; EC = embryonic canyons; LAF = Lametini-Alcione flat; LAFV = Lametini-Alcione flat valleys; LS = Lametini seamounts; IS = Intermediate slope; PR = Paola ridge; EA = erosional areas; SI = linear scarp with seafloor instability; ASC = Angitola slope channel; CVH = submarine extension of Capo vaticano high; SV = Stromboli valley; MB = Marsili basin).*

Paola intraslope basin, an intermediate slope, the Lametini flat and a further slope that marks the boundary with the Marsili basin (fig. 5). The upper slope and the Paola basin whose axis lies at a depth of around 700 m (GALLIGNANI 1982) were not investigated during the two cruises of data acquisition. Since an elevated ridge, topping at around 600 m, bounds the Paola basin seaward (ARGNANI & TRINCARDI 1993), the intermediate slope is not directly connected to the emerged areas; only in the southern portion of this margin sector, north of Capo Vaticano high, in fact, does the Angitola drainage network originate in the upper slope (GALLIGNANI 1982), and runs in the intermediate slope before connecting with the Stromboli canyon (fig. 5).

The intermediate slope spans the margin with a width of around 40 km down to depth of around 2000 m (fig. 5). In the seismic lines, the structural grain of this slope sector is evident as basement culminations and depressions (fig. 6a); however, a mantling of slope deposits has almost obliterated the resulting topography as evidenced by the very subdued morphologic expression in the bathymetric map (fig. 5). North of the Lametini seamounts, the main characteristics of the intermediate slope are mass-wasting scars and associated packages of downslope translated deformed sediments that straddle almost the whole slope (figs. 5, 6a); in addition, in the lower sector, flat-bottomed upslope narrowing elongated areas of focussed erosion occur on the surface of the displaced sediments that could represent embryonic canyons (fig. 5).

To the south of the Lametini seamounts, seafloor instability is concentrated along a linear, NNE to N trending scarp that coincides with a step in the basement and represents the western limit of the intermediate slope (fig. 5). From the linear scarp, however, seafloor instability propagates upslope. The linear mass-wasting dominated escarpment is in fact connected upslope to a large amphitheatre shaped erosional area with a width of around 15 km and with bounding scarps as high as 100 m and to a 2 km wide 20 km long erosional area that spans the whole intermediate slope, indenting the ridge that bounds the Paola basin seaward (figs. 5; 6b).

Although known as a canyon in the literature, the Angitola submarine conduit presents some segments that have a morphology more akin to slope channels (fig. 5). The upper segment of the Angitola slope channel presents in fact a meandering planform and a negative relief of around 100 m; oxbows and lateral accretion packages are the evidence of the swinging and sweeping of the channel within a larger channel-belt (fig. 7a). Downslope from the high that bounds seaward the Paola basin and of the submarine extension of the Capo Vaticano high, the Angitola slope channel has a straighter planform, is more incised reaching a negative relief of around 200 m, and is characterized by the development of inner terraces (figs. 7b, c). Along the whole course of the Angitola slope channel, outer levees are in general very narrow and have low relief over the adjacent slope areas (fig 7b). Mass-wasting scars and slump deposits are present in the flanks of the channel and the surrounding slope sediments, particularly in the lower reach of the channel (figs. 5, 7c). In the Lametini-Alcione flat, two low relief valleys, around 15 km large, bottomed by several smaller scale channels are present; they are likely originated by sediment gravity flows that originate owing to the widespread instability processes that characterize the intermediate slope (fig. 5). The lower reach of the Stromboli valley runs in the southern part of this sector of the Calabrian margin (fig. 5); however, since it originates in the Gioia Basin it will be described in the following section.

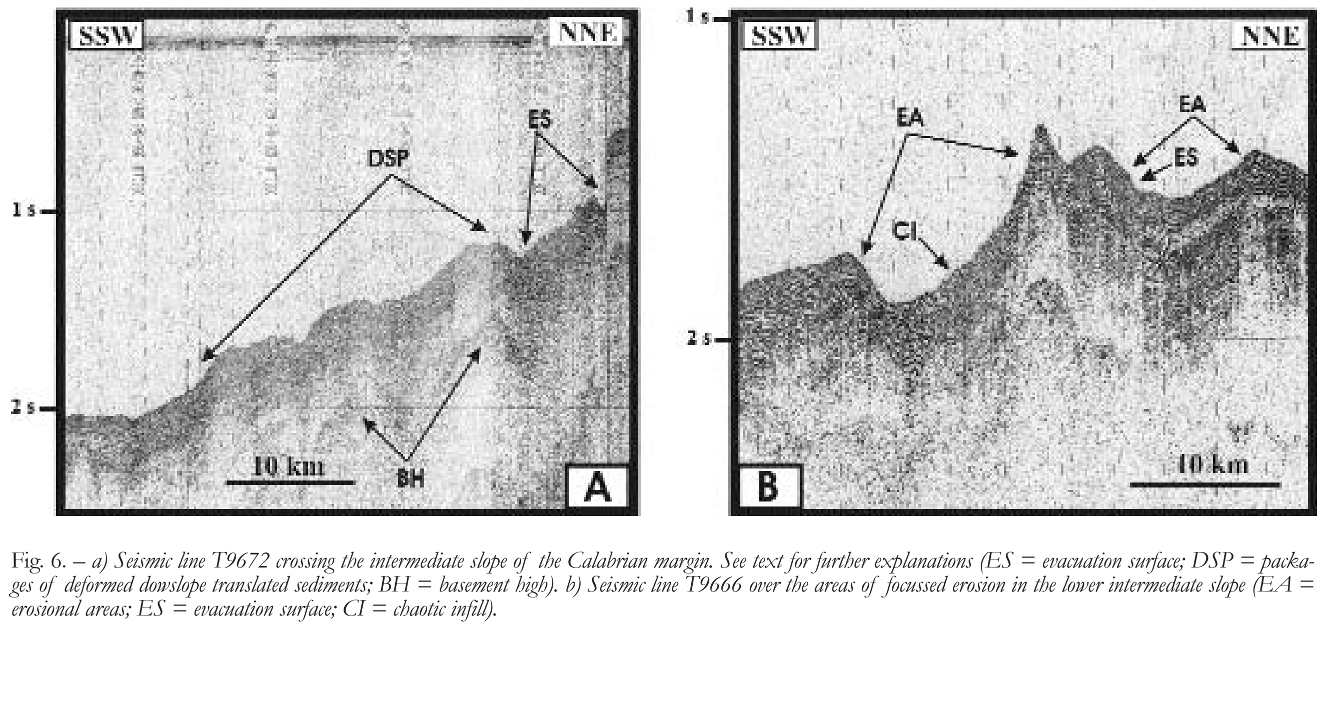

Fig. 6. – *a) Seismic line T9672 crossing the intermediate slope of the Calabrian margin. See text for further explanations (ES = evacuation surface; DSP = packages of deformed dowslope translated sediments; BH = basement high). b) Seismic line T9666 over the areas of focussed erosion in the lower intermediate slope (EA = erosional areas; ES = evacuation surface; CI = chaotic infill).*

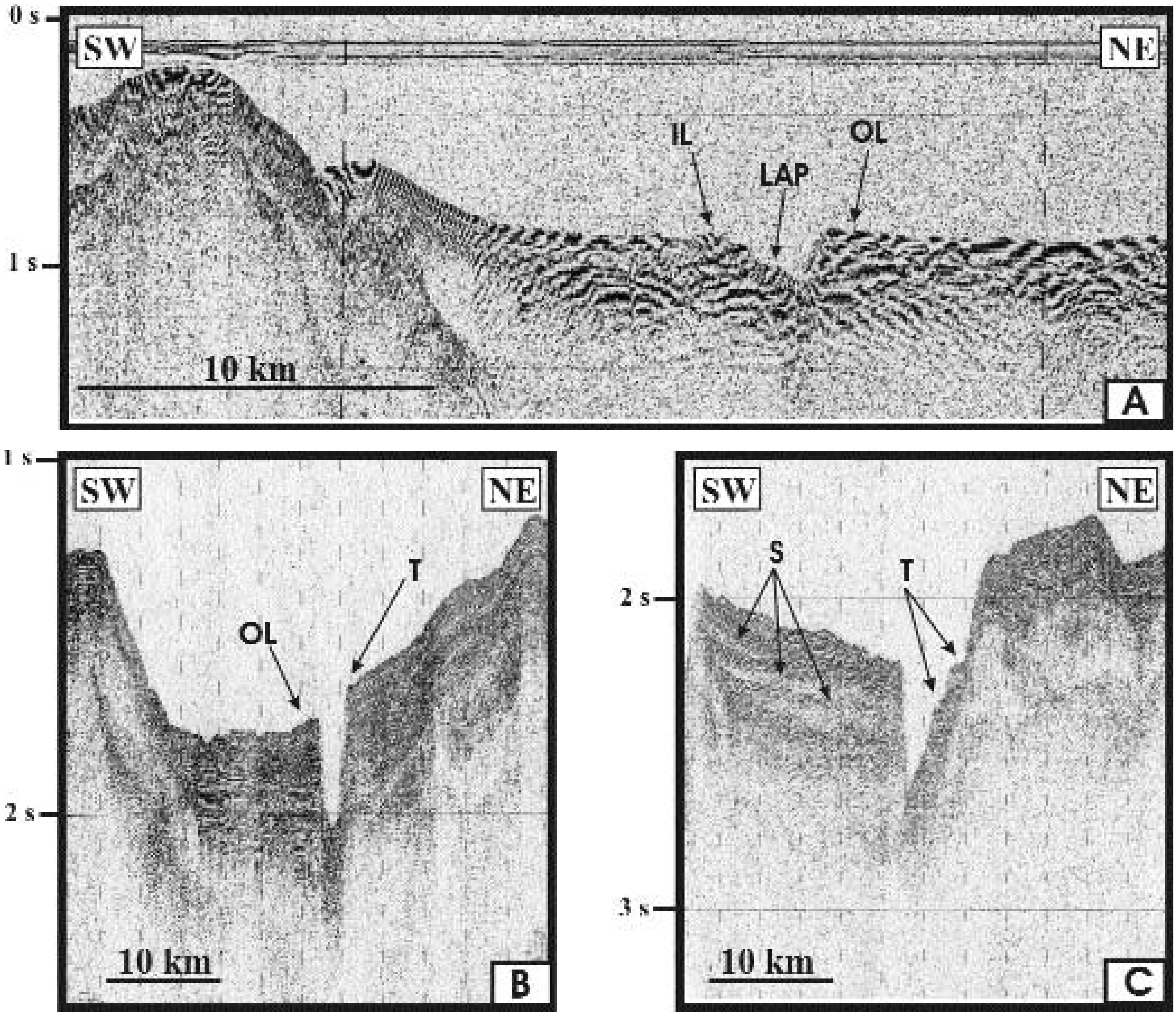

Fig. 7. – *Seismic lines showing the downslope variations in the Angitola slope channel.* ***a)*** *Upper, meandering segment of the Angitola slope channel (line T99221). The asymmetry of the channel is due to outer bend erosion and deposition of lateral accretion packages (LAP) on the inner bend (OL = outer levee; IL = inner levee).* ***b)*** *Intermediate segment of the Angitola slope channel (line T9664). Note the very low-relief and small areal extent of the outer levee (OL) on the southern side of the channel (T = terrace).* ***(c)*** *Lower reach of the Angitola slope channel (line T9666) showing inner terraces developed in the left side of the channel. Transparent packages (S) in the surrounding slope are slump bodies due to instability likely fostered by the canyon dynamics.*

4. - GIOIA BASIN

Gioia Basin is a SW-NE trending trough enclosed between Sicily and Calabria to the SE and the Aeolian Island arc to the NW (fig. 8). It has a length of about 80 km and a width that increases from 40 to 80 km northeastward; the basin axis that is the site of the Stromboli canyon deepens northeastward from to 1000 to 1500 m (fig. 8). Gioia Basin was formed as a result of the extensional tectonics that affected the circum-Tyrrhenian regions from late Miocene (FABBRI *et alii* 1980) Different slope and base-of-slope depositional systems, each characterized by specific sedimentary environments and processes, co-exist along the Gioia basin margin (figs. 8, 9a) (GAMBERI & MARANI 1998). The Milazzo and the Niceto canyons are developed in the southwestern slope sector; in particular, the Milazzo canyon is an up to 400 m deep erosional feature. The canyons pass downslope to leveed-channels with an average width of around 2 km and levees that elevate up to 100 m from the channel floor and display at times sediment waves (fig. 9a). The leveed-channels coalesce into a prograding channel-levee system that spans the Sicilian margin for a total width of 20 km (figs. 8, 9a). To the northeast of the channel-levee system, a destructional slope is present; the recent Villafranca mass-transport complex, with an average width of 10 km and a length of around 25

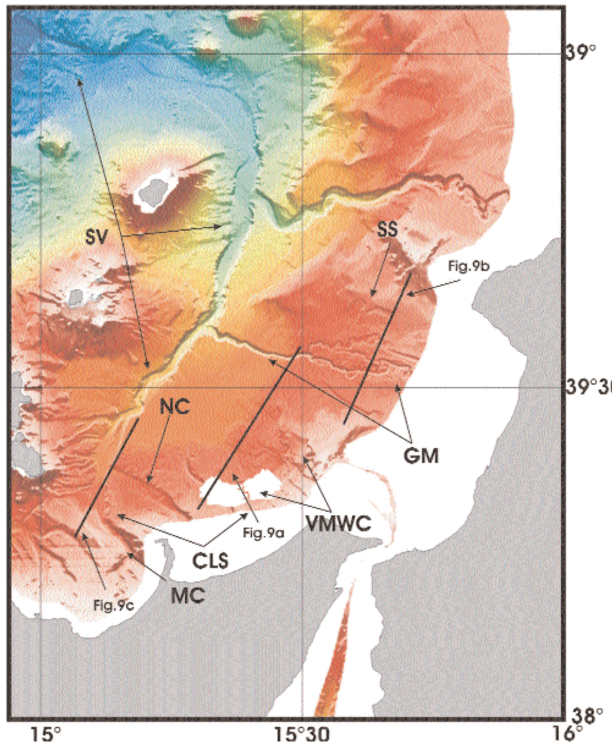

Fig. 8. – *Colour-shaded map of the Gioia basin (MC = Milazzo canyon-channel; NC = Niceto canyon-channel; CLS = Channel-levee system; VMWC = Villafranca mass-wasting complex; GM = Gioia-Mesima slope channel; SS = slump scars; SV = Stromboli valley).*

km occupies in fact the whole slope and basin plain down to the Stromboli valley. Mass-wasting is widespread also in other sectors of the basin and in deeper stratigraphic levels as evidenced by transparent and chaotic mounded bodies at different heights in the Gioia basin infill (fig. 9a). The Gioia-Mesima slope channel occupies the northern portion of the Gioia basin (fig. 8). It starts in the Gioia Tauro coastal area (COLANTONI *et alii* 1992) and has been imaged in the bathymetric data from a depth of around 600 m. In the upper part it comprises various channels with both meandering and straight planforms and with a negative relief of around 20 m running within a wide channel-belt (figs. 8, 9b); some of the straight channel segments are flanked by abandoned meander loops that are likely the evidence of a temporal progression from meandering to straight channels (fig. 8). The various channels join at a depth of around 1000 into a single trunk that deepens downslope to reach a negative relief of around 200 m in its distal part close to the junction with the Stromboli valley (figs. 8, 9a). The channel is v-shaped and a narrow levee is developed in its right side (fig. 8).

In the southwestern portion of the Gioia basin, the Milazzo, the Niceto channels and numerous chutes and valleys that run in the Vulcano volcaniclastic apron (GAMBERI 1998) join to originate the Stromboli axial sea valley. This valley runs in the central portion of the Gioia basin and after a turn to E-W strike, north of Stromboli Island, reaches the Marsili back-arc basin. Along its course it receives numerous tributaries from the Sicilian and Calabrian margin and from the Aeolian volcanic slope (fig. 8). The proximal segment of the Stromboli valley is flat-bottomed with a maximum width of around 6 km and is flanked on its right side by a depositional levee (fig. 9c). A first morphologic change occurs where the valley crosses a basement step located at the base of the Panarea volcanic edifice; here the valley is 400 m deep and only 2,5 km wide and slump scars, terraces and gullies characterize its flank. At a depth of around 1900 the Stromboli valley resumes a flat-bottomed morphology and a wider cross-sectional area and is characterized by a meandering thalweg running in the valley floor; in this area the valley has an aggradational character as evidenced by a thick chaotic infill above the erosional margin of the valley and by the seafloor sedimentary features (GAMBERI & MARANI 2003). After the turn north of Stromboli Island the valley maintains a large width (up to 10 km) is characterized by braiding thalwegs and retains a mainly aggradational character down to its debouching into the Marsili basin.

5. - CEFALU BASIN

The Cefalu basin, with a length of around 150 km, is located along the northern Sicilian margin (fig. 10). The basin was originated through various phases of extensional tectonics of mainly Pliocene age. Tectonic structures were oriented with NE-SW and NW-SE and E-W direction (FABBRI *et alii* 1981; PEPE *et alii* 2000). The interaction of the various trends of the tectonic structures resulted in the Finale intrabasinal high that separates the Cefalu basin into the Orlando Basin to the east and the Palermo basin to the west (WEZEL *et alii* 1981).

The Orlando basin is around 50 km in width and 80 km in length and is completely confined to the north by the ridge of the Aeolian volcanic arc; the basin plain is flat and lies at a depth of around 1500 m (fig. 10). The Orlando basin was investigated by multibeam swath bathymetry up to depth of around 500 m and as a consequence the bathymetric data cover the slope, the base-of-slope and the basin plain (fig. 10). In the eastern sector, that is directly connected with the emerged areas, a system of canyons that evolves downslope into a channel-levee system is evident. The channels have a NW-trending course and are as much as 6 km wide; they are mainly flat-bottomed and are flanked by levees that elevate up to 100 m from the adjacent channel floor (fig. 11a). Seismic lines evidence that the channels migrate toward the west in time and that as a whole the channel-levee system is prograding with a NW trend over the basin-plain deposits (fig. 11b). This evolution appears to reflect the location of the main sediment entry points in the Milazzo and the Aeolian arc areas.

The western portion of the Orlando basin is on the contrary flanked to the south by the Palermo basin and as a consequence it is not directly connected to

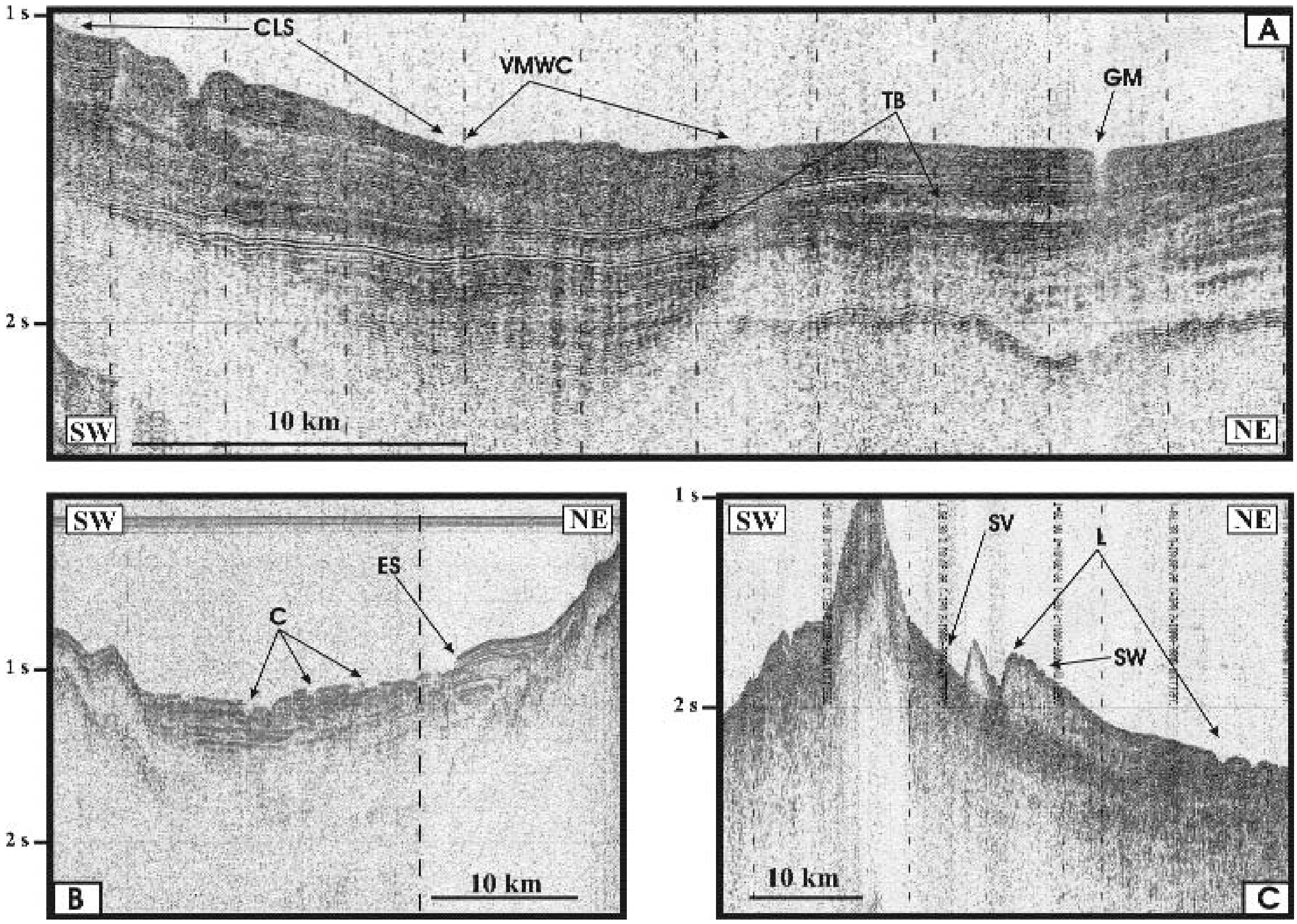

Fig. 9. – *a) Seismic line T9662 crossing the different sectors of the Gioia basin. The channel-levee system (CLS) is visible in the southern side of the line and is flanked in the centre by the Villafranca mass-wasting complex (VMWC), a thick package of transparent and chaotic reflections. Laterally, smaller scale slump bodies (TB) are present within the Gioia basin infill. In the northern portion, the distal segment of the Gioia- Mesima submarine conduit (GM) is evident. b) Seismic line over the upper segment of the Gioia-Mesima slope channel (C = channel; ES = evacuation surface). c) Seismic line T9966 running along the Stromboli Valley (SV), showing the coarse-grained high reflective infill of its upper trunk and its right levee with sediment waves (SW) displaying downslope decreasing height. The levee deposits (L) present a thickness that diminishes downslope to completely disappear where the canyon is a mainly erosional feature.*

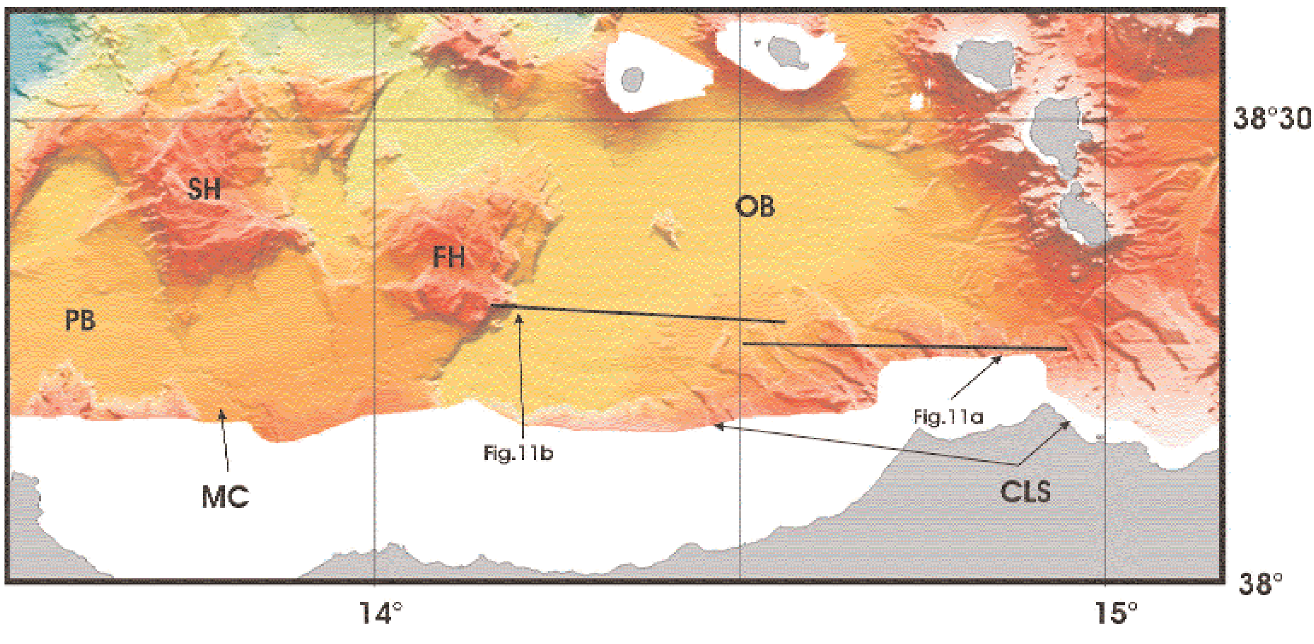

Fig. 10. – *Colour-shaded map of the Cefalù basin (OB = Orlando basin; PB = Palermo basin; FH = Finale high; SH = Solunto high; CLS = channel-levee system; MC = meandering channel).*

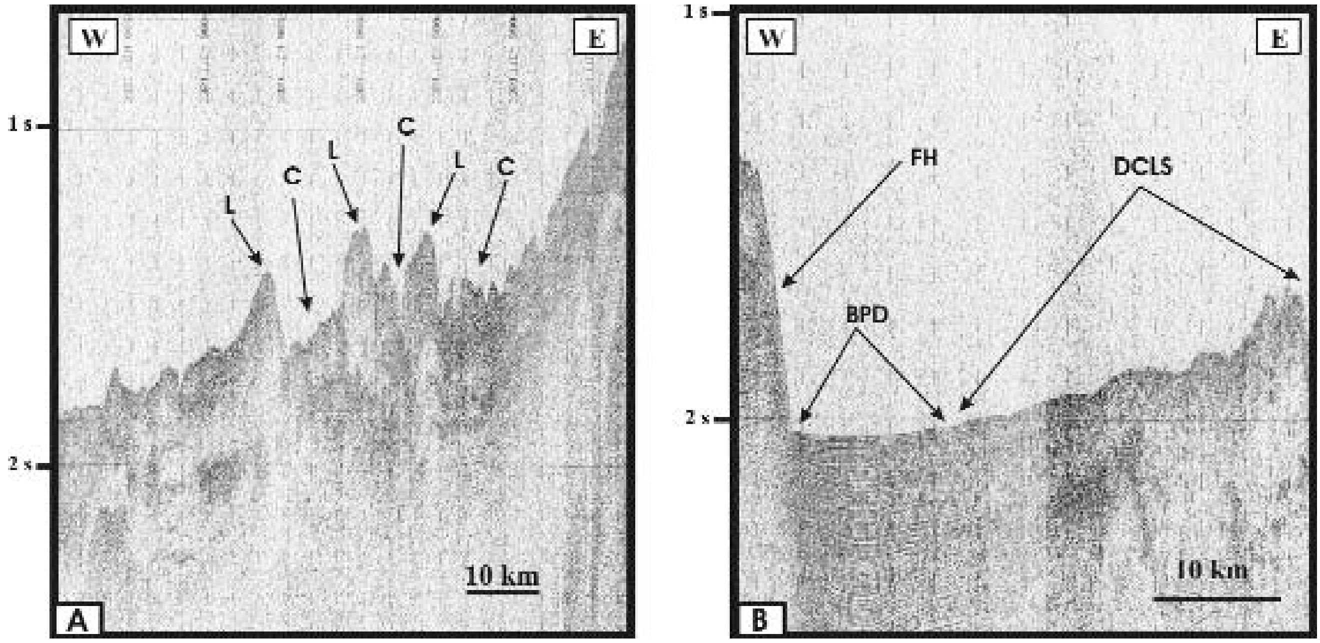

Fig. 11. - *Seismic lines over the Cefalu' Basin. a) Proximal part of the channel-levee system in the Orlando basin. See text for further details (C = channel; L = levee). b) Distal part of the channel levee-system (DCLS) and transition to basin plain deposits (BPD) with continuous parallel reflections indicative of distal sheet turbidites onlapping the Finale high (FH).*

emerged areas. Due to reduced sediment input destructional processes characterize the slope that in the seismic lines is onlapped by the basin-plain deposits. Sediments are fed to the Orlando basin also from the slope of the Alicudi and Filicudi volcanoes; a volcaniclastic apron consisting of thick packages with chaotic seismic facies mantles in fact the submarine portions of the edifices and interfingers with the distal basin plain sediments.

The Palermo basin is directly connected to the emerged areas only to the east and west; in its central portion in fact the Termini basin is interposed between the Sicilian platform and the Palermo basin (PEPE *et alii* 2003). The resultant basin morphology consists therefore of a narrow 20 km wide trough elongated in WNW-ESE. Few data have been acquired over the slopes that surround the Palermo basin; the main interesting feature that emerges from the combination of multibeam bathymetric data and seismic lines is a basin axis fan fed by a shallow meandering channel (fig. 10).

6. - SARDINIAN MARGIN

The Sardinian margin is characterized by the upper slope, various intraslope basins elongated parallel to the margin with a depth variable between 1500 and 1700 m and the Cornaglia Terrace that lies at a depth comprised between 2500 m and 3000 m. A basement step at a depth of around 3000 m separates the Cornaglia Terrace from the western portion of the Vavilov basin. To the north, the Etruschi and the Baronie ridges bound seaward the Olbia and the Baronie basins; further elevated basement blocks and intervening confined basins, the largest of which are the Tavolara and the Vercelli ones, are developed between the Etruschi and the Baronie highs and the Cornaglia Terrace (fig. 12). To the south, on the contrary, a single elevated ridge that spans northward from the Quirra seamount marks the deepening from the Ogliastra and Sarrabus-Ichnusa intraslope basins to the Cornaglia Terrace (fig. 12). The Sardinian margin was formed during extensional tectonics of mainly post-Messinian age (SARTORI *et alii* 2001). The tectonic structures are mainly oriented in N-S to NNE-SSW and E-W directions (SARTORI *et alii* 2001). The present-day morphologic differences between the southern and northern sectors reflect the progressive eastward rift migration in the northern area at variance with a stable rifting locus in the southern area (SARTORI *et alii* 2001).

The Olbia basin is the northernmost intraslope basin; being flanked by a 20 km large platform and by a very large slope with a width of around 50 km it lies at a distance of around 70 km from the coastline (fig. 12). The Olbia basin has a length of around 70 km and a maximum width of around 30 km. The slope is incised by single canyons and by canyon systems consisting of various upper slope trunks that connect downslope into single canyons (fig. 12). The Caprera is the largest canyon system and consists of two tributaries in the upper slope that join in a single, 2.5 km wide canyon, at a depth of around 1000 m (figs. 12, 13a). An abandoned canyon is still morphologically expressed in the bathymetry presenting a passive infill consisting of plane parallel reflections (fig. 13a). It has a deeper level of incision than the presently active canyons (fig. 13a).

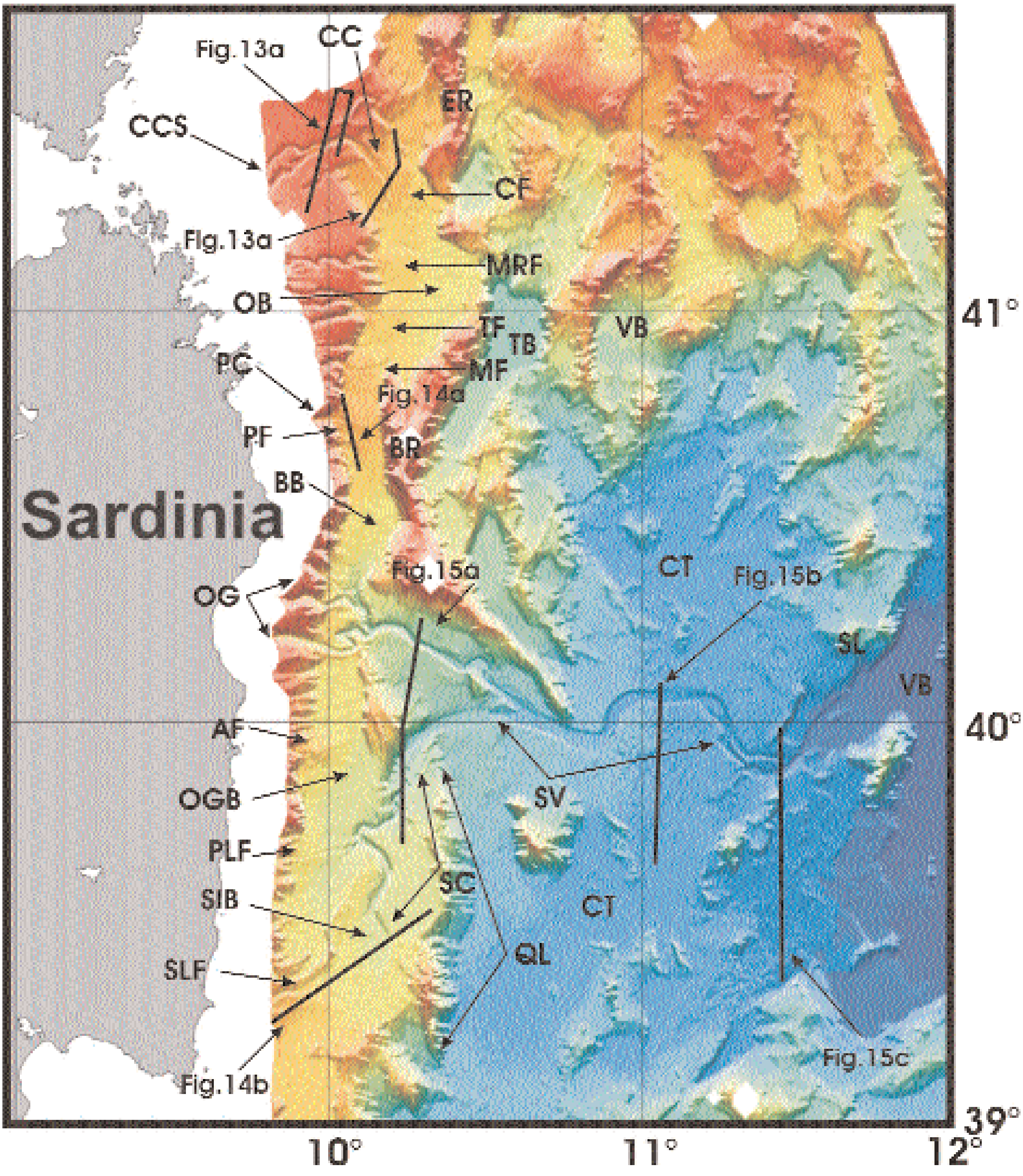

Fig. 12 . – *Colour-shaded map of the Sardinian margin (CC = Caprera channel; CCS = Caprera canyon system; ER = Etruschi ridge; CF = Caprera fan; MRF = Mortorio fan; OB = Olbia basin; TF = Tavolara fan; TB = Tavolara basin; MF = Molara fan; VB = Vercelli basin; PC = Posada canyon; PF = Posada fan; BR = Baronie ridge; BB = Baronie intraslope basin; OG = Orosei-Gonone canyon system; AF = Arbatax fan; OGB = Ogliastra intraslope basin; PLF = Pelau fan; SIB = Sarrabus-Ichnusa intraslope basin; SLF = San Lorenzo fan; SC = Sarrabus canyon; QL = Quirra lineament; CT = Cornaglia terrace; SV = Sardinia valley; SL = Selli line; VB = Vavilov basin).*

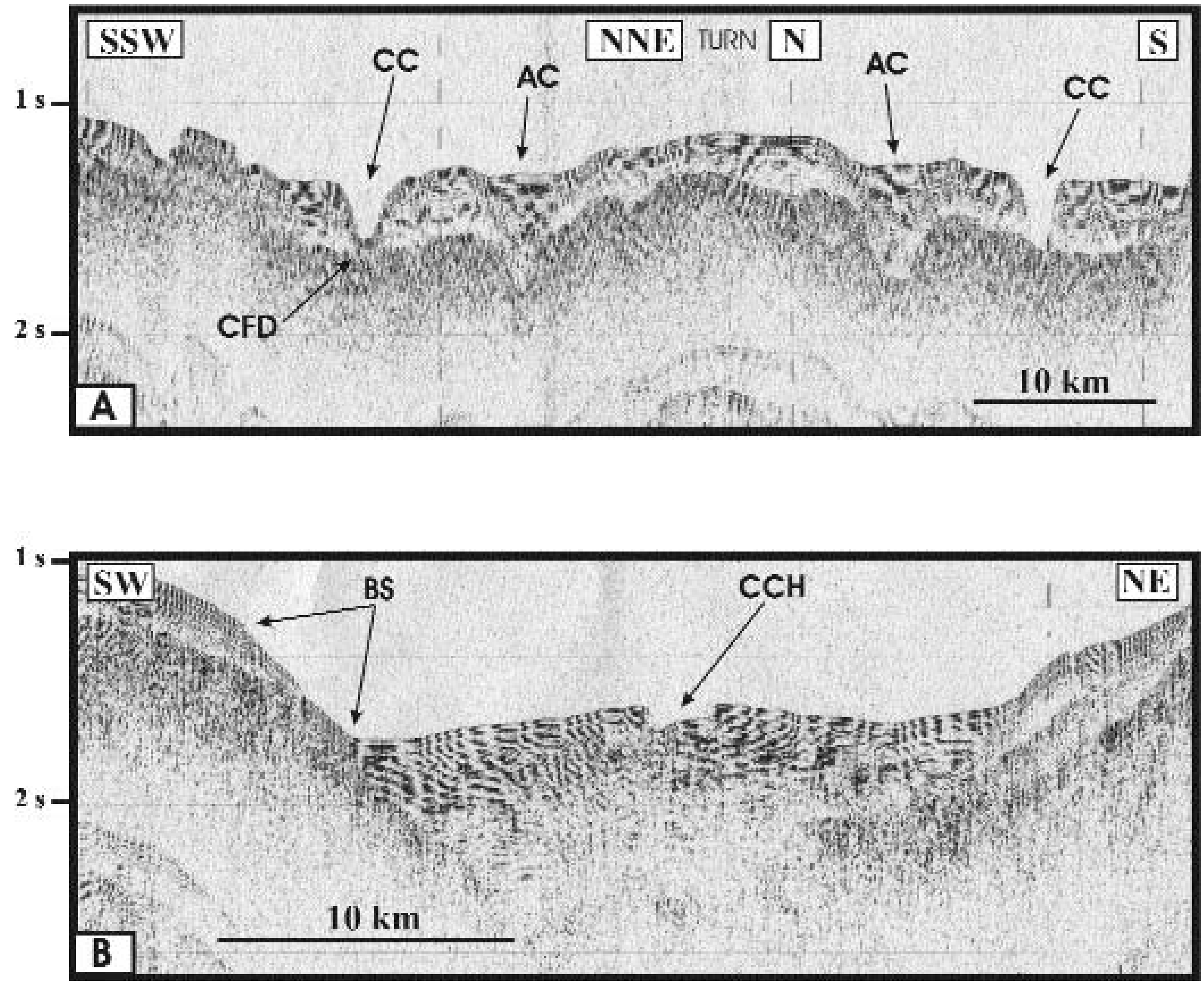

Fig. 13. – *a) Two crossings (lines T99101 and T99102) of the Olbia Basin slope and of the Caprera canyon system. The lines cross the single trunk segment of the Capreera canyon (CC); downslope variations in the sediment-gravity flows result in the presence of a thin high amplitude reflection in the canyon floor (CFD) that is not present in the downslope following line. Note an abandoned canyon (AC) that incises the slope to a deeper level than the present-day one. b) Line T99105 crossing the northern portion of the Olbia Basin site of the Caprera leveed-channel (CCH). A small inner thalweg is present in the southern side of the channel. Note that the lower slope of the Olbia basin (BS) is mainly affected by sediment bypass.*

At the base-of-slope the Caprera canyon evolves into a leveed channel with a width of 2 km with levees that elevate up to 100 m above the channel floor (fig. 13b). Further downslope, in the axis of the basin, the Caprera channel gives way to small relief channels that run on the surface of the Caprera fan spanning much of the northern portion of the Olbia basin (fig. 12). The fan surface is characterized by bifurcating channels that become shallower downslope. In the southern basin portion, smaller scale canyon-mouth fans with a radius in the order of 5 km face the Mortorio, Tavolara and Molara canyons (fig. 12). The Baronie basin is a narrow, 10 km wide and around 60 km long, trough that deepens southward from 1300 m to 1800 m, bounded seaward by the Baronie ridge that tops at around 80 m below sealevel (fig. 12). The northern slope portion of the basin is incised by the up to 400 m deep Posada canyon, while the Orosei-Gonone canyon system represents the southern margin of the basin. The slope between the Posada and the Orosei-Gonone canyon system presents the unique tract in the Sardinain margin of being completely devoid of canyons (fig. 12). At the base-of-slope the Posada canyon evolves into a leveed channel and further downslope into a branching channel pattern running on the surface of a fan with an along basin length of around 10 km, spanning the whole basin transversally (fig. 14a). Channels with a negative relief in the order of 20 m continue beyond the extent of the fan and run in the axial part of the basin with a braiding pattern between depositional longitudinal bars. At the southern end of the basin they connect into a single erosional feature with an erosional relief uf up to 100 m that then joins the Orosei-Gonone canyon system.

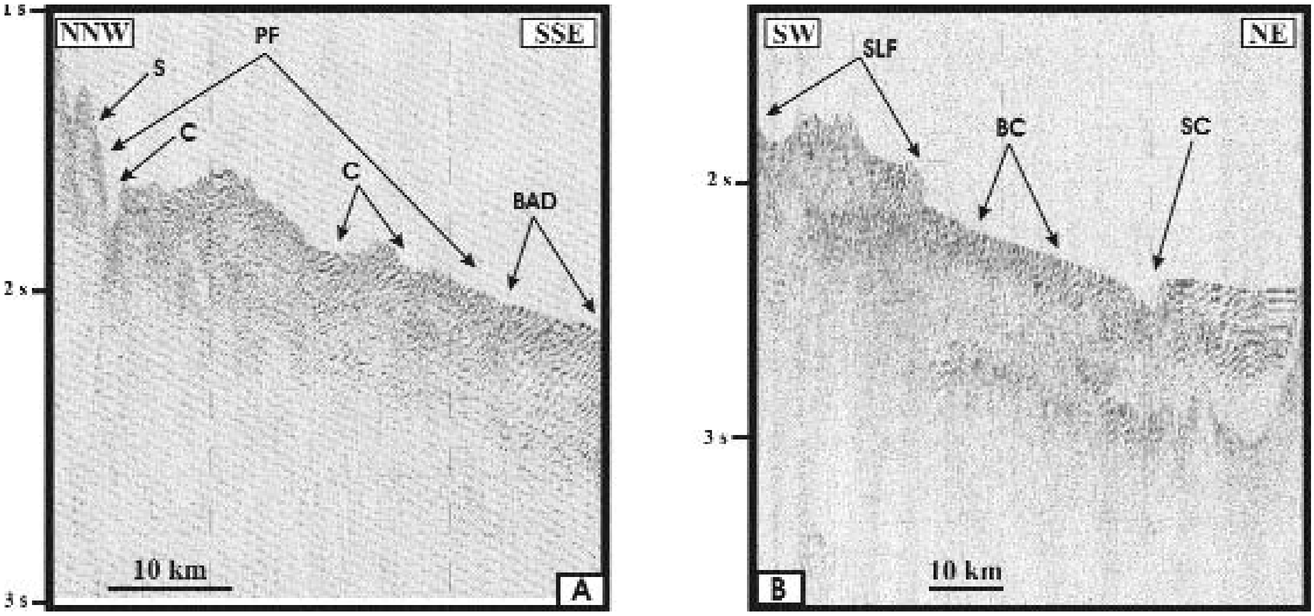

Fig. 14. – *a) Strike seismic line (T9916) over the Posada fan (PF). A major channel (C) scours the northern side of the fan at the base-of slope (S); smaller-scale channels (C) are however evident further downslope. Note the abrupt termination of the fan over basin axis deposits (BAD). b) Dip seismic line (T9929) over the San Lorenzo Fan (SLF); a network of braiding channels (BC) is present downslope of the fan, connecting with the Sarrabus canyon (SC).*

The Orosei-Gonone system spans the Sardinian margin for a length of around 20 km and consists of 3 canyons (fig.12). The Gonone canyon incises the slope at a depth of around 500 m. At the base-of-slope the various canyon of the system evolve into leveed channels that connect in a single trunk at a depth of around 1800 m. The levees are very narrow. Downslope of the junction, the Gonone-Orosei system is straight, has a levee in the right side while slumping dominates the left side adjacent to the southern tip of the Baronie ridge (fig. 15a); an abrupt turn of the channel at a depth of 2300 m (fig. 12) corresponds to the obstruction of a salt diapir that pierces the seafloor. The Ogliastra and the Sarrabus-Ichnusa intraslope basins develop south of the Gonone Orosei drainage system and are separated by a very subdued intraslope high. Canyons that incise the slope and canyon-mouth channelized fans are the main features of the Ogliastra basin. The Arbatax fan is the largest fan and having around 15 km length, occupies much of the basin with its distal portions adjacent to the Quirra high (fig. 12). The proximal part of the Arbatax fan is scoured by a single, up to 50 m deep meandering channel that loses relief downslope and repeatedly branches into numerous low-relief channels. A smaller-scale fan is developed at the mouth of the Pelau canyon; the Pelau channel that runs in its surface continues beyond the fan as a single v-shaped 50 m deep feature that connects with the Sarrabus canyon (fig. 12). At the southern limit of the investigated slope portion, in the Sarrabus-Ichnusa basin, the Picocca submarine drainage network originates the San Lorenzo fan characterized by a complex morphology that likely reflects the control of basement highs over depositional processes (figs. 12, 14b). The main morphologic feature of the Ichnusa-Sarrabus basin is the axial Sarrabus canyon that runs in the axis of the basin (fig. 12). It nucleates as a single evident erosional feature at a depth of around 1700 m but appears to be connected upslope to a braided valley consisting of a widespread area of less focused seafloor erosion (fig. 14b). The Sarrabus canyon gradually enlarges and widens downslope within the axis of the basin (fig. 12); however, a striking increase in both relief and width is evident where the canyon crosses the Quirra tectonic lineament. Here the canyon is up to 400 m deep and up to 8 km large; much of the morphologic change appears to be related to undercutting and related slumping of the slope deposits flanking the erosional fairway (fig. 15a).

The Sarrabus Canyon and the Orosei-Gonone system connect at a depth of around 2600 forming the Sardinia Valley that crosses the whole Cornaglia Terrace and reaches the Vavilov abyssal plain (fig. 12). The Sardinia valley is mainly flat bottomed with an average width of around 5 km and a floor that lies around 100 m below the surrounding basin plain (fig. 15b). A breach in the right, outer valley flank coincides with a northward turn of the valley at a depth of around 2800 m (fig. 12); it could represent an avulsion point as also shown by the sedimentary features of the Cornaglia Terrace downslope of the breaching point (fig. 15b). In the crossing of the Selli Line, the Sardinia Valley becomes strongly erosive with a v-shaped profile and a depth of more than 200 m (fig.15c). In addition, a recent southward shift has occurred in this area; an abandoned fairway is in fact visible hanging north over the present-day active Sardinia Valley (fig.12).

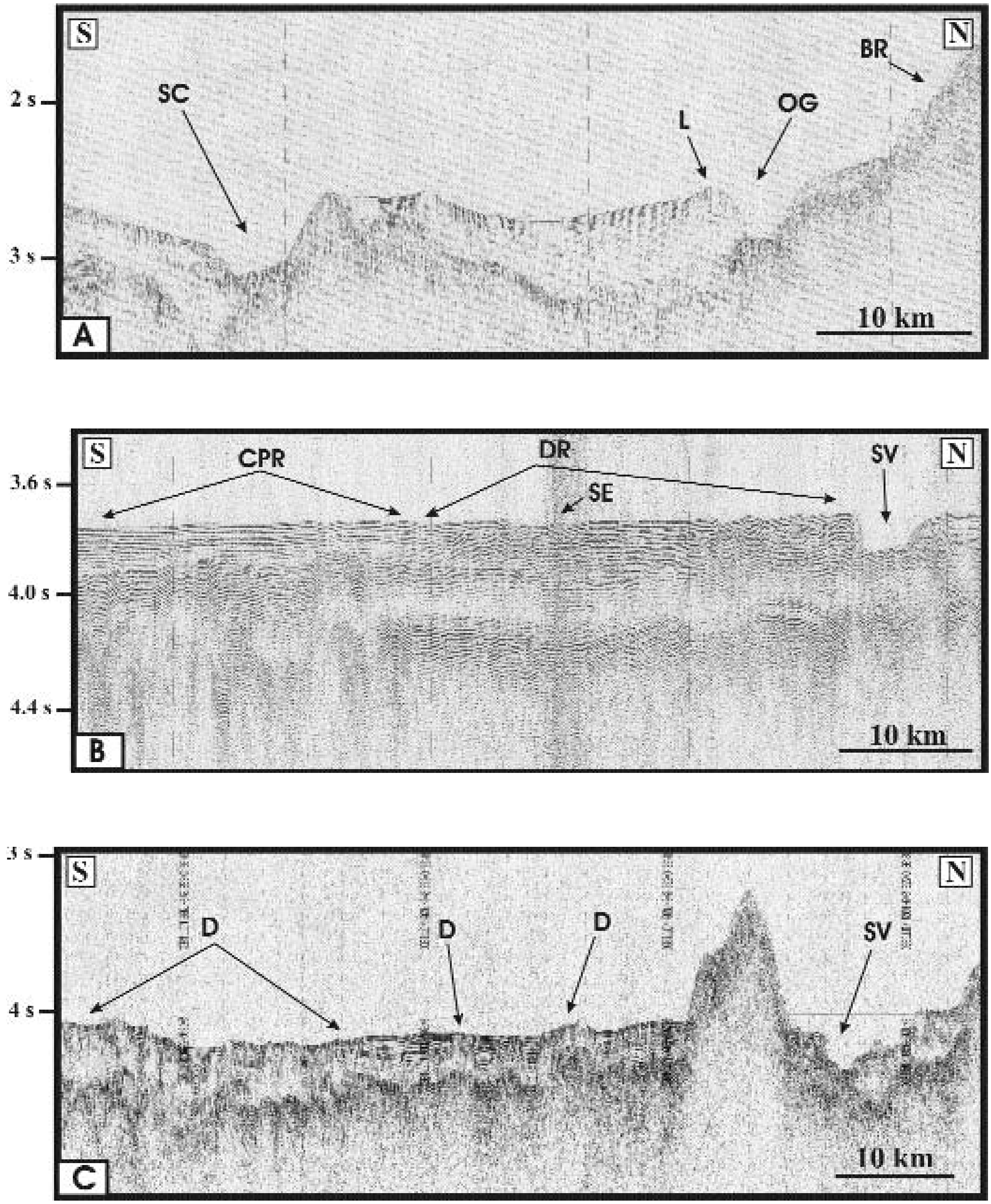

Fig. 15. – *a) Seimic line T9916 crossing the distal portion of the Sarrabus canyon (SC); the erosional conduit is much more incised in the surrounding slope deposits than in figure 14b. The distal portion of the Orosei-Gonone canyon system (OG) is imaged to the north at the base of the Baronie ridge (BR); a small levee (L) is developed in the right side of the conduit. b) Seismic line T9925crossing the Sardinia valley (SV). Note the seafloor erosion (SE) in the centre of the line that is underlied by highly discontinuos reflections (DR) at variance with the continuous parallel reflections (CPR) further south ; it could represent a conduit developed in the Cornaglia terrace as a consequence of avulsion of the Sardinian valley in correspondence of a tight northward turn. c) In correspondence of the Selli line the Sardinia Valley (SV) resumes an highly erosive character. South of the Sardinian Valley, the Cornaglia Terrace is the site of salt diapirs (D); some of them pierce the whole sedimentary package and are evident at the seafloor.*

7. - VAVILOV BASIN

The Vavilov basin, dating back to 6 Ma is the oldest back arc basin of the Tyrrhenian region (KASTENS & MASCLE 1990). The D'Ancona ridge and the Vavilov volcanic seamount separate the Vavilov basin into two distinct areas: the Gortani basin to the northeast and the Magnaghi basin to the southwest (fig. 16).

The distal portion of the Sardinia Valley, the main submarine sedimentary pathway that collect siliciclastic sediments from the Sardinian passive margin runs in the Magnaghi basin south of the D'Ancona ridge (fig. 16). It is a very low-relief channels that does not terminate with any evident depositional body; likely because much of the coarse-grained sedimentary load of the Sardinia valley is deposited in the Cornaglia terrace and only high-efficencies flows reach the deep basin. In the Gortani basin, adjacent to the base of the Campanian slope, recently acquired high resolution seismic data show that a depositional fan with a very low areal extent (radius of around 5 km) is present at the mouth of the Ischia Valley (GAMBERI *et alii* 2003). The main seismic characteristic of the sedimentary infill of both the Gortani and Magnaghi basins is that of continuous parallel reflections evidence of distal turbidites with a basin-wide areal extent (fig 17a). This pattern is interrupted however by a thick acoustic transparent layer (ATL) at a depth of around 50 m (fig. 17a). As a matter of fact, recently acquired chirp data have shown that at least 4 ATLs are present within the recentmost basin infill (GAMBERI *et alii* 2003). The thickness and areal extent of the deeper, thicker ATL, shown in figure 17, leads to a volume of around 150 km^3.

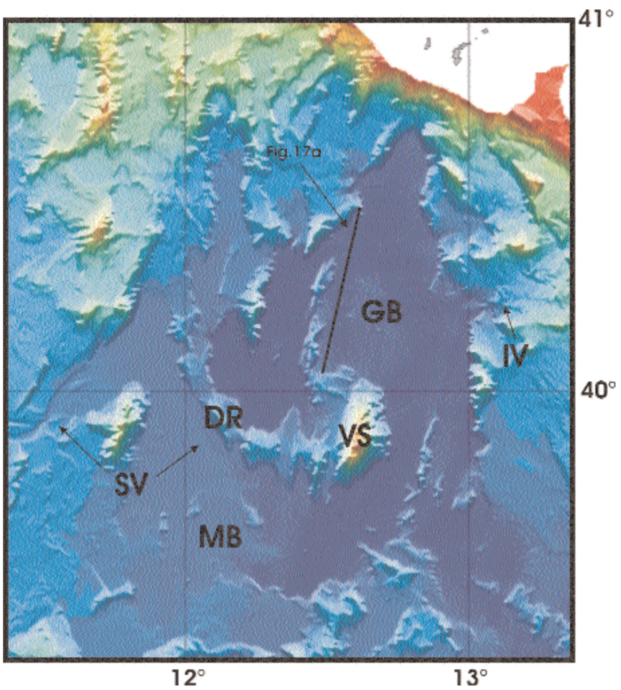

Fig . 16. – *Colour-shaded map of the Vavilov basin (GB = Gortani basin; MB = Magnaghi basin; VS = Vavilov seamount; DR = D'Ancona ridge; SV = distal segment of sardinia valley; IV = distal segment of Ischia valley).*

8. - MARSILI BASIN

The Marsili basin occupies the deepest portion of the southeastern Tyrrhenian Sea and lies at a depth of around 3300 m. The Stromboli valley funnels to the eastern portion of the Marsili basin a large input of siliciclastic and volcaniclastic material. As a consequence, a deep-sea fan is developed, with apex in the eastern basin margin and distal portions that reach the base of the Marsili seamount (fig. 18) The fan has a length of 40 km and a width of 20 km, and is fed by various branching channels that scour the surface of the fan down to its distal part (figs. 17b, 18). Lobes are developed at the mouth of the channels that at times display the development of outer levees and intra-channel longitudinal bars (GAMBERI *et alii* 2003). The resulting seismic facies consists of highly discontinuos reflection arranged in lens-shaped bodies and frequent erosional surfaces.

A markedly different depositional environment characterizes the western portion of the basin sheltered by the Marsili seamount from the main sediment entry points (fig. 18). Here, distal turbidites with continuos, basin-wide parallel reflections are evident; sedimentation rate is however very high with a thickness of quaternary deposits of 650 m (HIEKE *et alii* 1990).

Besides the Stromboli valley, the surrounding steep slopes feed sediments to the basin. In particular, a volcaniclastic input to the northeastern portion of the basin occurs through chutes and channels that develop on the southern slope of the Palinuro volcanic complex and on the northern slope of the Aeolian volcanic arc (fig.18).

9. - CONCLUSIONS

The present-day morphosedimentary features and the character and distribution of depositional systems within the Tyrrhenian Sea reflect the recent geological evolution of the area consisting of distinct, eastward migrating episodes of extensional tectonics and backarc basin opening. Numerous intraslope basins, bounded seaward by fault blocks, are located along the rifted Latium-Campanian, Calabrian, Sicilian and Sardinian margins that surround the two abyssal plains of Vavilov and Marsili, where extensional tectonics has progressed up to back-arc basin formation. Due to the variability in age and style of the tectonics that have shaped the different margins and of the present-day geodynamic setting of the adjacent emerged areas, however, contrasting sedimentary processes are active and are responsible for the distinct depositional settings of the intraslope basins.

A striking difference emerges for example between the depositional architecture of the Sardinian passive margin and that of the Cefalu and Gioia basins located along the Sicilian active margin. While both margins have slopes with numerous canyons, they show a markedly different setting of deposition at the base-of–slope. The Sardinian intraslope basins (Olbia, Baronie, Ogliastra and Ichnusa-Sarrabus) are in fact characterized by the development of distinct mounded depositional bodies with circular or elongated planform and dimensions up to 15 km consisting of small fans developed at the mouth of the main canyons. In the Cefalu and in the Gioia basins, on the contrary, canyons pass downslope to leveed channels that at the base-of slope build a prograding wedge of channel-levee deposits forming a constructional depositional apron elongated along the basin margin. Different sedimentary processes are also responsible for the destructional slope sectors that characterise both the Sardinian and the Sicilian margin. In the Gioia basin in fact a 20 km wide slope sector is affected by seafloor instability that results in the Villafranca mass-wasting complex straddling transversally the whole basin. In the Sardinian margin, on the contrary, slope destruction occurs through erosion focused along canyon systems that in the case of the Orosei-Gonone system affect a slope sector with a longitudinal dimension of 20 km.

In spite of a general fundamental homogeneity of the depositional tracts of the single margins, major differences do however still arise when comparing single intraslope basins along the same margin. Variations in canyon morphology and distribution are evident in the slope of the Sardinian margin intraslope basins. In the Olbia basin slope, isolated, widely-spaced canyons or canyon systems are present; in the Ogliastra basin a network of closely spaced canyons, at times with merging flanks, dissect the slope; the Baronie basin slope is completely devoid of canyons

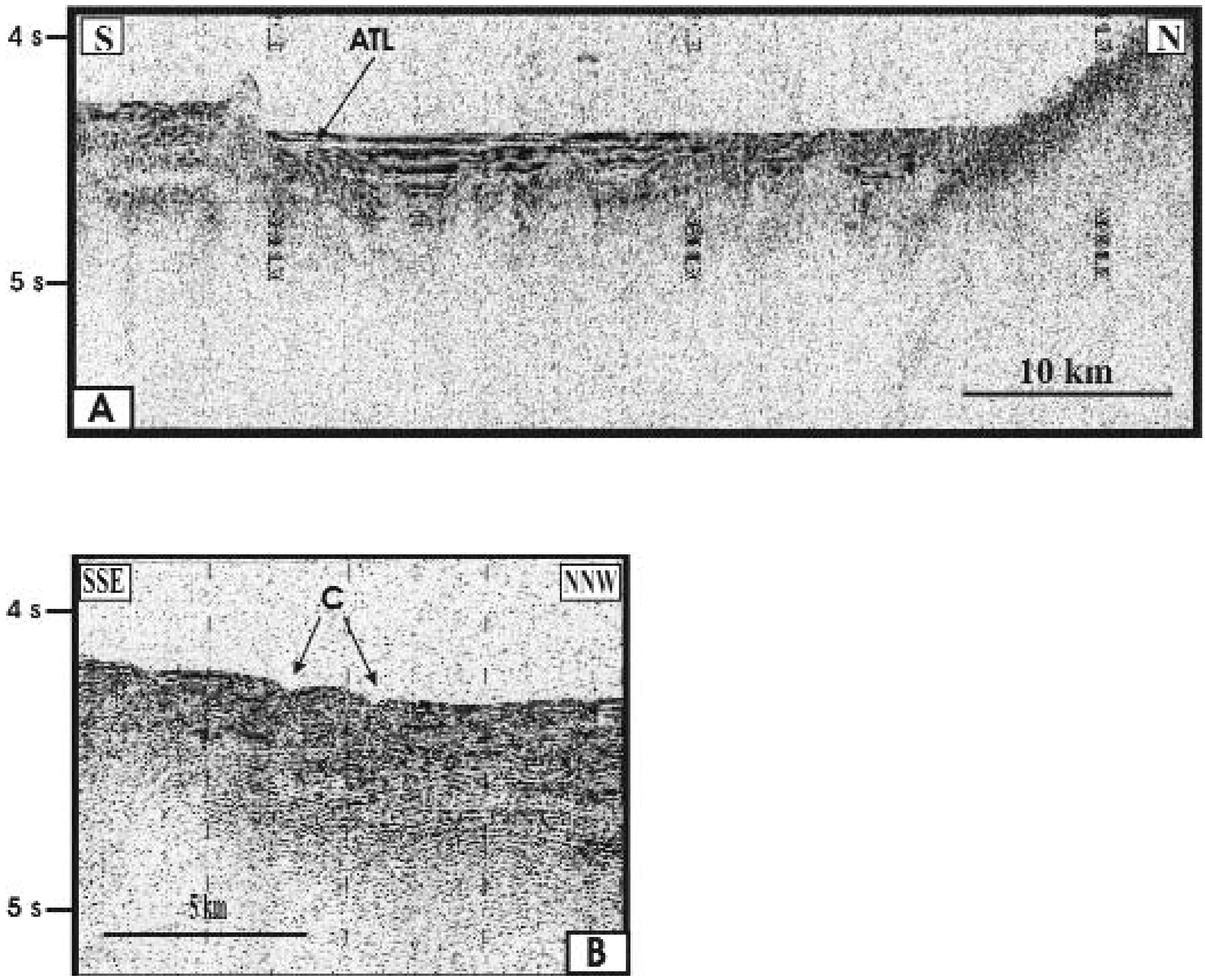

Fig. 17. – *a) Seismic line over the Gortani Basin showing the continuous and parallel character of the reflections within the basin infill; however a transparent layer (ATL) is evident in the upper portion of the basin infill. b) Seismic line crossing the Marsili basin deep-sea fan; channels (C) are evident on the surface of the fan.*

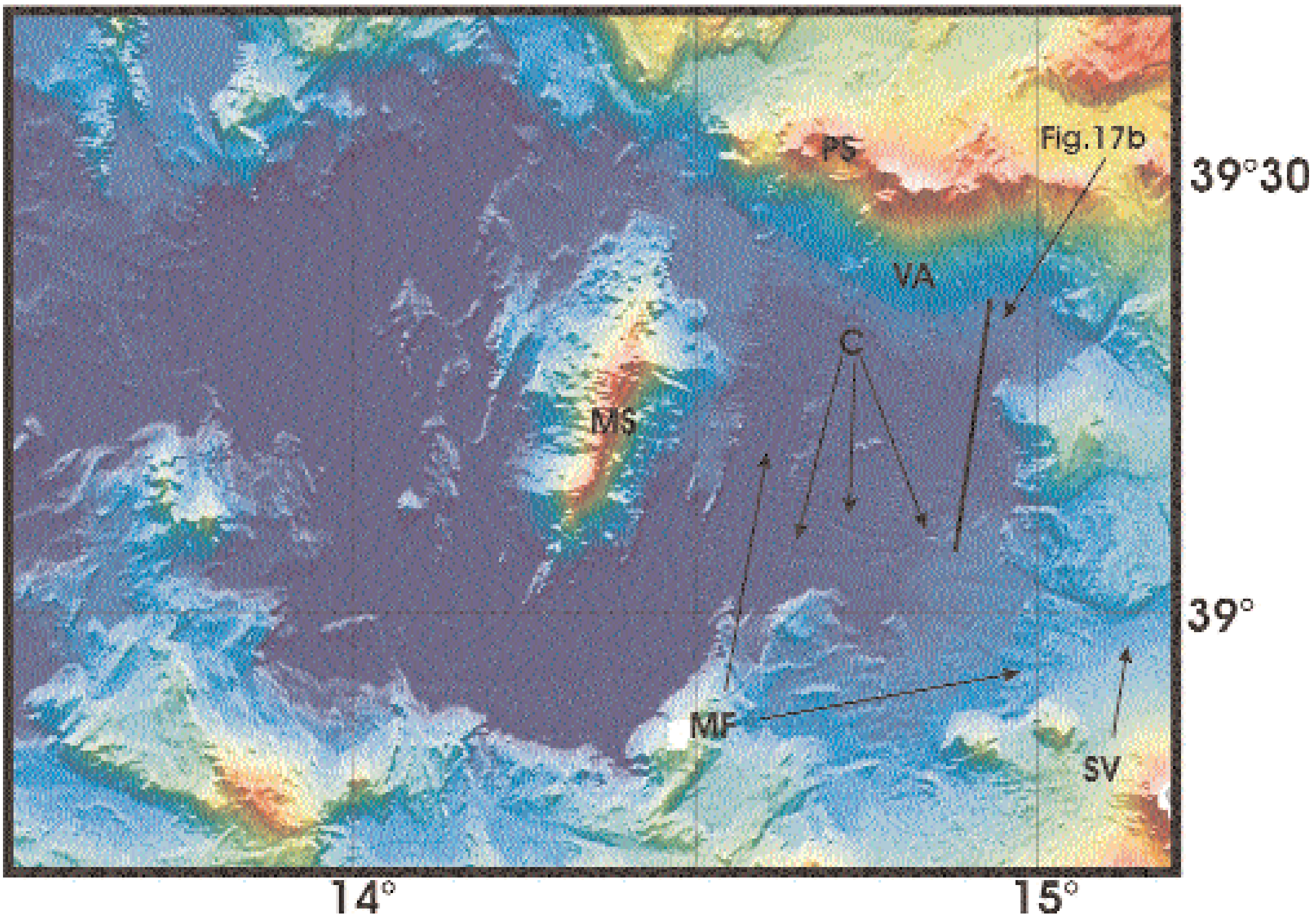

Fig. 18. – *Colour-shaded map of the marsili basin (MF = Marsili fan; SV = Stromboli valley; MS = Marsili seamount; PS = Palinuro seamount; VA = volcaniclastic apron; C = channels).*

while the large Posada and Orosei-Gonone canyon systems are developed at its southern and northern margin. A different stage of slope erosion, with the mature Olbia basin slope canyons and Posada and Orosei-Gonone systems as compared to the younger fairways in the other slope areas can be envisaged to explain the observed differences. In addition, variations in the character of the sediment-gravity flows running within the canyons can be reasonably expected. As a matter of fact, differences in the architecture and dimensions of the base-of-slope fans developed at the canyon mouths can be explained by variations in the efficiency of the sediment-gravity flows delivered to the base-of-slope. The Olbia fan has in fact a proximal leveed channel that passes downslope to a radiating network of distributary channels in the distal fan portions closely matching the architecture of fine-grained fan models. All the other fans, on the contrary, develop a radiating pattern of channels, with diffent planforms and extending directly from the canyon mouth, more akin to coarse-grained fan models.

Markedly different depositional environments characterize even adjacent sectors of single intraslope basins. In the case of the Gioia Basin for example, a constructional slope apron made up of prograding channel-levee deposits is flanked by a destructional slope area In the Orlando basin a prograding apron of channel-levee deposits is present to the west where the basin is directly connected to the emerged areas; to the east an authochtonous slope apron characterizes the slope that is separated by the emerged areas by the Palermo basin.

The deep abyssal plains of the Vavilov and Marsili basins represent the ultimate base level for the sedimentary processes active in the Tyrrhenian region. However, some of the intraslope basins such as the Cefalu and the Olbia basins are completely confined by their seaward bounding structures and represent therefore isolated depositional systems. Other intraslope basins develop, on the contrary, submarine drainage networks resulting in sea valleys that cross the whole margin and are throughoing sedimentary fairways connecting the coastal areas to the deep abyssal plain. The obstacle effect of tectonic and volcanic features control the general course of the sea valleys. This is particularly evident in Latium-Campanian margin where, due to the recent age of the tectonics that has shaped the margin, the Ischia-Magnaghi and the Dhorn Valleys are characterized by sharp bends between fault-parallel and –crosscutting segments. The control of volcanic features is displayed by the Stromboli valley that in the Gioia basin runs toward the NE parallel to the Aeolian arc and then turns to an E-W direction in correspondence of a breach in the Aeolian arc between the Stromboli and the Lametini volcanic edifices. Tectonic features also promote changes in the sedimentary dynamics within the sea valley. The Ischia-Magnaghi and Dhorn valleys, that have a depositional character in the Ventotene and Capri basins, become highly erosive in the crossing of the Sirene and the Sartori lineaments. Also, the distal portion of the Sardinia valley undergoes a change from depositional to erosional character in the crossing of the Selli line.

In the Calabrian margin and in the Gioia Basin slope deposits have almost completely mantled the basement highs and as a consequence the Gioia-Mesima and the Angitola slope channels follow a more direct downslope route. However, the downslope evolution of the Angitola and the Mesima-Gioia slope channels, from meandering segments running through a wider depositional cahnnel-belt to straight mainly erosional segments, likely reflect changes in slope gradients in turn controlled by basement structures.

The different characteristics of the margins are also basically the major control of the depositional processes in the deep Vavilov and Marsili Basin. The Marsili basin surrounded by the active Sicilian and Calabrian margin and by the Aeolian volcanic arc receives a large sedimentary input mainly through the Stromboli valley. As a consequence it displays a deep-sea fan that occupies the eastern side of the basin with a length of 40 km a a width of 20 km. On the contrary, the Vavilov basin is mainly filled by distal sheet turbidites due to several factors. These include the distance from the Sardinian margin with the Sardinia alley depositing much of its sediment load in the Cornaglia Terrace, and the underfilled nature of the Latium-Campanian margin that stores much of the supplied sediments.

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