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Structural framework of the Tyrrhenian Sea unveiled by seafloor morphology
Struttura del Mar Tirreno svelata dalla morfologia del fondale

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ABSTRACT - A review is made of the principal morphological characteristics of the Tyrrhenian basin from a structural point of view. On this basis, four geodynamic provinces are defined: the basin and range province of the northern Tyrrhenian, the passive margin province of the Sardinia block, the active Apenninic margins of the eastern and southern Tyrrhenian and the ocean floored deep central basins.
The four provinces are characterised by distinct development of structural elements both from a stress state point of view and their timing.

KEY WORDS: seafloor morphology, structural provinces, tectonic activity, Tyrrhenian Sea

RIASSUNTO - E' presentato un quadro generale delle principali caratteristiche strutturali del Tirreno da un punto di vista morfologico. Sono state distinte quattro province geodinamiche: la provincia *basin and range* del nord Tirreno, la provincia di margine passivo della Sardegna, la provincia Appenninica attiva del Tirreno orientale e meridionale e la provincia di crosta oceanica del Tirreno centrale.
Le quattro province possiedono caratteri distinti sia dal punto di vista del campo di stress originario che dalla loro età di attività.

PAROLE CHIAVE: morfologia del fondale, province strutturali, attività tettonica, Mar Tirreno

1. - INTRODUCTION

The Tyrrhenian Sea, the youngest back-arc basin of the Mediterranean, has been entirely surveyed by means of multibeam swath bathymetry, from 400 metres water depth up to its deeper portions. The resulting data set provides baseline morphological information to corollary research in portions of the Tyrrhenian involving rock sample collection and deep-towed side scan sonar surveys and acquisition of high resolution seismic data.

Detailed seafloor morphology in evolving arc/back-arc settings offers the opportunity of revealing surface features that, for the most part, result from the deeper geological processes that act in the region. It is evident that deep-seated events influence the pattern of structural styles, the development of volcanism and even the occurrence of large sedimentary transport and depositional systems. Therefore, a comprehensive characterization of the surface morphology offers a means to define the properties, structure and dynamics of its ultimate source region, the mantle.

In some cases, as this paper attempts to show, the effects of events occurring as deep as within the asthenosphere or at the asthenosphere-lithosphere boundary are largely revealed through surface morphology.

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2. - REGIONAL SETTING

The formation of the Tyrrhenian Sea occurs within the overall context of slow convergence between the African and Eurasian plates, which presently characterises the Mediterranean (DEWEY *et alii*, 1989; ARGUS *et alii*, 1989; DE METS *et alii*, 1990; WARD, 1994). Bordered to the east and south by the Apennine-Maghrebides mountain belt and to the west by the passive Sardinian margin, the Tyrrhenian basin formed as a consequence of rifting and back-arc extension of the Alpine/Apennine suture above the north-westerly-subducting Ionian oceanic slab, (KASTENS *et alii*, 1988; KASTENS, MASCLE *et alii*, 1990; SARTORI, 1990; JOLIVET, 1991).

E-W directed rifting in the northern Tyrrhenian in lower-mid Miocene (~15 Myr) and along the western margin of Sardinia in Tortonian (~11 Myr) (ZITELLINI *et alii*, 1986; KASTENS, MASCLE *et alii*, 1990) marks the initial opening of the Tyrrhenian basin leading to the formation of oceanic domains in the Central and Southern Tyrrhenian. First, production of ocean crust occurred westward, during the Pliocene spreading of the Vavilov basin (4.3-2.6 Myr), (KASTENS, MASCLE *et alii*, 1990) accompanied by the thermal subsidence of the thinned western margin crust. A subsequent change to ESE-directed extensional stress in Late Pliocene-Quaternary resulted in the emplacement of basaltic crust southeastwards, generating the Marsili backarc basin (2 Myr), (KASTENS, MASCLE *et alii*, 1990).

The most widely accepted mechanism to account for the migration in space and time of rifting, volcanism and ocean crust emplacement links the eastwards migration of crustal thinning and oceanic accretion to the passive rollback of the Ionian plate (MALINVERNO & RYAN, 1986; SAVELLI, 1988; ARGNANI & SAVELLI, 1999). Since Early Miocene, time of the Alpine/Apennine collisional suture in the future Tyrrhenian area (BECCALUVA *et alii*, 1994), most of the pre-existing Mesozoic oceanic lithosphere in the western and central Mediterranean had been consumed, with the exception of the remnant Ionian ocean, delimited to the southwest by its ancient margin, the Malta escarpment

The Tyrrhenian opening, induced by the rollback of the remnant slab, was matched by the eastward and southward radial growth of the Apennine-Maghrebides fold and thrust belt on the Italian peninsula and Sicily (SARTORI *et alii*, 1989). In step with backarc basin development, the subduction-related island arc volcanism of the southern Tyrrhenian basin migrated from west to south-east, from Sardinia (32-13 Ma) to the currently active Aeolian island arc (SERRI 1997 and references therein), developing the present-day arc/backarc configuration of the southern Tyrrhenian region.

The deep-water, ocean crust floored, central and southern Tyrrhenian Sea is surrounded by different geodynamic margin settings. The western Tyrrhenian margin represents a typical passive continental margin while the eastern and southern margins are associated with high seismicity, active volcanism and elevated rates of uplift of land areas represented by the Apennine-Maghrebid mountain chain.

3. - GEODYNAMIC PROVINCES OF THE TYRRHENIAN BASIN

Due to the young age of the Tyrrhenian Sea, tectonic and associated volcanic processes exert a strong control on the seafloor make-up. Consequently, simple examination of the morpho-bathymetry of the basin consents a primary subdivision (fig. 1) of the region on the basis of its morphology: the northern Tyrrhenian zone; the eastern Sardinia margin; the eastern Tyrrhenian margin of peninsular Italy and Sicily and the deep, central and southeastern abyssal plains. This classification based on purely morphological features, which undeniably derives from the history of the basin, is substantiated, however, by distinctive geological and geophysical information that characterizes each zone. As a result, the morphology of the Tyrrhenian seafloor matches the distribution of four principal geodynamic provinces related to its formation and development.

3.1. - BASIN AND RANGE PROVINCE: THE NORTHERN TYRRHENIAN

Bordered to the north by the Tuscan Archipelago and to the south by the conjunction of Baronie seamount and the Pontine Islands, this sector is

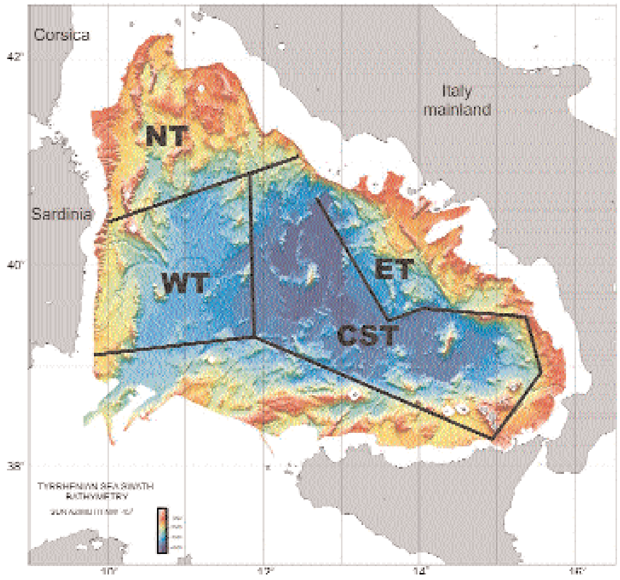

Fig. 1. - *Shaded relief bathymetric map of the Tyrrhenian Sea showing the surveyed region. Depths are colour-coded, illumination from the NW. Black lines divide the four geodynamic provinces discussed in text: NT, Northern Tyrrhenian Basin and Range province; WT, Western Tyrrhenian passive margin province; ET, Eastern Tyrrhenian active margin province and CST, Central and Southern Tyrrhenian ocean crust floored province.*

roughly triangle-shaped and extends between 42º N, (northern edge of survey) and 40º30' N (fig. 2).

Previous work in the region, based on single channel seismic reflection profiles, has shown the extensional nature of the northern Tyrrhenian terrain (ZITELLINI *et alii*, 1986; MARANI & ZITELLINI, 1986; BARTOLE 1995), composed of a series of rotational normal faults resulting in a tectonic framework of tilted blocks, half-graben and graben-horst structures.

Extensional thinning of the significantly thickened crust resulting from the Alpine/Apennine collisional suture that previously occupied this region began in early-mid Miocene (CARMIGNANI & KLIGFIELD, 1990; JOLIVET *et alii*, 1991; PASCUCCI *et alii* 1999). Extension with accompanied magmatic activity gets younger from east to west (BECCALUVA *et alii*, 1989; SERRI *et alii*, 1993; CARMIGNANI *et alii*, 1995), from ~15/20 Myr in the Corsica Basin to the presently active normal faults in the northern Apennines. The Northern Tyrrhenian is presently characterized by relatively thin crust (SCARASCIA *et alii*, 1994) in the order of 22 km and a shallow asthenosphere, 50 km deep (SUHALDOC & PANZA, 1989; SERRI *et alii*, 1993; FINETTI *et alii*, 2001). Bathymetrically, the northern Tyrrhenian principally develops as a series of N-S and NNW-SSE trending structural highs and adjacent, relatively flat-lying basins. On average, the structures have a length of ~40 km and are set 20/25 km apart. The bathymetric base level of the region, corresponding to the basin depths, is ~1500 meters in the northern portion of the region and reaches 2000 meters only in the southernmost part of it. The major structures (fig.2), such as the Etruschi samount in the West and the Civitavecchia Valley in the East, have a continuity of more than 70 km and the average elevation of the highs, with respect to the basin lows, is of more than 1000 meters with the summits reaching 300/400 meters below sea level.

Detailed seafloor bathymetry thus furnishes a comprehensive picture of the array of extensional features that affected a thickened crustal wedge in the 200 km wide northern Tyrrhenian marine region. The overall surface topography of this broad extensional system reveals a striking similarity to areas of diffuse continental extension such as the Basin and Range province of the western United States. This comparison between structural styles, based only on morphological grounds, is also however supported by the finding of low angle detachment faults and core complexes in Corsica and Tuscany (CARMIGNANI & KLIGFIELD, 1990; JOLIVET *et alii*, 1991), by the extensive block faulting and by the diachronous development of extension and magmatism. In effect, all these traits are common to the Basin and Range province, namely extension involving low angle extensional faults coupled to high angle, rotational block faults and the documented migration in time and space of extension and magmatism (WERNICKE, 1981; LISTER & DAVIS, 1989; SURPLESS *et alii*, 2002).

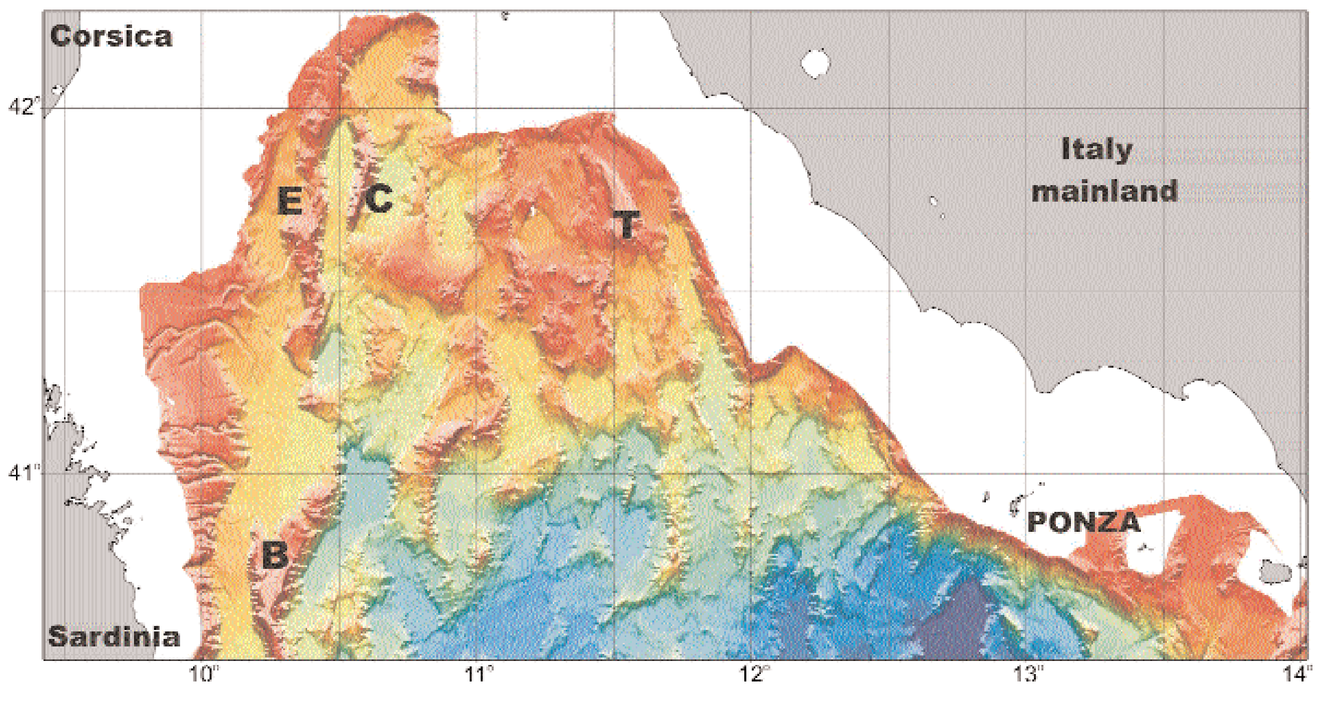

Fig. 2. - *North Tyrrhenian Province. Colour code and illumination as in figure 1. The relatively shallow base-level of the seafloor is interrupted by mostly N-S trending structural highs and intervening basins. Major seamounts are Etruschi (E) Cialdi (C) and Tiberino (T). Baronie seamount (B) to the west and Ponza offshore structures to the east delimit the region to the south. Refer to text for further discussion.*

3.2. - Passive Margin Province: the eastern Sardinia margin

The eastern Sardinia province is delimited to the north by the Baronie Seamount at 40°30'N and to the south at 39°N, covering the marine area westwards to 11°30E (fig. 3). Baronie seamount, the largest structural high in the Tyrrhenian Sea, with a length of over 120 km is the morphological link between the northern Tyrrhenian Basin and Range province and the Passive margin province of western Sardinia. Moreover, from a geodynamic point of view, Baronie seamount represents the tectonic boundary between the two provinces, being made up of Alpine units, analogous to those outcropping in eastern Corsica, and Alpine foreland units that make up most of the islands of Corsica-Sardinia (Structural model of Italy, 1991). South of Baronie Seamount, in fact, only the latter units seem to persist, according to rather extensive seafloor sampling.

The initiation of tectonic activity in this sector has been established by the drilling results of ODP Leg 107 (Kastens & Mascle *et alii*, 1990.). A date of mid-upper Miocene (Tortonian ~10myr) is established from hole 654. However, due to the fact that undatable conglomerates make up the base of the sequence, one cannot rule out that the age of inception of the activity could be older.

Thus, the Sardinia slope area morphology records the rifting episode that resulted in the subsequent formation of the ocean crust floored deep Tyrrhenian basin domain. During this latter period, the Sardinia slope area began to represent the passive margin geodynamic province of the basin. Crust thickness is a clear record of this process, thinning from ~30 km beneath Sardinia to less than 10 km in the Vavilov basin (Panza & Suhaldoc, 1989, Scarascia *et alii*, 1994).

The margin consists broadly of 2 distinct physiographic belts parallel to the Sardinia coastline and with increasing water depth. At a regional depth of ~1000-1500 meters, an upper slope belt, about 50 km wide, of sediment-filled, flat lying intraslope basins develops, bounded seawards by a series of structural highs. The basins, generally termed the Sardinia basin (SB) are delimited landwards by the outer continental shelf and slope dissected by numerous canyons (fig. 3). These promote basin filling but also contribute to the development of the larger-

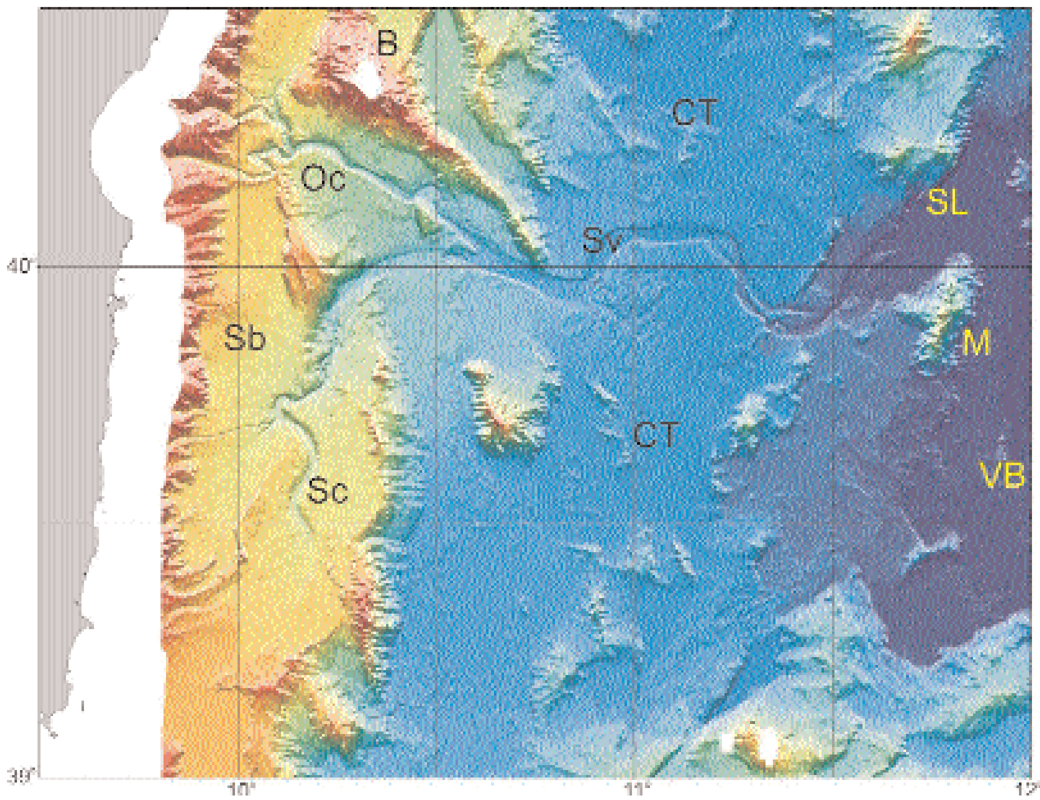

Fig. 3. - *Western Tyrrhenian Province. Colour code and illumination as in figure 1. The region is subdivided into two separate physiographic zones by the outcropping morphological highs: the Sardinia basin (Sb) and the Cornaglia Terrace (CT). The trend of the southern portion of Baronie seamount (B) allows breaching of the Sarrabus (Sc) and Orosei (Oc) canyons seaward where they merge to form the Sardinia Valley (Sv). The western province is delimited eastwards by the Selli Line (SL) which drops down into the deep Vavilov basin (VB). Magnaghi seamount is one of the two volcanoes that characterise the VB. Refer to text for further discussion.*

scale Sarrabus and Orosei canyon systems that merge at a breach in the bounding structural highs, in proximity to the southern Baronie seamount, to continue to the deeper ocean as the Valley of Sardinia (fig. 3).

The Valley of Sardinia extends within the second belt, the Cornaglia Terrace (CT), which is also morphologically well defined. This consists of a relatively flat lying deep-water plain (~2500-2800 meters water depth), extending about 70 km seawards. The plain is bounded eastwards by a NE-SW-trending fault scarp, the Selli Line that separates the Sardinia margin from the Vavilov abyssal plain (fig. 3).

Apart from the Baronie seamount, the structural highs that bound the SB display a subdued topography. Numerous seismic reflection studies in the region show that the structural highs are actually the uplifted footwall leading edges of large tilted blocks, formed by the development of rotational faults generally dipping eastwards, with the half-grabens formed by block tilting now practically filled in by the SB sediments. Similar structures underlie the CT, although the thinner sediment cover does not register block tilting as adequately as in the SB.

3.3. - Active Margin Province: the eastern Tyrrhenian

For the purpose of this paper, the eastern Tyrrhenian margin is defined as the continental slope region between the Pontine Archipelago and the Palinuro seamount. It has variable width, between a minimum of a few kilometers to about 60 km and runs parallel to peninsular Italy, in a NW-SE direction (fig. 4). The southern Apennine chain represents the emergent area to the East of the margin.

Morphologically, the limits of the area are well revealed. To the north, a series of ~25 km long fault scarps that develop in a NE-SW direction west and south of Ponza Island are seen to clearly separate the structural trends of the eastern Tyrrhenian margin from the northern basin portion. The western limits of the area are the flat lying, deep-water, Vavilov and Marsili abyssal plains (fig. 4).

Differently from the passive margin geodynamic province the structures in this region are morphologically distinct, despite the undoubtedly large sediment supply due to the proximity to the Apennine mountain chain, implying a very recent or on-going

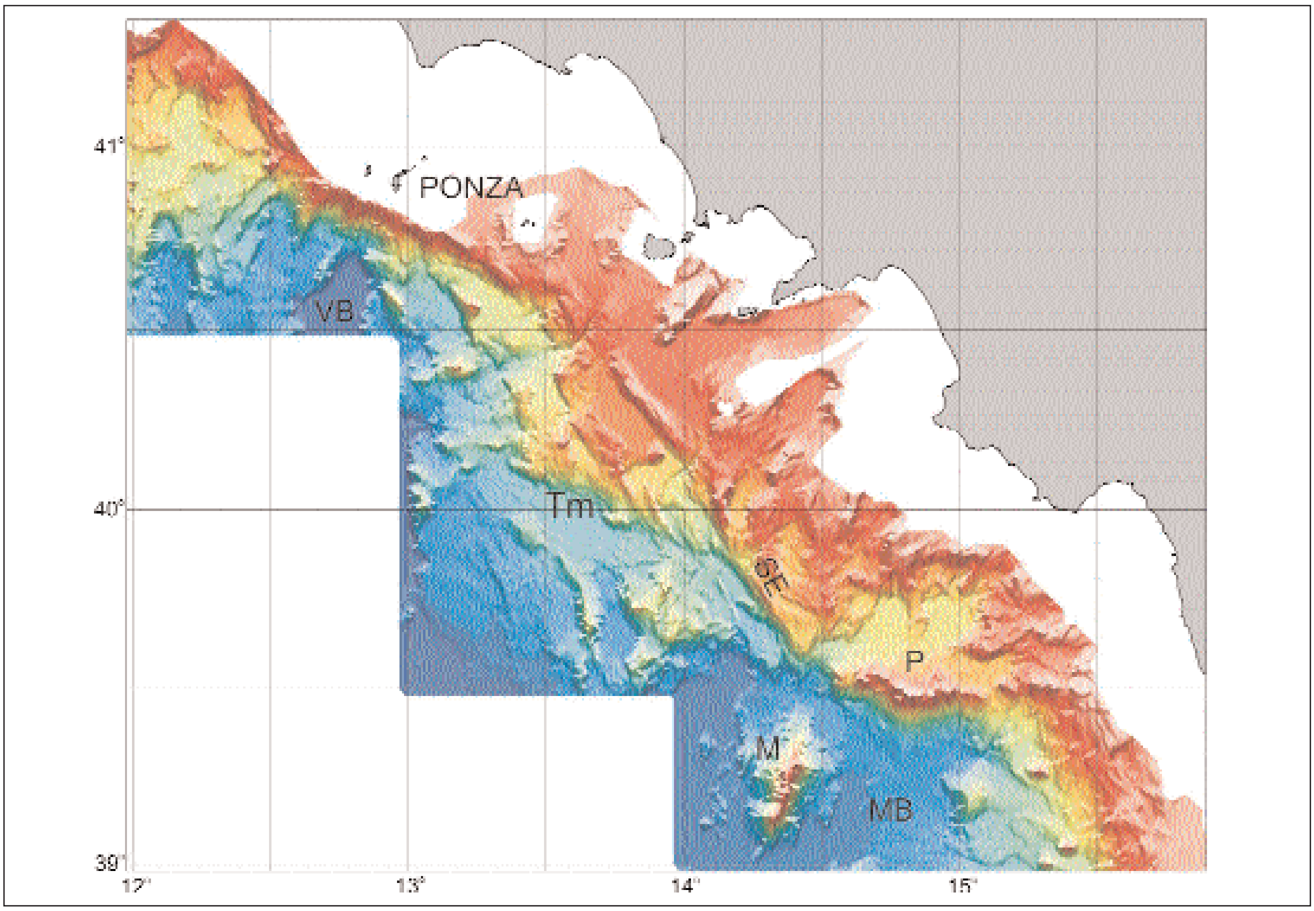

Fig. 4. - *Eastern Tyrrhenian Province. Colour code and illumination as in figure 1. The outstanding feature of the region is the Sartori Escarpment (SE) that separates the structurally diverse upper ("Apenninic" type margin, Am) and lower ("Tyrrhenian" type margin, Tm) slopes of the area. Also visible are the Palinuro volcanic complex (P) forming the southern boundary to the province, the Marsili volcano (M) within the Marsili basin (MB) and the northern extension of the Vavilov basin (VB) offshore Ponza Island. Refer to text for further discussion.*

tectonic activity. On the basis of its morphology, the eastern Tyrrhenian margin can be structurally subdivided into two sectors roughly corresponding to the upper (<2000 m depth) and lower (>2000 m depth) continental slope regions.

Structural partitioning of the margin is brought about by a NNW-SSE trending, 80 km long normal fault system (fig. 4). The system basically consists of a 330º directed, west-dipping master fault with displays increasing throw southwards, from ~400 meters to over 1 km. Adjacent to the southern portion of the master fault, an east-dipping 60 km long conjugate fault develops with a 340º trend and a throw in the order of 300 meters. The resulting graben consequently has southward increasing widths, from ~5 km in the north to ~ 12 km in the south. Between the two faults, three NW-SE faults develop with 200-meter throw, producing three steps, distanced roughly 15 km, within the graben. Based on its overall morphological characteristics, the fault system, named the Sartori Escarpment (SE) (Curzi *et alii*, 2003) has been interpreted to be a left lateral transtensive system (Musacchio *et alii*, 1999). The southern termination of the SE is in proximity of the conjunction between the Palinuro and Marsili volcanic seamounts.

The upper slope region is characterized by numerous relatively short, 100 to 250 meter high fault scarps (fig. 4). Fault orientation falls within the N-S quadrant mostly in the seaward portion of the region while mostly NE-SW trends are present to the East. The scarps extend on average 20 km and dissect the region into several small, N-S/NE-SW trending horsts and grabens, each on average about 8 km wide.

The development of these upper slope structures occurs exclusively to the north of the SE, they are not present to the east of the SE southern termination. Moreover, the southern terminations of the structures are directly juxtaposed to the major SE hanging wall. This seems to indicate that there may well be a structural connection between these two tectonic regimes.

A distinctive morphological characteristic prevails within the lower slope of the Eastern Tyrrhenian margin, west of the SE system. The striking morphological differentiation from the upper slope region is brought about by the development of a number of linear fault scarps that closely follow the trend of the SE. The faults affect the entire lower slope area, up to the limits of the deep-water abyssal plain. Average fault length is in the order of 35 km with down-to-the-West variable throw between 100 and 400 meters. The SE trend is dominant, with virtually the only exception being the N-S fault bounding Flavio Gioia seamount.

The SE in point of fact bounds a lower slope affected by extensional structures directly linked to the generation of the deeper portion of the Tyrrhenian basin, or a "Tyrrhenian-type" lower slope, and an "Apenninic-type" upper slope area that can only be loosely associated to this event. South of Palinuro seamount, a remarkable change occurs in morphology and structure style since it is both the northern limit of the ocean floored Marsili basin and the associated active Aeolian volcanic arc

A deep-seated cause can be advanced to better comprehend these structural differences. Considering that the seismicity related to subduction beneath the southeastern Tyrrhenian Sea is rather well delimited by the entire length of the SE, occurring practically only to the West of it, mantle stress gradients generated by slab rollback and sinking may have propagated to superficial crustal levels to form structural divides, such as the SE, approximately aligned along the deep slab edge (Marani & Trua, 2002). In this sense, this region is defined as the active margin geodynamic province, notwithstanding that, since at least mid-Pleistocene, the inner portions of the Apennine fold and thrust belt bordering this sector are affected by normal faulting, the compressional front having migrated to the Adriatic Sea.

3.4. - Oceanic Terrain Province: central/southern Tyrrhenian back-arc and arc

The central and south-eastern, deep-water (>3000 m) portions of the Tyrrhenian Sea are floored by oceanic crust produced during two distinct episodes of accretion, first in the central Tyrrhenian Vavilov backarc basin (VB), followed by a shift to the south-east to the Marsili backarc basin (MB). Generation of the VB and MB are dated 4.3-2.6 Myr and <2 Myr respectively. Regional lithosphere models for both basins concur with their oceanic nature giving crustal thicknesses of <10 km and a 30 km LID.

Outstanding morphological features of the otherwise flat lying, turbidite-filled abyssal plains are the large seamounts that occupy the central parts of the VB and MB (figs. 5, 6). The submerged portion the Aeolian Island volcanic arc associated to the development of the MB, moreover, is well developed both to the West and East of the islands.

The deep plains of the Vavilov basin have roughly a triangular shape, delimited to the West by the Selli Line and to the east by the lower slope of the southeastern Tyrrhenian active margin and the MB (fig.5). The vertex of the triangle, the northernmost limit of the VB, occurs only a few km south of Ponza Island, forming one of the highest gradient slopes (from 0 to -3500 m) in the Tyrrhenain Sea. The southern border of the VB occurs in a region of complex, sediment capped topography north of western Sicily.

Several large seamounts, along with seamount chains and linear trending fault scarps complicate the morphology of the VB. Extensive previous (Structural model of Italy, 1991) and recent (Gamberi *et alii*, in press) seafloor sampling shows that the structural features are related either to basement terrains or to the development of large submarine volcanoes.

Outcropping "Corsica-type" alpine units and Upper Miocene rocks characterise the scarp of the NE-SW Selli Line (SL). It is morphologically distinct for about 80 km and has on average 250/300 m.

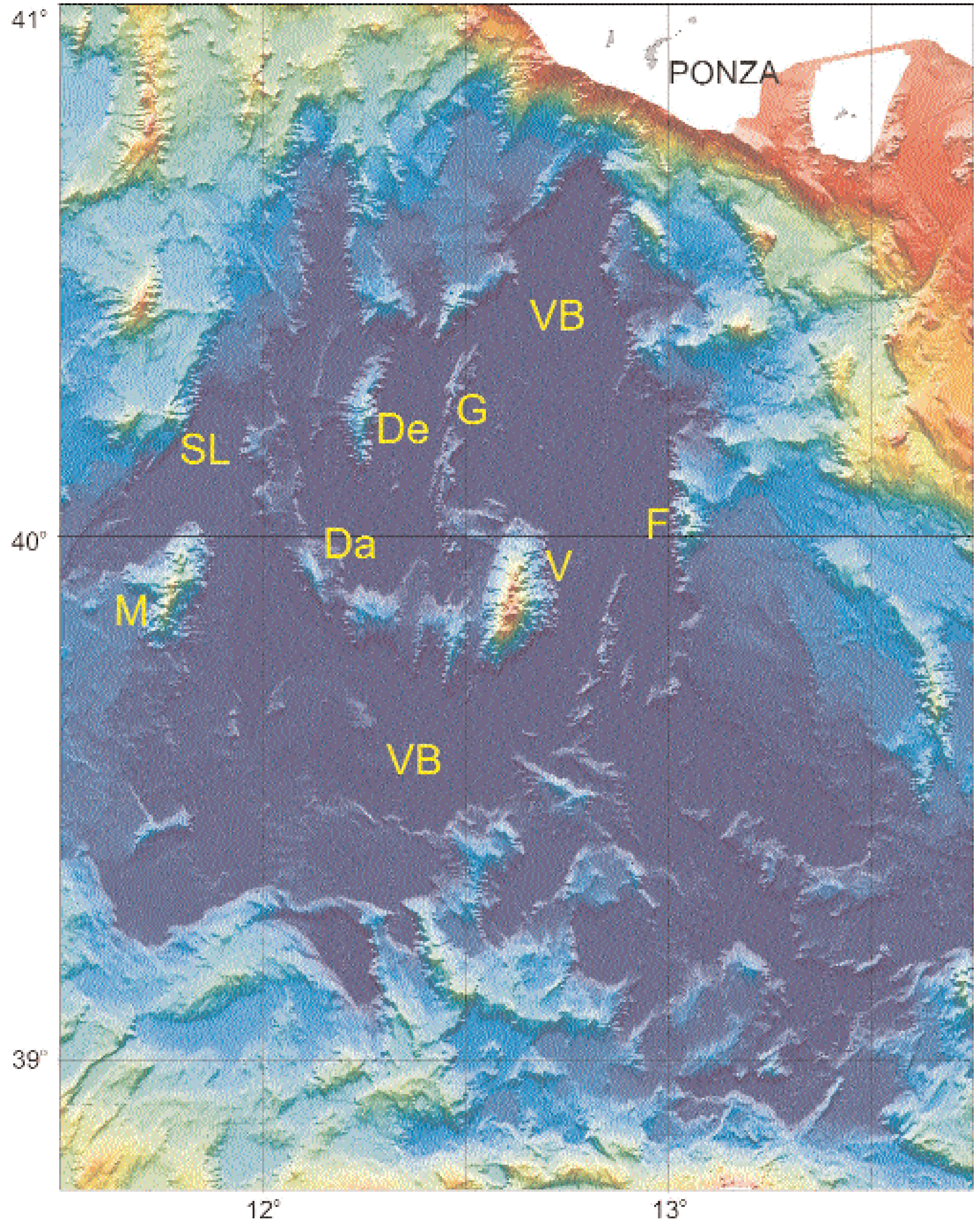

Fig 5. - *Vavilov Basin Province. Colour code and illumination as in figure 1. The deep Vavilov basin (VB) plain is interspersed with diverse morphological elements. These are the Selli Line (SL), fault, the De Marchi (De) and Flavio Gioia (F) tilted blocks, the Gortani (G) and D'Ancona (Da) ridges and the large volcanoes Vavilov (V) and Magnaghi (M). Refer to text for detailed discussion of each feature.*

throw, dropping down to the VB abyssal plain. Fault throw is variably distributed along close spaced splays in some cases connected by relay ramps. The SL is a fault system of significant structural importance, dividing the passive margin province from the Tyrrhenian oceanic domain.

Within the northern part of the VB, two seamounts represent a second and probably definite boundary between the oceanic crust of the basin and the surrounding thinned crustal blocks. These are the western De Marchi and the eastern Flavio Gioa seamounts. They are 80 km apart, both are N-S trending and characterised by a distinct asymmetry, the former presenting a steep eastwards dipping fault scarp and gentler western slope, the latter being a mirror image, with a steep westwards dipping fault scarp and gentler eastern slope. Both have an elevation of 1200 m, rising from the ~3600 m deep VB plain. The seamounts, composed of metamorphic units related to Alpine Corsica in the case of De Marchi and to Calabride units in that of Flavio Gioia, in effect represent the final trace of rotational crustal blocks within the VB.

The Gortani Ridge, a ~40 km linear morphological high with a maximum elevation in the order of 300/400 meters is positioned between the two tilted blocks, about 20 km from De Marchi seamount and 60 km from Flavio Gioia seamount. ODP drill-site 655 showed this feature to be made up of T-MORB basalt flows, considered by KASTENS & MASCLE, 1990 to be the earliest evidence (~4 Myr) for emplacement of oceanic crust in the VB.

The central VB is more intricate from a morphological point of view. The major feature is the axially located Vavilov volcano. It is positioned just south and midways between the De Marchi and Flavio Gioia seamounts. Vavilov volcano is elongated NNE/SSW for 40 km, is on average about 10 km wide and stands 2800 meters above the abyssal plain with summit depth at 730 meters. Its distinctive asymmetry, displayed by a steep, smooth western flank and a gentler eastern flank, where satellite cones develop, presupposes a probable collapse event of the western flank of the volcano. Deep-tow side scan sonar data along the base of the western flank do not definitely clarify this hypothesis since the areal extension of the isolated patches of large blocks that have been found to crop out cannot be verified due to the area being mostly sediment covered (MARANI *et alii*, 2003). However, reflection seismic data along the western base region show a very shallow acoustic basement respect to the eastern base, which could correspond to infilling of rock avalanche deposits.

One other large volcano, Magnaghi seamount dominates the western part of the central VB, in proximity to the SL. It has approximately the same trend of the Vavilov, with a length of ~25 km and a summit height of 1470 meters.

Both Vavilov and Magnaghi volcanoes are made up of tholeitic to alkalic basalts (ROBIN *et alii*, 1987; SAVELLI, 1988) of Late Pliocene age (KASTENS, MASCLE *et alii*, 1990; SAVELLI, 1988). These Authors therefore conclude that the large volcanoes of the VB were formed after the bulk of the low standing basaltic crust of the basin had been generated.

The final morphological feature of the central VB casts some doubt on the actual position of the boundary between continental and oceanic crust in this portion of the basin. The D'Ancona ridge is an arcuate high-standing feature that initiates in the region between the SL and the De Marchi seamount and terminates against the southern tip of the Vavilov volcano. The structure is made up of a series of highs, with elevations reaching even 800 meters but on average with heights between 200 and 400 meters. In proximity to the Vavilov volcano, the D'Ancona ridge is formed by sharply defined N-S striking linear features, similar to the trend of the volcano and to the trend of the linear, subdued ridge to the east of the Vavilov seamount. Recently acquired high resolution air-gun seismic reflection data (MARANI *et alii*, 2003) show that the central portion of the D'Ancona ridge positioned between the Magnaghi and Vavilov seamounts possesses a sedimented (~250 meter thick) cover, faulted basement with a seismic facies more akin to continental basement, very different from the strongly reflective, basaltic crust. Although Vavilov seamount has been recently extensively sampled (GAMBERI *et alii*, in press), no samples were collected from the nearby linear part of the D'Ancona ridge which could, due its morphological character and proximity to the volcano, be of a volcanic nature. However, the continental basement type characters of that portion of the D'Ancona ridge lying between the Magnaghi and Vavilov volcanoes demonstrates that the alleged geodynamic setting of the northern VB does not apply to the central VB. The differentiation could be simply brought about by the presence of isolated rafted blocks of continental crust within the basaltic basement of the central VB, which did not develop in its northern portion. Alternatively, the D'Ancona ridge could play a more important role as a strong demarcation in crustal nature in some way involving the development of the two large volcanoes that characterise this region.

To the southeast, across a region of subdued seafloor topography corresponding to a saddle of ~15 km thick crust (SCARASCIA 1994, PANZA & SUHALDOC, 1989), the Vavilov basin passes to the more recent Marsili basin (fig. 6) where crustal thickness returns to less than 10 km. This small, ~2 Myr-old near-circular backarc basin stands at 3500 meters water depth. Kilometre-scale fault scarps, which develop at the southern part of the basin, delimit the upper slope area in which the Aeolian volcanic arc develops. To the north, the Palinuro volcanic complex bounds the deep basin plain. More subdued topography characterises the eastern boundary of the MB along the course of the Stromboli Canyon as it reaches the abyssal plain.
Most of the MB is occupied by the homonymous Marsili volcano, which is practically the only morphological element of relevance. The volcano

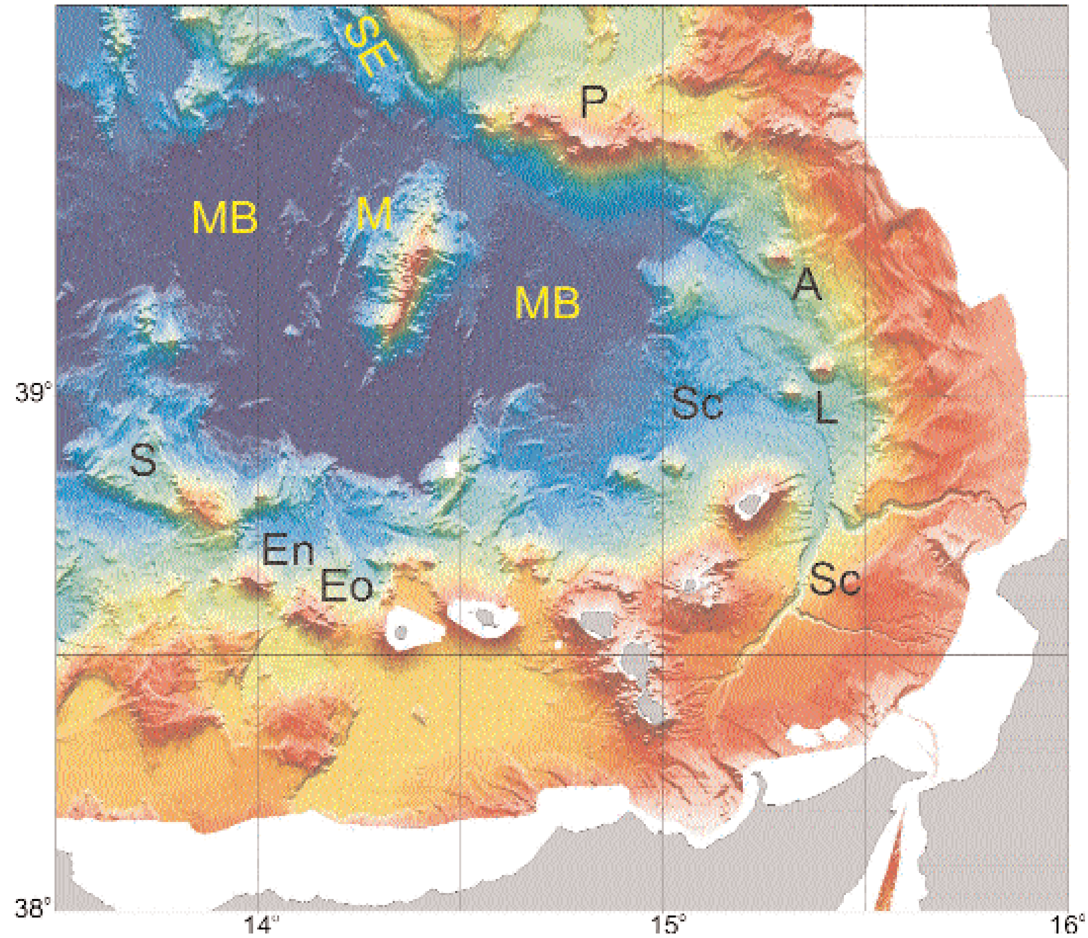

Fig. 6. - *Marsili basin Province. Colour code and illumination as in figure 1. Marsili basin (MB) is the recent-most ocean crust floored basin, characterised by the large, axially located Marsili volcano (M). The deep basin is delimited by the Palinuro volcanic complex (P) and by the Aeolian volcanic arc located on the upper slope which is cut by the Stromboli Canyon (Sc). Submarine extensions to the arc are represented by the Lametini seamounts (L) and Alcione volcano (A) to the east and Eolo (Eo), Enarete (En) volcanoes and the Sisifo volcanic (S) ridge to the west. Refer to text for detailed discussion of each feature.*

rises 3000 metres from the deep plain of Marsili basin to a minimum depth of 489 metres, and is elongated NNE-SSW with a length in the order of 50 km and a mean width of 16 km. It is flanked by a series of linear basin-floor fault scarps that form a symmetrical horst and graben structure at its sides (fig. 6). In its summit region the volcano is characterised by a marked linearity formed by coalesced or single elongated cones. The development of fields of small volcanoes with mostly flat tops, and several with breached craters, characterise its lower flanks.

Sampling data (MARANI *et alii*, 1999; TRUA *et alii*, 2002) show that the volcanoes of the cone fields and the lower flanks of the volcano are composed of calc-alkaline basalts while evolved high-K andesites were recovered only in the summit cones. Moreover, modelling results (TRUA *et alii*, 2002) indicate that the formation of the andesites is compatible with the differentiation of the type of basalts found in the lower reaches of the volcano, indicating a possible upper magma chamber within the volcano. The age of the volcano is estimated at ~0.7 Ma, based on the magnetic anomaly pattern of the edifice (FAGGIONI *et alii*, 1995) which indicates that the bulk of the volcano erupted within the normal polarity geomagnetic chron C1 (Bruhnes). Radiometric dating of rocks collected from near the summit area (SELLI *et alii*, 1977) furnish ages of ~0.1 Ma. The volcano has been interpreted to result from a strong thermal pulse of asthenospheric material produced by a rapid phase of slab rollback during Mid Pleistocene (MARANI & TRUA, 2002).

The islands and submarine volcanoes comprising the active volcanic arc associated to the Marsili backarc basin occupy the upper slope of the southeastern Tyrrhenian Sea. Submarine volcanoes, developed since 0.8 Ma (BECCALUVA *et alii*, 1985), form an extension to the emerged islands both eastwards and westwards. The arc is well delimited to the north by the 50 km E-W development of the ~0.35 Ma old (COLANTONI *et alii*, 1981) Palinuro composite basaltic andesite volcano. The volcano morphology is made up of at least 6 distinct volcanic cones developed at a base level in the order of 1400 metres in the slope margin between the active margin geodynamic province to the north and the MB oceanic terrain to the south. In fact, the southern flank of the Palinuro volcanic complex drops more than 3 km to the MB abyssal plain (fig. 6).

The complex morphology and the key location of Palinuro volcano, at the boundary between two wholly distinct geodynamic provinces, point to an important role played by this structure during the recent evolution of the southeastern Tyrrhenian Sea. Its structural importance may be followed also through its extension to the emerged areas of the Italian peninsula, where the boundary between the Apennine terrains and the Calabride complex occurs.

South of Palinuro volcano the three submarine volcanoes that form the eastern extension of the Aeolian arc, Alcione volcano and the twin cones of the Lametini seamount are morphologically distinct (fig. 6). The submerged western extension of the arc is formed by the NW-SE alignment of the Eolo and Enarete volcanoes and the Sisifo volcanic ridge.

4. - QUATERNARY MANTLE DYNAMICS IN THE SOUTHEASTERN TYRRHENIAN SEA

The preceding account has attempted to show the geological development of the Tyrrhenian Sea by way of the present-day seafloor morphology. It is evident that seafloor makeup furnishes more immediate information the more recent are the geological events that contribute to its creation. The Marsili basin is thus the region of the Tyrrhneian Sea where a possible link between seafloor morphology and deep structure can be established. In fact this recent backarc basin is underlain by a steeply dipping subducting slab of Mesozoic oceanic crust and contains or is surrounded by some of the major shallow seated structures described in this paper. If one extends a view to the surrounding southern Apennine chain and Calabrian arc, the geological overall picture becomes of geodynamic importance.

Recently, various authors have put forward models relating deep mantle dynamics induced by rollback of the Ionian slab to the coupled effects observable at the seafloor. Gvirtzman & Nur, 1999, based on crustal modeling studies, link the formation of Etna volcano to sideways asthenospheric flow induced by slab decoupling beneath Calabria, giving also rise to the uplift of Calabria itself. Based on the morphology of the southern Tyrrhenian seafloor, its structural makeup and with the support of petrographical studies of recently sampled rocks (Trua *et alii*, in press), Marani & Trua, 2002 suggest that dip-directed tears at the sides of the slab induce the rise of deep asthenospheric material to the Marsili basin area and surroundings, and recognise the surface traces of the tears.

This paper has endeavoured to show that seafloor morphology can serve a variety of functions in regions of recent formation. Particularly in cases where detailed topographic data may indirectly reveal the surficial effects of deep-seated processes, the same information becomes the baseline data for subsequent research, for instance seafloor sampling and petrological studies or geophysical surveys that can be undertaken to substantiate the surface observations.

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