Crustal image of the Ionian basin and accretionary wedge

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(Received November 8, 2005; accepted May 2, 2006)

ABSTRACT The interpretation of the CROP-MARE deep seismic lines has revealed the structure of the Ionian crust and the geometry of the subduction beneath the Calabrian Arc. CROP seismic lines crossing the Ionian abyssal plain and the south-eastern Tyrrhenian, through offshore southern Calabria, return an image of a well-developed SE-vergent accretionary wedge and the NW-dipping oceanic basement. In the abyssal plain, the Ionian basement images a highly reflective, layered body and a transparent and unstratified band with overlapping hyperbolae, corresponding to an oceanic crust; the oceanic Moho deepens northwards from 9 to more than 10 s/TWT in a few kilometres. The crystalline crust is still coupled with the oldest sedimentary layers. In the intermediate Ionian sector the crust progressively deepens with a complex trajectory, appearing offset by a WNW-ESE lateral (?) discontinuity. The Moho develops at about 11 s/TWT. In approaching the SE Calabrian offshore area the oceanic crust becomes steeper as the Moho discontinuity occurs at more than 14 s/TWT. The upper crust, strongly deformed in some tectonic slices, is overlain by a 2 s/TWT thick sedimentary rock-imbricated wedge, in turn underlying a 3 s/TWT thick seismically transparent to chaotic body, correlatable to the adjacent Calabrian units. The reflection seismic lines imagery shows that both sedimentary and crystalline Ionian crustal bodies are progressively detached from their substrate more deeply and markedly towards NW. As a consequence, the sedimentary and oceanic crust units appear imbricated to form the SE verging accretionary wedge. The subduction hinge zone is seismically imaged in the area where the Calabrian crystalline units overthrust the deformed oldest sediments deposited on the Ionian crust. The occurrence of an oceanic crust certainly favours subduction in this area, generating the Aeolian volcanic arc and the deep seismicity in the south-eastern Tyrrhenian, as well as the ascent of the Etna magmas. The comparison with the crustal setting of the adjacent continental crustal sectors (Sicily and Southern Apennines) highlights the importance of the crustal and lithospheric heritage of the downgoing foreland. The convergence of two continental crusts causes more difficulty in the subduction of the Sicilian crust with respect to the Ionian sector where a greater convergence rate facilitates both a southward advancing of the deformation front (arcuate shape of the Apenninic front) and a vertical separation between the Ionian and Sicilian crusts. The surface expression of this behaviour is the shorter propagation of the Sicilian frontal accretion and the building of a chain with a greater topographic relief than the accretionary wedge of the Calabria-Ionian sector.

1. Introduction

In recent years, the nature of the Ionian crust has been a matter of debate between two end-member hypotheses, based mainly on controversial interpretations of the geophysical data. Using geological and geophysical evidence, Le Pichon (1982) described the Ionian region as a land-locked oceanic basin, while Makris (1975), Finetti (1982, 2004), Makris and Stobbe (1984), Finetti and Del Ben (1986), Makris *et al.* (1986) and De Voogd *et al.* (1992) pointed to the occurrence of "oceanic" features of the crust beneath the Ionian. Other researchers suggested the occurrence of a denser continental crust (Calcagnile and Panza, 1981; Giese *et al.*, 1982) or a thinned continental crust (Boccaletti *et al.* 1984; Cernobori *et al.*, 1996; Panza *et al.*, 2003; Ismail-Zadeh *et al.*, 1998; Locardi and Nicolich, 2005), on the basis of seismic reflection, petrological and tomographical data, as well as subsidence modelling. Recent studies based on seismic facies analysis and seismostratigraphic geometries, calibrated by seismic refraction data, highlighted the occurrence of a passive continental margin (Iblean-Pelagian platform) from offshore south-eastern Sicily to the western Ionian, and of an "oceanic" crust in the adjacent Ionian abyssal plain (Catalano *et al.*, 2000 , 2001, 2002).

Many doubts remain about the timing of the opening of the presumed Ionian oceanic crust since its age is attributed to the Permian (Vai, 1994; Stampfli and Borel, 2004; Finetti, 2004), Permian-Triassic (Finetti, 2004; Stampfli 2005; Argnani and Bonazzi, 2005), Jurassic (Della Vedova and Pellis, 1992; Finetti *et al.*, 1996), Late Jurassic (Catalano *et al.*, 2000) and Cretaceous (Dercourt *et al.*, 1985, 2000). Others regard this ocean as having opened during the Late Triassic or Early Jurassic (Garfunkel and Derin, 1984; Sengor *et al.*, 1984; Robertson *et al.*, 1996), possibly in conjunction with the opening of the Alpine Tethys in the Central Atlantic. Two continental shelf areas (Pelagian and Apulian shelves) bounding the western Ionian that could represent the conjugate continental margins of the ancient ocean (Doglioni *et al.*, 1999; Catalano *et al.*, 2000, 2001) have been described. They may have formed only after a Late Permian-Triassic continental rifting affecting the northern African margin (Catalano *et al.*, 1988; Robertson, pers. comm.).

In the framework of plate tectonic reconstructions, which show that Africa has been moving north with respect to Eurasia (Bellon *et al.*, 1977; Malinverno and Rian, 1986; Dercourt *et al.*, 1986; Scotese and Sager, 1988; Stampfli *et al.*, 1991; Oldow *et al.*, 2002; Stampfli and Borel, 2004), there is more agreement on the final fate of the Ionian crust as currently moving north-west beneath the Calabrian Arc [Calabria-Peloritani Units: Bonardi *et al.*, (2001)], in a subduction setting. The present-day deep earthquakes in the Tyrrhenian depict a steep Benioff zone (Gasparini *et al.*, 1982; Selvaggi and Chiarabba, 1995).

Most of the relative motion between the hanging wall and the subducting plate is to be attributed to a progressive retreat of the Ionian lithospheric slab.

The Ionian slab is imaged across the entire upper mantle according to Spakman *et al.* (1993), Amato *et al.* (1993), Piromallo and Morelli (1997), also supported by detailed local tomography models (Selvaggi and Chiarabba, 1995).

Nevertheless, the classic B type subduction model is not commonly accepted owing to the "funnel-shaped" geometry of the Benioff plane.

Whether the motion is active (roll back) or passive is still under debate, as the slab is envisaged as being detached from the Ionian ocean by a very small gap (Spakman *et al.*, 1993;

Wortel and Spakman, 2000). Extrusion of a crustal block, as a result of continuing Africa-Europe convergence above a detached slab setting, continues to be substained (see Cavazza *et al.*, 2004).

Active subduction zones, set off by external convergence forces, are not recognized by Locardi and Nicolich (2005), who support the hypothesis of a process of mantle “swelling” at the top of a migrating thermal plume (Locardi and Nicolich, 1988).

Last but not least, the Ionian abyssal plain oceanic crust is overthrust by a complex accretionary wedge formed by the Calabrian crust, at its top, and a stack of sedimentary thrust units (Finetti, 1982, 2004; Nicolich *et al.*, 1995). This Ionian crustal wedge was preliminarily described by Catalano *et al.* (2002) as a composite wedge formed by crustal (oceanic) slices and a thrust stack of sedimentary bodies that originally deposited on the oceanic and/or thin continental basement.

The occurrence of so many geodynamic processes and the controversial interpretation of the crustal structure are crucial for the understanding of Central Mediterranean crustal paleogeography and for the reconstruction of the pattern of the convergence between the rims of the African and European plates.

Catalano *et al.* (2000), (2001) and (2002) have already presented preliminary information on some Ionian geodynamic sectors, such as the continental margin-abyssal plain complex and the Calabrian accretionary wedge.

The main aim of this paper is to add new details showing the main Ionian setting and the geometries of the accretionary wedge.

Very little is known about the geometry of the structural edifice forming the accretionary wedge, as also about the nature of the lithologies involved. A direct knowledge of the sedimentary and crystalline rocks is necessary to constrain models and hypotheses that have been previously advanced only on the basis of not-borehole-calibrated seismostratigraphy and theoretical crustal behaviour (Finetti 2004; Stampfli, 2005, among others).

Several seismic lines of the CROP Project, an Italian public crustal seismic reflection acquisition, recorded many years ago and only recently made available in a volume published by Scrocca *et al.* (2003), were used to understand the meaning of the Ionian geodynamics in the framework of the Central Mediterranean evolution during the Permian-Cenozoic time interval.

2. Geological and geophysical framework

The study area (Fig. 1), located in the central Mediterranean between eastern Sicily-Calabria and the Hellenic Arc, is a very complex sector where the Ionian Sea, more than 5000 m deep in its central part, covers a thin high-density crust.

From Calabria to the Ionian abyssal plain two main morphostructural elements can be distinguished: the Calabrian Arc, or Calabria-Peloritani block, and its offshore prolongation [known as the External Calabrian Arc, Selli and Rossi (1975)]. The former is an arc-shaped tectonic wedge that outcrops in NE Sicily (Peloritani Mountains) and Calabria, extending to the adjacent offshore; it consists of a stack of crystalline rootless nappes with remnants of Mesozoic-Tertiary sedimentary cover (Amodio Morelli *et al.* 1976; Bonardi *et al.*, 2001) inserted in the Apenninic-Maghrebian chains. The Calabria-Peloritani block overthrusts the Sicilian and Southern Apenninic chain, advancing in the Ionian sector more than in the adjacent areas (Boccaletti *et al.*, 1984; Doglioni *et al.*, 1999).

The External Calabrian Arc has been described by Rossi and Sartori (1981), Tramutoli *et al.* (1984), Pescatore and Senatore (1986), Senatore *et al.*, (1988), Doglioni *et al.* (1999) as a few-hundred-km-long accretionary prism (Sartori, 1982) resulting from the offscrapping and piling up of crystalline and sedimentary rock bodies.

On the north-western side of the Calabrian arc, the southern Tyrrhenian embayment (Fig. 1) is considered to be a fore-arc basin bounded to the north-west by the Aeolian Volcanic Arc. In this area, the seismicity clearly depicts a steep NW-dipping subduction (Gasparini *et al.*, 1982), also demonstrated by mantle tomography and calc-alkaline magmatism in the Aeolian Islands, mainly ascribed to the slab pull of a retreating, old and dense oceanic lithosphere (Ritsema, 1979; Malinverno and Ryan, 1986). Conversely, Locardi and Nicolich (2005) are in favour of stresses induced at the front of the convective cell associated with a hot asthenolith and opposing mantle.

In the eastern Sicily-Malta offshore a steep physiographical feature (Malta Escarpment, ME) separates the Iblean-Pelagian platform from the westernmost Ionian sector, which is floored by continental-to-thinned continental crust (Catalano *et al.*, 2000).

The ME is a NNW-SSE trending-fault zone believed to be tectonically active only in its northern part (Argnani and Bonazzi, 2005). The main evolution of the ME occurred from the Mesozoic and after the Tortonian (Scandone *et al.*, 1981; Casero *et al.*, 1984; Charier *et al.*, 1987).

3. Data set

We have used a set of seismic reflection profiles that cross the study area from the Ionian to the south-eastern end of the Tyrrhenian (Fig. 1).

The seismic reflection data of the CROP-Mare (recorded in offshore areas) were gathered in the framework of the AGIP-CNR-ENEL joint venture (1991-1994), using a 4500 m long, 180-channel digital streamer and an airgun-tuned array, towed at an average depth of 8 m. The shot interval was 50 m, the sampling rate 4 ms, and the recording length 17 s.

During processing, the number of channels was reduced to 90, giving a 45-fold coverage, with the data resampled to 8 ms. Processing procedures, based on conventional techniques, included trace equalization, predictive deconvolution, velocity analysis, f-k filter, multiple attenuation, time-variant filter, NMO corrections and stack. The seismic lines are not migrated and, in places, residual multiple energy remained. Care was thus taken in interpreting the crustal sections.

The analysis of the seismic facies and the reflection pattern was compared with industrial seismic lines (supplied by AGIP) and calibrated by boreholes in the upper levels along the Iblean-Malta margin, to include controlled geological information on the areas crossed by the CROP seismic profiles. Interpretative techniques attempted to distinguish several seismic facies to estimate the lithology and geometry of the reflecting units and to discriminate between sedimentary and crystalline units.

Previously published seismic reflection line interpretation (Finetti, 1982; Casero *et al.*, 1984; Cernobori *et al.*, 1996; Nicolich *et al.*, 2000), magnetics, gravity (Finetti and Morelli, 1973; Morelli *et al.*, 1975), heat flow (Della Vedova and Pellis, 1992) and bathymetry, as well as seismic refraction data [ESP, DSS, EGT and WARR: Hinz, (1973), Makris *et al.*, (1986), Ferrucci *et al.*, (1991), Avedik *et al.*, (1995)], were used to constrain, at a regional scale, the crustal segment

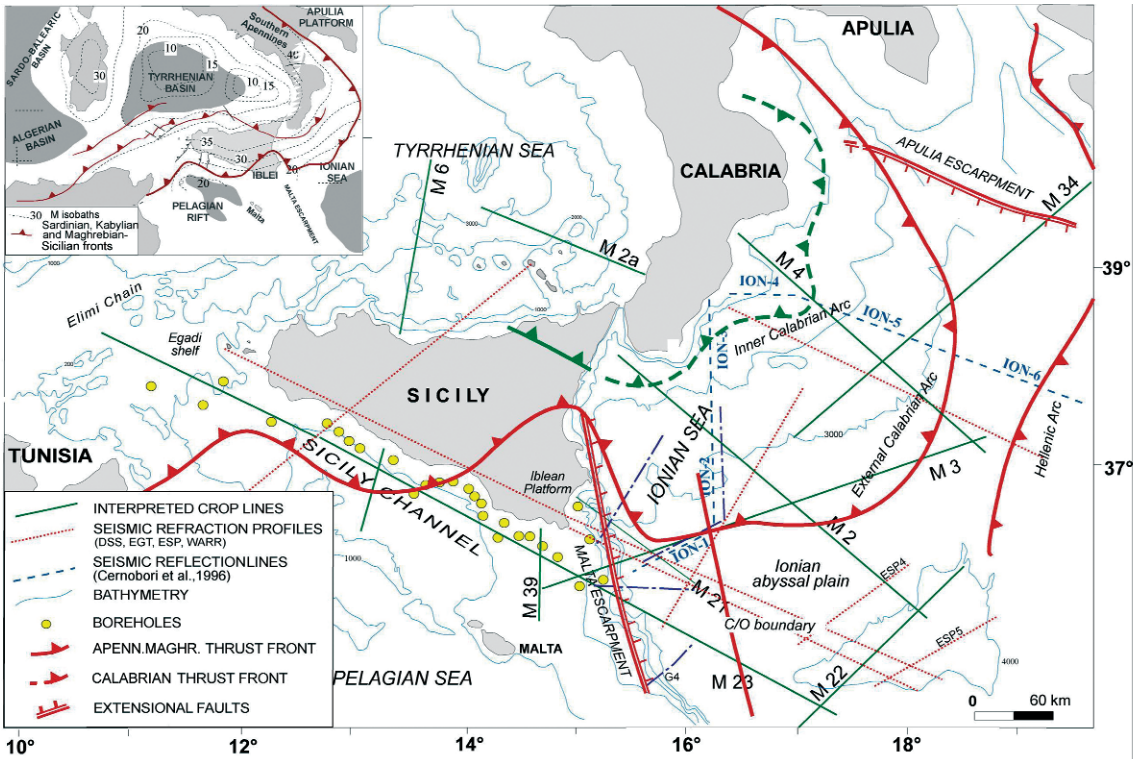

Fig. 1 - Index map of the study area showing bathymetry and main locations [modified from Catalano *et al.*, (1996)]. The grid of the interpreted deep crustal (CROP) seismic profiles is accompanied by traces of seismic refraction profiles. Previously published seismic reflection interpretations and borehole locations are reported. The top left corner presents a tectonic sketch of the central Mediterranean area. Dotted lines represent Moho isobaths.

interpreted from the seismic reflection profiles.

4. Results

Some regions, characterized by different crustal patterns, have already been recognized in the study area, on the basis of a previous seismic reflection analysis (Catalano *et al.*, 2000): the Iblean-Pelagian shelf, the Iblean-Pelagian continental margin in the western Ionian Sea, the Ionian abyssal plain and the Ionian accretionary wedge. Morever recently performed research has enabled us to define the characteristics of these regions in greater detail.

4.1. The Iblean-Pelagian continental margin

The structure is composed of the Iblean-Pelagian continental shelf and its continental slope and rise (Figs. 1, 2, and 3). The crustal features show a Moho discontinuity that develops at the base of strong reflectors located at about 8-9 s/TWT (Figs. 2 to 4) corresponding to a depth of 27 km. Chironi *et al.* (2000), using wide-angle seismic investigation, detected a Moho depth of about 30 km. The crystalline basement is a strong, almost continuous, reflector dipping from 5 s/TWT down to 6.5 s/TWT, and rising up to 4.5 s/TWT towards the upper slope along the ME (Fig. 4). The basement is clearly faulted (Figs. 2 and 4).

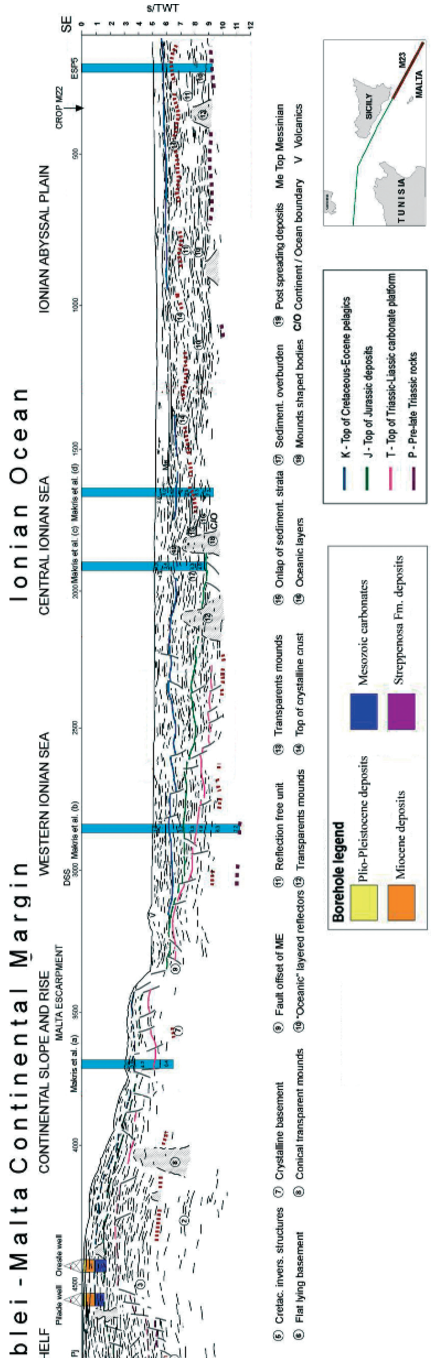

Fig. 2 - M23 geoseismic section showing the crustal pattern and geometries of the continental margin to the ocean transect.

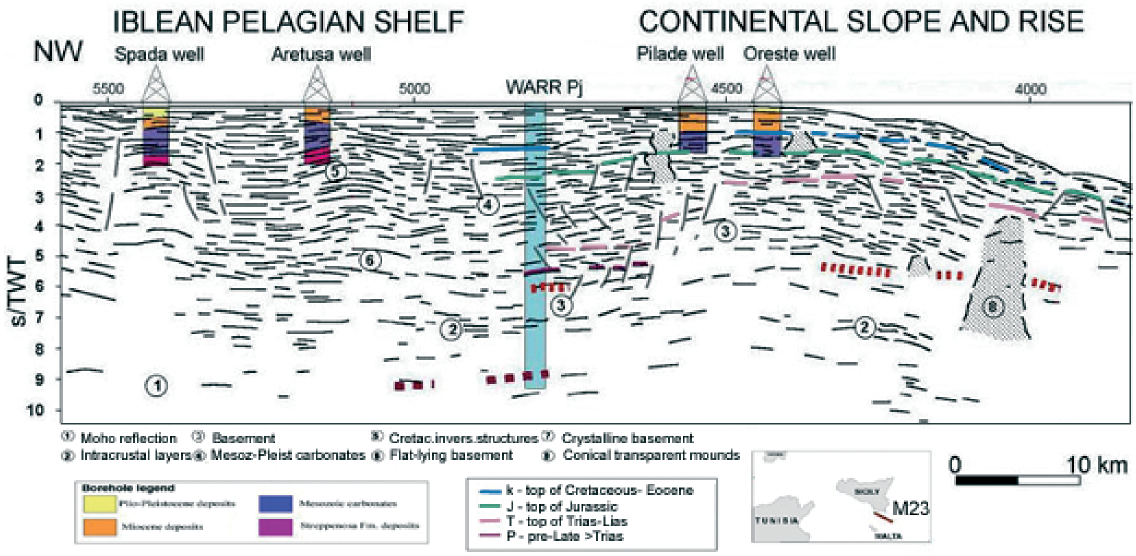

Fig. 3 - Detail of the M23 geoseismic section highlights rifting events starting in pre-late Triassic and lasting until the Jurassic-Cretaceous.

A lower seismic body, strongly block-faulted, and a group of overlying reflectors, which extend through the whole continental shelf, are generated by the 7-9 km-thick sedimentary cover (Fig. 3).

Interpretation based on seismic facies analysis, calibrated by a large number of boreholes, assigns the block-faulted interval to upper Triassic-to-Jurassic carbonate platform rocks, and the overlying reflectors to the Cretaceous pelagic succession (Fig. 3). All these horizons are arched locally in broad folds and are slightly detached from the flat-lying basement. Asymmetric troughs are filled by the well-known upper Triassic-lower Liassic slope-to-basin deposits of the Streppenosa and Modica formations (Patacca *et al.*, 1979). Tabular or mound-shaped volcanics and extensional faulting structures, already described by Scandone *et al.* (1981), Antonelli *et al.* (1991), Casero and Roure (1994), are fossilized in the sedimentary body.

Along the continental slope and rise the Moho discontinuity rises eastwards from 30 to 20 km [as reported by Scarascia *et al.*, (1994)]. Seismic refraction data (Makris *et al.*, 1986; Nicolich *et al.*, 2000) suggest the Moho reaches a depth of about 18-19 km in the western Ionian.

The top of the faulted crystalline crust is traceable between 4.5 s/TWT (11.5 km below sea level) and 6.5 s/TWT (11 km) beneath the ME (Fig. 4). In our interpretation the thinning of the crust is further supported by location of the geophysically controlled (Avedik *et al.*, 1995) crystalline basement reflector. There, it is overlain by a 3.5 s/TWT thick sedimentary overburden (Fig. 2).

Close to the ME zone, the crystalline basement is abruptly downthrown to about 8-9 s/TWT, by a crustal extensional fault system (Fig. 4) previously dated as post-Tortonian (Casero *et al.*, 1984). The sedimentary prism thickens from 3 s/TWT (7-7.5 km) in the upper slope to 4.0 s/TWT (7.5 km) downslope in the area located in the western Ionian abyssal plain (Fig. 4).

Avedik *et al.* (1995) described the seismic features of a section (Bin Hai line), in this region

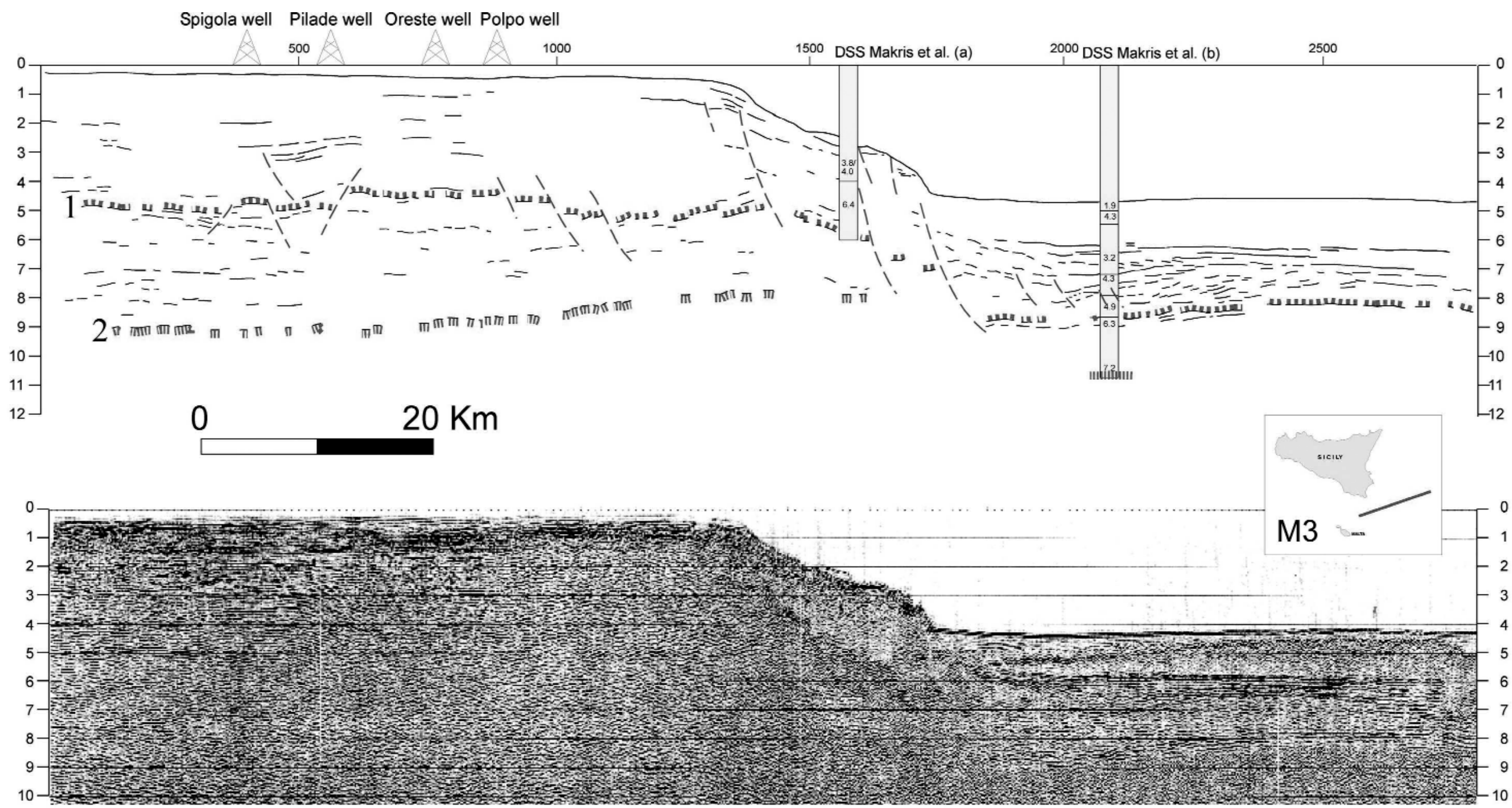

Fig. 4 - M3 CROP seismic line and geoseismic section highlighting a block faulted horizon occurring at 5 s/TWT, interpreted as the top of the crystalline basement (1). The Moho discontinuity (2) rises up from 9 s/TWT to 8 s/TWT below the slope. Continental crust progressively thins out eastwards.

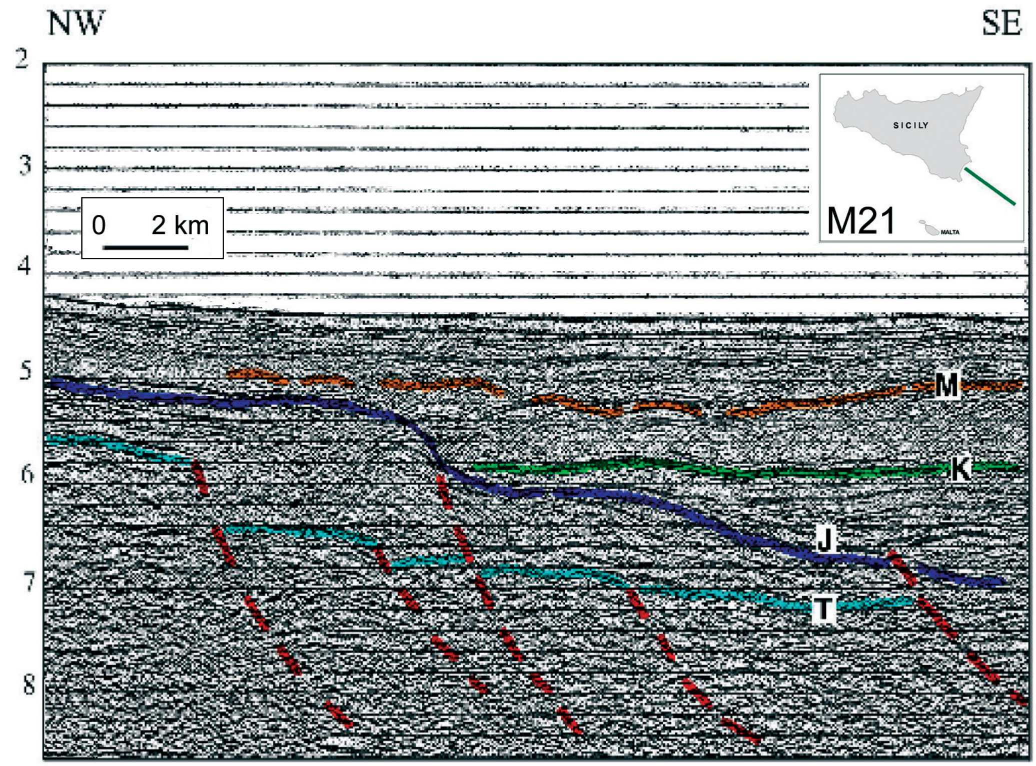

Fig. 5. Detail of M21 CROP seismic line in the western Ionian region. The interpreted line highlights the architecture of the original continental margin. T: Triassic-Liassic carbonate platform; J: Upper Jurassic deposits; K: Late Cretaceous-Eocene pelagics; M: Messinian horizon.

(Fig. 1), as pertaining to an attenuated continental crust. While Stampfli *et al.* (2001), who did not properly calibrate this seismic section with refraction velocities recorded by Makris *et al.* (1986) farther east, in the western Ionian, attributed it to an oceanic crust. Our seismic data fit entirely with the Avedik *et al.* (1995) calibration.

Seismostratigraphy is insufficient to clearly image a physical correlatability between the key horizons in the footwall (Iblean-Pelagian slope and rise) and the hanging-wall (western Ionian) of the ME. This correlatability is inferred here on the basis of the comparable seismic facies recognized, both in the Iblean-Pelagian shelf edge and in the western Ionian, as pertaining to carbonate platform rocks (Catalano *et al.*, 2000, 2001). The occurrence of Triassic-Jurassic carbonate platform deposits, crossing the ME slope, was already claimed by Biju Duval *et al.* (1977) and Scandone *et al.* (1981). Casero *et al.* (1984), describing an Eocene-Mesozoic succession flooring the western Ionian abyssal plain, pointed out that post-middle Eocene neritic deposits are present both westwards and eastwards across the ME, and Cernobori *et al.* (1996) suggest a Jurassic-Pleistocene age for the sedimentary multilayer occurring some kilometres farther east from the ME.

Also, in the hanging wall of the ME, seaward-prograding sigmoidal reflectors, interpreted as a Triassic-Jurassic carbonate platform (Catalano *et al.*, 2000), thin out eastwards (Fig. 5). They

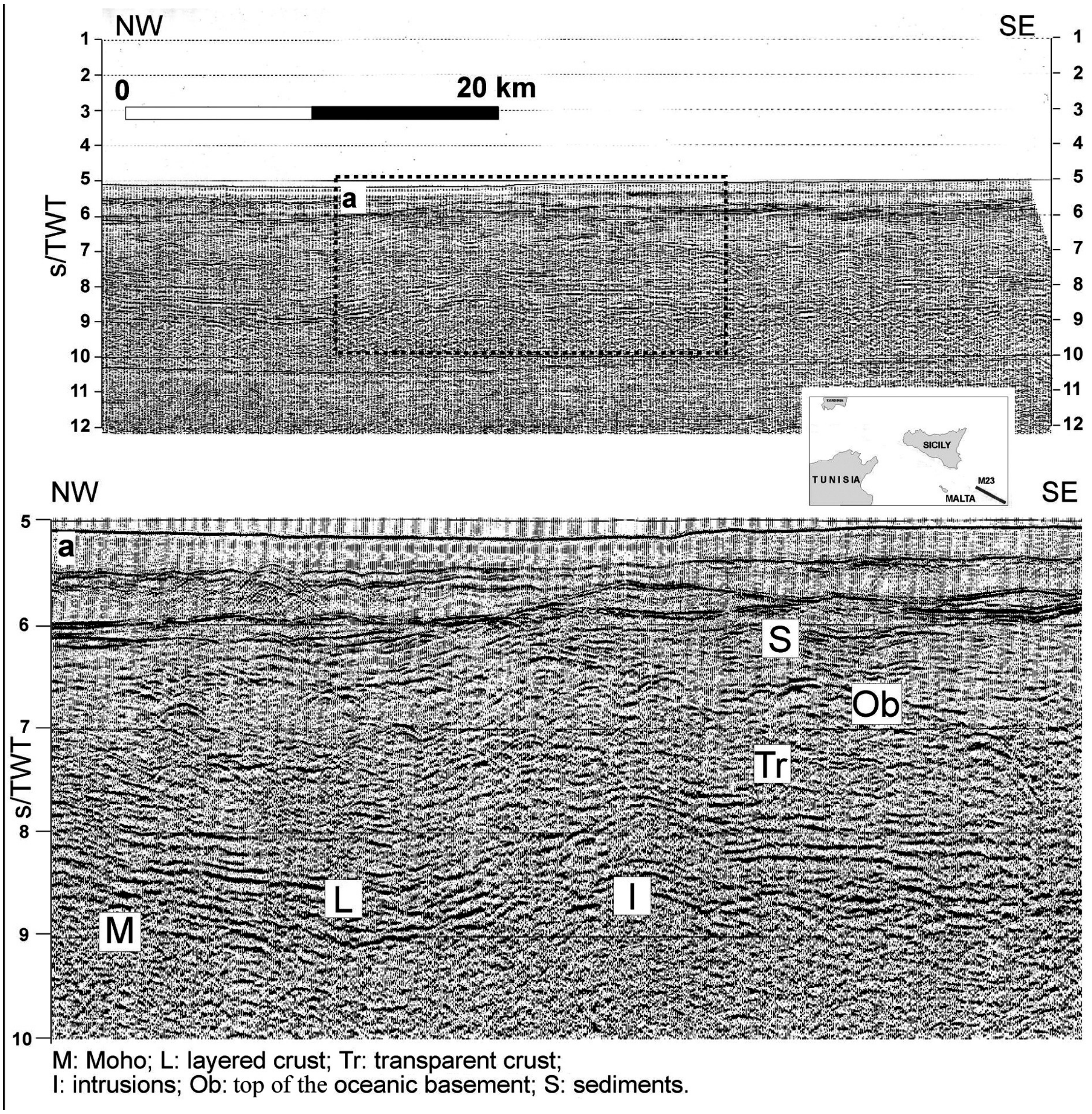

Fig. 6 - Details of M23 seismic line showing the Ionian abyssal plain oceanic crust. At the bottom an enlarged view showing the layered crust. Oceanic crustal parameters:
- Moho discontinuity depth between 8.8 to 9.2 s/TWT (16 km);
- crystalline crust, 7 to 8 km thick;
- sedimentary cover, 5 to 7 km thick (3 to 2 s/TWT) using ESP and DSS velocity model;
- Mesozoic to Lower Messinian deposits, about 3 km thick.

are onlapped by flat-lying transgressive pelagic deposits that thicken seawards. This stratal pattern images an original continental margin edge (Fig. 5).

The Iblean Pelagian continental margin has recently been described by Cantarella *et al.* (1997) and Catalano *et al.* (2001) as the conjugated margin of the Apulian swell on the other side of the Ionian.

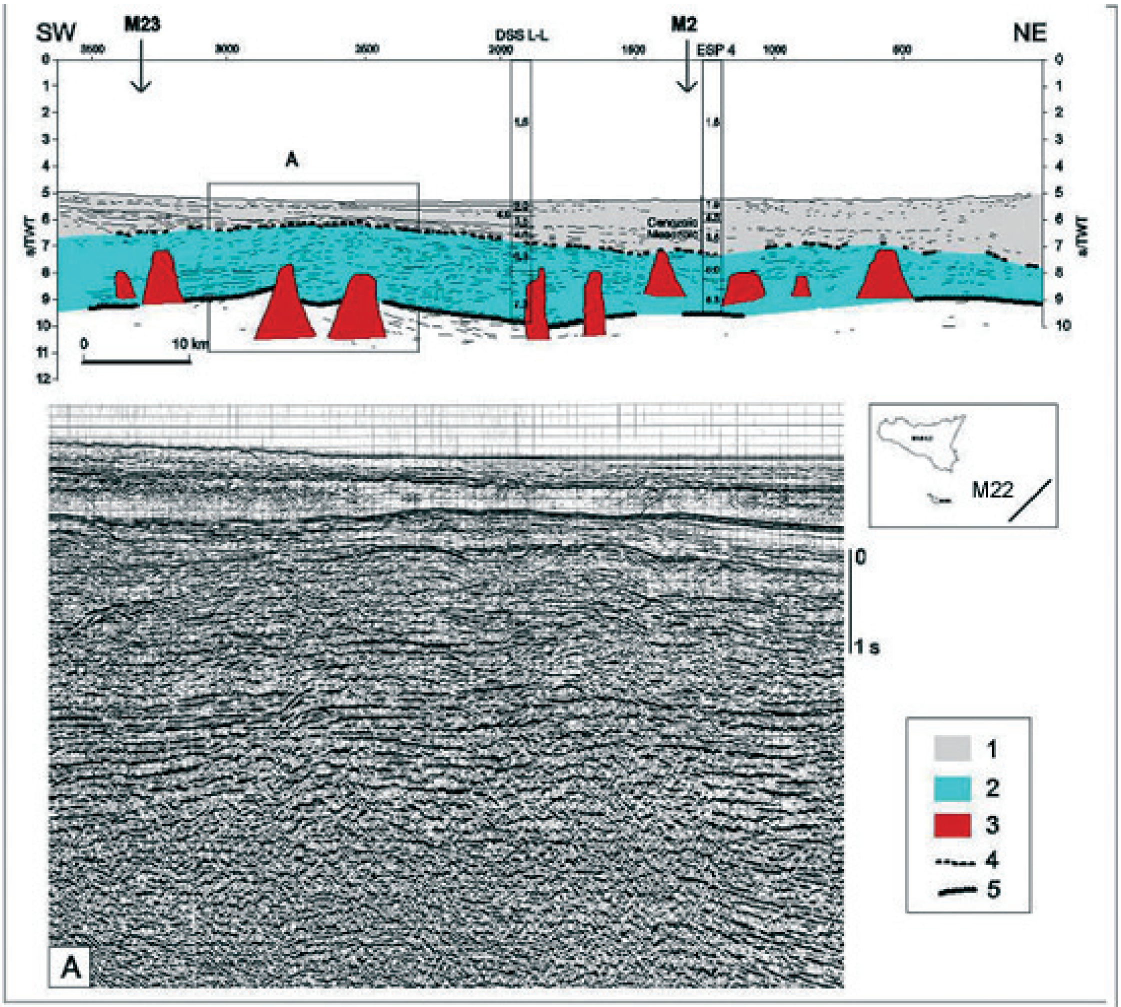

Fig - 7. M22 geoseismic section showing the Ionian oceanic crust overlain by Meso-Cenozoic basinal deposits (1). In A, details of the seismic image of the crust (2) intruded by suspected igneous body with dyke geometry (3) are figured. (4): crystalline basement; (5): Moho discontinuity.

4.3. The Ionian abyssal plain

4.3.1. The crust

Seismic profiles crossing the present-day abyssal plain (Figs. 6 to 8) image, at a depth between 7 and 9 s/TWT, a) a group of flat-lying, layered reflectors (0.5-1 s/TWT thick), followed upwards by b) a seismically transparent and unstratified band, topped by c) a discontinuous, high-amplitude reflector, highlighted by widespread coalescing diffractions, that develop at approximately 7 s/TWT (Catalano *et al.*, 2000). This reflector is considered to be the top of the basement; its depth is correlatable with the values inferred by De Voogd *et al.* (1992), on the basis of refraction data. The diffraction hyperbolae have been illustrated elsewhere as a typical seismic facies of the top of the oceanic basement (Wade and Mac Lean, 1990; White *et al.*, 1990).

A Moho discontinuity can be traced at the base of the high-reflectivity package, located

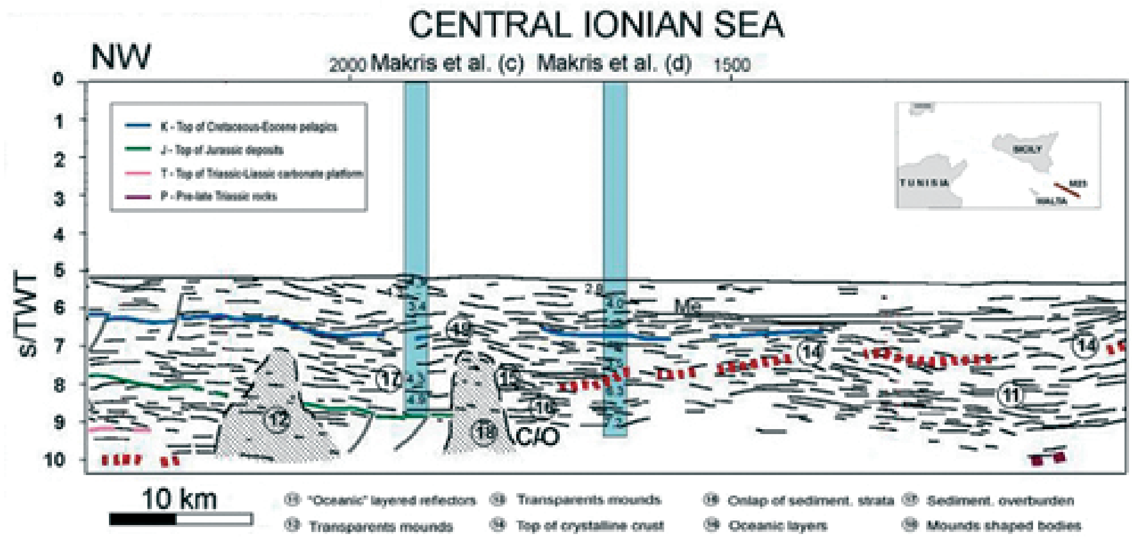

Fig. 8 - Geoseismic section of the M23 seismic profile, where it crosses the transition area between thinned continental crust and oceanic crust.

between 8.8 and 7.2 s/TWT (Figs. 6 and 7). Its depth is calculated at about 16 km, a value that has a good correlation with the calibration performed by Makris *et al.* (1986), Ferrucci *et al.* (1991), De Voogd *et al.* (1992) and Truffert *et al.* (1993), who identified the Moho depth from high refraction velocities, at least 8.1-8.2 km/s, on OBS and ESP profiles. On the whole the crystalline crust has been evaluated to be as thick as 7-8 km. Schematically, the layered unit (a) could have the significance of the tabular bodies with petrological features of gabbroic and dunitic cumulites (Cann, 1974; Bott, 1982; Detrick *et al.*, 1987); the overlying reflection-free unit (b) could be composed of basaltic rocks, as can be confirmed by the distinct Vp functions, measured by De Voogd *et al.* (1992), that described the occurrence of layers 2 (basalts) and 3 (gabbros) at a depth of 9 and 12-13 km, respectively.

A band of about 20°-25°-dipping reflectors occurs at the base of the crust beneath the Moho discontinuity (Fig. 7) and does not crosscut the crust.

At a regional scale, the reflective band (unit a) is clearly arched with indication of plunging both towards the Calabrian arc and the Hellenic arc, a pattern already described by Ferrucci *et al.* (1991).

4.3.2. The sedimentary cover

A high-amplitude and high-frequency package, lying between 5 and 8 s/TWT (above the top of the presumed basement; Figs. 6 and 7), corresponds to the eastward thinning sedimentary blanket. A flat-lying regional unconformity, located at about 5.4 s/TWT (Fig. 8), separates the blanket into two main prisms.

The upper one, 2 km thick, shows the seismostratigraphic characteristics of the Messinian evaporites and Pliocene-Pleistocene strata. An equal thickness was calculated by De Voogd *et al.* (1992) in the same region, using ESP data.

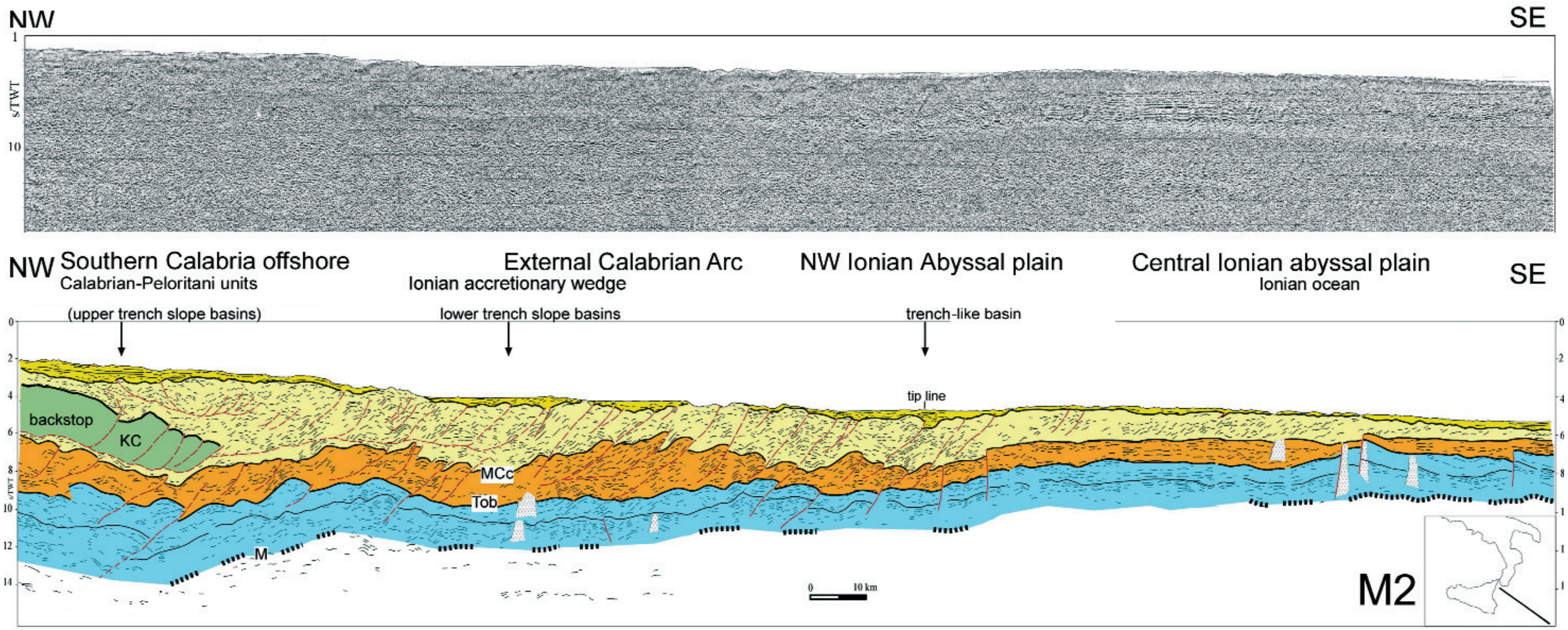

Fig. 9 - Geoseismic section showing the NW deepening oceanic crust and the SE verging Ionian accretionary wedge that is formed by slices of oceanic crust and its sedimentary cover. KC: Kabilian-Calabrian units; MCc: top of the Meso-Cenozoic Ionian sedimentary units; TOB: top of the Ionian oceanic crust; M: Moho.

The lower sedimentary prism, onlapping the crystalline basement, has a variable thickness between 1.8 and 1.2 s/TWT; assuming the VP velocity calculated for ESP 5 by De Voogd *et al.* (1992), we estimate that this unit is 3 km thick (Fig. 8). The seismic grain suggests that a pelagic facies (limestone, mudstone and indurated marls) could be present. Their age is bracketed between Mesozoic and Miocene times.

4.3.3. The continent/ocean (C/O) boundary

The flat-lying region comprised between the ME and the Ionian abyssal plain (Fig. 8) images an abrupt lateral change of the crustal characteristics.

Seismic evidence shows that a) the layered Ionian crust ends abruptly westwards against the mound-shaped bodies sited in the western Ionian; b) a strong change occurs in the topography of the top of the basement, located at 9 s/TWT and 7 s/TWT respectively in the western and the eastern Ionian; c) the thickness of the sedimentary package varies suddenly from 4 s/TWT, found to the west, to 2.5 s/TWT, found to the east. Our observations and the values of the crustal thickness, supplied by wide-angle and refraction data (De Voogd *et al.*, 1992; Avedik *et al.*, 1995), would suggest a thinned continental crust, to the west, abruptly passing to an oceanic crust in the eastern sector. This points to the occurrence of a thinned continental crust in the western Ionian and to the lack of transition between the two types of crust.

4.3.4. Intrusive features

The crustal and subcrustal layers are intruded by transparent bodies with dyke geometry that have been interpreted as evidence of basalt ridges trapped in the oceanic crust (Catalano *et al.*, 2000).

Magmatic intrusions in the Ionian crust have been predicted (Makris and Stobbe, 1984; Makris *et al.*, 1986; Cernobori *et al.*, 1996) or described as generating the high-frequency magnetic anomalies (Morelli *et al.*, 1975) but they have not yet been imaged on seismic lines or reported in the literature. These features, recognized in our unmigrated seismic lines, if real, could be helpful to our understanding of the mechanism of oceanic spreading. Presumed oceanic spreading has not yet been supported by the description of any of the characters that could confirm this event (i.e. median ridge). New working hypotheses are now proposed by Valenti *et al.* (2006).

4.4. The Ionian accretionary wedge

Several interpreted CROP lines cross the study region showing the grain of the Ionian accretionary wedge, a structure already imaged, if only partly (Finetti, 1982; Cernobori *et al.*, 1996; Catalano *et al.*, 2002).

Among the interpreted CROP-Mare lines, the M2 line (Fig. 9), chosen because of the good-quality data, crosses the Ionian abyssal plain reaching southern Calabria and the NE Sicily offshore (Fig. 1).

The morphostructural setting consists of (Fig. 9):

1) an undeformed flat-lying area submerged by a deep sea (up to 5 km) in the central Ionian abyssal plain;
2) a poorly deformed area in the NW Ionian abyssal plain, where a trench-like basin can be recognized;
3) a SE-vergent accretionary wedge in the region of the External Calabrian Arc, overlain in

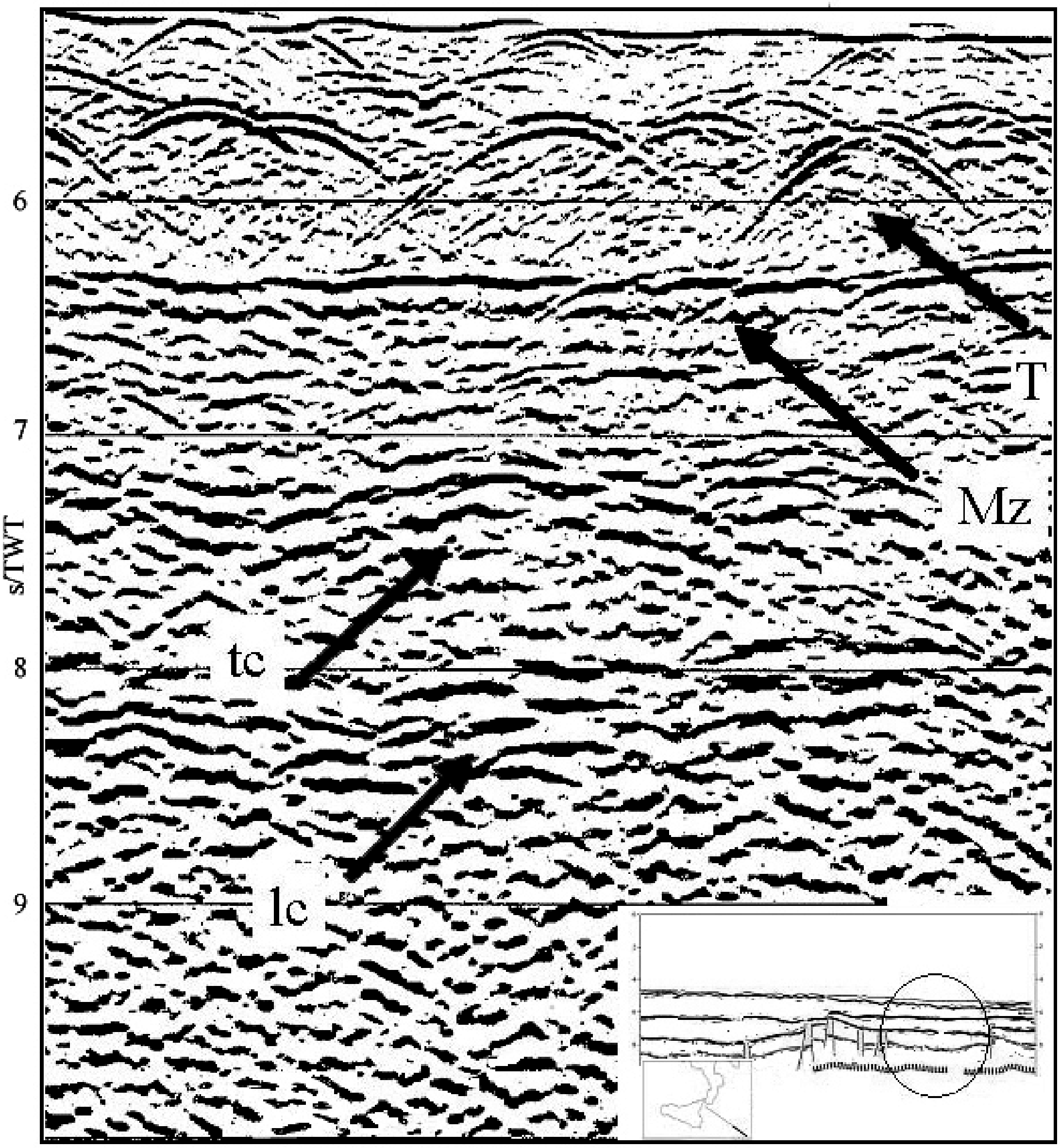

Fig. 10 - Detail of M2 seismic line showing a close-up of the not yet deformed crystalline and sedimentary crust in the central Ionian abyssal plain. lc: layered crust; tc: top of crust; Mz: Mesozoic deposits; T: Tertiary deposits.

the southern Calabria offshore by

4) a thick stack of deformed crystalline and sedimentary units, belonging to the submerged continuation of the Calabrian- Peloritani units.

The minor hanging troughs, mainly overlying the Ionian accretionary wedge in the External Calabrian zone, are interpreted here as lower trench slope basins.

Along the section, we have recognized three main crustal levels (Figs. 9 and 10): the lowest

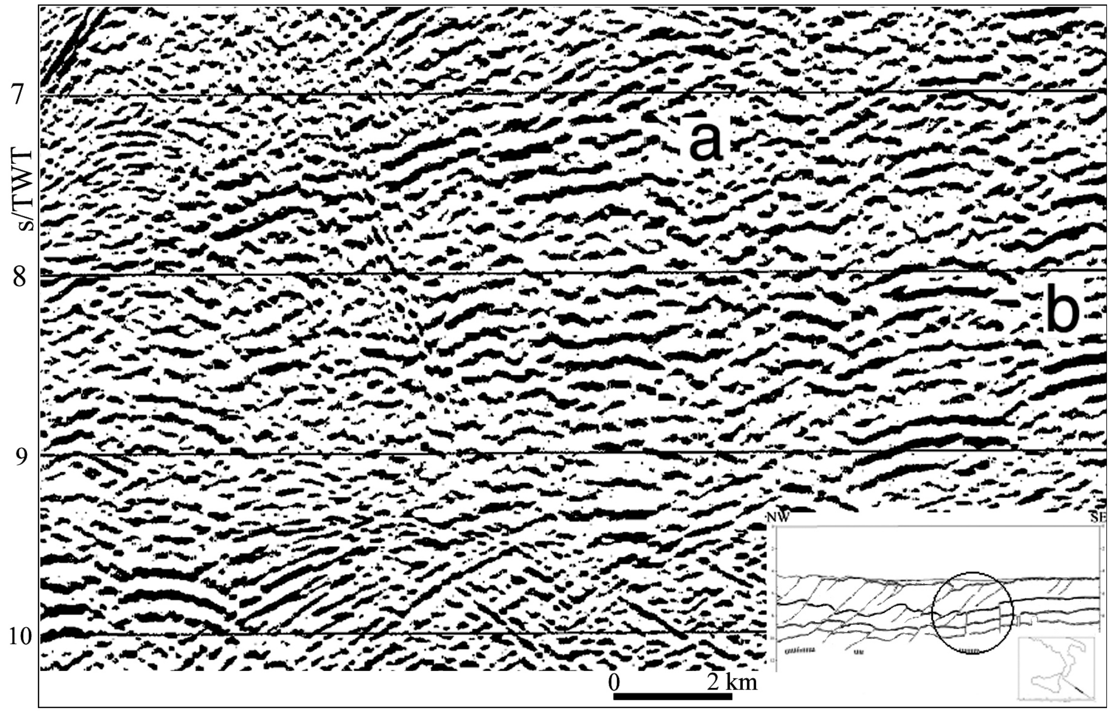

Fig. 11- Detail of M2 seismic line showing a close-up of the NW-ward dipping reflector in the NW Ionian abyssal plain. a: layered crust; b: carbonate deposits.

level is interpreted as the Ionian oceanic crust; the intermediate one represents the Meso-Cenozoic, mostly deformed sedimentary cover, overlain (only in the NW sector) by a stack of crystalline units pertaining to the Calabrian continental crust; and the uppermost level is composed of Tertiary-Quaternary deposits and thrust nappes (Sicilidi and Numidian flysch) of upper Mesozoic to Cenozoic deep water rocks.

The lower crystalline level is represented, as already said, by a couplet consisting of a highly reflective layered body and a transparent and unstratified band with overlapping hyperbolae (Figs. 6, 7 and b in Fig. 11), already presumed to be an oceanic crust (Catalano *et al.*, 2000). Along the transect, in the central abyssal plain zone, this crust appears overlain by an undeformed sedimentary prism, consisting, from the top, of i) Miocene-Quaternary (T) deposits; and ii) a Mesozoic to Paleogene rock succession (MZ, Fig. 10). These layers are offset by WNW-ESE lateral sharp discontinuities (Figs. 9 and 12), here interpreted as palaeofaults that break up the Ionian crust (lc in Fig. 12).

The basement deepens abruptly north-westwards (Fig. 9) from 7.2 s/TWT in the abyssal plain to more than 10 s/TWT beneath the Calabrian-Peloritani units (Fig. 9). The Moho discontinuity, previously illustrated at the base of the reflective layered body, is recognized at about 9 s/TWT in the abyssal plain and can be traced towards NW, deepening down to about 14 s/TWT near the Calabrian offshore.

The intermediate crustal level images, on the whole, a tectonic wedge (Figs. 7 to 9) that shows

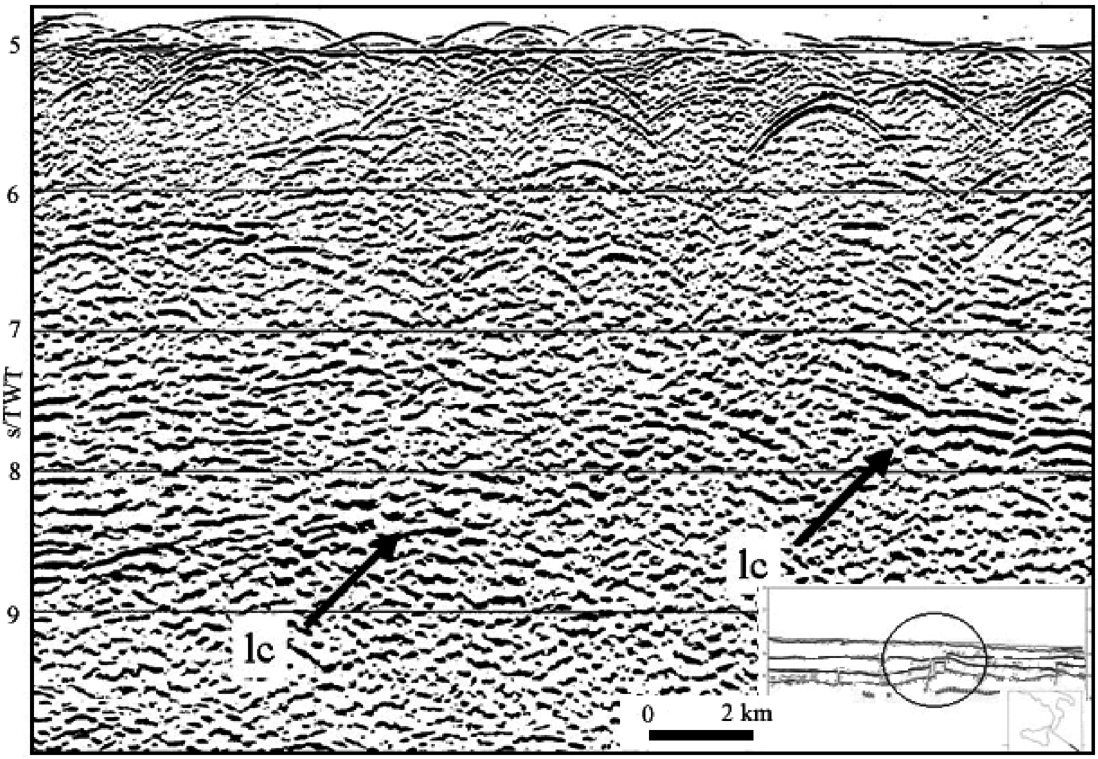

Fig. 12 - Detail of M2 seismic line showing a close-up of transform (?) faults offsetting the crust in the central Ionian abyssal plain. lc: layered crust.

different geometries and reaches a total thickness of 2 s/TWT, in the central abyssal plain, that becomes more than 5 s/TWT near the Calabria offshore, owing to tectonic piling.

In the central Ionian abyssal plain, the sedimentary cover is largely coupled with the crystalline crust and not deformed, showing a flat-lying setting and a minor thickness (Fig. 9).

The younger deposits are detached from the underlying strata and are chaotically arranged, without a coherent organization of the resulting tectonic bodies (Fig. 9).

Leaving the trench-like zone, towards NW, the sedimentary cover is progressively involved in a structure formed by coherent thrust ramps that merge to the tip line of the External Calabrian Arc. The sole thrust is sealed at the surface by about 1 s/TWT thick deposits filling the trench-like basin (Fig. 9).

North-westwards, the deepest and oldest deposits are tightly imbricated, giving rise to a 4 s/TWT thick tectonic stack, clearly detached from the underlying crust (Figs. 9 and 13). The latter is a gently arched body (Fig. 13) slightly offset by faults, seismically well imaged in the 9 to 12 s/TWT depth interval.

In approaching the SE Calabria offshore, also the top of the Ionian crystalline crust (dc, Fig. 14) is involved in some tectonic slices (Figs. 9 and 14), that are bounded by reverse faults dipping north-westwards. The 3 s/TWT thick tectonic stack is composed of rocks originally lying on the internal and now subducted portions of the Ionian crust (Fig. 14).

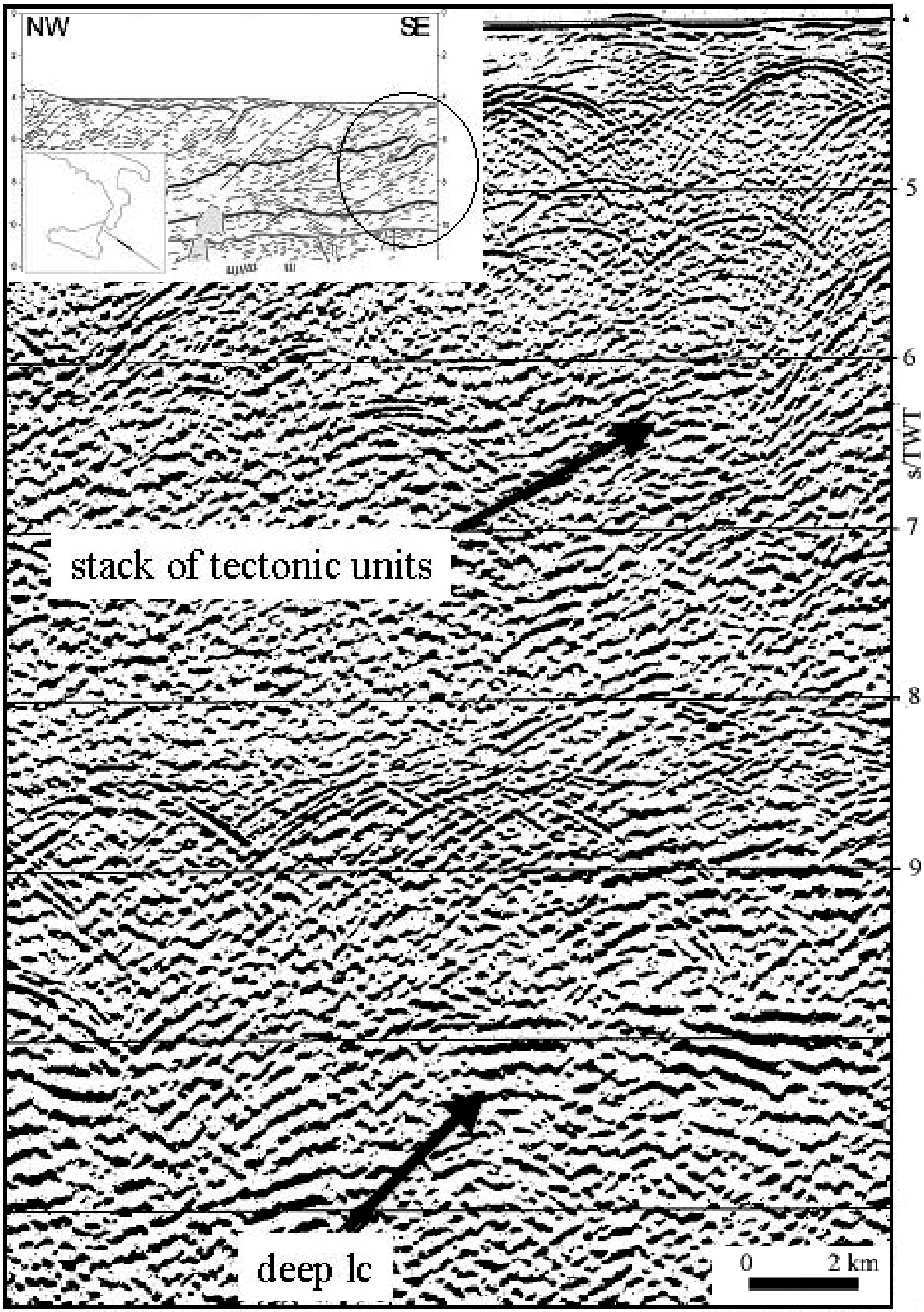

Fig. 13 - Detail of M2 seismic line showing a close-up of the tectonic stack of carbonate units. At the bottom, the deep layered crust.

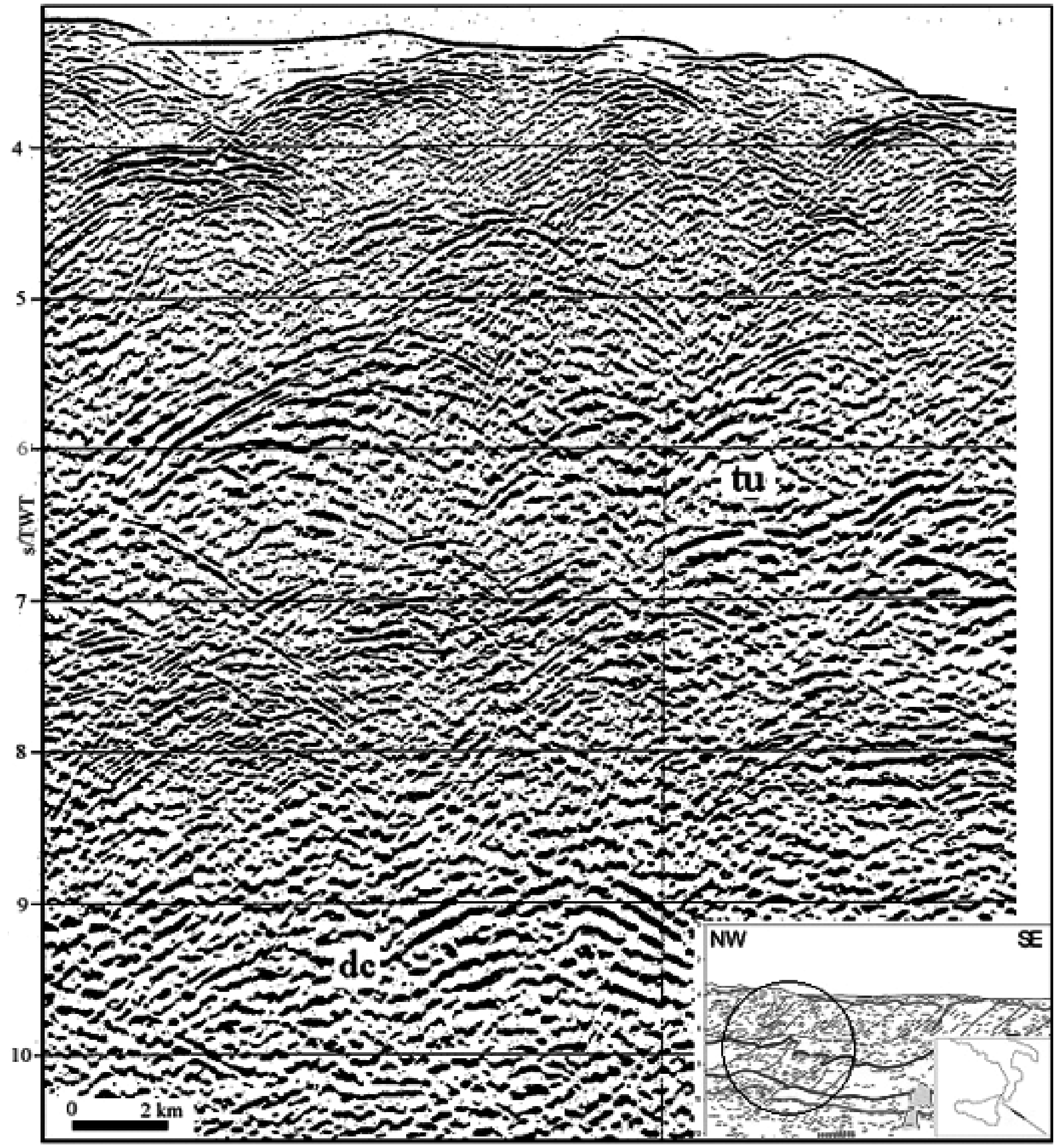

Fig. 14 - Detail of M2 seismic line showing a close-up of the External Calabrian Arc, where the stack of the tectonic units (tu) and the deformed crystalline crust (dc) can be observed.

This tectonic body on the whole is described here as the Ionian accretionary wedge resulting from the offscraping of the sedimentary cover and the detaching of its oceanic crust.

In the southern Calabrian offshore (Figs. 1 and 9), the accretionary wedge underlies a thick, high-velocity, seismically transparent-to-chaotic body (a, in Fig. 15). The wedge-shaped body is topped by a high-amplitude, continuous reflector, which outlines its south-eastward-thinning geometry.

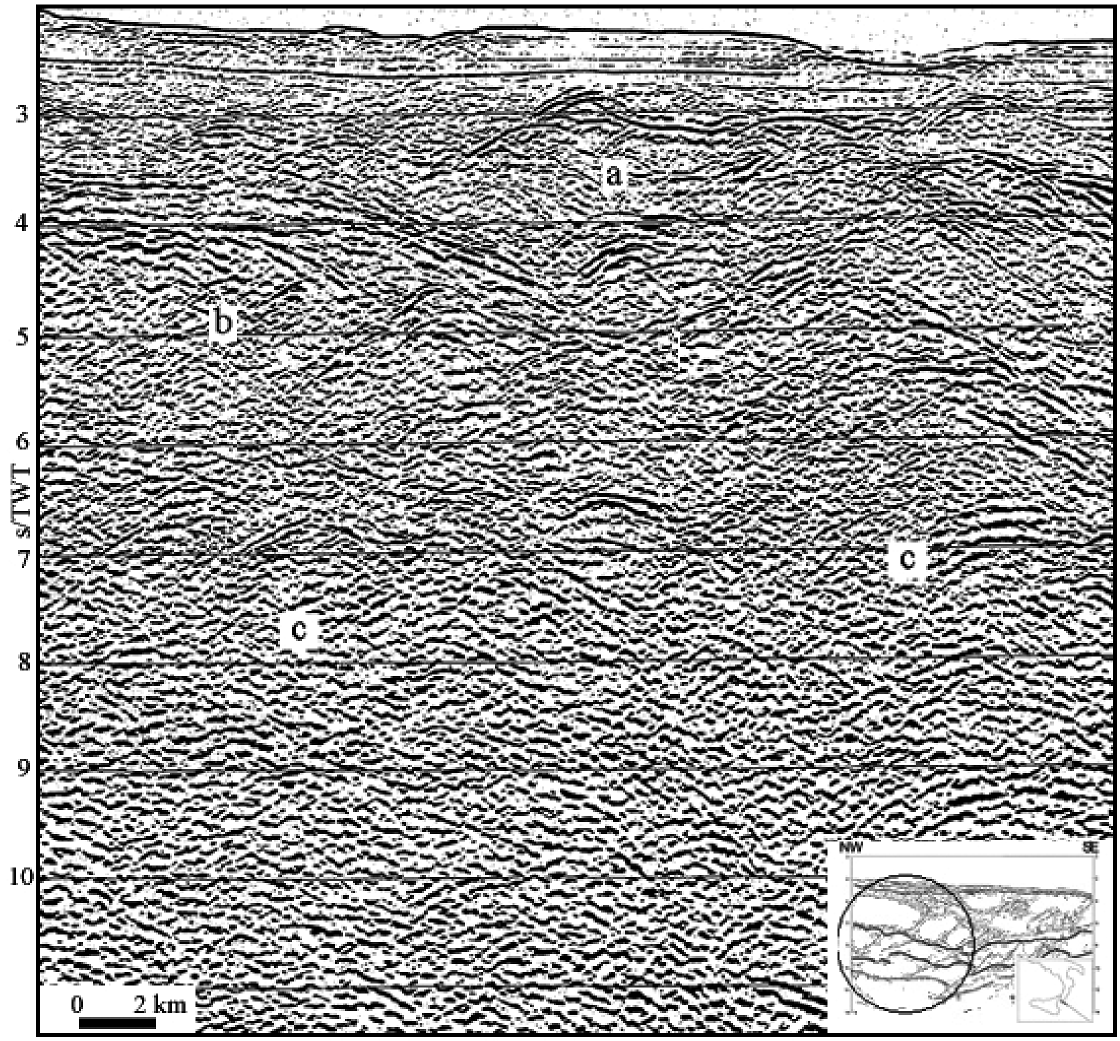

Fig. 15 - Detail of M2 seismic line showing a close-up of the offshore Calabrian Arc. The Neogene sedimentary cover (a) is involved in backthrusting over the continental crystalline stack (b) buried continuation of the Calabrian Peloritani massif, overlying the deformed *melange* type deposits of the Ionian crust (c).

Seismic features indicate that this seismic unit is originated by crystalline rocks and is conformably overlain by a layered 0.5 s/TWT thick group of reflectors originated by sedimentary rocks.

When depth-converted, the seismic body has a thickness of 10 km and its top appears to be located at about 4 km below sea level. Physical correlation with onland outcropping rocks led to its being assigned to the continental crystalline units of Calabria and NE Sicily Peloritani mountains (Figs. 1 and 9).

The offshore Calabrian units and their adjacent carbonate cover are tectonically overlain by more than 2 s/TWT of sedimentary layers. These appear imbricated mostly along back-verging thrusts.

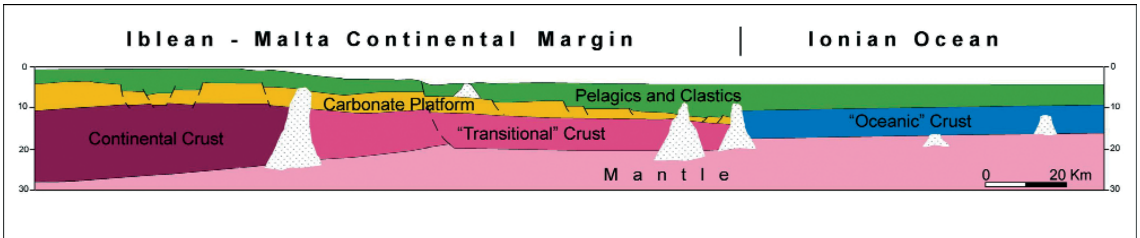

Fig. 16 - Simplified geological cross-section from the Iblean-Malta shelf to the Ionian abyssal plain (from depth conversion of CROP M23 seismic line), showing the thinned transitional crust and the geometry of the interpreted oceanic crust.

This body is unconformably sealed by Plio-Pleistocene filling depressions, which could represent upper trench slope basins.

5. Discussion

5.1. The passive continental margin

The Iblean-Pelagian passive continental margin resulting from the seismic interpretation (Fig. 16) shows extensional faults dissecting both the mainly (interpreted) Triassic carbonate platform

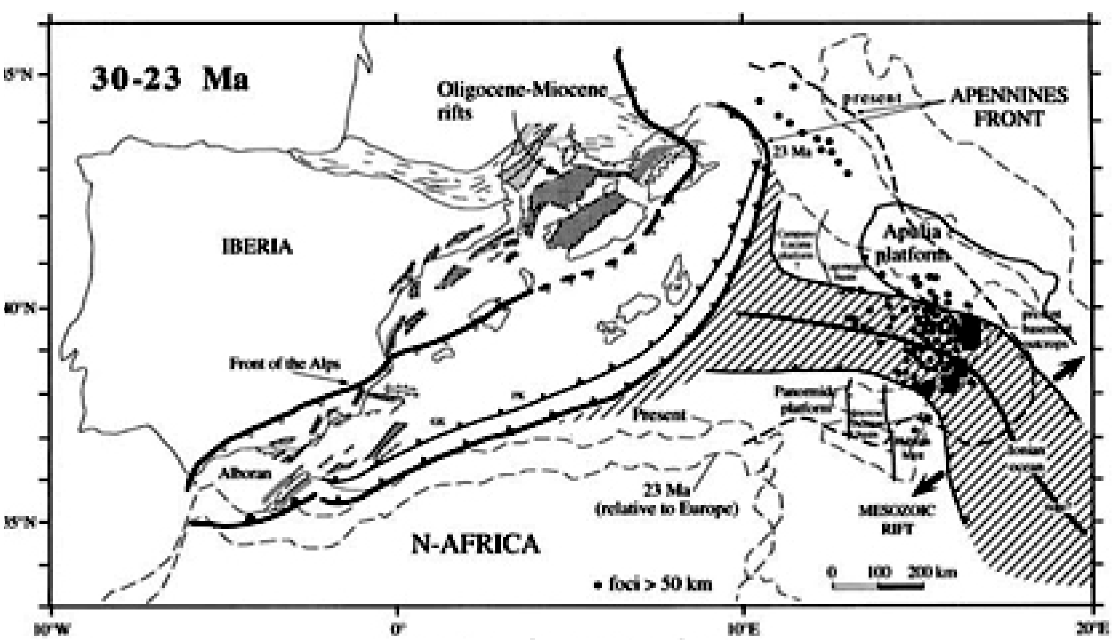

Fig. 17 - Late Oligocene-Early Miocene palaeogeography of the central-eastern Mediterranean, with the preserved Mesozoic palaeogeography in the Apennine foreland to the east. The 330 km wide Ionian Mesozoic Ocean must have been transferred to the west-northwest, since the restoration of the southern Apennine thrust sheets implies thinned but still continental crust to the north of the Ionian Sea. The present-day seismicity, deeper than 50 km (after Amato *et al.*, 1993), closely matches the oceanic palaeogeography.

and the overlying Jurassic-Cretaceous pelagic deposits, originating from the rifting events that started in pre-Triassic time (Catalano *et al.*, 1991, 2000; Stampfli *et al.*, 1991). These events continued later, as shown by some extensional features that dissect the top of the Triassic carbonate platform and the upper Jurassic-lower Cretaceous pelagic deposits (Fig. 3).

Rifting clues throughout the Permian-Triassic are to be found in central-western Sicily from unmetamorphosed Permian-Triassic basinal carbonates and clastics (Catalano *et al.*, 1988, 1990, 1991).

The rift setting is consistent with the occurrence of basaltic igneous rocks found in the Sicilian Permian (?)-Triassic deposits (Censi *et al.*, 2000). Rifting events, beginning in the Late Triassic and lasting throughout the Jurassic-Cretaceous, are known both from the Iblean-Pelagian region (Yellin Dror *et al.*, 1997) and from Sicily (Catalano and D'Argenio, 1982).

Our seismic lines indicate, in addition to the early Mesozoic block-faulting of both the basement and the sedimentary cover, the occurrence of large igneous intrusions previously shown in Catalano *et al.* (2000), while Finetti and Morelli (1973) and Morelli *et al.* (1975) recognized widespread and strong magnetic anomalies in the study regions interpreted as having been generated by igneous intrusions.

Such features are mentioned as being peculiar to the rifting evolution in the continental margins (Bott, 1982; Bonatti and Seyler, 1987; White and McKenzie, 1988). These arguments support the "transitional" nature of the crust flooring the ME slope and the western Ionian sector. Widespread volcanism and subsidence of carbonate platform (Iblean, western Sicily) during middle Jurassic were largely coeval with spreading in central North Atlantic. This rifting was believed to be related to the onset of sea-floor spreading to form the Ionian Sea (Catalano *et al.*, 2001).

The seaward-dipping horizons (Figs. 3, 4, 7) detected in the Iblean-Pelagian slope and rise and in the western Ionian sea can be compared with the seaward-dipping wedge (SDW) described by Reston (1990), Flack *et al.* (1990) and Rosendhal *et al.* (1991), who interpreted them as the remnants of rifting that produced several tilted blocks.

Triassic to Neogene mafic volcanic levels, sandwiched in the sedimentary strata (Antonelli *et al.*, 1991; Longaretti and Rocchi, 1992), and the igneous intrusion in the crust (illustrated also by Ciminale and Wasowsky, 1989) support the hypothesis of a magmatic underplating of the thinned continental crust in the framework of a mantle-dominated plume passive margin model previously illustrated by Bonatti and Seyler (1987) and Della Vedova and Pellis (1992).

The sedimentary cover, lying above the transitional crust, is made up of a) lower Mesozoic carbonate platform rocks, as revealed by the physical continuity between the rocks across the ME (Scandone *et al.*, 1981; Biju Duval *et al.*, 1982) followed upwards by b) upper Mesozoic-lower Tertiary pelagic limestones. The lateral continuity across the ME of these sedimentary facies and the vertical to lateral depositional relationships between the carbonate platform and basinal deposits make it possible to locate the original edge of the Mesozoic continental margin in the western Ionian, well to the east of the ME (Figs. 2 and 8) and not along the ME as some researchers believe (Finetti, 1982, 2004; Stampfli *et al.*, 2001; Argnani and Bonazzi, 2005). As a consequence the ME does not separate the continental from the oceanic crust, since it owes its morphogenesis to the reactivation along previous structures caused by more recent vertical and/or transtensional tectonics (Adam *et al.*, 2000; Catalano *et al.*, 2001). With regard to the depositional geometries, the seaward thickening of the upper Jurassic-Cretaceous post-carbonate platform strata might be explained as the result of a rapid increase in the subsidence rate. Rapid foundering during the Jurassic-early Cretaceous has been suggested by tectonic subsidence analysis (Ismail-Zadeh *et al.*, 1998) of the Iblean-western Ionian area. A deep water, thousands of metres thick, sedimentary wedge of Streppenosa as well as Modica and Buccheri Formation deposits, mostly of Liassic to Malmian age (Patacca *et al.*, 1979), rest in this area above a drowned carbonate platform.

5.2. The Ionian crust

The Ionian abyssal plain and its north-eastern side are floored by a crust-type whose seismic characteristics strongly differ from those detected seismically in the crust of the adjacent western Ionian and Iblean-Pelagian margin (Fig. 2).

In addition to the previously described evidence, this oceanic crust shows: i) the lack of seaward- or landward-dipping reflectors that, in agreement with Allmendinger *et al.* (1987), Jenyon (1987), Holbrook *et al.* (1991), Pickup *et al.* (1996) and Ross and Eaton (1997), are indicative of tilting or block-faulting commonly occurring in a thinned continental crust; and ii) that the dipping reflectors imaged beneath the Moho (Fig. 7) do not crosscut this discontinuity. These features, excluding shear mechanisms, are often associated with spreading zones (Flack *et al.*, 1990).

The occurrence of a NW-dipping oceanic crust and the identification of an accretionary wedge suggest that an oceanic slab can be supposed from the NW Ionian to the SE Tyrrhenian, through Calabria and NE Sicily.

We locate the hinge zone of the slab, at depth, beneath the submarine continuation of the Calabrian block. Here the top of the oceanic crust abruptly deepens from 9 to 14 s/TWT in a few tens of kilometres (Fig. 9), plunging towards the NW beneath the Calabrian wedge, as illustrated by Cernobori *et al.* (1996) and Catalano *et al.* (2002).

Seismological research (Cassinis and Ranzoni, 1987) has demonstrated that the Calabrian block is a tectonically active zone, whose deep seismicity (Caputo *et al.*, 1970, 1972; Gasparini *et al.*, 1982; Cristofolini *et al.*, 1985; Selvaggi and Chiarabba, 1995) indicates the subduction of the Ionian crust.

Seismological data (Gasparini *et al.*, 1982) locate the north-westward subducting Ionian lithosphere in this sector, at a depth of about 400-500 km, depicting a more than 70°-dipping Benioff zone, that cannot therefore be imaged in a seismic line.

The high angle of subduction in the SE Tyrrhenian is believed to be due to the roll back of the subduction hinge of the Ionian litosphere (Caputo *et al.*, 1970; Doglioni *et al.*, 1999), which retreats south-eastwards, causing extension in the southern Tyrrhenian.

Recently, the geometry of the subducting slab was referred to the polarity of its direction (Doglioni *et al.*, 1999) in the framework of a W-directed subduction of the Ionian crust.

As already said, several considerations support the oceanic nature of the crust in the Ionian abyssal plain, based on geological considerations, geophysical measurements, and seismostratigraphic data interpretation; among these, seismic refraction data (Makris *et al.*, 1986; De Voogd *et al.*, 1992; Avedik *et al.*, 1995), heat flow values (Della Vedova and Pellis, 1992), and the highly reflective layered features (Catalano *et al.*, 2000) appear the most sustainable.

Conversely, this crust has been considered as: i) a dense lower continental crust (Calcagnile and Panza, 1981); the thickness of the whole crust, not exceeding 4 s/TWT, is actually low, even for a dense lower continental crust; ii) an extremely thinned lower continental crust (Cernobori *et al.*, 1996), on the basis of the features of the layered part of the seismic body; this interpretation, when referred to the ION 1 line sector (Cernobori *et al.*, 1996), is consistent with our imaged thinned continental crust. The same features cannot be assigned to the crustal sector imaged in ION 2 and 3 lines that cross the central Ionian Sea.

We are, however, aware of the uncertainties of this interpretation, particularly as the supporting data are confusing or contradictory. Among such data, we disagree with the MS 26 seismic line interpretation of Finetti (1982), later redrawn by Stampfli *et al.* (2001), as supporting an oceanic crust. This age-dated interpretation, published by the former, does not, in fact, support either the stratigraphic identification or the occurrence of seismic features typical of an oceanic crust.

Also, the attribution of a short sector at the toe of the ME crossed by the M 3 CROP profile [strikingly coinciding with the Bin Hai line of Avedik *et al.*, (1995)] to an oceanic crust (Finetti, 2004) contrasts with the interpretation of Avedik *et al.* (1995), who attributed it to a thinned continental crust.

If we make a comparison, the seismic grain imaged in both the Bin Hai line and the M 3 CROP sector (Fig. 4) is quite different from the layered crust features imaged in the CROP seismic lines crossing the Ionian abyssal plain (Figs. 6 and 7).

This interpretation (Figs. 6 to 8) shows the abyssal plain oceanic crust to be overlain by 5 to 6 km of seismically interpreted pelagic deposits (see also Biju Duval *et al.*, 1982); this value is generally accepted and confirmed by geophysical data (De Voogd *et al.*, 1992). According to this interpretation, the oldest sedimentary strata onlapping the presumed oceanic crust occur immediately to the east of the C/O boundary (Fig. 8) and can be laterally followed westwards where they onlap the lower Mesozoic (mostly carbonate platform) deposits lying on the thinned continental crust described above. These stratal relationships suggest that the sedimentary cover of the oceanic crust is younger than the adjacent lower Mesozoic carbonate deposits (Scandone *et al.*, 1971).

Looking at the geometry of the sedimentary layers, one could argue that the age of initial oceanic spreading corresponds to an event that occurred after the onlap of the pelagic strata on the drowning carbonate platform; thermal subsidence of the carbonate shelf in the region is commonly believed to have taken place since the early Jurassic (Ismail-Zadeh *et al.*, 1998), as supported by crustal seismic velocities, subsidence analysis, deep sea floor (>4000 m in the abyssal plain), and low heat flow values (Della Vedova and Pellis, 1992).

Margin-to-margin restoration (Catalano *et al.*, 2001) suggests the occurrence of an original domain that evolved into two rifted continental margins from late (?) Permian to Jurassic. These margins could have attained their passive stage probably only since the Jurassic, when the Ionian Sea started to open up.

In recent years, Stampfli and co-workers in several interesting papers have described the Ionian setting in the framework of Eastern Mediterranean plate tectonics.

Notwithstanding the agreement on the general framework, our view disagrees with recent opinions of Stampfli *et al.* (2001) and Stampfli (2005), who proposed a late Permian onset of the seafloor spreading in the Ionian, on the basis of certain arguments, including:

1) the tectonic subsidence pattern calculated for Sicily (in the Gela 1 well). This argument is poorly supported since this borehole, located 100 km farther west of the ME, drilled only a few tens of metres of upper Triassic carbonate platform, whilst middle Triassic deposits have never been documented (AGIP, personal communication);

2) the occurrence of pelagic Permian-lower Triassic deposits outcropping in the Sosio Valley (Sicily). Catalano *et al.* (1988, 1991) first suggested the Sicilian Permian successions could have been deposited at the westernmost end of the Paleotethys, above an extremely thinned continental crust or probably oceanic crust. Stampfli (1989) proposed (IGCP 276) that the Eastern Mediterranean corresponded from the late Paleozoic, to an oceanic basin subsequently considered by Stampfli *et al.* (1991) as the Neotethys ocean. Among these deposits the red mudstones and thin, graded redeposited neritic carbonate, with radiolaria and conodonts, suggested (Catalano *et al.*, 1991; Kozur, 1995) a correlation with the upper Permian "Halstatt" type pelagic limestones, found in Oman as resting on MORB. In the Sosio Valley, these rocks rest above older sediments (Catalano *et al.*, 1991); there is no doubt about their direct pelagic connection in the late Permian throughout the Eastern Mediterranean but the occurrence of the same type of basement is not implied;

3) recent seismostratigraphy of the Ionian Sea performed in the framework of the CROP Project (Finetti, 2004). The lack of borehole-controlled stratigraphy capable of calibrating lithology and defining the age of the oldest deposits, as also the poor crustal analysis, offers few certainties as regards the true nature of the sedimentary wedge resting on the Ionian crust.

All stratigraphic interpretations, or land-to-sea correlations, possess scant evidence and are a matter of debate. The attempt to attribute the reflectors, lying above the "debated" oceanic crust, to a Permian-Paleogene succession correlatable with the middle Triassic-Oligocene basinal Lagonegro deposits (Finetti, 2004) is lacking in substance, since i) it compares a seismic multilayer sited near the Malta Escarpment (Fig. 1) to a succession outcropping some hundreds of kilometres farther north-east in the Southern Apennines; ii) the seismic features, as also the seismic thickness of about 1.4 s/TWT shown by the on-land Sicanian basin succession (middle Triassic-middle Miocene), are quite different to those described for the Ionian cover; and iii) the meaning of "condensed sequences" (Finetti, 2004) related to the seismic horizons not calibrated by borehole is obscure and inappropriate.

5.3 The Ionian accretionary wedge

The structure is formed from the bottom of a) slices of oceanic crust, b) south-east-verging tectonic units of Mesozoic carbonate that grew on the oceanic crust and less on the adjacent thinned continental crust, both forming the Ionian accretionary wedge; c) crystalline and sedimentary rock units (occurring only in the inner part of the wedge) correlatable to the Calabrian-Peloritani outcropping units; d) back-verging nappe structures (Sicilidi Auct.) and Miocene sediments hanging on the Calabrian Units; e) Plio-Pleistocene deposits, often filling basins sealing the main structures and elements.

In the NW Ionian, the deformed sedimentary rocks and the slices of oceanic basement intervene between the Calabrian stack and the top of the Ionian crust. Thus, part of the interpreted tectonic melange found in the easternmost Sicily-Calabrian offshore area might be the sedimentary cover of the Ionian crust that has been transported down into subduction, supporting the hypothesis of decollement surfaces within the sedimentary layers (Lenci *et al.*, 2004).

The main problem is still the features and the age of the rocks forming the accretionary wedge:

do they derive from the deformation of a Permian to Mesozoic rock body or are they a melange of upper Jurassic-Quaternary deposits and slices of oceanic crust?

The tectonic wedge appears deformed here by both fore- and backthrusting features, due to the occurrence of the rigid inner part of the Calabrian arc, behaving probably as a backstop. The geometry of the accretionary wedge, which shows uplift towards the north-west, as well as the articulated topography of the downgoing slab, could be controlled by relic hot features formed before the subduction time, such as the supposed medioceanic palaeoridge (Cantarella *et al.*, 1997; Catalano *et al.*, 2001), transform faults, neptunian dykes, or individual seamounts. These ancient morphostructures can make subduction difficult and/or complicate its geometry (Font *et al.*, 2001).

5.4 The regional setting in the Tyrrhenian-Ionian sector

The crustal setting is characterized here by the occurrence on both sides of the Ionian Sea of a continental crust (African) that also collides with the Calabrian crustal block, giving rise to the Sicilian and Southern Apennines chain.

The different setting is shown a few kilometres westwards, in the North Sicilian continental margin, where a seismic line crossing the Cefalù basin-Solunto Mount transect (Agate *et al.*, 2001) shows a northward inflection of the Sicilian (African) continental crust beneath a crystalline wedge, here believed to be a lateral offshore continuation of the Calabrian block. This occurrence is related to a north-directed continental subduction, as suggested by Doglioni *et al.* (1999), and suggests the absence of the oceanic crust, that appears confined below the Calabrian block.

The convergence of two continental crust sectors (Sicilian, i.e. African, crust and Calabria) causes more difficulty in the subduction processes than the Ionian vs. Calabria crustal system, where the greater convergence rate facilitates both a southward advancing of the deformation front (arcuate shape of the Apenninic front) and an abrupt vertical boundary between the Ionian and Sicilian crusts.

The surface expression of this behaviour is a shorter propagation of the Sicilian frontal accretion and the building of a chain with greater topographic relief and shortening than the accretionary wedge of the Calabria-Ionian sector.

The occurrence of an oceanic crust certainly favours active subduction in this area, explaining the development of the Aeolian volcanic arc and the deep seismicity in the south-eastern Tyrrhenian, as well as the ascent of the Etna magmas (Doglioni *et al.*, 2001). These considerations highlight the role of the crustal and lithospheric heritage of the downgoing plate in a convergence setting.

Inland constraints, i.e. the Sicilian and Southern Apennine carbonate platform margins and adjacent basin settings (Catalano *et al.*, 2001), suggest that the Ionian continued to the north-west (Fig. 17). As, the commencement of the main deformation of the Ionian area dates from the late Neogene, the reconstruction of Fig. 17 is viewed as an inherited Mesozoic crustal palaeogeography.

6. Conclusions

The interpretation of deep crustal seismic reflection lines (recorded in the framework of the CROP Mare Project) provided deep geological data in a sector that is crucial for the understanding of the evolution of the Central Mediterranean.

In this area, a volcanic passive continental margin, with an eastward-thinning continental to "transitional" crust lying below the Pelagian-western Ionian Seas, developed during the early Jurassic, following a rifting stage, that started during the Early(?) Permian-Early Mesozoic. From the (?) Mesozoic an "atypical" layered oceanic crust grew beneath the central-eastern Ionian abyssal plain. Towards the Sicily-Calabria offshore the NW-dipping oceanic crust can be related to the subduction beneath the Calabrian crust. The deformation rate of the Ionian crust increases towards the Sicily-Calabria offshore. The features of the accretionary wedge and its vertical and lateral setting indicate the influence of the Ionian features in the geometry of the downgoing slab.

The data collected and presented in the present paper encourage further study and provide important constraints on geological models. Nonetheless, some questions remain to be answered, such as which is the oldest rifting in the Ionian margin, the origin of the layered Ionian oceanic crust and its age, the meaning and the origin of the suspected "mafic" intrusions into the oceanic crust, the fate of the Ionian slab beneath the Calabria-easternmost Sicilian transect and the southern Tyrrhenian Sea, and the relationships with the adjacent deformed continental sector.

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