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Tectonics of eastern Sicily offshore: preliminary results from the MESC 2001 marine seismic cruise

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Abstract - The Malta Escarpment represents the dominant morphological feature offshore eastern Sicily and appears as a steep, eastward-sloping surface partly onlapped by the flat laying sediments of the adjacent Ionian Basin. Both tectonic structures and seismicity indicate a peculiar neotectonic activity along the eastern Sicilian slope. In order to investigate the neotectonics of this region, a multi channel seismic survey (MESC 2001) was carried out on the eastern Sicilian slope. The Malta Escarpment can be divided into two portions characterised by different tectonic structures. Along the segment south of Siracusa, the Malta Escarpment is not affected by recent faulting and appears as a steep surface that flattens out towards the Ionian Basin. The escarpment appears as an original slope, likely inherited from Mesozoic (or earlier) times, linking the deep Ionian Basin to the east with the Hyblean carbonate platform to the west. A recent deformation, characterised by a broad area of uplift, occurs 20-30 km east of the slope, along a NNW-SSE trend. The segment of the Malta Escarpment extending north of Siracusa, on the other hand, is characterised by the presence of NNW-SSE, east-dipping recent extensional faults located along the morphological escarpment and a few km east of it. In some instances, splays of the western extensional faults join the sloping surface of the Malta Escarpment, whereas the easternmost extensional faults, and related sedimentary basins, are affected by contractional deformation.

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1. Introduction

The narrow and steep Eastern Sicilian Escarpment connects the narrow shelf of Sicily with the deep Ionian Basin (Fig. 1). The Eastern Sicilian Escarpment is the site of intense seismic activity, reported both in historical catalogues and in recent instrumental records and is part of the Malta Escarpment, a regional morphological feature that extends further south for some 100's km (Scandone et al., 1981; Casero et al., 1984). The destructive earthquakes that struck Catania, Messina and the towns of southern Calabria several times, are in several instances due to faults located at sea, as the contours of the maximum felt intensity in eastern Sicily are open to the sea (Boschi et al., 1995b). Furthermore, the largest tsunamis that affected the coasts of Italy, with waves as high as 13 m originated in this region (Piatanesi and Tinti, 1998). The MESC 2001 cruise was planned with the aim of investigating the neotectonics of the Eastern Sicilian submarine slope in the frame of the GNDT "Programma Quadro 2000-2001" named "Hazard evaluation of the submarine geological processes in the Italian seas: earthquakes, tsunamis and slides". The survey aimed at acquiring multichannel seismic profiles and was carried out by the R/V Urania from 27 July to the 16 August 2001.

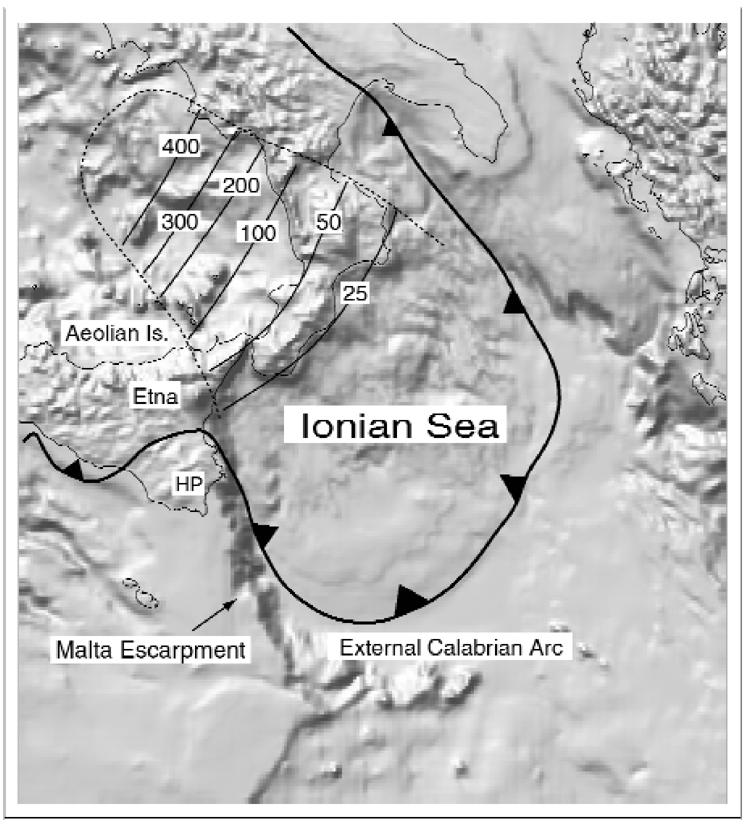

Fig. 1 - Topography of the Ionian Sea and adjacent regions illustrating the steep and narrow Malta Escarpment that separates the shallow Hyblean-Maltese shelf from the deep Ionian Basin. The extent of the external Calabrian Arc, a low-taper accretionary wedge, is also indicated, together with the isobaths of the top of the subducted lithosphere, as deduced from seismological observations (Selvaggi and Chiarabba, 1995; Frepoli et al., 1996). HP: Hyblean Plateau.

2. Geological setting

The steep slope connecting the narrow shelf of eastern Sicily with the deep Ionian Basin represents the northern prolongation of the Malta Escarpment, which continues further south towards the coast of Africa (Fig. 1). This slope has long been recognised as being a tectonic feature (Scandone et al., 1981; Casero et al., 1984; Finetti, 1982, 1985; Makris et al., 1986; Catalano et al., 2000a, 2000b) although the interpretation of its age, as well as of the age of the adjacent Ionian Basin, is still controversial, ranging from early Cretaceous (Dercourt et al., 1993; Catalano et al., 2000b), to early Jurassic (Finetti, 1985; Catalano et al., 2000a) or to late Palaeozoic-early Triassic (Stampfli et al., 1991, 2001; Argnani, 2000b).

Refraction profiles crossing the Malta Escarpment show an abrupt crustal thinning, from c.a. 30 km in the Straits of Sicily to c.a. 18-20 km in the Ionian Sea. This happens in a distance of 20-30 km (Makris et al., 1986; Scarascia et al., 1994). The nature of the crust underlying the Ionian Basin has long been a matter of debate. Although several authors considered it as thinned continental crust (e.g. Calcagnile and Panza, 1981), ESP experiments recently carried out in the Ionian Basin show that the crust ranges from 12 to 16 km in thickness and presents a velocity structure comparable to that of the oceanic crust (de Voogd et al., 1992). The Malta Escarpment, therefore, appears to be the expression of a passive continental margin connecting the continental crust of the Straits of Sicily to the oceanic crust of the Ionian Basin. On the basis of a deep seismic reflection survey, carried out across the Malta Escarpment, Catalano et al. (2000b) located the continent/ocean (C/O) boundary about 50 km east of the escarpment, with the deep part of the continental margin considered to be floored by transitional crust originated by the thinning and underplating of the continental crust. According to these authors, rifting started in pre-Late Triassic times, but major extensional faults occurred from Late Triassic to Early Cretaceous and oceanic drifting started in Early Cretaceous, although, other authors (Catalano et al., 2000a) infer a Permian to Triassic continental rifting, evolving to oceanic spreading already during the Late Jurassic using the same set of data.

Despite the early history of the Malta Escarpment, the slope of eastern Sicily is currently the site of a significant seismic activity that has been recorded in recent instrumental catalogues (Selvaggi, 1998; INGV Web Site) and that can also be inferred from the compilation of the maximum felt intensity reported in the historical chronicles (Boschi et al., 1995a, 1995b). The contours of the map of the maximum felt intensity, in fact, are open to the sea in eastern Sicily (Boschi et al., 1995b). The disastrous earthquakes that struck Catania, Messina and other cities of south Calabria several times quite likely originated from the tectonic structures present at sea (Bianca et al., 1999; Adam et al., 2000; Monaco and Tortorici, 2000). Moreover, the largest tsunamis that affected the Italian coasts, originated from these marine regions; the December 1908 tsunami, with wave hights of up to 13 m, which hit north-eastern Sicily and southern Calabria (Caputo and Faita, 1982; Tinti, 1991, 1993; Piatanesi and Tinti, 1998) for instance.

After the early pioneering geophysical surveys in the Ionian Sea and adjacent shallow sea areas (Rossi and Borsetti, 1977; Finetti, 1982, 1985), some deep reflection seismic profiles were acquired in various surveys along the Malta Escarpment over the past five years. These studies, however, were mainly aimed at investigating aspects such as the crustal structure of the Malta

Escarpment and its relationships with the Ionian Basin (STREAMERS, Hirn et al., 1997 and CROP Mare, Catalano et al., 2000a, 2000b) or the deep geology of the areas adjacent to Mount Etna (ETNASEIS, Cernobori et al., 1996). A system of NNW-SSE extensional faults, in a 30 km-wide belt, has been detected along the northern portion of the Malta Escarpment (Cernobori et al., 1996; Hirn et al., 1997; Bianca et al., 1999; Nicolich et al., 2000). Part of these seismic profiles have been used in conjunction with geomorphological and structural mapping from onshore to describe the neotectonics of north-eastern Sicily (Bianca et al., 1999). Although grid spacing seems too large to univocally constrain fault geometry, the occurrence of active faulting is well documented and seismic profiles show half grabens filled by sediments with growth geometry (Rossi and Borsetti, 1977; Cernobori et al., 1996; Hirn et al., 1997; Bianca et al., 1999; Nicolich et al., 2000). Unpublished multibeam morphobathymetries recently acquired in the western Ionian Sea (Bortoluzzi et al., 1999) show linear features affecting the topography, and, further support the presence of active faults cutting the sea floor. Therefore, active faulting of regional extent is affecting the slope of eastern Sicily and the adjacent Ionian Basin. However, the complexity of the tectonic system in the region is far from being fully resolved, mainly because of the lack of a properly spaced seismic survey.

An additional aspect, relevant to seismic hazard evaluation in the investigated area, concerns the relationships between regional tectonic activity along the Malta Escarpment and the volcanic activity of Mount Etna that, according to some authors, are rather close (Hirn et al., 1997; Monaco et al., 1997; Nicolich et al., 2000). Monaco et al. (1997) consider the magmatism of Mount Etna as related to dilational strain on the footwall of an east-facing crustal-scale extensional fault. In their model, Mount Etna originated as it is, located roughly at a fault direction bend from NNW-SSE to NNE-SSW. Faults crossing the eastern flank of Mount Etna have a late Pleistocene – Holocene age and belong to a regional system that is connected to the extensional faults of southern Calabria (Monaco and Tortorici, 2000). These faults, together with the faults of the Aeolian Islands, are interpreted as a rift zone, actively extending in a WNW-ESE direction and dissecting the Calabrian Arc (Monaco et al., 1997; Monaco and Tortorici, 2000). Changes in an along-strike direction are commonly observed in crustal-scale extensional faults (Rosendahl, 1987), without being associated with large volcanoes. To find the origin of Mount Etna, therefore, additional tectonic controls must play a role. On the other hand, other studies (Hirn et al., 1997) evidence a link, in time, between volcanic and seismic activity at a large scale. It has been noted (Hirn et al., 1997) that over the millennium the reported ends of episodes of high output rates of magma are followed by the reported occurrence of earthquakes with magnitude larger than 7 located offshore along the eastern Sicilian slope. The growth of the Mount Etna volcano itself is also related by Hirn et al. (1997) to the occurrence of the large extensional faults located offshore. In the few reported cases, however, large magnitude earthquakes followed the end of large eruptions with a delay of up to c.a. 30 years; therefore, due to the rather poor statistics, this hypothesis remains still speculative.

Finally, the basal portion of the eastern side of Mount Etna appears located at sea where it intercepts the Malta Escarpment. It has been suggested that the steep topographic gradient of the escarpment can affect the stability of the volcanic edifice (McGuire, 1996; Borgia et al., 1992, 2000). If this assumption is correct there should be evidence of radial contraction at the submarine base of the volcano (Borgia et al., 2000). The role played by gravity on the evolution of Mount Etna, and of the faults affecting its eastern side in particular, is, however, disputed by other authors (Lanzafame and Bousquet, 1997) on the ground of field data, but so far no clear offshore data has been presented to support or to reject the hypothesis of volcanic spreading.

The second area of interest is located in the Aeolian Islands which represents a volcanic arc bordering the south-eastern side of the Tyrrhenian Basin (Barberi et al., 1974, 1994). Unlike the rest of the arc, the islands of Salina, Lipari and Vulcano are aligned along a NNW-SSE volcanic ridge, apparently located on the prolongation of the Malta Escarpment. Within this volcanic ridge the age of onset of volcanic activity becomes progressively younger towards south-east, going from c.a. 430 ka at Salina to c.a. 130 ka at Vulcano (Mazzuoli et al., 1995). The evolution of this line of volcanoes has been interpreted as being controlled by NW-SE-trending dextral strike-slip faults and N-S to NE-SW extensional faults in a transtensional pull-apart system (Mazzuoli et al., 1995). It has been suggested that the NW-SE-trending faults of Salina-Lipari-Vulcano can be kinematically connected to the NNW-SSE faults affecting the eastern flank of Mount Etna, defining a sort of transform fault system that allows a differential migration of the Aeolian Arc towards SE (Bousquet et al., 1997).The occurrence of recent faults connecting the NW-SE-trending volcanic ridge of the Aeolian Islands with mainland Sicily and crossing the Peloritani mountain range, however, is not well documented. To the best of our knowledge a set of old and broadly-spaced single-channel Sparker seismic profiles (Barone et al., 1982) are about the only seismic data available around the Aeolian Islands. Although over most of the area seismic penetration is impeded by the thick volcanics, some NNW-SSE faults, parallel to the trend of the Malta Escarpment, have been reported.

3. Objectives

Published maps of active faults affecting the slope of eastern Sicily and the adjacent Ionian Basin are currently based on a seismic grid that is loosely spaced (Cernobori et al., 1996; Hirn et al., 1997; Bianca et al., 1999; Nicolich et al., 2000) and, therefore, both direction and extent of faults are only weakly constrained. Because a good knowledge of the architecture of a fault system is a pre-requisite to evaluate its hazard potential, we planned and carried out a seismic survey aiming at mapping the active fault system of eastern offshore Sicily (Fig. 2) more closely. The survey consists of a 5-nautical miles (nm) spaced grid of reflection seismic profiles covering the Malta Escarpment and adjacent Ionian Basin; only towards the deeper Ionian Basin plain, away from the Malta Escarpment, has spacing been enlarged to c.a. 10 nm. The acquisition totalled c.a. 2500 km of seismic profiles. The main objective was to better define the architecture of the active fault system affecting the eastern slope of Sicily. This task was tackled first, by better outline in plan view the direction and continuity of fault segments. Secondly, by studying the small sedimentary basins showing growth strata geometries that originated by extensional faulting. The analysis of stratal geometries also helps to estimate the amount of throw and relative age of the activity of the fault segments.

Finally, the high-resolution Chirp sonar profiles, acquired together with the seismic data, could

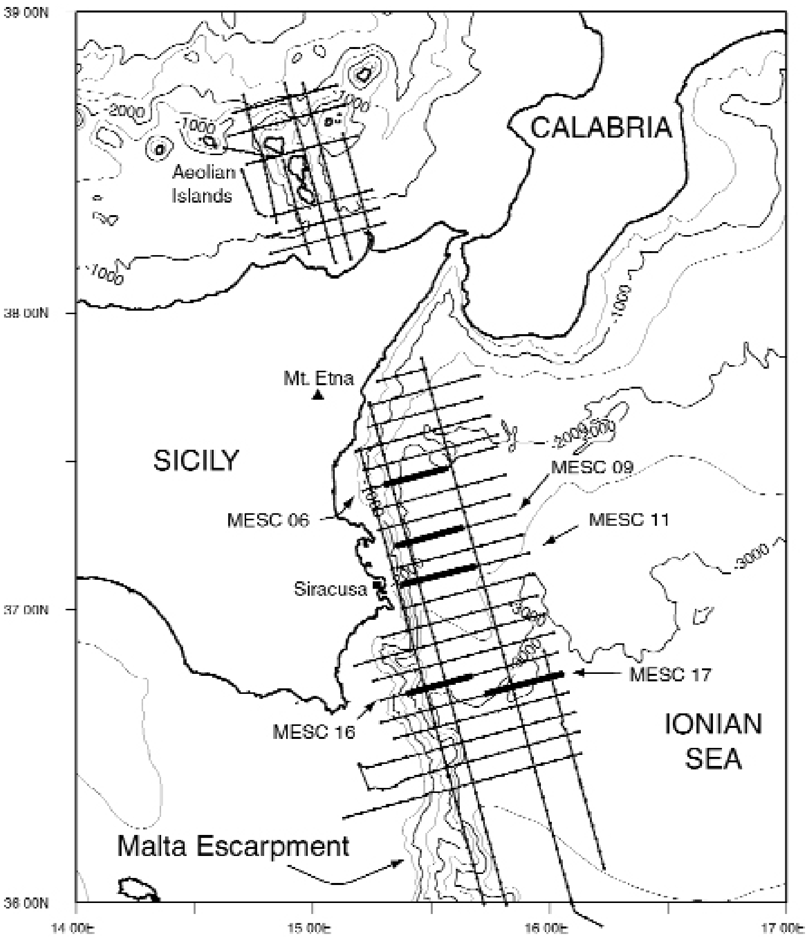

Fig. 2 - Traces of seismic profiles in the two study areas: along the Malta Escarpment offshore eastern Sicily; and across the NNW-SSE trend of the Aeolian Islands. The portions of seismic profiles shown in Figs. 3 to 7 are indicated with bold lines.

bring information on the occurrence of large mass movements along the slope. Such processes may play a role in triggering or modulating tsunamis in a tectonically active environment.

An additional seismic survey, of limited extent, was carried out to cover the sea surrounding the islands of Vulcano, Lipari and Salina with the aim of mapping the regional tectonic features controlling the evolution of the line of volcanoes and the stability of the individual edifices.

4. Cruise activity

The study area covers about 2 square degrees along the Eastern Sicilian Escarpment, going from offshore Mount Etna, in the north, down to the latitude of Malta, in the south. The MCS survey, carried out from July 27 to August 16, 2001, onboard the R/V Urania of the National Council of Researches (CNR), led to the acquisition of c.a. 2500 km of seismic profiles.

Following the initial operations of installing and connecting the instruments, activity onboard was carried out in shift work during the 24 hours, with 4 hours of work followed by 8 hours of rest for each operator. For more details on the cruise activity see the IGM-CNR technical report n. 71 (Bortoluzzi et al., 2001).

4.1. Navigation and positioning

Positioning during the operation was obtained using the NAVPRO V5.6 system by Communication Technology (Cesena, Italy). The integrated system was based on a Microtecnica Gyrocompasse and a Trimble 4000 Differential Locator, with a DGPS Satellite link by Fugro. WGS84 was taken as the reference datum while the Direct Mercator on 38°N, and UTM 33 were chosen as map projections for navigation and display, respectively. Timing was set to UTC.

4.2. Chirp sonar

Sub-bottom profile data were acquired by a 16-transducer hull-mounted Datasonics Chirp-II profiler, with operating frequencies ranging between 2-7 kHz. The analog record was printed in real time on an 22" EPC recorder, while the digital data were recorded in SEG-Y format on magneto-optic removable disks, subsequently backed up on a hard disk support.

4.3. Seismic survey

ACQUISITION. - Data acquisition was carried out using a 48-channel Teledyne streamer and a Sodera G.I. gun in harmonic mode (105 + 105 c.i.) powered by 2500 l/min, electrically driven Bauer compressor. The group interval of the acquisition streamer was of 12.5 m for a total active length of 600 m. Including the 150 m tow leader and two 50 m stretch sections, the streamer reached a total length of 850 m. The pressure to the gun was set at 175 Bar (2500 psi), with on actual range of 165 to 185 Bars. The shot interval was 50 m, giving a coverage of 600 %. The depth of the energy source ranged between 5 to 6 m whereas the streamer was kept at a 10-12 m depth by 4 Syntron RCL-2 cable-levelers.

Seismic data were collected by a Teledyne 48-channel streamer and digitized and recorded on DDS-1 and DDS-2 DAT tapes by a Geometrics’s Stratavisor seismograph in SEG-D format, with a sampling rate of 1 ms and a record length varying from 8 to 12 s.

PROCESSING. - The seismic data were processed onboard, using a standard sequence (Yilmaz, 1987) up to time migration, using the software Disco/Focus by Paradigm. The main processing steps were:
1. resampling every 2 ms of the original record;
2. spherical divergence gain to recover signal amplitute;
3. editing and CDP sorting;
4. velocity analysis every 200 CDP;
5. normal move out correction;
6. stack;
7. muting to remove noise in the water column, and
8. finite-difference time migration.

5. Preliminary results

During the 18 days of operation we collected 38 seismic profiles in two separate surveys, 25 along the slope of eastern Sicily and 13 around the Aeolian Islands (Fig. 2). Chirp sonar profiling was performed through out the area, along with the seismic acquisition, whereas magnetic data were collected in the southern part of the Ionian survey and in the Aeolian survey. Seismic profiles were all processed onboard up to time migration.

Favourable weather conditions allowed us to work continuously during the cruise, also limiting the noise due to the roughness of the sea, and the amount and quality of the data collected are a good premise for the fulfillment of our research goals.

Seismic profiles acquired along the slope of eastern Sicily are of pretty good quality and show a number of interesting features. Extensional faults, often cutting the sea floor, have been well imaged, particularly on the E-W-trending profiles. Some of these faults are linked to the slope of the Malta Escarpment, whereas others are located further to the east. Half grabens filled by sediments with growth strata geometries are typically associated with the faults.

As a side aspect which has relevance to the regional geology of the area, the extent of the Calabrian Arc accretionary wedge and the way it interferes with the Malta Escarpment have also been rather well imaged. The Malta Escarpment itself appears quite clearly on the seismic profiles, and often, reflections that are continuous with the escarpment can be followed eastwards for 20-30 km, under a sedimentary pile of variable thickness. In the southern part of the survey, where the water depth was larger, the quality of seismic images was a little degraded, with reduced penetration. Besides the greater water depth, this degrading of the image is related to the nature of the geological units encountered; in fact, the sedimentary cover of the Calabrian Arc accretionary wedge is greatly reduced, leaving a tectonised unit close to, or at the sea floor.

Seismic profiles acquired around the Aeolian Islands are not as good as those of the first survey, quality-wise. The shallowness of water, steep slopes and abundance of volcanic rocks contribute to lowering the quality of seismic data. However, some interesting features have been imaged along the volcanic ridge, particularly south of Vulcano, where steep faults cutting the substrate of the sedimentary cover have been detected. The side slopes of the volcanic edifices have also been well imaged. The data acquired around the Aeolian Islands and their preliminary interpretation will not be discussed in this paper.

The fault system characterising the Eastern Sicilian Escarpment appears well imaged on the seismic profiles and presents some additional complexity when compared to the previously published structural maps (Cernobori et al., 1996; Hirn et al., 1997; Bianca et al., 1999; Nicolich et al., 2000).

The Malta Escarpment represents the dominant morphological feature of the surveyed area and appears as a steep eastward-sloping surface partly onlapped by the flat laying sediments of the Ionian Basin. Offshore eastern Sicily, the Malta Escarpment can be divided, for the sake of description, into two portions with different tectonic structures.

The segment of the Malta Escarpment extending north of Siracusa is characterised by the presence of NNW-SSE-trending east-dipping extensional faults located along the morphological escarpment and a few km east of it. Profile Mesc 09 (Fig. 3) shows a half-graben basin, filled

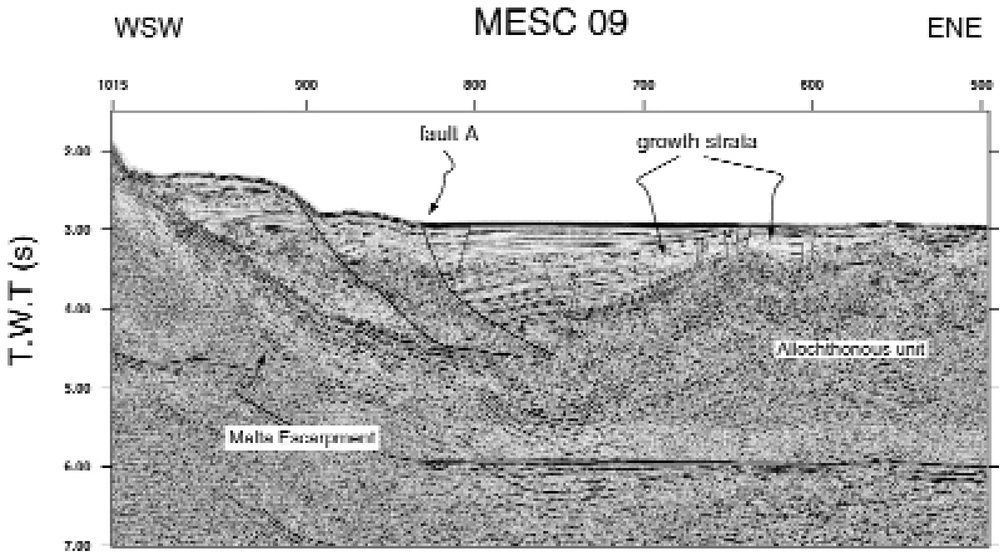

Fig. 3 - Seismic profile MESC 09 showing the structural features in the northern sector of the eastern Sicilian slope. Note the steep eastward-dipping package of reflectors representing the Malta Escarpment. Allochthonous unit refers to the external Calabrian Arc accretionary prism. Fault A is the principal extensional fault. Horizontal distance for this and the following profiles, is 100 shots = 5 km. Location in Fig. 2.

with up to 1 s (TWT) of sediment and bounded to the west by two extensional faults. The fault to the left seems to flatten out onto the Malta Escarpment reflectors, whereas the fault to the right appears as the master fault (fault A in Fig. 3), having a substantially larger throw. Wedging of reflections, identifying growth strata, can be observed within the recent sediments at the eastern margin of the half graben. The two above-mentioned faults represent the western extensional fault system in the region, which dies out northwards where the main extensional fault is located further to the east (Fig. 4). Although the half-graben geometry of the sedimentary basin is still well observable, the left margin of the basin has been reactivated in contraction, leading to the uplift of the sea floor with respect to the former extensional footwall.

Moving south along the eastern Sicilian slope, the previously mentioned western extensional fault system dies out rapidly (Fig. 5). The recent deformation of this sector is located about 20-30 km eastwards of the morphologic slope and is characterised by a broad area of uplift, trending NNW-SSE, apparently bounded by reverse faults (Fig. 5). The recent activity of this uplifted feature is documented by the growth geometry displayed by the adjacent sediments.

The Malta Escarpment does not seem affected by recent faulting in the segment south of Siracusa (Fig. 6). In this part, a thick package of reflectors is visible underneath the slope and continues undisturbed further eastwards, underneath the chaotic units of the external Calabrian Arc (Fig. 6). Limestone samples attributable to this package of reflectors have been dredged along the southern scarp of the Alfeo Seamount (Fig. 7), presenting Jurassic microfossils and pelagic facies (Rossi and Borsetti, 1977). It is worth noting that the sedimentary cover, capping the Mesozoic sediments, is quite reduced (Fig. 7), particularly when compared to the adjacent sea floor, where a thick sedimentary succession, inclusive of the external Calabrian Arc accretionary wedge, overlies the Mesozoic reflector package (e.g. Fig. 6). Seismic facies

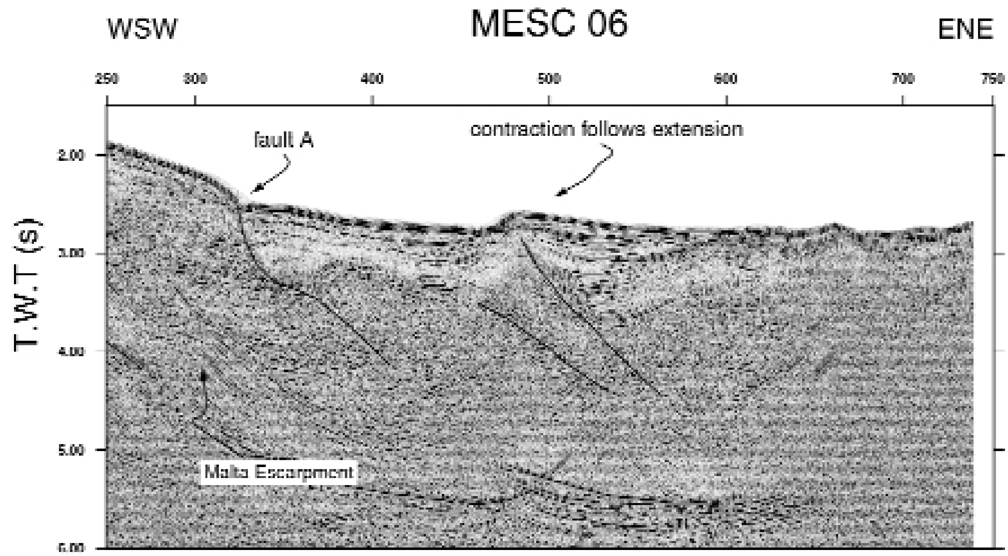

Fig. 4 - Seismic profile MESC 06 showing the western margin of a sedimentary basin that has been reactivated in contraction. The half graben geometry of the sedimentary fill is still visible in the hanging wall of the reverse fault. See Fig. 2 for location.

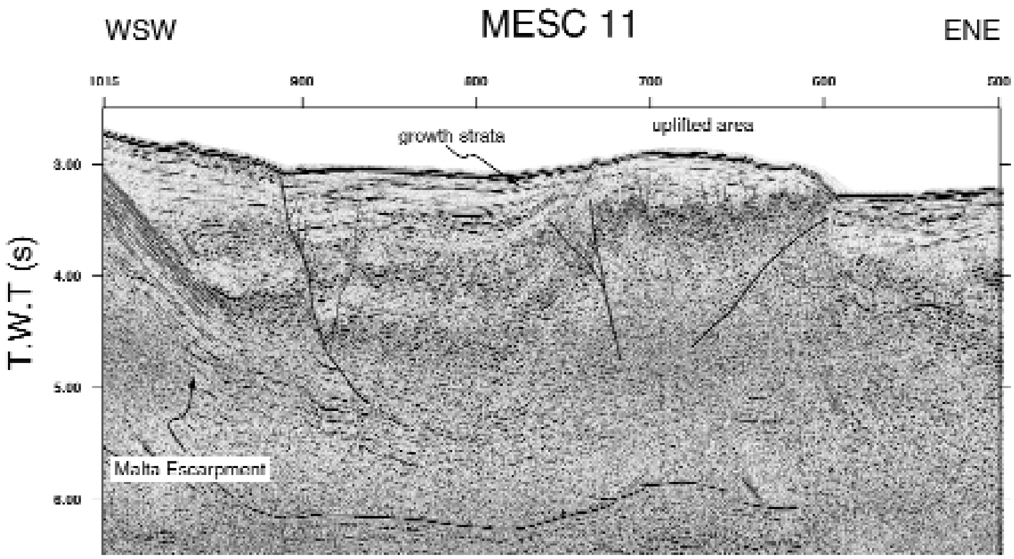

Fig. 5 - Seismic profile MESC 11 showing the limited throw of the western extensional fault system that dies out southwards, and the uplifted area, bounded by reverse faults, located further to the east. Note the good continuity of the steep reflectors marking the Malta escarpment. Location in Fig. 2.

indicative of chaotic sediments belonging to the Calabrian Arc accretionary wedge are not present on top of the Alfeo Seamount, suggesting that this relief was already present when the accretionary wedge reached that area. The stratal geometry of the sediments adjacent to the Alfeo Seamount, and the abundant normal faults dissecting its sedimentary cap suggest that the seamount has been extensively reactivated in recent times.

The simplified structural map of the eastern Sicilian slope and adjacent regions illustrates

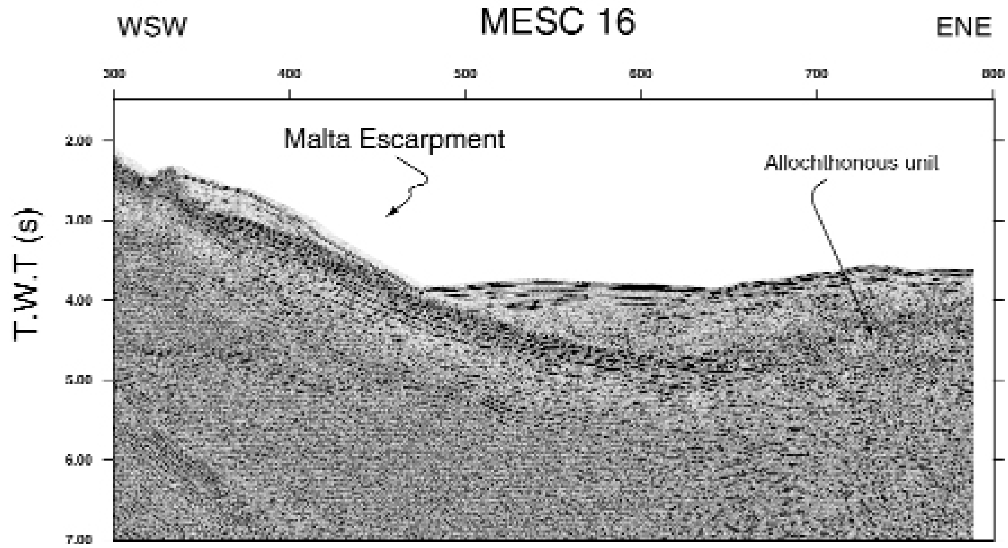

Fig. 6 - Seismic profile MESC 16 showing the regional aspect of the Malta Escarpment in the southern sector. Note the absence of faults and the continuity towards the Ionian basin plain of the package of reflections that characterises the Malta Escarpment. See Fig. 2 for location.

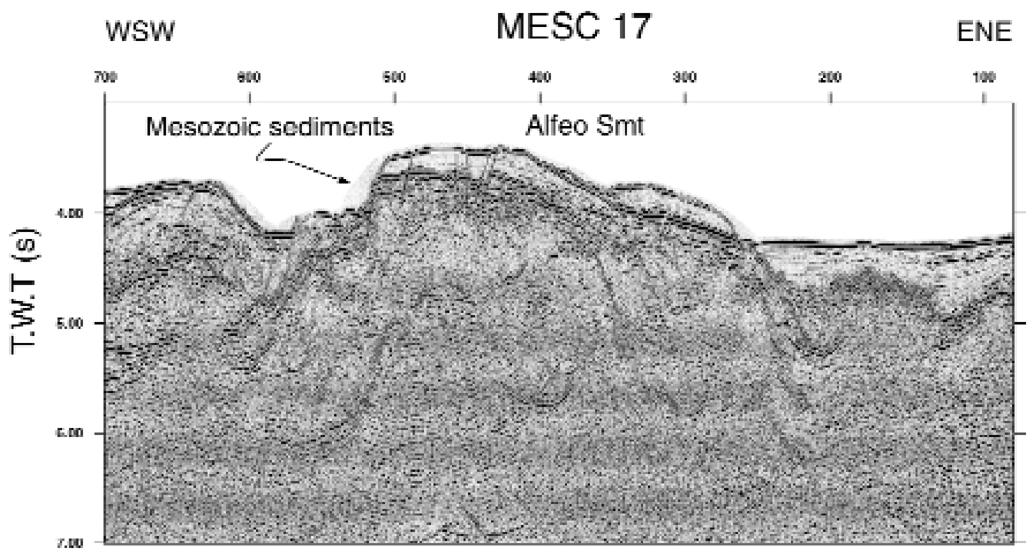

Fig. 7 - Seismic profile MESC 17 crossing the Alfeo Seamount, where pelagic carbonate sediments of Jurassic Age have been dredged (Rossi and Borsetti, 1977). Note the thin sedimentary cover on top of the Mesozoic reflectors which is affected by minor extensional faults. Location in Fig. 2.

the location of the neotectonic features with respect to the Malta Escarpment (Fig. 8). The mapped structures all lie on the accretionary wedge of the external Calabrian Arc which is encroaching the Malta Escarpment at the latitude of Siracusa. With the exception of the Alfeo Seamount, which trends NNE-SSW, most of the structures present a NNW-SSE orientation that recalls the trend of the Malta Escarpment. The extensional faults located at the eastern end of the deformed belt present features indicative of more or less pronounced, contractional reactivation. In one instance a reactivated extensional fault passes southwards to a broad uplifted region where evidence of extension are lacking (Fig. 8). On the other hand, the westernmost extensional fault system, located above the Malta Escarpment, does not present any contractional reactivation.

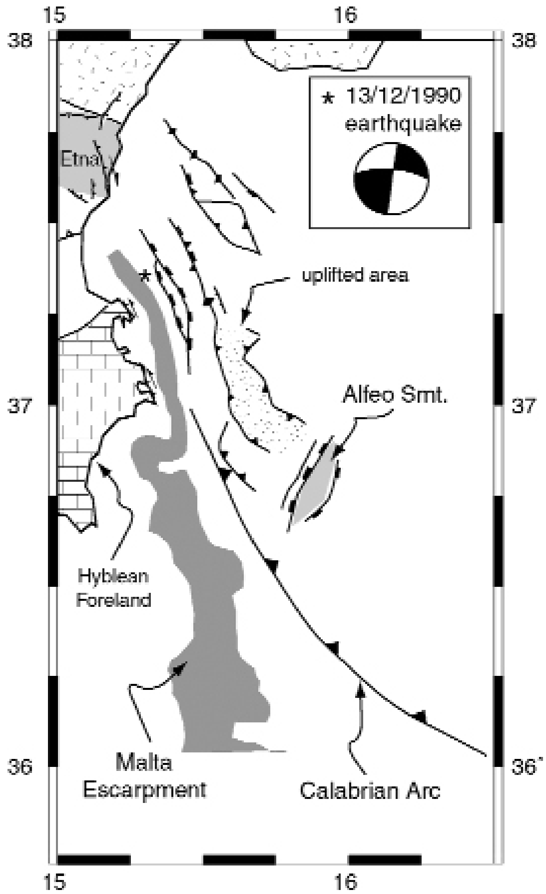

Fig. 8 - Simplified structural map along the eastern Sicilian slope and adjacent regions. Random dashes indicate the outrcopping Calabrian Arc terrains, whereas the foreland units outcropping in the Hyblean region are represented by a brick pattern. Lines with ticks or black rectangles represent extensional faults, whereas lines with black triangles are thrusts and reverse faults. Contractional reactivation occurred where extensional and thrust symbols are present along the same line. A morphologic relief of up to 3 km is accomplished across the Malta Escarpment. Inset shows the focal mechanism obtained for the 13 December, 1990 earthquake (Amato et al., 1995; Giardini et al., 1995).

6. Discussion and conclusions

The interpretation of the seismic data set shows that sedimentary basins displaying half-graben geometry are related to the extensional faults in the northern sector of the eastern Sicilian slope. In some instances, splays from the western fault seem to join the sloping surface of the Malta Escarpment. The central and eastern extensional faults, and related sedimentary basins, are affected by a subsequent contractional deformation. Altogether, the NNW-SSE belt displaying recently deformed structures seems to end around the Alfeo Seamount (Fig. 8).

Along the segment south of Siracusa, the Malta Escarpment does not seem affected by recent faulting and appears as a steep surface that flattens out towards the Ionian Basin (Fig. 6).

The first investigations, based on seismic data and dredging (Scandone et al., 1981), viewed the Malta Escarpment as a large vertical relief (due to faulting) already existing in Messinian times, as Messinian crusts and veins occur in rocks as old as Late Triassic, therefore they were exposed to the sea floor. This feature, however, was not considered to mark the C/O boundary, as the Mesozoic rocks of the Siracusa facies belt extend up to the Alfeo Seamount (Rossi and Borsetti, 1977). The main faulting event responsibile for the morphological expression of the Malta escarpment was interpreted to be of Tortonian Age, although a recent (post-Trubi, i.e. post early Pliocene) important reactivation occurred (Casero et al., 1984). Finetti (1985) interpreted a Mesozoic onset for the activity of the fault defining the Malta Escarpment, that is considered to bound the mid-Jurassic Ionian oceanic basin and its thinned continental margin.

More recent studies based on the acquisition of the CROP project deep reflection profiles suggest that the Malta Escarpment originated by rifting in upper the Permian-Triassic followed by spreading from Jurassic to upper Cretaceous-Early Tertiary (Catalano et al., 2000a). The timing of rifting and spreading events along the Malta Escarpment is considered slightly different by other authors (Catalano et al., 2000b): continental rifting from pre-Triassic to Early Cretaceous, followed by spreading in Early Cretaceous. The C/O boundary is thought to be about 50 km east of the escarpment and the deep part of the continental margin is considered to be floored by transitional crust originated by thinning and underplating of continental crust. A Triassic-Jurassic carbonate platform is interpreted as prograding on the transitional crust up to the C/O boundary (Catalano et al., 2000b); however, if the interpretation of the prograding Triassic-Jurassic platform is correct, the thinning of the margin should precede the prograding of the platform and, therefore, drifting should be older than Jurassic. The Malta Escarpment is interpreted as fault bounded but with the faulting age much younger (Late Miocene?) than that of the rifting.

It is not easy to compare our data set with literature data, considering that the grid of CROP profiles over the Malta Escarpment is rather loose and that published images of the escarpment are often of poor quality and with great vertical exaggeration. The erosional character of the escarpment, in places rather pronounced, and its steepness can easily mask its nature from seismic prospecting. Where the sloping is less extreme, however, our data show that a continuity of the reflection package can be seen from the Ionian Basin to the upper part of the slope. In our interpretation, the escarpment would be a feature inherited from Mesozoic, or perhaps earlier (Argnani, 2000b; Stampfli et al. 1991, 2001) times, linking the deep Ionian Basin to the east with the Hyblean platform to the west. In addition, the Alfeo Seamount with its pelagic Mesozoic facies can be considered an original seamount, separated by the Hyblean plateau already at the early stage of passive margin formation. Its structural trend, at odds with respect to the recent faulting along the Malta Escarpment, supports this interpretation.

Putting the investigated area within a regional geodynamic context, it appears that the oceanic Ionian lithosphere, presently subducted under the Calabrian Arc, is on its way to being torn off from the adjacent continental lithosphere of the Hyblean region along a line that follows the Malta Escarpment (Argnani, 2000a). The NNW-SSE-trending Aeolian volcanoes (Vulcano, Lipari and Salina) and Mount Etna are considered to be located along a line which possibly acts as a guide to magma uprise. Both the supra-subduction mantle wedge and the African asthenosphere magmas can find their way upward along this lateral tear. In fact, a lateral window at the side of the subducted Ionian lithosphere has been inferred from a 3-D geometric reconstruction (Gvirtzman and Nur, 1999). This gap can allow an asthenospheric flow from under the subducted plate to the base of the upper plate, where it can eventually give rise to melting and can feed the Mount Etna volcano. A differential rollback between the retreating Ionian lithosphere and a "stationary" Sicilian lithosphere has also been considered (Doglioni et al., 2001). This process, together with the parallel extension arc, defines the Malta Escarpment as a dextral transtensional window that favours magma uprise. The focal mechanism solutions of the 13 December 1990 earthquake (Mw 5.8), however, seem to indicate sinistral strike-slip along the Malta Escarpment (Fig. 8; Amato et al., 1995; Giardini et al., 1995), making the picture perhaps more complex. In this respect, our seismic profiles indicate that the Malta Escarpment south of Siracusa is not affected by lithosphere tearing, whereas north of Siracusa the tectonic expression is not quite straightforward. Although both extension and contraction have been recorded in the latter region, it is difficult to unravel the eventual contributions due to strike-slip motion from those originated from the interplay between extension along the Malta Escarpment and contraction within the external Calabrian Arc (Fig. 8).

The epicentre of the 13 December 1990 earthquake, the largest event recorded instrumentally, is located in proximity to the extensional fault occurring near the coast of Sicily, although the focal mechanism of this earthquake indicates strike-slip (Fig. 8; Amato et al., 1995; Giardini et al., 1995). The total length of the principal extensional fault, which is of crustal scale, is more than 50 km (Fig. 8) long. Modelling the tsunami that followed the 1693 earthquake, one of the most distructive events striking the region, Piatanesi and Tinti (1998) reached the conclusion that the most likely source for that earthquake was an extensional fault located offshore Siracusa and trending NNW-SSE, i.e. the same trend as the extensional fault recognised in this study (Fig. 8). This fault can well be the source of the 1693 earthquake both for magnitude and direction. However, given the structural complexity observed, partitioning between strike-slip and extensional components needs to be better understood and the seismogenic potential of the structural architecture outlined with this new survey is still to be worked out.

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