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THE SUBMERGED ALPIDIC CHAIN FROM SOUTHERN SARDINIA SHELF TO THE PELAGIAN RIFTING: TECTONIC HISTORY

Abstract. The structural grain and tectonic evolution of the NW-SE Sicilian-Maghrebian sector and of its Pelagian foreland forming the submerged Sardinia-Sicily Alpidic belt is described, mainly with a reinterpretation of the known seismic grid. In the Sicilian Maghrebian sector the crust is formed by an allochtonous belt composed of flysch-type thrust slices stacked on an imbricate wedge composed of basin and platform carbonate thrusts derived from the deformation of the old Sicilian continental margin. Lower Miocene to lower Pleistocene foredeep (terrigenous and carbonate) deposits clastics filled the progressively onlapping foreland basins during compression. Timing of deformation spanned from early Miocene to early Pleistocene. The structural evolution of the Gela foredeep shows the kinematics and timing of emplacement of the "Gela Nappe", believed to be the present-day thrust front of the Sicilian accretionary wedge. In the Pelagian foreland the Plio-Pleistocene tectono-sedimentary history of the Lampedusa-Linosa sector reveals that middle Pliocene extensional tectonics indicate a rifting mechanism for the Sicily Channel. This event was followed by inversion tectonics and late Pleistocene strong vertical tectonics.

INTRODUCTION

This paper illustrates in detail the structural grain and the Neogene-Pleistocene evolution of two sectors of the submerged Sardinia Sicily Alpidic belt: the Maghrebian Sicilian chain with its Gela foredeep and the eastern sector of the rifted Pelagian foreland. Multichannel seismics, mostly already published calibrated with well data, and dredge hauls, were used, as well as high resolution monochannel seismic profiles (Fig. 1).

GEOLOGICAL FRAMEWORK

Four main tectonic units are recognized in the submerged body (Fig. 2). They are geometrically arranged in a thrust-pile verging toward the east and southeast (Fig. 3).

1. The highest structural element occurs along the eastern margin of the Sardinia block (Sardinia Channel, Cornaglia basin) which tectonically overlies the "Kabilian-Calabrian" units. The Sardinia Thrust Front is located within the Cornaglia basin (Torelli et al., 1985; Catalano et al., 1987, 1989). The Eastern Sardinia block is crystalline basement that has not been metamorphically overprinted during deformation. It is unconformably overlain (Fig. 4) by thick, presumably Aquitanian-early Burdigalian clastics (Compagnoni et al., 1986) that have been deformed (Brancolini et al., 1989 and Fig. 4). Upper Miocene-Pliocene deposits related to the Tyrrhenian opening (Fig. 4) unconformably underlie upper Pliocene-Pleistocene clastics (Barbieri et al., 1984).

2. The Kabilian-Calabrian units (Fig. 2) consist of a wedge of imbricated thrusts of Hercynian

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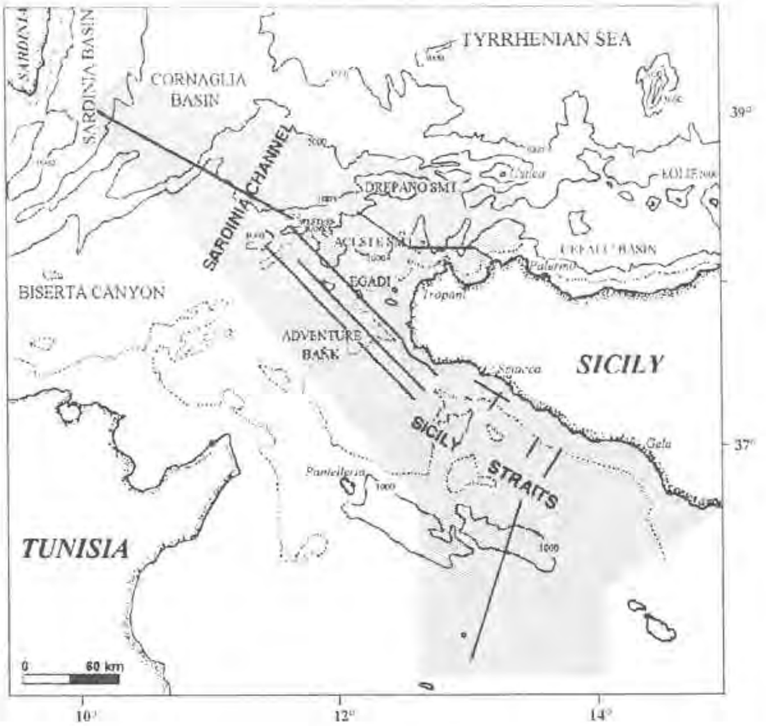

Fig. 1 — Sardinia Channel, Northwestern Sicily offshore and Straits of Sicily morphology. The studied area (grey) is crossed by some geological sections.

crystalline basement with a metamorphic overprint of Alpine age (Compagnoni et al., 1986), recently also described in Southern Calabria. They are covered by lower Miocene foreland basin arkosic deposits and middle Miocene-Pleistocene clastics, characterized by regional unconformities (Barbieri et al., 1984). The Kabilian-Calabrian tectonic units overthrust the Sicilian Maghrebian sector of the chain along the Drepano Thrust Front (Fig. 3 and Catalano et al., 1985).

3. The Sicilian Maghrebian sector (described in detail below) consists of a huge tectonic body more than 12 km thick formed by several imbricate thrust units. A thrust-front occurs in offshore southern Sicily, between Gela and Sciacca, where a tectonic wedge of thin-skinned thrust sheets of mostly Oligocene-lower Pliocene rocks ("Gela Nappe") is sandwiched in the Pleistocene sedimentary packages of the Gela basin, acting as a late Pleistocene foredeep.

4. The foreland area is located in the southeastern Sicily offshore and in the Sicily Channel (Pelagian Block). A major acoustically imaged body contains a sedimentary succession, mostly outcropping on land in southern Sicily. The Sicilian Maghrebian sector and the southeastern sector between the Malta and the Linosa graben will be illustrated here in detail.

THE SICILIAN MAGHREBIAN CHAIN AND ITS THRUST FRONT ("GELA NAPPE")

The Chain

Seismic reflection profiles characterize (Figs. 1, 2): a) an inner strongly shortened segment, which extends from the Western Bank southeastwards to the Egadi Islands and eastwards to the NW Sicily offshore; b) an outer, less deformed, tectonic element extending across the Adventure Plateau; and c) a deformed foreland forming the western and southern Sicily offshore, as well as southern Sicily mainland (Catalano, 1988). Detailed geological sections built on the basis of seismic lines cross the submerged body along a NW-SE trend (Fig. 3).

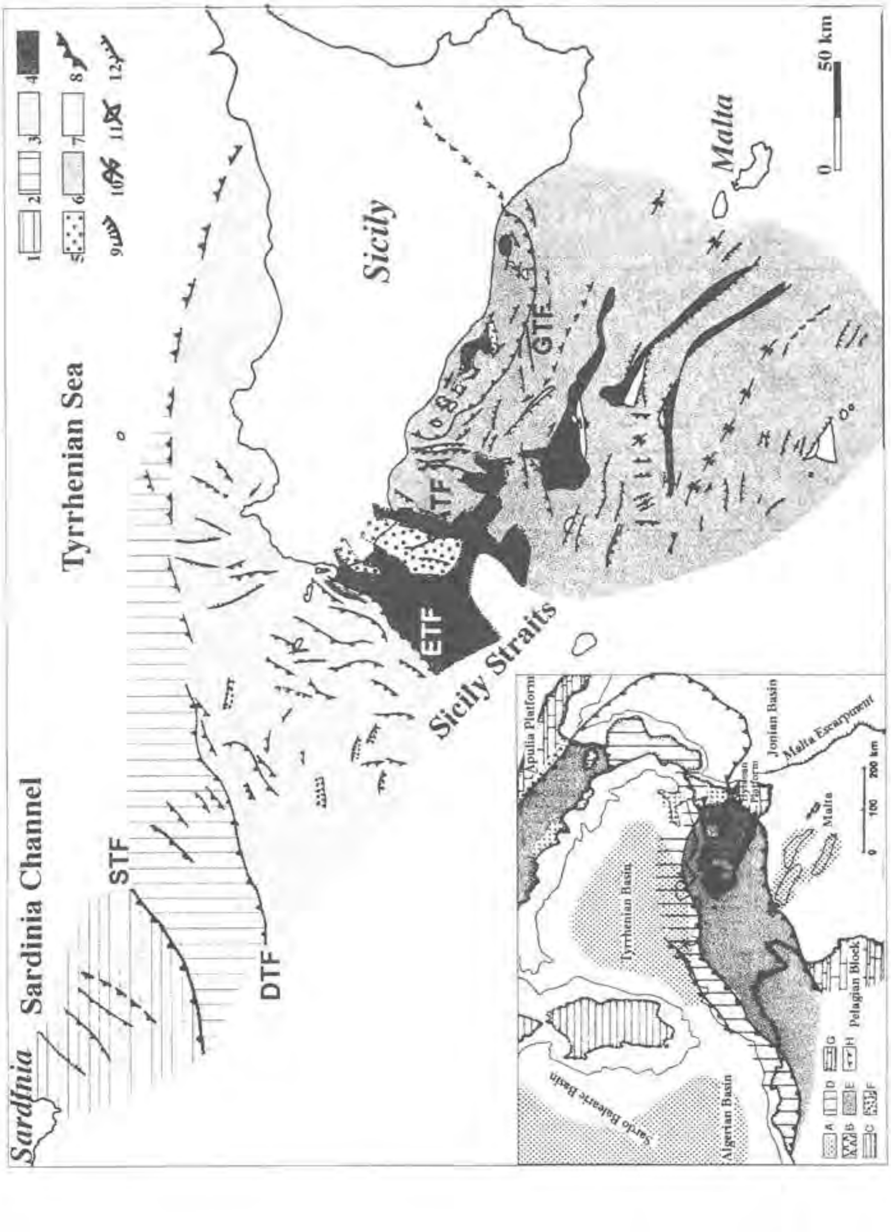

Fig. 2 — Structural map of the Sardinia Channel-Sicily Straits area built up on the basis of the known seismic profile grid. 1) Eastern Sardinia structural units emplaced during earliest Miocene; 2) Kabilo-Peloritan Units emplaced before Langhian; 3) Sicilian-Maghrebian Units emplaced before Late Tortonian; 4) Deformed Tortonian terrains; 5) Deformed lower Pliocene terrains; 6) Plio-Pleistocene deposits; 7) Uplifted Meso-Cenozoic substrate; 8) Thrust; 9) Post-Messinian half-grabens inverted during the late Pliocene-early Pleistocene; 10) Syncline; 11) Anticline; 12) Normal faults. The tectonic scheme, in the left corner shows: A: superimposed extension, B: Plio-Quaternary volcanoes, C: Corsica-Sardinia, D: Calabrian Arc, Kabilias and "internal" flysch ophiolites, E: Maghreb-Sicily-Southern Apennines imbricates and deformed foreland, F: foredeep, G: foreland and mildly folded foreland (Tunisian, Hyblean, Apulia), H: main overthrust front.

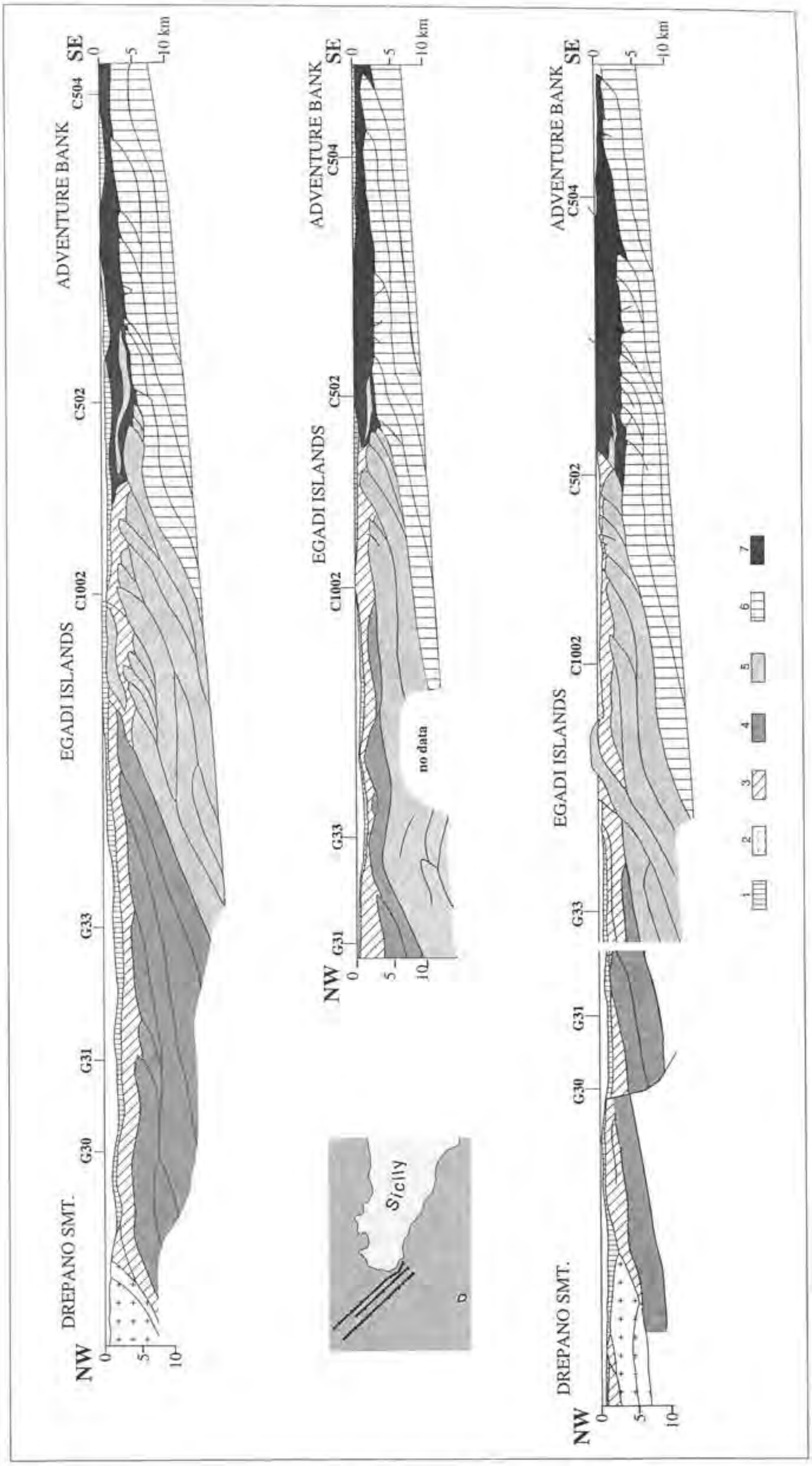

Fig. 3 — Geological cross-sections from seismic profiles from Western Bank through Egadi Islands to Adventure Bank. The figure shows from the top: (1) Plio-Pleistocene deposits, (2) crystalline and sedimentary Kabilo-Calabride equivalent units, overthrust on (3) detached and accreted flysches, (4) basin carbonate wedge slices, (5) platform and basin carbonate thrusts (Panormide and Pre-Panormide), (6) platform carbonate (Trapanese and Saccense) thrust units, overlain by the Lower-Upper Miocene foreland basin deposits (7) (G and C with numbers indicate Seismic profiles crossing the geological sections).

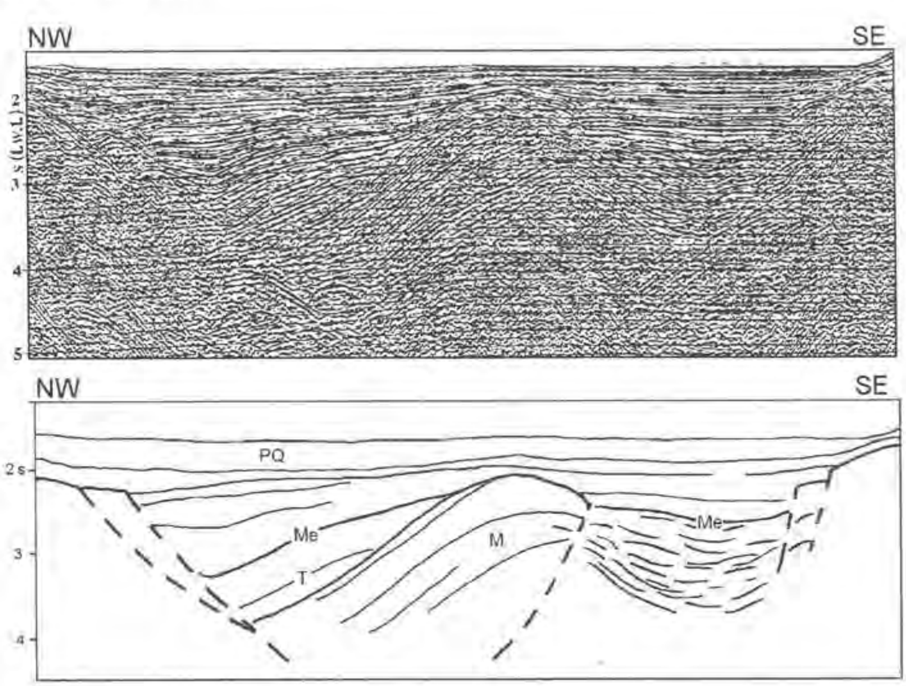

Fig. 4 — Eastern Sardinia margin. NW-SE multichannel seismic line shows thick? Mesozoic-Tertiary deposits that cover the inferred crystalline substrate folded and faulted prior to the Late Tortonian. Synrift deposits contain Messinian horizons. Faulting, tilting and erosion continued in more recent times. Legend: PQ: Plio-Quaternary; Me: Messinian; T: Tertiary; M: Mesozoic.

1. The inner sector. The inner segment of the Sicilian-Maghrebian chain is bounded to the north by the already mentioned Drepano Thrust Front (DTF, Figs. 2, 3), outcropping along the Western Bank and the NNE-SSW trending Elimi Chain (Southern Tyrrhenian). The southern boundary is represented by the Egadi Thrust Front (Figs. 2, 3, 7). In this sector the geometrically highest tectonic units show the reflecting character of a thinly layered succession, which is interpreted as Numidian flysch, or equivalent clastics (Figs. 3, 6). The wedge structurally overlies stacked thrust-sheets that show the acoustic character of deep water carbonate facies assumed to be of Mesozoic age, as demonstrated by the Triassic deepwater packages found in the Egadi Islands (Di Stefano and Gullo, 1993). The piled rock bodies are derived from the deformation of a more internal basinal paleogeographic domain. The lower tectonic units are formed by thickly bedded Triassic-Liassic carbonate-evaporitic platform and Jurassic-Oligocene deep water deposits unconformably overlain by Early Miocene shallow clastics and open-shelf carbonates. These deposits, partially outcropping in the Egadi Islands, appear to pass westwards, where they are recognized as Panormide and Pre-Panormide domains (Catalano, 1987). Basinal Cretaceous-early Miocene packages detached from their Paleozoic-Mesozoic substrate overthrust the array of stacked carbonate platform units (Figs. 7, 8). These units are unconformably overlain by late Tortonian terrigenous and clastic carbonatic prograding sequences, Messinian evaporites, early Pliocene pelagic marly limestones and Plio-Pleistocene clastics (Figs. 7, 8). The Pliocene-Pleistocene basin-filling appears to be deformed by growth faulting later followed by inversion tectonics (Catalano et al., 1988; Catalano and Milia, 1990). The inner sector appears to be laterally continuous with the structures of the Northern Western Sicily offshore (Figs. 1, 2) pointing out a common tectonic evolution during the early Miocene deformation (Agate et al., 1993).

The NW Sicily offshore has already been recognized as a marine prolongation of the land chain (Selli, 1974; Catalano et al., 1985). The area, crossed by a geological section based on a seismic grid, shows the Kabilo-Calabrian thrust units that tectonically overlie a stack of

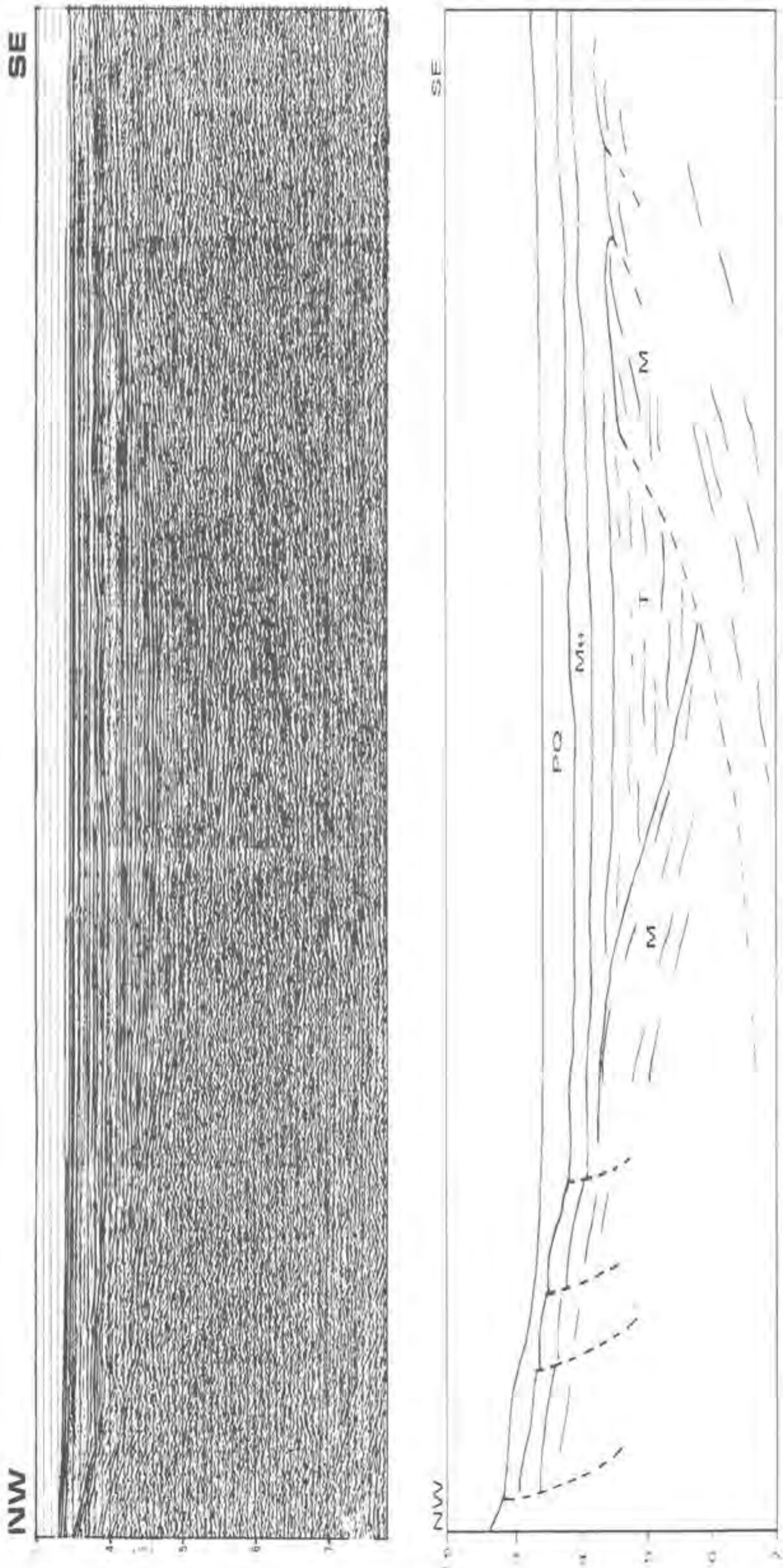

Fig. 5 — The NW-SE seismic profile shows the Miocene - Pleistocene infilling of Cornaglia Basin and the underlying Meso - Cenozoic Kabilo - Calabrian Units with SE-vergence.

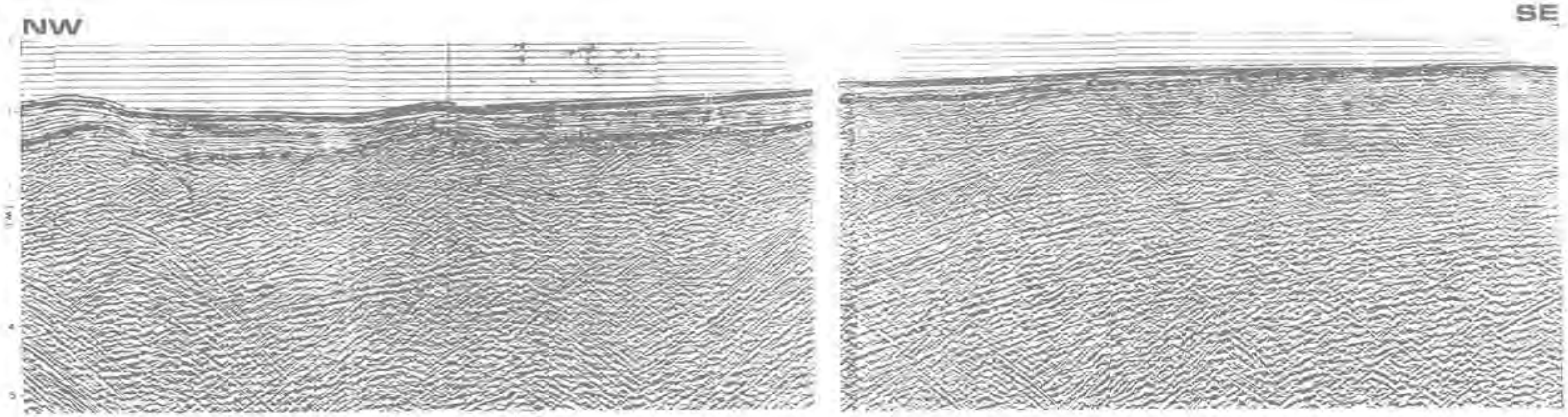

Fig. 6 — The NW-SE trending seismic profile shows several stacked large ramps (apparently duplex) consisting of inferred basinal Triassic-Oligocene carbonates. Overlying thin layered reflectors are lower Miocene Flyschs. Post-Messinian faulting is shown at top of profile.

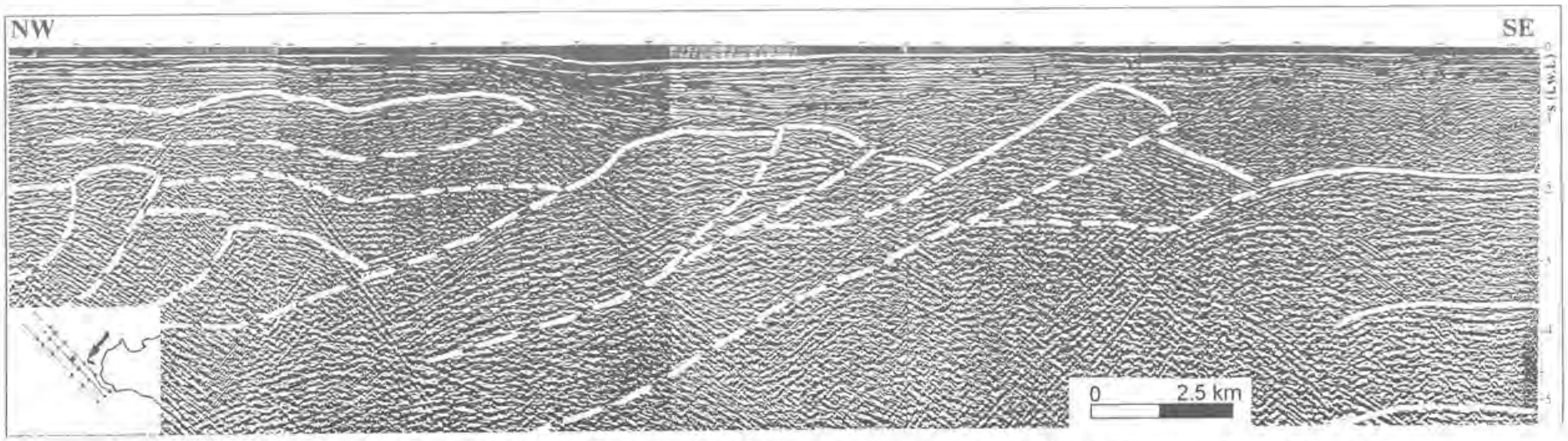

Fig. 7 — NW-SE seismic line showing a wedge of mainly carbonate platform rocks in the Egadi Thrust Front area. To the extreme southeast the Trapanese type carbonate stack is overlain by lower Miocene and uppermost Miocene foreland basin deposits.

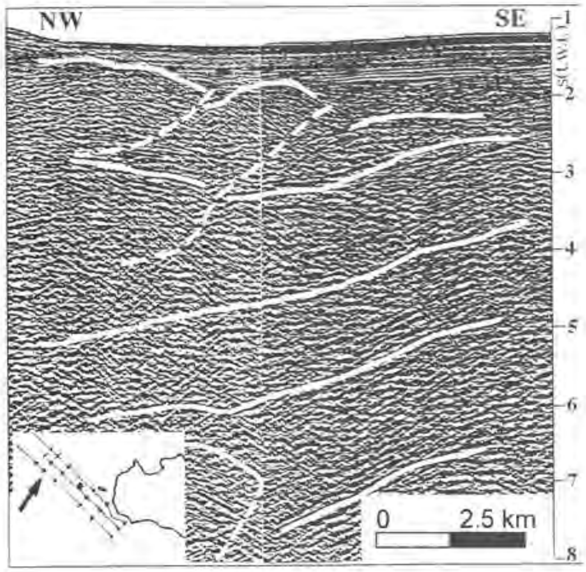

Fig. 8 — NW-SE trending seismic profile showing, between 6 and 8 sec t.w.t., some strong reflectors interpreted as the carbonate top of deeper thrusts.

southeastward vergent basin and platform carbonate imbricates and their detached terrigenous cover (Fig. 9). The array of thrusts has an eastward- and southeastward-vergence (Figs. 9, 10). The emplacement of the Kabilo-Calabrian Units on the Sicilian Maghrebian rocks is believed to have taken place during early Miocene (Amodio Morelli et al., 1976) or late Burdigalian (Nigro, 1992): in the studied area the Drepano Thrust Front is superimposed on Messinian reflectors (Figs. 3, 9). Similar relationships are seen in places on land and sea. The Drepano Thrust Front present-day setting has to be considered the result of a post-Messinian out-of-sequence high-angle thrusting that followed the early Miocene emplacement.

2. The outer sector. The reflecting body on Adventure Plateau consists of: a) a deformed (3000 m thick) thin-layered wedge bounded to the NW by the Egadi Thrust Front (Figs. 3, 11) and to SE by the Adventure Thrust Front (Fig. 3) overlying b) a lower, deformed carbonate substrate.

a. The thin-layered wedge lithologically represented by terrigenous and clastic carbonate deposits includes, from the top: folded and faulted lower Messinian - upper Tortonian deposits equivalent to the Terravecchia Fm. on land unconformably overlying early Miocene to early Tortonian clastics (Catalano et al., 1987; Argnani et al., 1989) locally stacked in thrust slices. These thrusts have a common basal detachment plane above the carbonatic substrate (Fig. 11). A post-middle Pliocene erosional surface forms the top of the entire sedimentary body (Catalano, 1987). Thin-skinned thrust packages of upper Mesozoic-Tertiary rocks of more northern domains are tectonically sandwiched between the lower and upper Miocene rocks (Fig. 11).

b. The carbonate substrate consists of a wedge of Mesozoic ramp units with internal duplex geometry (Figs. 3, 11). Transport direction appears to be eastward and southeastward, while the shortening decreases southeastwards. Its stratigraphy includes Triassic-Liassic carbonate platform deposits overlain by Jurassic - Eocene seamount-type deposits (Ammonitico Rosso), pelagic marly carbonates and earliest Miocene open-shelf clastic carbonates. These beds are known in western Sicily as pertaining to the Trapanese and Saccense paleogeographic domains (Catalano et al., 1987, 1989; Antonelli et al., 1988).

3. The third sector shows the characteristics of a deformed foreland. It develops from the Adventure Thrust to the Gela Thrust front (Sciacca offshore, Fig. 12) and appears as a crustal salient showing pre - late Miocene to middle Pliocene compressive (or transpressive?) deformation. This area is believed, according to Argnani (1989), Argnani et al. (1989), Antonelli et al. (1988),

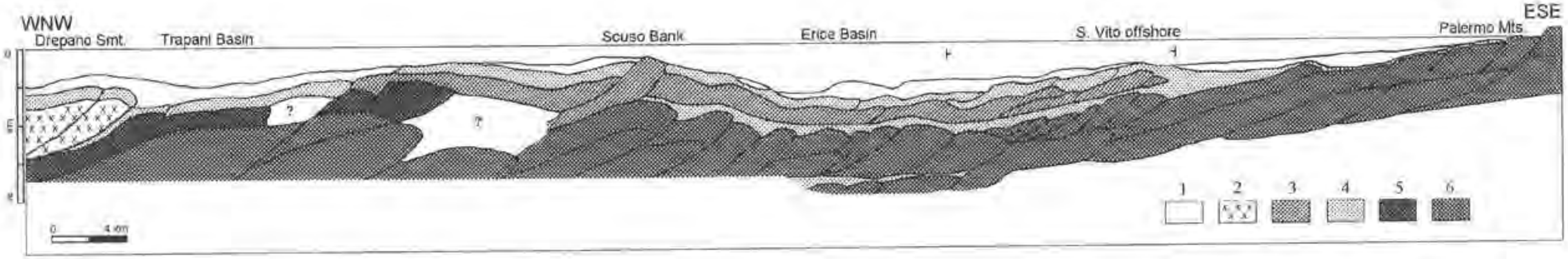

Fig. 9 — Geological cross-section along the Northern Sicily offshore built up on the basis of the available marine seismic reflection lines (G 82 multichannel seismic grid from Ministry of Industry and monochannel seismics) calibrated by dredge hauls collected in the area. The geological profile runs from the Elimi Chain southeastwards to the Palermo Mts. offshore. The Kabilian Calabrian units appear to overthrust the carbonatic thrust wedge after the Messinian. Legend: 1) Plio-Pleistocene deposits; 2) Kabilo Calabrian units; 3) Miocene clastics; 4) Cretaceous - Paleogene slices; 5) (?) basinal derived units; 6) carbonate platform derived units. The arrows indicate the seismic line of Fig. 10.

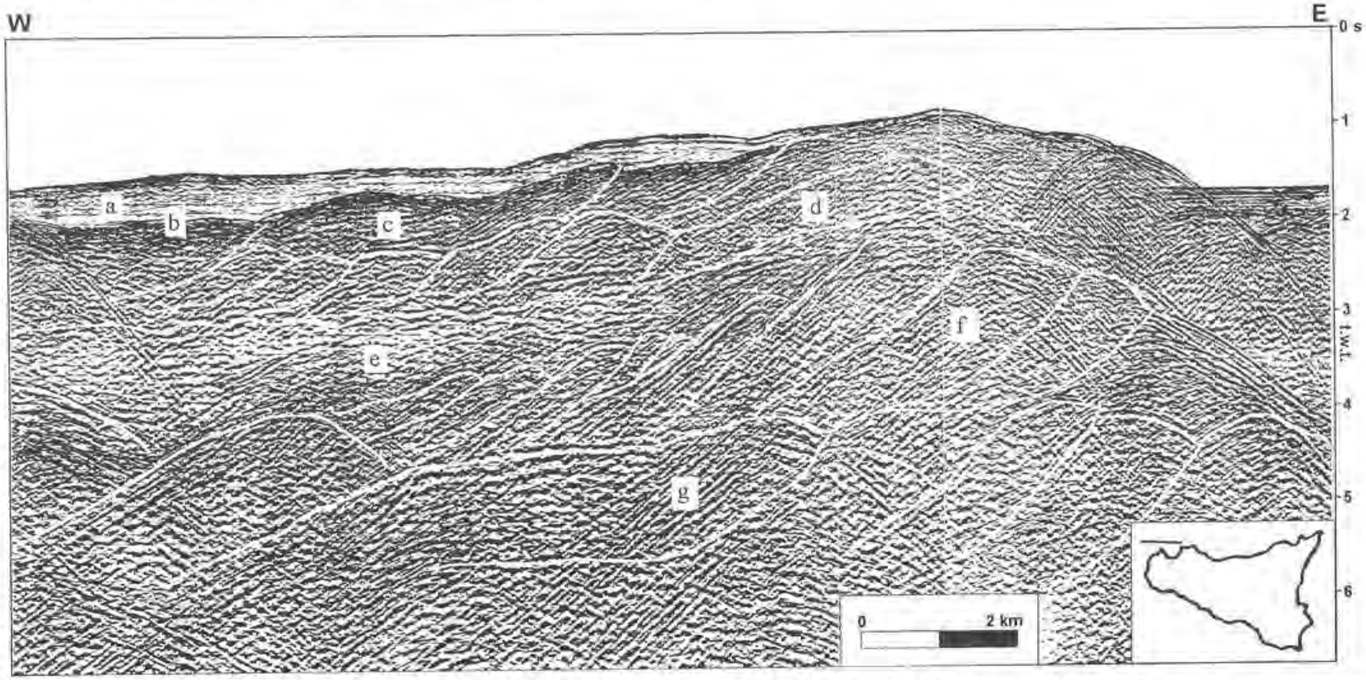

Fig. 10 — W-E trending multichannel seismic profile across the S. Vito Peninsula offshore (detail of the geological profile of Fig. 9). The interpretation is based on seismic character of the reflectors, samples from nearby dredge hauls and adjacent mainland structures. Legend: a) Plio-Pleistocene deposits; b) Messinian horizon and erosional surfaces; c) Miocene clastics (Numidian Flysch?); d) duplex-type slices wedge of deepwater late Mesozoic-Paleogene carbonates; e) Miocene clastics; f) carbonate platform ramps (Panormide equivalent?); g) carbonate thrust wedge (Trapanese carbonate platform?).

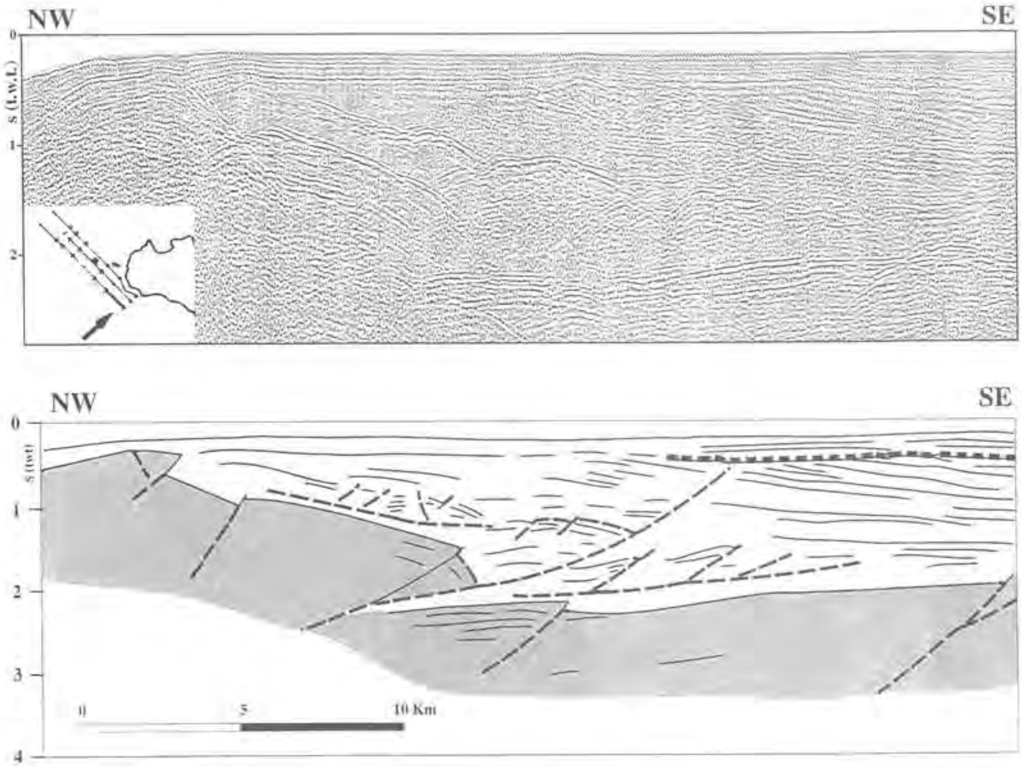

Fig. 11 — NW-SE trending seismic profile and line drawing showing the Egadi Thrust Front area and its relationships with the Miocene foreland basins. The main pre-Panormide stacked carbonate thrusts are tectonically overlain by thinner late Mesozoic-Tertiary sheets which towards the SE remain sandwiched between the stacked lower Miocene slices and the upper Miocene syntectonic clastics.

Torelli et al. (1991), to have been subjected to transcurrent deformations. The structures continue southeastwards below the "Gela Nappe" thrust front.

The "Gela Nappe" and its foredeep basin

The "Gela Nappe" (Ogniben, 1969) is a thin - skinned accretionary wedge (Fig. 13) which overthrusts its foreland marine sediments (Catalano et al., 1987, 1989; Antonelli et al., 1988; Argnani, 1989). It extends laterally into southern Sicily (Catalano et al., 1987, 1989; Bianchi et al., 1989; Grasso et al., 1991) where its thickness increases (Gela Thrust System, Catalano et al., 1993b).

The structures within the wedge trend NW-SE, orthogonal to the NE-SW main transport direction (Fig. 14). Widespread back-thrust features are exposed on Sicily (Catalano et al., 1993b).

The "Gela Nappe" body is formed from repeating packages of upper Cretaceous and Oligocene to lower Pleistocene folded and faulted deposits that are complexly thrust, and mostly showing duplex geometry. The "Gela Nappe" deposits are: a) Oligocene-Miocene clayey arenaceous Numidian Flysch; b) Oligocene to Tortonian clastics representing Miocene foreland cover; c) unconformable upper Tortonian-lower Messinian clastics and carbonates; d) Messinian evaporites and lower Pliocene Trubi; e) upper Pliocene and lower Pleistocene clastic carbonates. The thrust-front of this wedge, well seen on the seismic profiles (Figs. 14, 16), is sandwiched in the Plio-Pleistocene succession of the Gela foredeep basin (Catalano et al., 1993a).

The WNW-ESE trending Gela foredeep (Fig. 2) is a narrow, weakly deformed depression, partially buried by the frontal termination of the Sicilian Mountain belt. It extends from land (Hyblean Plateau) to the southern Sicily offshore (Figs. 2, 14, 15). The basin formed from

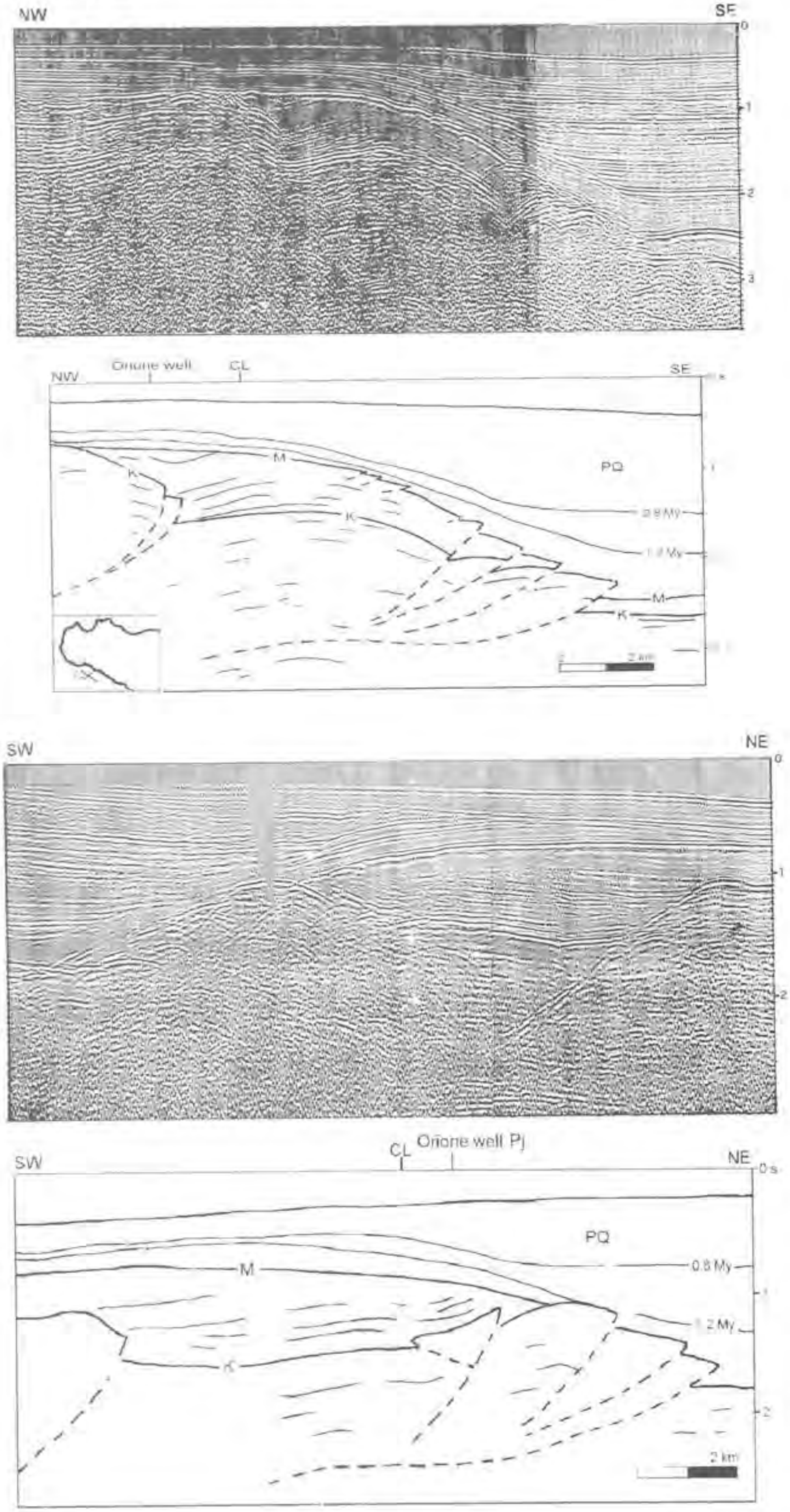

Fig. 12 — Deformed foreland in the Sciacca offshore. The two seismic lines crossing at C.L. show the structural setting of the Sciacca salient. Seismic analysis, controlled by deep borehole stratigraphy, shows folding and faulting before the late Tortonian, followed by erosion and emersion at place. The structures are unconformably sealed by Messinian eveporites and lower Pliocene (Trubi). The deformation of the whole succession took place during the middle Pliocene.

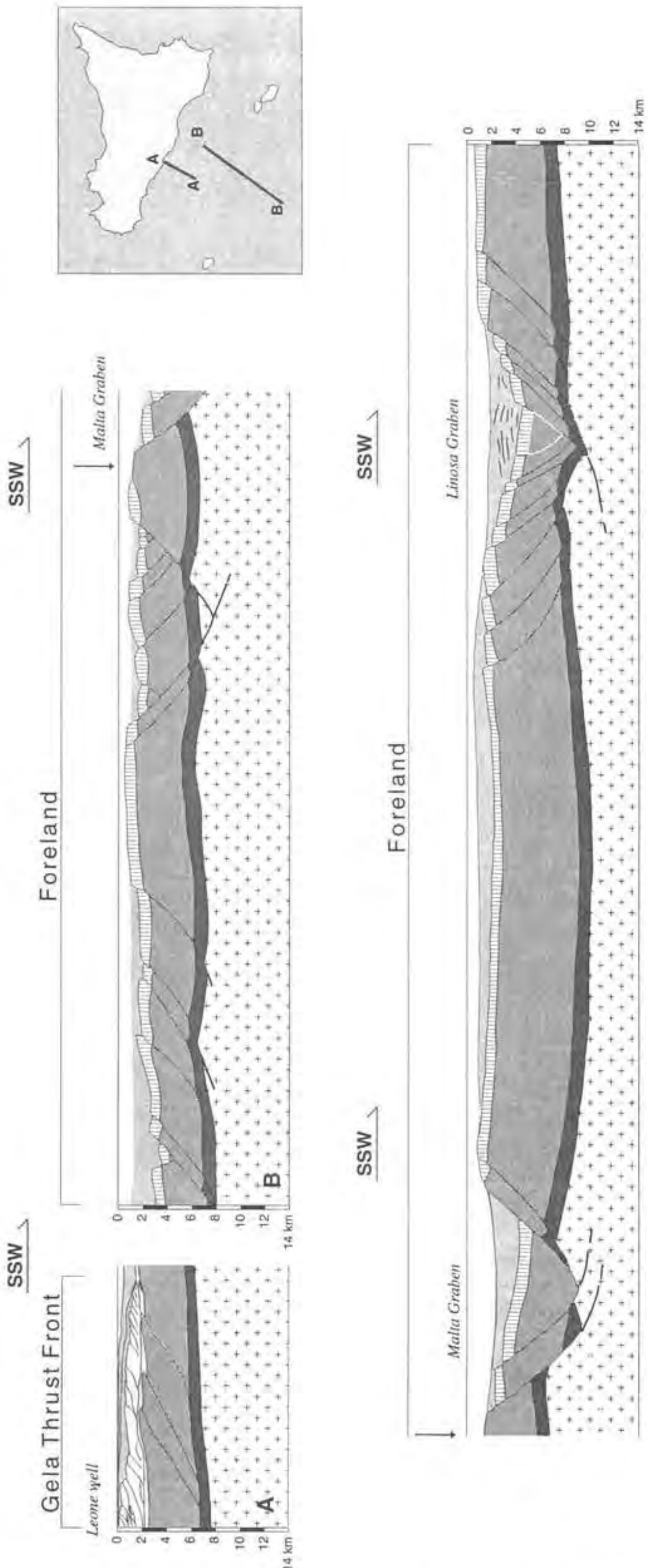

Fig. 13 — Simplified geologic section across the rifted Pelagian foreland and the "Gela Nappe" Thrust Front. 1) Plio-Pleistocene deposits; 2) Gela Nappe; 3) Clastic and Carbonatic substrate of the Hyblean and Pelagian foreland; 4) basement.

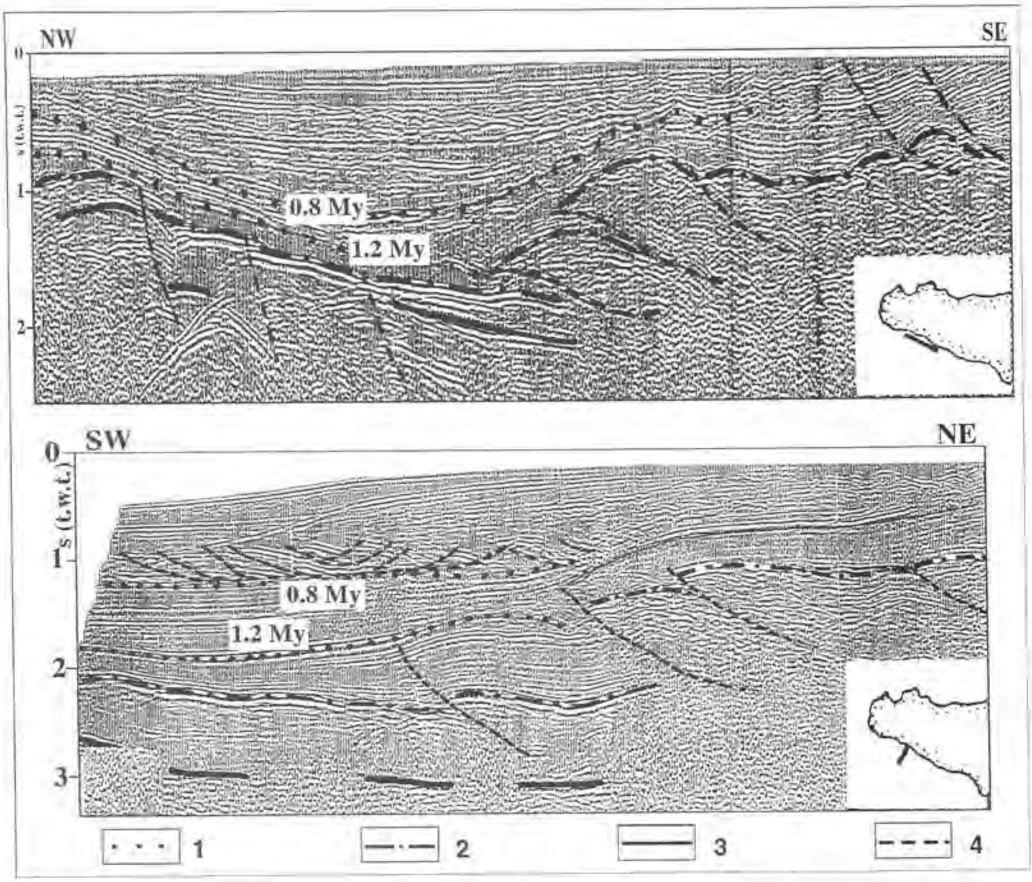

Fig. 14 – Thrust front of the "Gela Nappe" (lateral view above, frontal ramp below). Relationships between the Gela foredeep basin and nappe emplacement. The basin initiated during latest Pliocene and was filled with Pleistocene sediments. Third order sequence boundaries are present (Di Stefano E. et al., 1993). 1) Sequence boundaries, 2) Messinian horizon, 3) Top Carbonates, 4) Faults.

the late Pliocene and is related to the inflection of the carbonate substrate due to the frontal nappe loading. The depositional filling consists of pelagic marly limestones (Trubi Fm.), silty pelites and sandy clays lying unconformably above Messinian evaporites. High resolution integrated calcareous plankton biostratigraphy (Di Stefano et al., 1993) reveals three main gaps in the Plio-Pleistocene sequence, respectively in the basal Pliocene, middle Pliocene and basal Pleistocene. Seismic facies and well log analyses differentiate a thin package of Pliocene deposits (about 350-400 m) overlain by a thick Pleistocene sequence (1900 m). Seismically the Pliocene layers show low amplitude, while the Pleistocene deposits are characterized by high amplitude, lateral continuity and, topwards, chaotic reflections.

Paleogeography

The stratigraphy of the reflecting body deduced from commercial deep boreholes (see lithostratigraphic schemes in Catalano, 1987; Catalano et al., 1987, 1989; Antonelli et al., 1988) and palinspastic restorations of the Sicilian-Maghrebian chain reveal that the stacked Mesozoic rock units pertained essentially to two main paleogeographic domains: a northern "internal" trough and a southern external carbonate to evaporitic platform. These were based on a common deep-water Permian substrate (Catalano et al., 1991). The rocks are believed to belong to the paleogeographic domains that formed the Sicilian continental margin, prior to collision with European Sardinia. Some can be correlated with onshore domains (e.g. Pre-

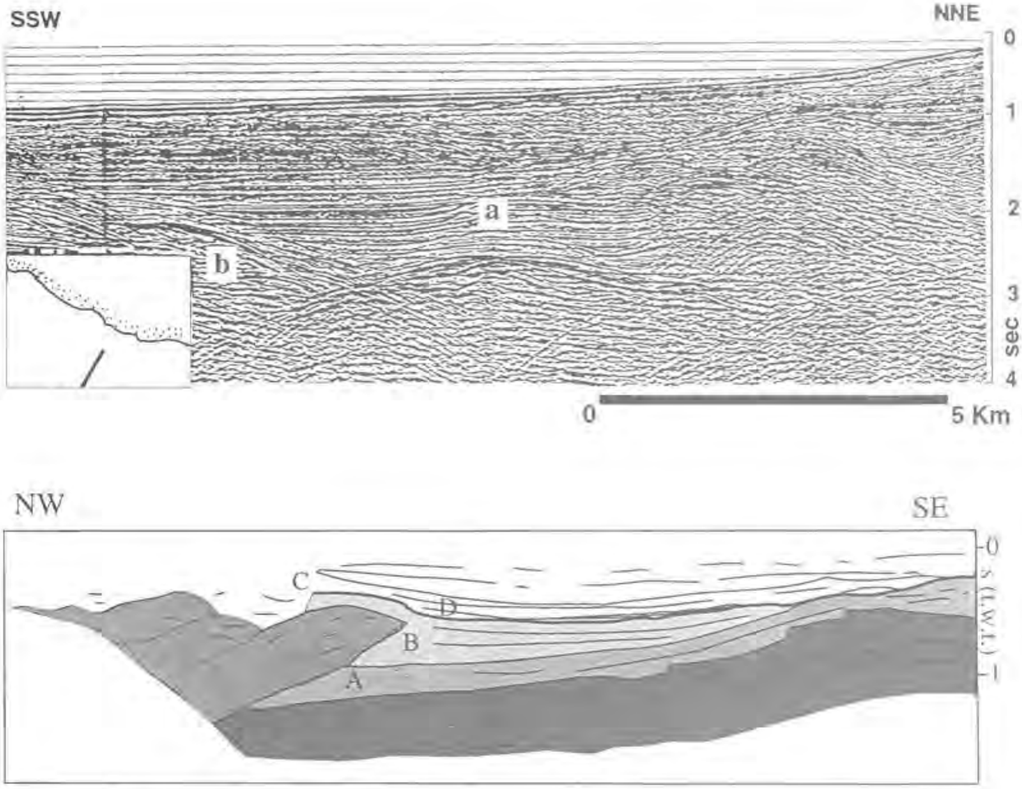

Fig. 15 — On the top a SW-NE seismic profile showing (a) an incipient thrusting on the front of "Gela Nappe" and (b) extensional tectonics towards the flexuring substrate. On the bottom, the line drawing of a different seismic profile illustrates the interpretation of the development of the Gela thrusts. The bearing nappe loading determined a prenappe tilting with coeval formation of a distal bulge and N dipping normal faults in the unit A. Basinal sedimentary package (unit B) onlapped the tilting surface. Sediment thickness thinned southeastwards while on the bulge erosion took place. Horizon C seals the deformation. A structural high synchronous with the deposition of package D shows development of a new thrust-sheet.

Panormide, Panormide, Saccense, Trapanese and Hyblean; Catalano et al., 1987; Antonelli et al., 1988). Basinal sequences forming the submerged geometrically higher carbonate thrust-sheets were deposited in a Triassic seaway named the "Marettimo basin" and outcropping on the Islands (Catalano et al., 1993b). This basin is considered the western prolongation of the former Imerese and Sicanian domains (Catalano and D'Argenio, 1982; Catalano et al., 1993b).

The widespread Triassic-Liassic carbonate and evaporitic platform rocks and their slope to basin Jurassic-Paleogene cover, have been assigned respectively to the Pre-Panormide (and its lateral continuation, Panormide), Trapanese and Saccense paleogeographic domains (Catalano 1987; Catalano et al., 1987, 1989; Antonelli et al., 1988).

A new and more complex paleogeographic setting was created after the early Miocene collision between Sardinia and the Maghrebian Sicilian continental margin. Progressive foreland basins grew up in front of the eastwards-advancing chain from the earliest Miocene to early Pleistocene. Numidian Flysch and equivalent deposits, middle Miocene terrigenous and clastic carbonates, late Miocene Terravecchia Fm. type clastics and Plio-Pleistocene carbonates and clastics filled these syntectonic basins.

Seismic analyses and land data (Catalano and D'Argenio, 1982; Catalano et al., 1993c) show that the original trend of the late Miocene foreland basin (now incorporated in the deformation) was approximately N-S (Catalano et al., 1987, 1989; Argnani et al., 1989). The orientation has been restored on the basis of the large scale dextral rotations (Channell et al.,

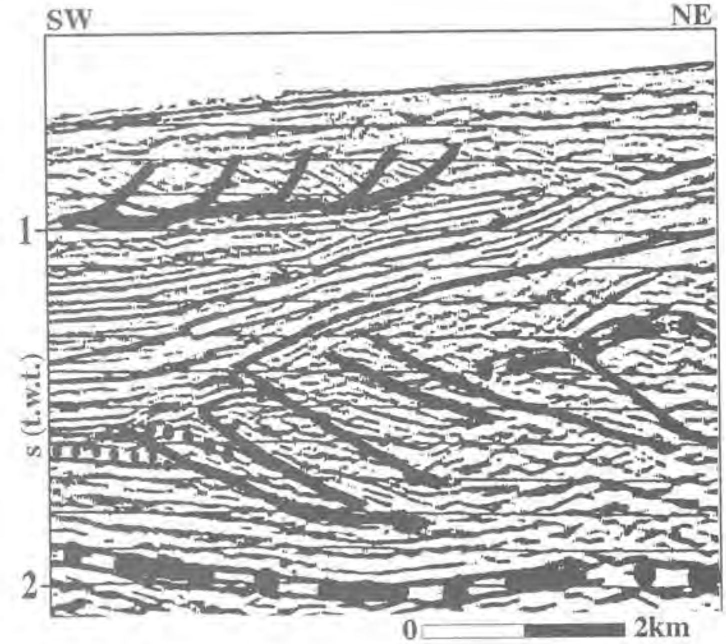

Fig. 16 — NE-SW line showing in detail the progression of the deformation at the Gela thrust front. Messinian evaporite duplex stack is overlain by lightly deformed, upper Pliocene-lower Pleistocene deposits. Towards the front only Pleistocene deposits are detached and accreted after 1.2 Ma (dotted horizon) at the toe of the thrust. The thrust sequence indicates that deformation proceeded from the north towards external domains of the foredeep.

1991; Catalano et al., 1986; Oldow et al., 1990) that developed after the above time interval. The present-day setting (mostly south-vergent structures) of the late Miocene foreland and piggyback basin deposits is the result of the dextral transpressional large scale rotations.

The Plio-Pleistocene foreland basin, as before said, has a roughly E-W trend while the structures, on the whole, show southwards-directed tectonic transport.

Kinematics

Tectonic analysis of the Sicilian-Maghrebian sector indicates that deformation began after the earliest Miocene emplacement of the Kabilo-Calabrian Unit. During the Langhian-early Tortonian interval the Cretaceous-lower Miocene incompetent cover of the internal (northern) basin, as well as carbonate platform domains, was detached and then thrust over more progressively external (southeastern) domains acting at this time as foreland (Pre-Panormide and Trapanese). Numidian Flysch type and chronostratigraphically equivalent deposits were stacked to form the highest thrust-sheets (Fig. 3). Synchronously, or just afterwards, deep water and shallow water carbonate rocks forming the substrate were detached and accreted as ramp and flat thrusts. Upper Tortonian-lower Pliocene deposits seal this part of the chain. Duplex development appears to be the normal thrust expression. This thrust-sheet pile reaches its main elevation along the Egadi Thrust Front that trends NNE-SSW along a belt of almost 80 km (Figs. 2, 3). The present day setting of the Egadi Front could also be the result of post-late Miocene "thrust envelopment" (Catalano et al., 1993c).

The lower Miocene-lower Tortonian clastics deposited on the foredeep were complexly accreted southeastward almost contemporaneously with their carbonate substrate (Figs. 3, 11). Late Tortonian-early Pliocene clastics, evaporites and pelagic chalks syntectonically covered unconformably this previously shortened substrate. These deposits were later folded and thrust in their frontal portions (Fig. 11). Decollements progressively decoupled the Late Miocene to Pliocene sedimentary cover, giving rise to the Gela thrust system between 2.4 and 0.8 Ma

(Catalano et al., 1993a). The most recent detachment planes appear to involve deposits as old as 1.2 Ma (Fig. 14). Seismic analysis of the more recent stacking structures of the "Gela Nappe" front offers some indications on its deformational evolution (Figs. 15, 16): the increased thrust driven loading is related to inflection of the Gela foredeep. Higher subsidence rates and formation of a frontal bulge (Fig. 15) associated with normal faults on the southern (external) flank of the Gela basin (Fig. 15) are consequent basin modifications. Deeper decollement planes have shortened underlying Mesozoic-Cenozoic substrate, just following emplacement of overlying Miocene-Pleistocene packages, which in turn, appear to be passively transported (Fig. 16).

Northwards in the belt (hinterland zones), post-Messinian tectonic history shows that the already imbricated substrate was eroded and block-faulted along listric and growth normal faults. This extensional event opened half-grabens (hinterland intramountain basins) that were progressively filled by clastic wedges. This event has been related to the opening of the Tyrrhenian Sea. Subsequently, structural inversion of the half-graben deposits took place between 2.4 and 1.2 Ma (Catalano et al., 1988; Catalano and Milia, 1990). This deformation, described by Tricart et al., 1990, in the Eastern Sardinia domain, and shown on land and in the Sicily Channel, appears to be related to a change in the stress field implying compression along a N-S stress axis (Catalano and Milia, 1990). The compressive (or transpressive?) deformation took place between 2.4 and 1.2 Ma (Catalano et al., 1988). Between 1.2 to 0.8 Ma extensional structures dissected the basins that again experienced compressive deformation between 0.8 and 0.5 Ma. The last 0.5 Ma has involved strong vertical tectonics.

The Eastern Sicily Channel

The Sicily Channel as part of the Pelagian Block is characterized by thinned continental lithosphere (60-70 km), shallow Moho depth (20-25 km), high heat flow density, positive Bouguer anomaly and significant volcanic activity associated with magnetic anomalies (Della Vedova et al., 1989 with references). The region, which is considered as a foreland of the Tunisian - Sicilian and Ionian chains, displays a tectonic evolution for the last 5 Ma that is matter of controversial interpretation: it is believed to be the locus of transtensional or extensional tectonics (Finetti and Del Ben, 1986; Argnani et al., 1989; Boccaletti et al., 1987; Antonelli et al., 1988; Grasso and Reuther, 1988; Gardiner et al., 1993) or of rifting processes (Colantoni, 1975; Illies, 1981; Finetti, 1984; Grasso et al., 1993). Most previous studies have been performed on land (Tunisia, Pelagian Islands); seismic data from marine investigations have been reported in Finetti, 1984; Finetti and Del Ben, 1986; Antonelli et al., 1988; Torelli et al., 1991.

A large scale stratigraphic framework is known from various contributions (seismic reflection profiles, well data, land geology; see Antonelli et al., 1988; Montanari, 1989; Catalano et al., 1993a; Grasso et al., 1993, with references) the main paleogeographic evolution of the Pelagian Block is characterized by a widespread Triassic carbonate platform floored on a Permian shallow to deep-water domain; during the Rhaetian-Liassic, transtensional tectonics opened large basins (Streppenosa basin, Catalano and D'Argenio, 1982). Basinal conditions developed throughout the Mesozoic and Paleogene, with the exception of the Malta and Lampedusa area where shallow water conditions prevailed until the Miocene.

The southeastern sector of the Pelagian platform is here analyzed using public multichannel seismic profiles. Seismostratigraphic and facies analyses calibrated by correlations with known regional horizons and published well stratigraphy have been used with the aim of recognizing the Plio-Pleistocene tectono-sedimentary evolution of the Malta-Linosa sector.

In the area we have distinguished three seismostratigraphic units bounded by two unconformity surfaces. The lower unconformity separates Mesozoic-Oligocene carbonates from a Miocene thin layered (? clastic) succession. The upper discontinuity bounds upper Miocene sediments, mostly evaporites, from well layered clastic Plio-Pleistocene rocks. Southwards, the bulk of the pre-late Miocene rocks is affected by folding probably due to a weak compressional pulse. Fold structural axes are oriented NW-SE. This tectonic episode can be correlated with the Langhian deformation seen in the Hyblean foreland onshore (Letouzey and Tremoliere, 1980) and in Western Sicily. The upper seismic unit consists of Plio-Pleistocene sedimentary packages. They display both extensional and transpressional or inversion synsedimentary tectonics (Catalano

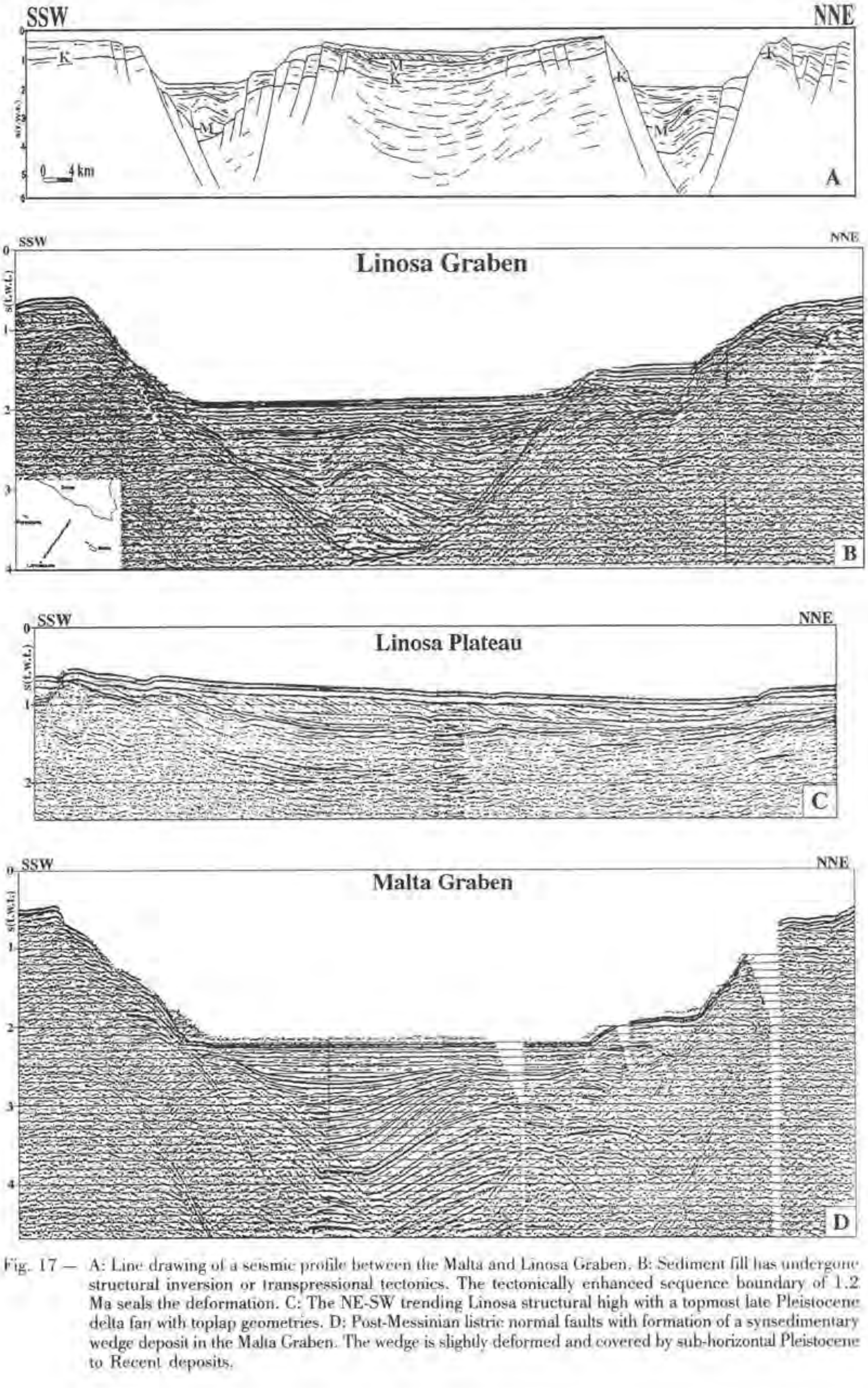

Fig. 17 — A: Line drawing of a seismic profile between the Malta and Linosa Graben. B: Sediment fill has undergone structural inversion or transpressional tectonics. The tectonically enhanced sequence boundary of 1.2 Ma seals the deformation. C: The NE-SW trending Linosa structural high with a topmost late Pleistocene delta fan with toplap geometries. D: Post-Messinian listric normal faults with formation of a synsedimentary wedge deposit in the Malta Graben. The wedge is slightly deformed and covered by sub-horizontal Pleistocene to Recent deposits.

et al., 1993a) that are here documented.

The Malta Graben has, on the whole, a NNW-SSE trend, with a sigmoidal shape, and merges to the west with the Pantelleria trough. In the studied area (Fig. 2) there is a large basin, 1600 m deep, filled by up to 1500 m of Plio-Pleistocene clastics. The basin opened after the Messinian as proved by truncation in the inferred Messinian seismic horizon (Fig. 17a, b, d). Wedge-like sedimentary bodies (syn-rift deposits?) formed (Fig. 17a, b). A strong discontinuity is developed in older sediments that are slightly deformed. Up to 500 m of sediments, Pleistocene to Recent, are shown; at the base of the package, the 1.2 Ma horizon is recognized, being previously correlated across the area with age calibrated horizons (Di Stefano et al., 1993). Strong down faulting again modified the most recent deposits (Fig. 17). Similar structural features are displayed by the Linosa Graben, 50 km south of the Malta basin. Some beds in the large basin show evidence of folding (Fig. 17d) interpreted as transpressional and/or inversion tectonics (see also Gardiner et al., 1993). These deformed sediments are unconformably covered by undeformed layers, which in their turn, have been affected by recent vertical faulting. The two basins are linked by a structural high, the Linosa Plateau (Fig. 17c), which is made up of a mildly folded pre-Miocene sedimentary body overlain by the Messinian horizon or Messinian erosional surface. An almost 300 m thick very recent NE-SW prograding wedge rests on a prominent discontinuity of late Pliocene-Pleistocene age. It indicates that the Linosa Plateau was near sealevel probably about 1 Ma ago.

The Malta-Linosa region was affected by early to late Pliocene growth faulting and extensional tectonics. This structural episode suggests a rifting mechanism for the opening of the Sicily Channel. At the Pliocene-Pleistocene boundary, folding tectonics were active. Deformed beds appear to be bounded above by an unconformity that is probably correlatable with the tectonically enhanced 1.2 Ma sequence boundary. Uplifting of the islands (Malta, Lampedusa) could have taken place during this time interval simultaneously with delta fan deposition on the Linosa Plateau. Later half-grabens again underwent a strong vertical tectonics, which was responsible for an almost 1800 m vertical displacement during the Pleistocene.

CONCLUSION

The tectonic evolution of the Central Mediterranean region extending from the Western Bank across the Egadi Islands to the Southern Sicily Offshore and the Eastern side of the Pelagian Block has been described using some geological cross sections based on revised interpretations of seismic profiles and new seismic reflection and stratigraphic data.

The Sicilian-Maghrebian sector mostly submerged in the Sicily Straits is represented by an eastward and southeastward verging thrust belt 12 km thick, formed by flysch-type thrust slices stacked on an imbricated pile of basin and carbonate platform thrusts, deriving from the deformation of the Mesozoic-Paleogene Sicilian continental margin. During early Miocene-Pleistocene compression the progressively onlapping foreland basins formed.

Since the Triassic this sector of the African margin is envisaged as resulting from two main depositional areas: a northern (internal) deep water basin and a southern (external) carbonate to evaporitic platform. These areas represent different paleogeographic domains which appear comparable to or continuous with the already recognized domains on land.

Deformational evolution of the more recent stacking structures of the Gela Thrust System showed that the increased thrust loading is related to the inflection of the Gela foredeep and the formation of a frontal bulge.

The post Messinian cover of the Eastern side of the Pelagian foreland analyzed on the base of sequence stratigraphy and basin analysis revealed evidences of middle Pliocene tectonics, supporting a rifting mechanism for the opening of the Sicily Channel. Furthermore the succession of the tectonosedimentary events during the last 5 Ma presents some similarities to the evolution in the hinterland zone of the chain (South Tyrrhenian Sea).

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REFERENCES

Agate M., Catalano R., Infuso S., Lucido M., Mirabile L. and Sulli A.; 1993: *Structural evolution of the Northern Sicily continental margin during the Plio-Pleistocene*. In: Max M.D. and Colantoni P. (eds), UNESCO Report In Marine Science, **58**, pp. 25-30.

Amodio Morelli L., Bonardi G., Colonna V., Dietrich D., Giunta G., Ippolito F., Liguori V., Lorenzoni F., Pagalionico A., Perrone V., Picarretta G., Russo M., Scandone P., Zanettin-Lorenzoni E. and Zuppetta A.; 1976: *L'Arco Calabro-Peloritano nell'orogene Appenninico-Maghrebide*. Boll. Soc. Geol., It., **17**, 1-60.

Antonelli M., Franciosi R., Pezzi G., Querci A., Ronco G.P. and Vezzani F.; 1988: *Paleogeographic evolution and structural setting of the northern side of the Sicily Channel*. In: 74° Congr. Soc. Geol. It., Relazioni, pp. 79-86.

Argnani A.; 1989: *The Gela Nappe: evidence of accretionary melange in the maghrebian foredeep of Sicily*. Mem. Soc. Geol. It., **38**, 419-428.

Argnani A., Cornini S., Torelli L. and Zitellini N.; 1989: *Neogene-Quaternary foredeep system in the Strait of Sicily*. Mem. Soc. Geol. It., **36**, 123-130.

Barbieri F., Cornini S., Marchetti F., Morlotti E., Terdich P. and Torelli L.; 1984: *Geological investigations in the Sardinia Channel area: preliminary results*. Acta Naturalia dell'Ateneo Parmense, **20**, 117-207.

Bianchi F., Carbone S., Grasso M., Invernizzi G., Lentini F., Longaretti G., Merlini S. e Mostardini F.; 1989: *Sicilia orientale: profilo geolofico Nebrodi-Iblei*. Mem. Soc. Geol. It., **37**.

Boccaletti M., Cello G. and Tortorici L.; 1987: *Transtensional tectonics in the Sicily Channel*. Journal of Structural Geology, **9**, 869-876.

Brancolini G., Catalano R. and Nicolich R.; 1989: *The Sardinia Channel-Sicily Straits segment. New data from reprocessed seismic lines. The potential of deep seismic profiling for hydrocarbon exploration*. In: I.F.P.-I.L.P.-I.U.G.S. Blackwell Sc. Publ., Arles, pp. 3.

Catalano R.; 1987: *Northeastern Sicily Straits. Stratigraphy and Structures from seismic reflection profiles*. Rend. Soc. Geol. It., **9**, 103-112.

Catalano R..; 1988: *Stratigraphy and structures of Sicily mainland and Sardinia Channel - Sicily straits. A comparison*. In: Relazioni, "L'Appennino Campano-Lucano nel quadro geologico dell'Italia meridionale", 74° Congresso Nazionale Soc. Geol. It., pp. 145-154.

Catalano R. e D'Argenio B.; 1982: *Guida alla geologia della Sicilia occidentale*. In: Guide Geologiche Regionali della Soc. Geol. It., pp. 9-41.

Catalano R. and Milia A.; 1990: *Late Pliocene - Early Pleistocene structural inversion in offshore Western Sicily. The Potential of Deep Seismic Profiling for Hidrocarbon Exploration*. In: Pinet D. and Bois C. (eds), editions Technip., Paris, pp. 445-449.

Catalano R., D'Argenio B. and Torelli L.; 1987: *A geologic section from Sardinia Channel to Sicily Strait based on seismic and field data*. In: The Lithosphere in Italy, Acc. Naz. dei Lincei, pre-print vol., pp. 99-114.

Catalano R., D'Argenio B. and Torelli L.; 1989: *From Sardinia Channel to Sicily Strait. A geologic section based on seismic and field data*. In: The Lithosphere in Italy, Acc. Naz. dei Lincei, Atti dei Convegni Lincei n. 80, pp. 109-127.

Catalano R., Di Stefano P. and Hozur H.; 1991: *Permian Circum-Pacific deep-water faunas from the western Tethis (Sicily, Italy). New evidences for the position of the Permian Tethys*. In: Channel J.E.T., Winterer E.L. and Jansa L.F. (eds), Palaeogeography and palaeocenography of Tethis (spec. vol.). Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 87, Elsevier, Amsterdam, pp. 75-108.

Catalano R., Infuso S. and Sulli A.; 1993a: *The Pelagian foreland and its northward foredeep. Plio-Pleistocene structural evolution*. In: Max M.D. and Colantoni P. (eds), UNESCO Report In Marine Science, **58**, pp. 37-42.

Catalano R., D'Argenio B., Channel J.E.T. and Oldow J.S.; 1986: *Contemporaneous thrusting and large-scale dextral rotationsin the late Cenozoic fold-thrust belt, western Sicily*. In: G.S.A., Abstract, Programs 18, pp. 562.

Catalano R., Di Stefano P., Nigro F. and Vitale F.; 1993b: *Sicily mainland and offshore structures. A comparison*. In: Max M.D. and Colantoni P. (eds), UNESCO Report In Marine Science, **58**, pp. 19-24.

Catalano R., Infuso S., Milia A. and Sulli A.; 1993c: *The submerged Sicilian-Maghrebian Chain along the Sardinia Channel-Sicily Straits belt*. In: Max M.D. and Colantoni P. (eds), UNESCO Report In Marine Science, **58**, pp. 43-48.

Catalano R., D'Argenio B., Montanari L., Morlotti E. and Torelli L.; 1985: *Marine geology of the North West Sicily offshore and its relationships with mainland structures*. Boll. Soc. Geol. It., **104**, 207-215.

Catalano R., Giangrande L., Grimaldi G., Infuso S. e Milia A.; 1988: *Il settore settentrionale degli Stretti di Sicilia. Evoluzione tettono-stratigrafica*. In: Atti 74° Congr. Soc. Geol. It., Sorrento, pp. 237-247.

Channel J.E.T., Oldow J.S., Catalano R. and D'Argenio B.; 1991: *Paleomagnetically determined rotations in the western sicilian fold and thrust belt*. Tectonics, **9**, 641-660.

Colantoni P.; 1975: *Note di geologia marina sul Canale di Sicilia*. Giorn. Geol., **40**, 181-207.

Compagnoni R., Morlotti E. and Torelli L.; 1986: *Crystalline and sedimentary rocks from the scarps of the Sicily-Sardinia Trough and Cornaglia Basin (Southwestern Tyrrhenian Sea). Paleogeographic and geodynamic implications*. Séance Oceans, Villafranche - sur - mer, 1-3 Dicembre, Abstract 31-32.

Della Vedova B., Pellis G. and Pinna E.; 1989: *Studio geofisico dell'area di transizione tra il Mar Pelagico e la piana abissale dello Jonio*. In: Atti 8° Conv. G.N.G.T.S., Roma, pp. 543-558.

Di Stefano E., Infuso S. and Scarantino S.; 1993: *Plio-Pleistocene sequence stratigraphy of south western offshore Sicily from well logs and seismic sections in a high resolution calcareous plankton biostratigraphic framework.* In: Max M.D. and Colantoni P. (eds), UNESCO Report in Marine Science, **58**, pp. 105-110.

Di Stefano P. e Gullo M.; 1993: *Dati stratigrafici sul Trias pelagico della Sicilia occidentale.* (Abs.), Paleopelagos.

Finetti I.; 1984: *Geophysical study of the Sicily Channel rift zone.* Boll. Geof. Teor. Appl., **26**, 3-28.

Finetti I. and Del Ben A.; 1986: *Geophysical study of the tyrrhenian opening.* Boll. Geof. Teor. Appl., **28**, 110.

Gardiner W., Grasso M. and Sedgeley D.; 1993: *Plio-Pleistocene stratigraphy and fault movement of the Malta Platform.* In: Max M.D. and Colantoni P. (eds), UNESCO Report in Marine Science, **58**, pp. 111-116.

Grasso M. and Reuther C.D.; 1988: *The western margin of the Hyblean Plateau: a neotectonic transform system on the SE Sicilian foreland.* Ann. Tectonicae, **2**, 107-120.

Grasso M., Butler R.W.H. and La Manna F.; 1991: *Thin skinned deformation and structural evolution in the NE segment of the Gela Nappe, SE Sicily.* In: Boccaletti M., Deiana G., Papani G. (eds), Studi Geologici Camerti, Vol., spec., Parma, pp. 9-17.

Grasso M., Mazzoldi G. and Torelli L.; 1993: *Structural and stratigraphic framework of the Tunisian shelf surroundings the islands of Lampione and Lampeduca (Pelagian Sea).* In: Max M.D. and Colantoni P. (eds), UNESCO Report In Marine Science, **58**, pp. 65-70.

Illies J.H.; 1981: *Graben formation: the Maltese Islands a case history.* Tectonophysics, **73**, 151-168.

Letouzey J. and Trémolières P.; 1980: *Paleo-stress field around the Mediterranean since the Mesozoic from microtectonics. Comparisons with plate tectonic data.* Rock Mech., Suppl., **9**, 173-192.

Montanari L.; 1989: *Lineamenti stratigrafico-paleogeografici della Sicilia durante il Ciclo Alpino.* Mem. Soc. Geol. It., **38**, 361-406.

Nigro F.; 1992: *L'Unità Longi-Taormina nel settore di S. Agata di Militello (Messina): studio geologico preliminare.* Naturalista Siciliano, **16** (1-2), 63-89.

Ogniben L.; 1969: *Schema introduttivo alla geologia del confine calabro-lucano.* Mem. Soc. Geol. It., **8**, 453-763.

Oldow J.S., Channel J.E.T., Catalano R. and D'Argenio B.; 1990: *Contemporaneous thrusting and large-scale rotations in the western sicilian fold and thrust belt.* Tectonics, **9**, 661-681.

Selli R.; 1974: *Appunti sulla geologia del Mar Tirreno.* Rend. Sem. Fac. Sc. Univ. Cagliari, 327-349.

Torelli L., Cornini S. and Marchetti F.; 1985: *Seismic stratigraphy and tectonic-structural setting of the Sardinia Channel (Western Central Mediterranean).* In: Galson D.A. and Mueller S. (eds), Proc. of II EGT Workshop, ESF, pp. 241-246.

Torelli L., Cornini S., Brancolini G. and Zitellini N.; 1991: *The Sardinia Channel (Central Mediterranean): a structural analysis of a submarien orogenic chain.* In: Boccaletti M., Deiana G., Papani G. (eds), Studi Geologici Camerti, Vol. spec., Parma, pp. 35-36.

Tricart P., Zitellini N., Torelli L., De Angelis, Bouhlel H., Creuzot G., Morlotti E., Ouali J. et Peis D.; 1990: *La tectonique d'inversion recente dans le Canal de Sardaigne: resultat de la campagne MATS 87.* C.R.Ac.Sc., Paris II, **310**, 1083-1088.