Peri-Tethyan Platforms
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Neogene Deformations at the Sicilian-North African Plate Boundary

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ABSTRACT

The Sicilian Neogene fold-and-thrust belt comprises various tectono-stratigraphic units detached from their substratum, the North African passive margin, along Triassic or even Permian horizons. Strong facies changes occur in the Upper Triassic and the Lower Liassic sequences of both the Sicilian thrust nappes and the autochthonous foreland, i.e. below the Sicilian Strait and the Pelagian Sea, thus allowing to map the present, altered, configuration of early Mesozoic isopic lines between Tunisia, Malta and Sicily.

In front of the Sicilian-Calabrian arc, three major wrench zones with Neogene decoupling can be recognized in the North African and Ionian forelands by the present displacement of these Mesozoic isopic lines and the discontinuous pattern of the Neogene foredeep basins and thrust fronts. These belts comprise: 1) the Malta Escarpment, a Mesozoic trend reactivated during Tortonian and Quaternary deformation; 2) the NNW-trending syn-compressional Middle Pliocene Segesta transfer zone; 3) the Quaternary Pantelleria rift system.

The influence of initial Mesozoic Tethyan rifting (between Europe and Africa) and of middle Cretaceous spreading (between Libya and Apulia) upon Neogene thrusting and Quaternary rifting is discussed in terms of the disintegration of the North African plate margin. A counterclockwise rotation and an abrupt westward dislocation of the Sicilian-North African plate boundary are thus observed during the Neogene. Sicily was still attached to North Africa in early Tortonian times, with an active Africa-Ionian plate boundary superimposed on the Malta Escarpment. Due to Pliocene and Quaternary rifting, Sicily no longer belongs either to Africa or to the Ionian plate.
This progressive lateral escape of Sicily thus occurred during three main episodes: intra-Tortonian, Middle Pliocene and Quaternary. This calls for balancing the deformations observed offshore in the Pelagian Sea with incipient motion farther to the southeast, either in the Sirte area or offshore from Cyrenaica.

INTRODUCTION

The Central Mediterranean domain today is a complex mosaïc of smaller and larger continental fragments (i.e. Apulia, Sardinia and Corsica, Sicily) and intervening small oceanic basins (Tyrrhenian and Ionian Seas) (Fig. 1). Its geodynamic evolution results directly from the relative motions and interactions between the African and European plates, and the smaller Adriatic and Iberian plates, coeval with the

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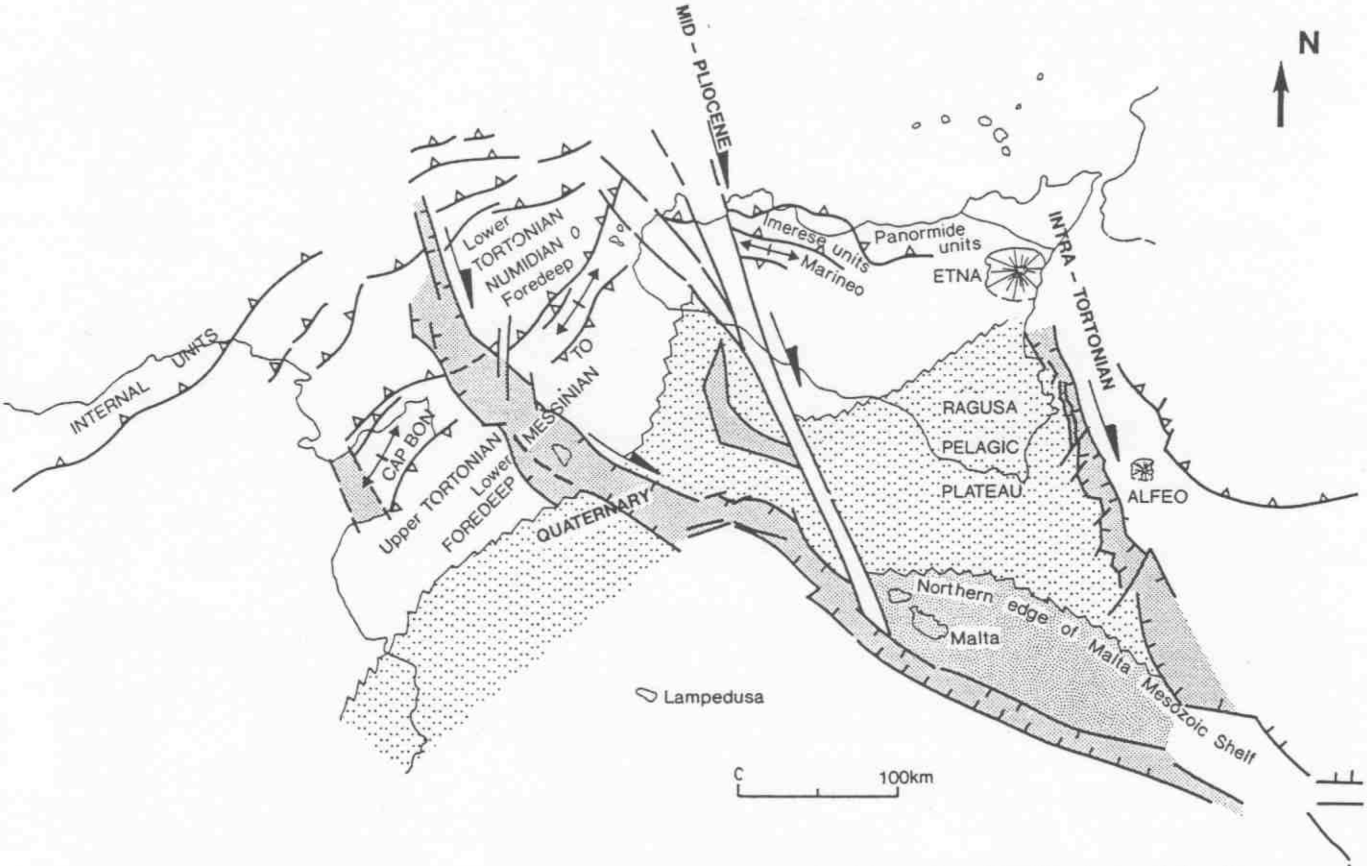
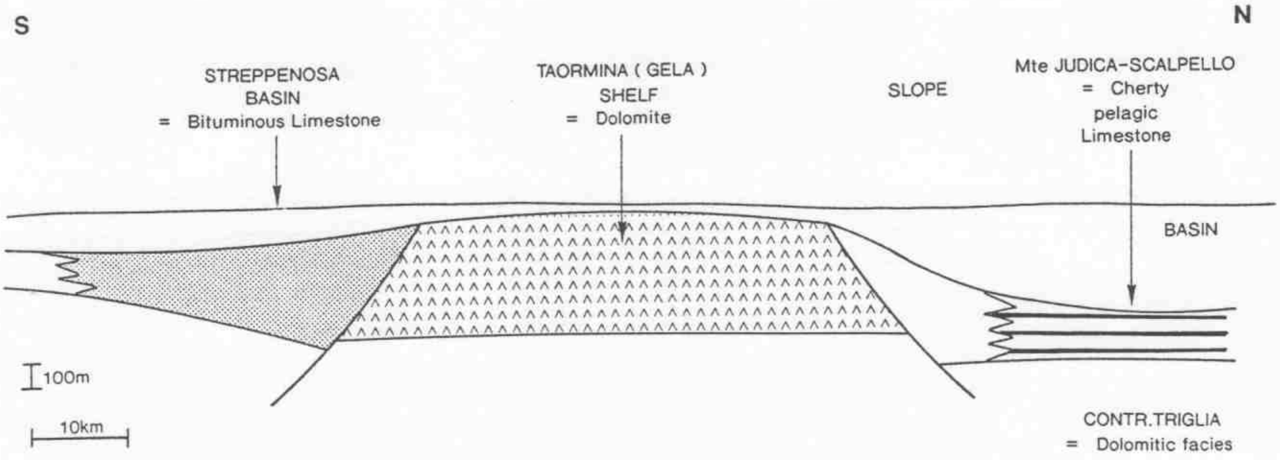


FIG. 1: Structural sketch of Sicily, and northeastern Tunisia. Note the distribution of the Lower Tortonian, Lower Messinian and Middle to Upper Pliocene foredeep deposits. Lower Pliocene flexural deposits are unknown in offshore Sicily.



LATE TRIASSIC PALEOGEOGRAPHY

FIG. 2: North-south cross-section outlining the regional Upper Triassic-Lias facies boundaries.

progressive closure of the Tethys Ocean (Alvarez et al., 1974; Barberi et al., 1974; Dewey et al., 1973; Biju-Duval et al., 1976; Biju-Duval and Montadert, 1977; Schuster, 1977; Laubscher and Bernoulli, 1977; Tapponnier, 1977).

Initial plate boundaries inherited from the Mesozoic Tethyan rifting were strongly modified during the Cretaceous and later on, in Tertiary times, leading to a progressive disruption of the North African margin. The Sicilian-Calabrian arc thus developed during Neogene times in front of the Pelagian and Ionian Seas, between the Apulian Promontory in the east and Tunisia in the west (Boccaletti et al., 1984). As in the Apennines in the north, this Neogene feature involved the thrust emplacement of various Mesozoic to Paleogene basin- or platform-derived tectonostratigraphic units onto the Adriatic, Ionian or African forelands, respectively (Broquet et al., 1984; Grandjacquet and Mascle, 1978; Bally et al., 1986; Roure et al., 1990; Casero et al., 1992). Compressional events there are synchronous with the opening of the Tyrrhenian Sea at the rear of the arc (Rehault et al., 1987a & b; Moussat et al., 1985; Kastens et al., 1987; Hippolyte et al., 1993). During these movements, early Mesozoic rift-related structures were reactivated and in part inverted.

In the Sicilian Strait, strong facies changes occur in the Upper Triassic and Lower Lias sequences, and help to draw regional isopic lines in the area between Tunisia, Malta and Sicily. Surface data, exploration wells and about 9000 km of seismic profiles have been integrated here to describe the Mesozoic paleogeographic affinities of the major tectonostratigraphic units in both the Sicilian allochthon (onshore and offshore) and its foreland. However, the initially continuous Mesozoic paleogeographic boundaries were later disrupted. As pre-existing geometrical elements, they provide a tool for tracing the Neogene and Quaternary intra-plate deformations in the Pelagian and Ionian forelands of the Sicilian-Calabrian arc, and for relating the progressive escape of the Sicilian block to the regional geodynamic evolution.

1 MESOZOIC TETHYAN DYNAMICS AND BUILD-UP OF THE NORTH AFRICAN MARGIN

A huge amount of lithostrati-graphic, tectonic and paleomagnetic data have led numerous authors to propose palinspastic reconstructions of the Mesozoic Tethyan margins (Biju-Duval et al., 1976 & 1978; Biju-Duval and Montadert, 1977; Laubscher and Bernoulli, 1977; Sengör et al., 1985; Dercourt et al., 1986; Dercourt et al., 1992). However, due to subsequent plate fragmentation, clockwise block rotation and collision processes, constraints are not always sufficient to provide reliable reconstructions, and thus alternative models still remain possible. This is indeed the case in the Central Mediterranean area, where the initial Tethyan configuration has been drastically modified first in the Cretaceous with the opening of the Sirte Basin and the drift of the Apulian Promontory, with contemporaneous oceanic accretion in the Ionian Sea; Channell et al., 1979; Letouzey and Trémolières, 1980; Besse et al., 1984; Lowrie, 1986; Anderson, 1987; Platt et al., 1989; Woodside, 1991), and later, in Neogene times, in relation to the emplacement of the Sicilian-Calabrian arc and the opening of the Tyrrhenian Basin (Kastens et al., 1987; Rehault et al., 1987; Argnani, 1990; Ben Avraham and Grasso, 1990).

1.1) LATE PALEOZOIC AND TRIASSIC SEAWAYS

The age of initial rifting itself along this portion of the North African margin remains conjectural. Most authors agree to limit the western extent of the Paleo-Tethys to the Eastern Mediterranean (i.e. Turkey; Sengör et al., 1985), but Permian pelagic sequences are known as far west as Tunisia (Jebel Tebaga; Bouaziz et al., 1994) or in the Sicilian allochthon (Sclafani-Imerese units; Mascle, 1973; Catalano et al., 1991), thus attesting to a connection between the area studied and a south-Tethyan seaway connecting the Pindos, eastern Mediterranean and Hawasina basins (Bernoulli et al., 1990).

1.2) TETHYAN RIFTING AND LATE TRIASSIC-LIAS ISOPIC LINES

In contrast to the Permian and Triassic evolution, the timing of the Neo-Tethys opening is well constrained in this portion of the

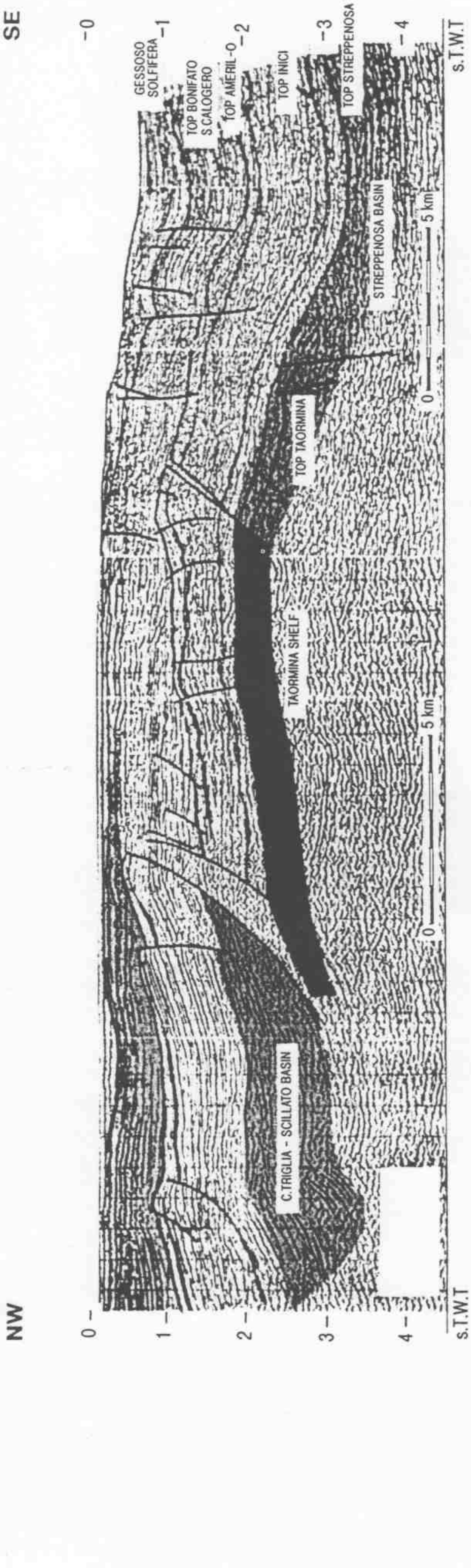


FIG. 3: Seismic profile in the Sicily Strait outlining major facies variations in the late Triassic-Lias sequences.

Mediterranean area, with the occurrence of late Triassic to Lias tilted blocks and mega-blocks on both the European (Western Alps or Peloritan units in Sicily; Bouillin et al., 1992) and African-Adriatic (Southern Alps and Apennines; Bernoulli and Jenkyns, 1974; Bally et al., 1986; Di Stefano, 1990) conjugate margins. The oldest oceanic crust in the Ligurian-Piedmont part of the Neo-Tethys is dated as late middle Jurassic both in the Southern Apennines (Ligurian units) and in the Western Alps ("Schistes Lustrés"; De Wever and Caby, 1981; Baumgartner, 1987; De Wever et al., 1987).

Accordingly, surface and subsurface data (wells and seismic) attest to strong facies variations in the late Triassic and Lias formations in Sicily and below the Pelagian Sea. Thus, the late Triassic is evaporitic, mainly salt, in Tunisia and the western part of the Pelagian Sea. On the contrary, most allochthonous units in Sicily relate either to thick Mesozoic carbonate platform sequences (i.e. the Panormide unit) or to thinner cherty basinal sequences (i.e. the Imerese unit), with all of them being detached along Triassic, Permian or even late Carboniferous incompetent horizons (Roure et al., 1990; Catalano et al., 1993 a).

Neogene deformation is also concentrated along the borders of the inverted Mesozoic basins (i.e. the Cape Bon, Marineo-Norma trough). Likewise, the frontal thrusts have directly emplaced allochthonous Jurassic and Cretaceous basinal sequences (i.e. the Monte Iudica-Monte Scalpello units in southeastern Sicily, the sequence encountered in the offshore Palma well, the Sicani Mountains in western Sicily, and in the sequence of the Tunisian shelf) onto more external domains (e.g. the Ragusa Plateau in southeastern Sicily, characterized by Upper Triassic to Lias shelf sequences and deeper Jurassic and Cretaceous overlying platform facies; Patacca et al., 1979), thus reactivating inherited Triassic facies boundaries.

Field observations and the application of cross-section balancing techniques underline the strong Neogene inversion (with large amounts of shortening and rotation) of the various basinal or platform tectonostratigraphic units of the Apennines and of theSicilian fold-and-thrust belt (Bally et al., 1986; Hill and Hayward, 1988; Endignoux et al., 1989; Roure et al., 1991; Sage et al., 1991; Casero et al., 1991 & 1992). These results are also confirmed by paleomagnetic studies (Channell et al., 1980; 1990; Oldow et al., 1990; Sagnotti, 1992; Hippolyte et al., 1993).

In the Pelagian foreland however, the original relationships between the contrasting Upper Triassic and Lias facies are locally preserved (Figs. 2 & 3) and help to analyze the geometry of the Tethyan paleomargin and to map its facies distribution (Fig. 4). From south to north, the following domains can clearly be identified in regional seismic profiles:

- evaporitic facies and salt in the western part of the Pelagian Sea (Hammamet basin);
- thick well-layered black shales of the Streppenosa Formation (Brosse et al., 1990);
- reflection-free dolomitic carbonates of the Gela (Taormina) Formation (shelf);
- well-layered pelagic cherty limes-tones of the northern deep marine Sicani basin.

In spite of the Cenozoic deformations, two distinct segments of the Mesozoic margin can still be identified (Fig. 4):

- in the west, in the Sicily Strait, a NNE trending segment parallel to other reactivated Mesozoic features known in Tunisia (i.e. the N-S Axis; Ouali, 1984);
- in the center, a NE-SW segment parallel to major trends of the North African margin (i.e. the Saharian Atlas in Algeria, Vially et al., 1994; Cyrenaica in Libya; Goudarzi, 1980; or Western Desert in Egypt).

In the east, however, the NNW trending segment that parallels the Malta Escarpment and borders the Ionian Abyssal Plain could correspond to an entirely younger, post-Triassic and pre-Tortonian right lateral, north-trending transfer fault zone having disrupted the initial Triassic paleogeographic boundaries.

These late Triassic-Lias isopic lines are clearly dissected and displaced between central and eastern Sicily by the NNW-trending Neogene Segesta fault zone (Fig. 4).

1.3) EARLY CRETACEOUS SPREADING AND DISINTEGRATION OF THE AFRICAN PLATE

Triassic and Jurassic facies are quite similar in the Imerese (Sicily) and Lagonegro (Southern Apennines) basinal units, suggesting a continuity of isopic lines between North Africa and Apulia prior to the Cretaceous

(Grandjacquet and Mascle, 1978; Wood, 1981; Casero et al., 1991). However, a former connection between the Malta shelf and the Apulia platform remains highly conjectural (Fig. 1). In addition, recent paleomagnetic data have demonstrated the relative motion and a Cretaceous rotation of the Apulian Promontory (Adria) with respect to the stable African craton (Channell et al., 1979; Lowrie, 1986; Anderson, 1987; Platt et al., 1989), synchronous with the opening of the Sirte and Gabes basins. This implies that a major plate boundary has to be found between Africa and Apulia for this period. The Mesozoic facies distribution and geological record document a permanent connection between Sicily and Tunisia; therefore the active boundary must be located either along the Malta Escarpment, or east of it in the Ionian Basin.

The Malta Escarpment itself could be superimposed on the initial (North African-Tethyan) continent-ocean transition (Scandone et al., 1981; Biju-Duval et al., 1982; Groupe ESCARMED, 1982; 1983; Casero et al., 1984 & 1988; Charrier, 1985). Recent refraction studies clearly document the occurrence of oceanic crust in the Ionian Abyssal Plain (Finetti, 1981; 1985; Morelli, 1985). This Ionian oceanic crust has also been proved to extend beneath the Mediterranean Ridge (Finetti, 1976; De Voogdt et al., 1992; Truffert-Luxey, 1992) and the Messina Cone, two subduction related accretionary wedges developed in front of the Hellenic Trench and the Sicilian-Calabrian arc, respectively (Fig. 1).

However, a Cretaceous reactivation of the Malta Escarpment cannot be totally excluded. Despite the fact that the age of the bordering Ionian oceanic basin itself is still debated - it could be either: 1) a Permo-Triassic remnant of the Paleo-Tethys; 2) a Jurassic remnant of the Neo-Tethys; or 3) even a crust formed by spreading in the Cretaceous - there are indeed a great deal of evidence for a major Cretaceous deformational event in the area:

- In early Cretaceous times, the opening of the Central Atlantic and Indian Oceans induced a relative displacement of Africa compared to Europe, with transtensive Albian pull-apart basins along the Iberia-Europe boundary in the north and intra-plate deformation in Africa itself in the south (Benoué and Central African basins; Burke and Dewey, 1974);
- Although it has also been interpreted as a result of hot spot activity, the nearby Sirte Basin rifting (Goudarzi, 1980) and other Albian-Cenomanian extensional features in the Pelagian Sea (Burollet et al., 1978; Ellouz, 1984; Burollet and Ellouz, 1986) or in onshore Tunisia (Jebels Serdj and Bou Dabouss; Sedjil, 1981) could also be related to this Cretaceous plate reorganization.

At the begining of the Alpine compressional movements, the North African margin was thus a collage of structures inherited from either Permian, late Triassic-Lias and Cretaceous extensional episodes.

2 FIRST ALPINE COMPRESSIONS AND NEOGENE SOUTHEAST-WARD MIGRATION OF THE SICILIAN-CALABRIAN ARC

The first Alpine compressions reflect a major change in the relative movement of Africa which, starting in the late Cretaceous, moved progressively northward and collided with Europe. At the begining, only the oceanic Tethyan domain was concerned, initiating its subduction beneath either the Adriatic margin (Austroalpine and Southern Alps) or Europe (Peloritan-Calabrian domain). Rapidly, however, compressive deformation propagated toward the bordering continents, inducing slight late Cretaceous to Paleogene basin inversions in the forelands and stronger Neogene folding and thrusting near the former ocean-continent boundaries.

2.1) CRETACEOUS TO PALEOGENE FORELAND INVERSIONS

Onshore Sicily, in the Monte Scalpello-Monte Iudica basinal units, the Eocene pelagic limestones of the Scaglia facies lie with a major unconformity on Upper Jurassic cherts or even Triassic carbonate rocks just north of the Mesozoic Ragusa Plateau which is part of the autochthonous foreland (Broquet, 1968; Pion-Leflaive et al., 1990; Larroque, 1993). Similarly, the lack of Cretaceous and Paleocene beds in the Imerese sequences near Caltavuturo, just south of the overthrust of the Panormide Platform, can also be interpreted as evidence of

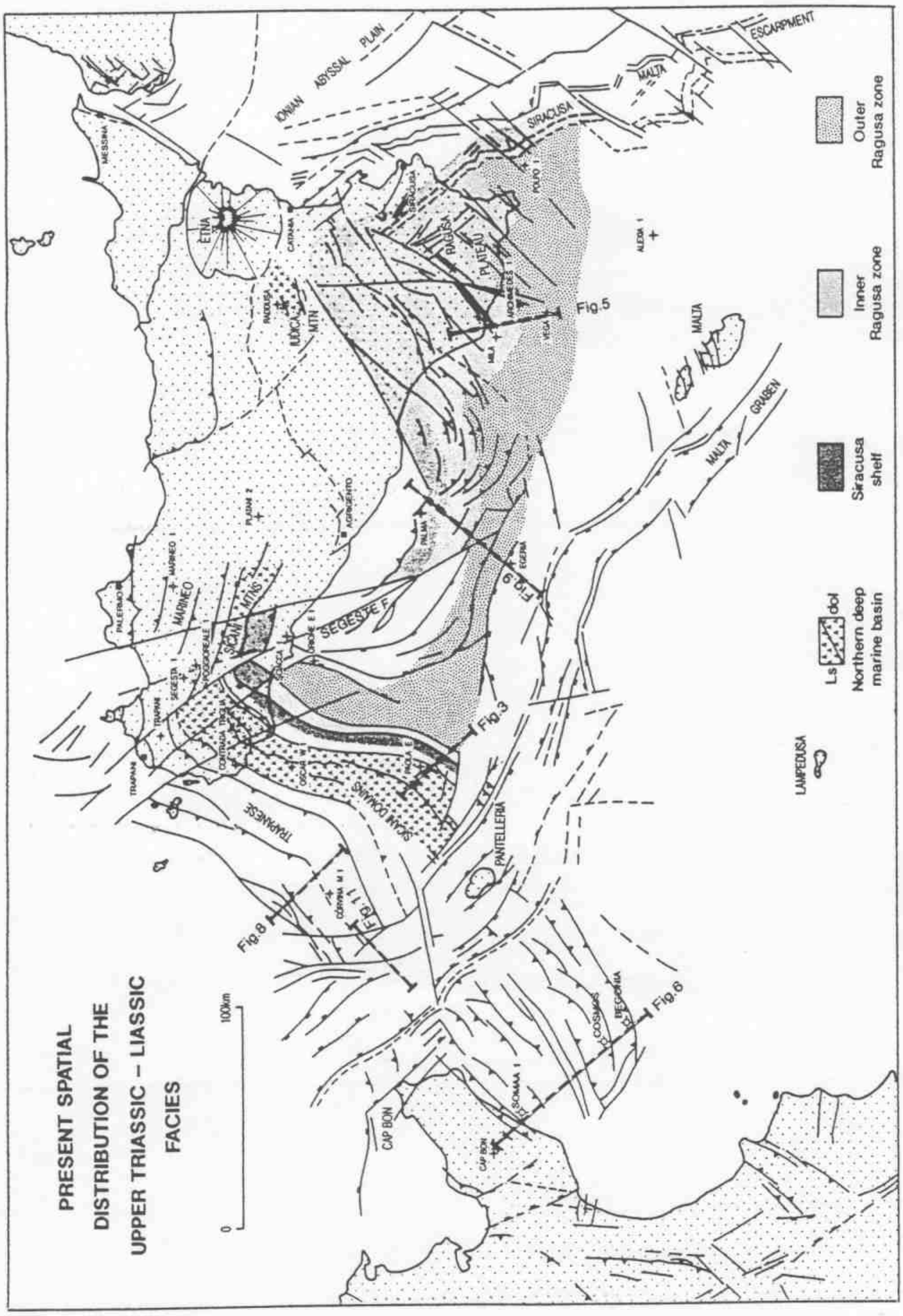


FIG. 4: Present spatial distribution of the different Upper Triassic-Lias facies. Note the total disconnection of the early isopic lines.

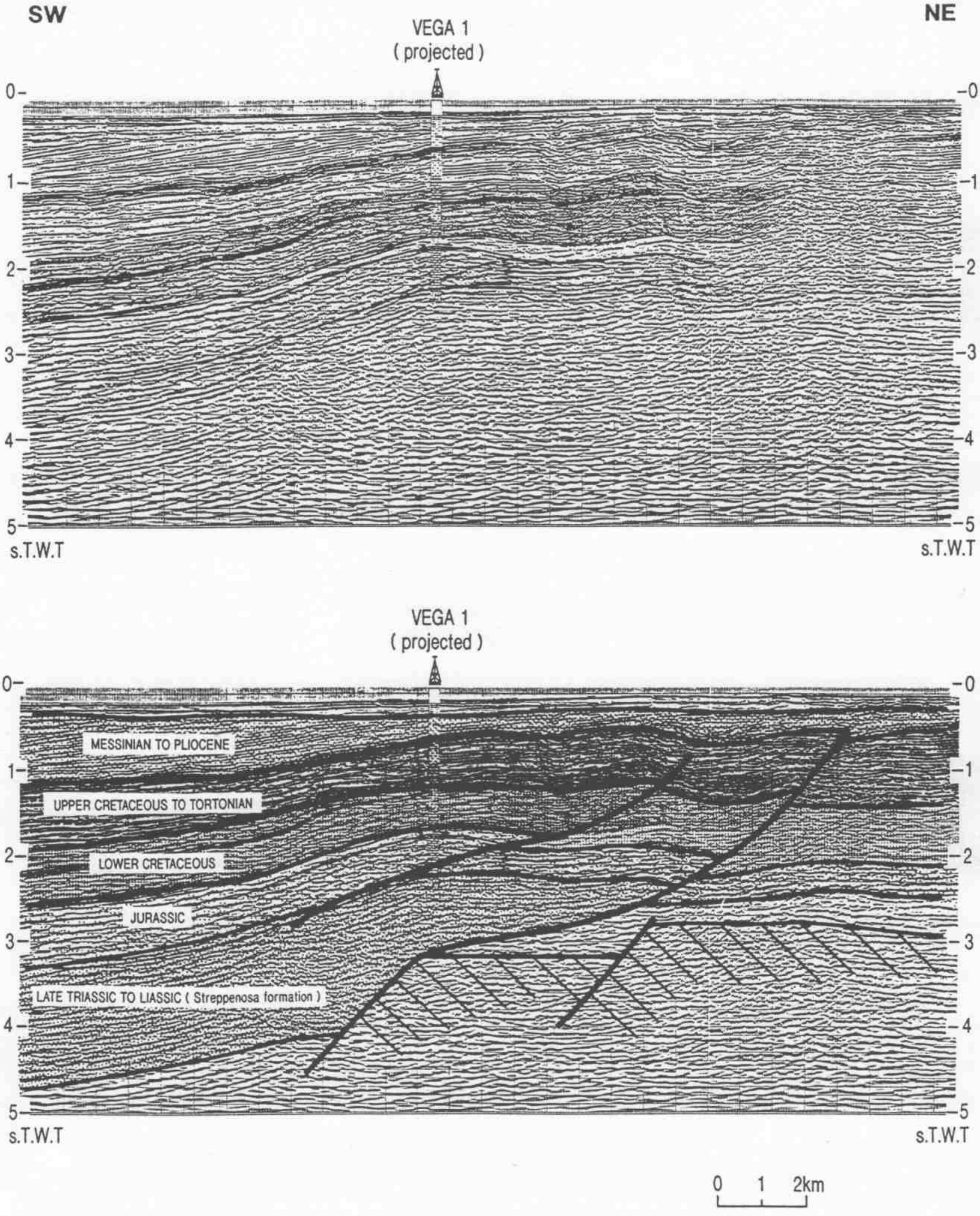


FIG. 5: Seismic profile imaging the Cretaceous inversion of the Streppenosa basin.

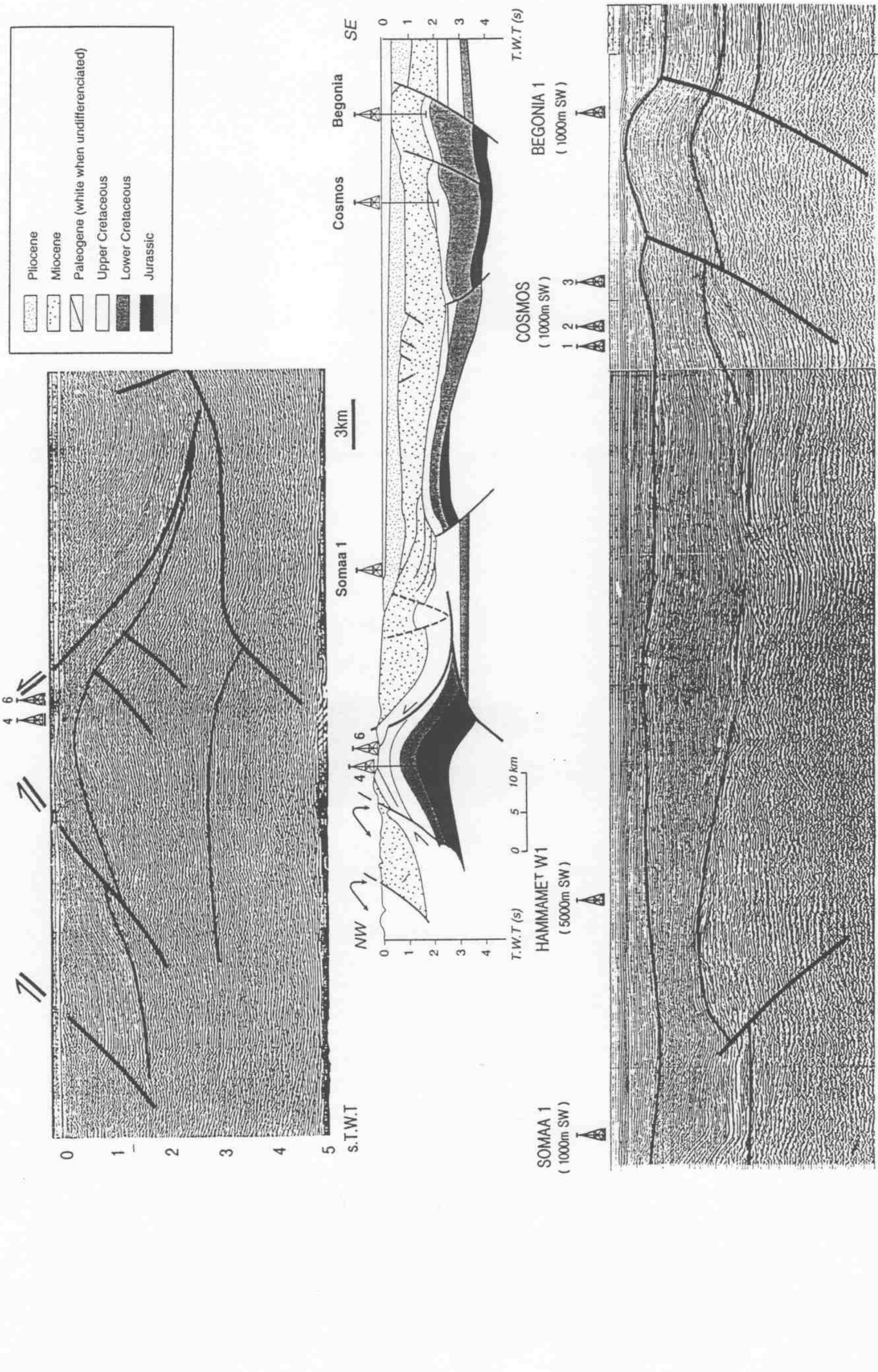


FIG. 6: Seismic profile in the Tunisian shelf imaging the Neogene structural inversion of the Cape Bon Mesozoic basin, as well as earlier Cretaceous inversions in the south.

early deformation and inversion of the basin margins, which occurred prior to large-scale Neogene overthrusts.

South of Gela, seismic data and deep wells document another Cretaceous basin inversion, with the thick late Triassic-early Lias Streppenosa basin being remobilized at its contact with the Upper Triassic dolomites of the Gela (Taormina) Formation (Mila and Vega structures, Figs. 3 & 5).
Apparently, most of the NE trending Mesozoic basins, however, only the North African margin were thus inverted for a first time during the late Cretaceous or Paleogene, as is imaged on the offshore seismic records of the Sicily Strait (Fig. 6). Coeval late Cretaceous and Paleogene unconformities have also been described onshore Libya, in Cyrenaica (Rohlich, 1974), documenting the wide distribution of this deformation episode. Due to Neogene reactivations of the basin margins in the north, the early inversion structures have rarely been preserved in the Sicilian fold-and-thrust belt, with the basinal units now being largely overthrust onto the previously bordering platforms, which also are largely allochthonous.

2.2) NEOGENE COMPRESSION AND SYNOROGENIC DEPOSITS

Besides the remnant Ionian Abyssal Plain, no part of the Tethyan oceanic domain escaped subduction, and by Neogene times a progressive subduction of the North African continental lithosphere itself below the Sicilian-Calabrian arc was initiated.
As the Neogene compressional fronts progressively migrated toward the foreland, synorogenic deposits were trapped in successively more external foredeep basins (Caire et al., 1966; Broquet et al., 1984; Figs. 7 to 9). However, the lateral extent of these Lower Tortonian (Figs. 7 & 8), Messinian (pre-anhydrite Terravecchia Formation, Fig. 7), and Middle to Upper Pliocene foredeep basins (Figs. 7 & 9; Argnani et al., 1986; Catalano et al., 1993 b) is locally interupted, with the younger foredeep being thus strictly restricted to south and southeastern Sicily.
Similarly, the age of the frontal thrust differs greatly from the west where major shortening predates the deposition of the Messinian anhydrite and of the Lower Pliocene Trubi Formation to the east where even the Lower Pliocene is largely involved in the deformations.

3 EVIDENCE FOR THREE MAJOR NEOGENE WRENCH ZONES DECOUPLING THE SICILIAN FORELAND

Three major zones of decoupling are suggested by the present disruption of Mesozoic isopic lines and the discontinuous pattern of the Neogene foredeep basins or thrust fronts. From east to west, they comprise:

3.1) THE MALTA ESCARPMENT

The Malta Escarpment is a major N trending morphologic feature which separates the Ionian Abyssal Plain in the east (with 2 to 4 km of water depth) from the shallow marine platforms of the Pelagian Sea or onshore Sicily (Fig. 1). In the north, it delimits the southward-propagating Messina Cone that outlines the still-active deformation front of the Sicilian-Calabrian wedge.
Dredging and diving with the Cyana submersible has recorded a complete Mesozoic sequence with the local occurrence of a condensed series (Scandone et al., 1981; Biju-Duval et al., 1982; Groupe ESCARMED, 1982 & 1984; Casero et al., 1984 & 1988). An unknown amount of post-Triassic offset of the early Mesozoic isopic lines is assumed to parallel the N trending Malta-Siracusa structure, and would account for the present disruption of the Triassic paleogeography. Indeed, Triassic platform facies, possibly related to the Siracusa zone where the Inici Formation lies directly on dolomites without any facies equivalent of the Streppenosa Formation, have been drilled into immediately west of the escarpment. Pelagic Jurassic facies, however, have been dredged from the escarpment itself (Biju-Duval et al., 1982), whereas Cretaceous platform facies do occur again southeast of the escarpment in the Medina Rise (Fig. 1).

Tortonian and Quaternary movements are documented by the thick sedimentary infill of the down-faulted block which occurs along the Malta Escarpment (Groupe ESCARMED, 1983; Casero et al., 1984 & 1988; Fig. 1). However, beside this evidence of vertical movements preceding the onlap of the Messinian evaporites, neither compression nor any wrenching can be

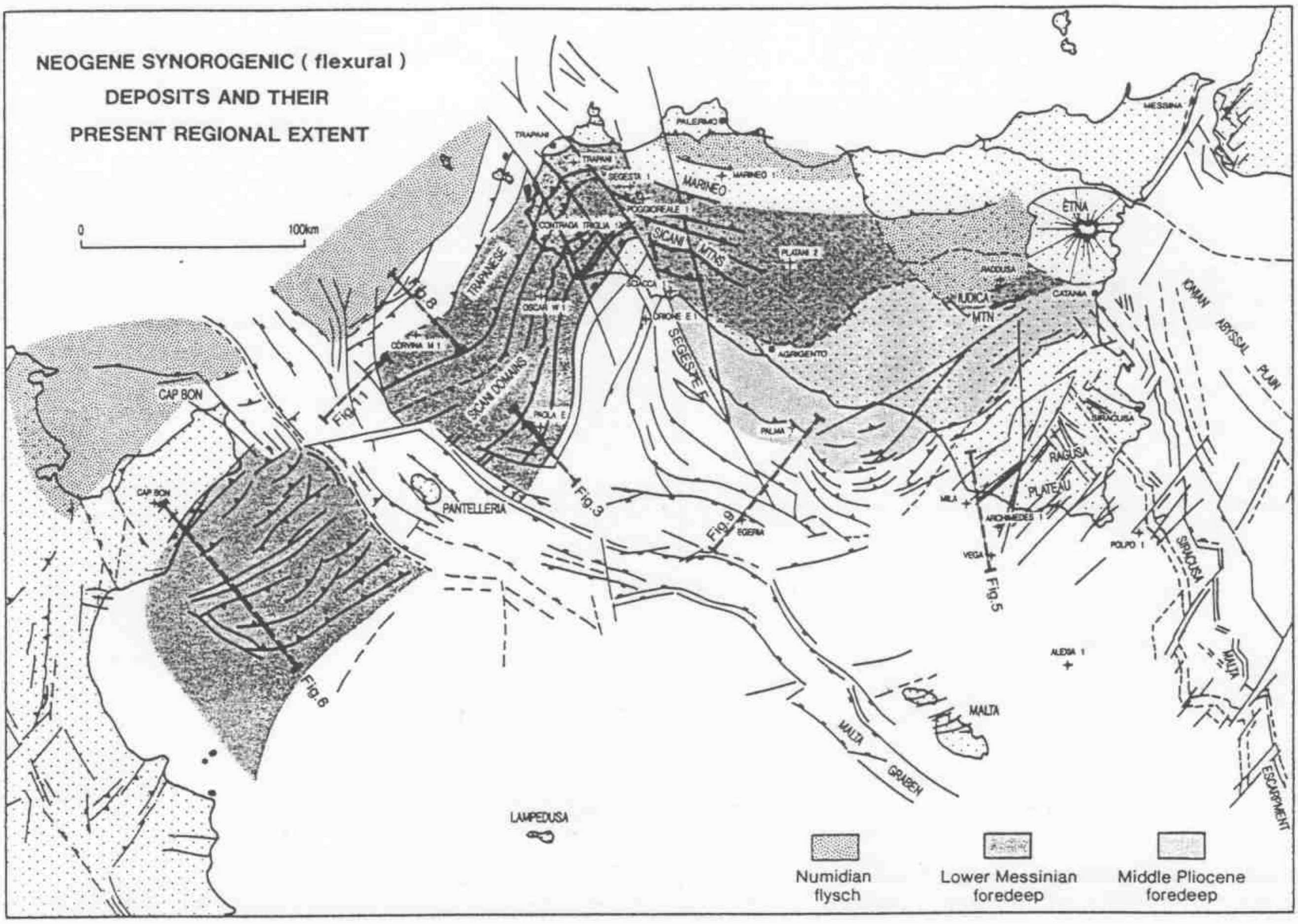


FIG. 7: Neogene synorogenic (flexural) deposits and their present regional distribution.

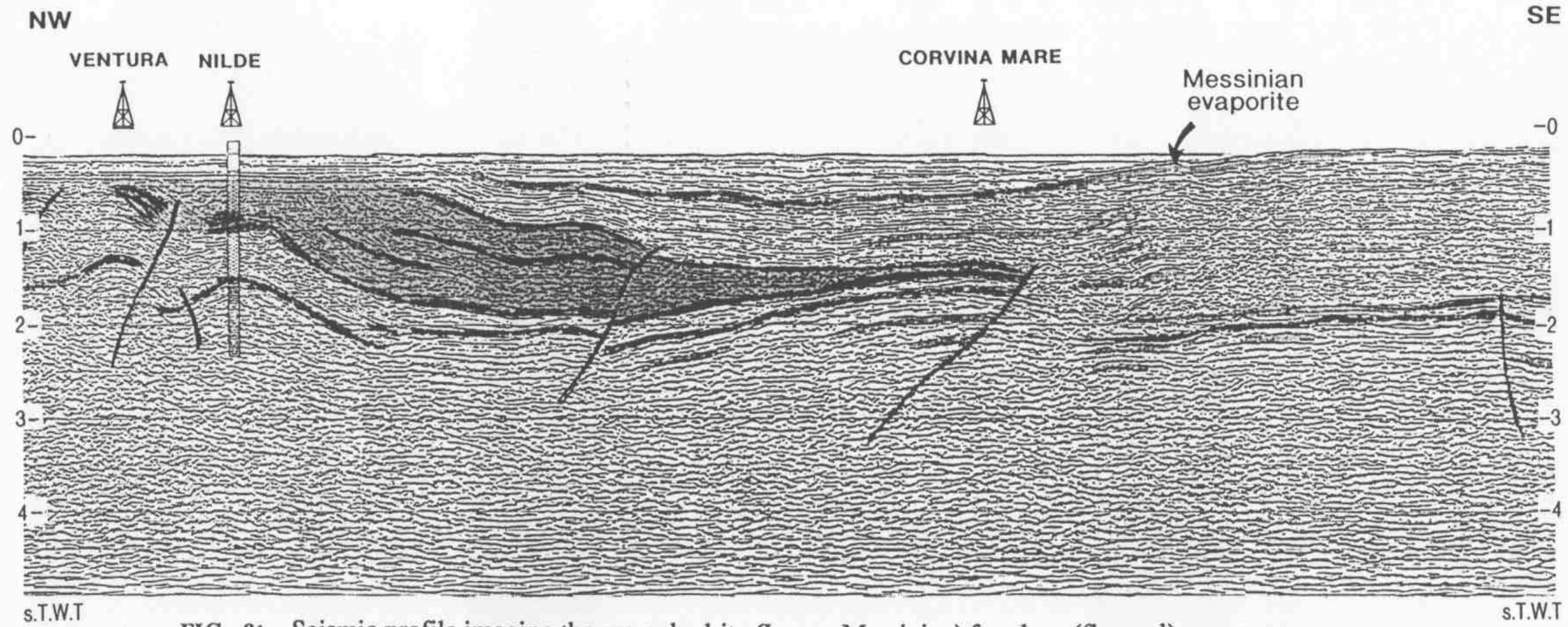


FIG. 8: Seismic profile imaging the pre-anhydrite (Lower Messinian) foredeep (flexural) sequences.

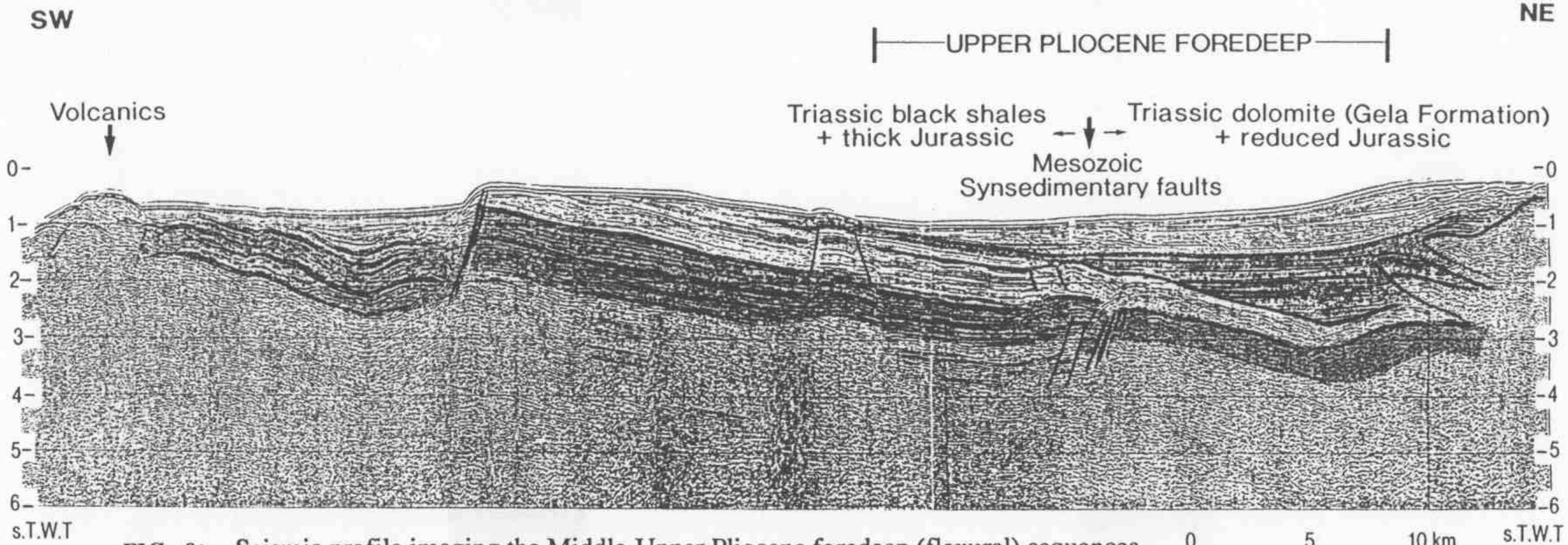


FIG. 9: Seismic profile imaging the Middle-Upper Pliocene foredeep (flexural) sequences.

directly identified on the available seismic sections along this structure. But still, these fragmentary data do not preclude the possible occurrence of Cretaceous or syn-Tortonian wrenching.

Direct evidence which would allow to properly evaluate the role of the Malta Escarpment during the Cretaceous deformation is also lacking. According to paleomagnetic data, the Cretaceous was a period of extension along the North African margin, preceding and in connection with the rotation and drift of the Apulian Promontory. Although a major plate boundary is required at that time to limit the African plate in the east, it has not yet been established whether this boundary corresponded more or less to the Malta Escarpment which is still active, or whether the junction between the African and Apulian plates was then located more to the east, below the Ionian Abyssal Plain or beneath the more recent accretionary wedges (Messina cone or Mediterranean Ridge), at a place where Cretaceous oceanic accretion occurred.

3.2) THE NNW TRENDING SEGESTA TRANSFER FAULT

The Landsat imagery of Sicily outlines a major NNW trending lineament that dissects western Sicily. Field reconnaissance (Trimaille, 1982) serves to trace accurately this structure in the Sicilian fold-and-thrust belt where it separates strongly contrasting facies and structures, especially around Segesta, with pelagic units of the Montagna Grande with Trapanese affinities, west of the lineament, being juxtaposed against more internal units, similar in facies to the sequence of the Marineo well, in the east (Segesta Mtn). Thus, the Tortonian rests directly onto the Cretaceous in the Montagna Grande, whereas marly Oligocene limestones occur in Segesta, without stratigraphic gaps between the Mesozoic and the Neogene, the Siccani domain itself being characterized by its complete Cretaceous sequence.
Offshore, intense wrenching and faulting (Fig. 10) allow to extend the trace of the Segesta wrench zone as far south as the Pantelleria-Malta rift system, where it apparently dies out or is masked by younger deformation. As this major structural feature onshore cuts the entire tectonic pile of the allochthon, it can be interpreted as a major transfer fault. However, as it also extends offshore into the autochthonous foreland (where it induces an offset of the Triassic platform and determines the extension of the Neogene foredeep), it must be interpreted as a first order crustal structure, with a decoupling horizon within the underthrust North African lithosphere (probably at the brittle-ductile transition, in the lower crust).

The main activity of this transfer structure was confined to the Pliocene and is related to the emplacement of the allochthon. West of the fault, all the compressive deformations predate the Messinian evaporites, whereas the Lower Pliocene itself is largely involved in the thrusting in the east.

3.3) THE LATE PLIOCENE-QUATERNARY PANTELLERIA RIFT SYSTEM

The Sicily Strait and the Pelagian Sea are dissected by a major NW to W trending rift system (Fig. 1 & 11), whose activity is well dated by the Quaternary sedimentary infill of the Malta and Linosa grabens and the age of related volcanics (Illies, 1981; Winnock, 1981; Groupe ESCARMED, 1985; Reuther and Eisbacher, 1985; Reuther, 1987; Cello, 1987; Calanchi et al., 1989).
In detail its movements cannot be related to simple extension but appear to be more complex: locally compressive structures (graben inversions) and wrenching document local right lateral transpression, more or less coeval with extension elsewhere (Fig. 11; Boccaletti et al., 1987 & 1990; Ben Avraham et al., 1987; Antonelli et al., 1988; Argnani, 1990; Catalano and Milia, 1990; Dart et al., 1993).
Despite there is evidence for transpression, the amount of Quaternary strike-slip movement along these structures should not be overestimated. As a matter of fact, no offset of the NE-trending isopic lines and of the pre-Messinian thrust fronts is observed in the Sicily Strait (Fig. 7). Instead, these structures correlate perfectly from one side of the rift zone (Tunisian shelf in the west) to the other (offshore and onshore Sicily in the east).

4. RELATIONSHIPS BETWEEN BASIN INVERSIONS, THRUSTING, RIFTING AND ESCAPE OF BLOCK

Following the Mesozoic events of oceanic accretion and the Cretaceous displacement of the

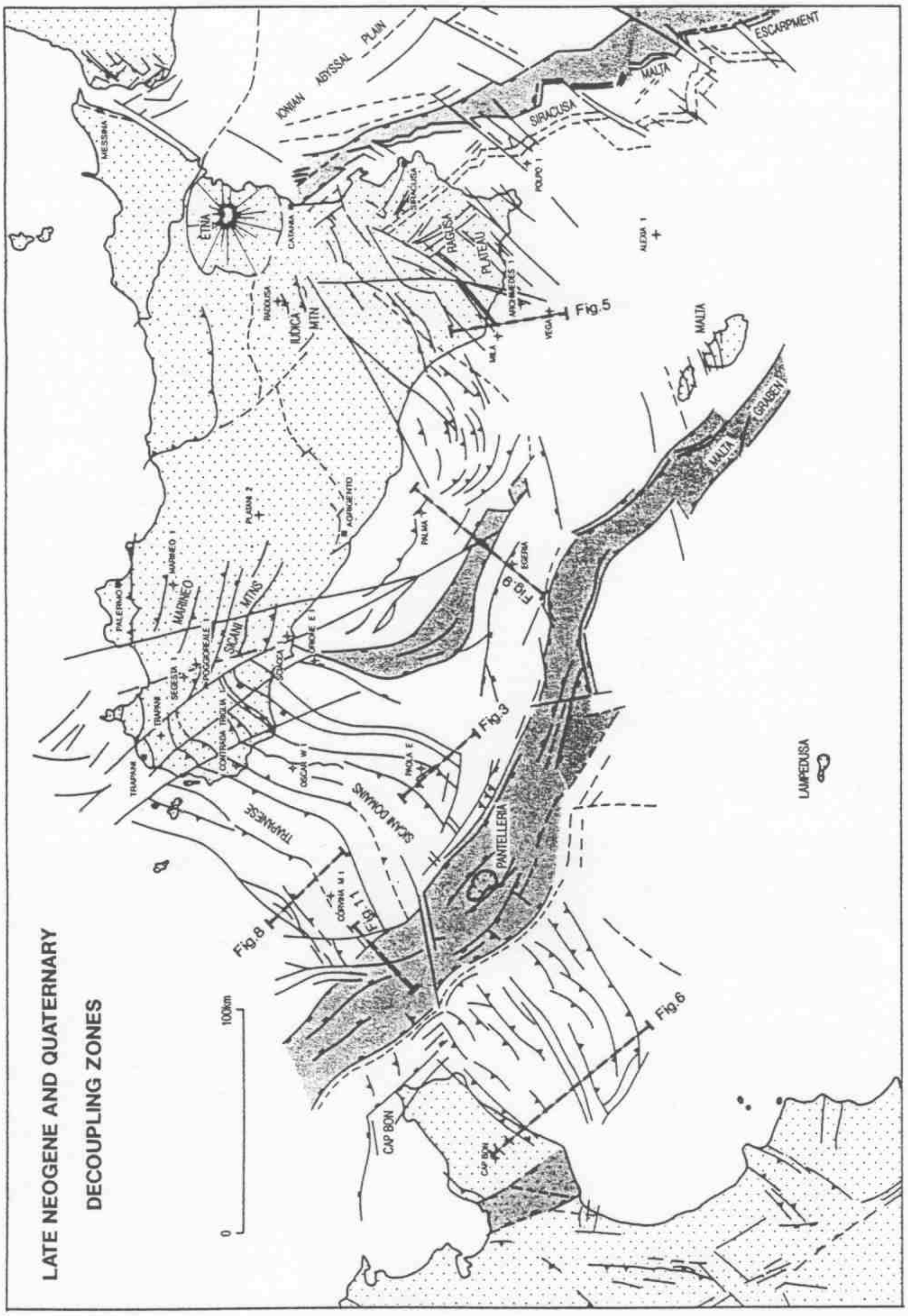


FIG.10: Late Neogene and Quaternary decoupling zones.

Apulian Promontory, the interaction of various competing Neogene to Quaternary geodynamic processes such as the Sicilian-Calabrian thrust emplacement and the subduction of the African and Ionian lithospheres, the opening of the Tyrrhenian and Ligurian-Provence oceanic basins, and the stetching in the Pelagian Sea has led to a very complex structural collage in the central Mediterranean area. The identification of major plate boundaries and a better understanding of the kinematics of the deformation may help in the following discussion of a scenario for the Neogene disintegration of the North African margin.

4.1) REGIONAL STRESS REGIMES AND PRESENT SEISMICITY

Paleomagnetic data in the Apennines and the Sicilian fold-and-thrust belt document important block rotations that occurred during the Neogene thrust emplacement (Channell et al., 1990; Oldow et al., 1990; Sagnotti, 1992). Therefore, paleostress measurements in the allochthon cannot directly provide information on the boundary conditions that prevailed during the successive episodes of the geodynamic evolution of the North African margin. Only the relatively undeformed foreland could provide the needed information, and, although most of this domain still remains unaccessible for the microstructuralist (Pelagian Sea), crucial paleostress data have already been obtained from the Ragusa Plateau, Malta and Lampedusa, and the Tunisian mainland (Letouzey and Trémolières, 1980; Cello et al., 1987; Barrier, 1992; Bouaziz et al., 1994).

Of course, these local data need to be carefully tied to the time scale, but they definitively add useful constraints to the overall plate kinematic reconstructions of the area. In fact, the major problem to be solved is whether the paleostress regime was homogeneous across the area, with an alternation of compression and extension in the North African foreland, or whether wrenching was the dominant mode of deformation, inducing local transpression contemporaneous with transtension elsewhere (Jongsma et al., 1985; Jongsma, 1991).

Accurate biostratigraphic and micros- tructural data are still required to give a definitive answer to this crucial question. In particular, the early Cretaceous and Eocene normal faults found in Tunisia or offshore Libya are separated from well dated late Cretaceous and Paleogene inversions by only a very small time interval - in our view too short to exclude the possibility of a regional synchroneity between these two opposite types of deformation. The same questions arise for the Quaternary, during which rifting in the Malta and Pantelleria grabens was synchronous with wrenching and local foreland inversion as well as with late-stage overthrusting along the front of the Sicilian-Calabrian arc near Caltagirone in southeastern Sicily.

The present seismicity is also very significant. Although no thrust-related shortening has been recorded along the Sicilian thrust front since the early Pleistocene, deep focal mechanisms and calc-alcaline volcanism in the Aeolian Islands document a still-active Benioff plane beneath the Calabrian arc (Gasparini et al., 1985). Earthquakes are also frequent along the Malta-Syracusa structural trend, and recurring volcanic activity in the area - troughout during the Mesozoic and up to the Pliocene in the Ragusa Platform, or even during the Quaternary at Etna - underline the longevity of this major ocean-continent boundary.

Offshore Tunisia in the Pelagian Sea, seismicity is concentrated in the vicinity of the Pantelleria rift system (Hfaiedh et al., 1985), whereas isolated events have also been recorded in Libya, offshore from the Cyrenaica coast (Ben Avraham et al., 1987).

4.2) EARLY RIFTING AND BASIN INVERSIONS

No data are available yet to constrain the geometry of the late Paleozoic basins, and the relative influence of late Triassic-Lias or younger early Cretaceous extensional crustal features on the Present architecture of the North African margin still remains conjectural. There is little doubt, however, that these earlier structures have been reactivated during the late Cretaceous and Tertiary basin inversion, which progressively deformed the North African margin. In fact, most of the foreland deformation is concentrated near earlier basin-platform boundaries (i.e. the Cape Bon or Vega structures; Figs. 5 & 6). Although the late Jurassic oceanic crust was still preserved until the Aquitanian between Europe (Calabria-Peloritan units or Sardinia-Corsica block) and

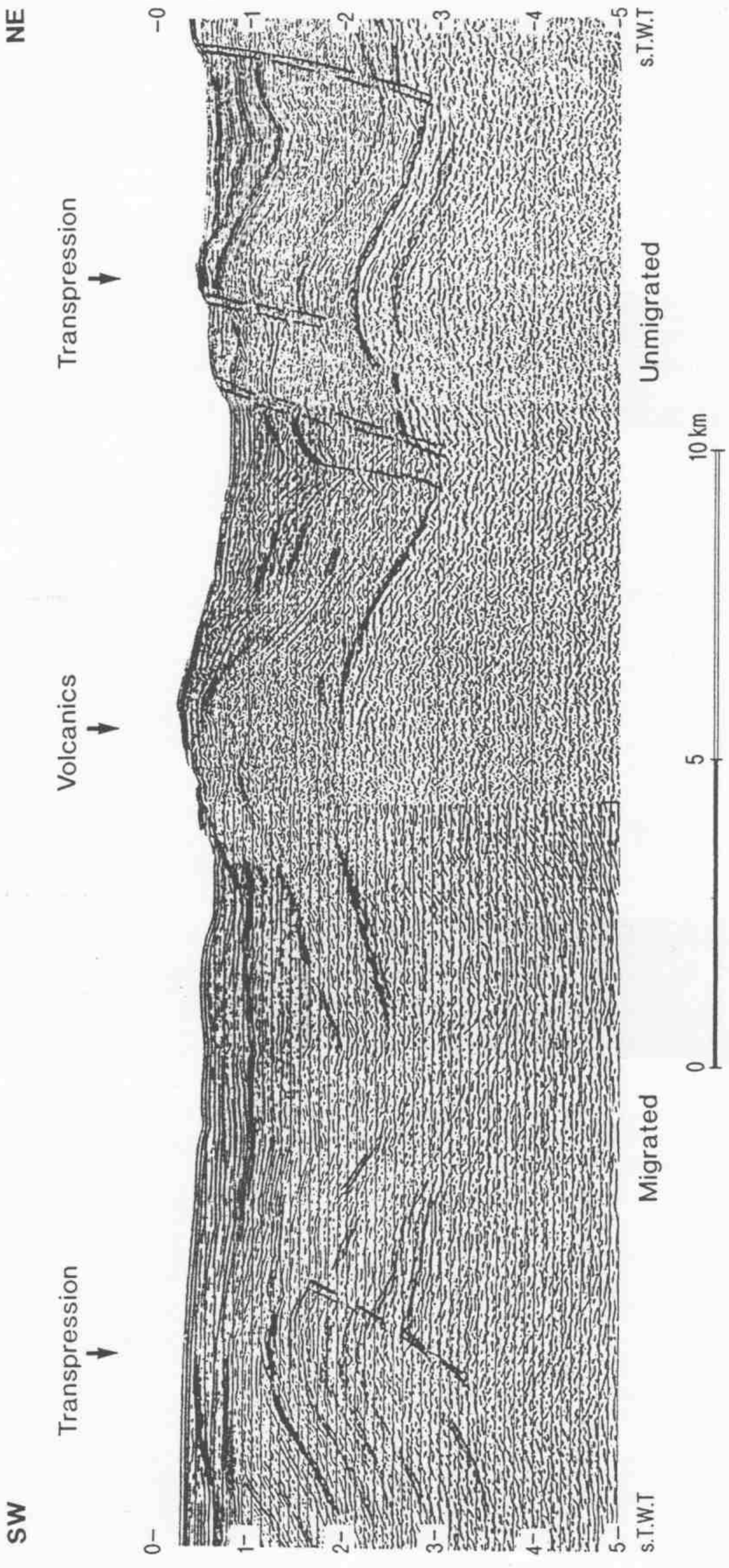


FIG.11: Seismic profile imaging Quaternary normal faults and the wrenching of the Pantelleria rift system.

Apulia or Africa, paleostress related to early Alpine deformation were entirely transmitted southward across the North African plate, inducing part of the observed inversions.
The decoupling level generating this far-reaching transmission of intra-plate stresses was probably located in the lower African crust, near the brittle-ductile transition zone through which all the former extensional structures were once connected.

4.3) INTRA-PLATE DEFORMATION AND LATERAL ESCAPE OF BLOCKS

Beside the occurrence and repeated reactivation of a wide intracrustal, horizontal decoupling level in the African foreland, lateral movements of crustal fragments have also been evidenced since the Cretaceous along the North African margin. All the observed lateral escapes of blocks are probably the result of local accomodation to fit the reorganization and oblique displacements of the major plates. Taking into account that lithospheric plates are relatively rigid and that intra-plate deformation remain a second order feature, strike-slip faulting and wrenching are two complementary modes of deformation required to balance, on a regional scale, the noncylindricity of compressive fronts.

At the beginning of Neogene times, Sicily was thus entirely and directly connected to the Tunisian shelf, with the major plate boundary with the Ionian and the Adriatic plate being located eastward, possibly east of the Malta Escarpment.
In the Maghrebides and western Sicily, compression stopped before the deposition of the Messinian evaporites, but shortening was still active in the Pliocene in Southern and Central Sicily or eastward along the Calabrian arc. Therefore, during the entire Pliocene, a major plate boundary must have isolated the major part of Sicily from its westernmost part which was still attached to the Tunisian shelf. The location of this major Pliocene structural boundary has clearly been identified and corresponds to the NNW trending Segesta transfer fault described earlier. Its documented southeastern extension parallels the E-trending Pantelleria structures southward to the Medina Ridge.

Since the Early Pleistocene, the Messina Cone is the only active thrust front, and Sicily is now totaly decoupled from both Africa in the west (along the Pantelleria rift system) and the Ionian-Adriatic plate (along the still active Malta Escarpment; Fig. 12).

5. CONCLUSIONS

At the begining of Alpine compression, the North African margin was a mosaic of structures inherited from Permian, late Triassic-Lias and Cretaceous extensional episodes. The disintegration of the North African margin started in the Cretaceous with the rotation and drift of the Apulian Promontory. However, the age of the oceanic accretion in the Ionian Basin remains highly controversial. It is doubtfull that only Cretaceous oceanic basement occurs in the Ionian Basin. More probably, oceanic accretion there initiated in the Jurassic (both middle Jurassic and Maastrichtian volcanics are known in the area; Casero et al., 1984-1986; Fig. 4), or possibly even earlier, in the Permian, in connection with the western termination of a south Tethyan seaway (Bernoulli et al., 1990).

In any case, the relationships between Neogene to Quaternary thrusting, rifting and lateral escape can be analyzed. The three major decoupling zones identified here may define a coherent history for the Neogene evolution of the Sicilian-North African plate boundary and illustrate its lateral displacement through time. A counterclockwise rotation associated with an abrupt westward displacement of the plate boundary is thus observed:

- In Mesozoic times, Sicily was closely attached to North Africa. If there was an active plate boundary with Apulia, it must have been to the east.
- In Tortonian times, the N-trending Malta Escarpment was active as a normal fault, with a possible right-lateral strike-slip component that still needs to be quantified, forming the new African-Ionian boundary.
- In middle Pliocene times, the NNW trending Segesta transfer zone of western Sicily acted as a major right-lateral fault separating "true" Africa, i.e. areas with no post-Messinian flexuring and shortening, from central and eastern Sicily and the Ionian Sea (areas where the deformation was still active in the middle Pliocene).

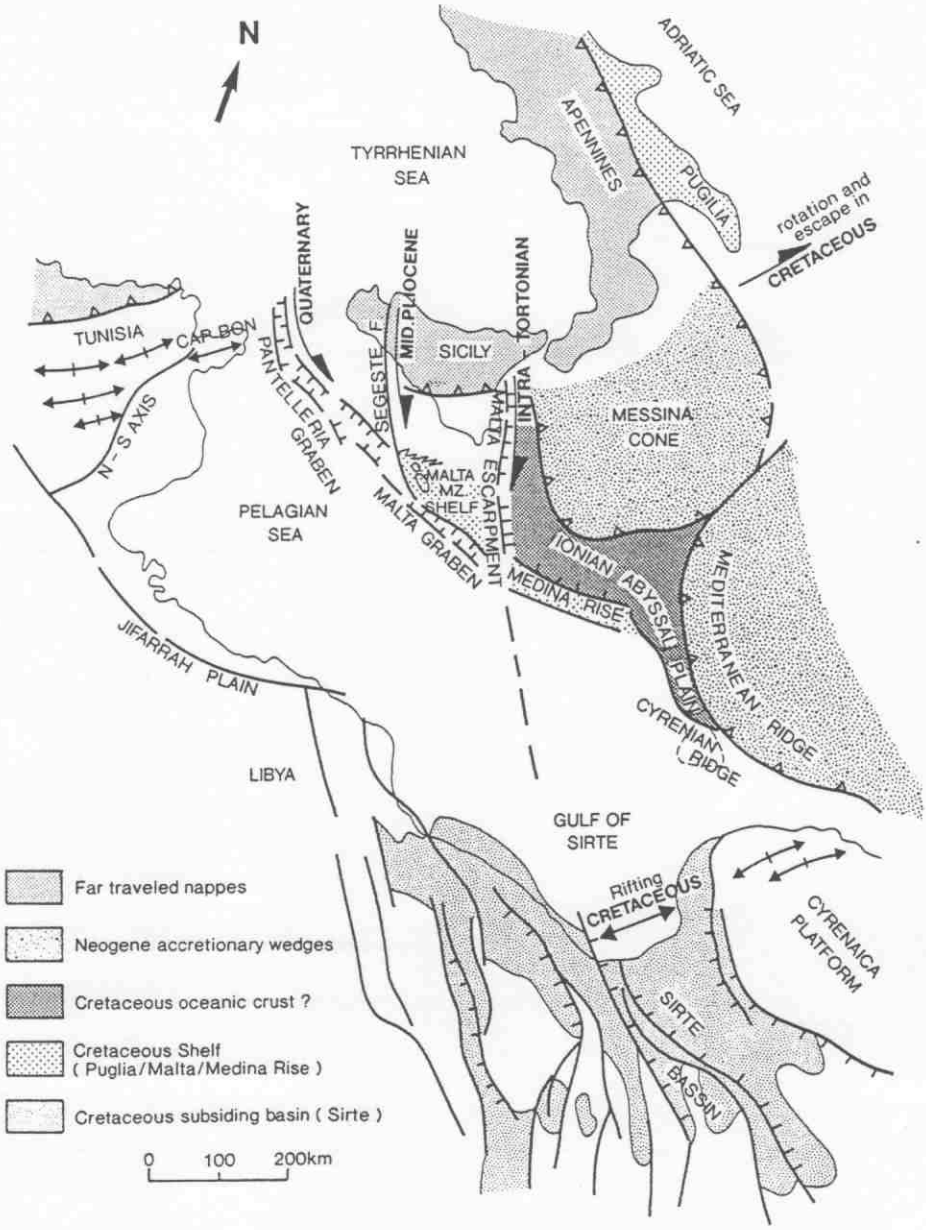


FIG.12: Thrusting, rifting and lateral escape.

- In the late Pliocene-Quaternary, the Pantelleria rift, associated with incipient strike-slip faulting, marked a new displacement of the plate boundary toward the west. For that time however, continuous deformation was still observed along the Malta Escarpment ; this means that all of Sicily no longer belonged either to Africa or to the Ionian plate.

The major remaining geodynamic problem in the Central Mediterranean is the eastward continuation of these Neogene and Quaternary plate boundaries. Two opposite solutions can still be discussed:

- The pre-Quaternary lateral move-ment recorded along the Segesta transfer fault as well as the Quaternary right-lateral movement in the Pantelleria rift die out in the Medina Ridge, where Aptian shallow-water platform carbonates have been sampled at great depth (Groupe ESCARMED, 1983);

- All the lateral movement offshore the Sicilian coast was transmitted southward, either along the Cyrenaican coast where Present seismicity has in fact been recorded (Ben Avraham et al.1987) or in the Sirte Basin, a favored solution for the Neogene, for which active deformation has been recorded as far south as the Libyan mainland.

A better understanding of the structure and initial location of the Medina and Cyrenian Ridges (Groupe ESCARMED, 1983), at the northern and southern extremities of the Sirte Rise respectively, would clearly help to solve this crucial geodynamic problem.

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