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THE SICILY MAINLAND THRUST BELT. EVOLUTION DURING THE NEOGENE

Abstract. The Neogene tectonic evolution of Sicily mainland is here illustrated using available data and performing new deep geologic sections. A South to Southeast vergent arched belt developed on Sicily mainland, involving the sedimentary cover of the old African continental margin. Facies and structural affinities along tectonic strike of the chain are pointed out, as well as synchronism in the kinematics and timing of deformation. Some variations in the architecture of the pile is induced by the local distribution of a number of thrust systems, having different size, geometry and paleogeographic origin. The role of the Upper Paleozoic complex, as important buried element of the belt, is emphasized; its development appears related to the accretion at depth of a multiduplex stack. A complex deformative history is outlined by several accretionary events, starting in the middle Oligocene-early Miocene with East-vergent transport direction, followed after the Miocene by rotation of thrusts. Transpression movements in the hinterland were simultaneous with thrust activity in the most external zones, during the latest Miocene to Pleistocene. Through the various stage of deformation, the wedging of the chain was accompanied by the development of foredeep and piggyback basins affected by strong subsidence and active synsedimentary tectonics.

INTRODUCTION

Sicily is part of a continuous late Cenozoic orogenic belt (Fig. 1) developing from the Apennines in Italy to the Maghrebides in North Africa across the Siculo-Tunisian platform (Catalano, 1988; Catalano et al., 1993a).

This paper aims to summarize the geology of the Sicily mainland showing the major structures of the chain along some deep N-S cross sections. Recent published and unpublished data of the present Authors support a geological scheme characterized by underplating and duplex accretion in the earlier stages of the collisional deformation. However, extensional and transpressional movements in the hinterland contemporaneous with the reactivation of the most external thrusts seem the dominant deformative mechanisms during the last five million years. The voluminous Permian and Carnian rock packages, which were involved together with the Mesozoic carbonate thrusts, are here believed to play an important role in constructing the chain.

STRATIGRAPHY AND PALEOGEOGRAPHY

Previous studies have identified the lithotectonic assemblages now outcropping in the Sicilian fold and thrust belt (Catalano and D'Argenio, 1978; 1982; Montanari 1987; Oldow et al., 1990; Catalano et al., 1991c) and recognized in adjacent submarine areas (Catalano 1987; Catalano et al., 1989). Lithotectonic type assemblages (Fig. 2) are related to - African margin paleogeographic domains (Catalano and D'Argenio, 1978).

Permo-Triassic stratigraphy of the Sicily mainland indicates that the paleo-Alpine evolution

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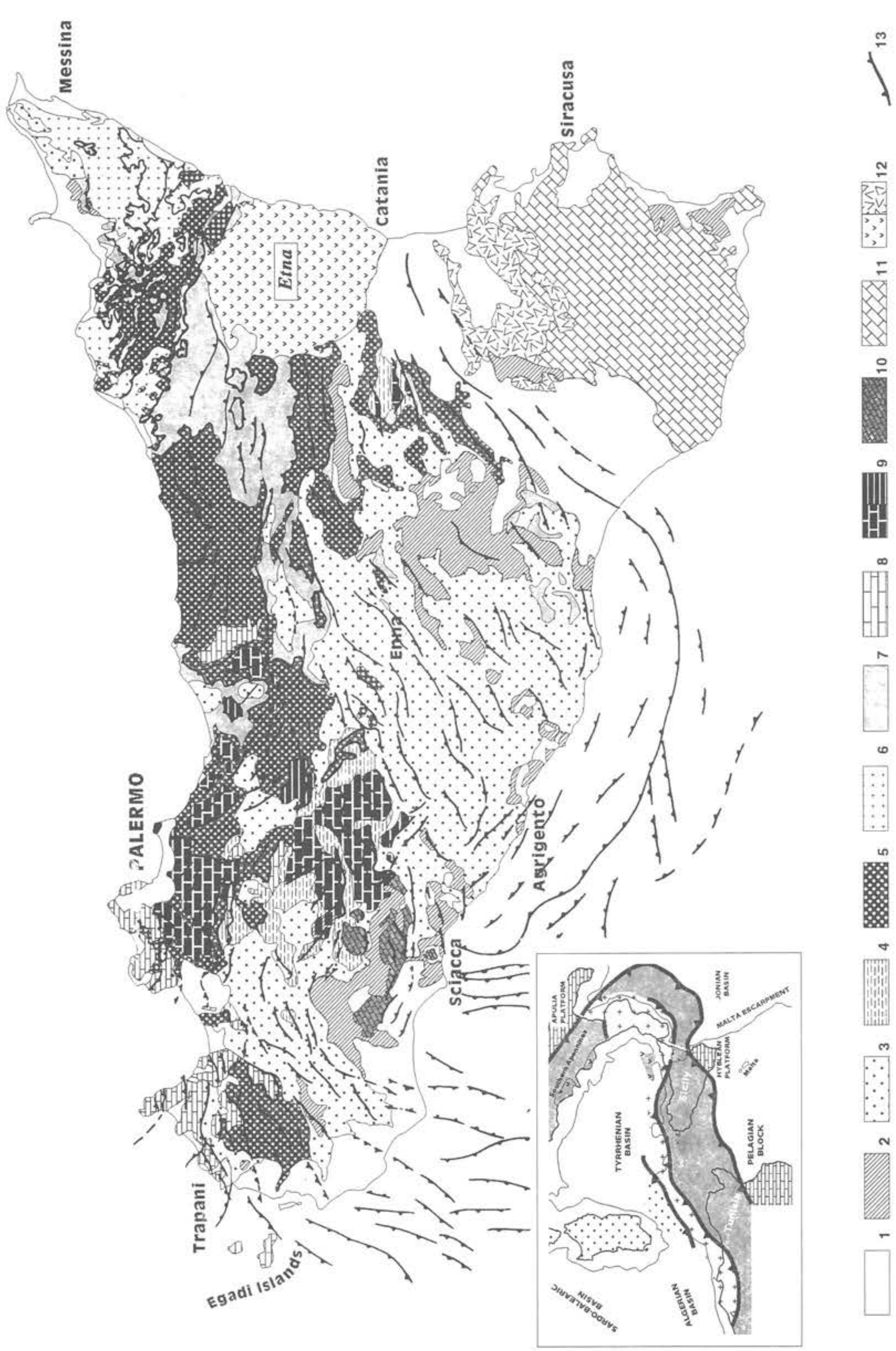
Messina
Siracusa
Catania
Etna
PALERMO
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Sciacca
Trapani
Egadi Islands
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13
TYRRHENIAN BASIN
ALGERIAN BASIN
SARDO-BALEARIC BASIN
APULIA PLATFORM
JONIAN BASIN
MALTA ESCARPMENT
HYBLEAN PLATFORM
PELAGIAN BLOCK
Malta
Sicily

of these domains began in early Permian times, contemporaneously with the last Hercynian compressive movements (Catalano et al., 1988; Catalano et al., 1991a; Di Stefano, 1990).

A thick sequence of siliciclastics and clastic carbonates were deposited in a broad, deep water basin during the Permian and middle Triassic times. The basin developed on a thinned continental (or? oceanic) crust and represented the westward prolongation of the Permian Tethys ocean along the northern Gondwanian margin (Catalano et al., 1991a). The eastward prolongation of the basin passed through the present day Ionian sea, which separated Apulia from Gondwanian Africa (Catalano et al., 1991a).

Our inferred pre-Triassic history and the structural evolution of the thrust pile forming the chain suggest, unlike previous paleogeographic interpretations (Catalano and D'Argenio, 1978; Montanari, 1987), a new organization of the Sicilian part of the African continental margin: it was covered during the late Triassic by a wide carbonate platform to the south, and a deep basinal area to the north. The western prolongation of the basinal area ("Northern Marettimo Basin", Fig. 3) appears to have been located north of the Panormide and Pre-Panormide Carbonate Platform as already assumed by Catalano et al., 1992, 1993a. Field evidences show the overposition of uppermost Triassic deep-water ammonoid-bearing cherty limestones (Di Stefano and Gullo, 1993) above the platform carbonate Units of the same age, outcropping in the Egadi Islands. When palinspastically restored the rock bodies relationships confirm the internal position of the basinal areas. The carbonate platform - seamount system (merging to the west) was separated from the more northerly basinal domains by a narrow, irregularly indented margin (Fig. 3).

The Sicilian margin was later strongly modified by transcurrent motions between Africa and Europe. Transtensile tectonics generated a new Jurassic paleogeography (Catalano and D'Argenio, 1982). Transpression or inversion tectonics during the Cretaceous-Paleogene deformed and locally arched the Sicilian continental margin (Catalano and D'Argenio, 1982; Catalano et al., 1991 b) before the onset of Tertiary compressional deformation.

Following the European Sardinia rotation and the collision with the African margin, a new paleogeography took place. Several foredeep and piggy back basins, filled mainly by flysch deposits (Fig. 2), were forming on the front of the advancing Sicilian tectonic wedge.

MAINLAND STRUCTURES

Deep N-S geologic sections across western and eastern Sicily (Figs. 1, 4 and 5) show a structural grain characterized by:

- A foreland region, outcropping in southern Sicily (Hyblean Plateau) and also present in the southern offshore. This autochtonous sedimentary succession is coupled with its basement and consists of thick platform, deep water carbonates and open shelf clastics (Patacca et al., 1979; Catalano and D'Argenio, 1982; Lentini, 1983; Bianchi et al., 1987; Montanari, 1987). The extent of the foreland carbonates below the main thrust wedge in Sicily is not known. From structural analyses we suggest it continues at depth northwards to the north coast of Sicily with gradual thinning and facies changes (Fig. 5). There it underplates accreted allocthons (Roure et al., 1990).

Fig. 1 - Structural map of Sicily (modified from Catalano et al., 1987; and Calatano et al., 1991, structural Model of Italy, sheet 6. Peloritani sector compiled from recent data of Nigro 1994 and Amodio Morelli et al., 1976 south eastern Sicily modified from Lentini et al., 1991).
1 - Pleistocene deposits. 2 - Deformed Foreland basin deposits (Lower Pleistocene Upper-Pliocene). 3 - Deformed Foreland basin deposits (Lower Pliocene-Upper Tortonian). 4 - Middle to Lower Miocene foreland deposits. 5 - Foreland basin flysch deposits (Lower Miocene-Upper Oligocene). 6 - Calabrian tectonic units (Oligocene-Paleozoic). 7 - Sicilide derived tectonic units (Early Miocene-Late Mesozoic). 8 - Panormide, Prepanormide and Trapanese carbonate platform-derived tectonic units (Paleogene Mesozoic). 9 - Imerese, Sicanian basinal-derived tectonic units: 9a - (Paleogene-Upper Mesozooic); 9b - Lower Permian-Middle Triassic. 10 - External Saccense carbonate platform derived units (Pliocene-Mesozoic). 11 - Hyblean tectonic units (Pleistocene-Mesozoic). 12 - Volcanics (a) Pleistocene, (b) Pliocene. 13 - Main thrust fronts. On the left corner a tectonic scheme of the central Mediterranean area, showing the Magrebian-Sicily-Southern Appennines thrust belt (in dark grey) and its foreland region.

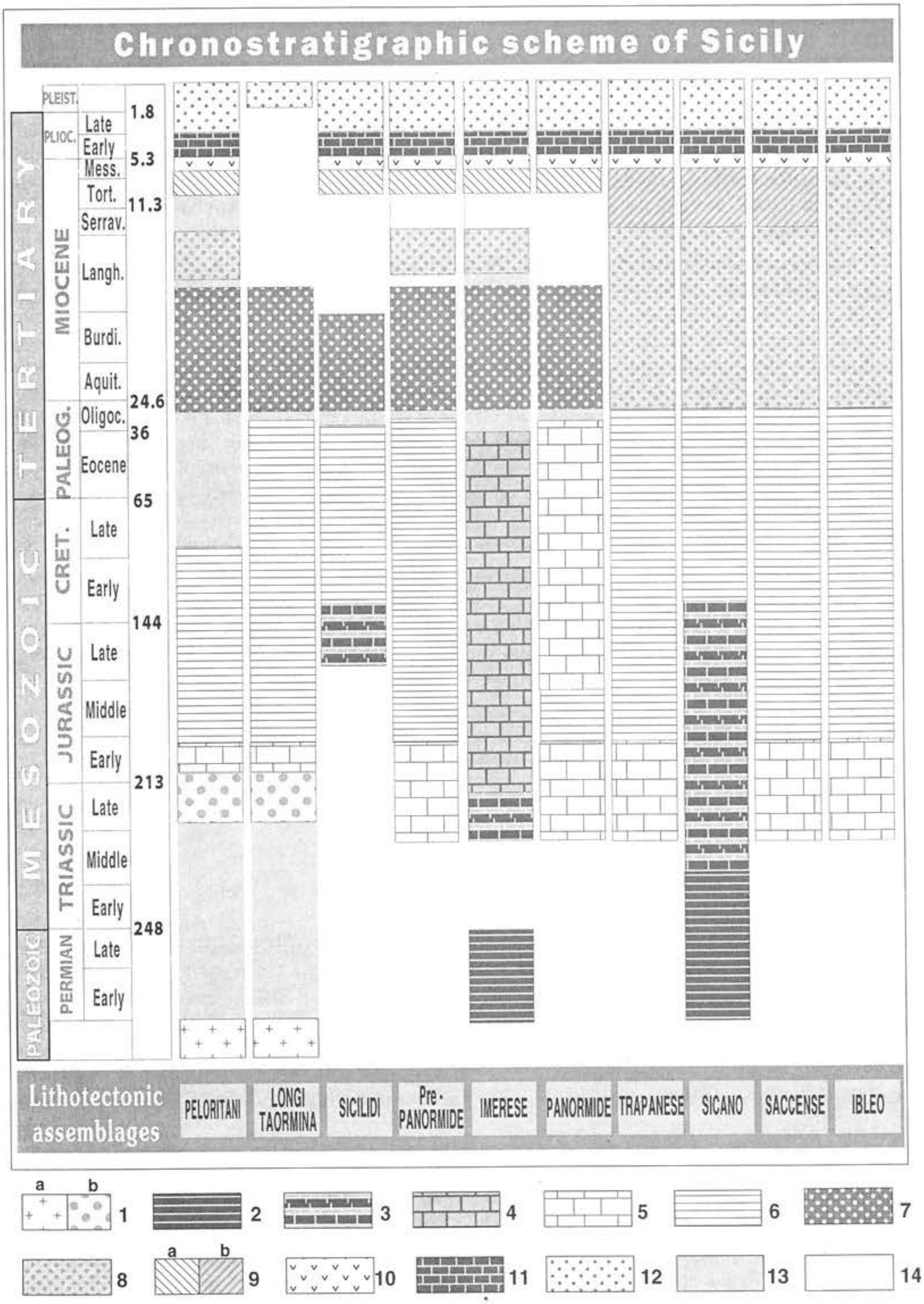

Fig. 2 - Summary of the stratigraphic relations of Sicily. The platform and basin rocks, now exposed as facies belts within the Sicilian thrust system, belong to different lithotectonic assemblages.
Legend: 1a) crystalline basament; 1b) continental deposits; 2) basinal siliciclastic and carbonates; 3) basinal cherty limestones and radiolarites; 4) slope to basin carbonates and radiolarites; 5) platform carbonate limestones; 6) pelagic carbonates; 7) flysch sandstone and shales; 8) open shelf sandstones and calcarenites; 9a) alluvial to strandplain conglomerate, sandstones and clays; 9b) hemipelagic shales; 10) Evaporites; 11) pelagic chalks; 12) coastal calcarenites and marls; 13) stratigraphic gaps; 14) no data.

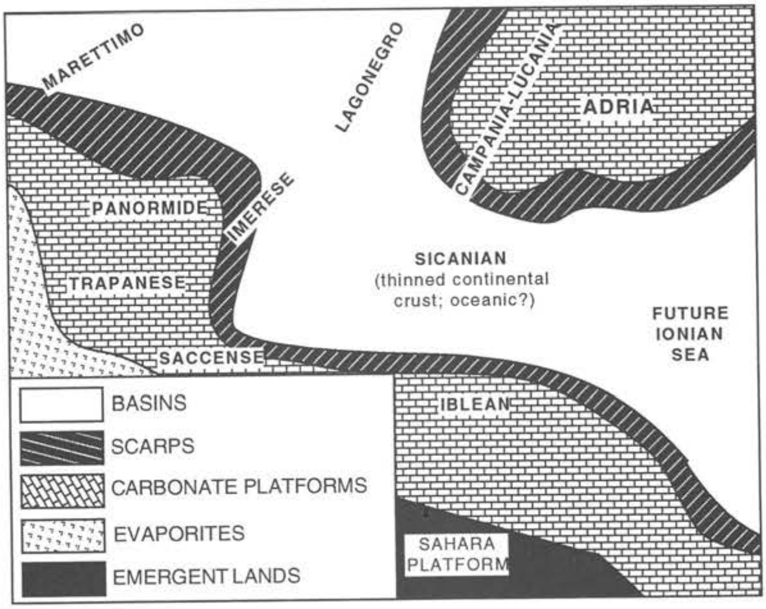

Fig. 3 - Late Triassic paleogeographic reconstruction of the Sicilian continental margin. The location of the Lagonegro Basin is inferred from Southern Apennine data (Marsella et al., 1992).

- A narrow, NW dipping, weakly deformed recent foredeep, which is partially buried on land and in the submarine Gela Basin (Fig. 1).

- A complex chain, locally more than 15 kilometers thick, which consists of imbricate thrust wedges. Three major tectonic elements can be recognized within the chain (Fig. 1, 4 and 5); each element contains a number of genetically related thrust systems (sensu Boyer and Elliot, 1982; here shortly named TS). These elements are described in the following.

1) An internal and highest element characterized by exposed crystalline emergent thrust sheets supporting remnants of a Mesozoic-Cenozoic sedimentary cover. They outcrop in the northeastern corner of Sicily (Peloritani Mountains) and are overlying the Sicilidi Units (Ogniben, 1960; Nebrodi TS, this paper).

The Peloritani structural edifice, that is the western continuation of the Calabrian arc, consists of two main stacked thrust systems (Fig. 4).

1a) A set of Hercynian Crystalline Units which consist of prevalent low to high grade metamorphic rocks (Ferla 1972, 1974) with thin veneers of Mesozoic cover (Duée, 1969, Amodio Morelli et al., 1976) structured in three main nappes (Fig. 4). These structural units (Falda dell'Aspromonte, Mandanici Unit, and Fondachelli-Portella Mandrazzi units in agreement with Amodio Morelli et al., 1976) are overlain by late Oligocene-Early Miocene clastic deposits (Flysch di Capo D'Orlando, Bonardi et al., 1980). These deposits are interpreted by many Authors as a molassic sequence post-dating the main collisional deformation. Differently, our data support their syn-tectonic characters, pointing out a progressive imbrication of the crystallyne basement with its overlying foredeep deposits (Nigro 1992, 1994; Catalano and Nigro 1993, Catalano and Nigro, in press).

1b) A wedge of thin-skinned thrust sheets (correlatable with the Longi Taormina unit Auct.) wich is made of thin crystalline basement with its latest Triassic to Paleogene mostly carbonate cover, overlain by Oligo-Miocene terrigenous deposits (Figs. 2 and 4). The internal geometry of the main imbricates is charachterized by duplex and imbricate-fan systems. The thrust planes merge along a sole thrust located above the top of the Sicilidi Units (Fig. 4). Late Tortonian-Pliocene deposits sutured the thrusts. Timing of compressional deformation and accretion of

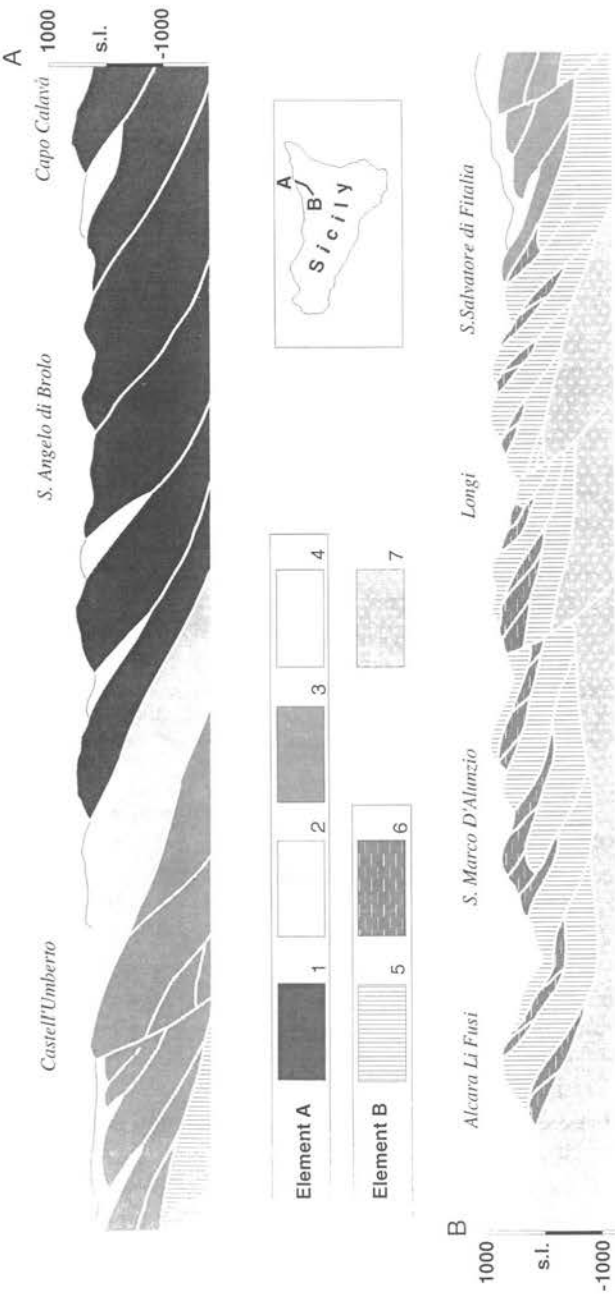

Fig. 4 - Structural geological profile across the western Peloritani Mts showing the two transects of the chain. In the first one, from the coastal Capo Calavà to Castell'Umberto, the crystalline structural units (Units A) are represented in a schematic sequence. They thrust over the more external Units (Longi-Taormina Unit equivalent, seen in the second transect). The late Oligocene-early Miocene foredeep and piggy back basin syntectonic deposits (Flysch di Capo d'Orlando) appear involved in the thrusting of the crystalline units. It implies a progressive deformation of the crystalline foreland together with its incipient foredeep basin deposits. The second transect, between Longi and Alcara li Fusi, shows the lowermost tectonic units (B) forming a wedge of thin skinned thrust sheets characterized in earlier stage by multiduplex and imbricate fan geometries. At place "envelopment" structures are seen. Again the younger deposits of the Capo D'Orlando Flysch are involved in the thrusting. It implies an early Miocene (Burdigalian) timing of accretion for this wedge. Both A and B systems are thrust over the Sicilidi Units that at place appear in tectonic windows. Element A: 1: "Falda dell'Aspromonte"; 2: Mandanici Unit; 3: Fondachelli Unit; 4: Capo d'Orlando Flysch. Element B: 5: Hercynian crystalline basement and Liassic carbonate platform sequences; 6: Liassic-Miocene pelagic-terrigenous sequences. 7: Sicilidi Units.

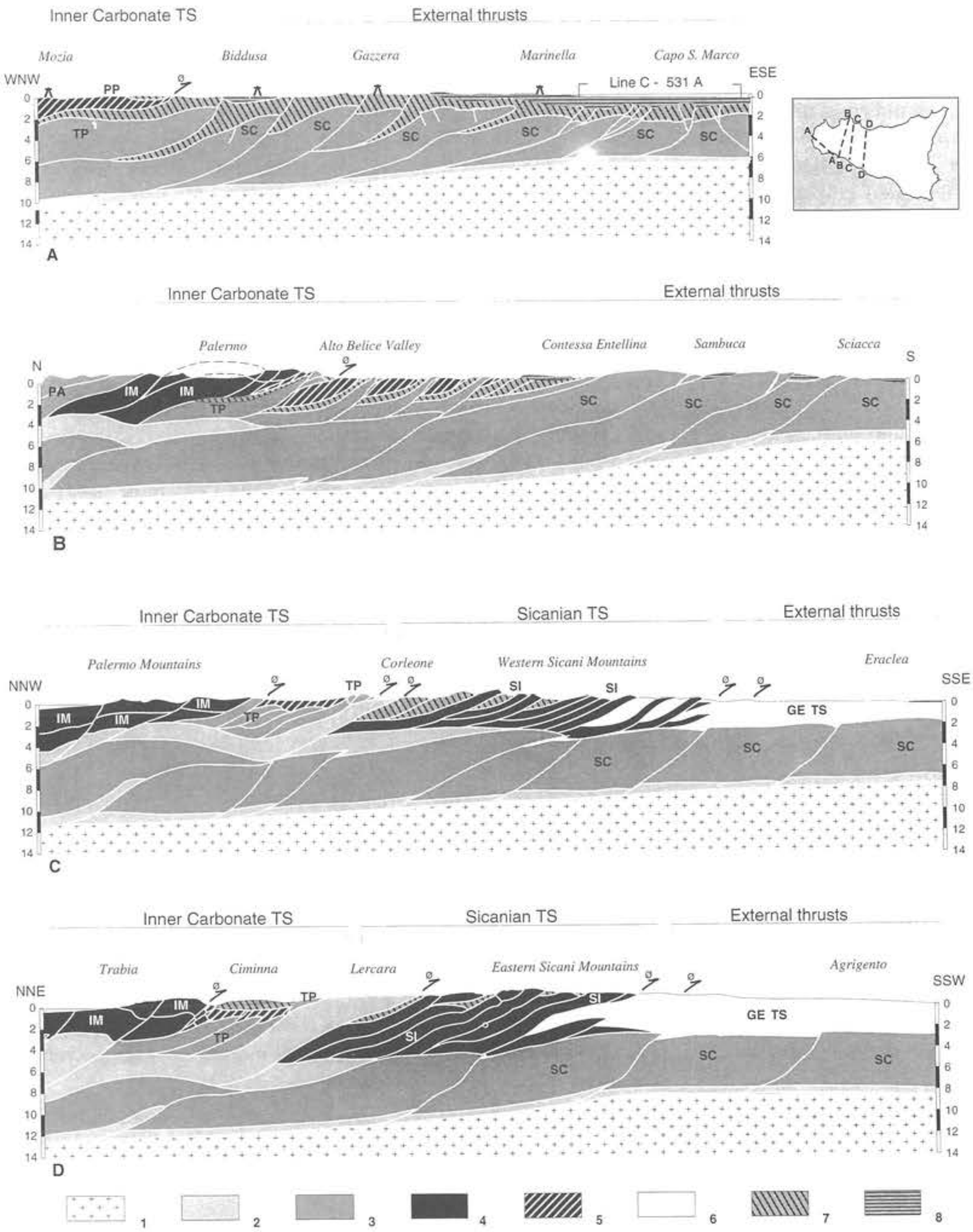

Fig. 5 - Geologic sections crossing Western and Central Sicily. 1: Basement; 2: Permo-Triassic clastics and carbonates; 3: Mesozoic platform carbonates and transition to basinal facies; 4: Mesozoic basinal facies; 5: Sicilidi and Numidian Flysch Unit (Late Mesozoic Early Tertiary); 6: Gela Thrust System; 7-8: Foreland and piggyback deformed deposits (7: Tertiary; 8: Plio-Pleistocene); SC: Saccense domain-derived thrusts); SI: Sicanian domain-derived thrusts; TP: Trapanese domain-derived thrusts; IM: Imerese domain-derived thrusts; PA: Panormide domain-derived thrusts; PP: Pre-Panormide domain-derived thrusts; GE TS: Gela Thrust System; Ø: major envelopment thrusts. Geometry of deepest structures inferred.

the Peloritani units is generally believed late Paleogene; their emplacement onto the African continental margin is described as early Miocene (Duée, 1969; Amodio Morelli et al., 1976; Bonardi et al., 1980; Giunta et al., 1992). However recent data from the eastern Peloritani suggest a different kinematic history (Nigro, 1992, Catalano and Nigro 1993) which supports an Oligocene early Miocene (Burdigalian) age of progressive deformation for the Peloritani element in the whole. According to this structural interpretation, the present day setting of the Peloritani element is due to post-late Miocene tectonics (see also Amodio Morelli et al., 1976). Equivalent Kabilian-Calabrian units have been recognized in the Western-Southern Tyrrhenian (Catalano et al., 1985; Beccaluva et al., 1986): here the submerged Drepano Thrust Front shows post Messinian emplacement of the inferred Calabrian units over the Sicilian-Maghrebian wedge (Agate et al., 1993, Catalano et al., 1994).

2) An intermediate element consisting of an imbricate wedge of late Paleozoic-Neogene sedimentary rocks, well exposed along an east-west structural high in the northern region (Fig. 1), and partly buried southward.

The major Thrust Systems (TS) are:

2a) The Nebrodi TS, which is composed of repeating slices of lower Cretaceous-Oligocene basinal carbonate mudstones and sandstones (Sicilidi Auct., Fig. 2). It also includes terrigenous Numidian and equivalent Flysch detached from their substrate. The Nebrodi TS reaches its greatest thickness in eastern Sicily where it has been preserved in the northernmost depression of the chain (Bianchi et al., 1987). There, the Nebrodi TS underlies the Peloritani crystalline thrusts (Figs. 1 and 4).

2b) The Inner Carbonate TS, which is an imbricate fan of mostly Mesozoic platform and basinal carbonates and cherts; it also involves thinner lower Miocene Numidian Flysch or foreland basin clastic slices. The Inner Carbonate TS, which outcrops in the Madonie to Palermo Mts., is buried eastwards beneath the Nebrodi TS (Sicilidi synclinorium). Westwards, in the Capo S. Vito-Trapani area, this wedge, consisting of only Mesozoic carbonate platform imbricates, shows similar geometries (Fig. 5a). This large allocthon, that is partly equivalent to the so-called Maghrebian units (Amodio Morelli et al., 1976; Lentini et al., 1991) is superimposed southward above the adjacent Sicanian TS and bounded by a post Miocene high-angle transpressional fault (Fig. 1, 5c, 5d).

The main lithotectonic assemblages, forming the northwestern Sicily TS, are derived from the deformation of the Pre-Panormide, Panormide, Imerese and Trapanese domains (Fig. 2).

Pre-late Tortonian deformation and emplacement formed these imbricates (Broquet, 1970; Catalano et al., 1978; Abate et al., 1978; Catalano and D'Argenio, 1982; Grasso et al., 1982; Catalano et al., 1989). Latest Miocene-Pliocene right oblique transpression faults (Oldow et al., 1986, 1990) are superimposed over the thrust imbricates (Fig. 5). These "envelopment" structures strike east-west in the hinterland zones, where they cross-cut older structural trends at deeper levels. This tectonism accompained clockwise rotation of the allocthons. There was a coexistence of thrusting and (paleomagnetically determined) large scale rotation of the structurally higher tectonic units during progressive deformation of the continental margin in central-western Sicily (Catalano et al., 1977; Catalano et al., 1986; Oldow et al., 1990).

2c) The Sicanian TS, which outcrops in the Sicani Mts. (Western Sicily), where it is bounded to the west by a complex lateral ramp structure (Fig. 1). It is buried in Central Sicily by the "Gela Thrust System" but outcrops again eastwards in the Judica ridge (Catalano and D'Argenio, 1978; Montanari, 1987; Roure et al., 1990).

The Sicanian TS is derived from the deformation of the Sicanian paleogeographic domain (Catalano and D'Argenio, 1978; Mascle, 1979). Compressional deformation began in the late Miocene (Catalano and D'Argenio, 1978; Mascle, 1979), and continued during the Plio-Pleistocene with folding and reactivation of simultaneously-active thrust fronts (Vitale 1993). New interpretations of exploration well logs and recent field data suggest the Sicanian sequence stacked in three different duplex fault zones composed of Paleozoic, Mesozoic-Paleogene and Tertiary strata: its deformation could have started from early Miocene (Vitale 1991; Vitale and Giambrone, 1992).

Late Paleozoic rocks, that originally formed the lowermost units of the duplex thrust wedge, are today superimposed over the carbonate Mesozoic duplexes stack ("Lercara salient", almost 3000 m thick; Figs. 5c, 5d). This setting is probably due to late high-angle transpressional tectonics, also developed in the more external fronts. Late in the Pliocene, the Sicanian wedge was thrust over the Gela TS (Catalano et al., 1989; Roure et al., 1990).

3) An external element characterized by:

3a) A tectonic wedge of incompetent sedimentary rocks (late Mesozoic-early Pleistocene) partly known as the "Gela Nappe" (Ogniben, 1960; Roure el al., 1990; Trincardi and Argnani 1990; Grasso et al., 1991). We use the term "Gela Thrust System" extensively to indicate an acretionary wedge of: a) polyphasally deformed carbonates and related terrigenous cover deposited in more internal domains (Mesozoic-Cenozoic "Sicilidi Units" and Miocene Flysch); and b) early Tortonian to early Pleistocene migrating foreland basin deposits. Centred in the Gela region of southern Sicily, the wedge occurs predominantly in east-central and southern Sicily from Catania to Sciacca (Fig. 1) where it reaches up to 3 km in thickness (Figs. 5c, 5d). It thins towards the submerged thrust front in the southern Sicily offshore. The main transport direction was toward the SE. Widespread backthrust features are exposed in the southwestern Sicily rim (Catalano et al., 1993a) as well as further east (Grasso et al., 1991).

The southerly displacement of the wedge is related to Pliocene transpressional tectonics in the structural hinterland. It was active up to the middle Pleistocene in the most external thrust fronts (Catalano et al., 1993b).

3b) A group of Mesozoic carbonate platform thrust sheets, which are emergent in the Sciacca area (Di Stefano and Vitale, 1993) and buried in the Castelvetrano basin (Figs. 1 and 5) as well as in the Agrigento offshore (Catalano et al., 1989). Each thrust reaches 3,000-5,000 m in thickness (Fig. 5a, 5b) showing short displacements towards the more external Sciacca and Hyblean foreland areas (Figs. 1 and 2). Their cover, consisting of lower Miocene-lower Pleistocene foreland basin deposits, appears detached and accreted southeastwards (Figs. 1, 5a and 5b).

DISCUSSION AND CONCLUSIONS

A SE-vergent arched belt developed on Sicily mainland, due to Neogene-Pleistocene compression. Regional overview of the available geological data describe the stratigraphic and structural evolution of the region.

Facies, structural styles and geometries. There are clear facies and tectonic affinities in the thrust pile along tectonic strike, but some variations in structural style and geometries are observed north to south along the belt.

In the Northern Sicily sector, which is the main structural culmination of the chain, the Mesozoic thrusts reveal an alternating stack of platform and basinal carbonates units. Individual thrust sheets are generally not more than 1,500 m thick, and few tens of km wide. The tertiary covers pertaining to those units are detached and transported more south to form tectonic stacks of some thousand meters thick filling some structural depressions of the chain. The 3,000 m thick Paleozoic wedge, outcropping only in restricted tectonic windows, represents an important buried element of the thrust pile.

The central-southern sectors of the region are characterized by Mesozoic basinal carbonate thrusts, generally about 1,000 m thick. They are stacked mainly in some duplex structures, separated, by a roof-thrust surface, from their overlying uncompetent Tertiary cover. The underlying Paleozoic levels outcrop in a more internal part of the wedge.

On the contrary, in the south-western Sicily, thrusts derived from the deformation of Mesozoic carbonate platform occur; these structures occur in imbricate fans to build up the most external sector of the belt. The thrusts are generally emergent in narrow culminations or covered by Plio-Pleistocene deposits. They appear slightly displaced above a sole thrust located probably at the top of the crystalline basement. Minor imbricated structures are observed also involving the terrigeneous tertiary covers.

Kinematic and timing of the deformation. Thrusting began during the early Miocene after the emplacement of the Calabrian crystalline units above the Sicilian continental margin. The upper Oligocene-lowermost Miocene foreland basin flysch (Numidian and more internal equivalents) were detached from their mostly carbonate substrate and emplaced eastwards over more external domains between the Langhian and lower Tortonian.

Contemporaneously, the deformation reached deeper levels at the base of the Permian and Carnian packages. Underplating and duplex accretion are the dominant tectonic mechanisms (see also Ben Avraham et al., 1992). The Mesozoic slices moved over a floor thrust at the top of the Permo-Triassic sedimentary substrate that was itself a duplex stack. The Tertiary clastic fill of progressively deformed Miocene foreland basins accreted mainly as passive roof-thrusts.

During the Pliocene, E-W higher-angle transpression faults dissected the whole belt in the northern and central part of the Island. Towards the foreland zone, the previously-formed structures exposed on surfaces appear to be substantially reoriented by transpressional tectonics. Towards the foreland, the reactivation of the thrust planes seems to be the dominant mechanism of deformation during the last five million years; here the older buried thrusts (both Mesozoic and Paleozoic tectonic stacks) were pushed-up to the surface, cutting the deformed Tertiary cover.

Development of the Gela Nappe appears to be linked to the transpressional event; its accretion is related to underplating, at deeper levels, of Mesozoic thrusts during the latest phases of deformation.

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