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THE NORTH-CENTRAL SICILY BELT: STRUCTURAL SETTING AND GEOLOGICAL EVOLUTION

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Abstract: North-Central Sicily represents an Apenninic-Maghrebian Chain sector, deriving from the Miocene–Pliocene deformation of different palaeogeographic domains-derived successions (carbonate platforms and pelagic basins), piled-up in ramp-flat and duplex style, and belonging during the Mesozoic–Tertiary to the Northern African Continental Margin. These domains are represented by outcropping basinal sedimentary successions (Imerese–Sicanian Basin), geometrically interposed between carbonate platform rock bodies: the Panormide (innermost) and the Hyblean–Pelagian Domains (more external).

In this paper, using stratigraphic and structural data, we propose a new palaeogeographic model, in which the main differences from previous interpretations consist in the position of the Imerese Basin, here identified as the juncture between the Panormide Domain and the Sicanian Basin *Auct.*, and the position of the Trapanese pelagic carbonate platform, considered as the juncture between the Hyblean–Pelagian Domain and the Sicanian Basin *Auct.*

Tectono-sedimentary steps characterising the evolution of the Sicilian Miocene–Pliocene Foredeep illustrate the deformational history of the area.

Two geological cross-sections depict the structural architecture of the tectonic edifice, characterised by different thrust sheets piled-up during the Miocene–Pleistocene time. The more external tectonic units are formed by elements deriving from the Plio-Pleistocene deformation of the northern margin of the Hyblean–Pelagian Domain. The "intermediate" tectonic units derive from the Miocene–Pliocene deformation of the Imerese–Sicanian Domain and the inner tectonic units are constituted by Panormide and Sicilide Domains-derived successions, deformed during the Miocene.

A mostly neotectonics-related transcurrent faults reoriented the previous thrust sheets through NW–SE and W–E trending faults, producing large-scale positive flower structures which involved the geometrically deepest Hyblean–Pelagian substrate.

Key words: Structures, palaeogeography, Sicily.

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INTRODUCTION

The studied sector (Western Sicily) is localised in the Central Mediterranean (Fig. 1); it is bounded eastward by the Madonie Mts. and the so-called "Caltanissetta Basin", westward by the line joining S. Vito Mts. and Sciacca area, northward by the Tyrrhenian Basin, and southward by the Sicily Channel.

This sector represents the central Sicilian Chain segment, made up of a set of tectonic units, in which axial fold surfaces indicate a south- and south-east vergence, over the Hyblean–Pelagian foreland during the Miocene and Pliocene deformation, and subsequently reoriented during the Plio-Pleistocene strike-slip tectonics (Finetti & Del Ben, 1986; Sartori, 1989; Finetti *et al.*, 1996, Lentini *et al.*, 1996; Abate *et al.*, 1998). These tectonic units derive from the deformation of several palaeogeographic domains-derived successions, which were part of the African Continental Margin during the Mesozoic and Tertiary.

The previous models (Ogniben, 1960; Broquet, 1968; Catalano *et al.*, 1979; Giunta & Liguori, 1973; Mascle, 1979; Abate *et al.*, 1978; Catalano & D'Argenio, 1982) indicate that the palaeogeography of the Mesozoic–Tertiary African Continental Margin includes for the Sicilian area a number of carbonate platforms and pelagic basins which, from the present-day north, are:

- Sicilide Domain; the more internal pelagic sedimentation area recorded in the outcropping Sicilian sedimentary rocks;
- Panormide Domain; a carbonate platform area, today outcropping in a W–E facies trend, from the Madonie Mts. to the Palermo Mts.;
- Imerese Domain; a pelagic sedimentation hinge area, interposed between the Panormide and the Trapanese Do-

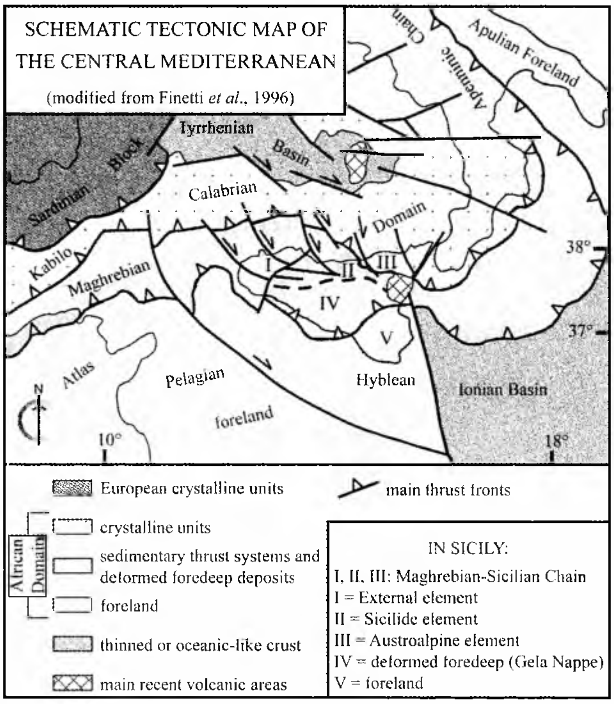

Fig. 1. Studied area in the frame of the Central Mediterranean geodynamic context

mains, outcropping southward with respect to the Panormide Domain, from the Madonie Mts. to Palermo Mts.;

- Trapanese Domain; a pelagic platform separated the Imerese Domain from the more external Sicanian Domain, mostly outcropping along several W–E trending structural ridges (Kumeta and Busambra Mts.) in the middle portion of the studied area;
- Sicanian Domain; a pelagic basin located between the Saccense carbonate platform and the Imerese Domains. It largely outcrops in the middle-southern portion of the studied area;
- Saccense domain; the more external domain (the present weakly deformed foreland) representing a Triassic carbonate platform evolving to a pelagic platform since the Liassic.

Starting from the Early Miocene, these domains were progressively involved in tectonogenesis, forming a south-verging tectonic pile (Giunta & Liguori, 1973; Scandone *et al.*, 1974; Catalano *et al.*, 1979; Catalano & D'Argenio, 1982; Broquet *et al.*, 1984; Giunta, 1991; Catalano *et al.*, 1995).

In these models, the described tectonic edifice would reflect the ancient palaeogeography and be constituted (from the top) by Sicilide, Panormide, Imerese, Trapanese, Sicanian and Saccense units.

Recently, the classical palaeogeographic scheme was partially modified by Catalano & Di Maggio (1996), who indicate a more internal and geometrically higher position of the Imerese units compared with the Panormide units.

In this paper, based on new and partly published field data (Pescatore *et al.*, 1987; Abate *et al.*, 1988, 1993, 1996; Incandela, 1995; Pedley & Renda, 1997), facies analysis of carbonatic and terrigenous deposits and structural observations, a tectonic edifice is recognised, made of several thrust units piled up with piggy-back sequence during the Early Miocene–Pliocene; the main geometries are represented by ramp-flat and duplexes.

The following tectonic events are characterised by transcurrent fault systems, probably related to the Tyrrhenian Basin opening (Finetti & Del Ben, 1986; Finetti *et al.*, 1996; Lentini *et al.*, 1996; Sartori, 1989), which produce large-scale positive flower structures. The flower structures, partially linked to deep-seated brittle structures, are NW–SE and W–E trending and determine the exposure of the geometrically deepest tectonic bodies of the Miocene–Pliocene tectonic edifice. Antithetic and synthetic structures also produced the rotation of the previous compressional structures, as thrust surfaces and fold systems.

The outcropping tectonic units derive from the deformation of a pelagic domain (Imerese–Sicanian Domain) confined during the Mesozoic between two neritic areas (Panormide and Hyblean–Pelagian Domains). In the field, these domains are represented respectively by basinal sequences (Imerese–Sicanian Basin) tectonically interposed between thrust sheets deriving from the deformation of rocks pertaining to the Panormide Carbonate Platform (to the north) and the northern margin of the Hyblean–Pelagian Domain *Auct.* (Fig. 2). In the present palaeogeographic model of North-Central Sicily, the Imerese Basin *Auct.* is interpreted as the internal margin or the juncture zone between the Sicanian Basin and the Panormide Carbonate Platform. The Trapanese Domain, partially according to Montanari (1987), is identified as the juncture area between the internal (northern) margin of the Hyblean–Pelagian Domain and the Sicanian Basin *Auct.* (Fig. 3).

The main evolutionary steps of the Sicilian Foredeep (from the Early Miocene to the Pliocene) illustrate the deformational history of the area.

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STRATIGRAPHY

PRE-OROGENIC DOMAINS

The pre-orogenic palaeogeography of the studied Sicily chain sector (Fig. 4a and b) may be summarised (from the internal areas) as:

- Internal or Sicilide Domain: a pelagic sedimentation area developed on thin continental crust, localised between the African continental margin and the adjacent Tethys Ocean (Ogniben, 1960);
- Panormide Domain: neritic sedimentation area interposed between the Sicilide and the more external Imerese–Sicanian Domains;
- Imerese–Sicanian Domain: pelagic sedimentation area developed between two mostly neritic sedimentation areas, on a progressively thinned continental crust, since the Triassic;
- Hyblean–Pelagian Domain: pelagic carbonate platform-like area characterised by a complicated physiography and by a neritic-to-pelagic sedimentation on a "normal"

Fig. 2. Schematic structural map of North-Central Sicily. Foredeep and coeval intramountain basin deposits: *1* – Middle Pliocene–Pleistocene; *2* – Late Tortonian–Early Pliocene; *3* – Serravallian–Middle Tortonian; *4* – Late Oligocene–Langhian. *5* – Sicilide Units (Cretaceous–Oligocene); *6* – Panormide Units (Late Triassic–Oligocene); *7* – Imerese–Sicanian Units (Early Liassic–Oligocene); *8* – Hyblean–Pelagian Units (Late Triassic–Late Miocene). Main thrust fronts: *9* – Early-Middle Miocene; *10* – Late Miocene; *11* – Pliocene; *12* – Pleistocene

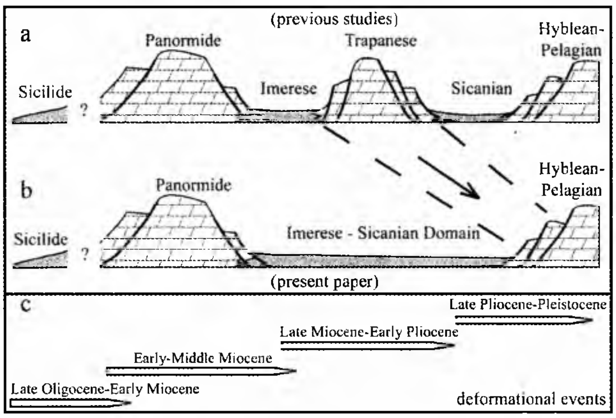

Fig. 3. **a-b)** Comparison between the palaeogeographic model of the Authors during the Mesozoic and the model proposed in the present paper; **c)** chronology of deformational events

thick continental crust (Winnock, 1981; Boccaletti *et al.*, 1987, 1990; Burollet *et al.*, 1987; Ben Avraham *et al.*, 1990; Torelli *et al.*, 1991).

Sicilide Domain

Represents the more internal domain. The derived tectonic units constitute the geometrically innermost portion of the Western Sicily Belt (Fig. 5). The Mesozoic–Tertiary succession is prevalently silico-clastic and calcareous-clastic and mostly outcrop in the Termini Imerese area. The more characteristic Sicilide lithotypes are represented by "variegated" marls and shales with resedimented arenitic horizons, cherty limestones and shallow-water limestone breccias ("argille scagliose", Late Cretaceous–Oligocene; Ogniben, 1960); limestones and marls including resedimented arenitic and ruditic limestones horizons with *Nummulites* fauna (Polizzi Fm., Eocene–Oligocene; Ogniben, 1960).

Panormide Domain

Mostly represents a neritic carbonate platform sedimentation area, confined between the Sicilide and the Imerese–Sicanian Domains. The most ancient outcropping lithotypes are represented by stromatolithic, loferitic, algae limestones and boundstones of Late Triassic–Early Liassic age, often heteropic to dolomitic breccia deposits. This carbonate platform sequence (Fig. 4a) is covered by a thin horizon of nodular limestones with ammonite fauna ("rosso ammonitico" *Auct.*) of Late Liassic–Dogger age and is unconformably covered again by stromatolithic and loferitic limestones, algae and sponges boundstones of Late Jurassic–Early Cretaceous age. Micritic limestones with planktonic foraminifers ("scaglia" *Auct.*) of Late Cretaceous–Eocene age follow unconformably. In the Madonie Mts. area, the top of succession is composed by marls, with inserted Oligocene *Nummulite*-rich resedimented limestones, evolving to quartz-bearing arenites (Gratteri Fm.; Ogniben, 1960).

Imerese–Sicanian Domain

Represents the pelagic sedimentation area interposed between the Panormide and the more external Hyblean–Pelagian Domains (Figs. 4a and b). The succession starts with silico-clastic deep-water deposits of Early-Middle Triassic age (Lercara Fm.; Schmidt di Friedberg, 1964–65), with inside alkali-basaltic lavas and breccias made of Palaeozoic carbonate platform elements. The Lercara Fm. is replaced by clays, marls and limestones with pelagic molluscs, characterised by resedimented carbonatic arenitic horizons and alkali-basaltic lavas (Mufara Fm.; Schmidt di Friedberg *et al.*, 1960) of Late Triassic age. The Mufara Fm. is followed by cherty limestones, with radiolarians and pelagic molluscs (Scillato Fm.; Schmidt di Friedberg *et al.*, 1960) of Latest Triassic age. In this part of the succession, slumps and resedimented carbonatic breccias are commonly present in the northern sectors of the studied area, along the connection areas with the Panormide rocks outcrops, and in the southern sector, along the hinge areas with the Hyblean–Pelagian foreland (Fig. 5). The Liassic sequence is characterised by widespread lateral facies variations; in the northern sector of the studied area the outcropping basinal sequences are made of thick dolomitic resedimented arenites and breccias (Fanusi Fm.; Schmidt di Friedberg *et al.*, 1960), southward heteropically to limestones and siliceous marls with interbedded thin horizons of resedimented ruditic

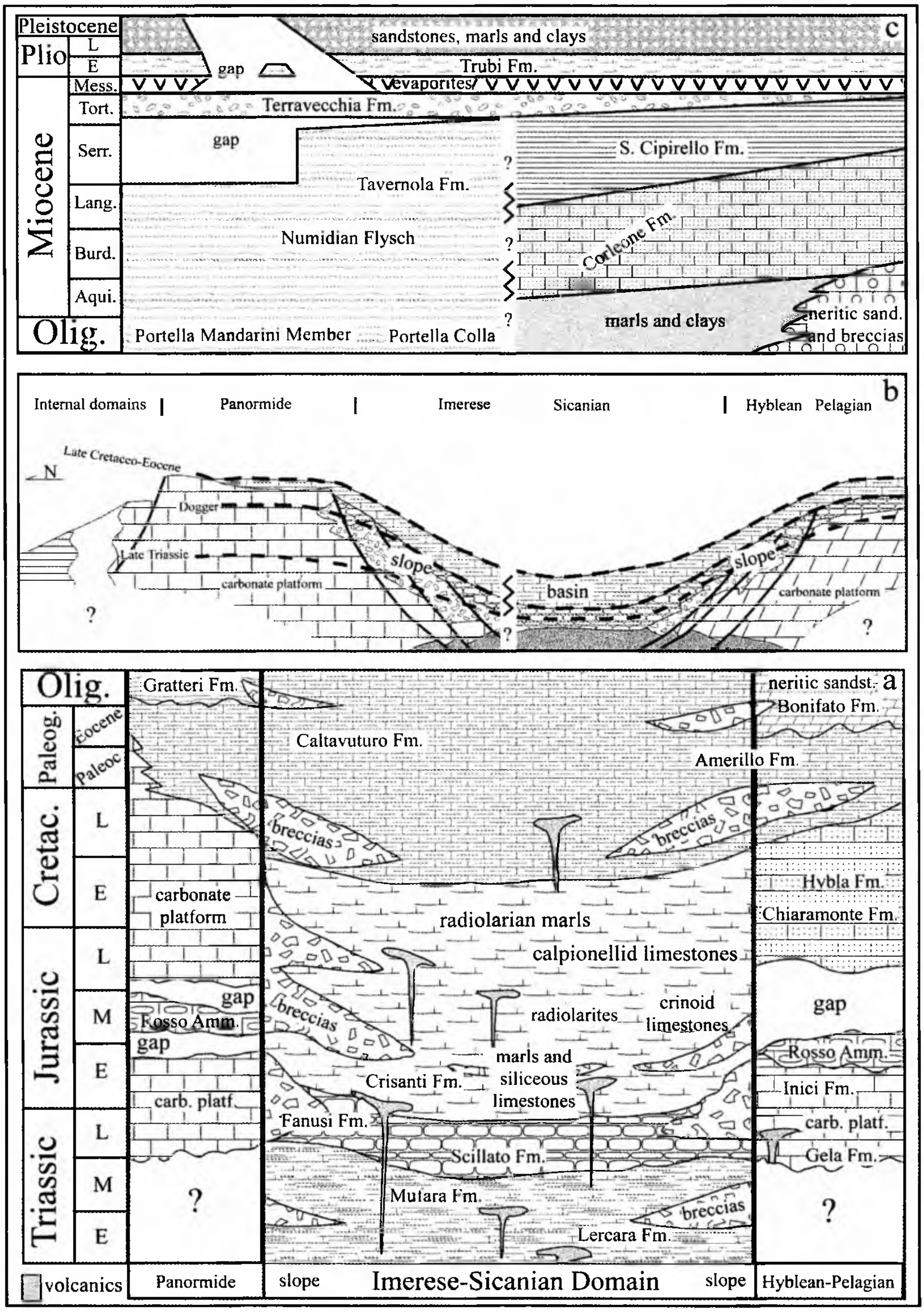

Fig. 4. Stratigraphic scheme and palaeogeographic domains of Western Sicily. **a)** Stratigraphy and facies distribution during the Triassic–Oligocene time. **b)** Palaeogeographic scheme during the Mesozoic–Tertiary. **c)** Stratigraphy and foredeep sequences distribution during the Late Oligocene–Pleistocene

and arenitic carbonates (Fig. 4a). In the southernmost sector, the coeval outcropping succession is mostly made of resedimented dolomitic breccias with oolitic interbedded limestones, constituting the sedimentary expression of the slope that separates the Imerese–Sicanian Basin from the Hyblean–Pelagian neritic area. The Middle-Late Jurassic succession is represented, in the internal flank of the basin, by radiolarites, clays and siliceous marls with thick arenites and breccias made of carbonate platform clasts (Crisanti Fm.; Schmidt di Friedberg *et al.*, 1960), while in the depocentral areas of bedded cherts, red and green marls, siliceous clays and radiolarites, with thin horizons of resedimented carbonatic arenites. The external flank is characterised in this time by crinoid and calpionellid limestones and sili-

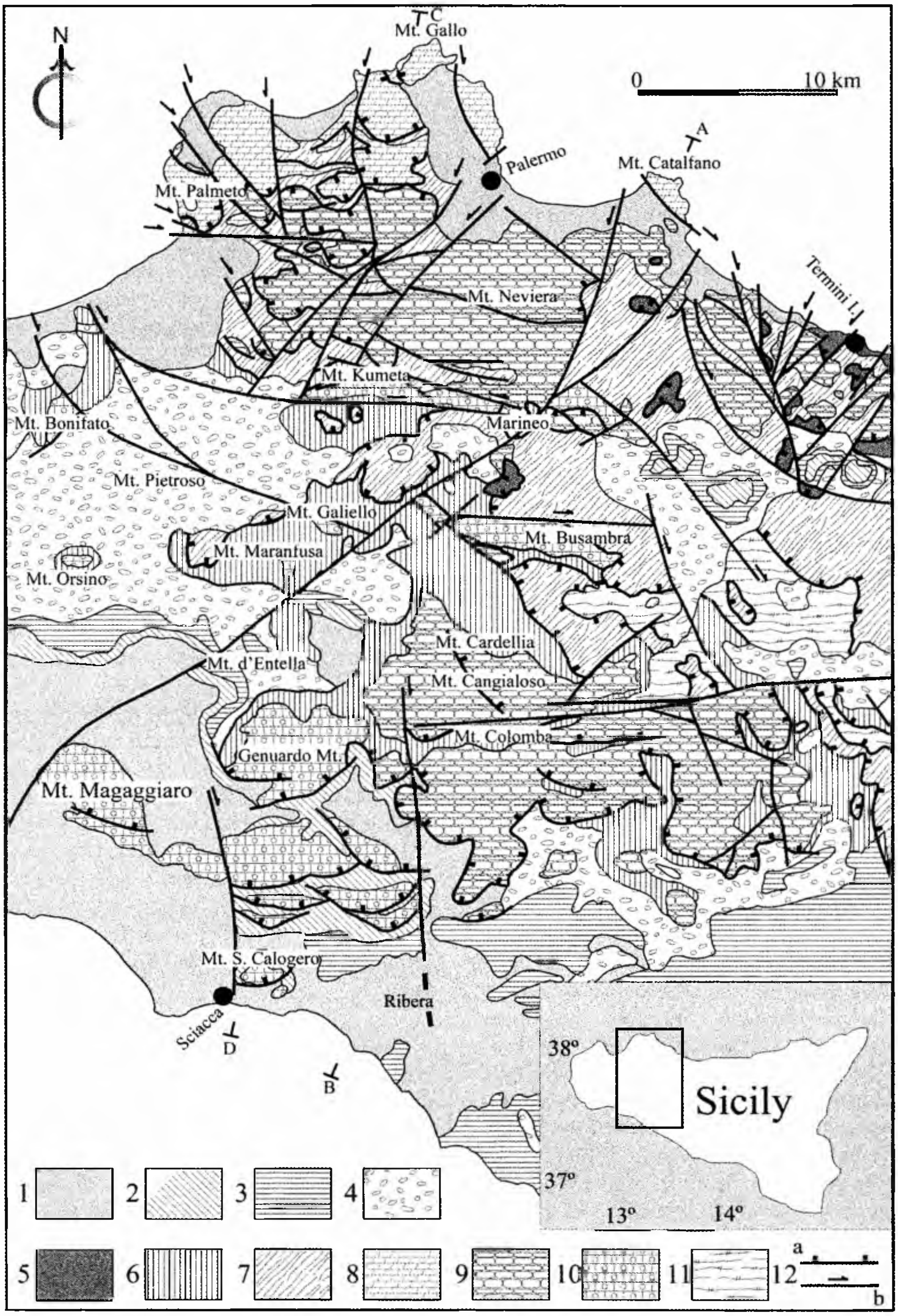

Fig. 5. Schematic geological map of the North-Central Sicily. *1* – marls, sands and arenites (Middle Pliocene–Pleistocene); *2* – Trubi Fm. (Early Pliocene); *3* – diatomitic deposits, evaporitic limestones, gypsum and clays (Messinian); *4* – conglomerates, sands, clays and reef limestones (Late Tortonian–Early Messinian); *5* – Sicilide sequences: varicoloured clays and micritic limestones with planktonic foraminifers ("argille scagliose" and Polizzi Fm., Late Cretaceous–Oligocene). Numidian sequences: *6* – clays, marls, quartz-arenites, carbonatic and/or glauconitic arenites and rudites, clays and marls with planktonic foraminifers (external Numidian sequences, Late Oligocene–Tortonian); *7* – clays, sandy clays and quartz-arenites (Numidian Flysch *s. s.*, Late Oligocene–Late Langhian); *8* – Panormide Domain-derived sequences: carbonate platform sequences, dolomites, marls and marly limestones (Late Triassic–Oligocene); *9* – Imerese–Sicanian Domain-derived sequences: clays, cherty limestones, dolomites, radiolarites, micritic limestones, marls and carbonatic breccias (Late Triassic–Oligocene); *10* – Hyblean–Pelagian Domain-derived sequences: carbonate platform sequences, marly limestones, marls and micritic limestones, boundstones and carbonatic arenites and rudites with benthonic foraminifers (Late Triassic–Miocene); *11* – "Lercara Basin" sequences: clays, marls and quartz-arenites with inserted carbonatic breccias made of Palaeozoic carbonate platform clasts (Early-Middle Triassic); *12* – main thrust front (a) and high-angle faults (b). Arrows indicate strike-slip movements. A-B and C-D indicate the geological cross sections of Fig. 6

ceous limestones, with slumps and resedimented horizons made of arenitic and ruditic carbonatic clasts. Even in the Middle-Late Jurassic sequence, alkali-basaltic rocks are frequently recognisable.

The Late Cretaceous–Early Oligocene succession is represented by planktonic foraminifer-rich marls and marly limestones ("scaglia"-like *Auct.*); these rocks are widely distributed in all the palaeodomains and are characterised by the presence of resedimented carbonatic arenites and breccias, both in the northern (Caltavuturo Fm.; Schmidt di Friedberg *et al.*, 1960) and in the southern sector of the studied area (Amerillo Fm.; Patacca *et al.*, 1979; Sestini & Flores, 1986). In the hinge areas between the Hyblean–Pelagian carbonate platform and the Imerese–Sicanian basin rock bodies outcrops, the sedimentation terminates with a rhythmical sequence of marls and arenitic and ruditic foraminifer-rich limestones of Oligocene age.

Hyblean–Pelagian Domain

Represents the most external palaeogeographic domain, characterised by a neritic sedimentation during the Late Triassic, evolving to a pelagic carbonate platform-like sedimentation during the Mesozoic and Tertiary times. In some places, the sedimentation is condensed with diastemic episodes. The Hyblean–Pelagian succession (Fig. 4a) starts with stromatolithic, loferitic and dolomitic limestones, with megalodont fauna, of Late Triassic–Early Liassic age (Inici Fm.; Schmidt di Friedberg, 1964–65). The Late Liassic–Malm carbonate platform succession is made of condensed horizons of nodular and ammonitic limestones, crinoid and cherty limestones ("Rosso Ammonitico" and Buccheri Fm.; Patacca *et al.*, 1979). The condensed succession is covered by calpionellid limestones and marls with planktonic foraminifers of Late Jurassic–Early Cretaceous age (Chiaramonte and Hybla Fms; Patacca *et al.*, 1979). The thickness of this portion of the Hyblean–Pelagian succession is a few meters in the Telegrafo–Maranfusa Mts. areas (Fig. 5), and up to one hundred metres in the slope areas (Kumeta–Bonifato Mts. areas). The Late Cretaceous–Eocene succession is made of scaglia-like *Auct.* equivalent pelagic limestones and marls with planktonic foraminifers (Amerillo Fm.; Patacca *et al.*, 1979). In the Genuardo–Telegrafo–Busambra–Kumeta–Bonifato Mts. areas (Fig. 5), thick carbonatic breccias deposits are recognisable inside the Amerillo Fm. The Oligocene–Early Miocene sequence is made of arenitic and ruditic limestones with benthonic foraminifers and calcareous algae and heteropic to patch-reef deposits.

COLLISIONAL DOMAINS (FOREDEEP-FORELAND COUPLE DURING THE MIOCENE–PLIOCENE)

During the Oligocene, inversion tectonics and thrusting of the innermost African continental margin start, as a consequence of the Sardinia–Corsica Block rotation (Cherchi & Montadert, 1982).

The collision between the Sardinia–Corsica Block and the most internal African continental margin produces in the Maghrebide areas foredeep systems filled by silico-clastic deposits (Fig. 4c); the Western Sicily Chain was realised through a progressive migration toward the foreland of a foredeep-compressional front couple and the chain body progressively incorporating foredeep deposits, which in turn carried piggy-back basins.

Foredeep-foreland system during the Late Oligocene–Early Miocene (Numidian Domain Auct.)

The "Numidian Basin"-derived successions (Giunta, 1985) start during the Late Oligocene and represent a basin with the internal flank developed on the incipient deforming substrate made of Sicilide, Panormide and internal Imerese–Sicanian areas, and the external flank on external Imerese–Sicanian and Hyblean–Pelagian areas, which at this time represent a structural high (peripheral bulge).

The Numidian succession (Late Oligocene–Late Langhian) unconformably overlies the Panormide substrate and the hinge areas with the Imerese–Sicanian Basin, and conformably overlies the pelagic deposits of the more external Imerese–Sicanian Basin.

The sedimentation in the more internal root of the Numidian basin is characterised by silico-clastic proximal chaotic and channelized facies. The sedimentation is also characterised by diachronic facies and by a marked time-regressive character of the sequence development, which finishes with pelitic hemi-pelagic deposits of Late Langhian age (Pescatore *et al.*, 1987). In the most external foredeep areas, the sedimentation is represented by marls and clays, with inserted resedimented levels of silico-clastic and arenitic limestones (Mascle, 1979; Vitale, 1990; Di Stefano & Vitale, 1993; Pedley & Renda, 1997), while in the peripheral bulge the sedimentation is characterised by open-shelf-like carbonatic deposits ("Corleone Fm.", Ruggieri, 1966a). The presence of "Numidian" quartz in these deposits reveals heteropic relationships between the typical Numidian terrigenous sedimentation and the external slope of the foredeep.

Foredeep-foreland system during the Middle Miocene (Serravallian–Middle Tortonian, External Numidian Domain Auct.)

During the Serravallian, a migration of the Sicilian foredeep depocentral areas took place, as a consequence of the deformational front advancement and the coeval and gradual collapse of the most external sectors which, at this time, are represented by the southern Imerese–Sicanian margin and by the slope areas of the Hyblean–Pelagian Domain; it represents the peripheral bulge characterised by open-shelf-like sedimentation prevalently represented by silico-clastic and pelitic deposits. In the internal flank of the basin, the succession is made of clays and sandy marls, with Numidian-derived quartz-arenites resedimented beds which unconformably overlie the Numidian flysch-like deposits of Early Tortonian (Tavernola Fm.; Ogniben, 1960; Schmidt di Friedberg *et al.*, 1960; Schmidt di Friedberg, 1964–65). In the more external sector of the foredeep, the succession is made of sandy marls and clays with slumps, quartz-arenite lenses, resedimented carbonatic arenites with benthonic foraminifers and breccias of foreland provenance (S. Cipirrello Fm.; Ruggieri & Sprovieri, 1970). Towards the Hyblean–Pelagian sectors, the deposits are represented by open-shelf patch-reef limestones, rapidly evolving to pelitic deposits.

Foredeep-foreland system during the Late Miocene (Late Tortonian–Messinian)

During this time, the Western Sicily Chain was partly built up; the internal flank foredeep sedimentation occurred in intramontane basins (*e.g.* Scillato and Ciminna areas). In these areas (and toward the foredeep depocentral sectors, today outcropping in a W–E trending ridge southward of the Kumeta Mt.), the sedimentation is represented by several hundred-metre-thick paralic-continental conglomerates, sands and clays, often organized in several cycles, made of clasts deriving from the uplifting and emergent chain areas (Terravecchia Fm.; Flores, 1958). In the depocentral foredeep areas (south-eastern sectors of the studied area, Fig. 5), the Terravecchia Fm. lithotypes are made of marine facies represented by marls, sandy clays and sands with planktonic foraminifers (Mascle, 1979; Di Stefano & Vitale, 1993). A remarkable sea level lowering during the Late Messinian and the contemporaneous migration toward the external areas of the progressively more restricted foredeep reduced the marine sedimentation areas, filled by two cycles of evaporites, separated by a regional trending strong unconformity ("Serie Gessoso-Solfifera" *Auct.*; Decima & Wezel, 1971).

Foredeep-foreland system during the Early Pliocene–Early Pleistocene

During this time, pelagic and deep-water marls with globigerinids (so-called "Trubi"), clays and sandy deposits (Marnoso-Arenacea Fm.; Ruggieri & Torre, 1974) filled the foredeep, showing an overall time-regressive trend (*e.g.* Belice Valley–Ribera areas; Vitale, 1990, 1995). The Trubi deposits unconformably overlie the Mesozoic and Tertiary substrate: in the northern sector of the studied area, they follow the intramontane Messinian evaporitic sedimentation and in places finish with a level (several meters thick) of resedimented biogenic-limestones of Middle-Late Pliocene age. In the southern sector, the Trubi deposits are characterised by several inserted horizons and lenses of breccias with clasts of clays (A. B. IV; Ogniben, 1966), slumps and thick breccias with carbonatic clasts. In these areas it is followed by chaotic clays with sand lenses and carbonatic breccias of Middle Pliocene age (Ribera Fm., Narbone Mt. Member; Schmidt di Friedberg, 1964–65), gradually passing into to the Marnoso-Arenacea Fm. of Late Pliocene–Early Pleistocene age, which is made of clays, marls, sands and turbidites. This formation is covered by sands and conglomerates of Early Pleistocene–Emilian age ("Calcareniti del Belice"; Ruggieri & Unti, 1977), heteropic to sands (Calcareniti di Marsala Fm.; Ruggieri & Unti, 1974), sandy clays, marls and marly sands of Early Pleistocene age.

STRUCTURAL SETTING

Mainland Sicily and its off-shore areas represent a belt composed by a foreland, located in the Sicily Channel, and the chain bulk characterising the island to the Tyrrhenian. The orogen is affected by an extensional regime with effects from Northern Sicily.

During the Miocene, the constructing Sicilian-Maghrebian chain is characterised by a chain body-foredeep couple migrating towards the foreland, progressively incorporating syn-orogenic deposits (Numidian Flysch and Serravallian deposits), which in turn carried piggy-back basins. Thrust tectonics is characterised by superposition of tectonic units over a gentle chain-dipping foreland, underplaying below the basal detachment horizon as a passive footwall.

Compressional tectonics is represented by several thrust sheets, characterised by frontal ramp anticlines. The general trending of plicate axial surfaces indicates an Africa vergence of the structures. The Miocene thrust surfaces generally dip towards NW in the Palermo Mts. and towards the north in the Trabia Mts. There are no pop-up structures or back-thrust near the main ramp anticlines.

In the Palermo Mts., Panormide and Imerese foreland vergent thrust sheets largely overthrust on the deformed external shallow substrate through a very low angle flat; here, thrust step-up geometries are characterised by a few degrees of plunge. Toward the external zones, the Sicanian stack tectonic units replace the Imerese imbricate fan over the foreland deformed substrate; here they link along a sole thrust and show a more highly thrust step-up angle. The deformed foreland is affected by an emergent thrust system in the more south-western Sicily (Sciacca Mts.), where the step-up geometries are characterised by the very high values of plunge of the described chain transept. From magnetic data (AGIP, 1981) we estimate that the regional monocline gently plunges towards the Sicilian wedge by about 4 degrees.

The meso-structural field data and the geometric relationships between the outcropping tectonic units and syntectonic covers make it possible to reconstruct the timing of deformation and the architecture of the Western Sicily Thrust Belt, as shown in the structural sections of Fig. 6, crossing the studied sector from the inner tectonic units to the Hyblean–Pelagian gentle dipping deformed foreland.

The main geometries are represented by an imbricate fan, made of Panormide-derived and Imerese–Sicanian-derived tectonic units, largely thrust over the northern margin of the Hyblean–Pelagian Block through a sole thrust.

The Panormide Domain-derived tectonic units thrust over deposits of Late Langhian–Early Tortonian age (Abate *et al.*, 1978; Catalano *et al.*, 1979) that represent the Imerese–Sicanian Domain syn-tectonic covers (Fig. 5). The Imerese–Sicanian Domain-derived tectonic units thrust over sequences of Early Tortonian age in the Marineo area, and over progressively younger and younger deposits in the southernmost studied sector (in the Cammarata 1 AGIP Well, the Oligo-Miocene Sicanian-like successions tectonically cover the Trubi deposits and the Mesozoic Hyblean–Pelagian substrate; Beneo, 1961).

The geometrically deepest Hyblean–Pelagian tectonic element is composed by several thrust units, bounded by high-angle faults in the southernmost and off-shore areas (*e.g.* Genuardo, Magaggiaro and Telegrafo Mts.), where Plio-Pleistocene sequences are involved in the deformation.

Also in the central-northern sectors of the studied area

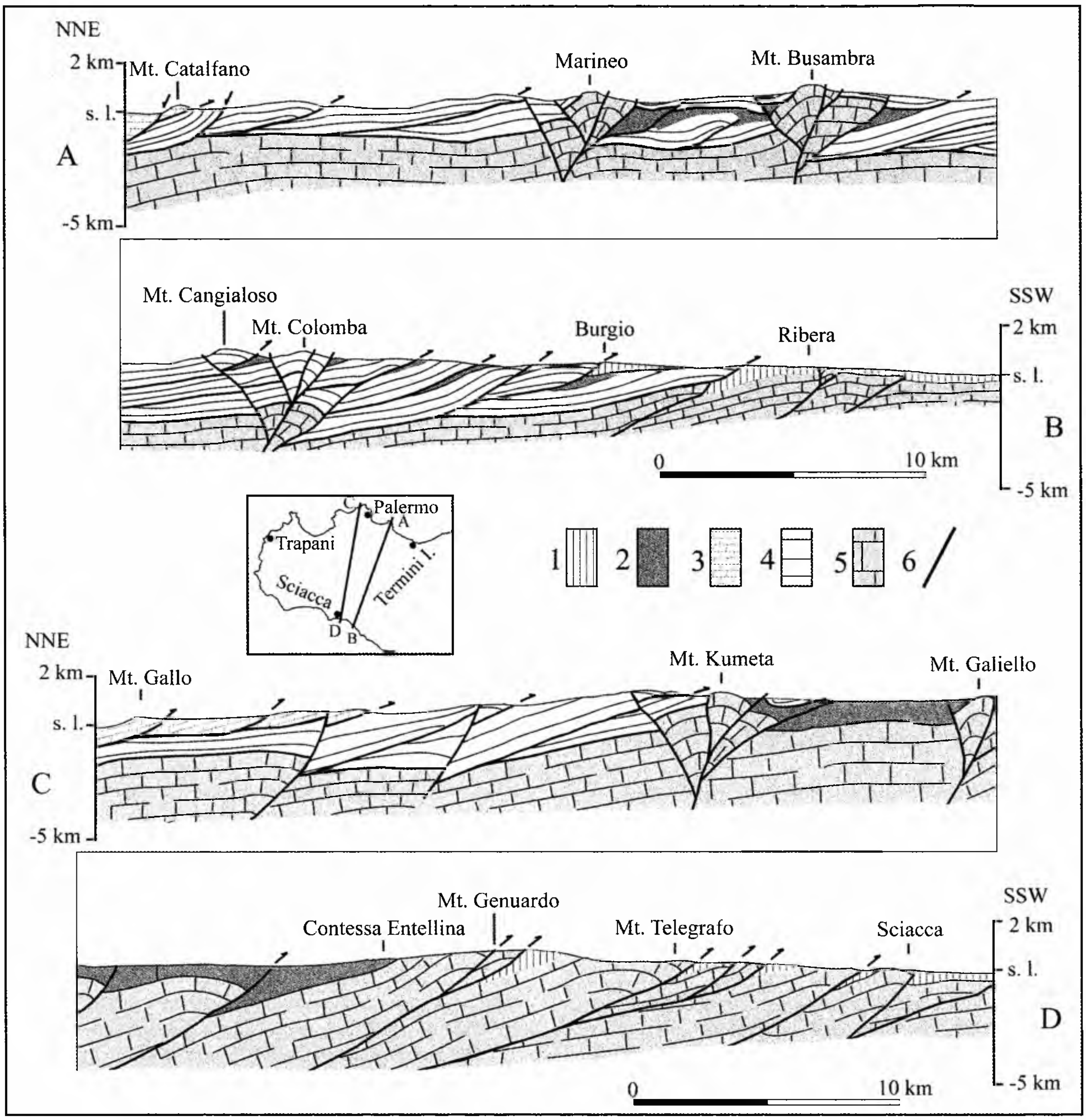

Fig. 6. Schematic structural sections across North-Central Sicily. *1* – Plio-Pleistocene deposits involved in the deformation; *2* – Late Miocene–Early Pliocene deposits involved in the deformation; *3* – Panormide units and their Numidian covers (Late Triassic–Late Langhian); *4* – Imerese–Sicanian units and their Numidian covers (Early Triassic–Middle Tortonian); *5* – Hyblean–Pelagian units (Late Triassic–Late Miocene); *6* – thrust and high-angle reverse faults

(Fig. 5), the Hyblean–Pelagian Domain-derived rock bodies outcrop along the main W–E trending tectonic ridges (Kumeta and Busambra Mts.) which, according to Ghisetti & Vezzani (1984), represent deep-seated positive flower structures.

The Hyblean–Pelagian Domain-derived tectonic units inflect toward the eastern sectors of the studied area, where the geometrically higher Oligocene–Miocene Imerese Domain-derived Numidian sequences outcrop (*e. g.* near Godrano-Cefalà Diana villages).

The "Panormide" and "Imerese–Sicanian" imbricate fan is up to 4–5 km thick in the northern sectors and up to 2.5 km southward of Busambra Mt. (Fig. 6). It tapers southward of Kumeta Mt., where it is up to 100–200 m thick. The continuity in outcrop of the Imerese–Sicanian Domain-derived tectonic units is interrupted in the Kumeta and Busambra Mts., which represent the main structures determining the tectonic "upwelling" of the geometrically deepest Hyblean–Pelagian substrate.

The Busambra and Kumeta positive flower structures seem to be connected to a prevalently right-hand deep-seated strike-slip fault system, NW–SE to W–E trending from Palermo Mts.–Castellammare Gulf to Kumeta–Busambra–Colomba Mts. (Ruggieri, 1966b; Ghisetti & Vezzani, 1984; Abate *et al.*, 1998).

DISCUSSION

Figure 7 shows a model of development of the Sicilian chain body-foredeep couple migrating towards the foreland during the Miocene–Pleistocene. An attempt at semiquantitative restoration of the Western Sicily Chain (Fig. 8) reveals the physical continuity of the so-called Imerese and Sicanian Basins, interposed between the Hyblean–Pelagian Domain (more external) and the Panormide Domain (more internal). Restoration is realised through two steps, in which retrodeformation of Plio-Pleistocene strike-slip and Miocene thrust tectonics was considered. It visualises the Hyblean–Pelagian Domain ranging from the Sciacca Mts. to the north-westernmost Sicily (Trapani Mts. and Egadi Islands), while the more internal carbonate platform facies of the Panormide units appear more and more similar to the Hyblean–Pelagian toward the west, in the Trapani Mts. (S. Vito Peninsula) and its off-shore.

On the basis of sedimentary facies distribution and the geometric relationships between the tectonic units, a hypothetical palaeoenvironmental-palaeotectonic evolution during the Mesozoic and deformation chronology during the Tertiary may be summarised as follows:

1. During the Early-Middle Triassic, as a consequence of early continental rifting stages, the African Continental Margin underwent a physiographic diversification, as the effect of dip- and strike-slip fault strands formation (Catalano & D'Argenio, 1982) that controlled the evolution of a few structural depressions, in which an epi-continental silicoclastic sedimentation developed (Lercara Basin). The fault systems seem deep-seated, as may be demonstrated by the presence of alkali-basaltic lavas inside the sequences of this age, and control the margin evolution, characterised by thick carbonatic breccia deposits made of Palaeozoic and Early Triassic carbonate platform clasts (Catalano & D'Argenio, 1982; Abate *et al.*, 1982).

2. During the Late Triassic–Liassic time, the continental rifting accentuated; the palaeogeographic domains progressively acquired physiographic features that characterise all the Mesozoic. During this time, the sedimentation developed in a pelagic basin (Imerese–Sicanian Domain) interposed between two neritic areas: the Panormide Carbonate Platform (internal) and the Hyblean–Pelagian Domain (external). The Panormide Domain is characterised by a typical carbonate platform sedimentation, with reefs and restricted lagoons (Abate & Catalano, 1974; Abate *et al.*, 1978, 1982) until the Late Cretaceous, when it partly subsided. Instead, the Hyblean–Pelagian Domain is characterised by an open-shelf neritic sedimentation until the Middle Liassic, and by a "pelagic" carbonate platform sedimentation until the Late Mesozoic. The Hyblean–Pelagian margin is physiographically articulated, as a result of transtensile tectonics (Montanari, 1987; Incandela, 1995). Along the fault scarps that constituted the junctures between the Imerese–Sicanian Basin and the two neritic sedimentation areas, thick carbonatic breccias were deposited during this time.

3. During the Cretaceous–Early Oligocene times, the physiography became more and more uniform. The sedimentation is represented by the basin plain sequences of the "scaglia" *Auct.* Lateral facies variations, still represented by carbonatic breccias rock bodies, may indicate the presence of active tectonic scarps both along the internal and the external Imerese–Sicanian Basin margins, as the effect of the mature Mesozoic extensional processes.

4. Starting from the Oligocene, the incipient opening of the Ligurian Basin and the Sardinia–Corsica Block rotation (Cherchi & Montadert, 1982) induces a progressive change of the African Continental Margin physiography, connected to the early deformational stages affecting the inner Peloritani areas. Thus, the more internal Maghrebian palaeogeographic domains are progressively involved in the deformation, losing their Mesozoic sedimentary characteristics; for the first time a foredeep-foreland system developed in the Sicilian area (Numidian Basin; Giunta, 1985). Its internal flank is filled during this period by terrigenous syn-tectonic deposits (Frazzanò and Stilo-Capo d'Orlando Fms; Nigro, 1996).

5. The Numidian foredeep has been incorporated in the Sicilian constructing chain since the Late Langhian (Pescatore *et al.*, 1987), when the Sicilide Domain deformation took place, thrusting over the Panormide sectors and both over the internal sector of the Imerese–Sicanian Basin (Fig. 7). During the Serravallian–Middle Tortonian, the foredeep basin migrated toward the more external sectors, as a consequence of the further Imerese–Sicanian Basin deformation; its external flank developed in the Southern Imerese–Sicanian sector. In this period, the Numidian foredeep was completely involved in the deformation (Fig. 7); the foredeep-foreland couple migrated toward the most external sectors, where the sedimentation began to acquire a clastic contribution deriving from the erosion of the uplifting and emerging chain.

6. During the Late Tortonian–Messinian, the most internal Sicilian Chain sectors partly emerged (Peloritani, Sicilide, Panormide and internal Imerese–Sicanian deformed areas) and the overall sedimentation filled intramountain basins. In the most external sector, the marine sedimentation again acquired a clastic contribution deriving from the chain erosion (Fig. 7).

7. During the Late Miocene, in the emerging internal chain body, the evaporitic deposits filled the Tortonian intramountain basins, while in the foredeep sectors they filled several perched basins on the back of the piling-up tectonic units (Imerese–Sicanian Southern sector and Hyblean–Pelagian margin *p. p.*).

8. Since the Early Pliocene, the more external Sicilian areas suffered incipient deformation. Marly and sandy sedimentation developed on the Hyblean–Pelagian margin, which continued to inflect because of chain loading, thus promoting the Plio-Pleistocene foredeep development (Valle del Belice foredeep; Vitale, 1990; Fig. 7). During this stage, the deformation widely involved in the chain construction the juncture sectors between the external Imerese–Sicanian Basins and the Hyblean–Pelagian margin, as demonstrated by the Genuardo Mt., Telegrafo Mt. and

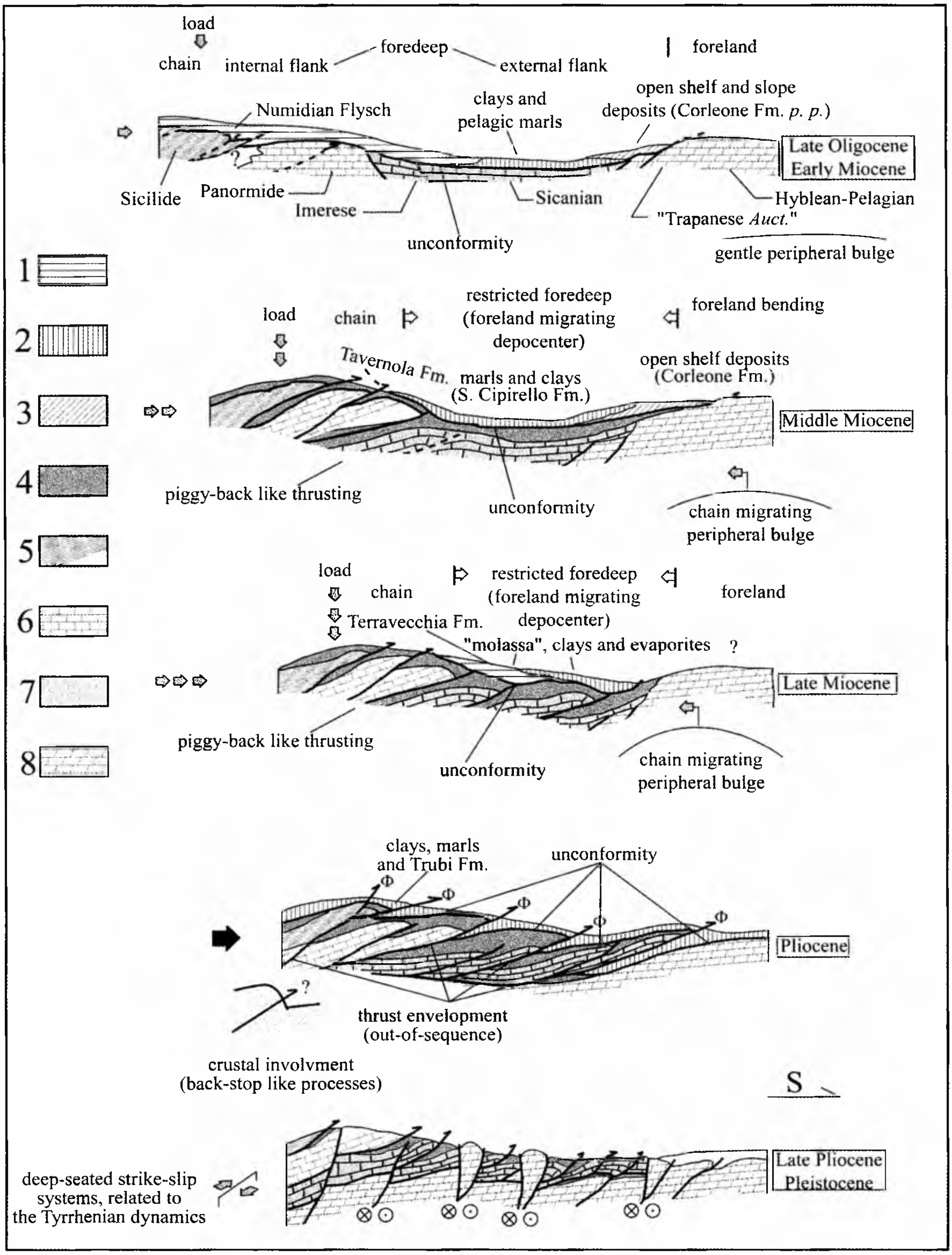

Fig. 7. Kinematic model of the tectono-sedimentary evolution of North-Central Sicily during the Miocene–Pliocene. *1* – internal flank foredeep deposits; *2* – depocentral foredeep deposits; *3* – external flank foredeep and/or foreland deposits; *4* – foredeep deposits progressively incorporated in the chain construction; *5* – internal Sicilide tectonic units; *6* – Panormide tectonic units; *7* – Imerese–Sicanian tectonic units; *8* – Hyblean–Pelagian tectonic units

Nadore Mt. tectonic units, which thrust over the Trubi Fm. of Middle Pliocene age.

9. Since the Middle Pliocene, strike-slip tectonics have occurred, related to the Tyrrhenian Basin opening (Finetti & Del Ben, 1986; Sartori, 1989; Argnani, 1990; Boccaletti *et al.*, 1990; Nigro, 1998); the Sicilian Chain was re-deformed starting from the peri-Tyrrhenian areas. The thrust fronts were cut by NW–SE to W–E trending prevalently deep-seated right-hand strike-slip fault strands (Figs. 1 and 5). These brittle systems induced the activation of new thrust

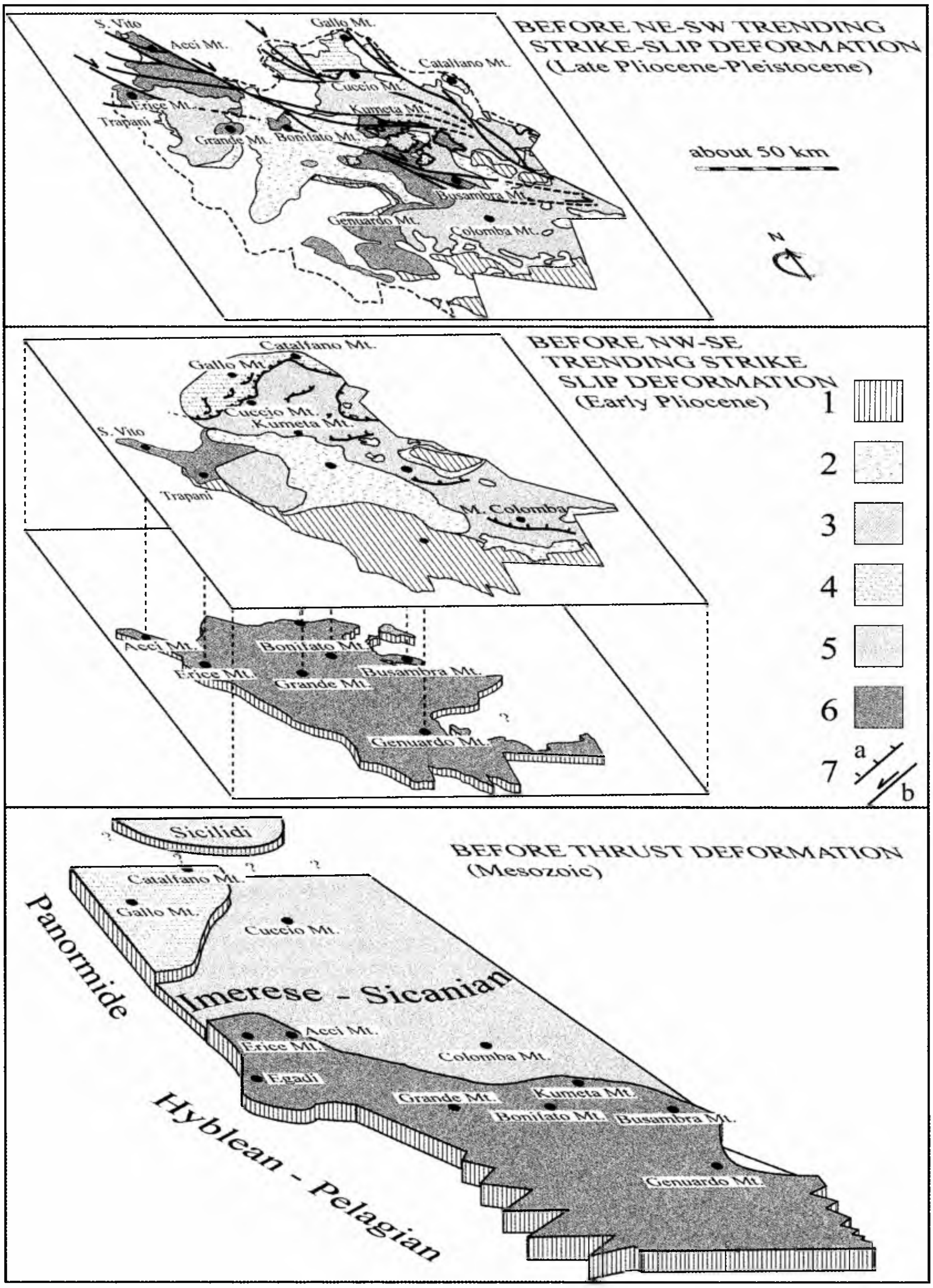

Fig. 8. Semiquantitative restoration of Western Sicily Chain. *1* – Messinian–Pleistocene successions; *2* – Tortonian successions; *3* – Sicilide units; *4* – Panormide units; *5* – Imerese–Sicanian units; *6* – Hyblean–Pelagian successions; *7a* – main thrust; *7b* – main strike-slip faults

surfaces, NE–SW trending, reorienting the previous tectonic units. The Hyblean–Pelagian substrate geometrically underlying the Imerese–Sicanian Miocene–Pliocene tectonic units was thus involved in the strike-slip tectonics through large-scale positive flower structures, represented by the Kumeta, Busambra and Colomba Mts. tectonic ridges (Figs. 6 and 7).

10. Since the Late Pliocene–Early Pleistocene, the tectonogenesis involved the southernmost mainland areas; the Magaggiaro Mt.–S. Calogero Mt. and the Sciacca–Ribera areas are involved in the high-angle transpressional faulting and thrusting (in the Montallegro AGIP Well, the Tertiary Hyblean–Pelagian carbonatic sequences overthrust the Early Pleistocene deposits; Beneo, 1961).

11. The fault and fold structures recorded in the Pleistocene sequences outcropping in the Sciacca area, the "Belice" transcurrent Fault and thermal springs distributed along its course, and the recent seismic events occurring in the studied area (Monaco *et al.*, 1996), indicate the recent tectonogenetic activity.

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