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PLIO-PLEISTOCENE WRENCH TECTONICS IN THE WESTERN SICILY CHAIN

Fabrizio NIGRO & Pietro RENDA

Department of Geology and Geodesy, University of Palermo, Corso Tukory n 131, 90134, Palermo, Italy

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Abstract: Western Sicily represents a fragment of the Apenninic-Maghrebian Chain, largely built during the Miocene and formed by a set of tectonic units with southern vergence of folds and ramp-flat style of thrust surfaces. The thrust tectonics-related structures are displaced by a high-angle fault system, which bounds the main Mesozoic "carbonatic massifs" and generally interpreted as a neotectonic dip-slip extensional tectonics-related faults.

The present paper, with the support of mesostructural analysis, presents an important Plio-Pleistocene strike-slip tectonics, represented by high-angle net- and strike-slip fault system. Different scale flower structures and associated fold systems, which cut the Miocene tectonic units, characterise the areas along the main transcurrent fault zones.

Strike-slip neotectonics is mostly represented by right-lateral NW–SE/W–E and left-lateral N–S/NE–SW transcurrent faults, which may represent a W–E trending deep-seated Riedel system connected to the Tyrrhenian spreading. The NW–SE first order synthetic structures appear to control the opening of several rhomboidal tectonic depressions located in north-western Sicily and its offshore, and are counteracted by W–E trending transpressional structures located in the central Sicily mainland.

An attempt at semi-quantitative restoration shows the neotectonic evolution of north-western Sicily during the Pliocene and Pleistocene, characterised by the progressive activation towards the east of en-échelon strike-slip fault strand, in an overall horsetail splay geometry, which produced releasing bends in off-shore and restraining bends in the mainland.

Key words: Strike-slip tectonics, neotectonics, Western Sicily.

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INTRODUCTION

The occurrence of strike-slip tectonics has been described in many examples, affecting the fold-and-thrust belts tectonogenetic evolution, the passive margins evolution and the extensional cratonic areas (Woodcock, 1986), where a component of oblique-slip is mostly required for the formation of sedimentary intracontinental, foreland and forearc basins (*e.g.*, Mann *et al.*, 1983; Christie-Blick & Biddle, 1985 and references therein). Strike-slip tectonics, associated with regional crustal extension or shortening, have been well theorised (*e.g.*, Moody & Hill, 1956; Chinnery, 1963; Wilcox *et al.*, 1973; Segall & Pollard, 1980; Aydin & Nur, 1982; Sylvester, 1988; Christie-Blick & Biddle, 1985; Woodcock & Fischer, 1986; Swanson, 1989), controlled either by pure shear or by simple shear mechanisms. Strike-slip basins occur in a wide range of plate tectonic settings, including intracontinental transform zones, as well as divergent and convergent plate boundaries.

With regard to the different tectonogenetic stages of mountain chain building, the role of strike-slip tectonics in the evolution of orogenic belts and associated basins has been recognised for several decades (*e.g.*, Ballance & Reading, 1980; Rodgers, 1980; Hill, 1981; Sylvester, 1988; Nilsen & Sylvester, 1995 and references therein). Strike- and oblique-slip mechanisms (with transpressive or transtensile components) in places pre-date accretion processes of subductional trench complexes and/or mobile belts, but mostly accompany *step-by-step* the mountain building processes, both in the chain bulks and their extensional back areas or in their more external sectors.

Transcurrent faults (Reid *et al.*, 1913) are the effects of strike-slip mechanisms (Segall & Pollard, 1980) and have been recognised at every scale (*e.g.*, Aydin & Nur, 1982; Kornprobst & Vielzeuf, 1984 and references therein), from metric scale (above all tear, transfer, *etc.*, during thin- and thick-skinned oblique thrusting) to regional scale, where they are represented first of all by a different set of synthetic and antithetic structures (see Moody & Hill, 1956 for theoretical wrench- and thrust-fault directions and Swanson, 1989 for terminology). These mostly represent the dominant brittle deformations of wrench tectonics (Moody &

Hill, 1956; Wilcox *et al.*, 1973) and the most common effects are represented by different-scale en-echelon arrays of fractures, faults, folds and buckles in narrow elongated zones (Sylvester, 1988).

Many examples of well-studied strike-slip deformation derive from the Western United States (*e.g.*, Jones *et al.*, 1977; Allen, 1981; Sylvester, 1988 and references therein), from South America (*e.g.*, Schubert, 1980 and references therein), and from the Alpine–Himalayan suture zone (*e.g.*, Molnar & Tapponier, 1975).

Orogen formation has also been revealed during the Palaeozoic–Tertiary times in the peri-Mediterranean areas and North Europe strike-slip tectonics (*e.g.*, Arthaud & Matte, 1977; Steel & Gloppen, 1980; Royden *et al.*, 1982; Anadon *et al.*, 1985; Giraud & Seguret, 1985; Royden, 1985; Şengör *et al.*, 1985; Steel *et al.*, 1985 and references therein).

The Apenninic-Maghrebides system represents an arch-shaped orogen located in the Central Mediterranean, affected by stretching in its inner part since the late Miocene, related to the Tyrrhenian Basin formation (Malinverno & Ryan, 1986; Patacca *et al.*, 1992). Along the Apenninic Belt or in the surrounding submerged areas, several examples of Neogene strike-slip deformations are known (*e.g.*, Boccaletti *et al.*, 1982; Finetti & Del Ben, 1986; Ben-Avraham *et al.*, 1987; Boccaletti *et al.*, 1987), mostly related to the late Neogene–Pleistocene Central Mediterranean geodynamic evolution, which controls the accretion processes in the orogen toe and, in opposition, the thinning of its inner portion.

In Sicily, wrench tectonics has been well described by Ghisetti & Vezzani (1977, 1984) and Ghisetti (1979), who recognised deep-seated W–E trending transcurrent faults superimposed on the Maghrebian Belt. Recently, Mauz & Renda (1995), Nigro & Sulli (1995), D'Angelo *et al.* (1997), Abate *et al.* (1998), Nigro (1998) and Giunta *et al.* (1998) have analysed the neotectonic brittle transcurrent structures of Northern Sicily and framed them in a geodynamic context related to the Tyrrhenian Basin development. The authors explain the widespread grid of strike-slip fault system as a consequence of the progressive activation toward the east of NW–SE trending, en-echelon deep-seated transcurrent faults. Particularly, according to Ghisetti & Vezzani (1984), who interpreted the Kumeta and Busambra ridges as two positive flower structures related to Plio-Pleistocene dextral wrench tectonics, Nigro (1998) and Nigro & Renda (1999a) interpreted these structures as the tectonic uplift of the underplated Maghrebides foreland, through a deep-seated transpressional fault system related to the Tyrrhenian Basin evolution. The eastern continuation of the deformed foreland (Hyblean Mts.) is also affected by Plio-Pleistocene strike-slip tectonics (*e.g.*, Grasso & Reuther, 1988; Grasso *et al.*, 1992 and references therein).

The present paper describes Plio-Pleistocene strike-slip tectonics, expressed by a complicated grid of high-angle net-slip transcurrent faults affecting the western Sicily Belt and its offshore. Strike-slip tectonics controls the morphostructural setting and the evolution of rhegmatic tectonic depressions in the western mainland and its off-shore areas. These depressions are located in stepover zones between the main NW–SE trending right-lateral transcurrent faults. The neotectonic system may be related to a W–E trending dextral simple shear mechanism, representing the recent evolution of southern Tyrrhenian province kinematics.

GEOLOGICAL FRAMEWORK

Mainland Sicily, located in the Central Mediterranean, represents a sector of the Maghrebian Chain, in which different structural domains can be distinguished (Fig. 1a). By the term Western Sicily we indicate a chain sector bounded by the Tyrrhenian sea to the north, by the Madonie Mts. to the east and by the Sicanian Mts. to the south (Fig. 1b).

The chain is represented by a W–E trending thrust system, which has been progressively emplaced since the early Miocene. The tectono-sedimentary evolution are expressed by foreland migration of the foredeep-deformation front couple and the chain body, composed of thrust and/or plastic covers. The thrust stack progressively incorporates terrigenous foredeep deposits and in turn carried piggy-back basins (Nigro & Renda, 1999a). The gently deformed foreland crops out in the south-east and westernmost island areas, and is widely inflected below the Sicilian-Maghrebian thrust system.

The chain front is located in the Southern Sicily offshore, where late Pleistocene deposits underplate beneath its toe region (the so-called Gela Nappe; Beneo, 1961).

The Western Maghrebides segment is located in the western part of the island, from the Trapani Mts. to the Madonie Mts. and is composed of different tectonic units (Fig. 2), representing a pelagic basin comprised between two carbonate platforms (from the inner so-called Panormide, Imerese-Sicanian and Hyblean-Pelagian, Nigro & Renda, 1999a). These tectonic units are today dismembered and partially juxtaposed from the west to east, and derived from the deformation and from a more and more clockwise rotation toward the east (Giunta, 1991) of different successions belonging to the Mesozoic African Margin.

The deformation of these successions occurred during Miocene thrust tectonics, progressively emplaced from the north to the south in a piggy-back sequence. The geometrical position of these units inside the tectonic edifice could reflect the ancient palaeogeography (Giunta & Liguori, 1973; Scandone *et al.*, 1974; Abate *et al.*, 1978).

From the bottom to upwards, the western Sicily Chain is composed of:

– pelagic external carbonate platform tectonic units (Hyblean-Pelagian, up to 1500–2000 m thick). These are exposed from the Trapani Mts. to the S. Vito Peninsula, but do not outcrop in the Eastern Sicilian-Maghrebian Chain. They form two W–E trending structural ridges (Kumeta and Busambra Mts.);

– pelagic carbonate tectonic units (Imerese-Sicanian, up to 1500 m thick). They crop out from the southern sector of the Palermo Mts. to the Trabia-Termini Imerese and Madonie Mts., and are represented by emergent largely displaced thrust sheets. Towards the east they are represented in outcrops by Oligo-Miocene Numidian covers (Giunta, 1985);

– carbonate platform tectonic units (Panormide, up to 1000–1500 m thick). These are mostly exposed in the Pal-

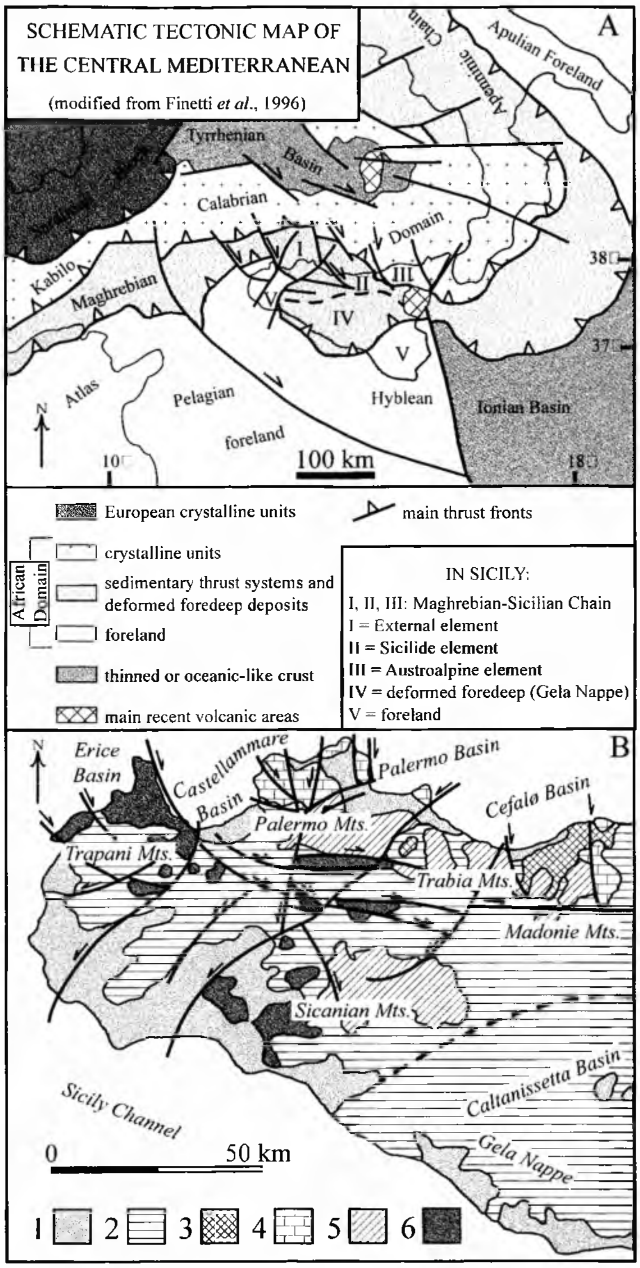

Fig. 1. A. Schematic tectonic map of the Central Mediterranean. **B**. Simplified structural map of Western Sicily. *1* – Late Plio-Pleistocene successions; *2* – Miocene-Early Pliocene foredeep-foreland deposits; *3* – Sicilide units; *4* – Panormide units; *5* – Imerese-Sicanian units; *6* – Hyblean-Pelagian units

ermo Mts. and the Madonie Mts., and thrust over the Imerese units;

– mostly pelagic shale tectonic units (Sicilide element, up to 200–300 m thick), with internal "chaotic geometries", discontinuously outcropping in the Palermo-Madonie Mts.

During the Miocene thrust deformation, foredeep deposits were unconformably overlain upon the carbonatic substrate (Giunta, 1985); the Oligo-Miocene foredeep deposits upon the Panormide and Imerese units are known as the Numidian Flysch. These successions, today detached from their substrate, are widely exposed in more southern areas with respect to the Palermo Mts., from the Sicani Mts. to the eastern Sicilian-Maghrebides. The foredeep deposits of the more external tectonic units (Sicanian and Hyblean-Pelagian) are mostly represented by Serravallian shales.

An arenaceous-conglomeratic succession (the so-called Terravecchia Fm.) unconformably overlies the early Miocene tectonic edifice. This is generally interpreted as a molassic deposit that post-dates the main deformation phase in the Sicilian-Maghrebides Chain (Broquet, 1968; Mascle, 1979).

The Northern Sicily coastal sector represents a complicated hinge zone between the emerged and submerged orogen, and is characterised by a network of variously trending Plio-Pleistocene brittle high-angle structures, often diachronous and with different tectonic significance (Nigro, 1998; Giunta *et al.*, 1998). On land, these structures show a variable trend, from NW–SE in the coastal areas to W–E in Central Sicily. They are often represented by a strike-slip faults system in the hinterland, and by a dip-slip fault system, mostly characterising its coastal areas. In offshore areas, several strongly subsiding Plio-Pleistocene basins are located in the shelf slope. The opening of these basins proceeded diachronously towards the east, from late Messinian–Early Pliocene times in the Trapani Mts. offshore to middle Pliocene times in the Palermo offshore. Also, the subsidence mechanisms appear diachronous towards the east, as revealed by the thickness and age of basin fill deposits, which show a decrease toward the east of Pliocene package, counterbalanced by an increase of Pleistocene package in the same trend. The submerged basins are generally interpreted as half graben-like structural depressions (*e.g.*, Agate *et al.*, 1993).

FIELD DATA

In the Sicilian Maghrebides Chain the main geometric characteristics are expressed by a complicated interference pattern related to Miocene thrust tectonics and a neotectonic high-angle strike-slip fault system.

Miocene thrust tectonics

Miocene thrust tectonics is represented by several tectonic units, characterised by frontal ramp anticlines (Fig. 3). The general trending of plicative axial surfaces indicates an African vergence of the structures (toward the south and south-east). The early and middle Miocene thrust surfaces generally represent the tectonic superposition of the Panormide units over the Imerese units (Abate *et al.*, 1978).

In the Palermo Mts., Panormide and Imerese-Sicanian foreland-vergent thrust sheets were largely overthrust in the late Miocene on the deformed foreland external shallow substrate through a very low angle flat (Nigro & Renda, 1999a); here, thrust step-up geometries are characterised by a few degrees of plunge. The deformed foreland widely outcrops toward the western sector (Trapani Mts. and S. Vito Peninsula).

Two main fold systems are recorded in the rock bodies, related to Miocene and Plio-Pleistocene deformation phases. The Miocene fold system is oriented N–S to

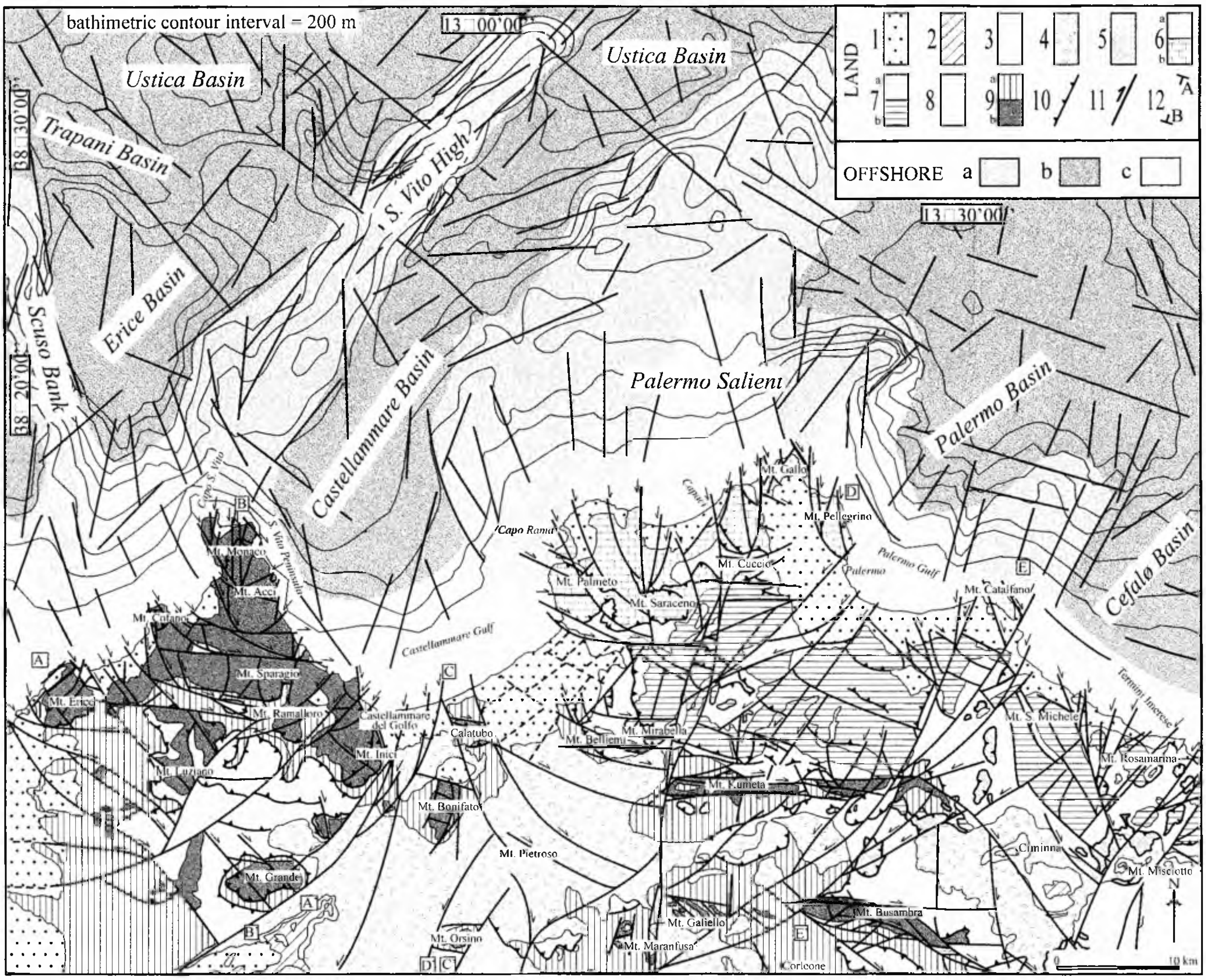

Fig. 2. Schematic structural map of north-western Sicily and its off-shore. *1* – Late Pliocene-Pleistocene clastic deposits; *2* – Early Pliocene deposits; *3* – Messinian evaporites; *4* – Terravecchia Fm. (Late Miocene); *5* – Sicilide units (Cretaceous–Tertiary); *6a* – Panormide foredeep successions (Oligocene–Early Miocene); *6b* – Panormide units (Mesozoic–Tertiary); *7a* – Imerese-Sicanian foredeep successions (Oligocene–Early Miocene); *7b* – Imerese-Sicanian units (Mesozoic–Tertiary); *8* – Mufara-Lercara Fms. (Palaeozoic ?–Triassic); *9a* – Hyblean-Pelagian foredeep successions (Miocene); *9b* – Hyblean-Pelagian units; *10* – main thrust; *11* – main transcurrent faults; *12* – traces of geological cross-sections of Fig. 3. *a* – morphostructural highs; *b* – Plio-Pleistocene subsiding sedimentation areas; *c* – Plio-Pleistocene uplifting sedimentation areas

NE–SW, whereas the Pliocene system is oriented W–E/NW–SE. The first, mostly recognised in the north-western sector of the area, shows a lower wave-length than the second system, and is composed of parallel and chevron folds, in a multi-harmonic configuration. This configuration is also revealed by the presence of several detachment surfaces along the multilayer. The second fold system is represented by wider wave-lengths and connects in the W–E direction near the carbonatic ridges of Mt. Kumeta and Mt. Busambra.

Plio-Pleistocene wrench tectonics

Plio-Pleistocene strike-slip-related structures are composed of three main different populations (Figs 3, 4):

– the NW–SE/W–E trending right-lateral transcurrent fault system, with associated NE–SW trending antithetic structures and variously trending high-angle reverse faults, forming different scale positive flower structures. Reverse faults with opposite dip with respect to the Miocene thrust are also recognised in the coastal areas between Palermo and Capo Rama (Fig. 5);

– the NNE–SSW/N–S trending left-lateral transcurrent fault system with kilometric course, mostly recognised along the joint between Mt. Catalfano-Mt. Galiello and between Capaci village-Mt. Galiello (Fig. 6);

– a dispersal dip- and net-slip extensional fault system, mostly in the southern sector of the area, whereas in the coastal zones it has a NW–SE and W–E trend.

The first strike-slip system widely characterises the area; it swings in a W–E direction in the southern sector, where it clearly bounds the Mt. Kumeta and Mt. Busambra morphostructures (Figs 7, 8), which may be interpreted as

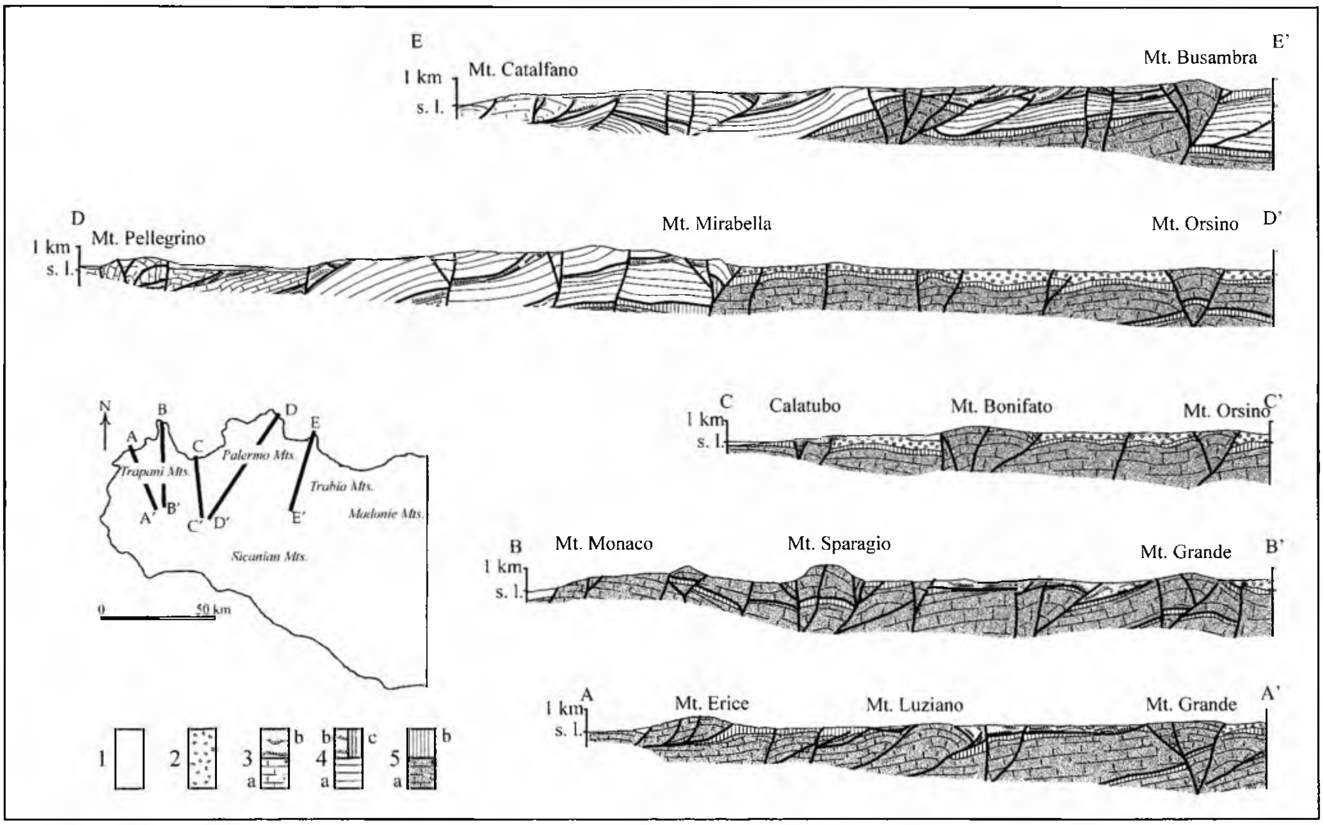

Fig. 3. Schematic geological cross-sections of Western Sicily. *1* – Plio-Pleistocene deposits; *2* – Terravecchia Fm. (Late Miocene); *3a* – Panormide units; *3b* – Oligo-Miocene Panormide foredeep successions; *4a* – Imerese-Sicanian units; *4b* – Oligocene-Early Miocene Imerese-Sicanian foredeep successions; *4c* – Middle Miocene Imerese-Sicanian foredeep successions; *5a* – Hyblean-Pelagian units; *5b* – Middle Miocene Hyblean-Pelagian foredeep successions

two macro-scale deep-seated positive flower structures. NW–SE trending flowers also characterise Calatubo (Fig. 9), Mt. Pietroso, Mt. Belliemi, Mt. Mirabella-Mt. Pizzuta (Figs 10, 11), Mt. Pellegrino and Mt. S. Michele.

The Tyrrhenian-dipping extensional fault system controls the coastal morphology and locally re-activates previous Miocene–Pliocene thrust surfaces.

Joints, fault systems and metric scale flower structures related to this fault system are also recognised in the Pleistocene deposits, outcropping at the coast of the S. Vito Peninsula (Fig. 12), Castellammare and Palermo Plains; here, the mesostructural analysis reveals two main NW–SE and N–S fault trends. The occurrence of slickensides within the Pleistocene deposits indicates that the deformation is characterised by strike-slip mechanisms which also produced several metric flower structures (Abate *et al.*, 1998). In addition, some continental deposits with remnants of Middle Pleistocene mammal faunas are affected by left- and right-lateral strike-slip faults near S. Vito lo Capo Village, and Capo Rama (Abate *et al.*, 1998; Nigro & Renda, 1999b). The first transcurrent system is in places cut by the NE–SW system, as at Mt. Catalfano, Mt. Cuccio and Mt. Galiello. In the coastal sectors, it also shows a NW–SE trend and is characterised by listric surfaces and net-slip extensional displacements in the eastern slopes of the main morphostructures (*e. g.*: Mt. Bonifato, Mt. Palmeto), whereas in the western slopes it is mostly represented by the same trend of transpressional structures. Morphostructural highs alternating with depressions of the coastal areas progressively attenuate towards the hinterland, where the NW–SE right-lateral transcurrent system swings in a W–E direction.

Surrounding areas

The above-mentioned morphostructures continue in the off-shore areas of Northern Sicily, where they form structural highs (Scuso Bank, S. Vito High, Palermo Salient; Finetti & Del Ben, 1986) alternating with deep Plio-Pleistocene fault-angle depressions (Trapani, Erice, Castellammare, Palermo and Cefalu Basins), in a *basin-and-range*-like configuration. They form a rough belt in the shelf slope, representing the southern Tyrrhenian province (Fig. 3). The Mt. Bonifato-S. Vito Peninsula range thus continues in the submerged areas, where it merges with the S. Vito High, separating the Erice Basin from the Castellammare Basin. The Mt. Palmeto morphostructural high continues offshore, where its equivalent separates the Castellammare Basin from the Palermo Basin. Finally, the Mt. Catalfano morphostructure represents the on-land continuation of the submerged highs dividing the Palermo Basin from the Cefalu Basin.

The main fold axes recognised through interpretations of high-resolution seismic reflection profiles show E–W and NE–SW trends, mostly in the westernmost basins, while the main extensional structures that controlled the ba-

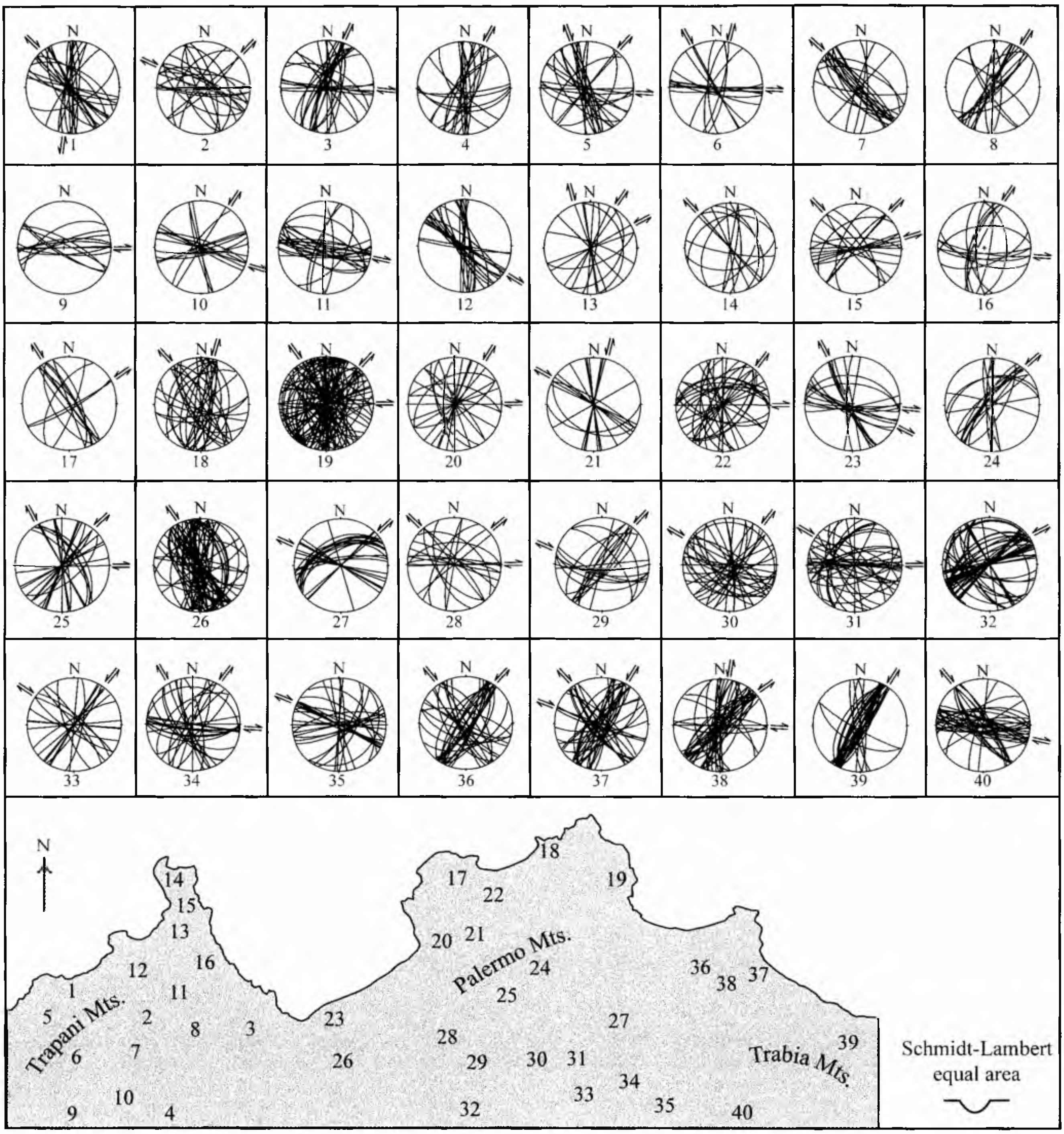

Fig. 4. Stereographic projections of mesostructural data set sampled in Western Sicily

sin formation are oriented N–S, NW–SE and NE–SW (Fabbri *et al.*, 1981, 1982; Wezel *et al.*, 1981; Selli, 1985; Wezel, 1985; Finetti & Del Ben, 1986).

The diachronous opening of these basins towards the east is a consequence of the Tyrrhenian opening (Hutchinson *et al.*, 1985; Malinverno & Ryan, 1986; Savelli, 1986). The oldest are the Trapani and the Erice Basins (Messinian–Early Pliocene), while the Castellammare and Palermo Basins originated during the Middle Pliocene (Agate *et al.*, 1993; Mauz & Renda, 1995).

The clastic deposits represent a post-Messinian semi-graben fill (Wezel *et al.*, 1981; Selli 1985; Torelli *et al.*, 1991), related to strike-slip tectonics and affected by inversion during the Late Pliocene–Pleistocene (Tricart *et al.*, 1990). The Plio-Pleistocene wrench tectonics in the offshore is supported, for example, by the rapid subsidence of the Erice, Castellammare and Cefalu asymmetric basins, which were ephemeral and ended abruptly.

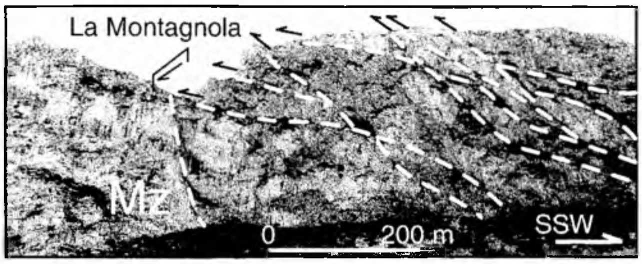

Fig. 5. Back-thrust geometries recognized in the Palermo Mts. coastal sectors. Mz – Mesozoic Panormide carbonate platform successions

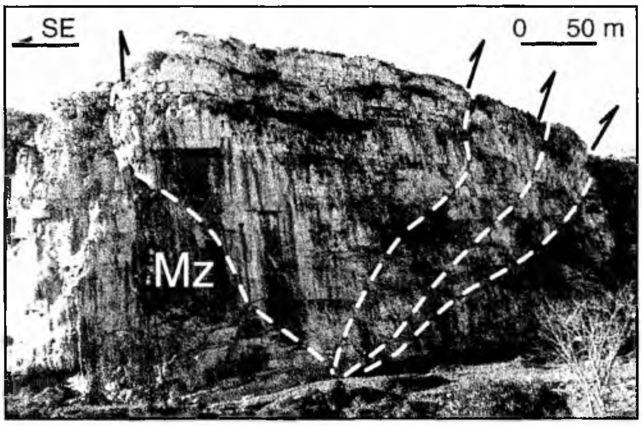

Fig. 6. N–S trending left-lateral transcurrent reverse fault strand affecting the Panormide successions in the Palermo Mts. Mz – Mesozoic carbonate platform successions

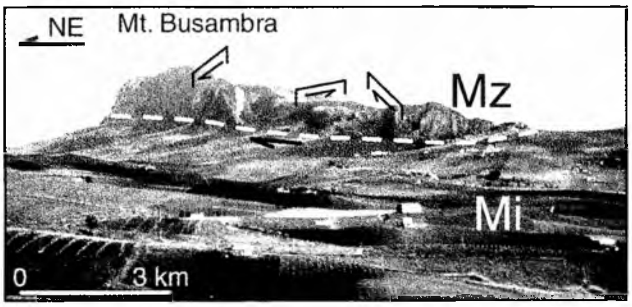

Fig. 7. Panoramic view of Mt. Busambra morphostructure. Mz – Mesozoic Hyblean-Pelagian carbonate platform successions; Mi – Miocene Imerese-Sicanian foredeep deposits

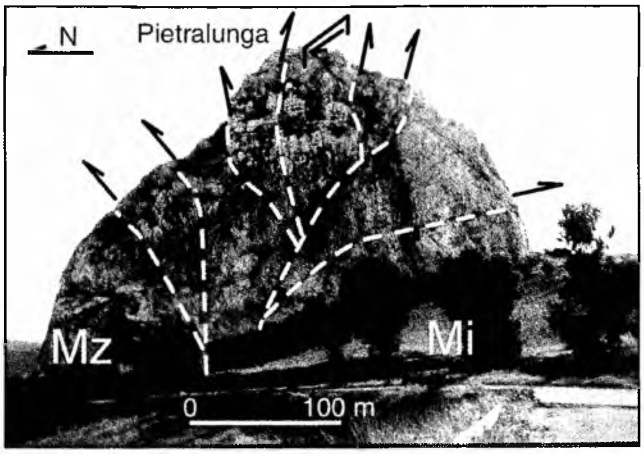

Fig. 8. W–E trending positive flower structure located south of the Kumeta Ridge. Mz – Mesozoic Hyblean-Pelagian carbonate platform successions; Mi – Miocene Imerese-Sicanian foredeep deposits

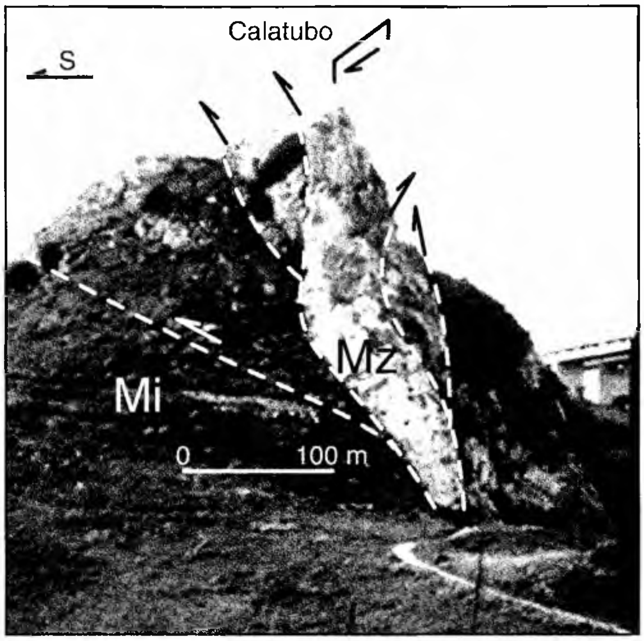

Fig. 9. W–E trending positive flower structure of Mt. Calatubo. Mz – Mesozoic Hyblean-Pelagian carbonate platform successions; Mi – Miocene Imerese-Sicanian foredeep deposits

In these sharp pull-apart basins, the bounding blocks may be torsionally rigid and deform only at their edges, and the subsidence history described by Agate *et al.* (1993) is due to extension only in a direction about parallel to the regional strike of the right-lateral transcurrent faults.

The basin asymmetry observed off-shore, with simple NNW–SSE sharp edges and more complex E–W margins, suggests that the former are controlled by right-lateral overstepping strike-slip faults (Abate *et al.*, 1998), whereas the margins are controlled by transtensional faults.

Strike-slip mechanisms connected to basin development are also revealed by the distinctive aspect of the stratigraphic record of filling deposits, as thick stratigraphic sections representing short time intervals (1.5–2 km versus 2–3 Ma) and the occurrence of abrupt lateral facies changes and local unconformities (*e.g.*, Erice and Castellammare Basins). These areas are characterised by marked differences in stratigraphic thickness, facies geometry and occurrence of unconformities from one basin to another (Agate *et al.*, 1993).

DISCUSSION

Fig. 13 shows a semi-quantitative restoration of the Western Sicily mainland during the Late Miocene and Pliocene, obtained through the juxtaposition of the displaced isopic facies bends. The palinspastic restoration allows us to

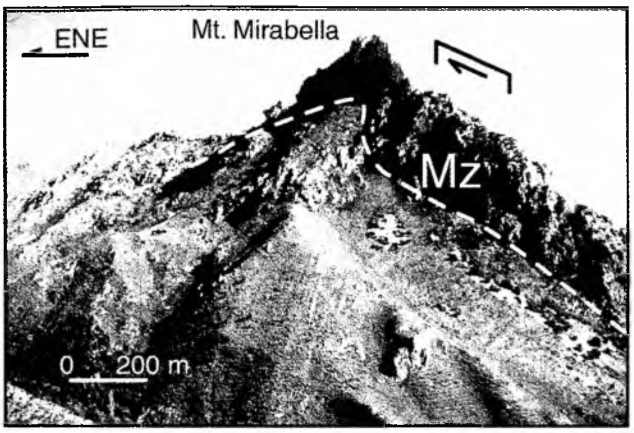

Fig. 10. W–E trending right-lateral transcurrent fault affecting the southern Palermo Mts. Mz – Mesozoic Imerese-Sicanian pelagic carbonatic successions

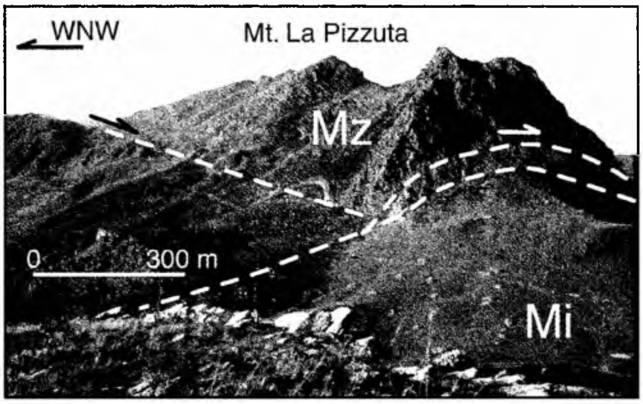

Fig. 11. W–E trending right-lateral transcurrent fault affecting the southern Palermo Mts. Mz – Mesozoic Imerese-Sicanian pelagic carbonatic successions; Mi – Miocene Imerese-Sicanian foredeep deposits

reconstruct the Miocene tectonic setting of Western Sicily thrust units. The main results may be summarised as follows:

– the Miocene tectonic edifice consists of a group of SE-verging Panormide tectonic units, overthrust on a more extended Imerese tectonic assemblage. Mt. Catalfano, Mt. Gallo and Mt. Palmeto (made of Panormide successions) formed during this time a NNE–SSW trending alignment, as well as the more southern and external tectonic units of Mt. Rosamarina, Mt. S. Michele and Mt. Cuccio (made of Imerese successions). The Hyblean-Pelagian units, today outcropping in the Trapani Mts., S. Vito Peninsula, Mt. Bonifato, Mt. Kumeta and Mt. Busambra, formed a NW–SE to W–E trending alignment;

– the Riedel shear system development controlled the Plio-Pleistocene basin fill clastic sedimentation, both in the submerged areas and in the uplifted zones located in the Castellammare, Capaci and Palermo coastal plains. The south-western limit of the Castellammare coastal plain is formed by Calatubo-Mt. Bonifato, representing the connection between the submerged releasing areas and the transpression zones of Mt. Kumeta and Mt. Busambra. Its north-eastern limit is instead formed by another first-order

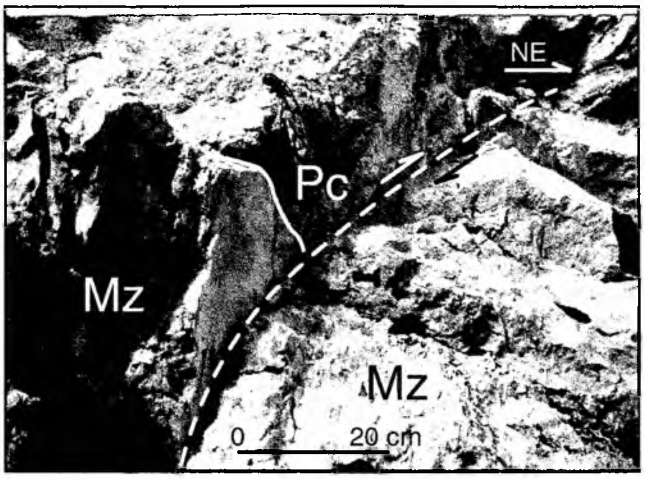

Fig. 12. NW–SE trending neotectonic fault displacing either both Hyblean-Pelagian Mesozoic succession (Mz) and the Pleistocene continental deposits (Pc) in the S. Vito Peninsula

synthetic Riedel structure, affecting Mt. Palmeto and Mt. Cuccio. In the Palermo Plain, the Plio-Pleistocene clastic sedimentation appears to be controlled by a rhegmatic system, where the 3D palm structures (*sensu* Ramsay & Huber, 1987) of Mt. Pellegrino progressively developed.

The present-day disposition of Sicilian tectonic units, juxtaposed in a W–E trend, may be brought back to a progressive more and more clockwise rotation towards the east of different chain sectors (Oldow *et al.*, 1990). The most evident effects of rotation are represented by the transcurrent faults, in which transtension occurs in the NW–SE system and transpression in the W–E and NE–SW system. Under this stress field, the neotectonic history can be marked by the continuous activation of NW–SE trending multiple en-échelon right-lateral overstepping strike-slip faults (first order synthetic Riedel shear system and associated minor order N–S/NE–SW antithetic structures), progressively affecting the chain from the west to the east. En-échelon strike-slip activation linked to clockwise rotation of dragged blocks (Beck, 1976) is more developed toward the east (Ghisetti & Vezzani, 1981; Grasso *et al.*, 1987; Oldow *et al.*, 1990; Giunta, 1991), as well as the antithetic structures, and may induce inversion of extensional structures, as suggested by Knott & Turco (1991) for the eastern Tyrrhenian and peri-Tyrrhenian areas.

The transcurrent faults found in the Northern Sicily may be related to the structures affecting the off-shore sectors. In fact, the Riedel shear system recognised on land continues in the offshore areas, where it forms a first-order NW–SE trending releasing bend system in a horsetail splay configuration, in which Plio-Pleistocene clastic sedimentation of Trapani, Erice, Castellammare and Palermo Basins occurs. The releasing process develops through the progressively increasing rotation towards the east of dragged blocks, which determines on land a W–E trending first-order restraining bend, represented by the Mt. Kumeta and Mt. Busambra ridges and their eastern continuation.

Strike-slip tectonics might, therefore, represent the expression of a control on the development of the Plio-

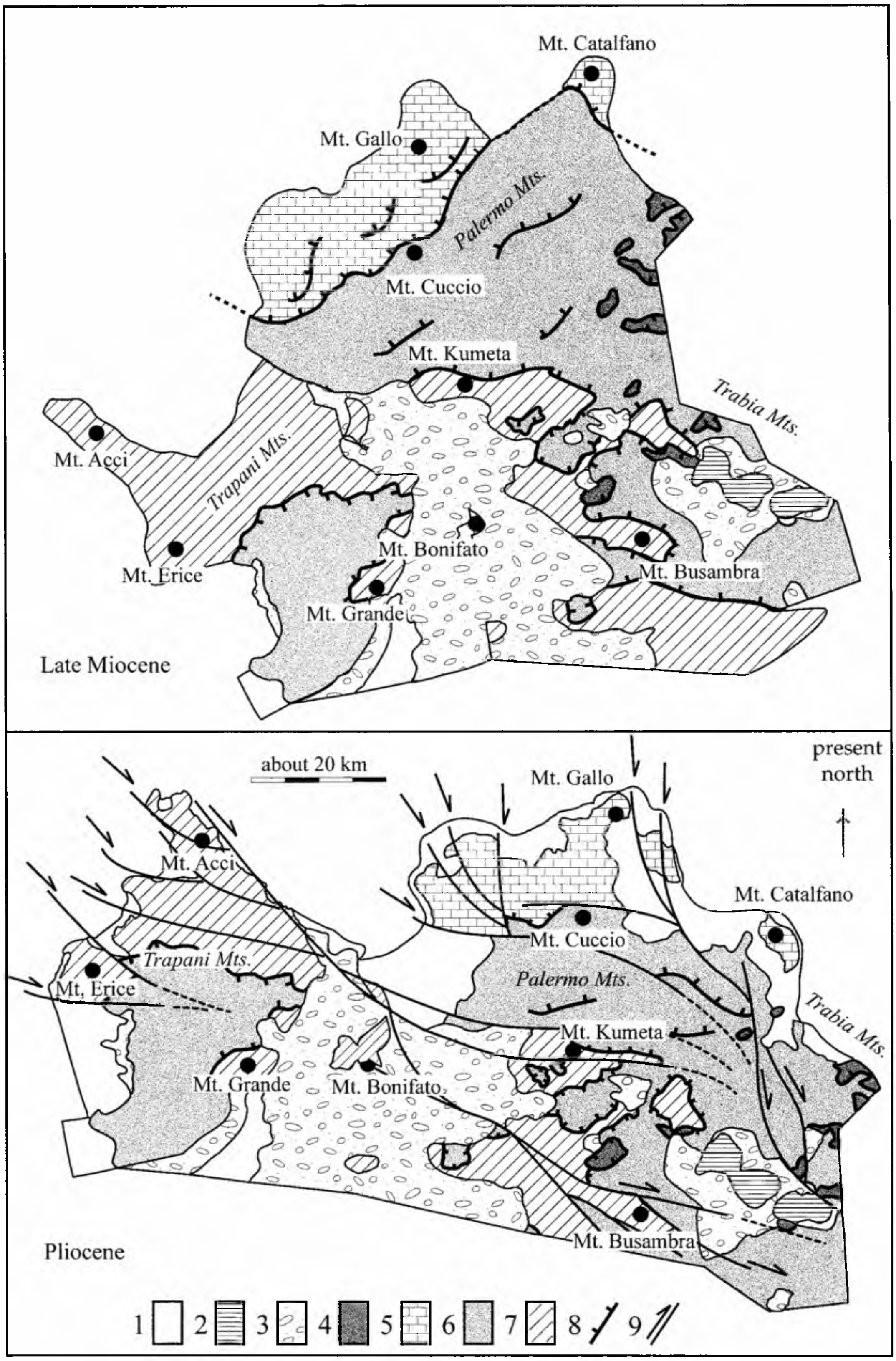

Fig. 13. Semi-quantitative restoration of the Western Sicily Belt during the Late Miocene and Pliocene. *1* – Plio-Pleistocene deposits; *2* – Messinian evaporites; *3* – Terravecchia Fm.; *4* – Sicilidi units; *5* – Panormide units; *6* – Imerese-Sicanian units; *7* – Hyblean-Pelagian units; *8* – main thrust; *9* – main strike-slip faults

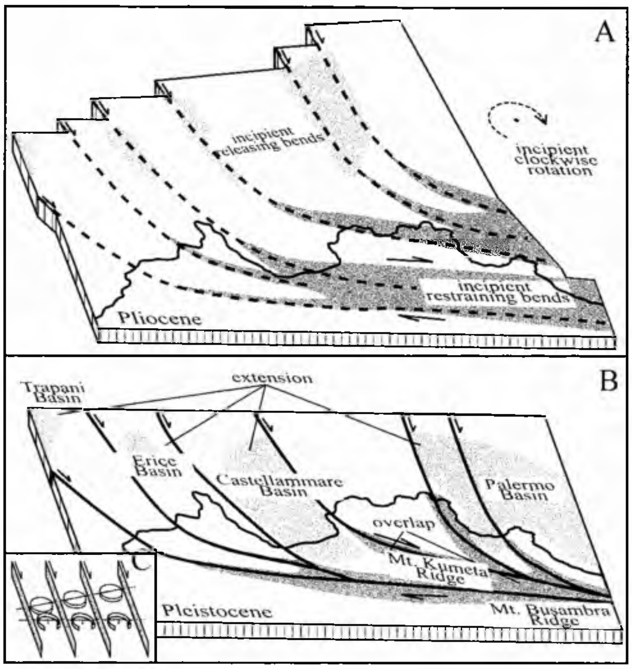

Fig. 14. Neotectonic kinematic reconstruction of Western Sicily Belt and its off-shore. The proposed rhegmatic model is based on the progressive activation toward the east of an en-echelon NW–SE trending overstepping right-lateral transcurrent fault system, organised in an overall horsetail splay configuration. The fault strand represents minor-order synthetic Riedel structures associated with the first-order W–E trending shear zone, bounding the southern Tyrrhenian Basin. The extension processes of submerged areas are counteracted by transpression tectonics, affecting the Sicily mainland. See text for further explanations

Pleistocene sedimentary basins, both in the submerged Sicilian Continental Margin and in the uplifted coastal Northern Sicily mainland. These basins may be interpreted as fault-wedge basins (*sensu* Crowell, 1974), located at several releasing junctions between the main strike-slip faults which have the same offset.

The diachronous opening of these basins and the overall transcurrent fault trends and their geometric relationships enable us to reconstruct the neotectonic evolution of the westernmost segment of the Sicilian Chain. An attempt at neotectonic kinematic reconstruction is shown in the model in Fig. 14, where post-Miocene wrenching accounts for the

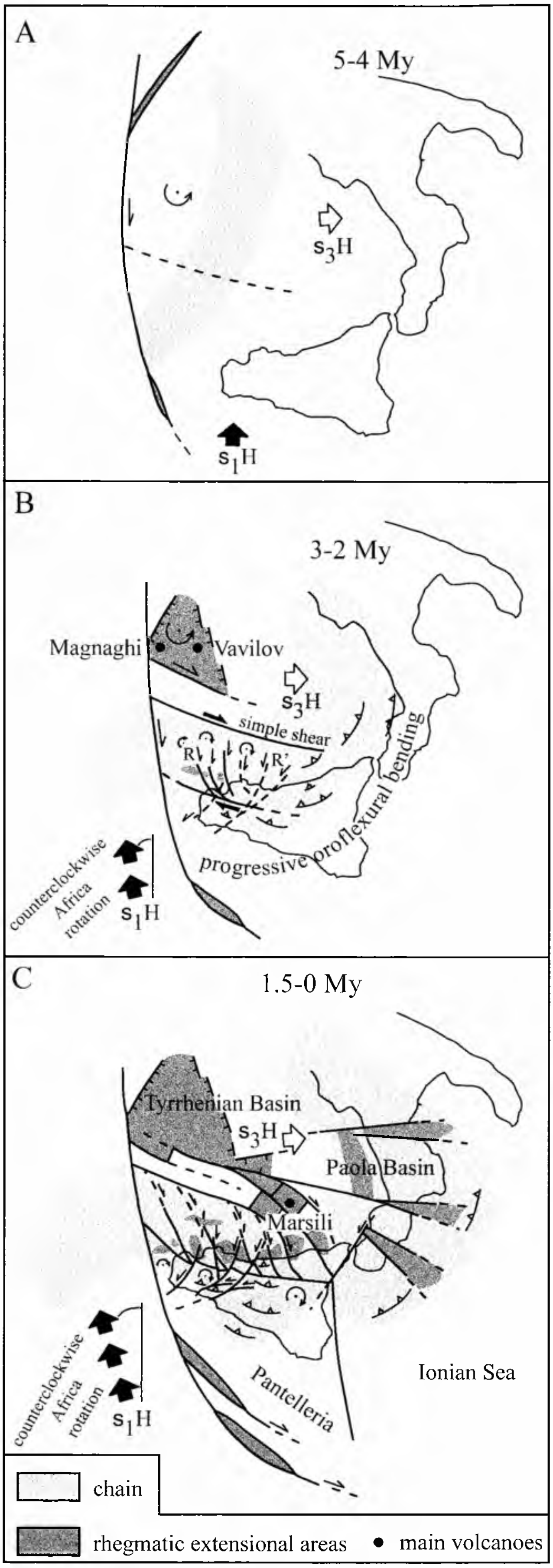

Fig. 15. Kinematic reconstruction of the Central Mediterranean during the last 5 My, based on wrench tectonics developed in the back areas of the Maghrebian Chain. The rhegmatic Tyrrhenian Basin appears to be an effect of deep-seated transcurrent fault movements, related to the counterclockwise rotation of the African Plate. The rotation induces W-E trending mega-shear zones and the progressive oroflexural bending of the chain. From A to C, the kinematic evolution of the Maghrebian Chain, is expressed by the progressive rotation of dragged blocks of various scale, extension processes superimposed on the more internal areas, and transpression and thrusting in the more external zones

opening of pull-apart basins filled with clastic sediments and where contemporaneous transtensional and transpressional mechanism are present.

According to the models of Chinnery (1963), Chinnery & Petrak (1967) and Rodgers (1980), the main occurrence of the main en-échelon faults is confirmed by the structural highs interposed between the main clastic sedimentation areas in the off-shore. In this context, the rhegmatic development of the basins appears to be confined to a first-order releasing bends (Trapani, Erice, Castellammare, Palermo and Cefalu Basins and their on land uplifted equivalent), organised in an overall horsetail splay system. The releasing process may have developed through the progressively more and more accentuated rotation towards the east of blocks bounded by the main NW–SE trending transcurrent faults.

In the submerged fault-wedge stretched basins, the extension areas occur along the main W–E (and locally NNE–SSW) dip-slip faults, which form releasing fault junctions in the submerged basins. In these areas the extension is counteracted by NNW–SSE and NE–SW trending strike-slip faulting-related thrust-inversion faults during the Pleistocene (Castellammare and Palermo Basins; Tricart *et al.*, 1990) .

In particular, the chronology characterising the neotectonic history of Northern Sicily Belt and its offshore may be summarised as follows:

– The earliest left-stepping dextral strike-slip faults were established in the Scuso Bank during the Early Pliocene. The adjacent transtensional depressions of Erice and Trapani Basins developed in different releasing oversteps. The on-land continuation of these submerged structures is represented by the strike-slip fault systems bounding the Trapani and western Palermo Mts.;

– The fault development during the Late Pliocene was also characterised by a more extended overlap between the main en-échelon right-stepping transcurrent faults, and led to further opening of the Erice and Castellammare Basins and the stretching processes in the Cefalu and Alicudi Basins. The on-land continuation of these submerged structures is represented by the strike-slip fault systems bounding the Madonie and Peloritani Mts.;

– During the Pleistocene, the activation of the more eastern en-échelon strike-slip system and the further development of the NW–SE system and their antithetic structures controlled the inversion tectonics in the Erice, Castellammare and Cefalu Basins. The on-land continuation of the main submerged structures is represented from the west to the east by the strike-slip fault systems bounding the junction between Mt. Inici-Mt. Grande and Mt. Catalfano-Mt. Galiello.

– The recognised transcurrent fault systems association may be interpreted as the expression of a deep-seated shear system (*sensu* Riedel, 1929), connected to the Tyrrhenian Basin opening (Boccaletti & Guazzone, 1972; Boccaletti *et al.*, 1976; Scandone, 1979) and its southeastern spreading migration (Rehault *et al.*, 1987; Kastens *et al.*, 1988) and to the counterclockwise African Plate rotation (Dewey *et al.*, 1989). The first-order structures are represented by the W–E trending transcurrent faults, with associated synthetic NW–SE trending R and antithetic N–S/NE–SW trending R' structures. The strike-slip network is also constituted by different orders of Riedel-like structures connected along the major order structures (see Moody & Hill, 1956 for theoretical wrench- and thrust-fault directions and Swanson, 1989 for terminology).

Fig. 15 shows the kinematic evolution of the Maghrebian Chain during the last 5 My, represented by its progressive oroflexural bending and related to the activation of the above-mentioned mega-shear deep-seated discontinuities. The main crustal transcurrent faults bound westward and southward the Tyrrhenian Basin, identifying its margins; along the southern margin, the W–E trending mega-shear zone produces the grid of minor order synthetic and antithetic Riedel structures in which the described pull-apart basins progressively develop from the west to the east. This first-order Riedel shear zone affects the belt, producing internal rotations of different scale chain blocks during the Plio-Pleistocene; in the submerged areas the strike-slip mechanisms mostly induce the accommodation space for the clastic sedimentation inside the main fault-wedge basins, while the transpressional regime, counteracting the Tyrrhenian spreading, characterises the central Sicily areas.

Strike-slip and rotation processes have induced NW–SE to W–E trending restraining bends characterising central Sicily, where the main evidence of restraining overstep faulting is represented by the Kumeta and Busambra push-up blocks (*sensu* Mann *et al.*, 1983). The convergence of transcurrent fault strands therefore appears to be the cause of the partial emersion of the Plio-Pleistocene basinal areas and of the overall uplift of the orogen.

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