PERGAMON

Journal of Structural Geology 26 (2004) 207–219

JOURNAL OF STRUCTURAL GEOLOGY

www.elsevier.com/locate/jsg

Structural evidence for deformation by block rotation in the context of transpressive tectonics, northwestern Sicily (Italy)

P. Guarnieri*

Dipartimento di Scienze Geologiche, University of Catania, Corso Italia 55, 95129 Catania, Italy

Received 23 March 2003; accepted 9 June 2003

Abstract

This paper presents geological and structural data on a sector of the Apenninic–Maghrebian Chain in northwestern Sicily. The predominantly strike-slip structures are related to the activation of a dextral strike-slip shear zone oriented N120°, which was active between the Late Miocene and the Early Pliocene. This structure (Caccamo Shear Zone) belongs to the Southern Tyrrhenian System that constitutes the southern kinematic junction to the Calabrian Arc. The identification of transpressive structures in the southern Tyrrhenian offshore that were active during the Messinian–Early Pliocene allowed the definition of this sector as transpressive back-stop of the chain.

During the transpressive stage dextral transcurrent movements along the Caccamo Shear Zone led to the activation of a multiple set of parallel sinistral faults, conjugate and antithetic to the master fault. The activation of these structures determined a deformation by block rotation which provoked an overall clockwise rotation of 38°.

The data show how the rotations observed in the internal sectors of the chain might be caused by the activation of multiple strike-slip fault sets and that the rotational mechanism around vertical axes is connected to transpressive tectonics. The use of kinematic models allow quantification of the blocks rotation due to the combined action of multiple sets of strike-slip faults with modest displacements and to demonstrate that the rotation of blocks and their lateral movement constitute two different, contemporaneous expressions of a single deformational event.

Keywords: Block rotation; Transpression; Late Miocene–Early Pliocene; Sicily

1. Introduction

The complexity of the internal structure of the Sicilian orogenic belt is a direct consequence of the complicated setting inherited since the Mesozoic, and of its long polyphase deformational history. The distinct character of the global evolution of the Apenninic–Maghrebian chain is that of thin-skinned tectonics that involves the Meso-Cenozoic cover in a ramp and flat style, causing the emplacement of extensive zones of frontal nappes. The structuring of the thrust belt occurred along an Africa-vergent vector that involved, from the Miocene onward, paleodomains of different crustal character (Fig. 1).

The present position and the curvature of the structures on a regional scale, like the Calabrian Arc (Fig. 1), suggest that the orientation of the main stress field (σ_1) has not undergone significant variations on a large scale between the Serravallian to the Pliocene; this is essentially due to the high degree of freedom of the Calabrian Arc as a result of the NW-oriented subduction of the Ionian slab (Scandone, 1979).

In Sicily, the Late Miocene to Pliocene syn-orogenic deposits are often exposed within NW–SE elongate depressions. Regarding the western portion of the Cefalù Basin, the same characteristics have also been observed in the Tyrrhenian offshore (Del Ben and Guarnieri, 2000).

The fact that the regional stress field and the structures present in all of Sicily are not coaxial has been attributed to clockwise rotation around vertical axes. Numerous paleomagnetic studies have been carried out recently all over Sicily on the pre-orogenic successions of the marly limestones of the Scaglia Fm. (Late Cretaceos–Eocene), which generally show clockwise rotation around vertical axes, in some cases exceeding 100° (Oldow et al., 1990). Paleomagnetic analysis has

---

* Tel.: +39-95-7195713; fax: +39-95-7195712.
E-mail address: guarnier@mbox.unict.it (P. Guarnieri).

0191-8141/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0191-8141(03)00102-0

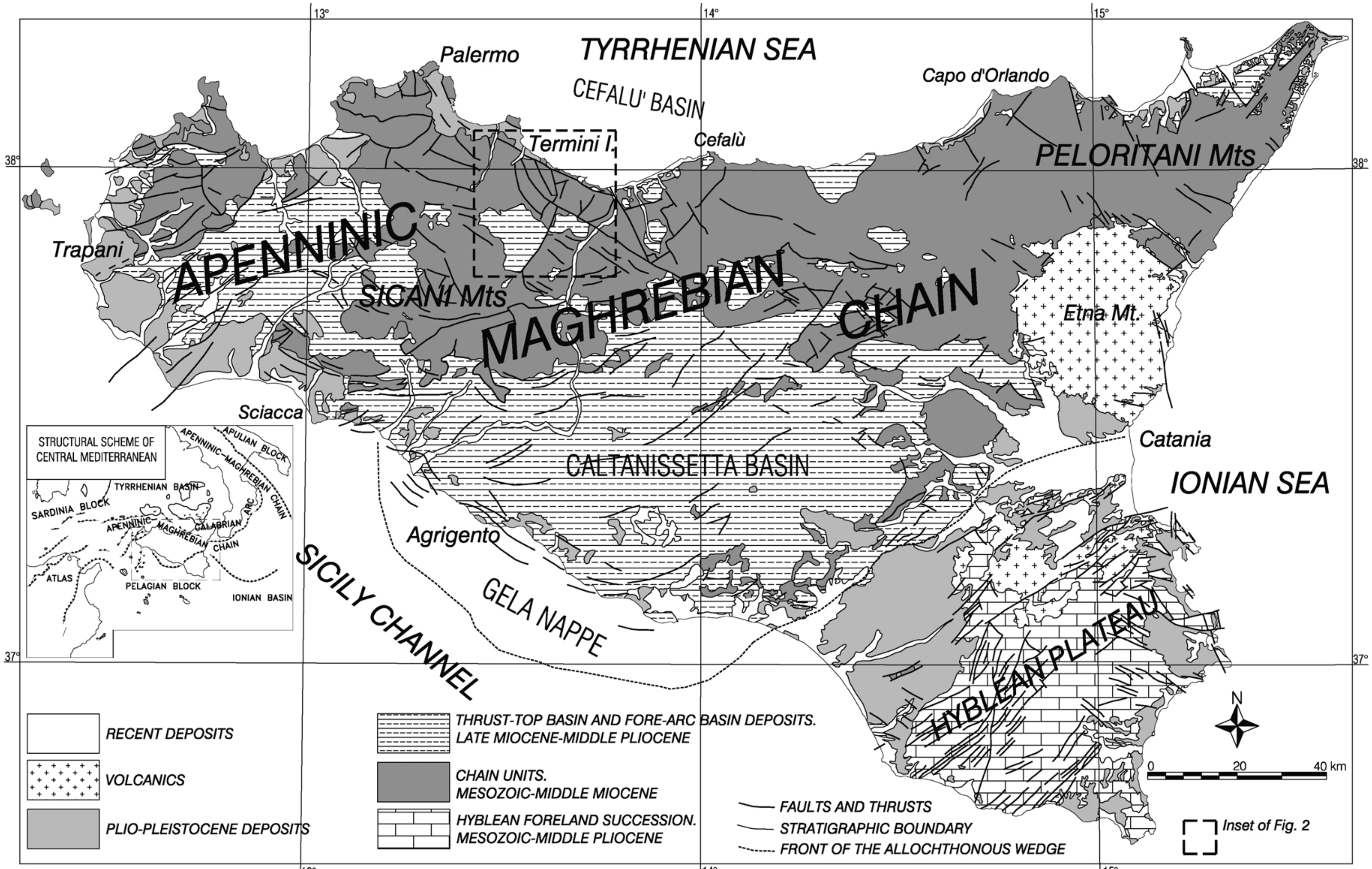


Fig. 1. Structural scheme of Sicily. Inset at left shows the structural setting of the central Mediterranean with the main structural domains. Boxed area encloses the study area.

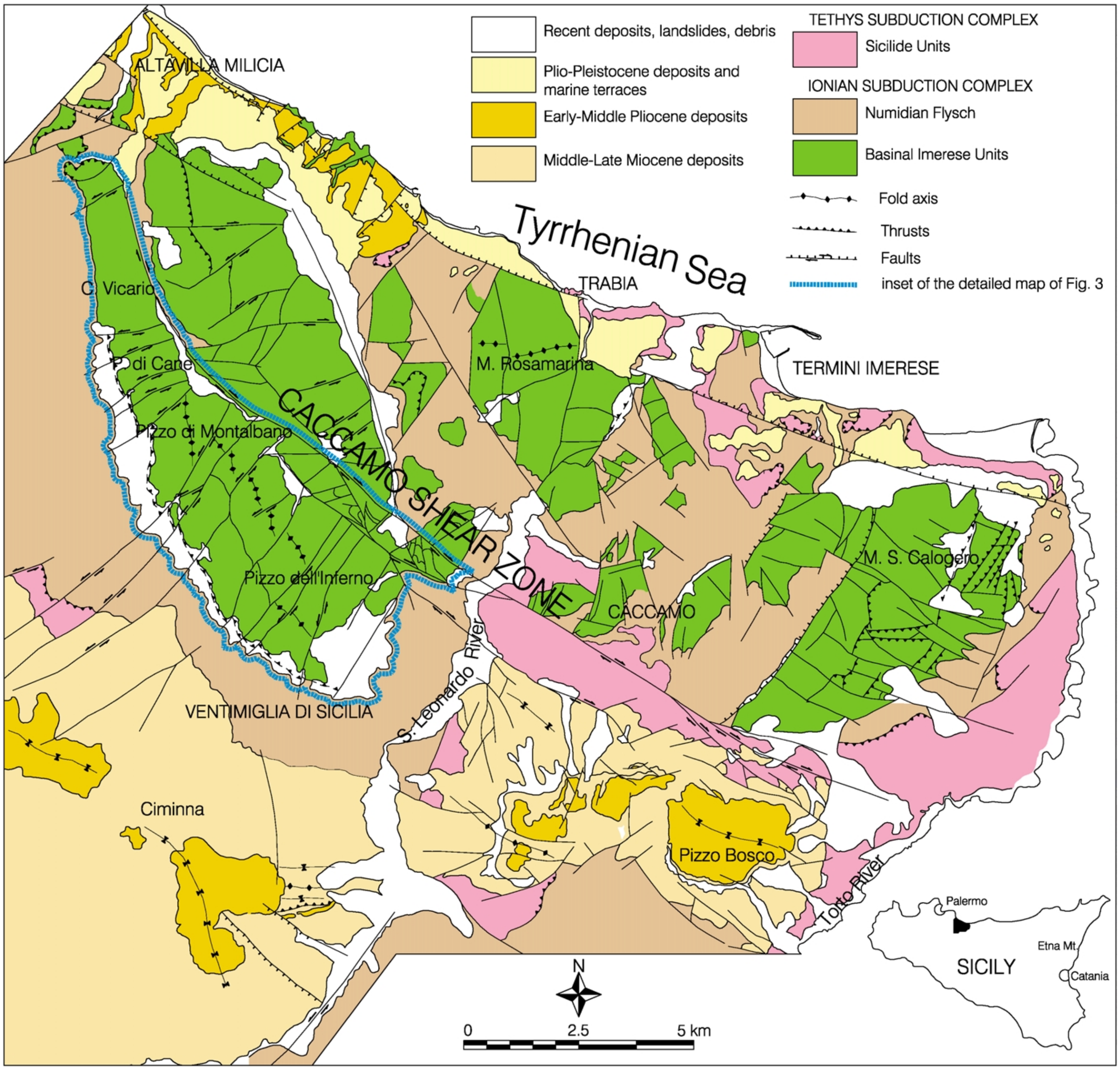


Fig. 2. Structural scheme of the Trabia–Termini Imerese Mountains. The Caccamo Shear Zone (CSZ) constitutes one of the main elements of dextral transpressive tectonics superimposed onto thrust structures with a middle Miocene kinematic vector oriented NW–SE. The deposits of the Ciminna–Pizzo Bosco basin are exposed within a footwall syncline elongated parallel to the CSZ, testifying to the transpressive character of the Messinian to early Pliocene deformation.

furthermore been performed on syn-orogenic successions that range from the Late Miocene to the Pleistocene, such as the marly limestones of the Trubi Fm. (Grasso et al., 1987), the Tortonian–Pleistocene sequences of southwestern Sicily (Speranza et al., 1999), or the Early–Middle Pliocene sequence exposed in the southwestern portion of the Gela Nappe (Scheepers and Langereis, 1994).

In general, rotational movements in Sicily show a clockwise sense attributed to the extensive overthrusting of the allochthonous covers of the Apenninic–Maghrebian Chain onto the African foreland in a context of thin-skinned tectonics.

It is the aim of the present study to furnish evidence of a block rotation deformative mechanism that is closely related to the transpressive–transcurrent tectonics observed in this sector of the chain, and to quantify the amount of rotation of fault-bounded blocks (Ron et al., 1984; Nur et al., 1989).

2. Tectonic setting

Recent works based on offshore CROP-seismic data illustrate the deep structure of the southern Tyrrhenian basin (Finetti et al., 1996; Del Ben and Guarnieri, 2000). In particular the Calabrian Arc–Tyrrhenian system represents an example of a forearc/back-arc system as the accretionary wedge was formed both on Africa continental crust (below Sicily) and on Ionian oceanic crust (below Calabria) (Finetti and Del Ben, 1986). This setting, started since middle Miocene, is testified by the curvature of the allochthonous front of the entire chain (Fig. 1), by the approach along transcurrent faults of tectonic units belonging to internal and external domains, by the development of foreland basin systems in Sicily and of a true forearc in the Ionian sector. During the Messinian–Early Pliocene, northwestern Sicily was affected by a deformative event related to dextral transpressive tectonics that marked the involvement of the deep crustal levels of the African margin. The identification of transpressive structures in the southern Tyrrhenian offshore (Cefalù Basin) (Del Ben and Guarnieri, 2000) that were active during the Messinian–Early Pliocene has allowed the definition of this sector as dextral transpressive back-stop of the chain (Guarnieri et al., 2002).

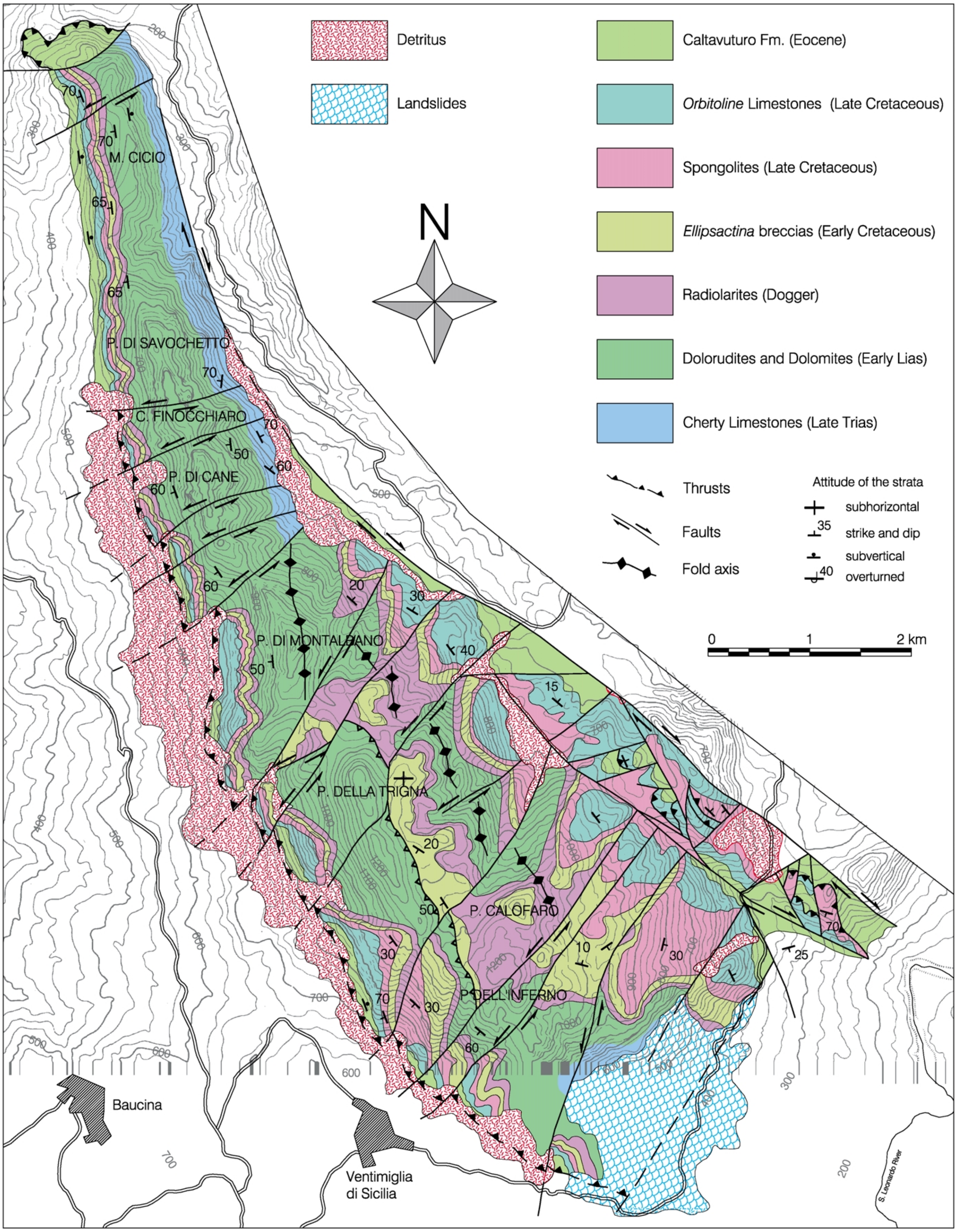
Activation of transpression is contemporaneous with the overthrusting of the tectonic wedge onto the African foreland during the Messinian to Early Pliocene, while from the Late Pliocene onward it becomes the southern kinematic junction of the Calabrian Arc (Guarnieri et al., 2002). The progressive indentation of the African continental margin has provoked complex deformation with the activation of transcurrent dextral fault systems prevalently oriented NW–SE, which constitute the Southern Tyrrhenian System (Lentini et al., 1996). The Southern Tyrrhenian System is an expression of the diachronous collision between the lithospheric buttress of the chain and the African margin. Collision did in fact initiate from the Late Tortonian onward, first involving the western areas of Sicily and later extending to its eastern part.

In northwestern Sicily, the mountain range on the outskirts of Termini Imerese village is mainly composed of the External Units of the Apenninic–Maghrebian thrust belt represented by Late Triassic to Late Oligocene basin and slope sequences, followed by Early Miocene quartz–arenitic flysch-type covers. Since the Early Langhian, foredeep sedimentation, marked by marl deposits, took place and was successively interrupted by the tectonic emplacement of the Sicilide Units. The Apenninic–Maghrebian Chain units were in turn deformed from Middle Miocene to Early Pleistocene time, progressively involving the units of the African margin (Trapanese Units) (Fig. 2). The Apenninic–Maghrebian Chain forms a regional duplex system in which the deeper element is represented by the External Thrust System (Bianchi et al., 1989; Roure et al., 1990; Lentini et al., 1996; Guarnieri et al., 2002). In the hinterland of the Chain, along the NW sector of the Sicilian Tyrrhenian margin, Messinan to Early Pliocene dextral transpressive structures have been recognised (Guarnieri, 1998; Guarnieri et al., 1998). These structures show crustal features and are present both in the Trabia Mountains area and in the corresponding offshore area (Cefalù Basin) (Del Ben and Guarnieri, 2000). These structures represent the superficial expression of the continental collision that, from the Tortonian onward, involved the African margin (Lentini et al., 1996); furthermore, they represent the kinematic junction to the progressive southeastward advance of the Calabrian Arc (Finetti et al., 1996; Del Ben and Guarnieri, 2000) related to the northwestward subduction of the Ionian crust (Scandone, 1979; Malinverno and Ryan, 1986; Mascle et al., 1988; Patacca and Scandone, 1989).

From the Late Tortonian to the Early Messinian, siliciclastics sedimentation occurred in these areas. These deposits unconformably overlie the allochthonous units of the chain and fill the Ciminna–Pizzo Bosco satellite basin. The Messinian evaporitic sequences were controlled by synsedimentary transpressive tectonics. During the Early Pliocene, pelagic sedimentation testifies a general deepening of the basins, followed along an unconformity by regressive sandy-calcarenite sequence of Middle Pliocene age. These deposits, that outcrop along the Tyrrhenian coast, are arranged in northward prograding foreset, and are cut upsection by a toplap surface, above which a transgressive sequence consisting of Late Pliocene–Pleistocene conglomerates and sands begins (Guarnieri et al., 1998) (Fig. 2).

The structural data allow interpretation of the Ciminna basin as a footwall basin of the thrusts of the deeper Trapanese Units (deformed African margin). First-order directions of the transcurrent postcollisional tectonics are N120°-oriented and appear oblique to the middle Miocene thrust fronts. The deformation evolved into two stages distinguished on the basis of their different deformative styles. The first stage shows a transpressive character and causes the activation of reverse faults related to the Caccamo Shear Zone, which brought about the uprise of the basinal carbonatic units of the Imerese Units of the Trabia Mountains, probably leading to the reactivation of an ancient oblique ramp. This structure is responsible for the

Fig. 3. Geologic map of the Pizzo dell'Inferno–Pizzo di Cane mountain belt. The mountain ridge consists of a fold anticline elongated NNW–SSE. In the southern sector (Pizzo dell'Inferno–Pizzo di Montalbano) both the WSW-dipping forelimb and the ENE-dipping backlimb can be observed. The northern sector is constituted only by the forelimb of the fold, which is cut to the east by the master fault. On the western flank the thrust that can be followed along the whole structure is related to transpressive tectonics. This tectonic contact is used to evaluate the amount of displacement along the antithetic transcurrent sinistral faults that bound the rotated blocks.


Detritus
Landslides
Caltavuturo Fm. (Eocene)
Orbitoline Limestones (Late Cretaceous)
Spongolites (Late Cretaceous)
Ellipsactina breccias (Early Cretaceous)
Radiolarites (Dogger)
Dolorudites and Dolomites (Early Lias)
Cherty Limestones (Late Trias)
Thrusts
Faults
Fold axis
Attitude of the strata
subhorizontal
35 strike and dip
subvertical
40 overturned
N
0
1
2 km
M. CICIO
P. DI SAVOCHETTO
C. FINOCCHIARO
P. DI CANE
P. DI MONTALBANO
P. DELLA TRIGNA
P. CALOFARO
P. DELL'INFERNO
Baucina
Ventimiglia di Sicilia
S. Leonardo River

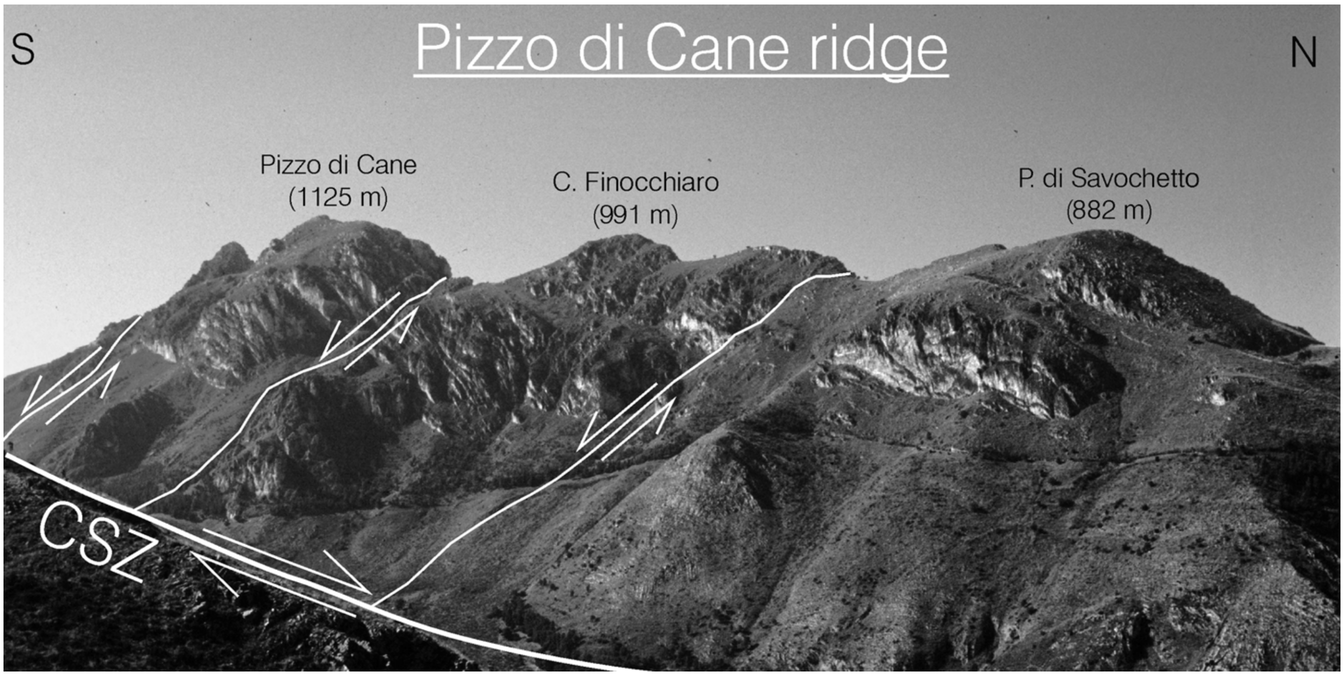


Fig. 4. Panoramic overview of the Pizzo di Cane ridge in the Trabia–Termini Imerese mountain belt. The photograph depicts the good exposure of the carbonatic rocks of the Imerese Tectonic Unit. In particular, the visible stratigraphic boundary between the Late Triassic cherty limestones and the Early Liassic dolomites to the right.

folding that affected the late Miocene covers of Ciminna (Guarnieri, 1998). The fold axes observed at Ciminna and in the Pizzo Bosco area (Guarnieri et al., 1998) are N120°-oriented and thus subparallel to the principal shear zone.

3. Structural data and geometrical analysis of fault patterns

The ridge of the Trabia Mountains is characterized by transcurrent structures connected to transpressive tectonics of Messinian to Early Pliocene (Guarnieri, 1998; Guarnieri et al., 1998; Del Ben and Guarnieri, 2000). The strike-slip structures are related to the development of a transcurrent dextral shear zone (Caccamo Shear Zone—CSZ; Guarnieri, 1998; Del Ben and Guarnieri, 2000) N120°-oriented, which is part of the Southern Tyrrhenian System (Finetti et al., 1996).

The deformation in this sector of the chain that occurred during the Messinian to Early Pliocene time interval is represented both by fold and fault systems. The folding phase in particular affected only the Messinian deposits, while Early Pliocene tectonics was mainly characterized by activity of transcurrent faults (Fig. 3). These latter are superimposed on previous fold structures. Most of the deformation was accommodated along the dextral master fault (CSZ) and conjugate fault systems, which show an overall fractal geometry regarding both the geometric distribution of faults and the strain accommodated by them (Guarnieri, 2002). The subsidiary faults probably develop at the tip of this shear zone.

This area has been selected for the excellent exposure of the fault planes (Fig. 4), and data regarding the orientation of fault planes have been collected for use in determining the direction of movement.

Data were obtained from 135 well-exposed fault planes scattered all over the area, and of varying dimensions (Fig. 5). The measurements include dip and strike of the fault planes and, where possible, the angle formed by striae (slip vector) with respect to the fault strike (pitch). The sense of movement along the fault planes has been determined according to the criteria discussed by Hancock (1985) and Petit (1987). In particular calcite steps (mineral steps), riedel shears, stylolithic peaks and conjugate shear fractures have been observed. The amount of displacement has been seen to vary from a few centimetres to several hundred metres.

The aspects of the abovementioned fault populations have been considered plotting the pole distribution of faults (lower hemisphere), the distribution of planes and the contouring of the pole trends. Furthermore left-lateral faults have been separated from right-lateral ones for better highlighting the presence of more fault sets.

Fig. 5 represents the whole fault data set, 77% of which is constituted by subvertically oriented planes with strike-slip movement. The dextral transcurrent faults fall into two classes oriented more or less N–S and E–W, respectively (Fig. 6), but the most interesting observations were made on the sinistral transcurrent faults (Fig. 7). In particular, two distinct fault sets oriented N30° (set #1) and N55° (set #2)

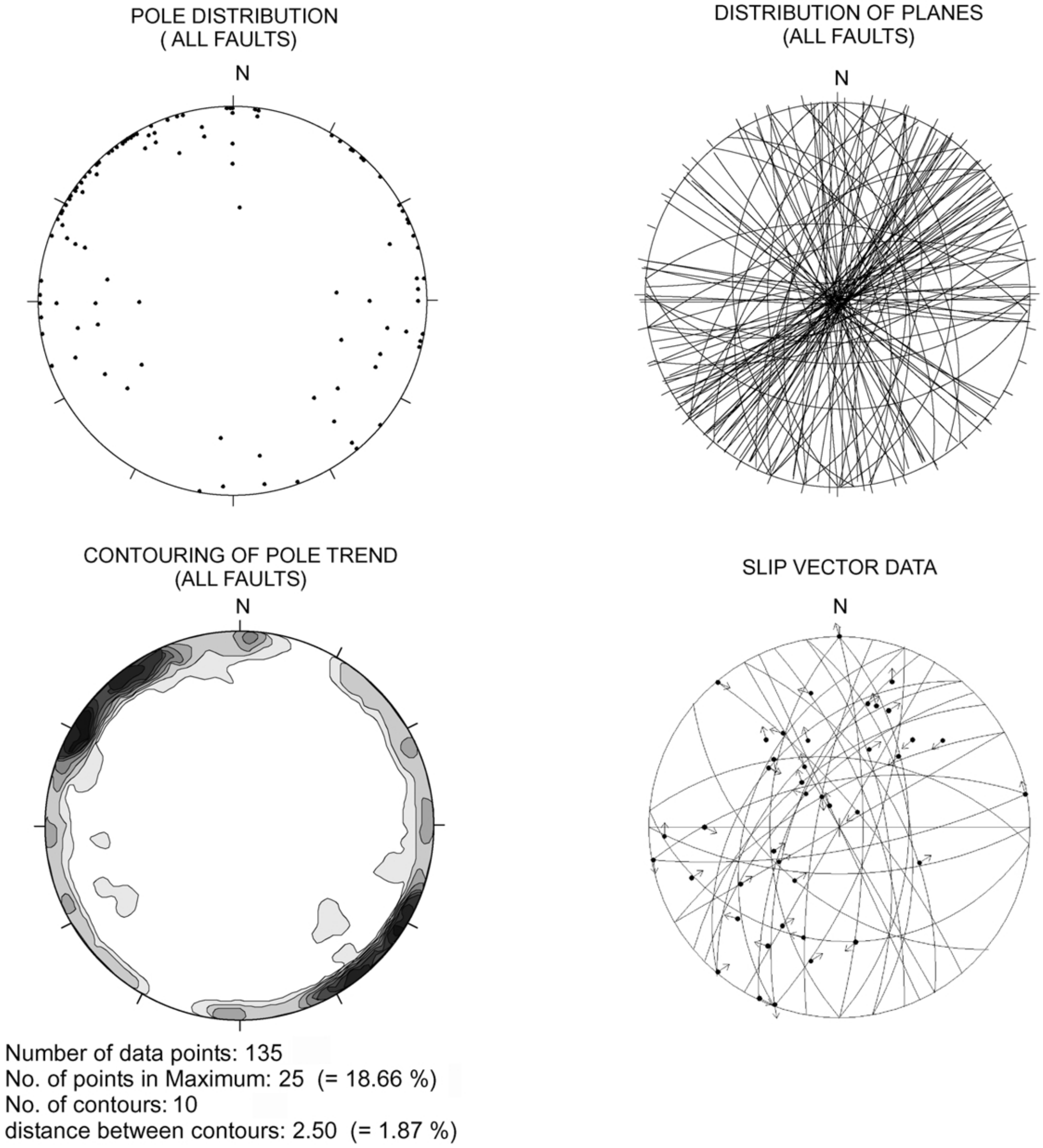


Fig. 5. Diagrams representing the mesostructural analysis carried out on fault planes along the Pizzo dell'Inferno–Pizzo di Cane ridge.

have been recognized. In the field, they are associated with two parallel fault sets; furthermore set #1 is the most recent and cuts the faults of set #2.

The two sinistral transcurrent fault sets represent antithetic systems to the master fault oriented N120° and connected with the Caccamo Shear Zone, while the right-lateral faults are synthetic to the master fault and coeval with the left-lateral, and in general they separate fault-bounded blocks (Fig. 2) with differential rotations. The age of these fault systems is, however, Messinian–Early Pliocene. In fact, the northward prosecution of the CSZ is interrupted by the N100°-oriented fault system with predominantly vertical displacements. These normal faults are sutured by the calcarenitic deposits of the middle Pliocene age.

The northwestward bending of the master fault from N120° to N150° provokes a different orientation of the conjugated fault systems that, however, maintain constant geometric relationships with the master fault.

4. Kinematic analysis

There are numerous publications dealing with deformation by block rotation (Freund, 1970; Ron et al., 1984; Garfunkel, 1989; Nur et al., 1989), and in general these authors show that the combined action of strike-slip faults with modest displacements and minor block rotation represents an efficient deformative mechanism that is able to modify significantly the length of the faulted zone and furthermore it is a deformational style that can be found in many places of the planet. One of the important concepts

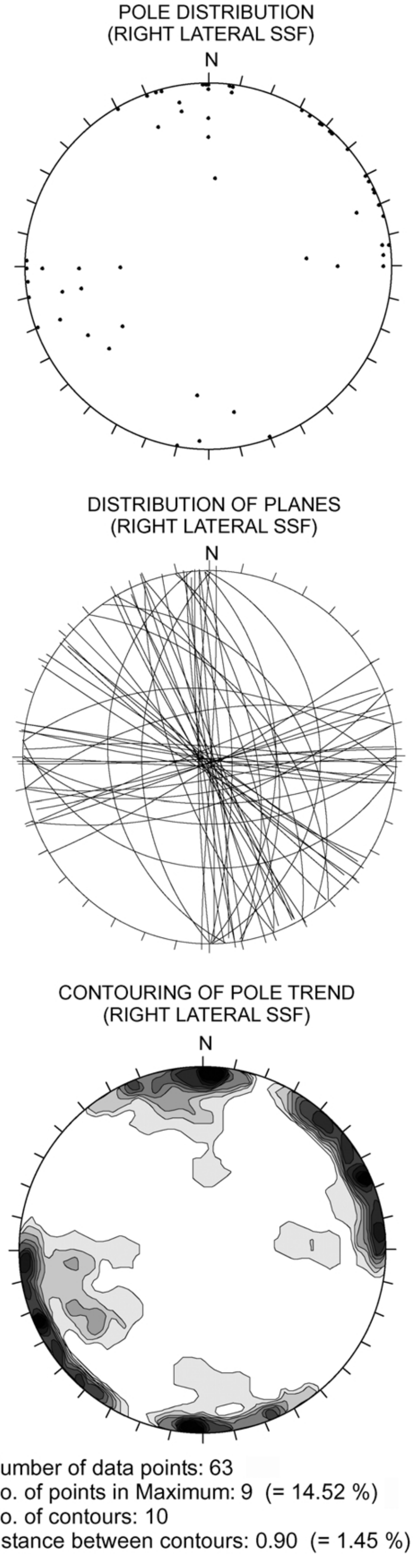


Fig. 6. Stereo-plot of dextral strike-slip faults. Two main fault sets can be distinguished, which trend E–W and NNW–SSE, respectively.

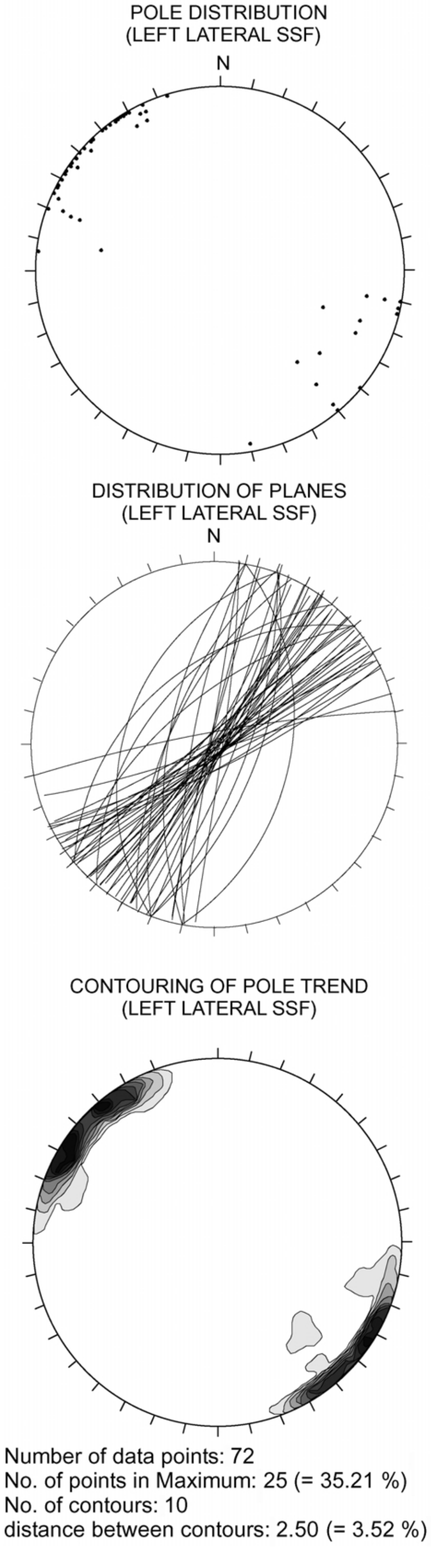
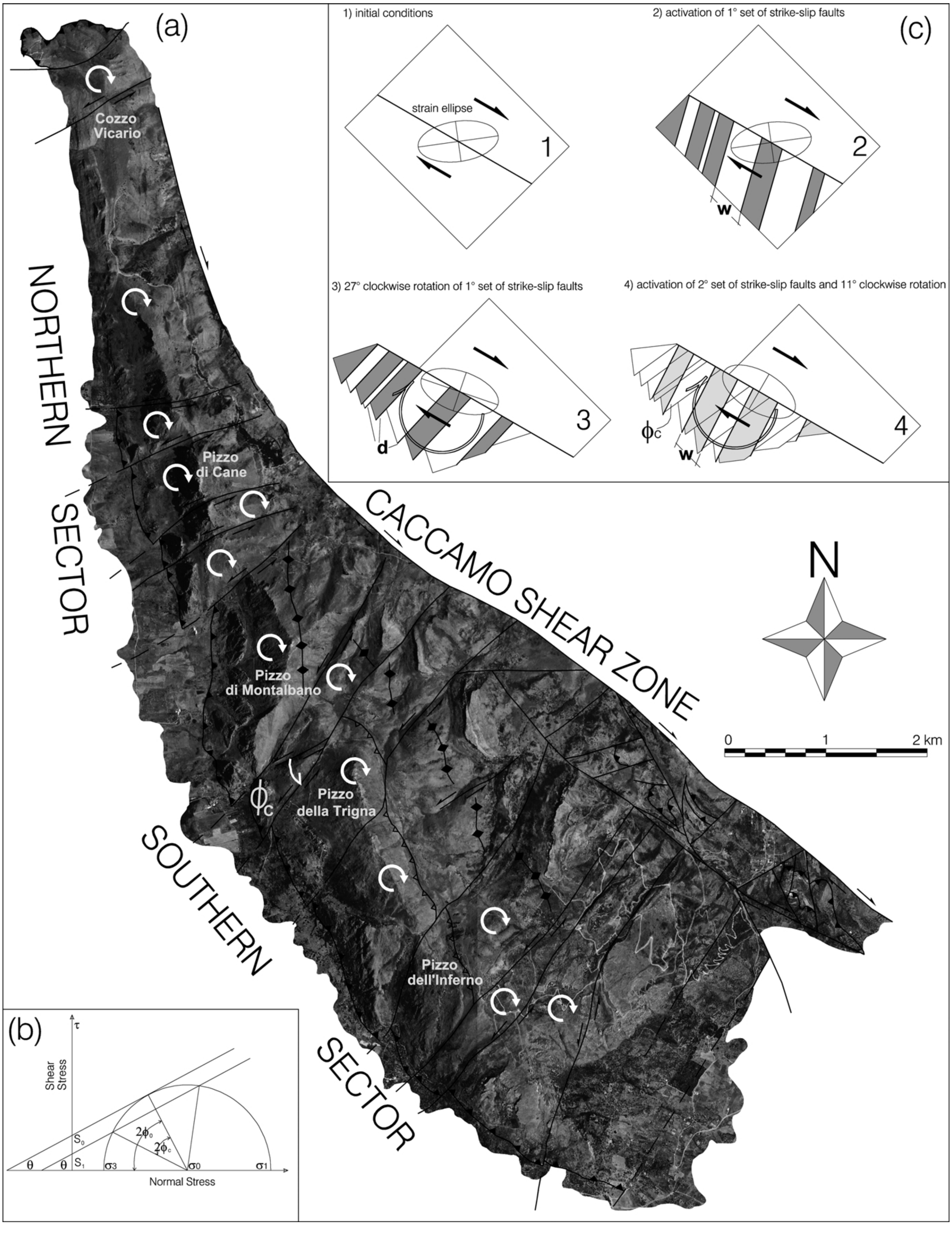


Fig. 7. Stereo-plot of sinistral strike-slip faults. These fall into two main sets: set #1 oriented N30°E, set # 2 oriented N55°E, which activated successively and constitute the boundaries of the faulted blocks.


(a)
Cozzo Vicario
NORTHERN SECTOR
Pizzo di Cane
Pizzo di Montalbano
Pizzo della Trigna
Pizzo dell'Inferno
SOUTHERN SECTOR
CACCAMO SHEAR ZONE
φc
N
0
1
2 km
(b)
τ
Shear Stress
S0
S1
θ
θ
σ3
σ0
σ1
2φ0
2φc
Normal Stress
(c)
1) initial conditions
strain ellipse
1
2) activation of 1° set of strike-slip faults
w
2
3) 27° clockwise rotation of 1° set of strike-slip faults
d
3
4) activation of 2° set of strike-slip faults and 11° clockwise rotation
φc
w
4

regarding deformation by faulting is that in the moment when a faulted block slides upon another, this block must necessarily rotate, just as happens with the books on a shelf, and in the same moment also the faults rotate since they represent the boundaries of the same rotating block. In this sense the rotation of blocks and their lateral movement constitute two different, contemporaneous expressions of a single deformational event. In the considered models (Freund, 1970; Ron et al., 1984; Garfunkel, 1989; Nur et al., 1989) it is assumed that the faulted blocks remain in contact with each other and with the reference boundary that is represented by the master fault delimiting the parallel transcurrent fault set. The parameters that can be obtained in the ideal case on a set of parallel faults, with varying space between each other, and a rectilinear reference boundary are the following (Fig. 8a) (Nur et al., 1989):

$$K = d/w \tag{1}$$

where $d =$ offset, $w =$ spacing and $K =$ shear gradient.

Furthermore all blocks rotate with the same angle δ considering that newly formed faults activate according to well-known directions that can be determined by the relationship $(45° - \Phi/2)$ from the principal stress direction. In this case $\alpha =$ the angle between the direction of the fault and the reference boundary. The equation that links angle α with rotation δ and the shear gradient K is the following:

$$K = \cot\alpha - \cot(\alpha - \delta) \tag{2}$$

From a geomechanic standpoint the shear strength that acts upon a fault plane must in the module exceed the resistance to slip along the same fault according to the equation:

$$\tau = S_1 \mu \sigma_0 = S_1 \mu (\sigma - p) \tag{3}$$

where $\tau =$ shear strength, $S_1 =$ cohesion strength, $\sigma_0 =$ normal effective strength, $\mu =$ friction coefficient, $\sigma =$ normal strength and $p =$ pore pressure.

If we consider newly formed faults that initiate in the optimum shear direction relative to the maximum stress, as visible in the Mohr diagram (Fig. 8b), it follows that in the moment when deformation and rotation begin, the shear strength acting on the plane diminishes and at the same time the normal strength increases to the degree that beyond a certain amount of rotation ($\phi_C =$ critical angle) it becomes mechanically easier to produce further rupturing rather than continuing to slide along the same plane; according to some authors (Nur et al., 1989) the critical angle lies in the range between 25° and 45°.

Table 1
Kinematic parameters of faulted blocks along the Pizzo dell'Inferno–Pizzo di Cane ridge

No.	w (m)	d (m)	$\alpha° + \delta°$	k	$\alpha°$	$\delta°$
Southern sector						
1	1250	300	86	0.24	72	14
2	350	100	90	0.29	73	17
3	650	125	90	0.19	79	11
4	1200	200	83	0.17	73	10
5	750	60	93	0.08	88	8
6	300	100	92	0.33	73	19
7	700	50	78	0.07	73	5
8	550	40	84	0.07	79	5
Average	719	122	87	0.18	76	11
Northern sector						
1	500	100	116	0.20	108	8
2	800	50	106	0.06	103	3
3	300	70	104	0.23	91	13
4	400	50	104	0.13	98	6
Average	500	68	108	0.16	100	8

In the mountains around Termini Imerese rotations relative to blocks bounded by a multiple set of subparallel faults have been observed with spacings of 0.5–1 km. The Pizzo di Cane ridge (Fig. 4) is elongated NNW–SSE and can be subdivided into two areas, namely the 'southern sector' between Pizzo dell'Inferno and Pizzo di Montalbano, and the 'northern sector' between Pizzo di Cane and Cozzo Vicario (Fig. 8a).

The southern sector constitutes a complete anticlinal fold with its forelimb dipping from WSW to SW and its backlimb dipping NE. The forelimb is truncated by a reverse fault connected to the transpression, while the backlimb is cut by the master fault belonging to the Caccamo Shear Zone, which in this sector shows an orientation of N125°. The strike-slip faults associated with the Caccamo Shear Zone are split into two subparallel sets; the first one is more developed with an orientation of about N30° while the second, less evident and with an orientation of about N55°, is cut by the former (to the east and west of Pizzo della Trigna) (Fig. 8c). Applying the previously described model a mean value has been calculated for the rotation of the N30°-trending transcurrent fault set (#2), $\delta = 11°$ (Table 1). The N55°-trending set of transcurrent faults is too poorly developed to permit application of the model, because it has not been possible to reconstruct the entire fault set; yet its presence alone furnishes an important piece of information, which is the angle ϕ_C. This angle corresponds to the rotation of set #1 with an orientation of N55°, before set #2 oriented N30° became active. In this case multiple transcurrent fault sets have formed, the most recent of which (#2) blocked and

Fig. 8. (a) Clipped aerial photograph of the Pizzo dell'Inferno–Pizzo di Cane ridge. The morphological lineaments highlight the faulted blocks that are bounded by sinistral strike-slip faults, and their rotational movement. (b) Mohr diagram showing how an increasing amount of rotation (angle ϕ) is accompanied by increasing stress up to a threshold value beyond which slip along the fault stops and the rotation is blocked (critical angle ϕ_C), with consequent activation of a new fault set. (c) Kinematic model of block deformation at the Pizzo dell'Inferno–Pizzo di Cane ridge. The fault set #2 accommodates a clockwise rotation of 27° while the set #1 attains up to 11° of rotation. Block rotation is furthermore proportional to the displacement measured along the master fault.

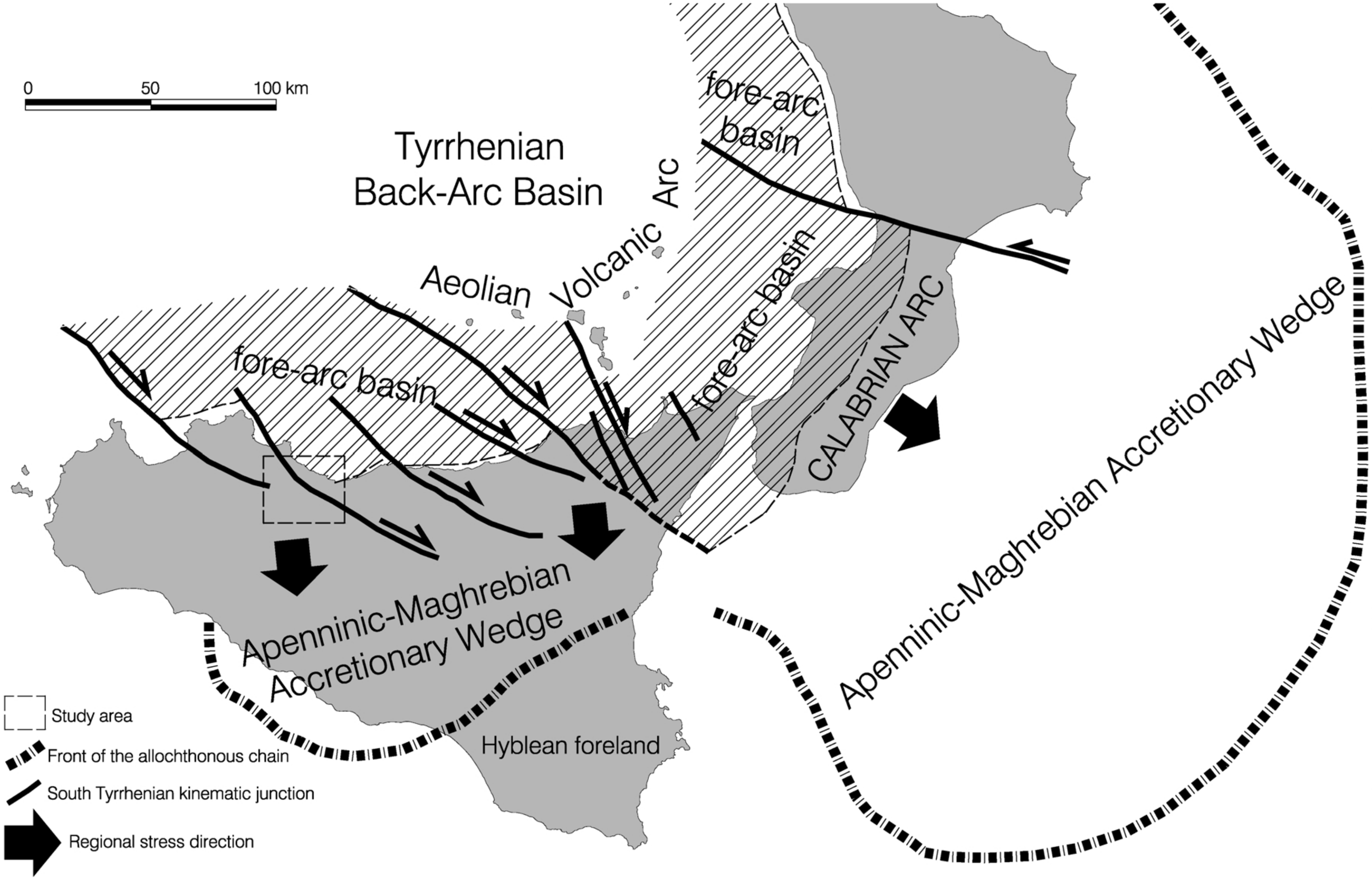


Fig. 9. Structural sketch-map of the Calabrian Arc–Tyrrhenian system. The northern margin of Sicily corresponds to the kinematic junction of the Calabrian Arc. The involvement of the Africa crust in the deformational front of the chain corresponds to the transpressive stage during which the stress direction acted at near N170° in Sicily and NW–SE in correspondence of the Calabrian Arc.

then rotated the older one (#1). Rotation of 27° at an angle (ϕ_C) occurred at set #1, which can be measured on the map (Fig. 8a). Considering the sum of rotations obtained in this way, the southern sector of the Pizzo di Cane ridge has undergone clockwise rotation by 38°.

In the northern sector only the forelimb of the thrust anticline of Pizzo di Cane can be found, and its dip is subvertical, in some cases even overturned. The direction of the master fault is such as to present a notable dip-slip component, and probably this orientation has conditioned the deformation in the northern sector, whose structural characters render it another type of fault domain as compared with the southern sector. The reference boundary has a general direction of N140° and the sinistral transcurrent fault set shows a mean orientation of N50°. The obtained rotations (δ) cluster around an average value of 8° (Table 1) but this value must be increased by at least 4° due to the displacement measured along the sinistral transcurrent fault that bounds the northern portion of Pizzo di Montalbano. This structure lies in a place that corresponds to the zone of maximum curvature of the master fault, which changes from N125° to N140°. The displacement measured at this fault very likely causes the additional rotation of 4°, acting concomitantly with the more northerly fault of the area at Cozzo Vicario, thus constituting a faulted block of major dimensions. These structures continue towards the SW and, in spite of appearing less evident in the field because there is a change in the outcropping lithologies from carbonatic deposits to the terrigenous clastic and evaporitic deposits of the Ciminna basin, the Messinian fold structures of Ciminna and Pizzo Bosco are as well translated and rotated in the same way as the deformation described above (Fig. 8c).

5. Discussion and conclusions

The rotational amounts obtained from the analysis of the structural data confirm those derived from paleomagnetic analysis conducted on the deposits of the Early Pliocene Trubi Formation in an adjacent area (Grasso et al., 1987). This means that the present-day orientation of the structural depressions hosting the siliciclastic and evaporitic sequences (Ciminna–Pizzo Bosco basin) must be corrected by an amount of rotation of about 40°. In this way it would be possible to obtain a principal paleostress direction σ_1 of about N170° (Fig. 9). When analyzing the regional stress field and considering the curvature of the Calabrian Arc and the opening of the Tyrrhenian basin, a NW–SE orientation is observed that can be taken as constant from the Late Miocene all through the Pliocene (Scandone, 1979; Malinverno and Ryan, 1986). The clockwise rotations determined by means of the analysis of the structural data can be attributed to the transpressive/transcurrent tectonics dominating in this sector as a transpressive back-stop of the Apenninic–Maghrebian chain from the Late Miocene onwards (Guarnieri et al., 2002), and not to the effect of oroclinal bending due to the advance of the allochthonous wedge of the chain. In conclusion, since the Caccamo Shear Zone has been found to have deep crustal features in connection with the African continental crust (Guarnieri, 1998; Del Ben and Guarnieri, 2000), it is possible to state that with the advance of the Calabrian Arc at a kinematic NW–SE vector, an oblique collision has been established (i.e. a transpression zone of Harland (1971)) in which the angle of convergence between the Calabrian Arc and Africa (Sanderson and Marchini, 1984; McCoss, 1986; Jamison, 1991; Krantz, 1995;) is about 30° and leads to a reorientation of the principal stress (σ_1) from NW–SE to NNW–SSE (Fig. 9).

Acknowledgements

The author thanks Prof. J.P. Evans and an anonymous referee for the fruitful comments and suggestions. This study was supported by the MURST Cofin-2002 and Fondi di Ateneo 2002 grants to F. Lentini.

References

Bianchi, F., Carbone, S., Grasso, M., Invernizzi, G., Lentini, F., Longaretti, G., Merlini, S., Mostardini, F., 1989. Sicilia orientale: profilo geologico Nebrodi-Iblei. Memorie della Società Geologica Italiana 38, 429–458.

Del Ben, A., Guarnieri, P., 2000. Neogene transpression in the Cefalù Basin (Southern Tyrrhenian): comparison between land and marine data. Memorie della Società Geologica Italiana 55, 27–33.

Finetti, I., Del Ben, A., 1986. Geophysical study of the Tyrrhenian opening. Bollettino di Geofisica Teorica e Applicata 28 (110), 75–156.

Finetti, I., Lentini, F., Carbone, S., Catalano, S., Del Ben, A., 1996. Il sistema Appennino Meridionale-Arco Calabro—Sicilia nel Mediterraneo Centrale: studio geologico-geofisico. Memorie della Società Geologica Italiana 115, 529–559.

Freund, R., 1970. Rotation of strike-slip faults in Sistan, southeast Iran. Journal of Geology 78, 188–200.

Garfunkel, Z., 1989. Regional deformation by block translation and rotation. In: Kissel, C., Laj, C. (Eds.), Paleomagnetic Rotations and Continental Deformation. NATO ASI Ser. C 254, pp. 181–208.

Grasso, M., Manzoni, M., Quintili, A., 1987. Misure magnetiche sui Trubi infrapliocenici della Sicilia orientale: possibili implicazioni stratigrafiche e strutturali. Memorie della Società Geologica Italiana 38, 459–474.

Guarnieri, P., 1998. Esempi di tettonica traspressiva: strutture e stili deformativi in Sicilia nord-occidentale (Monti di Trabia-Termini Imerese). PhD Thesis, University of Catania.

Guarnieri, P., 2002. Regional strain derived from fractal analysis applied to strike-slip fault systems in NW Sicily. Chaos, Solitons, Fractals 14, 71–76.

Guarnieri, P., Di Stefano, A., Platania, I., Romeo, M., 1998. Stratigraphy and structural context of the Neogene basins in the Termini Imerese area (North-Western Sicily). Annales Tectonicæ XII (1–2), 59–67.

Guarnieri, P., Carbone, S., Di Stefano, A., 2002. The Sicilian orogenic belt: a critical tapered wedge? Bollettino della Società Geologica Italiana 121, 221–230.

Hancock, P.L., 1985. Brittle microtectonics: principle and practice. Journal of Structural Geology 7 (3/4), 437–457.

Harland, W.B., 1971. Tectonic transpression in Caledonian Spitsbergen. Geological Magazine 108 (1), 27–42.

Jamison, W.R., 1991. Kinematics of compressional fold development in convergent wrench terranes. Tectonophysics 190, 209–232.

Krantz, R.W., 1995. The transpressional strain model applied to strike-slip, oblique-convergent and oblique-divergent deformation. Journal of Structural Geology 17 (8), 1125–1137.

Lentini, F., Catalano, S., Carbone, S., 1996. The External Thrust System in Southern Italy: a target for petroleum exploration. Petroleum Geoscience 2, 333–342.

McCoss, A.M., 1986. Simple constructions for deformation in transpression–transtension zones. Journal of Structural Geology 8 (6), 715–718.

Malinverno, A., Ryan, W.B.F., 1986. Extension in the Tyrrhenian Sea and shortening in the Apennines as a result of arc migration driven by sinking of the lithosphere. Tectonics 5, 227–245.

Mascle, J., Kastens, K., Christian, A., LEG 107 Scientific Party, 1988. A land-locked back-arc basin: preliminary results from ODP Leg 107 in the Tyrrhenian Sea. Tectonophysics 146, 149–162.

Nur, A., Ron, H., Scotti, O., 1989. Mechanics of distributed faults and block rotation. In: Kissel, C., Laj, C. (Eds.), Paleomagnetic Rotations and Continental Deformation. NATO ASI Ser. C 254, pp. 209–228.

Oldow, J.S., Channel, J.E.T., Catalano, R., D'argenio, B., 1990. Contemporaneous thrusting and large-scale rotations in the western Sicilian fold and thrust belt. Tectonics 9 (4), 661–681.

Patacca, E., Scandone, P., 1989. Post Tortonian mountain building in the Apennines. The role of the passive sinking of a relic lithospheric slab. In: Boriani, A., Bonafede, M., Piccardo, G.B., Vai, G.B. (Eds.), The Lithosphere in Italy. Accademia Nazionale dei Lincei 80, pp. 157–176.

Petit, J.P., 1987. Criteria for the sense of movement on fault surfaces in brittle rocks. Journal of Structural Geology 9 (5/6), 597–608.

Ron, H., Freund, R., Garfunkel, Z., 1984. Block rotation by strike-slip faulting: structural and paleomagnetic evidence. Journal of Geophysical Research 89 (B7), 6256–6270.

Roure, F., Howell, D.G., Muller, C., Moretti, I., 1990. Late Cenozoic subduction complex of Sicily. Journal of Structural Geology 12 (2), 259–266.

Sanderson, D.J., Marchini, W.R.D., 1984. Transpression. Journal of Structural Geology 6 (5), 449–458.

Scandone, P., 1979. Origin of the Tyrrhenian Sea and Calabrian Arc. Bollettino della Società Geologica Italiana 98, 27–34.

Scheepers, P.J.J., Langereis, C.G., 1994. Analysis of NRM directions from the Rossello composite: implications for the tectonic rotations of the Caltanissetta basin (Sicily). Earth and Planetary Science Letters 119, 243–258.

Speranza, F., Maniscalco, R., Mattei, M., Di Stefano, A., Butler, R.W.H., Funiciello, R., 1999. Timing and magnitude of rotations in the frontal thrust systems of southwestern Sicily. Tectonics 18 (6), 1178–1197.