Journal of Structural Geology, Vol. 10, No. 4, pp. 373 to 381, 1988
Printed in Great Britain

0191-8141/88 $03.00 + 0.00

Sense of overthrust shear in the Alpine nappes of Calabria (Southern Italy)

DOROTHEE DIETRICH

Geologisches Institut, ETH Zentrum, CH-8092 Zürich, Switzerland

(*Received* 13 *July* 1987; *accepted in revised form* 15 *December* 1987)

Abstract—Southern Italy consists tectonically of ophiolite and basement nappes thrust over the Apenninic sedimentary nappes. Whilst all more recent authors agree that the sediments of the Apenninic nappes were deposited on Apulian basement (i.e. on African continental crust), and that the ophiolites were associated with the oceanic basement of the Mesozoic Tethys, the provenance of the basement nappes is still debated.

New data based on microstructural criteria have shown that the main shear sense of the ophiolite nappes and of the overlying basement nappes in Northern Calabria is from west to east, in today's co-ordinate system. The basement nappes might not therefore be of Austroalpine (African) provenance, but could be of European origin.

INTRODUCTION

THE discovery of basement nappe structures of Alpine age in Southern Italy is now 80 years old (Lugeon & Argand 1906), but it was only in 1972 that it was explicitly suggested by Haccard *et al.*(1972) that the Calabrian nappes were part of a former continuous and structurally relatively uniform chain extending from the arc of the Western Alps over Alpine Corsica to Southern Italy, Sicily and North Africa. A comparison of a cross-section through the Alps with a cross-section through Calabria shows that in both chains the major tectonic elements occupy a similar geometric position. In the sections of Fig. 1, nappes of Jurassic ophiolites and overlying basement nappes, both with associated sediments, form an upper tectonic element (black in Fig. 1). This element is thrust over a lower tectonic element made up of continental margin sediments (dotted). The North Penninic belt of the Swiss Alps and the Campano-Lucana platform of the Southern Apennines were both important intracontinental elements in the European and African continental margins, respectively. The Campano-

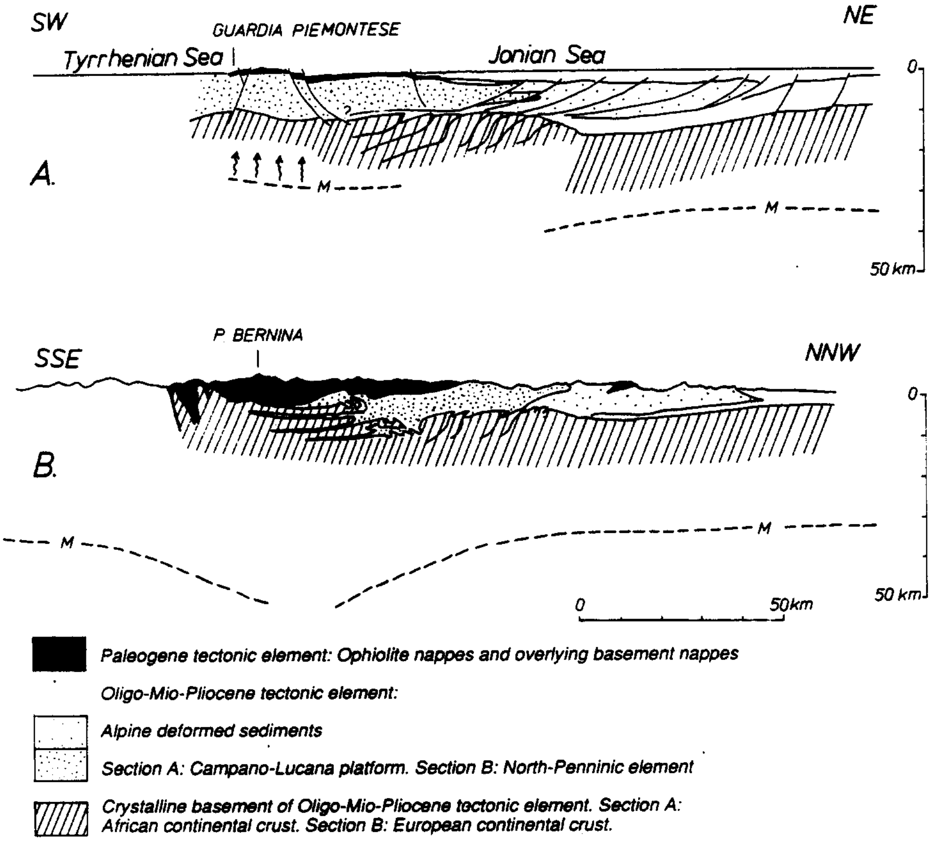


Fig. 1. Cross-section through Calabria (section A) and through the Swiss Alps (section B). Slightly modified after Cello *et al.* (1981) and after Laubscher (1983). Migmatization on the SW side of section A is assumed by Cello *et al.* on the basis of the heat flow data by El Ali & Giese (1978).

Lucana carbonate platform of the Southern Apennines was affected by subduction in the early Miocene (the age of metamorphism of the San Donato unit; Civetta, unpublished data), whilst the North Penninic belt was affected by subduction in the late Eocene (Laubscher 1983). The original depositional domain of all the continental margin sediments in section A is estimated to have been 400 km wide (Ippolito *et al.* 1975), whilst in section B the depositional domain from the North Penninic to the Helvetic belt was about 250 km wide (Laubscher 1983). Great parts of the crystalline continental basement that must have been associated with these belts are missing in both sections, indicating active subduction of both margins.

In summary, all along the Alpine chain a tectonically lower Oligo-Mio-Pliocene element can be distinguished from an Upper Paleogene element. The Oligo-Mio-Pliocene element appears on the surface as sedimentary décollement nappes, crops out around the arc of the Western Alps, and continues all along peninsular Italy and Sicily to North Africa. The Paleogene element consists of ophiolite nappes, basement nappes and associated sediments and extends from the internal Alps to Corsica and Tuscany; south of Tuscany it disappears, and it reappears in northern Calabria. Specimens dredged from the ocean floor between Corsica and Calabria have been correlated with the Paleogene element (e.g. Calcagnile *et al.* 1981). The disappearance of the Jurassic ophiolites of the Paleogene element south of Catanzaro (Bonardi *et al.* 1980) has been interpreted by Scandone (1982) as indicating an end of the Tethys Ocean against a major transform fault between the two continental blocks.

Haccard *et al.* (1972) suggested that three main events in the evolution of this chain were responsible for the geometric situation seen today. Their proposals also offer an explanation for an apparent change of vergence of the Oligo-Mio-Pliocene element along strike of the orogen, involving from the Alps to Corsica shortening of European crust, but along peninsular Italy shortening of African crust. The three events they recognized are: (1) creation of oceanic crust between a block of European continental crust in the west and a block of essentially African continental crust in the east, and deposition of cover sediments on the ophiolites (early Jurassic–early Cretaceous); (2a) convergence of the two continental blocks, with deformation and metamorphism of the ophiolites and associated sediments, and finally formation of Austroalpine nappes by continental collision and thrusting of the eastern block over the western block (Albian); (2b) a new compressional impulse leading to deformation and thrusting towards the west of the Briançonnais and Subalpine–Helvetic units, as well as to deformation and thrusting towards west of the Tuscan units (Aquitanian); (3) deformation of this NNE-SSW-striking chain into the curved form observed today by a shear couple acting towards SW in the north (formation of the arc of the Western Alps) and towards NE in the south (formation of the Calabrian arc). The opening of the Ligurian Sea and overthrusting of the Apennine units consecutively towards E, NE and N appears to be related to this shear. Contemporaneously, the Western Alps were thrust towards the W, SW and S (Aquitanian–Pliocene–Quaternary).

The fact that the upper tectonic element in both Calabria and the Alps contains similar granulite facies rocks indicative of the continental crust–mantle transition has led Haccard *et al.* (1972) to suggest that they were derived from the same Austroalpine block, which was thrust over the European continental crust from the Alps in the north to Calabria in the south. The granulite facies metamorphism in these rocks is of Prealpine age and is overprinted by Alpine metamorphism in the Polia-Copanello unit in Calabria (Amodio Morelli *et al.* 1976) and in the II Zona Dioritico-Kinzigitica and the Dent Blanche Nappe in the Alps (Carraro *et al.* 1970).

The observations of most of the subsequent authors on Calabria appeared to confirm the basic outline of the overthrust model proposed by Haccard *et al.* (1972). Dietrich & Scandone (1972) discussed the tectonic position of the basic and ultrabasic rocks in Southern Italy and distinguished an ophiolite nappe showing HP–LT metamorphism (Diamante-Terranova unit in Table 1, 'Piemontese ophiolites') from an ophiolite nappe showing only slight metamorphism (Malvito unit in Table 1, 'Ligurian ophiolites'). They inferred similar NW–SE subduction mechanisms all along the Austroalpine margin of the Tethys. Alvarez *et al.* (1974) and Alvarez (1976) expressed the model of the structural continuation of the Alpine chain in terms of Miocene–Quaternary microplate movements. From observations of fold vergence and of fold distortion in one of the ophiolite nappes Alvarez (1976, 1978) supported the Paleogene westwards vergence of the upper tectonic element in Calabria. Dietrich *et al.* (1976) discussed the metamorphic evolution of the individual Calabrian nappes in the framework of an Alpine chain consisting of ophiolite and Austroalpine nappes thrust over the Maghrebide-Apennine chain consisting of Mesozoic–Tertiary décollement nappes. Amodio Morelli *et al.* (1976), in a synthesis of the geology of the Calabrian arc, chose the same evolutionary model to account for the structural setting. A clear exposition of the two-vergence-model for Calabria is that of Scandone (1982), comprising a discussion of the evolution of the crustal structure and of the paleomagnetic data. Ogniben (1969), Boullin (1984) and Boullin *et al.* (1986) proposed a different model. These authors compared the Calabrian basement nappes with the Kabylian basement nappes and suggested an European provenance for both.

New data are set out below which also conflict with the previously proposed two-vergence model for the development of the nappe structure of Calabria.

DIRECTION OF OVERTHRUST SHEAR IN THE PALEOGENE NAPPES OF CALABRIA

The Paleogene tectonic element in northern Calabria consists of seven thrust sheets (Fig. 2 and Table 1). Some

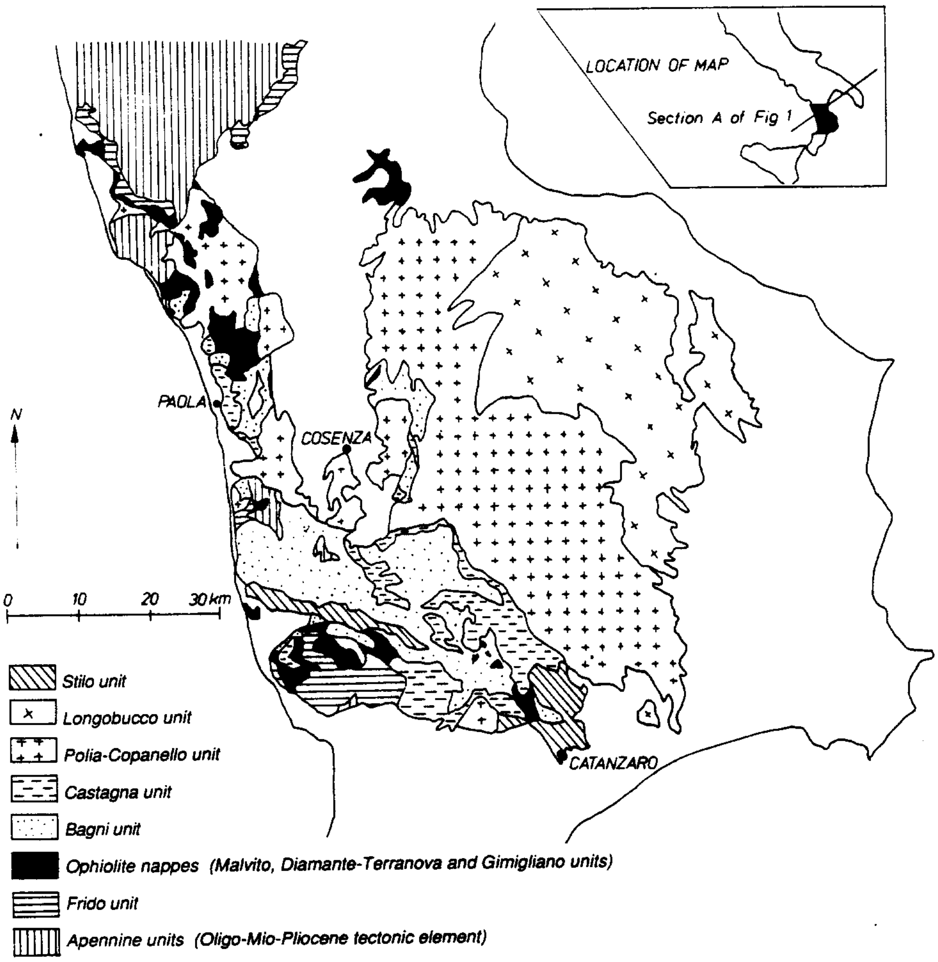


Fig. 2. Tectonic sketch map of northern Calabria. A short description of the lithology of the nappes is given in Table 1.

of these thrust sheets pinch out along strike, and all are affected by tectonic boudinage normal to the main stretching direction. Although the thickness of the Paleogene element varies it generally appears to be exceedingly thin relative to the lateral extent of the nappe sheets (Fig. 1). In the sections of Dietrich (1976) the thickness of the Paleogene tectonic element amounts to a maximum of 700 m. The microstructures of these thin slivers show features of ductile shear associated with mylonite development. Alpine retrograde metamorphism appears broadly contemporaneous with the deformation of Prealpine high-grade rocks and the prograde metamorphism with the deformation of Mesozoic sedimentary rocks (Table 1). These thrust sheets had therefore to be detached from the subducting lithosphere at some particular depth. They formed possibly in the zone of weakness and region of localized deformation between the subducting lithosphere and a cool, overlying mass, represented by the Stilo and the Longobucco Nappes (Table 1). European provenance for the Longobucco Nappe has been suggested by Knott (1987) and Bouillin & Olivier (1987).

In four of the thrust sheets listed in Table 1, the Polia-Copanello, Castagna, Gimigliano and Malvito units, there are microstructures clearly indicating an eastwards direction of overthrust shear. Since these microstructures are very well developed in the Alpine retrograde parts of the basement nappes, it appears that they should be correlated with the nappe emplacement. The displacement sense in sheared rocks is probably most reliably deduced from microstructural criteria rather than from observations of fold vergence. The vergence of folds is a function of the original angular relationship of a rock layer relative to the shear planes and of the amount of shear strain (e.g. fig. 4 of Ramsay *et al.* 1983).

Details of the microstructures which indicate a shear sense will now be described. All the rocks studied show macroscopically well developed subhorizontal fabric planes with an associated stretching lineation. For the Polia-Copanello, Castagna and Gimigliano units these fabric planes correspond with a tectonic cleavage, for the Malvito unit with bedding. The observations made are in accord with the principles of shear-zone geometry (e.g. Ramsay 1980). With increasing shear strain the *X–Y* trajectories of finite strain bend into parallelism with the shear-zone boundaries. The tectonic cleavage appears to be best interpreted as representing the *X–Y* plane of finite strain (Castagna unit), or as shear planes related to an oblique finite-strain fabric (Polia-Copanello and Gimigliano units). All the micrographs are from specimens cut perpendicular to the macro-

Table 1. Nappe scheme of northern Calabria, after Amodio Morelli *et al.* (1976), modified. The geographic orientation refers to Fig. 2

<table>
<tr><th>NNW</th><th></th><th>SSE</th></tr>
<tr><td colspan="3">Stilo unit
Devonian phyllites and paragneisses with a Prealpine metamorphic event, intruded by Hercynian granites. Unmetamorphosed Alpine sedimentary cover (?Trias-Miocene). Several hundred metres thick.</td></tr>
<tr><td colspan="3">Longobucco unit
Devonian phyllites with limestones and porphyroids, intruded by Hercynian granites. Unmetamorphosed Alpine sedimentary cover (Lias-Eocene). Several hundred metres thick.</td></tr>
<tr><td colspan="3">Polia-Copanello unit
Biotite-garnet gneisses with sillimanite and cordierite, metabasites and subordinate peridotites. Prealpine metamorphic history including events in granulite and amphibolite facies. During Alpine deformation retrograded to phyllonites, which can contain pumpellyite and lawsonite. Biotite ages between 120-150 m.y. (Borsi & Dubois 1968, Civetta et al.1973), interpreted as age of exhumation from the lower crust (Borsi et al.1977). Maximum 400 m thick.</td></tr>
<tr><td rowspan="2">Malvito unit
Jurassic-Lower Cretaceous metabasites with pillow lavas, gabbros and serpentinites. Sedimentary cover of radiolarian cherts and Calpionella limestones. Albite-Lawsonite facies overprinting a prehnite-pumpellyite facies. Maximum 350 thick.</td><td rowspan="2">?</td><td>Castagna unit
Micaschists, gneisses and granites. Prealpine metamorphic history including events in Upper greenschist and amphibolite facies. During Alpine deformation retrograded to greenschist facies, with, in part of the sequence, a HP/LT event (glaucophane and lawsonite). Maximum 700m thick.</td></tr>
<tr><td>Bagni unit
Hercynian phyllites with Alpine sedimentary cover (?Trias-Lower Cretaceous), with an Alpine metamorphic overprint (lawsonite). Several hundred metres thick.</td></tr>
<tr><td>Diamante-Terranova unit
Jurassic-Lower Cretaceous metabasites, serpentinites. Sedimentary cover of calcareous schists. Blueschist facies with superimposed greenschist facies. Maximum 250 m thick.</td><td>?</td><td>Gimigliano unit
Jurassic-Lower Cretaceous metabasites with pillow lavas, serpentinites. Sedimentary cover of metapelites, quartzites and limestones. Lower greenschist facies, overprinting a HP/LT event (glaucophane and lawsonite). Maximum 500 m thick.</td></tr>
<tr><td colspan="3">Frido unit
Upper Cretaceous slates with associated limestones and quartzites. Very low greenschist facies. Some hundred metres thick.</td></tr>
<tr><td colspan="3">Apennine units (Oligo-Mio-Pliocene tectonic element)</td></tr>
</table>

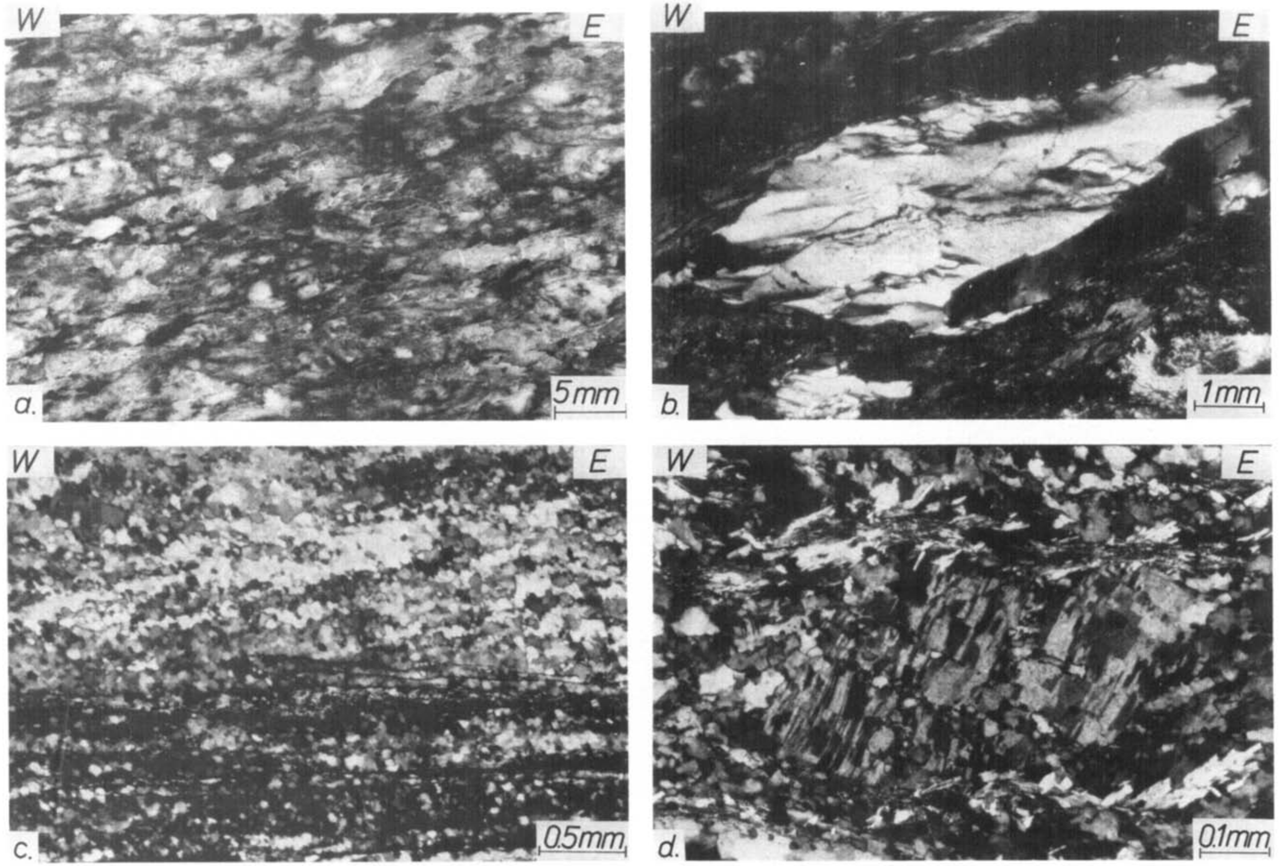
scopic fabric planes and parallel to the stretching lineation, so that these fabric planes appear horizontal in the micrographs. The orientation of the micrographs is comparable to the orientation of section A in Fig. 1, and the shear sense deduced from the micrographs is dextral.

Polia-Copanello unit

Figures 3(a) & (b) show the microstructure of a phyllonite, the product of retrogression of a kinzigitic gneiss. A strong planar anisotropy, visible in both figures, is developed obliquely to the macroscopic cleavage. The planes of anisotropy are parallel to the long axes of the quartz- and K-feldspar porphyroclasts, and are interpreted as representing finite-strain X–Y planes in this rock. The macroscopic cleavage planes have the significance of shear planes subparallel to the main shear-zone boundaries. The oblique S-surfaces and the horizontal C-surfaces (nomenclature after Berthé *et al.* 1979) are marked by phyllosilicates. This fabric indicates shear deformation compatible with an eastwards transport direction of the nappe. The small angle of 15° between the C- and the S-surfaces is a function of the high strain state of the rock. Strong ductile deformation is visible in the quartz porphyroclast of Fig. 3(b). Through-grain microshears are developed, and subgrains have formed along these shear planes. The stretching lineation on the macroscopic cleavage trends N 85° E.

Castagana unit

Figures 3(c), (d) and 4(a) are micrographs of three specimens of Alpine retrograde mylonites from this thrust sheet. In the quartz mylonite of Fig. 3(c) the horizontal fabric, marked by phyllosilicates, corresponds to the finite-strain X–Y plane in the rock. The quartz domain is fully recrystallized to a uniform grain size and defines an oblique fabric related to a late E-directed shear increment. A slight alignment of the individual quartz grains parallel to a macroscopically identifiable steeply E-dipping crenulation cleavage is visible. Feldspar porphyroclasts, in contrast to quartz,



surface of a phyllonite. *C*-surfaces horizontal (left side of the photograph), *S*-surfaces oblique. Specimen locality: road N107, SW of Monte Luta. (b) Polia-Copanello unit. Micrograph of a quartz porphyroclast from the specimen of (a). Overall shape and undulatory extinction relate to strong ductile deformation with nucleation of new grains along microshears. (c) Castagna unit. Quartz mylonite with a well developed horizontal fabric (*X–Y* plane of finite strain) marked by phyllosilicates, and with an oblique fabric (flattening plane of strain increment) marked by recrystallized quartz grains. Specimen locality: superstrada Paola-Cosenza, SSE of Paola, at junction with N107. (d) Castagna unit. Plagioclase porphyroclast in a quarzo-feldspathic mylonite with an overall sigma shape caused by fracturing. Specimen locality: superstrada Paola-Coscnza, 1.5 km SSE of Paola.

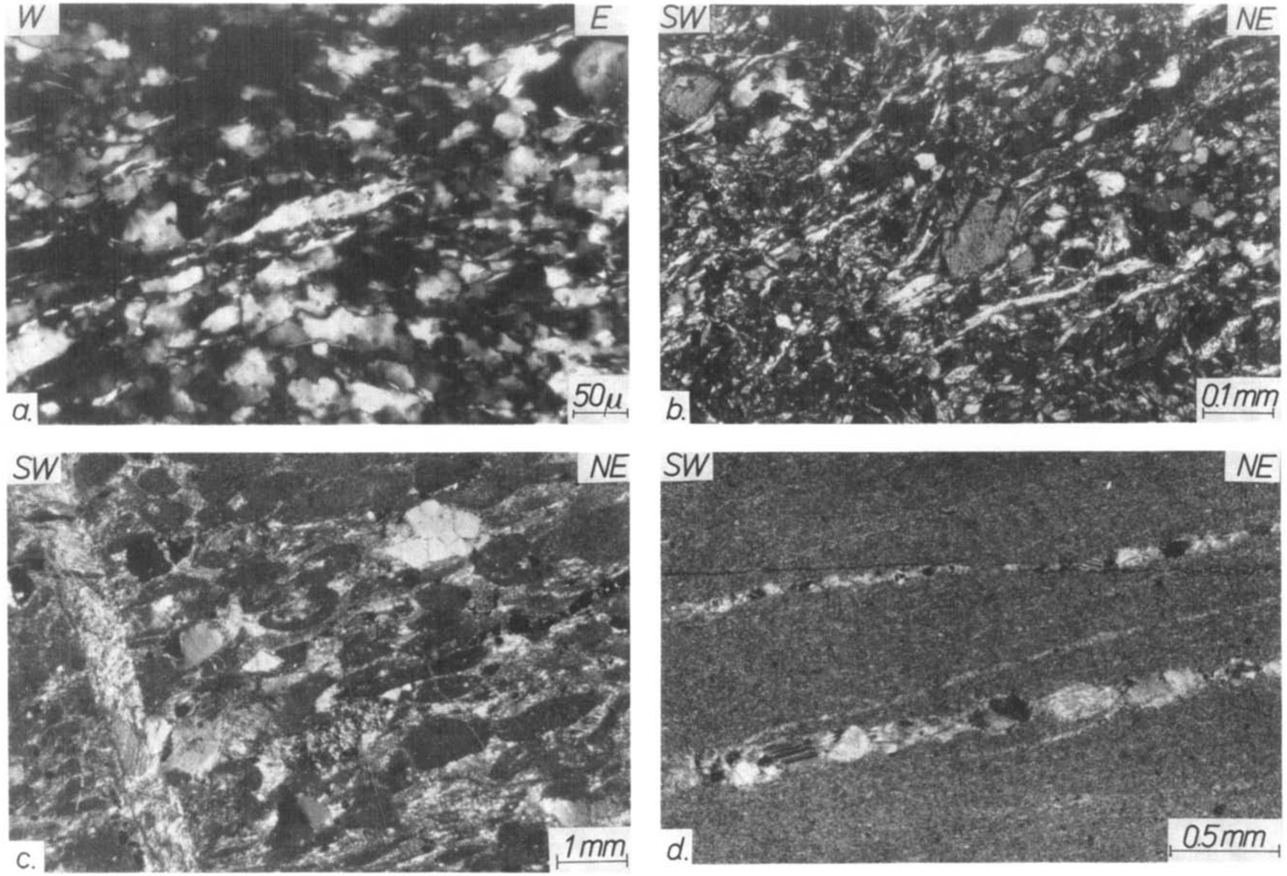


Fig. 4. Microstructures of the Calabrian basement and ophiolite nappes indicating E or NE-directed shear. (a) Castagna unit. Oblique mica flake in a quartz mylonite. Specimen locality: close to specimen of Fig. 3(c). (b) Gimigliano unit. Amphibole porphyroclasts in a metabasite. The sigma shape of the porphyroclasts and the *S*-surfaces marked by white micas indicate a dextral shear sense. Specimen locality: St. Cavorà, SE Gimigliano. (c) Malvito unit. Deformed microbreccia from the sedimentary cover, defining an *X–Y* plane of finite strain that is oblique to bedding. Extension direction of the vein is parallel to the long axes of the deformed clasts. Specimen locality: Laise, NE Belvedere Marittimo. (d) Malvito unit. Limestone from the sedimentary cover, showing stretched veins and an oblique grain shape fabric. Specimen locality: close to specimen of (c).

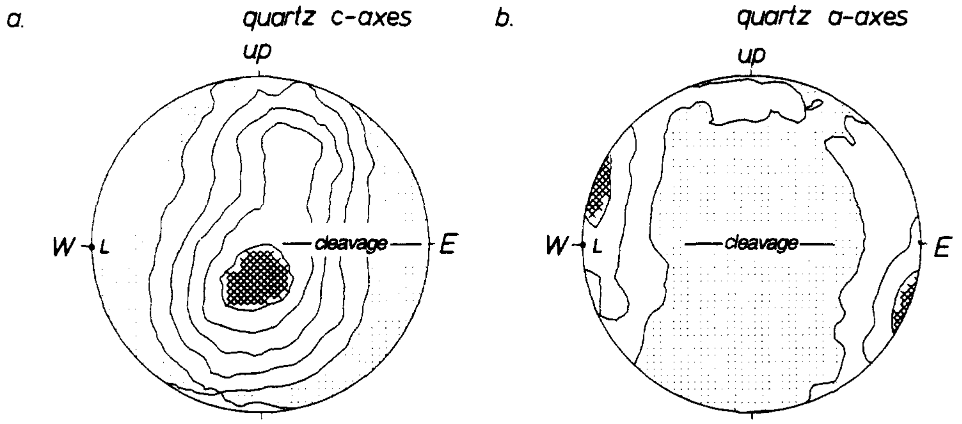


Fig. 5. Pole figures for quartz c- and a-axes from the specimen of Fig. 4(a), Castagna unit. Upper hemisphere equal-area projections. The orientation of the specimen measured is as for Fig. 4(a), i.e. the orientation of cleavage and stretching lineation corresponds to the equator of the pole figures. The contours are given in multiples of a uniform distribution. The cross-hatched areas represent maximum densities. (a) Pole figure for quartz c-axes. Contour values are 1, 1.5, 2 and 2.5. (b) Pole figure for quartz a-axes. Contour values are 1, 1.5 and 2.

show only limited ductility in these low-grade mylonites. The plagioclase grain in Fig. 3(d) is from a quartzofeldspathic mylonite and was deformed by fracturing to an overall sigma shape (e.g. Passchier & Simpson 1986) in accordance with an eastwards movement of the nappe. Figure 4(a) shows an oblique mica flake in a quartz mylonite. The sense of rotation of the mica flake relative to the cleavage plane indicates right-handed shear. The stretching lineation in this rock trends N81°E. The crystallographic preferred orientation of the quartz c- and a-axes was measured in this specimen by texture goniometry. The c-axis pole figure, Fig. 5(a), shows an asymmetric single girdle fabric indicating rotational deformation with a dextral sense of movement (e.g. Schmid & Casey 1986, especially their fig. 14). The corresponding pole figure of the a-axes, Fig. 5(b), shows a maximum oriented obliquely to the cleavage, which can be interpreted as being parallel to the shear-zone boundaries (e.g. Schmid & Casey 1986). The resulting small angle between the inferred shear-zone boundary and the cleavage planes relates to the high strain state of the rock.

Not all the microstructures in this nappe indicate an E sense of overthrust shear. Structures indicating a W shear-sense are known (Faure 1980, and J. P. Platt, personal communication). These could be related to the earlier prograde deformation history, or, alternatively, to later backthrusting. The E-dipping crenulation cleavage mentioned earlier would be in accordance with backthrusting shear.

Gimigliano unit

Figure 4(b) is a micrograph from a metabasite of the Gimigliano ophiolite nappe. The microscopic fabric, again oblique to the macroscopic cleavage, shows slightly undulating S-surfaces being deflected around porphyroclasts. The S-surfaces are formed by white micas, and the porphyroclasts are relics of Na-amphiboles. These amphiboles have been partly recrystallized to a sigma shape which is enhanced by the growth of chlorite and white micas with the forms of pressure-shadows. The geometry of this porphyroclast system is in accordance with the fabric defined by the S-surfaces and indicates rotational deformation by NE shear. The stretching lineation of this rock trends N40°E.

Malvito unit

Layers of deformed microbreccias form part of the sedimentary cover of the Malvito ophiolite nappe, Fig. 4(c). The anistropy plane defined by the long axes of the deformed clasts is oblique to the bedding and lies in the X–Y finite strain plane of the rock. The obliquity of the finite-strain fabric relative to the bedding implies rotational deformation, again with an E overthrust sense. Figure 4(d) shows a limestone from the sedimentary cover of the Malvito unit. Boudinaged old calcite veins indicate extension oblique to the bedding, which is parallel to a stylolite in the micrograph. The stretching lineation in this specimen trends N21°E. From this specimen a part of the matrix rock with uniform grain size was chosen for measurement of calcite preferred orientation by texture goniometry. Figure 6 shows the calcite a-pole

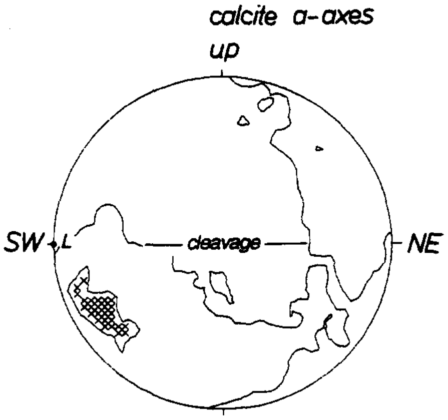


Fig. 6. Calcite a-pole figure obtained from the matrix rock of the specimen of Fig. 4(d), Malvito unit. Upper hemisphere equal-area projection. The orientation of the specimen measured is as for Fig. 4(d). Contour values are 0.8, 1 and 1.2.

figure obtained. The fairly weak great circle pattern of the poles to the calcite *a*-planes is used to infer the *c*-axis point maximum. The *a*-minimum corresponds with the *c*-maximum (Schmid *et al.* 1981, Dietrich & Song 1984). The *c*-axis point maximum is oblique to the normal to the cleavage, indicating NE overthrust shear. Crystallographic fabric and finite-strain fabric appear not to be parallel. The higher degree of obliquity of the crystallographic fabric relative to the bedding can be interpreted as being related to a late strain increment in a shear environment (Rutter & Rushbridge 1977).

Frido unit

The transport directions for this flysch are towards the east or northeast, as determined by Knott (1987) from stretching lineations, shear bands and minor thrust geometries. This author located the Frido sedimentary basin between a Calabrian (European) margin to the west and an Apulian (African) margin to the east.

CONCLUSIONS

There is a general agreement among all the previous authors that the highest tectonic elements in Northern Calabria are formed by widespread nappes of crystalline basement. Petrologically these rocks show affinities with the Austroalpine nappes of the Alps. They were therefore interpreted as representing rock material of the African continental margin of the Tethys, thrust over European continental crust (Sardinia). Later backthrusting over the African continental margin, followed by the formation of the Apenninic nappes, would have created the geometric situation seen today.

New evidence, presented here, has suggested that the main visible deformation in the rocks of the basement nappes, as well as in the underlying ophiolite nappes, relates to an overthrust shear directed towards the African margin. This deformation is associated with widespread mylonitization and with an Alpine retrograde metamorphism in the basement nappes (in the Castagna unit there is also an Alpine HP–LT event), and with a complex Alpine HP–LT metamorphic history of the ophiolite nappes. The Longobucco and the Stilo Nappes, both without Alpine metamorphism, may have represented parts of the orogenic lid (in the sense of Laubscher 1983) under which the deformation was concentrated.

The conclusion is therefore that the Paleogene tectonic element in Calabria either has European origin; or that the backthrusting event, which affected the originally Europe-vergent nappes, has overprinted the original fabrics. This would imply additional displacements between the individual nappes at least equal to their original displacements. The first possibility seems the more likely. This conclusion is also more in accord with the general regional distribution of the tectonic elements in Southern Italy: an eastern foreland overthrust by sedimentary cover nappes from the west, with these cover nappes themselves overlain by ophiolite nappes and the uppermost crystalline basement nappes. If this deduction is correct, it requires a major modification of the subduction kinematics along the Alpine continent–continent collision zone. The change-over had to occur between Corsica and Calabria.

Acknowledgements—The author wishes to thank G. Cello, J. G. Ramsay and E. Turco for discussion in the field, and J. G. Ramsay for critical reading of the manuscript. Financial support from Schweizerischer Nationalfonds is gratefully acknowledged (project 2.214–0.86).

REFERENCES

Alvarez, W. 1976. A former continuation of the Alps. *Bull. geol. Soc. Am.* **87**, 891–896.

Alvarez, W. 1978. Fold distortion: a new indicator of tectonic transport direction. *Geology* **6**, 657–660

Alvarez, W., Cocozza, T. & Wezel, F. C. 1974. Fragmentation of Alpine orogenic belt by microplate dispersal. *Nature* **248**, 309–314.

Amodio Morelli, L., Bonardi, G., Colonna, V., Dietrich, D., Giunta, G., Ippolito, F., Liguori, V., Lorenzoni, S., Paglionico, A., Perrone, V., Piccarreta, G., Russo, M., Scandone, P., Zanettin Lorenzoni, E. & Zuppetta, A. 1976. L'arco calabro-peloritano nell'orogene appenninico-maghrebide. *Mem. Soc. geol. Ital.* **17**, 1–60.

Berthé, D., Choukroune, P. & Jegouzo, P. 1979. Orthogneiss, mylonite and non-coaxial deformation of granites: the example of the South Armorican Shear Zone. *J. Struct. Geol.* **1**, 32–42.

Bonardi, G., Giunta, G., Perrone, V., Russo, M., Zuppetta, A. & Ciampo, G. 1980. Osservazioni sull'evoluzione dell'arco calabro-peloriatano nell'Miocene inferiore. *Boll. Soc. geol. Ital.* **99**, 365–393.

Borsi, S. & Dubois, R. 1968. Données géochronologiques sur l'histoire hercynienne et alpine de la Calabre centrale. *C.r. hebd. Séanc. Acad. Sci., Paris* **266**, 72–75.

Borsi, S., Hieke Merlin, O., Lorenzoni, S., Paglionico, A. & Zanettin Lorenzoni, E. 1977. Stilo unit and 'dioritic-kinzigitic' unit in Le Serre (Calabria, Italy). Geological, petrological, geochronological characters. *Boll. Soc. geol. Ital.* **95**, 219–244.

Bouillin, J. P. 1984. Nouvelle interprétation de la liaison Apennin-Maghrébides en Calabre: conséquences sur la paléogeographie téthyenne entre Gibraltar et les Alpes. *Revue Géogr. phys. Géol. dyn.* **25**, 321–338.

Bouillin, J. P., Durand-Delga, M. & Olivier, Ph. 1986. Betic-Rifian and Tyrrhenian arcs: distinctive features, genesis and development stages. In *The Origin of Arcs* (edited by Wezel, F. C.). Elsevier, Amsterdam, 281–304.

Bouillin, J. P. & Olivier, Ph. 1987. The Mesozoic Longobucco sequence (Calabria, Italy), at the junction of the Ligurian and Mograbin Tethyan segments. Abstract. *Terra cognita* **7**, 102.

Calcagnile, G., Fabbri, A., Farsi, F., Gallignani, P., Gasparini, C., Iannacone, G., Mantovani, E., Panza, G., Sartori, R., Scandone, P. & Scarpa, R. 1981. Structure and evolution of the Tyrrhenian basin. *Rapports et Procès Verbaux des Réunions. Commission Internationale pour l'Exploration Scientifique de la Mer Méditeranée, Monaco* **27**, 197–208.

Carraro, F., Dal Piaz, V. & Sacchi, R. 1970. Serie di Valpelline e 2° Zona Diorito-Kinzingitica sono i relitti di un ricoprimento proveniente della Zona Ivrea-Verbano. *Mem. Soc. geol. Ital.* **9**, 197–224.

Cello, G., Tortorici, L., Turco, E. & Guerra, I. 1981. Profili profondi in Calabria settentrionale. *Boll. Soc. geol. Ital.* **100**, 423–431.

Civetta, L., Cortini, M. & Gasparini, P. 1973. Interpretation of a discordant K/Ar age pattern (Capo Vaticano, Italy). *Earth Planet. Sci. Lett.* **20**, 113–118.

Dietrich, D. 1976. La geologia della Catena Costiera Calabra tra Cetraro e Guardia Piemontese. *Mem. Soc. geol. Ital.* **17**, 61–121.

Dietrich, D., Lorenzoni, S., Scandone, P., Zanettin Lorenzoni, E. & Di Pierro, M. 1976. Contribution to the knowledge of the tectonic units of Calabria. Relationships between composition of K-white micas and metamorphic evolution. *Boll. Soc. geol. Ital.* **95**, 193–217.

Dietrich, D. & Scandone, P. 1972. The position of the basic and ultrabasic rocks in the tectonic units of the Southern Apennines. *Atti Acad. Pontaniana Napoli* **21**, 61–75.

Dietrich, D. & Song, H. 1984. Calcite fabrics in a natural shear environment, the Helvetic nappes of western Switzerland. *J. Struct. Geol.* **6**, 19–32.

El Ali, H. & Giese, P. 1978. A geothermal profile between the Adriatic and Tyrrhenian Sea. In: *Alps, Apennines, Hellenides* (edited by Closs, H., Roeder, D. & Schmidt, K.). *IUCG* **38**, 324–327.

Faure, M. 1980. Microtectonique et charriage Est-Ouest des nappes alpines profondes de Sila (Calabre–Italie meridionale). *Revue Géogr. phys. Géol. dyn.* **22**, 135–146.

Haccard, D., Lorenz, C. & Grandjacquet, C. 1972. Essai sur l'evolution tectogenetique de la liaison Alpes-Apennins (de la Ligurie a la Calabre). *Mem. Soc. geol. Ital.* **11**, 309–341.

Ippolito, F., D'Argenio, B., Pescatore, T. & Scandone, P. 1975. Structural-stratigraphic units and tectonic framework of Southern Apennines. In: *Geology of Italy* (edited by Squyres, C.). The Earth Sciences Society of the Libyan Arab Republic, Tripoli, 317-328.

Knott, S. 1987. The Liguride Complex of Southern Italy—a Cretaceous to Paleogene accretionary wedge. *Tectonophysics* **142**, 217–226.

Laubscher, H. P. 1983. Detachment, shear and compression in the central Alps. *Mem. geol. Soc. Am.* **158**, 191–211.

Lugeon, M. & Argand, E. 1906. La racine de la nappe sicilienne et l'arc de charriage de la Calabre. *C.r. hebd. Séanc. Acad. Sci., Paris* **142**, 1107–1109.

Ogniben, L. 1969. Schema introduttivo alla geologia del confine Calabro-Lucano. *Mem. Soc. Geol. Ital.* **8**, 453–763.

Passchier, C. W. and Simpson, C. 1986. Porphyroclast systems as kinematic indicators. *J. Struct. Geol.* **8**, 831–844.

Ramsay, J. G. 1980. Shear zone geometry: a review. *J. Struct. Geol.* **2**, 83–99.

Ramsay, J. G., Casey, M. & Kligfield, R. 1983. Role of shear in development of the Helvetic fold-thrust belt of Switzerland. *Geology* **11**, 439–442.

Rutter, E. H. & Rusbridge, M. 1977. The effect of non-coaxial strain paths on the crystallographic preferred orientation development in the experimental deformation of a marble. *Tectonophysics* **39**, 73–86.

Scandone, P. 1982. Structure and evolution of the Calabrian arc. *Earth Evol. Sci.* **3**, 172–180.

Schmid, S. M. & Casey, M. 1986. Complete fabric analysis of some commonly observed quartz *c*-axis patterns. In: *Mineral and Rock Deformation: Laboratory Studies. Geophys. Monograph. Am. Geophys.* **36**, 263–286.

Schmid, S. M., Casey, M. & Starkey, J. 1981. The microfabric of calcite tectonites from the Helvetic Nappes (Swiss Alps). In: *Thrust and Nappe Tectonics* (edited by McKlay, K. & Price, N. J.). *Spec. Publs geol. Soc. Lond.* **9**, 151–158.