



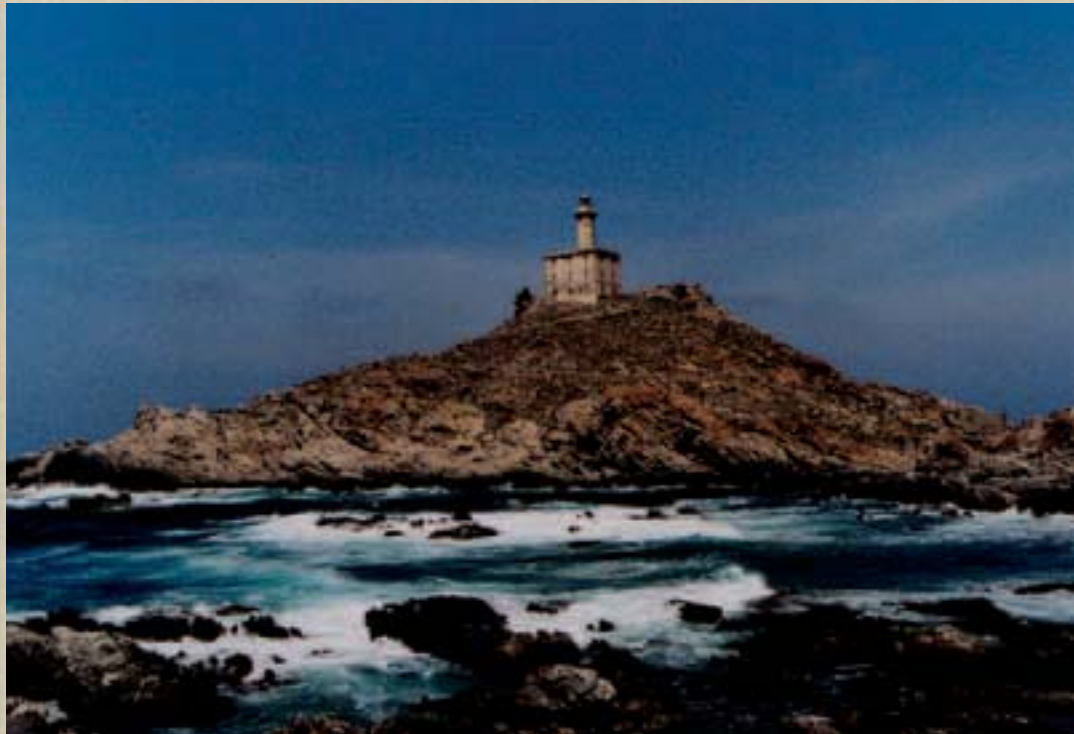
Field Trip Guide Book - P11

Florence - Italy
August 20-28, 2004

Volume n° 3 - from D01 to P13

32nd INTERNATIONAL GEOLOGICAL CONGRESS

VARISCAN BASEMENT IN NORTH SARDINIA AND CORSICA



Leaders: G. Oggiano, P. Rossi

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Post-Congress

P11

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Published by:

**APAT – Italian Agency for the Environmental Protection and Technical Services - Via Vitaliano
Brancati, 48 - 00144 Roma - Italy**



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Acknowledgments:

The 32nd IGC Organizing Committee is grateful to Roberto Pompili and Elisa Brustia (APAT, Roma) for their collaboration in editing.

Graphic project:

Full snc - Firenze

Layout and press:

Lito Terrazzi srl - Firenze

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**VARISCAN BASEMENT
IN NORTH SARDINIA AND CORSICA**

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Front Cover:
Faro di Punta Scorno (Asinara, Sardinia)

Leaders: G. Oggiano, P. Rossi

Introduction

The Corsica-Sardinia block represents an almost complete section across the South Variscan belt showing the transition from the low- to the medium-high-grade basement. The basement shows beautiful expositions of folded, sheared and metamorphosed Paleozoic rocks. From south to north the effect of the Variscan collision and the subsequent exhumation can be observed on all scales. The excursion will be focused on deformation and metamorphism at several locations. The aim of the field trip is to show the effects of progressive deformation and metamorphism along an almost continuous transect of the Variscan belt in northern and north-western Sardinia. The proposed transect offers very good exposures of Palaeozoic rocks along the western coast of the Nurra peninsula, in the Regional Park of Asinara Island in the Anglona area and on the island of Corsica.

From south to north we can clearly observe the effects of the D1 compressional deformation with south verging recumbent folds and shear zones affected by a D2 deformation, with strain increasing northward and tectonic transport parallel to the belt. The Paleozoic successions underwent progressive metamorphism increasing northward. In the Asinara Island a strand of the so called Posada-Asinara suture zone crops out. Here we can observe the superposition of the high-grade metamorphic complex onto the medium-grade rocks. The effects of LP-HT metamorphism, affecting the Barrovian one, are evident at the microscopic-scale and at the outcrop scale also by the growth of cm- to dm-size andalusite porphyroblasts.

The relationship among late orogenic plutons, dykes and metamorphites is clearly exposed in central Asinara island.

Regional geologic setting

The present position of Sardinia and Corsica islands is due to a 30° anticlockwise rotation of the Corsica-Sardinia block away from Europe, caused by the opening of the Western Mediterranean Ligurian-Provençal basin. The age of the rifting phase is dated as Oligocene (from 30 to 24 Ma) followed by a short Early Miocene oceanic accretion (ages ranging from 23 to 15 Ma, Ferrandini et alii, 2003 and references therein). Then the structural pre-drift directions, namely Hercynian, have to be restored by - 30° with respect to stable Europe.

The largest part of Sardinia and Western Corsica is made up of a Permo-Carboniferous batholith em-

placed between 340 and 280 Ma into a Variscan basement which crops out more extensively in Sardinia than in Corsica.

In northern Sardinia and in central and southern Corsica the pre-Permian basement has been affected by Variscan tectono-metamorphic imprint. This basement consists mainly of high grade rocks and was termed the "inner zone" by Carmignani et al. (1979), and, according to these authors it could represent the trace of a continental collision. The different structural Variscan zones were defined in Sardinia where Variscan metamorphic formations widely crop out and were more extensively surveyed.

1- Sardinia

In Sardinia, the basement retains good records of the entire Variscan cycle: in fact the Sardinia crust was only incidentally involved in the Alpine collision without any reactivation of the basement in later orogenic buildings. The Sardinia segment of the Variscan chain shows a NW-SE trend and crops with good continuity from the North to the South (Carmignani et alii, 1994 and reference therein).

Research in the last twenty years has highlighted in the Variscan basement of Sardinia also the possible occurrence of an oceanic suture along a major tectonic line (Cappelli et alii 1991, 1992) in the northern part of the island as well as an Ordovician arc-related calc-alkaline magmatism (Di Pisa et alii 1993). Both of these occurrences have been considered proof of a Precambrian-Cambrian oceanic domain that subducted during Paleozoic times before the continent-continent collision in the earliest Carboniferous. Therefore in addition, Carmignani et alii (1982) reject the intracratonic evolution, with only low-to intermediate P metamorphism, of the Variscan orogeny resulting also in Sardinia as previously stated by Burg & Matte (1978) and other French researchers (see references). The collisional structural frame results in three different structural zones (Carmignani et alii, 1982; 1994) (Fig. 1):

- i) a thrusts and folds belt foreland consisting of a sedimentary succession ranging in age from upper (?) Vendian to lower Carboniferous which crops in S-W part of the island;
- ii) a S-W verging nappe building which equilibrated under green schist facies conditions, consisting of a Palaeozoic sedimentary succession bearing a thick continental arc-related volcanic suite;
- iii) an inner zone characterised by medium to high

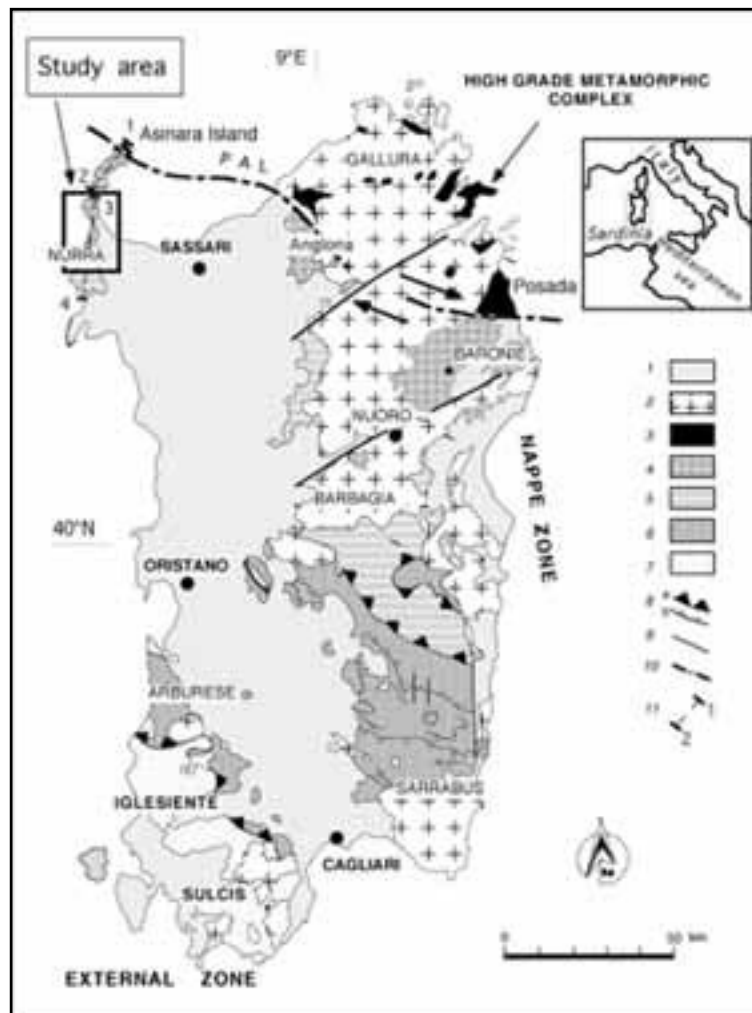


Figure 1 - Tectonic sketch-map of the Variscan belt in Sardinia and position of the study area (after Carosi & Oggiano, 2002, C. R. Geosciences, Elsevier). 1: Post-Variscan cover deposits; 2: Variscan batholith; 3: High Grade Metamorphic Complex; 4: Internal nappes (low-to medium-grade metamorphism); 5: Internal nappes (low-grade metamorphism); 6: External nappes; 7: External Zone; 8: Thrusts (a: main thrusts; b: minor thrusts); 9: Faults; 10: Posada-Asinara Line (PAL); 11: traces of the cross-sections in figure 2.

grade metamorphic rocks.

The inner zone consists of two different metamorphic complexes:

A) a polymetamorphic high-grade complex made up of anatexites and metatexites hosting minor amphibolite bodies which equilibrated in LP/HT con-

ditions which corresponds to the northernmost part of the island and extends to Corsica. In spite of this late re-equilibration, in places granulite relic assemblages of high-intermediate P and unknown age are still detectable (Miller et alii, 1976; Ghezzi et alii 1979; Di Pisa et alii 1993, Franceschelli et alii, 1982);

B) a medium grade, chiefly metapelitic complex, consisting of micaschists and paragneisses bearing $ky \pm stau \pm garnet$ (Franceschelli et alii, 1982) and including quartzites and N-MORB metabasalts boudins (Cappelli et alii 1991).

The contact between these two complexes is well exposed along the Posada Valley (Elter 1987) as well as in Southern Gallura and Asinara island (Oggiano & Di Pisa 1992, Carmignani & Oggiano 1997) and it coincides with a wide transpressive shear belt (Carosi & Palmeri, 2002) and it is affected by upper Variscan shear zones (Elter et alii, 1990).

Thrusting of complex A onto complex B has been inferred

in places where the contact is not complicated by upper variscan retrograde dextral strike-slip shear (Oggiano & Di Pisa, 1992).

Within the collisional frame the high grade migmatitic complex has been regarded as a crustal nappe comparable to the inner crystalline nappe of the French Central Massif and the high strained complex B has been regarded as the Sardinian segment of the south Variscan suture zone (Cappelli et alii, 1991; Carmignani et alii, 1994) which re-equilibrated under intermediate P amphibolitic conditions. As a matter of fact some of the metabasalts embedded within the high strain kyanite bearing micaschists retain clear relics of eclogitic assemblages (Cappelli et alii 1991, Di Pisa & Oggiano 1992)

In places this collisional frame is complicated by the

occurrence of a neovariscan (300 Ma) HT/LP re-equilibration affecting both the complexes (Oggiano e Di Pisa 1992; Del Moro et alii, 1993). This late HP/LP metamorphic evolution has been related to the post-collisional gravitative collapse of the chain, chiefly on the base of its age and of some meso and microstructural evidence. Aside from this late Variscan evolution, the few available thermobarometric estimates (Di Pisa et alii, 1993) joined with microstructural data suggest the two complexes sustained distinctive P-T trajectories before sharing an incomplete re-equilibration under low pressure amphibolite facies condition via a quasi-isothermal decompression.

On the other hand, some muscovite radiometric blocking ages (320 Ma, Carosi et alii 2002) seem to suggest that complex A experienced a HT/LP re-equilibration earlier with respect to complex B as indicated by ages close to 320 Ma as suggested by Ar/Ar (Carosi et alii 2002) and Rb/Sr ages on white micas (Del Moro unpublished data). This eventuality is also pointed out by the P-T trajectories available for the two complexes (Franceschelli et alii, 1989; Ricci 1993). Therefore the case of an earlier rapid decompression of complex A since the collisional stage might be taken into account. For instance the case of rapid syn-collisional decompression associated to an inverted metamorphic gradient have recently been documented in other sectors of the south Variscan Chain in Spain (Arenas et alii 1995).

As concerns the geochronological data in Nurra and in western Gallura the available Ar/Ar data on amphibole and muscovite yielded ages close to 350 Ma (Del Moro et alii, 1991).

In North-Eastern Sardinia an upper limit to the collision-related metamorphism could be represented by the age of 344 ± 7 Ma (Rb/Sr age of isotopic exchange blocking among different compositional domains on a banded gneiss; Ferrara et al. 1978). More recent data yielded 328 ± 8 Ma (U-Pb dating on zircons; Palmeri et alii, 1997) and at 330-340 Ma (Ar/Ar on white micas; Carosi et alii, 2002) for the collision related metamorphism. It is worth noting that U-Pb dating on zircons (Palmeri et alii, 1997) point out a HP event at nearly 420 Ma in the retrogressed eclogites of NE Sardinia.

The D2 transpressional deformation is constrained at 310-320 Ma (Ar/Ar on white micas; Carosi et alii, 2002); The upper age limit of the deformation is constrained by the crosscutting Carboniferous granitoids at ~ 290 -311 Ma (Rb/Sr whole rock isochron; Del Moro et alii, 1975, U-Pb on zircons; Rossi unpub-

lished data).

The structural evolution of the inner zone is well exposed along the transect provided in the field trip.

The D1 collisional event is well-recorded in the study transect producing SW facing folds, shear zones and the main fabric in the low-metamorphic grade rocks in the southern part of the section (Carmignani et alii, 1979; Franceschelli et alii, 1990; Simpson, 1989; Carosi & Oggiano 2002; Montomoli, 2003).

Recent structural investigations highlighted the transpressive kinematics of D2 deformation, related both to NNE-SSW direction of compression and to a NW-SE shear displacement (Carosi & Oggiano, 2002; Carosi & Palmeri, 2002). The deformation is continuous and heterogeneous, showing a northward strain increase, indicated by progressively tighter folds, occurrence of F2 sheath folds and vorticity analysis. D2 transpression is characterized by the presence of a crustal-scale shear deformation overprinting previous D1 structures, related to nappe stacking and top-to-the S and SW thrusting. The L2 prominent stretching lineation points to an orogenic-parallel extension and to a change in the tectonic transport from D1 to D2. It is attributed to the position of Sardinia close to the NE part of the Cantabrian indenter during the progressive evolution of the Ibero-Armorican arc (Carosi et alii, 1999; Conti et al. 2001; Carosi & Palmeri 2002). It has been suggested that D1 phase developed during initial frontal collision whereas D2 deformation characterized the progressive effect of horizontal displacement during the increasing curvature of the arc. The Nurra-Asinara transect is a clear example of heterogeneous transpressional deformation partitioned in the space. In fact, according to theoretical models proposed by Tikoff & Theyssier (1994) we have detected a switch in the attitude of L2 stretching lineation, going northward, from nearly sub-horizontal and parallel to A2 fold axes to down-dip in the northern part of Asinara island (Fig. 2, 3).

2- Corsica

Onshore and offshore sedimentological data on the Oligocene sandstone-conglomerate series of Vazzino near Ajaccio (Ferrandini et alii, 2000), argue in favour of the formation of relief in western Corsica during the Late Oligocene. Apatite fission-track data further document the timing of such relief formation between 27 and 20 Ma, and the coeval detrital sediments show this denudation was assisted by very active erosion (Jakni et alii, 2000), leading to the removal of a large part of the metamorphic Variscan host rocks overlying

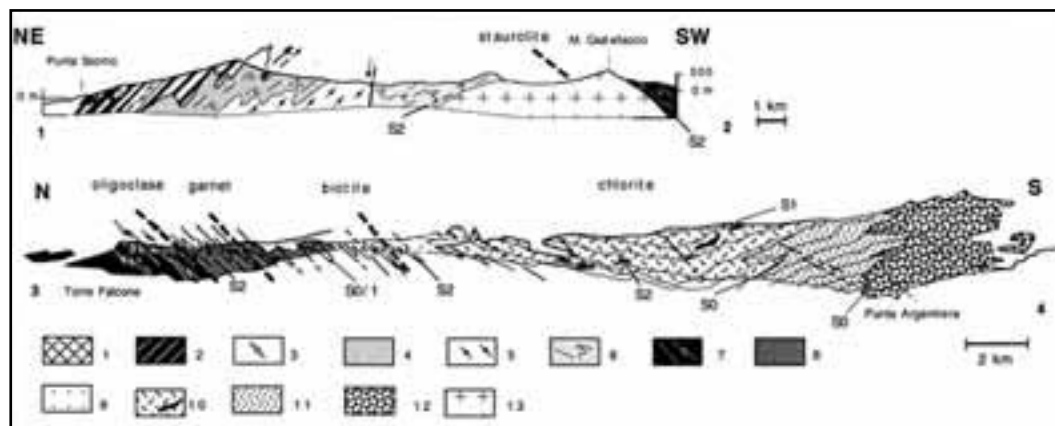


Figure 2 - Geological cross-sections across the Variscan basement in NW Sardinia (after Carosi & Oggiano, 2002, *C. R. Geosciences, Elsevier*). Section 1-2: Asinara island, Section 3-4: Nurra peninsula (redrawn from Carmignani et al. 1979). Isograds of the Barrovian metamorphism are from Carmignani et al. (1979) and Franceschelli et al. (1990). 1: Amphibolite; 2: Migmatite; 3: Cala d'Oliva orthogneiss; 4: Mylonitic micaschist; 5: Cala Reale orthogneiss; 6: Andalusite bearing micaschist and paragneiss, quartzites; 7: Micaschist, garnet+albite/oligoclase paragneiss, quartzites; 8: Paragneiss, micaschist, subordinated quartzite and phyllites; 9: Phyllite and metaconglomerate; 10: Graphitic phyllite, metabasalt and metagabbro (black) (Silurian – Devonian); “oolitic ironstone”, phyllites, metagreywacke, porphyroids (Ordovician); 11: Phyllite and metaconglomerate; 12: Metasandstone, phyllite and quartzites (Carboniferous ?); 13: Variscan granitoids.

the batholith.

Two types of basement host the batholith in Corsica: T1 has a Pan-African structure (related to the Armorica microplate [Matte, 2001]), whereas T2 has a Variscan structure (Durand-Delga and Rossi, 1992). T1 formations are composed of Upper Proterozoic micaschist overlain by non-metamorphic Paleozoic (Ordovician to Devonian) formations. The Eovariscan T2 basement mostly consists of a poly-metamorphic Paleozoic succession whose metamorphic peak occurred prior to 340 Ma. The T1 and T2 terrains were fused together around 340 Ma, during emplacement of the early U1 group of intrusions restricted to the Corsica batholith.

The Panafrican T1 basement: The best-preserved formations are found near Argentella and in the Tenda massif. Locally strongly folded, these rocks suffered only greenschist-facies metamorphism; they are composed of metasedimentary rock (metaquartzite and metagreywacke) and amphibolite derived from enriched MORB-type basalt, suggesting an intracontinental-rift-type setting. Near Argentella, south of Calvi, they are overlain by an Ordovician to Silurian succession.

Systematic dating of zircons in micaschist from the Western Tenda massif (Agriate desert) has shown that they were recycled from an older (2.2 Ga)

basement. The isotopic composition of neodymium, $+4.5 < \text{NdT} < +7.7$, in amphibolite shows that mass contamination phenomena by the continental crust were minor (Rossi et alii, 1994). A whole-rock ilmenite and amphibole isochron gave an age of 747 ± 120 Ma; although poorly defined, this age range dates the metabasalt between Late Proterozoic and Cambrian. This age can be compared to that of 957 ± 93 Ma for the amphibolite in the Posada-Asinara suture in northern Sardinia (Cappelli et alii, 1992).

The Variscan basement: The different basement fragments, now isolated within granitic intrusions of the batholith, show distinct and diachronous tectono-metamorphic evolution (Lardeaux et alii, 1994). U-Pb zircon dating on gneisses from different fragments (Porto-Vecchio, Zicavo) point to Late Cambrian to Ordovician ages for the orthogneiss protolith. These fragments are related to the inner zone of the chain and correspond to the polymetamorphic complex that is exposed in northernmost Sardinia.

Evidence of a polyphase evolution during Devonian and Carboniferous times was described in the Porto-Vecchio area (Libourel., 1985), and in Zicavo (Thévoix-Chabuel et alii, 1995) and Belgodere (Palagi et alii, 1985).

The older event, associated with Barrovian metamorphic conditions and related to a Variscan collisional

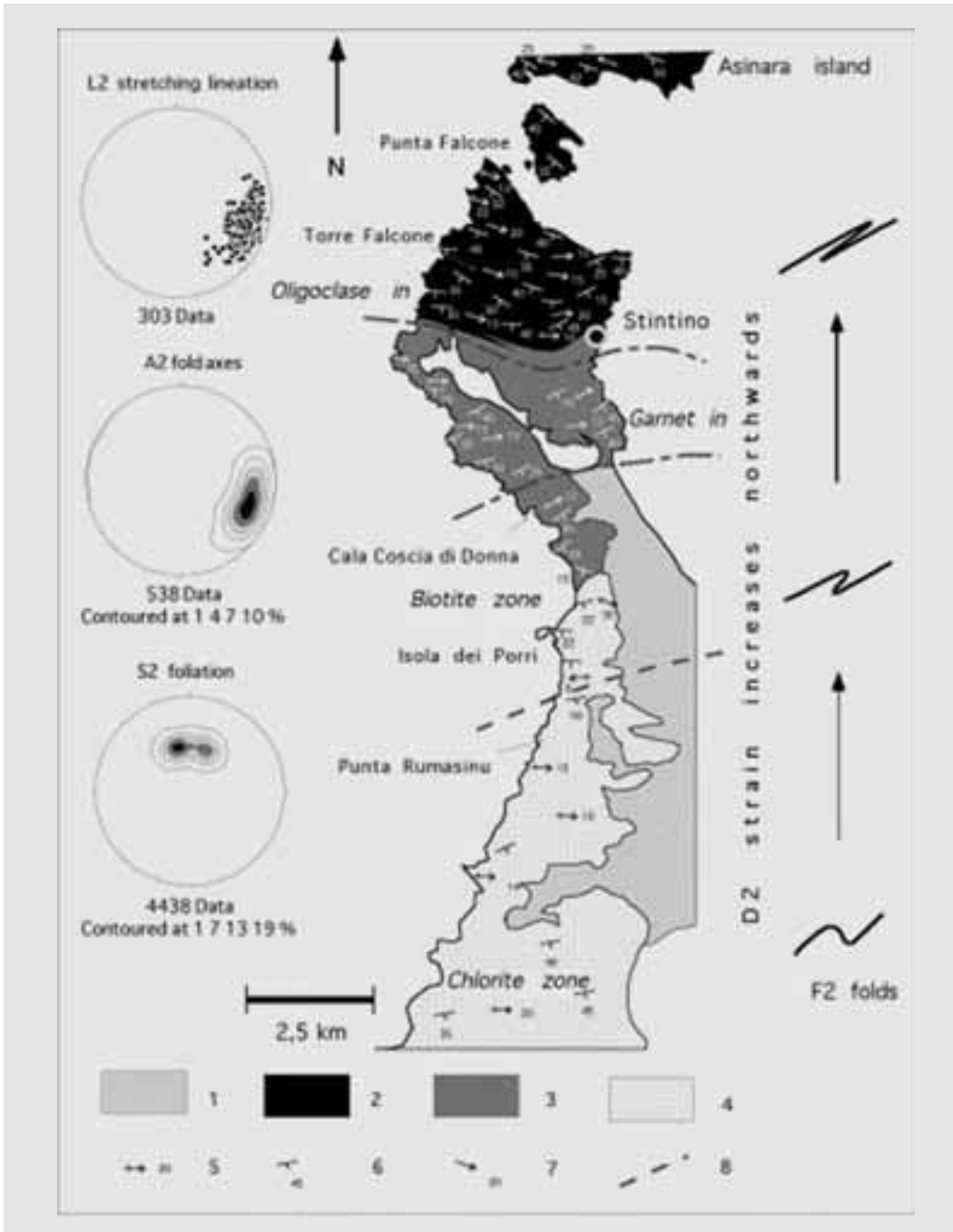


Figure 3 - Geological map of the basement in the Nurra – Asinara section and indication of the stops. 1: Post-Variscan covers; 2: Micaschists, garnet+albite/oligoclase paragneiss, quartzites; 3: Paragneiss, micaschists, subordinated quartzites and phyllites; 4: Phyllites, black phyllites, metavolcanites, metabasites, metasandstones and quartzites; 5: trend and plunge of A2 folds axes; 6: strike and dip of the S2 foliation; 7: trend and plunge of L2 stretching lineation; 8: isograds of the Barrovian metamorphism; after Carmignani et al. (1979).

stage, is well exposed in the Porto-Vecchio area. Here, the basement outcrops in two remnants: the Chiappa series to the south and the Fautea series to the north.

Within the Chiappa series, from south to north, a porphyric orthogneiss was dated (U-Pb / zircon TIMS; C. Guerrot, unpublished data) at $463 \pm 14/-11$ Ma. The Fautea series is mainly composed of garnet-kyanite granulitic paragneiss enclosing pyroxenite and pyrigarnite boudins, the southern and western part being bounded by migmatite. SHRIMP U-Pb zircon dating of pyrigarnite from north of Fautea gave an age of about 470 ± 30 Ma for the protolith, whereas ages of 450 to 380 Ma are interpreted as those of the metamorphic climax. An even younger age of 345 Ma reveals the age of anatexis of the basement, as constrained in other parts of the Variscan basement, specifically Belgodere.

Near Belgodere, where U1 Mg-K monzonite is in contact with gneissic basement, their relationship indicates that the monzonite was emplaced in an anatectic environment during the peak of amphibolite-facies metamorphism (5-6 kbar). Synkinematic granite "orthogneiss" of Belgodere was dated at 338.1 ± 0.8 Ma (U-Pb zircon; Paquette et alii, 2003). Along the west coast, south of Calvi, the Capo Cavallo granodiorite, which contains enclaves of both types of basement, was dated at 347 ± 1.3 Ma (op. cit.). Leucocratic granite with chilled margins against the Pan-African basement was dated at 337.7 ± 2.3 Ma (op. cit.). The setting of the high Mg-K calc-alkaline suite suggests that it was emplaced just after collage of T1 and T2.

The second event corresponds to late orogenic evolution that was controlled by continental-crust attenuation. In Zicavo and La Vaccia, a transtensional context, associated with LP-HT recrystallization, created a reduced metamorphic superposition involving greenschist-facies and up to cordierite-bearing anatectic rocks. Field relationships suggest that emplacement of the calc-alkaline plutonism (305-290 Ma) of the batholith took place during this extensional stage. Near the Verde pass and around the Renoso massif, leucocratic monzogranite dated (U-Pb zircon) at 287.1 ± 1.6 Ma intrudes anatectic basement rocks; at the contact, the granite presents peritectic reactions with the crystallization of garnet.

Field itinerary

DAY 1

Nurra peninsula.

The first day is dedicated to a cross-section through the Palaeozoic successions of Nurra peninsula starting from the southernmost and relatively less deformed area and going toward Punta Falcone, to the north. Along the itinerary peculiar Ordovician and Silurian metamorphic rocks along with increasing Variscan collisional deformation and Barrovian metamorphism can be observed.

Stop 1.1:

Argentiera area - D1 Collisional deformation.

After reaching the small village of Palmadula we turn left toward the old mine of Argentiera and the beach. Here the contact between pinkish ankerite bearing, quartzites and blackish fillites is exposed. In spite of the transposition of the primary contact, this stratigraphic boundary is quite detectable and it is marked by a meta-diamictite of supposed glaciomarine environment of Hirnantian age. This rock when observed at cuts parallel to the main schistosity, appears as a dark laminated metapelite bearing sporadic angular clasts, millimetric up to metric in size, made up of quartzites and meta-sandstones. Moving to the promontory of Punta Argentiera F1 recumbent folds, S1 penetrative foliation, S2 spaced crenulation cleavage, folds interference pattern and facing of F1 folds can be observed.

From the beach we climb toward Punta Argentiera. We stop at a gate and after 30-40 minutes of walking we descend a very steep slope to reach sea level. Here an hectometric-size F1 syncline affects phyllades and quartzites with nearly E-W fold axis. S1 axial plane foliation shows refraction through sedimentary layers. In a very few places some load casts allow us to detect the bedding polarity and the SW facing of the folds. The D1 structures are affected by open F2 folds and in places we can observe beautiful examples of interference patterns. S2 is a spaced crenulation cleavage dipping to the south. Locally we can see another crenulation cleavage conjugated to the S2 one. The outcrops are affected by several generations of veins, testifying a strong fluid activity during the deformation and prograde Barrovian metamorphism (Simpson, 1998) which here is confined within the chlorite zone of greenschist facies.

Stop 1.2:

North of Porto Palmas. F1 folds, late D1 shear zones and veins; fluid inclusions information, F2 open folds.

We come back on the same road until we reach the beach of Porto Palmas where we take a gravel road running northward for about 2 kilometers. At sea level, below some meters of Quaternary deposits, several F1 tight folds crop out. The sedimentary bedding is clearly visible at several localities highlighted by the alternation of quartzites, metasandstones and dark phyllades and metapelites. Late D1 ductile/brittle shallowly dipping shear zones show a top to the S and SE sense of shear. They are affected by S2 crenulation and they are characterized by abundant sigmoidal quartz veins.

Fluid inclusions trapped in quartz veins along secondary trails oriented both at high and low angles in respect to the shear zone boundaries highlight the presence of aqueous carbonic fluids. Bulk composition and densities, calculated on the basis of microthermometric and Raman data, point out to different types of fluid inclusions. A first type characterized by a lower density (0.84-0.87 g/cm³) and a second type with density values ranging from 0.88 to 0.92 g/cm³. The computed isochores of both types do not match the P-T peak conditions proposed for the area suggesting that fluid inclusions have been trapped or at least re-equilibrated during a retrograde metamorphic pattern.

Post-D1 flanking-structures, often of normal-type and associated to veins, are recognizable in the metapelites.

Stop 1.3:

Villaggio Nurra: oolitic-iron deposits; metabasites.

From Porto Palmas we move to the north following the road from Palmadula to Stintino, then, turn west and after about two hundred meters we stop at Villaggio Nurra, a tourist village of bungalows. Here on an overturned succession the contact between the Silurian black phyllites and the meta-graywackes, which host metabasites and metariolites, is exposed close to the cliff and in an old adit.

This contact is marked by a horizon of meta-diamictites made up of metapelites consisting of chamosite in which fragments of quartzite and micaschist are scattered, revealing the recycling of a pre-variscan

basement. Other objects dispersed within the chamosite matrix consist of goethite pebbles, phosphorite nodules and chamosite ooids. Also this chemical sediment has been referred to the glaci-marine setting which during late Ordovician extended over the north Gondwana shelf (Fadda et al. 2003).

The transition between upper Ordovician and Silurian is also characterised by the occurrence of alkaline to transitional metabasalts and metadolerites that occur as sub-concordant sheeted dikes well exposed on the upper part of the cliff.

Stop 1.4:

Road cuts in Le Saline area.

We go on toward the village of Stintino. Nearly 2 km south of Stintino we stop at a road cut in the Le Saline area. Micaschists and paragneisses are affected by close to tight F2 folds, testifying to a northward increase of D2 deformation transposing the D1 fabric. The metamorphic grade increases and we are near the zone of incoming of post-D1 garnets.

Stop 1.5:

Punta Falcone.

We reach Capo del Falcone in the Roccaruja village area. A few meters above La Pelosa beach we can see northward in front of us the southern part of Asinara Island. We can clearly recognize the granite of Mt. Castellaccio (pale yellow-pink) intruded in the metamorphites (lower dark rocks).

Albite and oligoclase bearing paragneiss and micaschists crop out. Plagioclase and garnet are of mm-size and visible with the naked eye. In thin section they preserve relics of S1 foliation and sometimes they are rotated during D2 with a top to NW sense of shear. The L2 stretching lineation is nearly parallel to F2 fold axes and strikes NW-SE. It is well-developed in quartz rods. Sheath folds are recognizable in transposed quartz veins in the paragneiss.

Beautiful examples of type-3 interference pattern between F1 and F2 folds are detectable in some road cuts (Fig. 4a).

DAY 2

The second day is entirely dedicated to the geology of the Asinara island natural park. The itinerary starts at Fornelli, the point of arrival of the ferry from Stintino (after 30-40 minutes of navigation), in the southernmost part of the island, and follows the main road till the old village of Cala d'Oliva to the north. From this

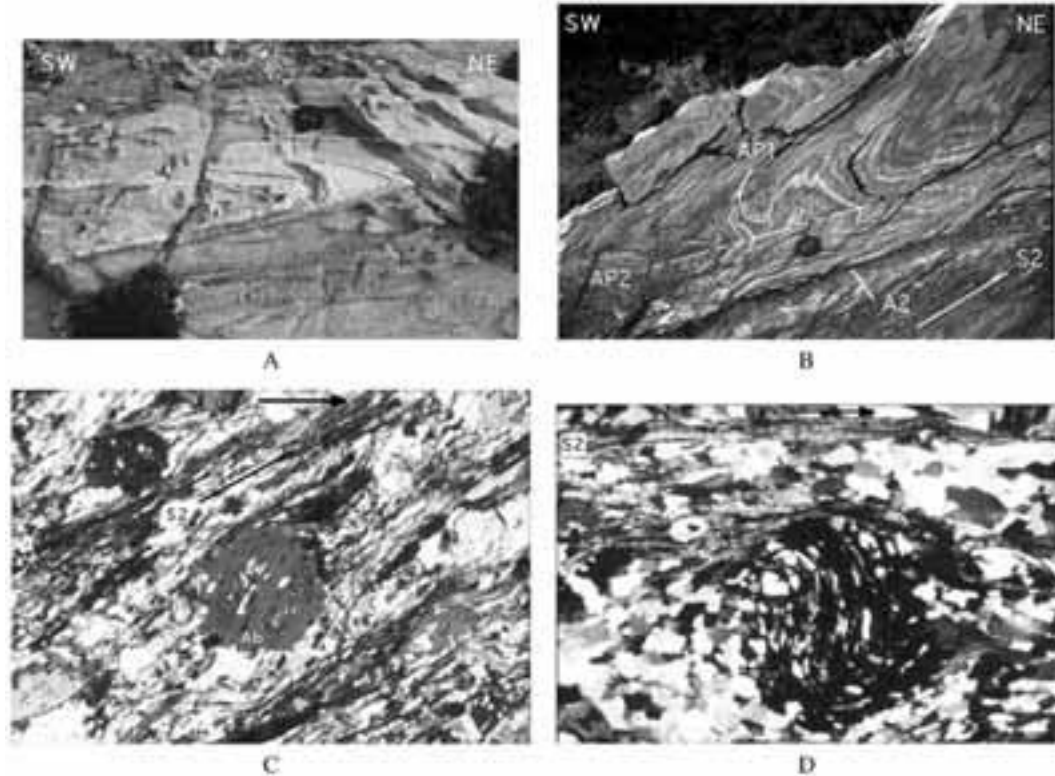


Figure 4 - A, C: rotated syn-D2 garnet in micaschists of northern Nurra; top-to NW sense of shear. CPL, *F*ow is 6.8 mm. Mylonitic foliation in B and C strikes roughly W-E and dips 40-60° to the South (after Carosi & Oggiano, 2002, C. R. Geosciences, Elsevier).

old village the itinerary goes on by a badly preserved dirt road toward the lighthouse of Punta Scorno, a beautiful wild place in the northernmost part of the island.

Stop 2.1:

Fornelli locality nearby the southern contact between Mt. Castellaccio granitoid intrusion and the Medium Grade Metamorphic Complex.

The Late Variscan Mt. Castellaccio intrusion consists of inequigranular granodiorite -monzogranite characterised by large laths of K-feldspar highlighting a magmatic fluidality. Small bodies of nearly equigranular and muscovite-rich monzogranitic facies also occur within the main intrusion (e.g. Cala S. Andrea) and at the northernmost part of the island.

Oligoclase bearing paragneiss and micaschists are mainly affected by the F2 tight to isoclinal folds and show the same structural and metamorphic history of the metamorphites outcropping at Punta Falcone.

It is worth noting that the effect of contact metamorphism on the intruded schists is absent or very weak. Only in thin section recrystallization of biotite into decussate texture and destabilization of garnet are detectable. Several brittle shear zones and faults affect the metamorphites but the lack of post-Variscan sediments does not allow to attribute them to the Variscan or to the Alpine cycle.

Stop 2.2:

We continue along the road to Cala d'Oliva and we stop a few tens of meters after the northern contact between the granitoid intrusion and the Medium Grade Metamorphic Complex in Punta Sa Nave and Stretti zone. Here, in contrast to the southern context, the LMGMC schists are affected by an HT/LP metamorphism which overprints the previous Barrow type one, giving rise to huge andalusite and sillimanite blastesis +/- cordierite. We can observe, paragneiss and micaschists bearing andalusite; at places centimetric blasts of chiastolite are also present (fig5).



Figure 5 - Chiastolite porphyroblasts near Asinara island; Punta Sa Nave.

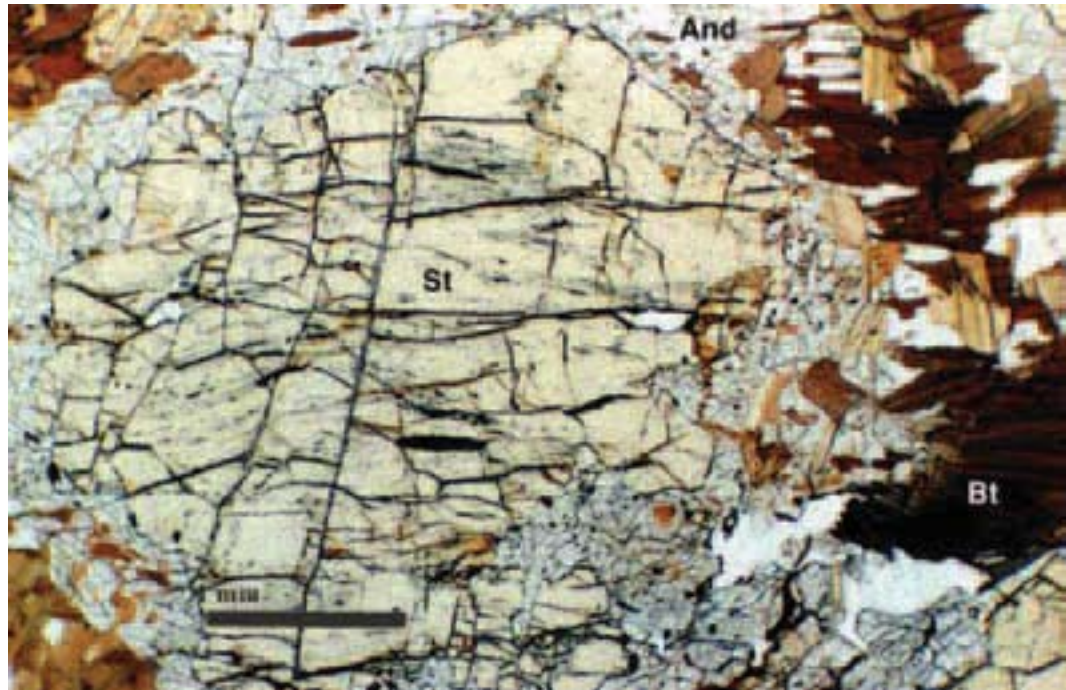
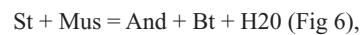


Figure 6 - Relic staurolite porphyroblast rimmed by andalusite and biotite intergrowths. Asinara Island; metapelites north of Castellaccio intrusion.

This new assemblage overprints an assemblage where Grt + Stau were stable; relics of these mineral are still easily detectable within the HT/LP related assemblages suggesting the following andalusite forming reactions:



Moving some hundred metres northward a horizon of massive quartzite crops out close to an alignment of hectometric to metric lenses and boudins of massive amphibolite. Relic gabbroic and basaltic texture joined to N-morb type signature according to Cappelli et al. (1992) led to consider these rocks as ophiolitic remnants. A Sm/Nd isocron on these amphibolite yield a late Proterozoic age. The two main deformation phases D2 and D3 give rise to interference figures visible both on the road cut and in the surrounding flat areas. The main fabric is due to D2 deformation phase, but differently from the area south of the Mt. Castellaccio intrusion F2 folds verge toward the SW and S2 schistosity dip northward.

In the Stretti zone a clear relationship between S1 that

is parallel to S0, D2 tight folds and upright D3 folds is shown. Pegmatite dykes intrude the MGMC both sub-parallel to the S2 schistosity and crosscutting the schistosity suggesting the existence of at least two intrusive events. In the Stretti zone the HT/LP overprint is characterized by static crystallization of cm-size andalusite crystals overprinting the D3 deformation phase. The L2 stretching lineation is well developed in the quartzites and it is nearly parallel to the F2 fold axes.

Stop 2.3:

La Reale

A few dozen meters behind the houses of La Reale an orthogneiss body crops out. The prominent linear fabric is defined by laths of alkali feldspar in a matrix characterised by a preferred orientation of quartz, plagioclase, microcline, and weakly fibrolitized muscovite. The fabric is apparently referable to a L-tectonites. However, a closer look allows us to recognize that this is due to interference between the main fabric (S2) and small-size collapse folds (with sub-horizontal axis and axial plane) related to a post-D3 nearly vertical shortening.

Stop 2.4:

Cala d'Oliva - Punta Scorno

We reach Cala d'Oliva and follow a gravel road on the left climbing a small hill and we descend toward Punta Scorno in the lighthouse area.

We crosscut the High Grade Metamorphic Complex, mainly composed of migmatitic gneiss, orthogneisses, metatexites and diatexites.

We make some short stops along the road to observe the Cala d'Oliva orthogneiss and andalusite bearing mylonitic micaschists.

The Cala d'Oliva orthogneiss is a sheet gneiss body with variable thickness defined by plagioclase-antiperthite and microcline-perthite interlayered with discontinuous domains depleted in feldspars and enriched in phyllosilicates. During the HT/LP evolution such domains experienced widespread static blastesis defined by cordierite, sillimanite and andalusite. The new static assemblage partially erased a mylonitic fabric which is still documented by annealed quartz ribbons.

On the most evident schistosity pronounced stretching lineation with a down-dip attitude is well exposed. Going northward we enter the migmatitic complex made up of diatexite characterised by either stromatic, nebulitic and agmatitic textures with sometime restitic biotite enriched domains. In the metatexitic complex nice examples of D4 structures (tension gashes, flanking folds) are recognizable.

Close to Punta Scorno the HGMC is defined from south to north by mylonitic micaschists, banded amphibolites, orthogneiss and sheared metatexites and diatexites.

The Punta Scorno orthogneiss, normatively a synogranite, consists of mylonitic augen gneiss characterised by large laths of alkali feldspar which exhibit both oblate and prolate shapes. The mineral assemblage is the same of Cala d'Oliva orthogneiss even if mica, garnet and sillimanite are comparatively more abundant. It is characterized by cm- to dm-size laths of k-feldspar with asymmetric recrystallized tails (visible to the naked eye) pointing out a top to the SW sense of shear with a down dip stretching lineation. Nice examples of rotated porphyroblasts both in the XY and XZ principal planes with well developed quartz tails are observable in the outcrops at sea level on the left side of the road.

F3 nearly upright folds affect the amphibolites and the surrounding rocks. It is easy to observe refolds, F2 folds and fold hinges.

Hectometric-size outcrops of banded amphibolites are

visible on the north-western coast south of the lighthouse and consist either of centimetric to decimetric dark amphibolites alternated with leptinitic layers, or massive hornblende-plagioclase amphibolites. The mineral assemblages sometime include calcic-pyroxene and garnet (both as relics of previous granulite metamorphic stage) and zoisite.

Following the road climbing toward the lighthouse we reach the north-western slope of the promontory. Under the lighthouse, the diatexitic complex with granitoid leucosome involve relics of folded (F2) banded amphibolite and a body of massive amphibolite and a poliphase restitic body. Here we can observe beautiful exposures of post-D2 high temperature shear zones. Rotated boudins of dark amphibolites of variable size (up to decametric-size) and leucocratic portions show a top down to the NE sense of shear.

They seems to be involved by D3 upright mesoscale folds and they probably accommodate the exhumation of the HGMC.

DAY 3

Road from Sassari to Santa Teresa di Gallura: during the morning two short stops along the Posada-Asinara shear zone. In the early afternoon we take the ferry to Bonifacio from where can observe the Palaeozoic basement of Corsica Island in a crustal sector not affected by alpine tectonics.

Stop. 3.1:

The small villages of Giuncana and Tunconi. Staurolite and kyanite bearing micaschists affected by the strike-slip retrograde shear zone

Close to the little village of Giagazzu we cross the same micaschists and paragneisses already seen in the Asinara. Unlike what we saw on that island, here no HT/LP overprint affects the barrovian assemblages.

Staurolite blasts and kyanite associated to quartz veins are well detectable in some outcrops.

Moving to the north we approach the retrograde shear zone that marks the contact between the barrovian micaschists of the MGMC and the migmatites of the HGMC. Close to the shear zone the micaschists exhibit shear bands with S-C relations pointing to a dextral strike slip motion. On quartz veins horizontal slickenside lineations also suggest both low thermal conditions and dominantly dextral wrench kinematics for this deformative event. Close to the contact with the HGMC 200 meters of a thick phyllonite belt oc-

curs. This rock derives from the green schist facies retrogression of both micaschists of MGMC and migmatites of HGMC.

Stop 3.2:

Partially retrogressed eclogite body embedded in micaschists

Within the micaschists, two kilometres south of the phyllonitic zone an hectometric body of eclogite partially re-equilibrated under amphibolite facies occurs. This rock appears weakly deformed by the different deformation phases that affect the host micaschists. The texture is controlled by amphibole, garnet and plagioclase assemblage. Symplectites of Cpx and albite are common, deriving from destabilization of omphacite. Relic omphacite also occurs within garnet.

The geochemical signature of this eclogite coherently with that of the several amphibolite slices occurring in the same structural position point to an N-MORB protolith.

2 - Corsica

DAY 1

The Variscan basement around Porto Vecchio.

The gneiss of the Porto-Vecchio basement is exposed over some tens of kilometres from the Chiappa series in the south to the Fautea series in the north. This succession is similar to that of the Zicavo basement in central Corsica.

From south to north, the Chiappa series consists of porphyric orthogneiss (Stop 1), a leptynic-amphibolic complex, and fine-grained micaschists.

The Fautea series is mainly composed of garnet-kyanite granulitic paragneiss enclosing pyroxenite and pyrogarnite boudins, the southern and western parts being bounded by migmatite. For discussion of the ages of both series, please see the section above, under the older event, as well as in the Stop descriptions hereafter.

The Chiappa series

Stop 1:

Porphyric orthogneiss

The porphyric orthogneiss found in the Chiappa area is quite widely exposed in the surrounding area. Specifically, good outcrops occur 4 km to the southeast,

on Forana Island (Cerbicale islands).

Its texture is that of a systematically porphyroclastic metagranite, generally with "eyes" of K-feldspar, 2 to 3 cm long but exceptionally as large as 5-10 cm, as well as of polygonal plagioclase that can enclose garnets. Biotite "1" and muscovite occur as spindles. A post-deformation, non-rotational, metamorphic episode is characterized by unoriented biotite "2". This metagranite has an aluminous composition, hosting uncoloured and clear zircons, locally as elongated prisms conferring them an acicular aspect; their average A-T index of 232-384 is characteristic of zircons from aluminous magmas.

The metagranite was dated at 463 +14/-11 Ma (U-Pb TIMS zircon, C. Guerrot, unpubl. data). On Forana Island, the dating of monazite in the metagranite gave an age of 338±6 Ma, which corresponds to the passage of T°C below 690±40 (Dahl, 1997) after the metamorphic peak.

Porphyric orthogneiss is common in the basement of the Corsica-Sardinia batholith. In Sardinia, the Lodé aluminous metagranite was dated (Rb-Sr) between 458±31 Ma and 441±33 Ma (Ferrara et alii, 1978). In the Zicavo series of Corsica, aluminous metagranite has been dated at 458±32 Ma (Pb-Pb evaporation on zircon).

The Punta di Fautea - Anse de Favone series

Stops 2 to 4 are described based on G. Libourel's PhD thesis (1985).

Stop 2:

Leptynite-amphibolite complex: Punta di Fautea

At Fautea, we can see a fragment of the leptynite-amphibolite complex, described by Arthaud and Matte (1975) and Ricci and Sabatini (1978). The biotite amphibolite is ribbon-banded, with a grano-nematogranoblastic texture. The compositional ribbons are marked by alternating amphibole- and plagioclase-rich levels. Biotite occurs as long lamellae that intersect the foliation and seem to post-date it. Pale-green amphibole, dominating many ribbons, is statistically elongated in the main foliation plane. Calcic (and-lab) plagioclase occurs as polygonal assemblages. No aluminium silicates were observed.

Between the Punta di Fautea and the Anse de Favone, granulitic rocks are only exposed in the southern sector over a distance of 6 km, between the Bocca di Guardia in the north and the Conca stream in the

south. They are mainly composed of alternating granulitic paragneiss layers in which sporadic boudins or lenses of basic granulite occur, whose size can vary from around 10 cm to over 50 m. Occasional cipolin lenses occur near Cervoniccia, intercalated in these rocks, either as thin laminated layers, or as small centimetre-size boudins. This core of granulitic rock is surrounded by migmatitic gneiss, exposed in the north around Punta Telica and Tossa Rossa, and in the south near Fica and around Ogliastriccione and the Punta di Fautea.

Within these migmatitic zones, amphibolite boudins, with or without garnet, are commonly observed; granulitic levels persist sporadically in the migmatitic gneiss of Ogliastriccione (southern area).

In the southern sector, the general foliation of the succession oscillates between N010° e N030° with a steep easterly dip. To the south, around Fautea, the foliation gradually changes to a generally east-west direction with a steep northerly dip. Within the granulite, a syn-metamorphic lineation has a variable pitch of 40° to 80°N in the foliation plane.

Stop 3:

Granulitic paragneiss: RN 198, Ogliastriccione

a. Primary assemblages

The garnet-kyanite granulitic paragneiss occurs as irregular bands of quartz-feldspar leucocratic layers, depleted in garnet, and darker layers of the same composition but enriched in biotite and garnet. They are commonly spotted for muscovite and blue kyanite is easily visible.

Along the RN 198 road near the hamlet of Ogliastriccione, granulitic paragneiss is remarkably conserved in the granulite succession as well as in migmatitic gneiss. Not showing any trace of retrograde metamorphism, these assemblages are composed of: quartz - garnet (alm-pyr) - perthitic K feldspar - antiperthitic plagioclase (An 20-25) - kyanite - rutile - zircon - apatite - graphite.

Textures are granoblastic to granolepidoblastic; globular or sub-automorphic garnet, commonly with helicitic inclusions, shows perfectly stable contacts with the K-feldspar. Kyanite, as elongated rods in the foliation plane or oblique to it, in places shows small inclusions of automorphic garnets, rutile, quartz and biotite. The stability of the garnet and the K-feldspar, as well as the presence of kyanite as the only aluminium silicate, indicate that the associations reflect a granulitic high-pressure episode.

b. Assemblages showing retrograde metamorphism

Retrograde metamorphic assemblages are marked by the development of biotite and muscovite associations at the expense of the initial garnet and K-feldspar assemblages, following a reaction of the type $Gt + FK + H_2O \rightleftharpoons Bi + Mu + Qtz$.

Garnet is enveloped by closely associated Bi + Mu over a limited distance. Occasionally, in granulite that underwent further retrograde metamorphism such as in the Conca stream near the migmatitic Fautea gneiss, this reaction results in garnet atolls that were drowned in a biotite and muscovite felting. Secondary quartz progressively moulds the garnet shape, which tends to disappear.

Parallel to the development of these assemblages, kyanite is commonly surrounded by a muscovite halo with quartz droplets, at the contact with K-feldspar. Such destabilization is caused by a reaction of the type: $Ky + FK + H_2O \rightleftharpoons Mu + Qtz$. As before, various operating stages of this reaction can be observed. The kyanite disappears in the end, leaving a few quartz granules within the muscovite felt.

The later stages of retrograde metamorphism remain entirely within the kyanite stability field, as is suggested by the accidental appearance of sillimanite in this granulitic succession, as well as the direct pseudomorphism of kyanite into andalusite. Finally, the development of chlorite at the expense of garnet must be attributed to these same processes of retrograde metamorphism.

Stop 4:

Mafic granulite: Ogliastriccione, seashore north of Tarcu

In the southern area, mafic granulite has been found in the scrub between Tozza Rossa and Ogliastriccione, between benchmark points 184 and 157, in the Tarcu cove and 500 m north of the shore. Dark green in outcrop, these extremely massive rocks contain garnet that can be recognized everywhere. In addition, these rocks are commonly loaded with amphiboles from the centre to the edges of the boudins or lenses. In certain cases, the lenses are surrounded by an amphibole "cortex", with or without garnet.

The primary paragenesis of these rocks is composed of clinopyroxene + garnet (alm-pyr, grossular rich ~30%) + plagioclase (~An 50) + quartz (±) rutile and opaques. Notwithstanding a locally strong, secondary amphibolitization, this paragenesis is characterized by the co-stability of garnet and clinopyroxene

in the presence of plagioclase. These metabasic rocks thus define a high-pressure granulite (pyrigarnite), even though the eclogite s.s. domain has not been reached.

The first stages of the later amphibolitization of this paragenesis are shown by characteristic kelyphitic textures, witness of retrograde metamorphism under hydrating conditions. The extreme stages of this metamorphism led to a complete resorption of garnet; the pyrigarnite boudins thus changed into common amphibolite, as can be seen in the migmatites of Ogliastriccione, where swarms of boudins present different stages of retrograde metamorphism.

Estimation of P-T granulitic assemblages

The primary crystallization conditions of the granulitic assemblages were determined from the Gt - FK - Plag - Ky - Bi - Qz association in granulitic paragneiss that did not suffer retrograde metamorphism and the Cpx - Pl - Gt - Qz association in slightly amphibolitized pyrigarnite.

The different geothermobarometers used shows them to be relatively concordant, indicating that the primary parageneses were created under pressure between 1.2 and 1.5 GPa and temperatures between 800 and 900 °C. These rigorous values that agree with the mineralogical assemblages, indicate that these rocks at one point in their history underwent high-pressure metamorphism.

Based on Vielzeuf's thermodynamic work (1980, 1984) on the stability fields of the Gt - Fk assemblage, we can assume that the Bi + Mu + Qz and Mu + Qz associations in the paragneiss that developed at the expense of Gt - FK and Ky + FK mark a high-pressure start of the retrograde metamorphism. The history of the subsequent retrograde metamorphism falls entirely within the kyanite stability field, as is attested by the absence of Ky + Sil pseudomorphs. This means that, based on the primary conditions, we cannot envisage a pressure decrease at constant temperature here.

Nevertheless, the presence of kyanite and andalusite pseudomorphs marking the end of this retrograde metamorphic evolution, as well as the partial re-equilibration of pyrigarnite in the amphibolite facies, indicate that the retrograde metamorphism was characterized by a major pressure decrease. Based on the stability conditions of the triple point of aluminium silicates (Althaus, 1967; Richardson et alii, 1969; Holdaway, 1971), the formation of these last assem-

blages might effectively indicate a pressure difference of around 0.6-0.7 GPa, when compared with the primary conditions.

Pyrigarnite geochronology (JYC 39), Ordnance Survey Map IGN 711

Samples for dating were taken on the path from Ogliastriccione to Tozza Rossa, 500 m west of benchmark point 184 m. The grains show zonation and commonly a core-and-rim structure. The youngest age at 345.2 ± 4.7 Ma (10 points), corresponding to the analysis of large zircon rims, corresponds to the anatectic age of the basement as constrained in other parts of the Variscan basement, such as Belgodere. The 560 ± 50 Ma and 688 ± 20 Ma ages are considered as inherited. Ages pointing to 466 ± 30 Ma (4 points) are seen as the age of the protolith, whereas ages at 440 ± 12 Ma and 412 ± 32 Ma are interpreted as those of the metamorphic climax.

Conclusions for Day 1

The para- and ortho-derived rocks of the Solenzara-Fautea basement were subjected to high-pressure –estimated at 1.2-1.5 GPa– metamorphism between 450 and 380 Ma, which implies an abnormally thickened crust of >45-50 km. The temperature estimates of 800 to 900 °C moreover indicate a low temperature gradient during the formation of these granulites.

After the metamorphic-climax, further evolution was marked by heterogeneous synkinematic retrograde metamorphism, starting under high-pressure conditions and falling entirely within the stability field of kyanite. This indicates major non-adiabatic decompression, related to a rise of at least 20 km of the granulites into higher structural levels of the crust (closure of the U-Pb system of the zircons at 345 ± 5 Ma. The granulite was then partially migmatized (relics of unaltered granulite indicate diffuse migmatitization) and pyrigarnite was amphibolitized. The heterogeneity of retrograde crystallization, the shear-type deformation, and the dynamic character of the retrograde metamorphism indicates that the crustal ascent of the granulites was rapid and occurred during a tectonic process with a strong tangential component.

DAY 2

The T1 Pan-African basement of Galeria

Stop 1:

Belgodere gneiss (T2)

Near Belgodere, where U1 Mg-K monzonite is in contact with gneissic basement, the relationships indicate that the monzonite was emplaced in an anatectic environment during the peak of amphibolite-facies metamorphism (5-6 kbar). Synkinematic granite "orthogneiss" at Belgodere was dated at 338.1 ± 0.8 Ma (U-Pb zircon, Paquette et alii, 2003). Along the west coast, south of Calvi, the Capo Cavallo granodiorite, which contains enclaves of both types of basement, was dated at 347 ± 1.3 Ma (op. cit.). Leucocratic granite with chilled margins against the Pan-African basement was dated at 337.7 ± 2.3 Ma (op. cit.). The setting of the high Mg-K calc-alkaline suite suggests that it was emplaced just after collage of T1 and T2.

Stop 2:

Ferraghjola: T1 Pan-African micaschist and amphibolite

Within the sericite-chlorite micaschist, quartzitic beds alternate with phyllitic beds that commonly are clearly ribbon banded. The unit stabilized under greenschist-facies metamorphism, and no higher-grade relics have been found.

The composition of the metasedimentary rocks is intermediate between those of metaquartzite and metagreywacke, with varying amounts of ferrotitanium oxides. Residual sedimentary textures are common, with clearly identifiable S0 surfaces and S1 surfaces that resulted from a cleavage that roughly followed axial fold planes. Folds are outlined by phyllitic beds with muscovite, chlorite and sericite.

The metasedimentary formations (with interbedded amphibolite) are strongly refolded in certain areas (axial fold planes are oriented NNW-SSE) and characterized by the presence of centimetre-size almond-shaped quartz eyes that may fill up about a quarter of the rock volume. Most of these exudations lie parallel to the foliation and their presence outlines centimetre- to decimetre-size isoclinal folds, with rounded and thickened hinges and stretched limbs. Such areas with very high concentrations of quartz eyes are characteristic of shear zones that were intersected by U1 granite, which makes them older than 340 Ma.

Geochronological analysis of inherited zircon populations (EPMA, Cocherie and Albarède, 2001) in micaschist sampled along the road between Chierchiu

and the Bocca a Vezzu (Cima a Forca Unit, Agriates), gives an average age of 2.28 ± 0.09 Ga.

Detrital Paleozoic rocks unconformably overlie the micaschist and amphibolite of Argentella. They consist of conglomerates and Late Ordovician to Ashgillian shale. The shales are overlain by Late Ordovician(?) glaciomarine diamictites that are topped by graptolite-bearing Llandoveryan lydite (Barca et alii, 1996).

Deposition of the sedimentary protolith –consisting of sandstone and pelite– of the micaschist thus took place during the Late Proterozoic, as the result of the erosion of a Paleoproterozoic basement; the micaschist formation can thus be attributed to the Pan-African cycle. As is usual in Gondwanian formations, no Grenvillian ages of around 1 Ga have been identified. Amphibolite is found in continuous levels, in places ribbon-banded, up to several tens of metres thick and alternating with metasedimentary layers. The leptynite-amphibolite complex described from north of Galeria in Crovani Bay (Gonord et alii, 1988) seems to be part of this amphibolite, the acid –leptynite– component being subordinate. The amphibolite shows a network of plagioclase that was transformed into albite and cryptozoisite; sulphides, ilmenite and ferrotitanium minerals are abundant. Deformation is outlined by syn-foliation amphiboles of a tremolite-actinolite composition that were created by the destabilization of pre-existing ferromagnesian minerals. Relict textures of ferrogabbro (?) can be identified. Based on their chemical composition (cf. Saint-Florent sheet, Rossi et alii, 1994), these amphibolites can be considered as having derived from enriched MORB-type basalt that may indicate an intracontinental-rift-type environment.

The Nd model age of the amphibolites falls around 600 Ma. A total-rock/minerals (ilmenite and amphibole) isochron gave an age of 747 ± 120 Ma for amphibolites sampled in the Cima a Forca Unit at Agriates (Rossi et alii, 1994). This age can be compared to the 957 ± 93 Ma found for the amphibolite of the Posada-Asinara suture, in northern Sardinia (Cappelli et alii, 1992). Although poorly defined, this measurement dates this metabasalt as between Late Proterozoic and Cambrian.

The Argentella terrane can be interpreted as the rest of a low-metamorphic high-level unit of innermost origin, connected with the inner Variscan Corsican high-grade metamorphic basement during a tectonic event prior to (or synchronous with) the emplacement of Mg-K plutonism around 340 Ma.

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FIELD TRIP MAP

