GUIDE-BOOK TO THE EXCURSION ON THE PALEozoIC BASEMENT OF SARDINIA

Edited by

Luigi Carmignani, Pier Carlo Pertusati
Dipartimento di Scienze della Terra - Università di Pisa
Via S. Maria, 53 - 56100 Pisa - Italy

Tommaso Coccozzi, Claudio Ghezzo and Carlo Alberto Ricci
Dipartimento di Scienze della Terra - Università di Siena
Via delle Cerchia, 3 - 53100 Siena - Italy

On the cover: The sharp unconformity (Sardic phase) located about 1 km south Nebida village, southwestern Sardinia, shows strongly dipping Cablita shale, overlying sub-vertical Lower Ordovician conglomerates (Cuddinga Auct.). Overturning and N-S trending schistosity was produced by the Hercynian orogenesis (Photo taken by V. Palmerino).

Printed with the financial aid of Assessorato all'industria della Regione Autonoma della Sardegna, Consiglio Nazionale delle Ricerche and Ministero della Pubblica Istruzione.
FOREWORD

The choice of Sardinia as the place for the Final Meeting of IGCP Project No. 5 was made for several reasons, among which the following were particularly important:

i) within the Alpine-Mediterranean belt, Sardinia is one of the most interesting regions when considering Paleozoic geology; fossiliferous Paleozoic rock sequences crop out extensively, and tectonic, magmatic and metamorphic processes of Paleozoic age are well recorded;

ii) the state of our knowledge of this region has significantly advanced, thanks to the generous contributions of numerous studies from several institutions: the Working Groups from the Departments of Earth Sciences of the Universities of Cagliari, Pisa and Siena deserve special mention from this point of view;

iii) the editors of the present volume and their co-workers readily and generously declared their willingness to take on the heavy task of leading the field trips, assuring their invaluable scientific support and compilation of the present Guide Book.

IGCP Project No. 5 would like to express its thanks to all those who have contributed towards writing the present volume, and to all those persons and institutions who have in various ways supported the organization of the Final Meeting.

F.P. SASSI
IGCP 5 Project Leader
CONTENTS

Preface ........................................................................................................... 7

Part 1: General features

Outlines of the Hercynian Basement of Sardinia
L. Carmignani, T. Cocozza, C. Ghizzo, P.C. Pertusati, C.A. Ricci .................. 11

The Palaeozoic Metallogenesi of Sardinia in Relation to its Geological Evolution
I. Salvadori, L. Urag, P. Zuffardi ................................................................. 23

Part 2: Guide to the field-trip

The Geology of Iglesiente
L. Carmignani, T. Cocozza, A. Gobbi, P.C. Pertusati ................................. 31

The Geology of Sassotetto
S. Barca, L. Carmignani, M. Manca, G. Oggiano, P.C. Pertusati ................. 51

The Geology of Gerrei
L. Carmignani, M. Gattiglio, M. Manca, G. Oggiano, P.C. Pertusati .......... 61

The Geology of Barbagia
L. Carmignani, F.M. Elter, M. Gattiglio, M. Manca, A. Moretti, G. Oggiano, P.C. Pertusati ...... 73

The Geology of Northern Sardinia
F.M. Elter, M. Franceschelli, C. Ghizzo, I. Memmi, C.A. Ricci .................... 87
CONTRIBUTORS

L. Carmignani, M. Franceschelli,
M. Gattullo, A. Moretti, P.C. Pertusati
T. Cocozza, F.M. Elter, A. Gandin,
C. Ghizzo, L. Maram, C.A. Ricci
S. Barca
M. Mazza
G. Oggiano
I. Salvatore, I. Urus
F. Zilliari

Dipartimento di Scienze della Terra - Via S. Maria, 53
56100 PISA

Dipartimento di Scienze della Terra - Via delle Cerchie, 3
53100 SIENA

Dipartimento di Scienze della Terra - Via Trentino, 51
09100 CAGLIARI

PROGEMISA S.p.A. - Via XXIX Novembre, 57
09100 CAGLIARI

Istituto di Scienze Geologico-Mineralogiche-Corso Angiol, 10
07100 SASSARI

Istituto di Giacimenti Minerali - Piazza d'Armi
09100 CAGLIARI

Dipartimento di Scienze della Terra - Via Botticelli, 23
20133 MILANO

PREFACE

In 1982, for the Centenary of the «Società Geologica Italiana» we organized a field-trip in Sar- dinia and edited the relative «Guida alla Geologia del Paleozoico Sardo» (22 notes and the guide to an excursion of four days).

This new guide-book, especially edited for the participants of the Final Meeting of the International Geological Correlation Program n. 5 (26-31 May 1986) is largely based on that «Guida». It consists of an up-dated review of the knowledge of the geology of the Hercynian basement of Sar- dinia, of the Paleozoic metallogenesis and of the guide to an excursion of five days.

The knowledge of the Hercynian basement can now be considered adequate to the beauty of its geology, but it was not in the past. Although considerable geological petrographic data were collected in the last fifty years, the lack of a complete and detailed cartography hampered an unitary synthesis. Until the 70's, most areas of Sardinia were not mapped at all and only the southwestern, where the classic Cambrian fossil-bearing sequences are exposed, had been subject of geological studies because of mining interests.

Only towards the mid-70's was the main structural, metamorphic and igneous evolution of the basement estimated to be related to the Hercynian cycle also on the basis of radiometric data. Remarkable shortenings and tectonic repetitions of regional importance where also recognized during these years in Central Sardinia. Therefore the evidence of a «Nappe chain» led us to revise the main stratigraphic, tectonic and petrological knowledge.

In the last ten years a large group of geologists and petrologists from various Italian and other European Universities, (such as Bologna, Cagliari, Ferrara, Pisa, Siena, Berlin, Marseille, Paris and St. Etienne) carried out interdisciplinary research, which allowed to reconstruct a suitable model of the stratigraphic, tectonic, metamorphic and plutonic evolution of this area.

These results, synthesized in a 1:500.000 map «Structural Model of the Hercynian Basement in Sardinia», constitute the basis of this guide-book.

The research on the Paleozoic basement has the advantages of drawing from the contributions of many people. In addition to all the authors of this guide, we would like to mention N. Minzoni and G. Naud and those novices who researched their doctoral theses in Sardinia and who of them still continue their studies with enthusiasm in spite of the fact that not all of them receive official recognition: C. Baldelli, B. Cappelli, R. Carosi, M. Cecherelli, G.P. Cherchi, A. Di Pisa, M.C. Falletti, M.L. Frezzotti, M. Moracchioni, G. Muscarelli, P. Palagi, R. Palmeri, E. Sarria, R. Senri, I. Temussi.

We hope that the excursion will be taken as a pleasant opportunity for profitable discussion on the geology of this both fascinating and hospitable land.

L. Carmignani
T. Cocozza
C. Ghizzo
P.C. Pertusati
C.A. Ricci

Pisa - Siena, April 1986.
Part 1 - General Features
OUTLINES OF THE HERCYNIAN BASEMENT OF SARDINIA

L. Carminati, T. Cocoza, C. Ghizzo, P.C. Pertusati & C.A. Ricci

INTRODUCTION

Although Caledonian calc-alkaline magmatism and deformations exist, it was the Hercynian cycle which caused the essential structure of the Sardinian basement. The Hercynian orogeny involved the whole of the island, causing intense deformations and synkinematic regional metamorphism followed by large-scale late to post-kinematic intrusive and effusive magmatism. The Hercynian age of this orogenic event is clearly defined both on stratigraphic and radiometric basis. The Fornaitain terrains (Oliveri, 1969) are deformed and slightly metamorphosed, whereas the Upper Carboniferous sediments over unconformably the metamorphosed Paleozoic sequences (Cocoza, 1967; Dau Rio, 1973). The radiometric age of the Gallura migmatic amphibolite facies (344 ± 7 Ma) and the closing age of the metamorphic minerals, which coincides with that of the emplacement of the granitoids (310-290 Ma), agree with the stratigraphic results (Ferrara et al., 1978).

The Sardinian segment of the Hercynian chain (fig. 1) trends NW-SE and is characterized by nappes, sectorial metamorphic zoning and shortening similar to those developed in continent-continent collision type orogeny (Carminati et al., 1978, 1979a, 1981). Polarity is marked by the gradient of the regional metamorphism: from low greenschists facies zones in southern Sardinia to intermediate-pressure amphibolite facies with migmatisites in the northeastern part of the island (Di Simplici et al., 1974).

STRATIGRAPHY AND HERCYNIAN TECTONICS AND METAMORPHISM

Three parallel NW-SE trending belts were identified on the basis of differences in the stratigraphic sequences and structural and metamorphic features: the External zone, limited to Iglesiente and Sulcis; the Nappe zone, cutting the island diagonally from Nurra to Sarrabus; and the Axial zone, in the north-east part of Sardinia.

1. External Zone (South-Western Sardinia)

The oldest paleontologically dated formations crop out in South-Western Sardinia: Nebila, Gomresa, Cabitza Formations are the typical sequences of Lower to Middle Cambrian in Iglesiente. In the Sulcis region (fig. 2), Lower Cambrian overlies a succession which is generally referred to as Infracambrian and/or Precambrian (Cocoza et al., 1973; Cocoza & Lion, 1977; Junker & Schindler, 1979; Junker & Schmidt, 1979; Naud, 1979) consisting of a basal complex constituted by poly metamorphic micaschists (Micaschi so di Monte Settibalisso; Minzoni, 1981) and by orthogneisses (Gneiss di Capo Spartivento AUCT,) deriving from acid migmatisites of crustal origin (Sr/Cr = 0.7122 ± 0.0032; Schäffer, 1978) with a radiometric age of 527 ± 34 Ma (Cocoza et al., 1973; Ferrara et al., 1978). This basal complex is covered by a thick, low grade metamorphic sequence mostly composed of clastic materials: the Bithia Formation (Junker & Schindler, 1979), referred to as Lower Cambrian because of its stratigraphical position. Therefore the oldest terrains of south-western Sardinia would crop out in the Sulcis region. The Bithia Formation would then represent a transgressive formation on an older basement constituted by the Settibalisso micaschists and, according to some authors, even by the Capo Spartivento orthogneisses: this is a very suggestive hypothesis even if it still requires further supporting data.

The Cambrian-Ordovician series is unconformably covered (Sardinia phase of Stüve, 1959) by polygenic metaglomerates (Puddingas) and metasandstones (fig. 2), passing gradually upwards to Upper Ordovician fossiliferous metsaeriments composed of original silites and argillites with lenses of oecanthites and rare volcanic intercalations (Cocoza & Lion, 1977).
The sequence continues with carbonaceous schists containing grapholites and lenses of *Orthoceras* limestones (Silurian) and then *tenuiculites* and crinoid-bearing limestones (Devonian). The presence of Lower Carboniferous has never been documented paleontologically. However, some small outcrops of metasandstones below the frontal zone of the Arburese nappe are probably of Carboniferous age (Barca et al., 1981b). This nappe consists of an extensive complex of metasandstones with metavolcanics (Postglacialian Auct.) in which early Ordovician acrinurids have recently been found (Arburese Unit: Barca et al., 1981b). This complex shows affinities with the pre-Silurian formations cropping out north-east of the Campidano area and probably represents the frontal allochthonous units of central Sardinia, overhauling the outermost part of the Hercynian chain.

In Iglesiente, the Sardinian phase is now well dated by a clear angular unconformity located between Arenigian, the age of the top of the Caffara Formation (Barca et al., 1988) and Caradocian, the age of the well-known paleontological horizons of the whole Sardinian Platform, the age of this phase probably includes both Llanvirnia and Llandeilo, though not documented up to today. This phase caused E-W trending folds of the Cambrian-Ordovician basal series, without developing either penetrative deformations (schistosity, lineations) nor appreciable regional metamorphism.

The main structure of Iglesiente is due to interference from a system of Caledonian E-W trending folds (accentuated by the first Hercynian phase?) with the N-S folds of the main Hercynian phase. The done and basin structures without evident overturning, are well illustrated in the geological maps of Iglesiente and have been described by many authors (Novarese et al., 1919, 1938; Tarlitz 1926-30; Poll & Zwart, 1964; Poll, 1966; BRUSCA & D'ORAZIO, 1968; ARTIMONI, 1970).

This sequence, with strongly dipping schistosity, is overlain to the east and north-east by allochthonous formations, including the Lower Ordovician (Barca et al., 1981b). Such unit presents structural features similar to those of the metamorphites cropping out in central Sardinia (isoclinal folds, sub-horizontal schistosity, etc.). The boundary between the *External zone* and the *Nappe zone* of the Hercynian chain which, in the past, had been placed near Campidano (CARMIGNANI et al., 1978, 1979; NAEM, 1979), must therefore be moved farther south-west, between Arburese and Iglesiente. On-going research in the Sulcis area confirms the extent of the allochthonous units to the south-west of Campidano (Barca et al., 1985).

2. Nappe Zone (Central Sardinia)

The broadest, low grade metamorphic complex of Sardinia crops out to the north-east of Campidano, between Sassari and Sassari granite (fig. 1). This is the *accumulation zone* of the allochthonous units of the Hercynian chain. Cambrian to Lower Carboniferous successions, sometimes with great stratigraphic differences, are tectonically overlain in this area.

South of the Gennargentu Mountains, both Upper Ordovician (Caradocian-Ashtington) and Silurian are always fossiliferous (fig. 2). Upper Ordovician consists of metasandstones, carbonatic phyllites, and fossiliferous and often alkali-rich metatuffites. Silurian contains rocks ranging from iditic to graphitic-bearing carbonaceous schists with lenses of *Orthoceras* limestones. These sequences are locally covered by metatuffites, again intercalated with carbonaceous schists or Devonian nodular metatuffites containing tentaculites and clymenes above which Lower Carboniferous is also found (OLIVIERI, 1979; SCALFRETTA, 1982). The Upper Ordovician-Devonian interval is thus palaeontologically well documented, and is composed of a more or less constant series over the whole Sardinian Platform on both sides of Campidano rift valley. These formations clearly show the polarity of the series and tectonic repetition.

Silurian effusive metabasites and more frequent intrusive rocks (metagabbros) suggest the presence of a mafic magnetic cycle.

Under the Upper Ordovician fossiliferous levels, the successions of central and south-eastern Sardinia are profoundly different from those of the same age cropping out in the south-western part of the island.

The oldest rocks are represented by a thick sequence of micaceous and quartz-rich metatuffites alternating with meta-argillites and meta-siltites, known as the *Arenarie di San Vito* in south-eastern Sardinia, and as the *Arenarie di Solanas* in the central part of the island (fig. 2). The age of these monotonous detritic sequences has been a matter of controversy for a long time. On the basis of recent findings of acritarch faunas (Barca et al., 1981a, 1983) of Middle-Upper Cambrian and then of Upper Cambrian and Upper Arenigian (TORREONI et al., 1984) we can establish that these rocks are coeval with some of the sequences affected by the Sardinian phase in Iglesiente.
This Middle Cambrian-Early Ordovician metasandstone sequence is constantly overlain by a complex of metavolcanic rocks in all the tectonic units of central and south-eastern Sar- dinia. This volcanic complex, which occurred between Arenigian and Caradocian, consists in a great number of highly effusive episodes accompanied by intrusions into the thick prevolcanic basement. The sharp lateral variabil-
ity in thickness and the different composition and nature of the products determine the remarkable stratigraphic differences which are locally observable in several areas. The most widespread rocks are original acid porphyrte lavas and rhyodacitic-rhyolitic ignimbrites, subordinate andesite-dacite volcanics and basalts.

On the basis of geochemical studies performed on igneous derived products within the metasedimentary sequences of the whole Sardinia (fig. 2) Masson et al. (1982, 1983) pointed out:

- that the metabasalts and metagabbros of the Silurian age show an alkaline affinity, similar to that of modern within plate basalts (fig. 3);
- that the metavolcanics of Middle Ordovician age constitute a "suite" ranging in com-

position from basalt to rhyolite of clear sub-
alkaline affinity, comparable to that of products of postorogenic igneous activity on the continen-
tal margin (fig. 3).

In the Sarraus region, the volcanic complex lies unconformably on Cambrian-Early Or-
dovician metasandstones, with intercrossed metacambrites (Calvino, 1961). This contact is marked by metacambrites. In other localities of central Sardinia although uncon-
formities have never been reported, this may be due to the difficulty of revealing angular uncon-
formities in strongly deformed metamor-
phites, or that the Caledonian deformations become increasingly less important from south-
west to north-east. However, petrologic affinities and geological data support the hypothesis of a coherent magmatic association, fitting into a picture of late-orogenic magmatism chronologically linked to Lower Ordovician orogenetic movements which in Sardinia, only produced slight deformational effects (Sardic phase) (Barca et al., 1984).

The Hercynian structure of central and south-eastern Sardinia is characterized by "polyphase" tectonics and synkinematic metamorphisms in green schist facies (chlorite) zone, with the occurrence of biotite in the deepest tectonic units of the nappe pile.

Salto di Quirra Units. The latter, together with the Arbuzese Unit may form a single allochthonous complex stepping over the Ger-
re Units, and overthrusts the most external part of the chain (Arbuzese Unit) (fig. 1 and 2).

The innermost units are composed of the metamorphic complex of the Barbaja region cropping out in the Gennargentu Mountains.

The «Nappe zone» is therefore composed of allochthonous units which appear to overthrust from NE to SW, as suggested by the metamor-
phic polarity of the chain and the direction of overturning of the first-phase folds.

There are notable structural differences between the allochthonous units of the innermost area of the «Nappe zone» (southern Nura, Go-
cano, Gennargentu Mountains) and those of the more external area (Sardicoli, Gerrei, Sar-
danese).
In the latter, the overthrusts cut the first-phase fold and the cataclasites and large tectonic slices. Sometimes the metamorphic grade abruptly changes by going into deeper tectonic units. Thus at least a part of the «displacement» should occur after the end of the regional metamorphism and also the emplacement of the allochthonous units should represent a later evolution of the first-phase shortening.

The innermost areas of «Nappe zone» (Southern Nurra, Gocceano, Gennarongo Mountains) on the eastern tectonic style of the deeper structural levels: the nappes are composed of large isoclinal folds with well-preserved inverse limbs and shear surfaces always subparallel to the first-phase schistosity (S1).

In the whole of the «central belt», first-phase fold and nappes are folded as antiforms and synforms, with E-W to N 140 striking axes.

Later folding phases produced axial depressions of the synforms and culmination of the antiforms (where the upper and deeper tectonic units, respectively, crop out).

3. Axial Zone (Northern Sardinia)

The highest-grade metamorphics and the largest late - Hercynian intrusions crop out in Northern Sardinia. From the tecto-metamorphic point of view Northern Sardinia means that part of the basement lying NE of the Stinton-Dorgali geometrical line and characterized by a rapid increase of metamorphic grade in a NE direction from the Biotite to the Sillimanite + K-feldspar zone (Francischielli et al., 1982 a et b).

The high-grade metamorphism and the complex structural setting lead to some difficulties in reconstructing the original stratigraphic sequences. However, the presence of thealvabitites, «Porfirodi», rhyolitic augen-gneisses (441 ± 33 Ma), granodioritic orthogneisses (458 ± 31 Ma), within plate alkaline metabasites, graphic phyllites and micaschists, calc-schists and marbles, suggest that this basement has been, as constituted by sequences similar to those cropping out in Central-Southern Sardinia and dated palaeontologically to the Ordovician and Silurian-Devonian age (Carmignani et al., 1985).

On the other hand, the presence within the migmatites of the Sillimanite + K-feldspar zone of nodules and small blocks of mafic rock, containing relics of eclogite and/or granulitic parageneses, suggests the possible existence of an old base-

...
On the basis of field relations, petrographical, chemical and isotopic data, and volume ratios of the different granite types (mainly tonalitic-granodioritic, monzogranites and leucogranites) it results that two main contrasting granite associations coexisted in space and time, 1. and S-type of the Carr. Pellegrini & Warren (1974). The former corresponds to the tonalite-granodiorite-monzogranite association, and the latter to the leucocratic andesitic granite associations. But for the Sardinian batholith some data point out a marked difference in comparison to other European Hercynian plutonic complexes (Weiler, 1983). Indeed the S-type granites, which usually predominate in the other areas, are very scarce in Sardinia and the I-type association is more similar to the I (Caledonian)-type in the scheme proposed by Persich (1983). A polycyclic origin of the whole batholith is assumed, that is a subcrustal origin for the basic magma, an anatexic intracrustal origin for the granite ones (which underwent successive local differentiation processes through fractional crystallization), and a hybrid origin by interaction between subcrustal and crustal magmas for the tonalitic-granodioritic rocks (Orsi, 1981; Bralas 1982; Cochieri, 1984).

2. The Dike Complex

A dike swarm cuts the Hercynian basement and locally, its Permian cover. It is composed of acid dikes (ultrabasic to granodioritic and tonalitic porphyries) mainly related to the Carboniferous plutonic complex and to the Permian calc-alkaline magmatism, and of basic dikes (dolerites and porphyrites of Permian age) and of some alkaline lamprophyres of Permian-Triassic age (Baldelli et al., 1985) clearly related to an extensional tectonic regime.

3. The Permian Volcanism

After the emplacement of the plutonic complex, and the regional uplift and erosion, a widespread subaerial calc-alkaline volcanism took place (Depalma & Locardi, 1983; Locardi & Moccia, 1984; Cossu et al., 1983; Bralas et al., 1984; Brogi et al., 1984; Brogi et al., 1985). As regards its composition this post-orogenic volcanism resulted in minor andesitic, minor rhyolitic and phylaxitic lavas and ignimbritic flows extending at present for 300 sq.km. The tectono-petrogenetic meaning of this magmatism is not yet clear (Bonn, 1983).

CONCLUDING REMARKS

The available data on the Caledonian events prove the occurrence of tectonic deformation (Sardian phase) (Barca et al., 1984) followed by large-scale faulting and the initial post-orogenic type (Mekmener & al., 1983), even though they are still too fragmentary to allow any hypothesis on the type of orogenic belt and its structural trends. Indeed, the essential features of the Hercynian orogeny may be defined in spite of the later extensive volcano-sedimentary covers and the important late post-tectonic intrusions. Siting the Hercynian deformation along a SW-NE cross-section, it is noteworthy that the regular distribution of the tectonic style and metamorphic zones proceeding from the "External zones" through the "Nappe zones", to the "Axial zone" is quite similar to those of many other orogenic belts.

Similar zoning also occurs in many southern European Hercynian masses, from Maures Massif to Iberian Meseta, where large scale tectonothermal events have been described (Reichert & Mattic, 1966; 1974; Mattic, 1968; Artigas et al., 1969; Artigas, 1970; Westphal, et al., 1976, etc.).

The lack of ophiolitic associations (Ricci & Sabatini, 1978; Marmi, et al., 1983) and our present knowledge on the sedimentary evolution show that the Hercynian cycle in Sardinia began and developed on continental crust. Such entire early Palaeozoic evolution of the chain does not conflict with the tectonic style similar to that of orogenic collision belts along continental margins. Subduction models of continental crust along simple shear zones, crossing the entire thickness of the crust and propagating from inside to outside the orogenic belt have been proposed both for many Tertiary chains which developed on continental crust (Haynes & McCullin, 1971; Hess & Torsvik, 1975; Lieber, 1975; Preciso, 1975; Mattafer, 1977; Baldelli & al., 1985; Mondolfo, et al., 1986; Mishra, 1987, etc.), as for some European Hercynian chains (Mattafer, 1974; 1977; Mattafer & Eichert, 1976; Bouroukiou, 1980).

This geodynamic model is also supported by many minor structural elements (sub-horizontal northerly orientated shear zones, style of folds, etc.) and many large-scale structural trends (regional overthrustings, basement remobilization, etc.). It also satisfactorily explains the correlation between the deformation and the metamorphism of the "north-eastern belt" (see Cossu et al., 1979a, b; Francolino et al., 1984).


0UTLINE OF THE INDUSTRIAL BASEMENT OF SARDINIA

21


THE PALEOZOIC METALLOGENESIS OF SARDINIA IN RELATION TO ITS GEOLOGICAL EVOLUTION

I. SALVADORI, L. ULRAS & P. ZUFFARDI

It is premised that there is clear evidence that many Paleozoic mineral deposits were formed by a chain of geological events which have contributed to mobilize, modify and concentrate pre-existing low grade dispersions of mineral substances present in the Paleozoic. These geological events have taken place at various stages, both Paleozoic and post-Paleozoic, up to the present time. The concept of «Paleozoic metallogenesis» is therefore to be extended to include both the processes that generated the early mineral deposits and the later events (including the post-Paleozoic) that determined the present composition, form and structure, of the deposits held in the Paleozoic. (For further details cfr. Cocozza et al., 1974; Salvadori et al., 1982; Zuffardi et al., 1970).

Having stated the above considerations, the following is a rapid synthesis of the Paleozoic metallogenesis. Its first events in Sardinia took place in the Lower Cambrian, in correlation with the establishment and evolution of the favourable conditions, to the formation of the carbonatic shell known as the «Gonnessa Formation». In fact both this formation and the underlying Punta Manna Member are made up of alternating pelitic, silicic and carbonatic rocks, and contain various galena, blende, pyrite, and barite concentrations of the «stratata-bound» type, which can be, at least partially, correlated to the underwater volcanic activity occurring in that time interval.

These mineralizations are highly zonated, with prevalent stratoidal barite and pyrite in the Punta Manna Member and in the lower part of the Gonnessa Formation, prevalent diffuse blende (blendeous limestone as the miners say) in the central part and prevalent galena in the higher part of the later formation. It has been hypothesized (Marcello & Zuffardi, in print) that one of the controlling factors of this high zonation could have been the variations in salinity in the environment of deposition, that has been recognized in recent studies by the Department of Mineral Deposits of the University of Cagliari together with the Ente Minerario Sardo (unpublished report).

The metallogenic province related to this period is South-Western Sardinia, and the most remarkable deposits are found in the Iglesias area, among which are Puntà Candiazzu for barite; Campo Pierno for blende and pyrite; S. Giovanni, Nebida and Massu for prevalent blende with galena; Montevioni for prevalent galena with blende. It has, however, to be pointed out that their present shapes and consistencies result from subsequent re-concentration processes.

The Cambrian-Ordovician orogenesis caused some parts of the carbonatic shell to emerge, and brought about the consequent formation of karstic concentrations, especially of galena and barite. The relative metallogenic province is the one quoted above and the most typical deposit is Arenas in Oridda (partim).

During the Silurian period, in contact with various types of underwater volcanic activity and with the frequent establishment of sedimentary environments of the «black shales» type, variously composed ores were generated; more precisely (i) mixed sulphide complexes; (ii) antimonite and scheelite; (iii) silver with blende and galena in fluorite paragne (the «argentiferous vein of Sarrabus» as the miners say); (iv) oolitic iron.

The related metallogenic province covers three sectors of Sardinia: the central-eastern part, the northern section of Iglesiente (Fluminesine area), the north-western corner of the Island (Nurra district). The most typical deposits are: Corbarina and Punta Ramonora (partim) for mixed sulfide complexes, Ballal and Villasalto for antimonite and scheelite; Monte Narba, Mascam, Giovanni Bono, Bacci Arbudas, Tuvors (the so-called «argentiferous vein» of Sarrabus) for silver (and fluorite), Canaglia della Nurra for oolitic iron. For further details cfr. Garbarino et al., 1980; Schniuder, 1972.

The Hercynian orogenesis and related intrusion of the granitoid plutons have caused remarkable metallogenic effects, that have involved both tectonic remobilizations of preceding accumulations (evident in many ore bodies of the Cambrian), formation of industrial-
The emersion of the Paleozoic in consequence of the Hercynian orogenesis and its paleogeography have had various metallogenic effects; more precisely:

(i) formation of residual concentrations of iron, still found on the Post-Hercynian plane, both in erosion residues of the Mesozoic cover and at the basis of it (so-called “ferrro dei Tacchi” of Central-Eastern Sardinia);

(ii) formation of sulphide accumulations in the erosion channels of the post-Hercynian plane (Monte Albo and — partly — Baccu Locci);

(iii) formation of karstic barite accumulations with or without galeu by remobilization of the pre-concentrations in the Gonnese Formation. Barrea is a typical example of this. For further details cfr. the study on Sardinian barites by Marcello et al. 1983.

(iv) re-elaborations and per descensum re-concentrations of sulphide ore bodies which were transformed into considerable deposits of oxidized minerals and of regenerated sulphides. This phenomenon is particularly evident in the Cambrian sector.

It should be noted that some phenomena of per descensum re-concentration are still in progress. This is what caused the clavial barite concentrations of industrial interest in the present soils around outcroppings of poor barite deposits; in some cases the mineralized baritic system are controlled by the present hydrostatic level (Barrea).

In conclusion it can be asserted that the Sardinian Paleozoic is the seat of useful concentrations of various types, some of which of great industrial interest. They are the result of five successive metallogenic events; in some cases they are superimposed and interacting.

REFERENCES


Part 2 - Guide to Field-trip
The itinerary for the excursions was chosen in order to give as complete a picture as possible of our model of the Hercynian basement of Sardinia in only a few days:

- from the «External zone» of the south-west, where both the typical Cambrian sequences and the less tectonized and metamorphic rocks are exposed (Day 1);
- throughout the «Nappe zone» of Southern and Central Sardinia where the repetitions of the Paleozoic sequences were for the first time revealed (Day 2, 3 and 4);
- to the «Axial zone» of the north, where the highest-grade metamorphic rocks and most of the Hercynian plutons crop out (Day 5).

In particular the itinerary covers the following areas:

Day 1 - Iglesiente
Day 2 - Ólmedo
Day 3 - Gerrei
Day 4 - Barbogia
Day 5 - Northern Sardinia

Itinerary, stops and location of geological maps included in the guide are shown in pl. 1.
THE GEOLOGY OF IGLESIENTE

by L. Carmignani, T. Coccozza, A. Gandin, P.C. Pertusati

SUBJECTS: Iglesiente Cambrian sequence - Sardinian unconformity - Iglesiente Hercynian sequence - Arbou Unit.


INTRODUCTORY NOTES
TO THE IGLESIENTE EXCURSION

Introduction

South-Western Sardinia consists mainly of two complexes: the first, generally considered as autochthonous, exposed in the Iglesiente and Sulcis area; the second, exposed in the Arburese region, constituted by an allochthonous unit.

IGLESIENTE-SULCIS AREA

The main peculiarity of the Iglesiente geology is represented by the effects of two orogeneses, Caledonian and Hercynian, although they did not strongly obliterate the sedimentary and biostratigraphic evolution. In the area covered during this first excursion, the Hercynian cycle of Upper Ordovician-Devonian, and perhaps Lower Carboniferous age, overlies with sharp angular unconformity the Caledonian cycle including Cambrian and Ordovician formations. In turn, they are unconformably covered by some small scattered post-orogenic lacustrine Upper Carboniferous and marine Triassic deposits.

CALEDONIAN CYCLE

The framework of the Iglesiente is made up by a Cambrian-Early Ordovician sequence, about 3000 m thick, divided in three formations (fig. 1.1). From bottom to top: Nebida, Goana and Cobizza (Ragni; 1972; Coccozza; 1980; Carmignani et al., 1982; Carannante et al., 1984).

1. The Nebida Formation (Arenarie Auct.)

The lower part of this formation, the Matoppa Member, shows a thickness of 400 m, but the base is not exposed. It consists of green shales passing upwards to shales and sandstones alternations containing limestone lenses built by algae and archeocyaths, grouped into at least three horizons, with thickness increasing from bottom to top. Remnants of trilobites and sponge spicules are commonly associated to the algae Epiphyton and Renalcites) whereas Hyolithes, Chancelloria, and echinoderms are less frequent (Gandin & Debrenne, 1984). The analysis of the archeocyath association has shown that the age of this member corresponds to Lower Botomian and possibly Upper Adiabanian (Debrenne, 1972; Gandin & Debrenne, 1984).

Directly on the terrigenous deposits and only locally on the limestone lenses, lies the "oolitic unit" - the base of the Punta Mannu Member. This unit, which varies from 30 to 100 m in thickness, exhibits fairly constant lithological and sedimentological features over the whole Iglesiente-Western Sulcis area. Oolitic and oncoidic facies prevail, and sandy-peloidal grainstones with cross- and bipolar-stratification of the "herringbone" type are frequent. The depositional environment has been interpreted as an oolitic shoal system with sub-environments of oolitic delta, lagoon and beach (Debrenne et al., 1980; Fanni et al., 1982; Debrenne et al., 1985).

(*) As the whole South-Western Sardinia is affected by a regional metamorphism, from very low grade to low grade. In this chapter the rocks are only defined on the grounds of the original lithofacies.
This unit is followed by a rhythmic alternation of sandstones (sometimes with bivalve, barnacle, and brachiopod fossils) and limestones, more or less dolomitized, either with oil-mat lamination or rich in fragments of archeocyaths, trilobites, echinoderms, and lingulids (Anasulina, 1970). In the upper part of the sequence, the carbonate intercalations are composed of early dolomite, showing desiccation structures, and algal matts, forecasting the features of the later Domolita rigata member. In the Iglesiente area, the geothermal-boring horizons are frequent (Fanti et al., 1982; Demirren & Gaddis, 1985). Average thickness of these members is 400 m.

The depositional setting of this member corresponds to a shallow-lagoonal-south environment with the marine carbonate deposition.

2. The Guestsa Formation (Metaclitites AUCT.)

This formation begins with the Domolita rigata member, generally marking the end of the Upper Lias and the stratigraphic platform and the beginning of a pure-carbonate sedimentation.

The Domolita rigata thickness varies from 20 to 250 m. It is mainly represented by early dolomite with algal mats and desiccation structures evolving to "vadose pisolith" (sensu Esteban, 1976). Thin oolitic or pellitid layers and lenticular red-beds are widespread, whereas only locally (Buggerru area) oncoids and archeocyaths have been found. In Eastern Sulcis, the stromatolitic facies consists exclusively of algal laminated limestone. The depositional setting has been interpreted as a tidal system in a hot arid environment (Gaddis et al., 1973, 1974; Caramanno et al., 1980). The presence of archeocyaths in the upper half of the sequence allows us to date the Domolita rigata member to the Devonian age (Demirren & Gaddis, 1985).

The transition between the Domolita rigata member and the Calcareo cerdo member is commonly marked by the occurrence of the "Domolita grigia." This lithofacies also occurs as irregular patches in any level in the sequence and locally, for instance in the Cabritas area, replaces all the calcareo cerdo member (Gaddis, 1980). Sometimes traces of the algal-peloidal or vadose structures of the surrounding lithofacies remain. From petrographic analysis the "Domolita grigia" clearly appears to be the product of diagenetic dolomitization. Its genesis has been related to a diagenetic process due to the mixing of fresh and marine waters in the sub-surface, occurrence of the block faulting and resulting from the Bahamian morphology of the carbonate platform (Gaddis, 1983).

The Calcareo cerdo is represented by pearl-grey or dark-grey limestone at the base of the sequence, generally massive and locally stratified, as in the Buggerru and southeastern Sulcis areas and in the lower part of the San Giovanni section. Its thickness is variable: from 160 to 500-600 m.

The Calcareo cerdo member shows four typical lithofacies (Boni et al., 1981; Fanti et al., 1982; Demirren & Gaddis, 1985):

1. - "vadose pisoliths", (sensu Esteban, 1976)

2. - mudstone-wackestone with bioclasts

3. - grainstone with ooids and/or oncoids, echinoderms and trilobite remains;

4. - cryptocrystalline dolomite, locally skeletal-algal (Ephphiton and renalcids) boundstones with archeocyaths.

These facies indicate environments which vary from the ferruginous inflow to subtidal. Their distribution reveals a "platform and basin" paleoenvironment related to tense synsedimentary tec-tonic (Gaddis, 1980). In the upper part of this member, karst features are frequent, characterized by fillings of fibrous-radial calcite or breccias with matrix made up of "terra rossa" and/or lithofacies of the overlying Cabitza Formation. The occurrence of archeocyaths in the upper half of the Cabitza cerdo member confirms a late Lower Cambrian age (Lower Middle Toarcian; Demirren & Gaddis, 1985).

3. The Cabitza Formation

The lower member of this formation (Calcareo nodulare = Calcosclerita Auct.) rests with clear parallel unconformity on the Calcareo cerdo member (fig. 1.1.) and more rarely on the "Domolita grigia" or on the lenticular breccia bodies (Gaddis, 1985). The Calcareo nodulare member is composed of a tight alternation of thin beds of red, green, and more rarely black shales, which are more or less sili-cy and gray, pink or locally black limestones sometimes having a nodular structure. They result to be bioclastic wackestone-packstones containing trilobites, echinoderms, brachiopods, Chemocollia, sponge and Hylolithes remnants (Gaddis, 1980).

The depositional environment was clearly neritic, locally restricted and probably very shallow (Gaddis, 1980; Gaddis & Pilloia, 1985). The Calcareo nodulare deposition marks the beginning of the "drowning" of the carbonate platform during the Middle Cambrian age. Its thickness varies greatly from 0 to 50-100 m, as a result of the extensional tectonics which was so active during this period (Gaddis, 1985). Gradually, but rapidly, the shale lithofacies prevail and the limestones disappear in the upper member of the Cabitza Formation. This characteristic sequence is formed by a rhythmic alternation of silty and thin limestones belonging to different colours, millimetric and centimetric in thickness, sometimes with carbonate lenticular layers near the base, and massive, generally fine-grained sandstones at the top. Frequent cross lamination and limestone nodules occur both in the silty and sandstone lithofacies (Pambruni et al., 1979; Gaddis & Pilloia, 1985).

This member is closely folded and locally deeply eroded so that its maximum measurable thickness is about 600 m. The lower part of the member has been attributed to the Middle Cambrian age on the basis of rich faunas with trilobites (Paradoxides of mediterraneus, Cenoceras, Itaburina sp., Paradoxides hippusa, Conocoryphe heberti, Conocoryphe bow, Riscella sp.) which can be related to the B-F levels of the Montagne Noire (Rasser, 1972; Gaddis & Pilloia, 1985). The age of the middle and upper part was uncertain until the very recent findings of early Ordovician acritarchs and graptolites (Dictyonema
HERCYNIAN CYCLE

The Caledonian series is covered in a clear angular unconformity with a polygenic unsorted conglomerate having red-violet silty-shaly matrix, «Puddings» AUC (fig. 1.1). Among the clasts, all the lithofacies of the underlying Cambrian sequence can be found. Towards the top, their size gradually decreases into a microconglomerate. On the western side of Igeslanti, along the coast, a megabreccia consisting of Cambrian carbonate olistoliths occurs, which testifies to the synsedimentary activity of a normal fault still evident towards the east. Further up, with the disappearance of the conglomerates, alternations of sandstones (grainstones) and marls exceeding a meter thick, fining, upward sequence (Tschmüller, 1931; Coccoza & Valera, 1966; Coccoza & Leone, 1977). In the middle part of this sequence only rare phylactograins have been found by Tarcocci (1922), but they have never been studied. The first well-developed horizon, occurring in the upper part of the sequence, is composed of weakly-carbonate shales and siltstones with abundant fossiliferous remains (brachiopods, pelecypods, trilobites, bryozoans, cystoids, etc.) of Cambro-Ordovician age (see bibliography in Maccanico, 1965; Giovannoni & Zandera, 1979; Serpalli, 1970a). Another fossiliferous horizon immediately above the Barcaredo, contains shaly bioclastic limestones, often completely silicified, whose abundant fauna is very similar to the underlying one, although Complutumbrania is lacking among the bryozoans and small Barcaredo-Ashgillian trilobites are present (Cyclonyctyidae). These Upper Ordovician fossil-rich horizons are also widespread in Central and Southern Sardinia and are the most important markers of the whole Sardinian Paleozoic.

The only evidence of post-Caledonian magmatism is a series of rare, thin layers of basic volcanics or their Upper Ordovician, reworked subaerial products (Bucciuva et al., 1981; Massim et al., 1982).

We are now concerned with Silurian consists of regular alternations of grey or black sandstone, silty and shales. The most complete sequence crops out above the conglomerate. The Pliensbachian: it is composed of black carbonaceous shales with graptolites of Llandovery and lower Wenlockian age (20-25 m thick) overlain by about 30 m of black carbonaceous shales with limestone lenses containing late Llandovery-Llanvirnian Orthoceras, Cardiola, conodonts, ostracods, etc. (Spinazzè, 1971). This condensed sequence was deposited in an epicontinental basin, well-oxygenated on the surface and definitely not toxic at the bottom as inferred by Giolli & Serpalli (1985) because of the occurrence of a large benthonic pelagiccod such as Slavia. According to these authors, the Silurian sequence begins here with two formations. The first one corresponds to the upper part of the ghorien of fig. 1.1 (considered by Coccoza & Leone (1977) as Ordovician in age), and the second to the "Scisti porfidi (Pliensbachiano, Sup.)" (Tarcocci, 1922; Novarese & Tarcocci, 1923) referred to as Lower Silurian. It seems to demonstrate that no hiatus exists between Ordovician and Silurian, as previously supposed.

The Devonian sediments are composed of shales and finely - banded limestone with lenses of "sucha facies", crinoids, cephalopods, conodonts and foraminifera. They are exposed in small scattered outcrops along a narrow belt running from the Plinian area to eastern Sardinia, its thickness ranging from a few metres to 20 m in the Plinianese more than 100 m at Mt. Patenceddu (eastern Sardinia). The presence of a common fauna of the horridus woschmidtii woschmidtii zone, ranging from the uppermost Silurian to the lowermost part of Lower Lochkovian, suggests that these sediments did not break between these two stages either (Serpalli, Martina, 1986; Oliveri et al., 1981; Serpalli, 1983). However, the finding of a Prudhoean conodont fauna, of the phekalekton and stenothermi- nius zones, but not of cripta and snajdii-latitulatus ones does not resolve the problem of whether this part of Silurian is represented in this area. The Ordovician-Silurian boundary is not well-known in the central and western Sardinia by unfossiliferous or tectonized shales, or if it is completely missing (Giolli & Serpalli, 1985). The presence of Upper Pragian-Uppermost Caradocian bioclastics, the Ordovician-Silurian boundary is found in a stromatolithic-bearing carbonate mound at Mt. Patenceddu and at Su Nisui near Donnusanos (Oliveri et al., 1981; Oliveri, 1984).

In south-western Sardinia the Hercynian depositional cycle ends with the Lower Famennian; however at the present stage of research we are not sure if the Tournaisian limestone occurring in south-eastern Sardinia is missing here for depositional or for tectonic causes (Orvieto, 1970). At any rate, a hercynian sequence is well-developed. Carboniferous has been repeatedly hypothesized although paleontological evidence is still lacking (Val & Coccoza, 1974; Barca et al., 1981b).

POSTHERCYNIAN DEPOSITS

In Igeslanti, the first sediments deposited after the Hercynian orogeny consist of the Lower Devonian, mostly in the area of San Giorgio, Igeslanti (Gambetta, 1987); a clastic fluvial lacustrine sequence composed of conglomerates, coarse, quartzitic sandstone ad detrital dolomite (maximum thickness 30 m) This sequence has been attributed to the Stephanian by Coccoza (1967) on the basis of a rich megafossil. Its Carboniferous age was later confirmed by microflora associations (Del Rio, 1973). A more recent ichnological study (Forni, 1980) suggests the Westphalian D for the oldest part of the sequence (fig. 1.2).

This continental phase, which persisted until the beginning of the Mesozoic age, led to the more or less evident peen сентя (see the stratigraphy of the Cambrian, partly resulting from the Permian-Triassic climatic conditions (Coccoza, 1967; Montecchio, 1972; Coccoza & Gambetta, 1977; Bosc, 1980).

The Middle Triassic transgression caused an extensive epigenetic dolomitization of the Cambrian limestone ('Dolomia gialla') and the sediments of this period are the continental, evaporitic and shallow marine conglomeratic, dolomitic or calcareous deposits of Campomarais Igeslanti; Coccoza & Gambetta, 1977). In Arenas (Capo Pecora), Sciria (Montevicchio), Cuccuru Zappera (Gugnini) (D'Arma & Gambetta, 1974) and Su Bagatu (Mone San Giovanni; Brusca et al., 1967).

TECNOTICS

In the structural zoning proposed by Car- micia & Zandera (1979, 1981), Igeslanti is the outermost part of the Hercynian chain cropping out in Sardinia. It is characterized by very low to moderate regional Hercynian metamorphism, and by folding tectonics associated with strongly dipping schistosity and without tectonic repetition of regional importance. The effects of the Caledonian deformations are easier to recognize because of the less intense Hercynian deformation in Igeslanti, than in other areas of the sedimentary basin.

The first detailed structural analysis of part of Igeslanti was carried out by Arndt (1963), who identified four deformation phases in the Cambrian rocks. A similar deformation sequence was also later described in northern Sardinia by Poll & Zwart (1964) and confirmed in subsequent works (Pell, 1966; D'Arma & Gambetta, 1969; Arndt, 1970).

At least in regards to the Igeslanti area, the deformation history accepted by most authors may briefly be described as follows:

1 — Sarcich phase: minor folds with E-W axes, in NNW-Archieve and Archeo-Caradic interval.

2 — First Hercynian phase: minor E-W trending folds, accentuating the former ones.

3 — Second Hercynian phase: small deformations with N-S trending folds accompanied by strongly dipping intense schistosity.

4 — Third Hercynian phase: small deformations with variable striking axes.

In fig. 1.5, the distribution of the formations clearly shows the existence of two structural directions. Throughout the Cambrian sequence in southern Igeslanti, the regional deformation structures are large E-W trending folds. Instead, the north-western Igeslanti area is mainly structured along N-S trending folds varying in size involving also the post-Caledonian sequence. The quadrilateral shape of the large outcrop of Lower Cambrian Arenaria (Nebida Formation), extending for the whole Areator Igeslan- liesla, is often quoted as a typical example of the interference of two fold systems with strongly dipping axial planes and approximately orthogonal axial directions.

1. E-W trending deformation

The presence of large structures with E-W axes is certain (fig. 1.2), but the age of this deformation remains very debatable.

The existence of Arenica-Caradic deformations is supported by the unconformity at the base of the Ordovician conglomerate (Puddings). This unconformity is well-exposed in various places (Masu, Nebida, Donnusanos, etc.) and seems to be of regional importance. Both in the Igeslanti (Vadambasso, 1940, 1956; Brusca & De Donnus, 1968; Donnus, 1969) and in the Sarcich (Poll & Zwart, 1964; Pell, 1966).

(1) Abbreviations such as N-S schistosity, N-S or E-W axis, etc. will be used to indicate the elements of the two main structural directions although these directions may very considerably.
Fig. 1.2 - N-S sections across Ighiserte. Their orientation points out folds of Serdian phase.
E; Nébilia Formation; E; Guzmens Formation; E; Maddalena limestone member; Kc; Cobizia shale Member; Oc; Ordovician and Silurian sediments; E; Upper Carboniferous sediments; Tr; Triassic sediments. These cross-sections are outlined on the bottom right of the fig. 1.1.

Fig. 1.3 - WSW-ENE sections across Ighiserte. Their orientation points out Hercynian folds.
E; Nébilia Formation; E; Guzmens Formation; E; Maddalena limestone member; Kc; Cobizia shale Member; Oc; Ordovician and Silurian sediments; P; Quartz porphyry; E; Triassic sediments; P; Upper Carboniferous sediments. These sections and the ones of fig. 1.2 are outlined on the bottom right.
large E-W structures in Cambrian rocks are unconformably covered by the Ordovician conglomerate.

The main difficulty in establishing the importance of the Sardic phase is due to the fact that even later formations were folded along E-W axes. Metric and decametric folds with E-W axes involve the Ordovician conglomerate north of Domusnovas (Dunnet, 1969; Arruda, 1970), south of Orsesa, and in many other areas in Iglesiente (Macia, pers. comm.). Most authors therefore agree in believing that both the Sardic phase and one of the Hercynian phases have produced the same E-W axial direction. The axes parallelism of these two phases introduces great uncertainty in distinguishing the effects of the Caledonian deformations from the Hercynian ones. Therefore, although there is clear proof of pre-Upper Ordovician tectonic movements, the difficulty in separating E-W Hercynian structural elements from Caledonian ones and the subsequent strong deformations of the main N-S Hercynian phase make the importance and style of the Sardic phase very hard to define. E-W folds with wavelengths of about 10 m are well exposed in the Iglesiente syncline, the Canalgrande area, the Gomesa anticline, etc. These are always concentric folds, without schistosity and with vertical or strongly dipped axial planes. In our opinion, these minor structures reflect the geometry of the large E-W structures, and the Sardic phase caused only small E-W folds with long wavelengths (Pol, 1966; Dunnet, 1969).

2. N-S trending deformation

This phase caused the greatest shortening. It produced local overthrusts and folds of all sizes, accompanied by well-developed, N-S dipping schistosity, and an extensional lineation which usually follows the maximum dip of schistosity.

The shape of the minor folds, the cleavage density and the development of the extensional lineation are quite variable and mainly depend on the lithology and position within the large structures.

As the cross-sections of fig. 3 show, the large structures of the N-S phase always display strongly dipped axial planes. The folds are often associated with local overthrusts towards East, sometimes bringing the Lower Cambrian in contact with Ordovician formations. The wavelength of this fold system varies, but it is always much shorter than that of the E-W system (compare sections of fig. 1.3 with those of fig. 1.2). The dip of N-S axes is more variable and strictly controlled by the E-W folds. On the flanks of the large E-W structures of the southern Iglesiente, the smaller axes and intersection lineations between the bedding and the N-S schistosity are always strongly dipped or vertical. In some cases, they produce even “false synclines” causing complex geometrical features as the geological sections n. 3 and 4 of fig. 1.3 show.

Of particular interest are the structures at the boundary between the “Metalliferous limestone and Cebitza Formation.” The characteristic "cup-and-lobes" shape of these structures is shown in sections n. 4 and 5 of fig. 1.4, and in fig. 1.4. The slabs are “pinched” in narrow synclines within the carbonate sequence, which is folded in anticlines with rounded hinges. This type of structure, already described by Zuffardi (1965) and Dunnet & Moore (1969), is common along the entire contact surface. The narrow N-S synclines of Masua, Acquasave and Buggerru, whose core is made by Cebitza slate and Ordovician “Pudin is, show similar geometrical features.

Subsequently these tectonic laminated belts were repeatedly reactivated as faults, therefore the history of the movement is complex. According to Valera (1967), the Iglesiente faults were repeatedly reactivated from Cambrian to Tertiary. In some cases, the movements may be reinterpreted as meanders of successive structures. The older movements are generally transcurrent and only later did these faults act as normal faults. The first movements probably represent a continuation of the Hercynian shortening and may be associated with the weak folding deformations following the N-S phase, largely represented by bands with variable trending axes. Extensive and transcurrent movements are post-Hercynian and Alpine in ages.

ARBUS AREA

Both in Iglesiente and Eastern Sulcis the Palaeozoic complex described previously is tectonically overlain by a low-grade metamorphic complex mainly composed of a monotonous alternation of greenish-grey sandstone and slate with layers of coarse, more or less conglomeratic sandstone. Sedimentary structures and turbidite sequences are common, showing a depositional environment corresponding to a deep-sea fan and basin-plain system (Val & Coccozza, 1974). Barca et al., 1981b).

This complex, which unconformably covers the Ordovician, Silurian and Devonian formations, is known in literature as “Postgondwanian” (Tarocco, 1922) and was long considered to be Upper Devonian-Lower Carboniferous in age (Val & Coccozza, 1974).

However, the recent discovery of abundant actinian associations (Stelliferidium, Cymnactinexa, Vulcanisphaera, Acanthodus eximius, Striatophora) has established that the age of this detritic complex is Tremadocian-Lower Arenigian (Barca et al., 1981b) and that it should therefore be considered as tectonically overlain by the Iglesiente and Eastern Sulcis formations (Arbus Unit: Barca et al., 1981b). Moreover, the lithological affinities of the “Postgondwanian” (AICT) of the Arbus Unit, with the “Amenza di San Vito”, indicate that the Arbus Unit may be correlated with the Gemi’ Argilias Unit that exposed in Garbars (Barca et al., 1981a). b) The Arbus Unit therefore represents the extreme south-western edge of the nappes of Central Sar- dinta (Carmignani et al., 1979, 1981) overthrusting the outermost zone of the Hercynian chain.

The affinity of the Arbus Unit with the Gemi’ Argilias one (Garbars) is also confirmed by the few outcrops of post-Lower Ordovician sequences in the Arbus Unit, north of Montevucchio and Monte Arcuentu. Actually, these Ordovician-Silurian and possibly Devonian sequences are those of Central and South-Eastern Sardinia. In fact, the acid volcanics are associated with conglomerate and silicic rich in bentonic fauna of Cambro-Ordovician age, schists, “slidite”, and lenses of dark limestone with Orthoceras and grapitoides (Barca & Salvadori, 1975).

However, although this complex (referred to in the past as Upper Devonian-Lower Carboniferous) turns out to be much older, the occurrence of a tectonogenic Lower Carboniferous in south-western Sardinia cannot be complete-
DESCRIPTION OF STOPS OF THE IGLESIENSE EXCURSION

During the first stretch from Cagliari to Iglesiente, we will cross the Quaternary alluvial deposits of the tertiary Campidano rift valley and then, after the village of Siliqua, the Eocene-Oligocene fluvio-lacustrine continental deposits of the Ocrieri Formation, composed of more or less clayey conglomerates and sands, well exposed along the road. At short distance from the road, some of the domes of the Oligocene calc-alkaline volcanic cycle arise, aligned along the faults bordering the Campidano graben.

— Sfor 1.1 · Near the Campo Pisano mine: The upper part of Gonnese Formation and lower Cabitza Formation; view of the E-W Iglesiente syncline (fig. 1.5).

In sequence, the following are exposed (fig. 1.6).

— Cabitza Formation (Middle Cambrian—Early Ordovician) composed of multicoloured shales and nodular limestones (Calcisistula) at its base;

— Gonnese Formation (Metalliferous—AUCT, Lower Cambrian), represented here by the Dolomia rigata member and Dolomia grigia lithofacies.

The transition from the grey dolomite to the nodular limestone should be particularly noted. The latter marks the breaking of the drowning of the pericontinental platform system (Calcare colare member) after a short period of emergence, and the continuation of the marine sedimentation influenced by terrigenous input.

To the west, there is the Iglesiente syncline, a large E-W trending structure (Sardinian phase) complicated in various ways (fig. 1.4) by the interference of the N-S trending structure (the main Hercynian phase). The shales of the Cabitza Formation at the core of the syncline occupy the bottom of the valley; the Gonnese Formation forms the abrupt reliefs bordering its flanks north and south.

— Sfor 1.2 · Opposite the Montepoli mine: Upper-Carboniferous sediments are unconformably lain on Cambrian (fig. 1.5).

The angular unconformity between the Cabitza Formation and the Upper Carboniferous deposits is clearly visible from the road. The contact is erosional and some small channels are evident near the base.

In regards to the Upper Stephanian age of the deposits in the San Giorgio basin, it should be remembered that the megflora with Pecopteris arborescens, Scholotia, Callipteridium pteridium (Scholotia), Neuropteris platanitii, Zelleria, Dictamnus plumeti, Scholotia stegani, and some others have been found in them. The Upper Carboniferous age (Westphalian-Stephanian) is also confirmed by the palynological data and by the ichnofacies with Sulfuricidae footprints (Geniturn).

We continue westwards amongst the shales of the Cabitza Formation, between the mines of Montepoli (north) and San Giovanni (south). All these mixed-sulphide mines are located in the carbonates of the Gonnese Formation, on the flanks of the syncline.

— Sfor 1.3 · Monte Agruzza: Transition between the Gonnese and Cabitza Formations (fig. 1.5).

In spite of the occurrence of the typical epigeanic—yellow dolomite, the transition between the Persei—Lower Cambrian: Gonnese Fm) and the Nodular limestone (Middle Cambrian: Cabitza Fm) is clearly exposed in an old quarry. The last few metres of the Persei—Lower Cambrian limestone are cut by fractures and cavities filled with calcite or redish hemi-pelitic material. At the summit, the Monte Agruzza breccia occurs. It is composed of angular clasts of Persei—Lower Cambrian limestone represented by the fossiliferous facies, with trilobites and echinoderms, glassstone and cryptalgal boundstone.

The matrix of the breccia, locally very abundant, is not only composed of hemipelitic red material (paleoest?) but also of yellow-pink marls of the type occurring in the nodular limestone of this area. The genesis of this breccia may be linked to the rapid drowning of the carbonate platform which, due to syndepositional extensional tectonics, had previously undergone local depressions and karstification.

Continuing further into the Cabitza shales and passing the San Giovanni mine we cross the «Sardinian unconformity» and thus reach the Lower Ordovician (Middle-Upper Cambrian) transgressive conglomerate (Pudding). Along the Nuraxiame coast, the Palaeozoic succession reaches the Silurian and is overlain in clear angular unconformity by the subhorizontal con-

Fig. 1.5: Schematic geological map and cross-sections of Iglesiente area with location of mines (After Carminati, Gonnese & Pertusati, 1963).

-GT: Quaternary and Tertiary sediments and volcanites; Tr: Conglomerates and conglomerates (Middle Triassic); Os: Carboniferous shales with Chondrites (late Mississippian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mississippian—early Permian); Os: Carboniferous shales (late Mis
glomerate and dolomite of the Middle Triassic Campumari plateau. These are post-orogenic alluvial and lagoon evaporitic deposits.

— Strp 1.4 - Road to Nebida: «Sardoic unconformity» (fig. 1.5).

The Cabirola Formation and the Ordovician conglomerate (Puddingia) crop out along this road. The latter is composed of variously sized clasts of all the Cambrian lithofacies, strongly flattened parallel to the schistosity of the main Hercynian phase (N-S phase). The unconformity between the two formations is sharp, and the unconformity surface is folded along subvertical Hercynian axes. Both formations are in turn covered, again unconformably, by Middle Triassic deposits.

Along the cliff are clearly exposed olistoliths (megabreccia) of the Lower Cambrian «Cervoide» limestone and grey dolomite which are embedded into the Ordovician «Puddingia». Their abundance and great variability in size (from 1 cm to several thousand cubic metres) suggest the collapse of an active fault during the Ordovician sedimentation.

We reach Nebida and then return to Iglesias, which is the most important mining centre in Sardinia. We take the road to Fluminimaggiore which cuts the whole «dome of sandstone» of the Lower Cambrian Nebida Formation in a N-S direction. About 2 km north of Iglesias, near the dam of Gennarato Lake, we can see the carbonate intercalations characterizing the Punta Manna Member, and the passage to Gonnese Formation (Metalliferous AUCT), still of Lower Cambrian age. Again moving north, we go down the sequence entering the Matoppa Member (the oldest Cambrian deposits of Iglesiente), the base of which is not exposed. At 48.7 Km along the road of Fluminimaggiore, in one of the limestone lenses with algae and archeocyaths characterizing this member, a fauna with bachiopods, molluscs and the oldest trilobites yet known in Sardinia has been found; the archeocyathian fauna, however, gives us an Upper Aidabian-Lower Botomian age.

After this outcrop, we rise to the Oolitic Unit at the base of the Punta Manna Member which is exposed along the road near the Cantoniera di Sant’Angelo.

— Strp 1.5 - Cantoniera di Sant’Angelo: Oolitic Unit (fig. 1.7).

It crops out over the whole region at the base of the Punta Manna Member. It is a sequence which can be related to a depositional environment of an oolitic shoal with channels. Fig. 1.8 shows two sections of this Unit exposed in this area.

After the Oolitic Unit, we continue to climb in the Lower Cambrian stratigraphic sequence. First, we cross the Punta Manna Member and then the «Dolomia rigata» member, almost at the bottom of the descent to Fluminimaggiore. We will detour to the Roman temple of Antas where the top of the Punta Manna Member is well exposed.

— Strp 1.6 - Temple of Antas: Transition between the Punta Manna Member (Nebida Fm) and the «Dolomia rigata» member (Gonnese Fm) (fig. 1.7).

The upper part of Punta Manna Member, characterized by early dolomite intercalations, in the north Iglesiente area is also characterized by the occurrence of goethite-bearing horizons. The sedimentological features are shown in fig. 1.9.

**Lunch at the Temple of Antas**

After lunch, we proceed towards Fluminimaggiore and leaving the Cambrian of Iglesiente behind, we again cross the conglomere (Puddingia) of the Ordovician transgression (Sardoic phase) and then the finer Upper Ordovician detrital deposits. Near the cemetery of Fluminimaggiore these deposits pass to the Silurian sequence, exposed on the eastern flank of the Iglesiente sandstone dome, made up of black shales and black limestones.

From the junction for Arbus, as far as the bay of Portoixeddu, the Upper Ordovician fossiliferous sil littie and shale are well exposed.

— Strp 1.7 - Portoixeddu: Upper Ordovician fossiliferous beds (fig. 1.7)

The most important relief of the bay are made up of the Cambrian limestone of Buggeru (another mining locality) which dip northwards under the unconformably overlying Ordovician sequences (see cross-section of fig. 1.7). The Portoixeddu coastline is composed of Upper Ordovician (Caradocian-Ashgillian) fossiliferous shales and slates. It is one of the most famous fossiliferous localities of the Sardinian Paleozoic and has been studied since the middle of the last cen-
Fig. 1.7 - Schematic geological map and cross-section of Fluminimaggiore - Buggerru area with location of stops (after L. Cerrignana, T. Cozza & P.G. Perusani, 1983).

Q: Quaternary deposits.
Arthritic Unit: Cor: Sandstones and shales (Carboniferous-Early Ordovician); A: Silicilastic Autochthonous; Os: Carbonaceous shales with Briocicopi, Bryoza, etc., transgressive conglomerates (Devonian-Ordovician); Eo: Cabrera shale Member (Upper Cambrian - Early Ordovician); E: Nodular limestone member (Middle Cambrian); Eo: Goedevo Exxon member and grey sand of beds; 2: Reverse faults and diapirs; 3: Axial plane traces of major folds related to the Hercynian phase; 4: Axial plane traces of major folds connected to the main Hercynian phase.

LEGEND
1 2 3 4 5

Fig. 1.8 - Lower part of the Punta Mima Member: Olistolith Unit:
1: Sandstone; 2: Slate; 3: Shale limestone; 4: Sandy limestone; 5: Limestone; 6: Oxide; 7: Poliedro; 8: Ovoido; 9: Fenestra;
This characteristic marker-horizon of the Upper Ordovician, which will be encountered again during our excursion, marks a return to generalized marine conditions after the continental episodes linked to the Caledonian deformation. North of Portixeddu, the Ordovician deposits grade to the Silurian and Devonian ones. The whole sequence is tectonically overlain by Cambrian and Early Ordovician terrestrial suite of the Arbureau Unit (Postgotlandiano AUCT). This is the outermost area of the Hercynian chain in which the allochthonous Arbureau Unit has palaeontologically been documented by acritarchs.

We will then go back to the junction for Fluminimaggiore and proceed northwards. Along the road, the Cambrian-Ordovician suite of the Arbucus Unit can easily be observed.

— Stop 1.8 - Road to Is Arenas: Arbureau Cambrian-Ordovician suite

Typical lithologies of the Arbucus Unit (Postgotlandiano AUCT) along the road are exposed. They consist of micaceous sandstones, grey quartzites, siltstones and greenish-grey shales with frequent sedimentary laminations. Early Ordovician (Tremadocian-Arenigian) acritarchs have been found in these rocks. This suite is attributed to Cambrian-Early Ordovician also because of its close lithological similarity with the Arenarie di San Vito in which Middle and Upper Cambrian is documented. This stop provides a view of the valley of the Riu Mannu. The autochthonous Cambrian-Ordovician and Silurian-Devonian sequences of Iglesiente, dipping northwards and overlain by the Arbureau Unit, are clearly visible beyond the valley.

To the north, in the background are the steep peaks of the Plio-Quaternary Arcuentu volcanic complex.

Not far from the junction with the unpaved road leading to the next step (Selvù), the Palaeozoic basement is unconformably overlain by the Triassic conglomerate and dolomite forming typical flat-topped hills like that of Campunari (see Stop 1.4).

— Stop 1.9 - Selvù: Tectonic contact between the Arbureau Unit and the autochthonous Silurian-Devonian formations.

The Cambro-Ordovician complex of the Ar-
THE GEOLOGY OF SARRABUS

by S. BARCA, L. CAMMIGNANI, M. MAXIA, G. OGGIANO & P.C. PERTUSATI

SUBJECTS: Sarrabus Paleozoic sequence, «Sarrabus Unconformity» and «Caradocian Transgression», Genn’Argiolas Unit and its relationships with the Gerrei Units.

ITINERARY: Cagliari - Dolianova - Punta Serpeddi - S. Nicolò Gerrei - Sillust - Villasalto - Munevara.

INTRODUCTORY NOTES TO SARRABUS EXCURSION

INTRODUCTION

The basement cropping out NE of Campidano underwent Hercynian metamorphism and tectonics to a more intense extent than the Iglesiente. It is characterized by regional scale Hercynian overthrusts. From the stratigraphic viewpoint it differentiated from the Iglesiente owing to the absence of Cambrian carbonate formations and the occurrence of large quantities of late Caledonian metavolcanics. Caledonian deformations are documented by angular unconformities in the Sarrabus («Sarrabus Unconformity»: CALVINO, 1961) and by coarse-grained metaglomerates occurring almost everywhere between the Lower and Upper Ordovician. In spite of this, large Caledonian structures which are well documented have not been described yet perhaps because of the absence of the easily mappable formations of Cambrian age or of the stronger overprinting of the Hercynian tectonics. Probably as in the Iglesiente area, the Caledonian event produced deformations without important metamorphism, at least in central and southern Sardinia.

The second day’s excursion is almost completely dedicated to the Genn’Argiolas Unit (Cammignani & Pertusati, 1977). It is a huge unit composed of very low to low grade metamorphites with an age ranging from Cambrian to Devonian. This succession is tectonically overlapped onto other successions of the same ages by a very remarkable tectonic contact which stretches uninterruptedly from the eastern coast to the Campidano plain. (Villasalto Overthrust: Cammignani & Pertusati, 1977).

In the structural scheme shown in fig. 1 of Cammignani et al. this volume, this unit is correlated with the Arburese Unit (see 1.8 and 1.9 stopes) and with the Meana Sardo Unit (see 4.3 stop). These three units show a great deal of affinities regarding both their stratigraphic sequences and their structural positions. It is probably the same huge allochthonous complex rooted to the northeast of the Gerrei region and now separated by the Flumendosa valley «postnappe» antiform and the Campidano Tertiary Graben into three main cropping out zones.

In this excursion, we will observe first, the stratigraphic succession of the unit and then its basal tectonic contact either in the typical outcrop (Villasalto) or in some tectonic windows recently mapped.

Succession of Genn’Argiolas Unit

As in the Iglesiente, the Hercynian succession unconformably overlies the Cambrian-Early Ordovician succession («Sarrabus Unconformity»: CALVINO, 1961). The age and importance of this unconformity was debated (SCHNEIDER, 1974; HELMCKE, 1973; CAMMIGNANI & PERTUSATI, 1977; CAMMIGNANI et al., 1978; BARCA & DI GREGORIO, 1979; NAID, 1981) until the recent palaeontological findings in the Cambro-Ordovician formations on the two sides of the Campidano (BARCA et al., 1981a, b) which linked the «Sarrabus Unconformity» to the «Suretian Unconformity» of Iglesiente and thus established the extent of the Caledonian deformations (Fig. 2 in Cammignani et al. this volume).

The description described here is a summary of the studies carried out by Barca & Di Gregorio (1979) and later by Barca (1981) and Barca & Maxia (1982).
1. Arenaire di San Vito Formation

This formation, palaeontologically dated, is the oldest of the entire Sarrabus. It includes a succession of more or less quartzitic sandstones, in decimetric or metre-thick layers alternating with greenish-grey or blackish-grey metasiltstones and slates. Kilometric recumbent folds occur in this succession (Carminati & Persutti, 1977) so that its original thickness is unknown and its complete lithostratigraphic sequence difficult to reconstruct. In spite of this, some particular beds characterize its upper part: reddish-mauve slates and thick layers of quartzites and fine-grained quartz-bearing metagranoclastites. We frequently find laminated levels of siltitic metasandstones and meta-argillites with un-dissolved and convoluted laminations and also basal impressions such as ripples, flute casts, and channel fills. As mentioned above, although thickness is difficult to determine, it certainly exceeds 500 m.

The sedimentary environment was probably a system of deep-water deltas, trending towards regression in the upper part of this succession.

On the basis of acritarch fauna dating, Barca et al. (1981a) have shown the presence of Middle Ordovician (in the lowermost part of the Arenaria di San Vito) and possibly also reaching Early Ordovician, since Tremadoc-Arenigian acritarchs have been found in formations which may be correlated with the Arenaire di San Vito both in the Fluminiense (Barca et al., 1981b; Pettai Demizia, 1985) and Sarcidano region (Tosconia et al., 1982a, b).

2. Ordovician Metavolcanic Complex

This metavolcanic complex is composed of originally rhylithic lavas, ignimbrites or tuffs. According to Calvino (1961) and Naudi (1981), the metavolcanics are separated from the Arenaria di San Vito by a remarkable angular unconformity and the contact is sometimes marked by coarse-grained metagranoclastites. The metamorphism of the entire Sarrabus succession was of very low grade, so that the original structural features of the volcanics may still be recognized. Especially in the more metasiltstones, the original thickness is limited to slight cleavages of the original phenoxyres, and microstructural lineaments due to penetrative schistosity are generally not present.

The lower part of the metavolcanic complex is often composed of original rhylithic flows: white or greenish-white rocks, nearly amphibolitic with the small, euhedral phenocrysts of quartz and feldspars within a microcrystalline quartz-feldspar groundmass (Porfidi bianchi: Calvino, 1967). In some cases, the groundmass is mainly composed of microcrystalline quartz due to widespread silification processes of still undefined origin. Associated with the metagranoclastites and more frequently above them, there are thin layers of volcanic metasandstones and probably original tuffs, tuftites, and metagranoclastites with well-rounded pebbles of the above-described rhylithes and, more rarely, of quartzites. The greater part of the metavolcanic complex is composed of the so-called Porfidi grigi (Calvino, 1967). They consist of an ensemble of original lava-domes, lava-flows, and probable ignimbrites of rhylolithic and subordinately dacitic composition. They are grey or sometimes blackish massive rocks without evident porphyritic structure. The abundant «phenoxyres» are represented by quartz, feldspars (microcline partially replaced by albite and albite plagioclases), biotite, partially converted into aggregates of iron oxides and hydroxides, chlorites, or white mica, within a microcrystalline groundmass.

The thickness of the metavolcanic complex is quite variable, and may exceed 250 m. Its age falls between Arenigian, probably present in the «Arenaire di San Vito» both in the Fluminiense (Barca et al., 1981a), and Cardadicin, proven in the overlying formation.

3. Punta Serpeddi Formation

The late Caledonian metavolcanic complex is covered by a detritic formation, generally coarser at the base («Caradoc Transgression»-AUCT). The lower part is generally composed of metakrokioclasites, metasandstones and metagranoclastites. In the upper part, fine-grained metasandstones and grey-metasiltstones, about 100 m thick, prevail. They contain rich bentholic faunas (brachiopods, bryozoa, crinoids, gastropods, etc.) of Upper Ordovician age (Barca & D. Gregorio, 1979; Giovannoni & Zampi, 1979). The depositional environment varied from continental and littoral at the base to neritic platform upwards.

4. Tuvossu Formation

This formation is composed of metasiltstones and meta-argillites alternating with metalimestones, in general completely silicified, still containing Upper Ordovician (Ashgillian) benthonic fauna. It has a maximum thickness of several dozen metres and is a characteristic stratigraphic marker in all southern Sardinia. The fossiliferous formations are widespread over the entire lower-grade Paleozoic basement and prove that, at the end of Ordovician, the Sarrabus had been re-established almost everywhere after the Caledonian deformations and magmatism.

5. Serra S'illai Group

Composed of blackish, more or less carbonaceous, metasiltstones and meta-argillites, this group is intercalated with layers of «hiditi» and basic metavolcanites. Upper Llandovery graptolites have been reported in the lower part of this group (Teschmiller, 1931; Helmecke, 1973; Jäger, 1977). The upper part contains lenses of grey meta-remolinites with orthococertates, crinoids, tentaculites and, in particular, conodonts of Lower and Upper Devonian age. The sedimentary environment was still epicontinental although, as shown by the change in fauna, more pelagic than that of the Caradoc-Ashgillian sediments.

6. Pala Manna Formation

This is composed of tens of metres of metasandstones and metasiltstones with layers of breccioi, sometimes with black «hiditi», clasts and reworked fossils. This formation has been assigned to Lower Carboniferous, since in the Pala Manna area it seems in stratigraphic continuity with a large carbonatic lens containing Middle Devonian conodonts and it also seems to be affected by the main Hercynian folds.

7. Tectonic Formation

Although the presence of Caledonian orogenic phenomena have also been proved in Central Sardinia (Sarrabus Unconformity) and Ordovician Volcanism) it is still not possible to evaluate the real importance of such an event.

The whole Sarrabus region is affected by Hercynian «polyphase» tectonics joined to a very low to low grade regional metamorphism. Just as in all of central Sardinia the main structural features are determined by a first deformation phase producing E-W trending isoclinal folds (Barca & Naudi, 1962) which were joined and followed by overthrusts.

LAte folding phases reformed the structures of the first phase and the nappes. In the western Sarrabus region, a main folding «post-nappe» phase produced folds which are locally overturned with NW-SE trending axes (Barca & Naudi, 1962).

The overthrusts represent the most typical structural features of the region: the most important lies at the base of the Gem'Argolas Unit which (Villasalto Overthrust: Carminati & Persutti, 1977), whereas others of less importance are described either in western (Barca & Maxia, 1985) or in eastern Sarrabus (Carminati et al., 1982). The presence of cataclasites, containing rock-fractures which belong to the entire Paleozoic succession along almost the whole length of the tectonic contact, confirms everywhere the regional importance of the «Villasalto Overthrust».

In some areas, the cataclasite may reach a thickness of several hundred metres and include large tectonic slices. The recent discovery of numerous tectonic windows east of S. Andrea Frius in the Gem'Argolas Unit, where below the Cambrian-Ordovician metasandstones the Silurian fossiliferous formations of the Gerrei crop out, should have confirmed even more the regional importance of the «Villasalto Overthrust».
DESCRIPTION OF STOPS OF THE SARRABUS EXCURSION

From Cagliari to Punta Serpeddi we will up to Dolianova. Cross the Lower Miocene transgressive sediments and then the various terrains of the Paleoaeocozos belonging to the Garigliano Unit.

— Scuro 21 - Punta Serpeddi: Ordovician succession of the Garigliano Unit and, in particular, the sedimentary transgression on the late Caledonian volcanic complex ('Calcararian Transgression' AUCT) (Fig. 2.1). The whole area between Punta Serpeddi and the Mt. Genis granite is a monoclinal dippin SE. From bottom to top it is composed of: 1) 'Arenaria di San Vito' (Middle Cambrian-early Ordovician); 2) Ordovician metavolcanic complex; 3) Caradocian detritic deposits (Punta Serpeddi Formation).

As the map and cross-section of fig. 2.1 show, this outcrop has tectonic relationships with the preceding succession.

Moving on to the next stop, along the road cutting the left bank of Rio Cerasa, we observe the typical lithologies of the 'Arenaria di San Vito': grey micaceous metasandstones, quartzites, greenish-grey, blackish or sometimes reddish-violet metasandstones and slates, with frequent parallel, undulating and convoluted laminations. This area has supplied Upper Cambrian arc-tachys and Medusa trails.

— Scuro 2.2 - Rio Cerasa. Contact between 'Arenaria di San Vito' and 'Porfidii grigi' and 'Sarrabus Unconformity' conglomerates (Fig. 2.1).

Along Rio Cerasa, near the sheepfold at 714 m, the contact between the 'Arenaria di San Vito' and the overlying pre-Caradocian volcanites (Porfidii Bianchi) and 'Porfidii grigi' is well exposed. It is marked by conglomerates with coarse, rounded pebbles of sandstones and quartzites of the 'Arenaria di San Vito' and volcanites. Slightly east of this outcrop, marked angular unconformities between the 'Arenaria di San Vito' and the volcanites have been described by Nann (1981). According to the most recent biostratigraphical research, this 'Sarrabus Unconformity' is related to the 'Sardic Unconformity', seen yesterday in Iglesiente. The former should have the same age as the latter (Arenigian to Caradocian). Continuing towards Dolianova, we will cross first, the area of tectonic repetitions east of Punta Serpeddi, in which mainly Ordovician and Silurian formations crop out, and then, along the valley descending to Dolianova, coarse fluvial conglomerates with rare intercalations of fossiliferous marly sands, ascribed to a basal continental Miocene. After Dolianova, we continue eastwards into the Miocene covers, cutting the various terrains of the eastern margin of the Sardinia-Oligo-Miocene Rift up to the plateau. These steps probably correspond to the faults as shown in fig. 2.2. At the 29 km mark we cross over the first morphological step composed of biota-bearing leucogranites overlain by the Miocene covers. After the ascent, along which we find dikes of pink porphyries and lamprophyres cutting the granite, we come
out onto the plain of S. Andrea Frius, still covered by Miocene coastal deposits.

At the 33 km mark, on the right of the road, the Miocene transgression is well exposed on the granites and the «Arenarre di San Vito» (Cambrian-Ordovician). Beyond the village of S. Andrea Frius, the Planu Saguini plateaus out: a relic of the post-Hercynian peeneplain, only slightly modified by Eocene transgression.

After S. Andrea Frius, along the climb to the plateau, only the Cambrian-Ordovician metasandstones of the Gent’Argiolus Unit crop out.

--- Stop 2.3 - S. Andrea Frius-S. Nicolò Gerrei: A tectonic window in the Gent’Argiolus Unit (Fig. 2.3).

At the 41 km mark, in a valley to the right of the road, Ordovician, Silurian and Devonian formations of the Gerrei Units crop out in the tectonic window overlain by Cambrian-Ordovician metasandstones. Along a path near the road the basic tectonic contact of the Gent’Argiolus Unit crops out: it is marked by a cataclastic belt containing fragments of metasandstones, metavolcanites and Silurian-Devonian schists. The Cambrian-Ordovician metasandstones overlie dark phyllites with nodular metahemitites typical of Lower and Middle Devonian.

Identical relations have been observed 70 km further east (see stop 1.9 at the base of the Arburese Unit), according to the writers it should be the same tectonic contact. The Arburese, Gent’Argiolus and Meana Sardo Units (the latter will be crossed during day 4 of our excursion) probably compose a single large unit which overthrusts as far as the external areas of the chain.

We now come to the Planu Saguini plateau, partially covered with Lower Eocene quartz-rich conglomerates dislocated by faults parallel to the Oligo-Miocene rift. Continuing towards Siusi, we enter the Gerrei Units; the contact with the Gent’Argiolus Unit is covered by the Eocene terrains. We then climb the spring of Is Alinos, where the «Porfraid» and their cover of metakorres and metasandstones («Caradocian Transgression», AUC). To the north of the road, the valley extends to the entire valley of the Flumendosara river as far as the Gent’Argiolus massif.

Lunch at Is Alinos spring.

Continuing towards Siusi, we cross the sequence from the «Porfraid» to the dark schists with tenuiclitic bearing nodular metahemitites which are also exposed beyond Siusi as far as the junction for Villasalto. Beyond the crossroad, we again enter the «Arenarre di San Vito» the contact is covered by the alluvial deposits of S. Nicolò Gerrei (Lower Miocene). Along the ascent to the Villasalto plateau, the deep fluviatile cuts reveal the great apparent thickness of the Cambrian-Ordovician metasandstones. To the left of the road, the reliefs on the opposite side of the valley are composed of Middle and Upper Devonian metahemitites dipping under the Cambrian-Ordovician metasandstones.

--- Stop 2.4 - Villasalto: The basal tectonic contact of Gent’Argiolus Unit (Villasalto Overthrust) (Fig. 2.4).

The overthrust between the Gent’Argiolus and Gerrei Units is marked by a wide belt of cataclasites which may be followed for tens of kilometres from the east coast north of Muravera, to the Campidano plain, south of S. Basilio: by means of this contact, the whole of the Sarrabus region is allochthonous above the Gerrei. Near Villasalto we will observe in detail the tectonic contact between the «Arenarre di San Vito» and the underlying nodular metahemites containing Upper Devonian and Lower Carboniferous (Tournaissian) faunas by means of the catastrophic belt which is particularly thick in this portion of the contact. Both on the scale of the outcrop and of the map, the tectonic contact is clearly folded by «post-map» tectonic phases (Fig. 2.4).
After Villasalto, we again cross the cataclasite and descend towards the Flumendosa river.

**Step 2.5 - Villasalto:** Mt. Ateri, a large tectonic slice within the tectonic breccia of the Villasalto Overthrust (Fig. 2.4).

Intensely foliated, Devonian metapelites crop out halfway down the descent on the left side of the road. On the other side of the valley there is a good view of the Villasalto Overthrust.

Between Brunci Siliqua and Mt. Sarbonedda, the Gemm'Argiolas Unit is separated from the Gerrei Unit (Monte Lora Unit) by hundreds of metres of cataclasites and tectonic slices. Mt. Ateri is a large tectonic slice of metapelites.
INTRODUCTORY NOTES TO THE GERREI EXCURSION

INTRODUCTION

The Gerrei Units consist of Cambrian to Lower Carboniferous low grade metamorphic formations. They crop out in correspondence with a huge post-nappe antiform trending NW-SE, which extends for about 100 km from the mouth of Flumendosa to Mount Grighi. The units imply an antiform arc covered by the Gensi'Argolas allochthonous Unit that we crossed in the second day excursion. As already mentioned, this unit is correlated to the "Meana Sardo Unit", which crops out to the north of the Flumendosa antiform and tectonically covers a slightly higher metamorphosed complex.

This complex, in turn, crops out on the main axial culmination of the above-mentioned post-nappe antiform and is known as the "Castello di Quirra" or "Castello Medusa" Unit (Fig. 1 of Carmignani et al., this volume).

The Gerrei metamorphic complex has been subdivided into several units in the S. Basilio area by Nault (1982) and in the lower Flumendosa valley by Carmignani et al. (1978, 1982). However, these units do not seem to extend laterally to any great extent. In the Gerrei region, the Paleozoic successions are quite similar and they probably derive from a single paleogeographic domain, strongly shortened and locally separated into distinct tectonic units, without relative translations having an extent comparable to those existing among the main complexes.

Conflicting opinions among the authors have arisen regarding the meaning of the slightly higher metamorphic complexes which crop out below the Gerrei Units (Castello di Quirra Unit, Castello Medusa Unit). According to Nault (1979), they would represent Cambrian complexes separated from the overlying Paleozoic formations by a stratigraphic unconformity. According to the authors, the occurrence of carbonaceous phyllites, metavolcanites, metagreywackes and the abundant conodont remains in marble from various localities suggest that this slightly higher metamorphic complex really consists of a succession varying in age from Cambrian to Devonian.

Disregarding the minor stratigraphic differences existing between the various units, a typical succession is shown in fig. 2 of Carmignani et al., this volume. It is worth noting that the succession is sometimes incomplete and also shows several lateral variations mainly due to the irregular paleogeographic features determined by the Ordovician volcanic activity.

SUCCESSION OF GERREI UNITS

1. Cambrian-Ordovician Metasediments

Lithological similarities and the stratigraphic position in the succession indicate that, in the Gerrei too, a Hercynian series may unconformably cover a Caledonian series. However, there is no direct proof of this unconformity: until now the Cambrian has only been paleontologically documented in a single place (Nault & Pett массив, 1985), and the more complex Hercynian tectonics makes it difficult to show pre-Hercynian structures or angular unconformities. In various places in the lower Flumendosa valley, the metasediments
underlying the Ordovician metavolcanic complex and of some of its levels of metaglomerates, have been referred to as Cambrian-Ordovician (Carmignani et al., 1982). It deals with more or less quartzitic micaceous metaglomerates, amphibolites with slates and metasiltites similar (in sedimentary structure too) to the Cambrian-Ordovician Arenarie di San Vito or the Arenarie di Solbiate (Carri). Owing to the scarcity of biostratigraphic data and the lithological similarity to an Upper Ordovician formation, the actual boundary of the Caldonian series in the Gerrei is still probably very approximate. However, even if all the metasandstones of arenaceous sediments were attributed to Cambrian-Ordovician, the extent of the Caldonian outcrops remains very limited, clearly inferior to that of the Cambrian-Ordovician formations in the Geenn Argiolas or Meana Sardo Unit. This subject will be discussed again in the part dedicated to tectonics.

2. Ordovician Metavolcanic Complex

The base of this complex is mainly volcanosedimentary and consists of volcanic metasandstones and metaglomerates with intercalations of grey phylitic metavolcanic rocks ranging in composition from basalt to andesite. Above this complex, separated by a metasedimentary sequence composed of metaglomerates, quartzites, arkose metasandstones and black mudmetasiltites, lie massive silicic metavolcanics, up to 200 m thick with evident augen fabric (pophhyroids with small phenocrysts; Celmi, 1961) derived from both lava flows and lava domes. The metavolcanics are generally covered by feldspathic metasandstones clearly derived from the underlying volcanics, and followed by the Caradoci metavolcanics.

Although this succession could be defined the most frequent, slight differences are found in some areas. For example, in the Arcu di Su Bentu Unit (Carmignani et al., 1983), under the Upper Ordovician levels, we find metaarkoses and then massive "porphyroids" with augen texture, determined by the presence of large "phenocrysts" (1-20 cm) of potassic feldspar (pophhyroids with large phenocrysts). This type of volcanics occurs in the Lower Flumenosada valley near S. Basilio and further North as far as Sarcidano. They correspond to original rholites, probably in the form of large domes or perhaps subvolcanic bodies. They are frequently associated with "porphyroids with small phenocrysts" (original lavas and partly arkose sandstones).

Most of these metavolcanics show marked clastics of the phenocrysts and strong recrystallizations of both quartz and feldspar (currently consisting of albite + microcline), forming orthoclase which only pseudomorphous flakes of sericite sometimes remain; mafic minerals are in general completely transformed. The most recent metavolcanics of the entire volcanic Ordovician complex are intercalated in the Upper Ordovician fossiliferous metasediments. These are fine-grained, greenish-grey intercalated arenitic and pelitic metavolcanics associated with volcanic metagraywackes. These volcanics appear discontinuously over the whole Gerrei, although rare intercalations are also found in the Upper Ordovician of the Igleisien. The Meana Sardo Unit also contains traces of an intermediate-mafic volcanism, associated with the Upper Ordovician fossiliferous metasediments.

The basaltic facies show a few remnants of small plagioclase phenocrysts and chlorite epilletic flakes, preferably referable to original mafic crystals. The quite common presence of rounded aggregations of quartz, calcite or even chlorite, which do not look to the naked eye, suggests derivation from basaltic with vesicular texture. Probably, some of the compositional features of these metabasalts also derive from their original spilitic character (LIEBHARD, 1975).

3. Upper Ordovician Metasediments

The Ordovician volcanism caused a great variety of depositional environments which determined a highly variable thickness (from a few to some hundreds of metres) and sudden lateral variations of the Upper Ordovician successions. In spite of this great variability, some common features do exist. The sequences overlying the volcanic complex are generally composed of a basal part characterized by immature metasediments deriving from the diaclensing of the volcanoes, and an upper part composed of finer metasediments, still of shallow marine type but less colored, characterized by rich biotite facies indicating re-establishment of a marine environment after the Caldonian movements. A typical sequence of Upper Ordovician in the Gerrei could be the following:

1. Feldspathic metasandstones, metarkoses, and light quartzites poorly stratified with levels of generally fine-grained metaglomerates.

2. Greenish or reddish, silty or sandy, carbonatic phylitic rocks, sometimes with a typical vascular aspect due to the dissolution of fossils. They contain benthonic fauna with bryozoans, crinoids, brachiopods, etc. Bodies of reddish metasediments of locally intercalated, composed almost entirely of crinoid remains (enclitides); when they are partially or totally silicified, they are identified as to those of the Tournaissian Formation of the Sarrazas. Also metabasites are characteristic intercalations.

4. Silurian-Devonian Metasediments

Mainly incompetent rocks, these are often found as "imprisoned" along the overtrusts, so that the great tectonic disorder does not allow detailed stratigraphic reconstruction. For the same reason, it is difficult to establish whether the local absence of certain horizons is due to original variations or rather to tectonic laminations.

In Silurian and especially in Lower Devonian, rather uniform sedimentations conditions involved huge areas; biofacies and lithofacies indicated that the southern coastal conditions of Upper Devonian became more pelagic in a basin which was oxidated on the surface and reduced at the bottom (Gosti et al., 1979). This was generally attributed to Silurian, is composed of black quartzites (cililidite) alternating with carbonaceous phyllites with graphitites and rare lenses of Orthoquartz-bearing metasequences.

Certain successions contain sequences with an apparent thickness of about 100 m composed of dark quartz-rich metasediments. This succession passes continuously to Lower and Middle Devonian and is composed of an alternation of dark or black phyllites and nodular metasequences characterized by thin black lithofacies that they may be repeated at the base of the Geenn Argiolas Unit.

Between Mt. Lora and S. Nicolò Gerrei, this succession continues with a thick layer of nodular metasiltites (Upper Devonian-Tournaisian Lovasato, 1894; Olivenza, 1977). Apparent thickness may reach hundreds of metres, although repetitions probably also exist in this formation.

Near Villasalvo, above the Upper Devonian-Tournaisian metasediments, several dozen metres of metasandstones and metaglomerates have been reported, representing the passage to the terrigenous domains of the Devonian-Lower Carboniferous carboniferous platform (TEICHMÜLLER, 1931; SPALTELA & VAI, 1962; BARCA & SPALTELA, 1984).

Tectonics

The Hercynian structuring is more intense in the Gerrei Units than in the Geenn Argiolas one. For instance, the acid metavolcanics which preserve much of their original fabric in the Geenn Argiolas Unit, almost always show a markedly augen texture in the Gerrei Units ("porphyroids"). Except for this higher "strain", probably due to their innermost position in nappe-pilo, the entire structural framework is similar to that above-described for the Geenn Argiolas Unit. Also in the Gerrei Units, the Hercynian tectonics consists of:

a) a diachronous first deformation phase with isoclinal folds and penetrative schistosity; b) remarkable overthrusts; c) a "late folding tectonics" that can be divided into several minor phases.

The structures of first deformation phase are generally overthrusts, essentially prolate. This variability results also from the axes reorientations in the direction of extension trending NE-SW and from the later deformations. Many tectonic overthrusts, documented by the repeating fossiliferous formations of Upper Ordovician and/or of Silurian-Devonian, have been found both in the lower Flumenosada valley (CARMIGNANI et al., 1982) and San Basilio (NAUD, 1982). Slickensides on tectonic contacts and also research studies on the elongated elements in the cataclasites suggest that the transport occurred from NNE towards SSW.

The tectonic elements of the first phase deformation and the overthrusts are overlain by two fold systems with NNE-SSW and NW-SE trending axes. The main "post-nappe" structure trending NW-SE is the complex anfiform of the Flumenosada valley which refolds all the allochthonous units and makes the innermost units crop out in correspondence to the main axial culmination: Castello di Medusa Unit and Castello di Corte Unit. Although the metachronous grade of these units still remains within the geenschists facies, they show a slightly higher grade which is clearly visible up to the carbonatic foliation transformed in marbles and calc-schists. From a structural point of view, the main difference from the Gerrei Units consists in the presence of at least
two deformation phases in the innermost units, producing isoclinal folds (Fig. 3.1). Their more complicated tectono-metamorphic evolution is also typical of the innermost units of the nappe zone around the Germagnenu mountains, as will be seen in Day 4.

The Gerrei Units are therefore situated between the Castello Medusa and the Castello di Quirra Units, (which constitute the relative autochthonous of the nappe zone), and the GennArgiolas and Meana Sardo Units, (which constitute the highest allochthonous complex in southern Sardinia) (see cross section in Fig. 1 of Carmignani et al. this volume).

The Gerrei Units show different deformation styles:

a) In certain outcrops, the Paleozoic successions can be folded according to more less preserved inverse limbs, rooted to the north-eastern limb of the

Flumendosa valley antiform and ending as «îîé plongeante» in the south-western limb of the same antiform;

b) Otherwise, five or six different units, constituted by the same Paleozoic successions, can be overlapped in way up position because of a progressive laminating of the inverse limbs of the recumbent folds.

Examples of both structural types will be shown later (see respectively 3.1., 3.2 and 3.5 stops).

The type and the complexity of structures in the Gerrei region suggest that their development would be due to the movement of the allochthonous complex constituted by the GennArgiolas-Arburese-Meana Sardo Units.

REFERENCES


DESCRIPTION OF STOPS OF THE BERREI EXCURSION

From Muravera we ascend in a W-NW direction along the lower Flumendosa valley, whose bottom is covered by an extensive alluvial cover lying on «Arenarie di San Vito». Once past the village of San Vito, we leave the Gem'Argiolas Unit and enter the Gerrei Units. The first outcrop of Paleozoic rocks (crossed by the road) consists of a small leucogranitic pluton which produced a thermometamorphic aureole at a remarkable distance from the contact.

We then enter the metavolcanics and metavolcanoclastic units of the Mt. Lora Unit and further the Upper Ordovician-Lower Carboniferous sedimentary cover of the same unit, tectonically lying on the Arcu de Su Bentu Unit.

**Stop 3.1 - Centomiera Mt. Lora: View of the outcrop of Mt. Lora Unit on Arcu de Su Bentu Unit (Fig. 3.3).**

The Mt. Lora and Arcu de Su Bentu Units are two of the Gerrei Units cropping out the Lower Flumendosa valley (Fig. 3.2). The view from the Centomiera clearly shows the two units superimposed.

The lower unit (Arcu de Su Bentu) is composed of porphyroids with decimetric crystals of K-feldspar covered by an Upper Ordovician-Devonian series. Naudi & Pittari (1985) have reported acritarch-dated Middle and Upper Cambrian metasedimentary rocks associated with the porphyroids, and maintain that these porphyroids are therefore older than Middle Cambrian.

The Early Ordovician metasedimentary units (Tremadoc-Arenigian; Naudi & Pittari, 1985) overlie this unit with tectonic contact; the metasediments are covered in turn by the metavolcanics and metavolcanoclastic units: they constitute the Mt. Rocca di Nuxi (Fig. 3.2).

About 1 km further upstream: next stop

**Stop 3.3 - Mt. Ferro: Gerrei type Upper Ordovician-Devonian sequence (Fig. 3.2).**

The Upper Ordovician-Devonian sequence is illustrated in the cross-section of Fig. 3.4. From bottom to top it is composed by:
1. Porphyroids;
2. Metaarkoses;
3. Upper Ordovician fossiliferous metasiltites;
4. Silurian (Lidice) and graphite carbonaceous schists;
5. Grey or carbonaceous phyllites with Lower and Middle Devonian nodular metagraywackes.

To the east, the Arcu de Su Bentu Unit maintains its Upper Ordovician-Devonian cover almost complete, while to the west the cover is strongly terminated and the Mt. Lora Unit lies almost directly on «Porphyroids» with megacrysts (see next stop).

**Stop 3.2 - East of Mt. Ferro: pre-Caradoc succession of Mt. Lora Unit and tectonic contact of the overlying Arcu de Su Bentu Unit (Fig. 3.3).**

During a short walk along the Flumendosa river, we cross the pre-Caradocian succession of the Mt. Lora Unit starting from the top of the Ordovician metavolcanic complex. Continuing along the river, beyond the ford, we enter the series and can observe (Fig. 3.4):

1. Folded quartzites and metasandstones immediately underlying the Upper Ordovician fossiliferous layers;
2. Porphyroids;
3. Acid to, more rarely, intermediate metavolcanics and abundant amphibibolite rocks deriving from the sedimentary reworking of volcanic materials.

Continuing about 1 km along the stream which flows from Mt. Su Perdusia, the previous succession clearly overtrusts the Arcu de Su Bentu Unit and the tectonic contact is marked by a thin layer of black schists with bodies of Silurian-Devonian metagraywackes representing the porphyroids' cover of the Arcu de Su Bentu Unit.

**Stop 3.4 - Mt. Rocca di Nuxi: View of the tectonic contact between the Mt. Lora and Arcu de Su Bentu Units.**

**Fig. 3.1 - Schematic geological map and cross sections of the Mt. Lora area with location of stops.**

**Fig. 3.2 - View of the tectonic contact between the Mt. Lora and Arcu de Su Bentu Units.**

**Fig. 3.3 - View of the tectonic contact between the Mt. Lora and Arcu de Su Bentu Units.**
Towards the south, the succession is completed with Upper Devonian-Tournaisian metasiltstones composing the limestone cliff of Mt. Loro, overlain by the «Arenarie di San Vito» to the south.

We climb the valley of the Flumendosa river, remaining among the Silurian-Devonian phyllites and metasiltstones, and enter the valley of the Rio Grappa as far as the core of the nappe antiform of the lower Flumendosa valley where the deepest unit of the nappe zone of Central and Central-Southern Sardinia crops out.

**Erra 3.4 - Rio Gruppo valley: marbles of Castello di Quirra Unit.** (Fig. 2.4)

On the right of the valley, calc-schists and marbles crop out in which only rare remnants of crinoids have been found. According to the authors they may belong to the Silurian-Devonian cover of the deepest outcropping unit; the slightly higher grade of metamorphism shown by these rocks may be due to their position in the nappe pile.

On the other side of the valley, the series containing marbles is tectonically overlain by a succession of «the Gerrei type» containing Upper Ordovician and Silurian fossiliferous levels.
Lunch at marble quarry.

These marbles are sometimes intruded by gabbro-diorites (Fig. 3.1). At the contact Ca- silicates (like wollastonite, vesuvianite, grossularite) are present.

After lunch, we climb the valley of the Fiumendosa along the Gerrei road to Ballao. Silurian-Devonian formations of the Gerrei Units crop out all along the road.

---

Ordovician metasandstones known in literature as "Arenarie di Solanna", constituting the base of the Meansardo Unit. According to the authors, the Meansardo Unit is to be correlated directly with the Genn Argiolis Unit.

We retrace our route to S. Vito, where we turn off for Villaputzu towards the sea at Porto Corallo. Along this stretch of road, the outcropping rocks consist of "Arenarie di San Vito" of the Genn Argiolis Unit.

---

At the Nuraghe su Franzese, the Genn Argiolis Unit overlies one of the Gerrei Units. Just passed the overthrust surface, stressed by a cataclastic belt, we enter the sequence of sometimes carbonaceous slates and thin alternations of marly slates and metaterrermites of Lower-Middle Devonian. Here, selective marine erosion highlights the geometry of the first deformation phase folds and the complex interference architecture.

We then return to Muravera.
Theme of excursion of fourth day

THE GEOLOGY OF BARBAGIA

by L. Carmignani, F.M. Elter, M. Gattiglio, M. Maxia, A. Moretti, G. Oggiano & P.C. Pecorai

SUBJECTS: Meana Sardo Unit, its sequence and its relationships with other Units. Low grade metamorphic complex of the Barbagia region. Permian discordant deposits.


INTRODUCTORY NOTES TO THE BARBAGIA EXCURSION

INTRODUCTION

During the fourth day we will cross the nappes-pile which constitutes the north-eastern limb of the Flumendosa antiform. First we will cross the Meana Sardo Unit and later, the low grade metamorphic complex of Barbagia. The former overlaps the Gerrei Units and corresponds to the Gem’Argiolos Unit out croppings to the south-west of the Flumendosa antiform; the latter crops out in correspondence to the Gem Ranciantu massif and corresponds to the low grade metamorphic complex of Barbagia, Gocciano and southern Nurra (cross-section of fig. 1 of Carmignani et al. this volume).

SUCCESSION OF THE MEANA SARDO UNIT

When Carmignani et al. (1978) defined the Meana Sardo Unit, this Unit was supposed to include two metavolcanic complexes:

a) Porfiroidi (metahyolitites and metahydroclasts) underlaying the Cambrian-Early Ordovician metasediments (Areararie di Solanas) and thus considered pre-Cambrian;

b) A second horizon of metavolcanites (metahyolitites to metaandesites, with minor metabasalts) lying over the same metasediments and thus connected with the remnants of the Medium Ordovician magmatism of Sardinia.

Recent research (Carmignani et al., 1985) indicate that the Cambrian-Ordovician Areararie di Solanas tectonically overlap the Porfiroidi, which still preserve an Upper Ordovician-Silurian fossiliferous metasedimentary cover identical to that of the Gerrei Units. Therefore, the lower Porfiroidi with their stratigraphic cover are now attributed to the Gerrei Units, whereas the Meana Sardo Unit, just like all the nappes zone units, begins with the Cambrian-Ordovician metasediments (Areararie di San Vito, Areararie di Solanas etc.) (Fig. 2 of Carmignani et al. this volume).

1. Areararie di Solanas Formation

The Areararie di Solanas Formation consists of a metric to decimetric alternation of more or less quartz-rich metasediments, metaoolites and greyish green slates. The thickness results quite difficult to evaluate owing to the complex tectonics, but it is surely superior to 500 m. The presence of levels of metaglomerates is reported in the middle part whereas the top is characterized by red metasiltic levels.

In the high part of the formation, rich acritarch associations give evidence of an age between the Lower Cambrian and Arenigian (Tomorcat et al., 1982a, b; Albani et al., 1985).

In the Sarabus region, the formation can be correlated with the Areararie di San Vito and, to the south-west of the Campidano plain, with the Cambrian-Ordovician metasediments of the Arbaretu Unit. They all have to be related to similar depositional environments.

2. The Ordovician Metavolcanic Complex

As in the Sarabus region, the contact between the Cambrian-Early Ordovician metasand-
stones and the overlying Middle Ordovician metaevolcanic-sedimentary complex is often marked by metagabbroic with metamorphoses with elements of metasediments and acid metavolcanics.

The lower part of the volcanic complex is constituted by white mafic CONTACTES with rare and small-sized quartz and K-feldspar « pheno-
crysts» enclosed in a micropyrolitic matrix more or less on account of the small size of the fragments of the rocks. Upper Ordovician fossils have also been found (NAD, 1979).

4. The Silurian-Devonian Metasediments

Representing the youngest formations of the Unit, and thickening in the vicinity of the granite, they are very thin in the ordovician volcanic rocks in the village of Meena Sardo to the Tyrrenian coast. Except for the slightly higher recrystallization, this sequence has much in common with the coeval one in the Iglesiente, Sarrabus and Gerrei regions. It is composed of basic quartzites (silica- quartzite), carbonaceous phyllites and nodular metaluminous metabasites. In some places, the presence of basic volcanics of basic compositions, referred to original alkaline basalt of continental rift environments (Rico & Sarracino, 1978, Mazzini et al., 1982, 1983), have been pointed out. The whole succession varies in thickness because of the frequent tectonic laminations, it may even reach 1500 m. Although no palaeontological research still exists, such succession might include at least the Devonian age.

5. The Problem of «Postglacialiano» (AUCT)

A main terrigenous complex known as «Postglacialiano» lies above the Silurian-Devonian formations of the Meana Sardo Unit. For a long time, it has been thought to be in the stratigraphic succession over the Silurian-Devonian formations (therefore the «Postglacialiano» name) and also to be referred to the Carboniferous formations. Some authors (Bonzani & Orosei, 1968, Nano, 1979, etc.) questioned this age, since they thought the relationship with the underlying Silurian-Devonian succession were tectonic. Even though no adequate studies have been carried out on this wide complex, the available data lead to the conclusion that the «Postglacialiano» unit is composed of some allochthonous units of innermost origin, in respect to the Meana Sardo Unit, and still constituted by formations of Cambrian to Devonian age. This wide complex is characterized by the 1:500,000 map «Structural Model of the Hercynian Basement of Sardegna» as the low grade metamorphic complex of Barbagia.

In the zone crossed during this excursion two units have been recognized: the Gennargentu Unit and the Fontana Bona Unit (Dezza et al., 1982). As the surveys are complete, a structural framework will probably result more complicated. The Gennargentu Unit

This unit is mainly constituted by a monotonous alternation of metasediments, phyllites and metapelites which crop out widely in the southern flank of the Gennargentu massif. From stratigraphic viewpoint, no fossils have never been found in this formation. It could be referred to the Cambrian- 
Early Ordovician age for the following reasons: a) lithologic affinity with the Cambrian-Ordovician metasediments found in the rest of Sardegna (Aranea di S. Vito, Aranea di Solanas); b) presence of a succession constituted by acid metavolcanics, metakarses and quartzites, carbonaceous phyllites and marbles with conodonts of Devonian age (Poli & Saba, 1975) in the southeastern flank of Mt. Gennargentu. It probably represents a Middle Devonian-Ordovician stratigraphic cover of the «Postglacialiano» of Gennargentu.

The Fontana Bona Unit

A recent study carried out on the arcu Cor-
reboi zone by Dezza et al. (1982) allowed to distinguish at least an other unit overlayers the Gennargentu one. At Arcu Correboi, the Devonian marbles of the Gennargentu Unit are overlain by the Fontana Bona Unit through an evident tectonic contact.

The Fontana Bona Unit is constituted by metasediments, metavolcanics, carbonaceous phyllites and marbles. A typical Cambrian to Devonian succession can be easily recognized even in spite of the lack of fossils and a higher grade regional metamorphism.

Tectonics

The Hercynian tectonics of the Meana Sar-
do Unit has much in common with the tectonics of the «Nappe zone». The axial orientations of the fold of the Southern Horn formation phase vary from N120 to N180. In the metapelitic complexes, the lineations of extension are clearly visible; their orientation ranges from N20 to N90 therefore, they are almost orthogon to the axes of the folds. The geological section (Fig. 4,3) shows large folding structures produced during the first deformation phase. Two later folding phases, producing weaker deformations, are well developed almost everywhere. The sec-
cond deformation phase shows very dipping axial planes which are accompanied by a fracture, or a strain-slip cleavage; the axial orientation trends E-W to N140. An interference between structures of first and second deformation phase is shown in Fig. 4,1 and 4,2.

The third deformation phase causes slight de-
fomations with N170 to N20 trending axes which produce axial culmination and depression of the second phase structure. The overthrust which occurred between the Gennargentu Unit and the Meana Sardo Unit is marked by cataclasites. The overthrust surface cuts tectonically the underlying unit, so that the Cambrian-Ordovician metasediments of the Gennargentu Unit lie on different formations of the underlying unit: from the Devonian metapelites to the Middle Ordovician metavolcanics.

The differences between the low grade metamorphic complex of the Barbagia region and the Meana Sardo Unit, the Gerrei Units, etc. are due to the increasing intensity towards the NE of the shearing directions. That determines either a higher recrystallization or a higher ductility of the rocks during the deformation: development of a very penetrative flow fabric implying a deep in-
ternal reorganization of fabric. A more complex structural evolution represents a further dif-
fERENCE. In the low grade metamorphic complex of the Barbagia, the isoclinal folds that can be recognized at the mesoscopic scale refuld an older foliation also related to another isoclinal fold system. The isoclinal folds are subsequent-
ly refolded by later deformation phases which are similar to the «post-nappe» phases in the southernmost tectonic units. The presence of at least two (isoclinal) folding phases seems to be a typical feature of the low grade metamorphic complex of Barbagia.

On the basis of our present knowledge, we do not know whether it depends either on the effects of a remarkably older tectonic phase, which would have affected the innermost zones only, or on a more complex evolution of the first tectonic phase at deeper structural levels, such as those of the innermost zones of the Hercynian chain of Sardegna. However, it is well known that ophiolitic belts like the Hercynian one generally imply shear zones which progressivively involve a rippling effect, the outer zones of the chain in the course of time.
DESCRIPTION OF STOPS
OF THE BARBAGIA EXCURSION

We climb the Flumendosa valley along the Gerrei road up to Ballao. Excluding few exceptions, like Mec Ferrero, Silurian-Devonian formations of the Gerrei Units crop out all along the road.

Towards north, beyond Ballao, we first cross the Silurian-Devonian formations of the syncline between Brunca Bonifacio and Mt. Marconis (Fig. 3.5 of Day 3). Then, along the climb leading to the Mt. Marconis pass, we cross the Ordovician metavolcanoclastics cropping out at the core of the antiline, the northernmost of Gerrei Units along this transversal.

Beyond the Mt. Marconis pass, we enter the Meana Sardo Unit represented here by its oldest formation: the «Arenarie di Solanas» (Medium Cambrian-Early Ordovician) (Fig. 4.1). Along the road, the tectonic contact with the Gerrei Units is hidden by Penninian deposits which crop out extensively up to Escalapiano and even further on.

On the left, just a few metres above the road, some rhyolite levels are interbedded with the Penninian red clayey sandstones.

— Str. 4.1 — Escalapiano: The Escalapiano Penninian-Triasic Basins (Fig. 4.1).

Along the road’s bank near Escalapiano the Permian bottom contact is well visible. The sequence lies in angular unconformity over the «Arenarie di Solanas». It begins with a metre of conglomerates with clasts of quartz and rarer metasandstones of the substrate having a considerable amount of red sandy matrix, and is then followed by a monotonous sequence of siltstones and reddish shales with thin gypsum horizons.

Together with the deposits of Seni, Seulo, Perdasdegudu, Mulariga Lake, etc., they represent the oldest post-Hercynian deposits of central Sardinia. Most of the authors (Fontana et al., 1982) consider them to be Autunian in age.

Passed Escalapiano, we go down again to the Flumendosa valley. Sediments and Penninian volcanoclastics (rhyolitic ignimbrites and rhyolitic lavas) crop out extensively along the road. The «Arenarie di Solanas» are the metamorphites cropping out beneath the Penninian.

Passed the Flumendosa river we then go up to the other flank dominated by a wall of Plio-Quaternary carbonates (the «Arenarie di Solanas»). The «Arenarie di Solanas» and the Ordovician metavolcanoclastics of the Meana Sardo Unit crop out in overturn-

sed succession along the road; almost at the top of the climb, near Aru St. Stefano they tectonically overlap the Silurian black schists of the «Gerrei» type series.

— Str. 4.2 — Road leading to the dam of the Middle Flumendosa lake: View of the refolded isoclinal folds of the Gerrei Units and of the overthrust between the Meana Sardo and the Gerrei Units (Fig. 4.1). During this stop, the SW flank of a huge post-drift anticline that refolds together the isoclinal folds of the «Gerrei» type series with the overlying Meana Sardo Unit is visible. Fig. 4.2 shows a series of «lenticle» anticlines with «Portofidus» of the Gerrei Units at the core, overlapped by the Meana Sardo Unit consisting of the «Arenarie di Solanas» and of Ordovician metavolcanoclastics. The former crops out near the bridge of the Flumendosa river and also towards east beneath the Escalapiano Penninian deposits, that we have seen for some kilometres.

The tectonic contact between the metavolcanoclastics of the Meana Sardo Unit and the Silurian schists of the Gerrei Units crops out along the road coming from the Flumendosa river.

We return to Escalapiano and carry on towards Esterazzu.

Leaving the village of Escalapiano, conglomerates and coarse Eocene sandstones crop out along the road. They lie in unconformity over the Medium Jurassic dolomites which crop out further on along the road up to Mt. Sa Colta (Fig. 4.3).

From the top of this mountain: to the east, the particular morphology of the Jurassic outcrops ("Tarchi di Jerusa") stands out; to the north, Mt. S. Vittoria constituted by the Meana Sardo Unit. After Mt. Sa Colta we return to the basement; along the road the «Arenarie di Solanas» crop out.

We cross the south-western slope of Mt. S. Vittoria finding Cambrian-Ordovician metasandstones which are isoclinally folded together with the Ordovician metavolcanoclastics (Fig. 4.3). The Upper Ordovician and Silurian-Devonian metasedimentary cover crops out on the northern-western slope of the mountain where it is tectonically over lain by the low grade metamorphic complex of the Barbagia region ("Postosigillanese" AUCT).
— **Stop 4.3 - Road leading to Mt. Santa Vittoria**

Contact between the *Arenarie di Solanas*, Ordovician metavolcanic complex and the interposed metagraywackes (Fig. 4.3 and 4.4).

In the first stretch of unpaved road going up to Mt. Santa Vittoria, the *Arenarie di Solanas* Formation is well visible: micaceous grey metasandstones alternated to grey-greenish phyllites with typical thin light laminae. The Cambrian-Ordovician metasandstones are covered by a metavolcanic, here composited essentially of coarse volcanic elements. The succession then continues with white metachertts bearing rare felsic pseudomorphs of quartz and K-feldspar within a microcrystalline more or less sericitic groundmass, which is sometimes hardly silicified (Mt. Corte Corbo Formations). In the Mena Sardo Unit, this usually constitutes the bottom of the Ordovician metavolcanic complex.

The succession above described presents remarkable affinities with that of the Sarrabus region (see 2.2 stop) where the metavolcanic rocks were interposed between the *Arenarie di Solanas* and the Ordovician metavolcanics. This fact therefore seems to confirm the diffusion of the Caledonian unconformity in the Sardinian basement.

**Lunch along the road leading to Esterzili.**

The road to Esterzili crosses several structures with the *Arenarie di San Vito* at the core, therefore the stratigraphic sequences are repeated several times up and down. Along the road we find: *Arenarie di San Vito*, metavolcanic rocks of the Caledonian unconformity, and different types of metavolcanic and Ordovician metagraywackes.

At Esterzili, the meta-sedimentary cover of the metavolcanic complex crops out: Upper Ordovician fossiliferous formations and Silurian Devonian phyllites.

Coming down from Esterzili, the road still remains within metagraywackes with phyllices of Silurian-Devonian age. At the top of the opposite slope of the valley, the unconformity between the Middle Jurassic conglomerates of the *Tacco di Sudali* and the basement is well exposed.

— **Stop 4.4 - Along the climb to the Esterzili station**

A typical fossiliferous Upper Ordovician outcrop of the Mena Sardo Unit.

Along the back of a country-road, fossiliferous meta-siltstones and metasandstones of Upper Ordovician age can be well observed. Some levels are very rich in crinoids, brachiopods, bryozoans.

On the opposite flank of the valley, the upper part of the Mena Sardo Unit is clearly visible. It dips towards NE, and is formed by the Ordovician metagraywackes, the Upper Ordovician metasediments and then the Silurian Devonian metagraywackes and phyllices cropping out along the road to Esterzili.

We now go up to the Esterzili station, the turnip bends of the road cross the Ordovician-Silurian boundary over and over again.

**Stop 4.5 - Near the Esterzili station: The Ordovician and Silurian Devonian succession of the Mena Sardo Unit (Fig. 4.4).**

For about one kilometre, we can observe the following succession along the back: first the terrigenous deposits transgressive on the Ordovician metavolcanics (*Caradocian Transgression* AUCT), then the pelagic Silurian-Devonian facies, and last the metasedimentary rocks of the basal formation of the low grade metamorphic complex of the Barbagia region overthrusting the Mena Sardo Unit (*Porto Ferroian* AUCT). Just before the station, there is an outcrop of the Ordovician metavolcanic complex represented both by metagraywackes with intermediate chemical composition and volcanic
metagraywackes; it is the Serra Tonnai Formation. In the Meana Sardo Unit, such formation usually constitutes the youngest term of the metavolcanic complex. The metavolcanic facies is covered by metarocks and coarse-grained metasediments which characterize the beginning of the transgression on the volcanics. At the station, we find Upper Ordovician fossiliferous metasediments, metagraywackes and phyllites. Beyond the station, carbonaceous phyllites with 'idiote' referred to the Silurian and also strongly laminated metasediments crop out. The original nodular structure, typical of Lower-Middle Devonian tectonite-bearing metagraywackes is still easily recognizable.

The Devonian is overlain by metasediments (Postglacialian AUCT.) alternated with phyllites cropping out for a short stretch of road before the cover of Middle Jurassic dolomites of 'Tocco di Sadali'.

According to the authors, the metasediments are correlated to the Cambrian-Ordovician metasediments of the Arburese, Sarraus, Sarcaido, etc. The bottom contact with the Meana Sardo Unit is tectonic.

At the end of our walk we can see a long stretch of the overthrust of the 'Postglacialian' over the Meana Sardo Unit on the opposite flank of the valley; fig. 4.5 shows the view and the cross-section of the whole slope.

Once beyond the Middle Jurassic dolomites of 'Tocco di Sadali' we go towards Usai Sadali and cross a long stretch of road composed only of the 'Postglacialian' metasediments.
our itinerary, the Ordovician formations of the Funtana Bona Unit show their Silurian-Devonian cover.

— Step 4.7 - Arca Correboi: The overthrust between Cambrian-Ordovician metasediments of Funtana Bona Unit and Devonian marbles of Mt. Pipinari (Fig. 4.6).

From the pass, the marbles of Mt. Pipinari overlying Silurian phyllites are clearly visible on the southern flank. Devonian conodonts have been found in the marbles of Mt. Pipinari. Ordovician quartzites overthrusting the marbles are also visible on the northern flank (Mt. Armario); the basal tectonic contact is in slight unconformity with the main schistosity which affects both units.

A thick subvertical acid porphyry dike crossing the marbles is visible on the same flank; from such dyke, thin sub-horizontal apophyses branch off and penetrate along the schistosity.

A few dozens of metres away from the pass, in a small marble quarry, we can view a late-Cambrian porphyry dike with very fine sub-horizontal slickenlines due to the Alpine transcurrent fault which extends for the whole length of the Rio Correboi valley (Fig. 4.6).

We set out again towards NW, quartzites and metasediments of the Funtana Bona Unit are visible on the bank of the road.

Beyond the Garavol pass, we go down to the rio Vavari valley and cross the Alpine transcurrent fault again. Towards north, along the morphologic depression individuated by this fault, about one kilometre later we find the biotite monzogranitic granodiorites. These outcrops are the southernmost of the Ogliastra-Calattra Batholith, which we will cross in the excursion of Day 5. These plutonic rocks accompany us along the entire road to Nuoro.

Some kilometres later, the succession becomes mainly phyllitic and the Devonian marbles are visible above the Silurian black schists. They represent the peaks of Mt. Arbù and Punta Sa Bitta, on the western slope of the valley, and Mt. Pipinari, on the eastern slope.

The lower formations of the Funtana Bona Unit, composed of quartzites and metasediments which can probably be referred to as Ordovician, overthrust the Devonian marbles of the "Postgondwanian" sequence, precisely at Arca Correboi. A few kilometres towards NE, outside
Theme of excursion of fifth day

THE GEOLOGY OF NORTHERN SARDINIA

by F.M. ELSNER, M. FRANCESCHELLA, C. GHEZZO, I. MEMMI & C.A. RICCI

SUBJECTS: The zones of regional metamorphism of northern Sardinia (from Biotite to Sillimanite + K-feldspar zones).


INTRODUCTORY NOTES TO THE NORTHERN SARDINIA EXCURSION

INTRODUCTION

The basement of northern Sardinia, overlain by the post-Hercynian cover, consists of volcano-sedimentary sequences tectonized and metamorphosed during the Hercynian orogeny and invaded by a large amount of late tectonic Hercynian granitoids.

The granitic bodies dominate the central and eastern part of this basement, while the metamorphic sequences formed patches resembling roof pendants over the granitic rocks. The metamorphic complexes are mostly concentrated along the eastern (Baroniec-Gallura) and western coast (Nurris-Asinara) or in the mid region (Goecono and Anghona) of the north of the island.

The style of deformation and the degree of metamorphism vary widely between the southern (Baronie, Goecono and southern Nurra) and northern areas (Gallura). The transition between the two contrasting areas may be observed in detail in two zones of excellent exposure (Nurra and Baronie-Gallura regions) along the western and eastern coast, respectively.

STRATIGRAPHIC OUTFOLDS

We have no available detailed data on the stratigraphy of the metamorphic basement of northern Sardinia, except that of the basement of the Nurra. For southern Nurra, Carmignani et al. (1979), gave the following stratigraphic reconstruction from bottom to top:

1) Porphyroclasts, volcanic metagraywackes and metabasites;
2) Metasandstones and black phyllites with levels of dolomitic ironstones;
3) Metagreywackes with metabasites and rare intercalations of Orthoceras-bearing calcisandstones;
4) Black phyllites and metasandstones with metaconglomerates and quartzites;
5) Metasandstones, pinkish quartzites and phyllites.

Only the third term contains fossils which consent a founded attribution to Silurian and Devonian (Cosmo, 1913). For the other terms, on the basis of lithological analogies, Carmignani et al. (1979) supposed an Ordovician age for the first two terms and a Carboniferous age for the last two. In the sequence of southern Nurra, Di Pisa & Gogiana (1984) also found carbonatic levels and proposed a correlation between these levels and the calcareous levels attributed to the Carnoc-Ashgill in central Sardinia.

In Nurra, metagreywackes, paragneisses, porphyroblast microgranitoids crop out; they are considered (Carmignani et al., 1979) as the equivalent of the fourth and fifth terms of southern Nurra in higher metamorphic stage.

In the Goecono region, a stratigraphic reconstruction has not yet been made. However, the following rock types have been found: Porphyroclasts, black schists, calc-schists, marbles, metabasites and volcanic metagraywackes (Ghezzo & Rucci, 1970; Rucci & Sbarbati, 1976, 1978).

In the Baronie and Gallura regions six lithological complexes have been distinguished. Moving northwards they are:
a) Phyllites and metasandstones with biotite;
b) Micaschists and paragneisses with garnet + (white + oligoclase);
 c) Granodioritic orthogneisses and augen gneisses;
 d) Micaschists and paragneisses with staurolite + biotite and kyanite + biotite;
 e) Amphibolites with relics of granulite facies paragneisses and rarely eclogites partially retrogressed.

D) Gneisses and migmatites.

The age of the rocks of the a, b, d, e and f complexes is unknown. For the terms of the c complex, radiometric data give Rh/Sr ages of 486 ± 1 Ma for the granodioritic orthogneisses and 441 ± 33 Ma for the rhythmic augen gneisses, which have been interpreted as the age of the emplacement of magmatic bodies (Fiorari et al., 1978).

Nard (1979) considers the granodioritic orthogneisses (Lödde) of pre-Cambrian age without having convincing evidence.

Granulites and eclogites occur as small bodies within the migmatic rocks. They may represent the relics of a pre-Hercynian basement (Guiraud, 1962).

In our opinion, only the following correlation among the southern and northern Sardinian terranes can reasonably be proposed:

1) Granodioritic orthogneisses and rhythmic augen gneisses of Barerone-Gallura, "Porfiroti di Nurra and Gocciano with the Middle Ordovician igneous activity of Sicariado, Gerrei and Sarrabus (Meehi et al., 1982, 1983; fig. 2 of Carmignani et al., this volume).

2) Volcanic metagraywackes and subalkaline metasediments of Nurra and Gocciano with the Ordovician subalkaline volcano-sedimentary complexes of Sicariado and Gerrei (Meehi et al., 1982, 1983).

3) Alkaline metabasites of Nurra, Gocciano and Barone with those attributed to Silurian in Sascardino and Barbagia regions (Meehi et al., 1982, 1983; fig. 2 Carmignani et al., this volume).

4) Marbles, calc-schists and black schists present in all the northern Sardinia basement with the gneotolite-bearing slates and orthoceras-bearing metaglimmerites of Silurian-Devonian age (Carmignani et al., 1982a; fig. 2 Carmignani et al., this volume).

Tectonics

In the metamorphic basement of northern Sardinia, three main fold systems have been distinguished which are supposed to represent distinct deformation phases (D1, D2, D3). Using several criteria (including orientation of axes, sense and sequence of folding in time), three groups of folds may be correlated with the equivalent fold groups recognized in the metamorphic sequences of central and southern Sardinia.

A clear example of superposition of three main deformation phases is the basement of Nurra (Carmignani et al., 1979). The change in style of the main deformation phase and associated axial plane cleavage from southern to northern area is summarized in fig. 5.1 (after Carmignani et al., 1982b).

D) Deformation Phase

D1) Structures are the early, mesoscopic scale, that folded the sedimentary contacts. The main structure, originated during this phase, is very large recumbent fold which constitutes the whole basement of Nurra (Carmignani et al., 1979). Some mesoscopic isoclinal folds, overturned towards SW and showing an axial plane schistosity (S1), striking about N120°, are also related to D1. In the zone of highest grade in the Nurra and Gallura, we now find only few traces of this deformation phase and it can be documented only at microscopic scale.

In thin section, the S1 schistosity is defined by a strong orientation of phyllostactite and quartz-epctite layers. Moving towards the zones of higher metamorphic grade, the S1 surface is progressively transposed and obliterated by the S2 schistosity. In the low grade rocks, the main minerals grew during the development of S1 schistosity. An extensive growth of biotite and muscovite, involving trails of S1 schistosity, occurred in low and medium grade rocks (Carmignani et al., 1979; Franceschelli et al., 1982a).

D2) Deformation Phase

This phase refolds all D1 structures and produces folds striking E-W which are the most obvious structures in the field. The style of the folds changes progressively moving northwards. In the low grade zone, the folds are open and then become gradually tighter up to isoclinal. The megastuctures originated during this phase have been mapped in the Nurra and Barone regions. In the Nurra, the most remarkable D2 structure is a kilometre synform with the axes striking about E-W and plunging eastwards. In the Barone, a kilometre anticline, with axes trending E-W and plunging eastwards has been mapped in the Sinaicola-Mamone area (fig. 5.2). The S2 schistosity can easily be observed in all rock types. In the low grade rocks it is generally associated only with an incipient crystallization of muscovite. Moving northwards, the modal amount of mineral growth parallel to the S2 schistosity increases and the textures of the rocks are dominated by pre-S2 porphyroblasts and syn-S2 minerals. In the high grade zone, the migmatic layers are disposed parallel to the S2 schistosity and no trace of pre-S2 porphyroblasts remains (Carmignani et al., 1979; Franceschelli et al., 1982a).

D3) Deformation Phase

The third phase of deformation is represented by chevron, box and kink folds whose axial planes strike about N-S. The main structure of this phase is an antiform mapped in the Nurra. The set of mesofolds, produced
during this phase, are associated with a roughly spaced cleavage and scarce mineral crystallization (Carrington et al., 1979; Franceschelli et al., 1982a).

**Shear Deformation**

During the latest evolution of the Hercynian orogeny, the metamorphic rocks of some areas in the Gallura and Anglona regions were affected by shear deformations. The shear deformation of Gallura is known quite well (Elvert, 1985). This shear zone trends E-W and affects a 10 km wide area from the Sanuddii to the Sillamante grade. Microscopic studies reveal the presence of a variety of mylonitic rock types such as cataclasites, protomylonites, mylonites and ultramylonites in a quite regular order moving northwards. These rock-types appear to be the product of a heterogeneous deformation in a suite of similar lithologies. In the various mylonitic rock-types, we can distinguish two well-developed foliations (S and C planes) which tend progressively into parallelism in the north margin of the shear zone.

The shear deformation in the Gallura region is overprinted to the regional D3 structures and predates the contact metamorphism connected to the intrusion of Late-Hercynian granitic bodies.

**Metamorphism**

The basement of northern Sardinia is characterized by an increase in metamorphic grade towards N-E. Utilizing microscopic analyses of relationships between the two main Hercynian deformation phases and the growth of time of minerals, two main episodes of crystallization (M, episode and M, episode) have been distinguished (Franceschelli et al., 1982a). We believe that the main features of the Hercynian metamorphism of Sardinia were determined by overprinting of the two episodes.

**The M, Episode**

The M, episode of crystallization includes minerals formed before the S, schistosity. During this episode, the key minerals in their own zone are synkinematic compared to S, in the low grade zones, and postkinematic in the low medium grade ones. The M, episode appears to be an episode of prograde metamorphism connected with a progressive P-T evolution. On the basis of the mineral assemblages, in pelitic-pyroxenitic schists, predating the S, seven metamorphic zones are defined reflecting the change in the configuration of AKPM projection (fig. 5.2, 5.3 and 5.4) (Franceschelli et al., 1982a, 1982b).

1. **The Chlorite Zone**
   This zone is that of lowest metamorphic grade of northern Sardinia. It has been mapped in the Nurra, Gocceano and Barone regions. Quartz, muscovite, albite and paraamphibole are common minerals found in various proportions. As AFM phases, we detected chlorite and chloritoid (fig. 5.4a). Relevant minor phases are tourmaline, graphite, ilmenite, apatite and zircon.

2. **The Biotite Zone**
   This zone has been encountered in the Nurra (fig. 5.4b), Gocceano and Barone regions. Although biotite is not always present in the rock, this zone is defined by the incoming of biotite in the muscovite, albite, quartz, and chlorite bearing assemblages. Other minerals are chloritoid and carbonates. As minor phases we found tourmaline, ilmenite, epidote.

3. **The Garnet Zone**
   This zone has been encountered in the Nurra and Barone-Gallura regions. The Garnet isograd is based on the first incoming of garnet in pyroxenitic rocks, while the spaciness of the garnet zone is defined by the persistence of the assemblage grt+chl+bi (mineral abbreviation as Kretz, 1985). The AFM assemblages observed in this zone are shown in Fig. 5.2. - 1: Detrital deposits (Holocene); 2: Continental and beach deposits (Pliocene-Quaternary); 3: Platform carbonate sediments (Oranian-Cretaceous); 4: Confluent carbonates-sediments (Trassic-Liasic-Cretaceous); 5: Acid and granitic rocks; 6: Platform carbonates-sediments (Cenozoic); 7: Biotite and granite gneiss; 8: Biotite and granite gneiss; 9: Muscovite and granite gneiss; 10: Muscovite and granite gneiss; 11: Muscovite and granite gneiss; 12: Muscovite and granite gneiss; 13: Muscovite and granite gneiss; 14: Muscovite and granite gneiss; 15: Muscovite and granite gneiss; 16: Muscovite and granite gneiss; 17: Muscovite and granite gneiss; 18: Muscovite and granite gneiss; 19: Muscovite and granite gneiss; 20: Muscovite and granite gneiss; 21: Muscovite and granite gneiss.

![Fig. 5.2](image-url)
in fig. 5.4c. Other major minerals are muscovite, plagioclase, quartz. Minor phases are the same as we found in the previous zone. Plagioclase is generally albite; albite with an oligoclase rim is found in the rocks of the northern part of the zone. On the basis of plagioclase composition, the Garnet zone has been subdivided into two mappable sub-zones, i.e., Garnet + Albite zone and Garnet + Albite + Oligoclase zone (Franceschelli et al., 1982a, 1982b).

4. The Staurolite + Biotite Zone
This zone has been mapped in the Asinara islet and in the Baronia-Gallura region. Here, the low grade limit of this zone coincides with the lithological contact between the granitic orthogneisses and micaschists and therefore, it is openly controlled by the chemistry of the rocks. The AFM assemblages observed in this zone are presented in fig. 5.4d. They also include muscovite, quartz and plagioclase and the usual minor phases.

5. The Kyantite + Biotite Zone
This zone has been mapped in the Anglona and Gallura regions. The Kyantite + Biotite isograd is defined by the incipient of kyanite in the st + bt + grt assemblage encountered in the previous zone (for AFM assemblages see fig. 5.4e).

6. The Sillimanite + Muscovite Zone
This zone has been mapped in the Asinara islet and Anglona and Gallura regions. The lower boundary is based on the first appearance of sillimanite. In some samples, kyanite and sillimanite coexist and then this boundary also marks the polytopic kyanite = sillimanite transition. Both fibrolitic and prismatic habitus are observed, but fibrolite prevails. (For AFM assemblages see fig. 5.4f). Other minerals are the same as in the previous zones.

7. The Sillimanite + K-feldspar Zone
This zone has been mapped in the Asinara islet, Anglona and Gallura regions. It constitutes...
the northernmost portion of the metamorphic basement. The Sillimanite + K-feldspar zone is defined by the coexistence of sillimanite and K-feldspar. Primary muscovite persists after the isograds. The final mineral assemblages are reported in fig. 5.4g.

The rocks of the Sillimanite + K-feldspar zone are in general migmatized. Two kinds of migmatite have been found: throrhombic migmatite and granitic migmatite. The compositional layering of the throrhombic migmatite is masked and transposed by the S2 schistosity. This migmatitic composi- tional layering is supposed to have been formed during or after the D2 deformation phase. The throrhombic migmatites occur at the beginning of the Sillimanite zone and also persist in the Sillimanite + K-feldspar zone. Qtz + pl + bi + lls is the common and simple com- position of leucosomes, and Qtz + pl + bi + ros + gts + all + that of mesosomes. For these types of rocks an anastetic origin cannot be documented. The granitic migmatites appear just at the Sillimanite + K-feldspar zone isograd. The migmatisitic rock types include stromatolite, fluflake, neblulite, agmatite and layered migmatites. The leucosomes are essentially composed of Qtz + pl + kfds in modal proportion similar to the minimum melt composition. Other minerals are muscovite, garnet, biotite and sillimanite in varying combinations. This suggests an anastetic origin and that the leucosomes/generating reactions involved dehydratation-melting of muscovite.

THE MIGMATITIC EPISODE

The M2 episode includes a mineral growth during or after the development of S2 schistosity. In the lower part of the Chlorite zone, no metamorphic crystallization has been observed along the S2 schistosity. In the upper part of the Chlorite zone, we observed an incipient crystallization of muscovite, chlorite and Fe-oxides.

In the Biotite zone, some biotite flakes are oriented parallel to the foliation but, as previously reported, the first appearance of this key mineral is related to the M1 episode. In the Garnet zone, the S2 schistosity is composed of the growth of muscovite, chlorite, biotite, quartz and Fe-oxides. Some other minerals such as plagioclase and quartz are rotated and reoriented. Garnet is corroded and replaced around margins and along cracks by biotite.

These rocks are widespread in all the migmatitic zones, and they form nodules with a size ranging from a few centimeters up to one metre. The nodules are composed of quartz, plagioclase, sphene, Fe-oxides, amphibole, clinopyroxene and garnet. The nodules show a concentric zoning, a dark rim and a light green to pink core; moving from core to rim, we can observe an increase in the modal proportion of the minerals and a decrease in clinopyroxene and garnet.

According to Miller et al. (1976) and Gasco et al. (1982) the eclogitic rocks experienced an early metamorphic history partially independent of that of the migmatites, wherein the amphibolites and chlorite schists retain their original metamorphic assemblages, not contrasting with that of the migmatites. The amphibolite assemblage could have been formed during M1, while the subsequent retrogression and hydration during and after the M2 episode.

It is noteworthy that the development of the significant parageneses and/or mineral index was diachronous in the different metamorphic zones. In the low to medium grade zones, mineral index like biotite, garnet, staurolite as well as the most paragenetically related during the first tectono- thermometric phase (D1 + M1); in the high grade zones, the main parageneses grew during or after the second tectono- thermometric phase (D3 + M2).

Eclogites with amphibolite parageneses and calc-silicate nodules:

Up to now, eclogites, amphibolites with relics of granulate parageneses and calc-silicate nodules have been found only in the high grade metamorphic rocks of Guallur. However, we cannot exclude that the different metamorphic zones record different pathways in the P-T plane, in the course of time:

- Prograde path for the rocks of low medium grade zones, possibly developed during the first tectono-thermal stage (thickening + heating);
- Retrograde, eventually decompressive for the rocks of high grade zone, possibly developed during the exhumation of the basement (Elder et al., 1985).

Radiometric data indicate that the entire polyphase metamorphic evolution of the Hercynian metamorphism of northern Sardinia prob- ably took place in a time interval between 344 and 310-290 Ma (Ferrara et al., 1978).

This evolution is consistent with the models of P-T-X space, deformed continental crust, recently elaborated by England & Thompson 1984 and Thompson & England 1984.

The plutonic complex represents the major structural feature of the segment of the Hercynian chain of Sardinia. It crops out widely in the axial zone intruded into the high to medium grade metamorphic complex. The com- posite batholith extends southwards cross- cutting the low-grade metamorphic cover in the "Nappes" zones of central Sardinia. The rocks range in composition from tonalities to leucogranites with minor gabbro- dioritic bodies.

The intrusive sequence began (no radiometric data are still available) with the emplacement of small syenitic dikes and bodies of strongly foliated tonalites, granodiorites and granites (some of the two-mica type with a peraluminous character) associated with the high-grade metamorphites (i.e. outcrops of Barbagia, Aggius, Bortiggia etc.).

These first magmatic events were followed by the emplacement of several plutons of biotite±amphibole medium-grained tonalites and granodiorites, rich in melanoconic xenoliths of dioritic to tonalitic composition. Their emplace- ment age is estimated to be about 307 Ma, but some of these plutons are probably older. This group of intrusions is now located mainly along the eastern part of the batholitic belt (Pontile d'Aguillu, Pattada, Orosei, Sarule-Lanusu) or constitutes some satellite intrusive masses (Bitti, Sorgono) mainly cross-cutting low to medium grade metamorphites with strong thermal ef- fects that postulate the regional metamorphism. These plutonic rocks often show a planar flow foliation and field relations that suggest a syn- to late-protolith emplacement.

Subsequently, the emplacement of a huge quantity of large plutons took place. They are constituted by monzogranitic granodiorites and monzogranites, generally coarse-grained and often inequigranular for the presence of K-feldspar megacrysts. These plutons frequently show a flow foliation; they bear basic to inter- mediate xenoliths of magmatic origin.

Among these sequence of intrusions, at least three main groups of gneissoid can be recognized:

- piakki inequigranular, coarse-grained monzogranites cropping out in the norher part of the region (Gallura, Calangianus) type ad "Anchise" type
- piakki inequigranular or equigranular, coarse-grained monzogranites and mon- zogranitic granodiorites cropping out in the southern part of the region (Barbagia, Ogliastra, ...)
The two micas and the cordierite-bearing granites, cropping out in the Mt. Senes massif (East from Nuvolau), are probably contemporaneous with this sequence of late-tectonic intrusions.

— The post-tectonic intrusive cycle is composited exclusively of pinkish or whitish equigranular, intrusive leucogranites that form several large composite plutons (Costa Smeralda - Mt. Llumbra - Mt. Puciliano, Oschiri, Mt. Lerno, Concas, Capo Comino massifs).

These younger potassium and silica-rich granites are all characterized by a shallow intrusive level of emplacement and crystallization (fine-grained border facies; presence of numerous vesicles, dikes and stock of microcrystal granites and leucogranites; mafic and gabbroic caviates); by an extensive post-magmatic hydrothermal alteration; and by practically the lack of microgranular magmatic xenoliths. On this type of intrusion the ages of 280 ± 1 Ma (D. Moro et al., 1975) and of 281 ± 5 Ma (for the Concas massif, Cocherie, 1984) have been obtained by Rb/Sr whole isochrons.

In northern Sardinia, several basic gabbro-diabase bodies crop out: Punta Falcone, Olbia, Borrigiadas, Osida, etc. These bodies have often field relations that suggest a mega-inclusion nature. They always show a complex pattern of chemical and mineralogical features connected with the interaction processes between subcrustal basic and crustal anecatic acidic magmas (Ossini, 1979, 1980; Braia et al., 1982).

REFERENCES


DESCRIPTION OF STOPS OF THE NORTHERN SARDINIA EXCURSION

We move from Nuoro towards the north. The town, which is the main center of Barbagia, is on plutonic rocks (tonalites and biotite inequigranular monzogranites) and we remain on granitic rocks up to the bottom of the Isulana river valley. Here, we catch the highway to Olbia, which is on a NE-SW post-Hercynian transcurrent fault, up to the crossroad to Lula.

We go towards Lula and the southernmost metamorphic rocks of the Barocne-Gallura region are well exposed along the road.

— Stop 5.1 About one kilometre along the road to Lula: metamorphoses of the Biotite zone.

Along the road leading to Lula, a sequence of polydeformed phyllites and metasandstones crops out. These rocks show some lithological affinities with the «Postglacialzand» AUC of Barbagia. The most evident structural element on a mesoscopic scale are D2 isoclinal folds. The S2 schistosity parallel to the compositional layering (S1) is still clearly visible.

At mesoscopic scale, these rocks are characterized by a basic paragenesis consisting of quartz-muscovite, albite, chlorite to biotite epidote, carbonates and limonite are sometimes associated.

The biotite, the index mineral of this zone, is synkinematic with D3 and is preserved in microblinds bounded by S2.

Continuing north, along the road to Lula, both the metamorphism and the deformation increase in intensity and Garnet + Albitite and Garnet + (Albitite + Oligoclase) zones occur in succession.

— Stop 5.2 Lula: Mica schists and parageneses of the Garnet + Albitite zone.

Near the village of Lula, it is possible to observe the metamorphic rocks of the Garnet Albitite zone. They are parageneses (sometimes with albite porphyroblasts) and micaschists. Their appearance is quite similar to those of the previous stop, apart from the coarser grain — sized, related to the increase in the metamorphic grade.

The main foliation on the mesoscopic scale is an S2, which wraps around microblinds and/or albite porphyroblasts carrying microscopic overgrowth of the S2 schistosity.

The paragenesis essentially includes quartz, muscovite, biotite, chlorite, albite and sometimes garnet, which first appears a few hundred metres south of this outcrop.

Moving from Lula, we leave a tonalitic pluton on the left and the unpaved road crosses the parageneses and the micaschists, sometimes carbonaceous, of the Garnet + Albitite zone.

The road then runs along the NW flank of Mt. Albo made up of mesozoic limestones.

— Stop 5.3 Road from Lula to Cantoneira S. Anna: Metamorphoses of the Garnet + Albitite + Oligoclase zone. Micaschists, porphyroblastic parageneses and augen gneisses (metagyrolities).

Along a short stretch of road, the contact between the basal levels of the porphyroblastic parageneses and the augen gneiss is visible. It is the southern limb of the overturned Murore-Siniscola antiform, developed during the second deformation phase with axis trending E-W and plunging towards N. The porphyroblastic parageneses are characterized by the presence of plagioclase porphyroblasts with albite core and oligoclase rim. They are rotated and flattened according to S3, which represents the most evident foliation.

These porphyroblasts contain, as solid inclusions, quartz, biotite, muscovite, chlorite and garnet, all having the same orientation. They probably represent remnants of a pre-S3 foliation.

The Augen Gneiss Formation is mainly composed of layered bodies of augen gneisses alternated with thin micaschist levels. These rocks are considered the products of the Hercynian metamorphism over rhyolites and arkose volcanic sandstones. The Rb/Sr rock isochron yields an age of $441 ± 33$ Ma.

The road now crosses the Augen Gneiss Formation up to Cantoneira S. Anna; here we are just on the hinge of the Siniscola-Mamone antiform.

Moving towards Lodé, we enter the granodioritic orthogneiss, constituting the core of the antiform, and then we pass to the northern liths, also composed by augen gneisses (here strongly laminated) and northerly, by micaschists.

— Stop 5.4 Road from Canti. S. Anna: Lodé: Metamorphoses of the Garnet + Albitite + Biotite zone. Garnet + staurolite micaschists

Micaschists carrying porphyroblasts of garnet and staurolite can be observed at the northern contact with the augen gneisses.

The porphyroblasts of garnet, staurolite and plagioclase, grown during a pre-D3, plastic event, were rotated, flattened, and sometimes reduced in grain size during the second deformation phase responsible of the S3 foliation.

To the north along a forestal road, we pass the Kyanite + Biotite isograd.

— Stop 5.5 Bruncu Nieddu: Metamorphoses of the Kyanite + Biotite zone. Garnet + staurolite + kyanite: micaschists, dikes of amphibolite lamprophyre.

Along the road up to Bruncu Nieddu, the outcrops consist of typical blue-gray micaschists containing abundant and well visible porphyroblasts of kyanite, staurolite and garnet. Here the micaschists are intruded by dikes of amphibolite lamprophyres of Permian-Triassic age. Northwards (at the bottom of the Rio Pozzolana valley) there is the Silvanite + Muscovite isograd that coincides roughly with the first appearance of migmatic facies (quartz - plagioclase - muscovite-bearing leucosomes).

We return to the main road and continue towards Lodé. On the bank of the road, augen gneisses and seldom micaschists are exposed. At the village of Lodé, we enter the granodioritic orthogneiss, that we will see, in detail, in the next stop.

— Stop 5.6 Rio Mannu: Lodé granodioritic orthogneisses.

Along the Rio Mannu there are good exposures of the granodioritic orthogneisses of Lodé which constitute the core of the above-mentioned Mamone-Siniscola antiform. In origin they were intrusive rocks of granodioritic composition with a radiometric age of about $458 ± 31$ Ma that underwent amphibolite facies metamorphism occurring during the Hercynian orogenetic event (age of the closure of mineral 290-310 Ma).

The rocks present a sharp subvertical schistosity striking E-W and preserve a large number of migmatisitic inclusions which have the same schistosity's orientation.

The road to Mannu crosses first a granodioritic orthogneiss intruded by mafic dikes and then the northern limb of the antiform. Augen gneisses and micaschists often show remarkable thermo-tectonic effects linked to the Hercynian plutonites (mainly granodiorites).

Lunch at Nuraghe Loelle.

The road to Budusò crosses granodiorites and then the monzogranites of the Budusò intrusion.

— Stop 5.7 Quarry near Budusò: Monzogranites.

The Budusò massif is one of the youngest intrusion belonging to the late-tectonic calc alkaline cycle. It shows a concentric zoning (Fig. 5.5), probably formed through a multiple intrusion mechanism, composed by a border biotite amphibole granodiorite with minor tonalite, by an intermediate zone of whitish coarse-grained massive leucocratic monzogranite (the quarry is located on this type), and by a central body of fine-grained more felsic leucogranite. The massif is cross-cut by the post-tectonic leucocratic plutons, belonging to the Mt. Lerno and Concias massifs.

Along the left side of the road, we view the leucogranites of Monti di Ali and afterwards dei Sardi, granodiorites and then again leucogranites.

— Stop 5.8 Punta Teplora: Stock of garnet-bearing leucogranite.

The road cross-cuts the Concias massif (one of the youngest post-tectonic Hercynian granites) constituted by a pinkish equigranular leucogranite, usually with a strong post-magmatic alteration, characterized by the presence of frequent almandine-spessartine garnet.

We go along the shore of the Posada artificial lake and then, along the bottom of the Posada river, we enter migmatic rocks of the Silvanite + Muscovite zone.

On the right, southwards, there is a broad blastomylonitic belt trending E-W. Within the blastomylonitic belt, which essentially affected parageneses and micaschists of the Kyanite +
Biotite zone, there are lenticular, stretched and retrogressed bodies of amphibolite, eclogite (7) and augen gneiss.

Further on, we pass the village of Torpé and continue on the Posada plain, up to the crossroad with "Orientale Sardo". In front of us we can see the Castello della Fava, which is above the village of Posada; both set on mesozoic limestones of the Mt. Astore group, that are here transgressive just on the hinge of the Siniscola-Mamone anticline.

Going towards Olbia, we take the crossroad to Brucella.

Stop 5.9 - Crossroad to S. Lorenzo-Brucella: Metamorphites of Sillimanite + K-feldspar zone. Banded migmatites.

Along the bank of the road to S. Lorenzo-Brucella, just to the south of S. Lorenzo, typical stromatic migmatites are exposed. Gneisses of variable grain size and biotite-content alternate with leucocratic bands (constituted by quartz, plagioclase, biotite, muscovite, sillimanite) and with melanocratic layer richer in biotite and sillimanite.

On similar banded migmatites cropping out near Brucella, a Rb/Sr isochron, constructed using the different layers, yielded an age of 344 ± 7 Ma, possibly representing the climax of the Hercynian metamorphism.

Rare grey-green, fine-grained nodules and pods are present in the migmatites; they are amphibole-rich rocks which preserve remnants of an original anhydrous paragenesis constituted by clinopyroxene, garnet and plagioclase.

We return to the main road and after a few kilometres we take a secondary road to the sea.

--- Stop 5.10 - Punta Batteria - P. dell'Asino: Migmatites and associated rocks of Sillimanite + K-feldspar zone.

Along the coast between Punta dell'Asino and Punta la Batteria, one of the most typical sequences of the migmatitic complex of the Sillimanite + K-feldspar zone is exposed.

Proceeding towards the north, we encounter different lithologic types:
- Biotite-sillimanite mesocratic gneisses;
- stromatic migmatites with rare Ca-silicate lenses;
- stromatic migmatites with abundant leucosomes and mesocratic gneisses and Ca-silicate lenses and nodules;
- Granodioritic orthogneisses.

From the structural point of view, there is a regional schistosity (S2) trending about E-W and dipping towards the south. Mesoscopic evidence of pre-S2 fissions are scaly; whereas late folds, without axial plane foliation and different geometry (kink, box, chevron) are abundant.

Biotite-sillimanite mesocratic gneisses in the outcrop of Punta dell'Asino show, on the foliation plane, abundant iso-oriented rods constituted by quartz and fibrolitic sillimanite.

Leucosomes are rare in this outcrop, whereas they are abundant near Mt. Rasu, where they reach 1 m. in thickness. These leucosomes are sometimes garnetiferous with aplogranite composition and parageneses which includes Qtz + Pl + Kfs + Grt + Bt + Sil ± Ms. Associated mesocratic gneisses are lacking in K-feldspar and contain, together with Qtz + Pl + Bt + Ms + Grt + Sil, some relics of kyanite.

Near Mt. Rulj, mesocratic gneisses are partially lacking in leucosomes, but contain abundant Ca-silicates nodules. These nodules have a foliated shape and are finely fractured and lack in any fission. They show concentric zoning; the light green to pink core consists of Qtz + Pl + Cpx + Grt; the green to dark green rim is characterized by the increase of the amount of hornblende and sphene, instead of Cpx + Grt.

The granodioritic orthogneisses crop out near Mt. Nuraghe. It shows augen to banded structure and is relatively homogeneous containing only some mafic inclusions trending E-W.

Both on petrographic and chemical grounds it is quite similar to the granodioritic orthogneisses of Lodé (see stop 5.6) and plot on the same Rb/Sr whole rock isochron of 458 ± 31 Ma.

We return to the "Orientale Sardo" and continue northwards until the crossroad for the touristic village of Punta Ottiolo. The mountains on the left are composed of migmatites with rare lenses of marble or calc-silicate rocks.

--- Stop 5.11 - Punta de Il Tulchì: Metamorphites of Sillimanite + K-feldspar zone. Migmatites, calc-silicate nodules, and masses and lenses of retrogressed eclogites.

Along the coast, the migmatites of Sillimanite + K-feldspar zone are clearly visible. Leucocratic bands of variable size consisting of quartz, plagioclase, K-feldspar, biotite ± sillimanite ± muscovite are repeatedly altered both with very biotite-rich gneisses and with rarer augen-gneisses. The differentiation of leucosomes has undergone a considerable evolution: in some places the stripped or banded structures disappear and the rock loses the regular layering.

The morphology of the folds which refold the migmatitic layering, gives evidence of the ductile behaviour of the rocks even during the later deformation phases.

Also these migmatites contain green-grey nodules and pods (5-30 cm) as we have seen during the previous stop.

Near Punta de Il Tulchì, small masses of eclogite rocks crop out within the migmatitic complex.

Such eclogite rocks, probably constituted by an early omphacite-pyroxene association, appear to have been greatly retrogressed through a successive recrystallization, under amphibolite facies conditions, which caused the development of hornblende and symplectite structures (hornblende-salite) amphibole-plagioclase hydrous plagioclase.

Along the road to Olbia the ria coast is constituted by pyroxenite leucogranites. Some rounded pebbles of metamorphic rocks, like those we will visit at the next stop between Olbia and Golfo Aranci, are present.

--- Stop 5.12 - M.Giu Niedda - Golfo Aranci: Migmatites and metasabulites with relics of granulite paragenesis.

A large mass of plagioclase- and ultramafic-amphibolites (olivine melagabbros on normative basis) crops out on the inside of heterogeneous migmatitic rocks. In ultramafic terms, some
anhydrous phases of granulite facies environment (olivine, garnet, orthopyroxene, clinopyroxene) coexist in structural disequilibrium with other phases (hornblende, spinel, chlorite) of amphibolite facies. Also in the migmatic, microstructural evidence indicates that the widespread Hercynian recrystallization in amphibolite facies affected rocks already containing high grade anhydrous minerals (kyanite, orthoclase, garnet).
Finito di stampare nel mese di Maggio 1986 presso le Officine Grafiche della Pacini Editore FISA