CARMIGNANI LUIGI

IGCP
PROJECT N. 5
CORRELATION OF VARISCAN AND PRE-VARISCAN EVENTS
OF THE ALPINE-MEDITERRANEAN MOUNTAIN BELT
FINAL MEETING, SARDINIA, MAY 26-31, 1986

NEWSLETTER, *special issue*

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 COCOZZA, Claudio GHEZZO and Carlo Alberto RICCI
Dipartimento di Scienze della Terra - Università di Siena
Via delle Cerchia, 3 - 53100 Siena - Italy

PACINI EDITORE - PISA

ON THE COVER: The sharp unconformity (Sardic phase) located about 1 km south Nebida village, southwestern Sardinia, shows strongly dipping Cabitza shale, overlying sub-vertical Lower Ordovician conglomerates («Puddinga» Auct.). Overturning and N-S trending schistosity was produced by the Hercynian orogenesis (*Photo taken by* V. PALMERINI).

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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

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CONTRIBUTORS

L. Carmignani, M. Franceschelli, M. Gattiglio, A. Moretti, P.C. Pertusati — Dipartimento di Scienze della Terra - Via S. Maria, 53, 56100 PISA

T. Cocozza, F.M. Elter, A. Gandin, C. Ghezzo, I. Memmi, C.A. Ricci — Dipartimento di Scienze della Terra - Via delle Cerchia, 3, 53100 SIENA

S. Barca — Dipartimento di Scienze della Terra - Via Trentino, 51, 09100 CAGLIARI

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

G. Oggiano — Istituto di Scienze Geologico-Mineralogiche - Corso Angioi, 10, 07100 SASSARI

I. Salvadori, I. Uras — Istituto di Giacimenti Minerari - Piazza d'Armi, 09100 CAGLIARI

P. Zuffardi — 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 Sardinia 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 partecipants 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 Sardinia, 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. Ceccherelli, G.P. Cherchi, A. Di Pisa, M.C. Falletti, M.L. Frezzotti, M. Moracchioli, G. Musumeci, P. Palagi, R. Palmeri, E. Sarria, R. Serri, I. Temussi.

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

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

Pisa - Siena, April 1986.

Part 1 - General Features

Guide-book to the Excursion on the Paleozoic basement of Sardinia
IGCP project no. 5 - Newsletter 1986, special issue, 11-21

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

OUTLINES OF THE HERCYNIAN BASEMENT OF SARDINIA

L. CARMIGNANI, T. COCOZZA, C. GHEZZO, 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 Tournaisian terrains (OLIVIERI, 1969) are deformed and slightly metamorphosed, whereas the Upper Carboniferous sediments cover unconformably the metamorphosed Paleozoic sequences (COCOZZA, 1967; DEL RIO, 1973). The radiometric age of the Gallura migmatites in 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, tectono-metamorphic zoning and shortenings similar to those developed in continent-continent collision type orogeny (CARMIGNANI *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 migmatites in the northeastern of the island (DI SIMPLICIO *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 Sàrrabus, and the «Axial zone», in the northeast part of Sardinia.

1. *External Zone (South-Western Sardinia)*

The oldest paleontologically dated formations crop out in South-Western Sardinia: Nebida, Gonnesa, 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 (COCOZZA *et al.*, 1972; COCOZZA & LEONE, 1977; JUNKER & SCHOERSCHER, 1979; JUNKER & SCHNEIDER, 1979; NAUD, 1979) consisting of a basal complex constituted by polymetamorphic micaschists («Micascisti di Monte Settiballas»: MINZONI, 1981) and by orthogneisses («Gneiss di Capo Spartivento AUCT.») deriving from acid magmatites of crustal origin (Sr^{87}/Sr^{86} = 0,7122 ± 0,0058: SCHARBERT, 1978) with a radiometric age of 427 ± 34 Ma (COCOZZA *et al.*, 1977; 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 & SCHNEIDER, 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 Settiballas 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 (Sardic phase of STILLE, 1939) by polygenic metaconglomerates («Puddinga») and metasandstones (fig. 2), passing gradually upwards to Upper Ordovician fossiliferous metasediments composed of original siltites and argillites with lenses of encrinites and rare volcanic intercalations (COCOZZA & LEONE, 1977).

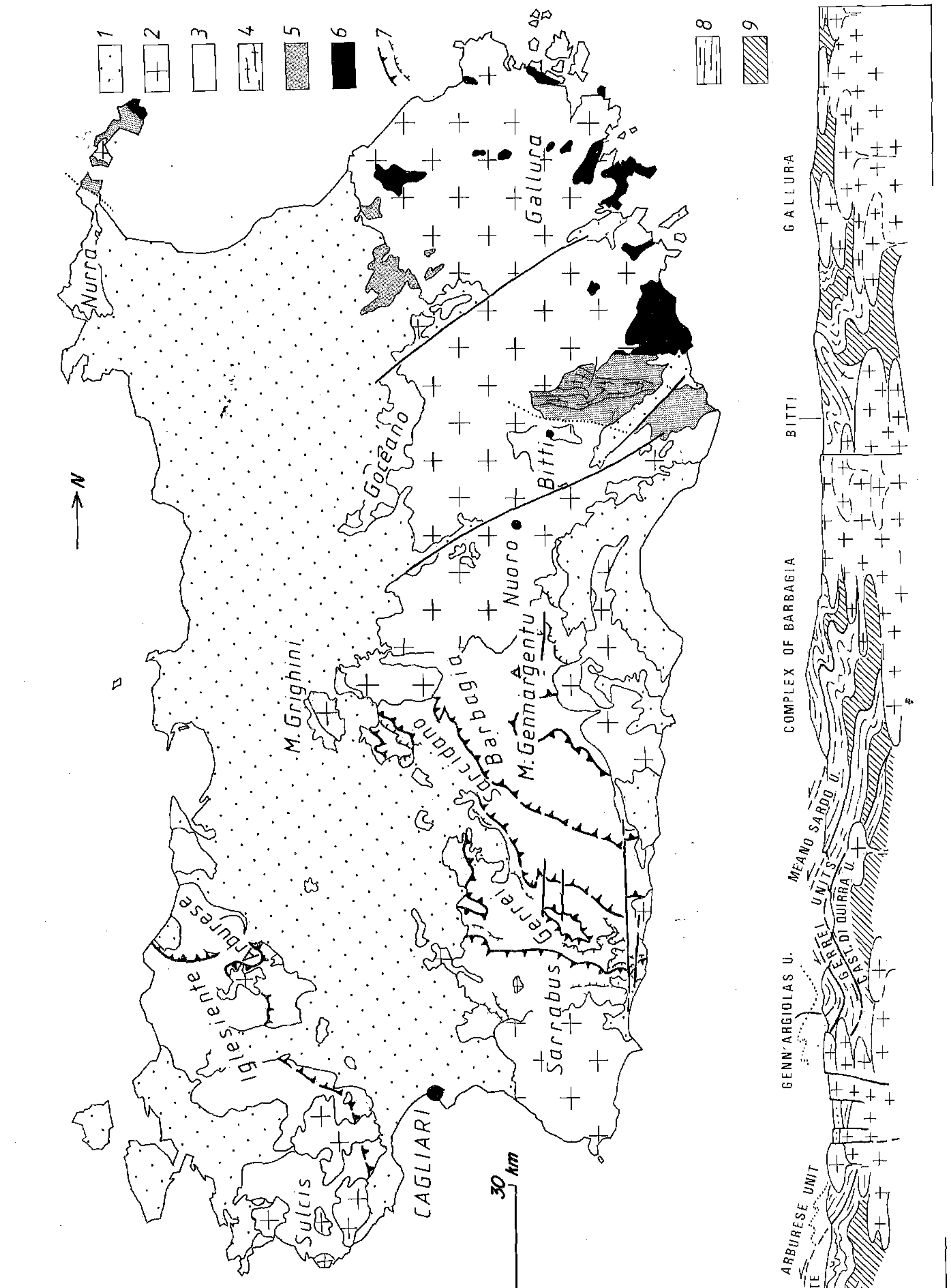


Fig. 1 - Synthetic structural sketch of Sardinian basement. 1: Post-Hercynian sediments and volcanites; 2: Granitoids; 3: Very low (south-west Sardinia) to low-grade metamorphites; 4: Main orthogneiss outcrops; 5: Intermediate-pressure amphibolite facies metamorphites; 6: Intermediate-pressure amphibolite facies migmatites containing nodule and lenses of rocks carrying relics of granulitic and seldom eclogitic parageneses; 7: Major and minor overthrusts; 8: Hercynian covers: 9: Pre-Hercynian basement (?).

The sequence continues with carbonaceous schists containing graptolites and lenses of «*Orthoceras* limestones» (Silurian) and then «tentaculites 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 («Postgotlandian» *Auct.*) in which early Ordovician acritarchs 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 area» of the allochthonous units of central Sardinia, overthrusting the outermost part of the Hercynian chain.

In Iglesiente, the Sardic phase age is now well dated by a clear angular unconformity located between Arenigian, the age of the top of the Cabitza Formation (BARCA *et al.*, 1986) and Caradocian, the age of the well-known paleaontological horizons of the whole Sardinian Paleozoic: the span of this phase probably includes both Llanvirnian and Llandeilian, 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 «dome 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; TARICCO, 1926-30; POLL & ZWART, 1964; POLL, 1966; BRUSCA & DESSAU, 1968; ARTHAUD, 1970).

This sequence, with strongly dipping schistosity, is overlain to the east and north-east by allochthonous formations, including the early 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, 1979a; NAUD, 1979), must therefore be moved further south-west, between Arburese and Iglesiente. Ongoing 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 Sarrabus and Barbagia granites (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-Ashgillian) and Silurian are always fossiliferous (fig. 2). Upper Ordovician consists of metasandstones, carbonatic phyllites, and fossiliferous and often silicified metalimestones. Silurian contains rocks ranging from «lidite» to graptolite-bearing carbonaceous schists with lenses of «*Orthoceras* limestones». These sequences are locally covered by metalimestones, again intercalated with carbonaceous schists or Devonian nodular metalimestones containing tentaculites and clymenies above which Lower Carboniferous is also found (OLIVIERI, 1979; SPALLETTA, 1982). The Upper Ordovician-Devonian interval is thus paleontologically well documented, and is composed of a more or less constant series over the whole southern Sardinia on both sides of Campidano rift valley. These formations cleary show the polarity of the series and tectonic repetition.

Silurian effusive metabasites and more frequent intrusive rocks (metagabbros) suggest the presence of a mafic magmatic 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 metasandstones alternating with meta-argillites and metasiltites, 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 (TONGIORGI *et al.*, 1984) we can establish that these rocks are coeval with some of the sequences affected by the Sardic phase in Iglesiente.

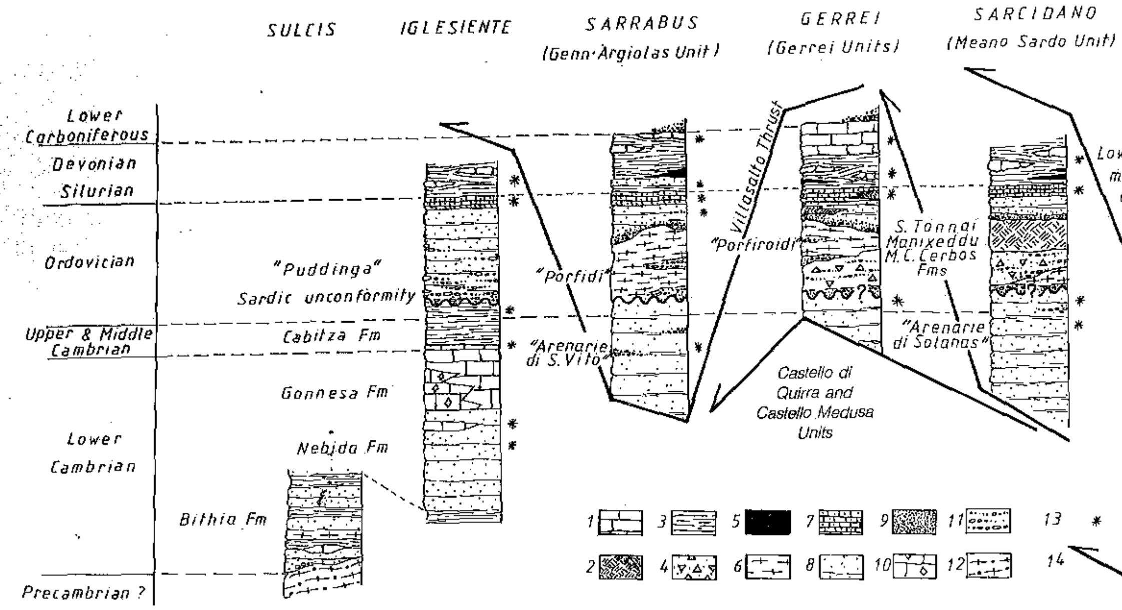


Fig. 2 - Scheme of the Paleozoic sequences and their tectonic relationships.
1: Metalimestones; 2: Metavolcanites with intermediate chemical characters; 3: Slates and schists; 4: Metamorphic products of reworked volcanites; 5: Alkaline metabasites; 6: Metarhyodacites and metarhyolites with «augen texture» and sometimes with large «phenocrysts» of K-feldspar («Porfiroidi» of Gerrei); Metarhyodacites and metarhyolites weakly deformed, with minor intermediate-type metavolcanites («Porfidi grigi» and «Porfidi bianchi» of Sàrrabus); Metarhyolites and metarhyodacites of Mt. Corte Cerbos Fm of Sarcidano, etc.); 7: Carbonatic metasiltites and metalimestones often silicified, of Upper Ordovician age; 8: Metasandstones; 9: Metarkoses; 10: Dolostones; 11: Metaconglomerates; 12: Capo Spartivento orthogneiss and Settiballas micaschists; 13: Fossils; 14: Tectonic contacts and vergence of overthrusts.

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 Sardinia. This volcanic cycle, which occurred between Arenigian and Caradocian, consists in a great number of mainly effusive episodes accompanied by intrusions into the thick prevolcanic basement. The sharp lateral variability in thickness and the different composition and nature of the products determine the remarkable stratigraphic differences which are locally observable in various areas.

The most widespread rocks are original acid porphyritic lavas and rhyodacitic-rhyolitic ignimbrites, subordinate andesite-dacite volcanics and basalts.

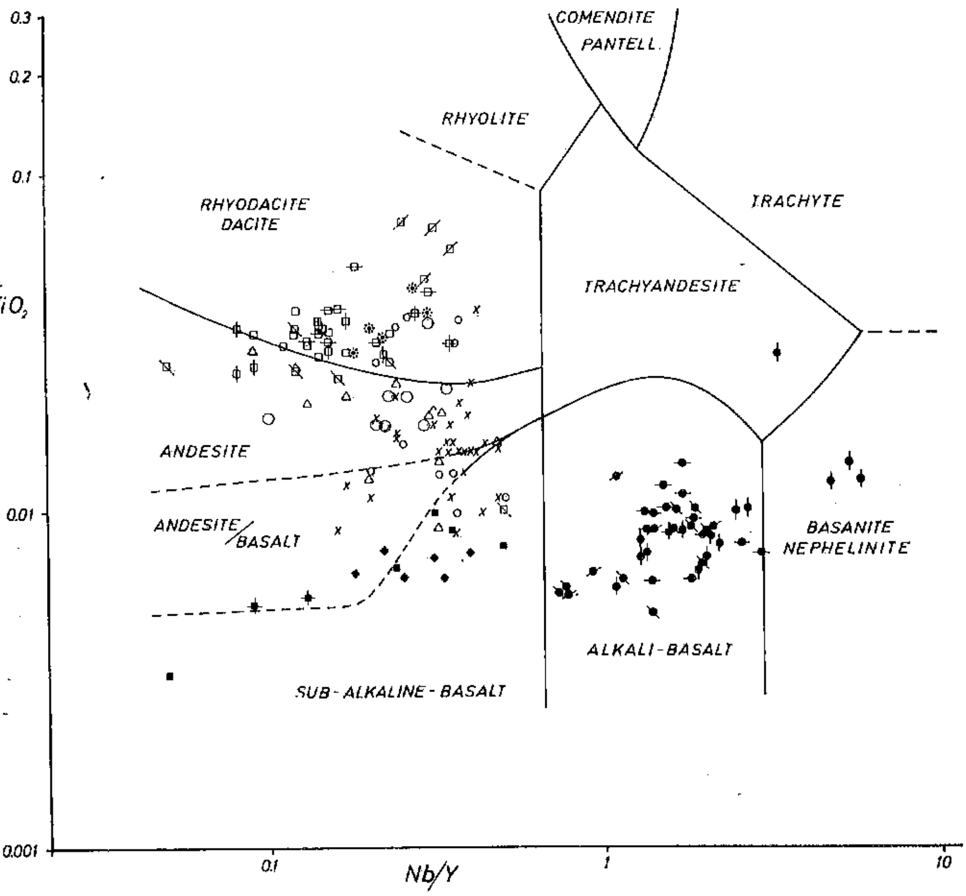
On the basis of geochemical studies performed on igneous derived products within the metasedimentary sequences of the whole Sardinia (fig. 2) Memmi *et al.* (1982, 1983) pointed out:

— 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 composition from basalt to rhyolite of clear subalkaline affinity, comparable to that of products of postorogenic igneous activity on the continental margin (fig. 3).

In the Sàrrabus region, the volcanic complex lies unconformably on Cambrian-early Ordovician metasandstones, with interposed metaconglomerates (Calvino, 1961). This contact is marked by metaconglomerates. In other localities of Central Sardinia although unconformities have never been reported; this may be due to the difficulty of revealing angular unconformities in strongly deformed metamorphites, or that the Caledonian deformations become increasingly less important from southwest 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 metamorphism in greenschist facies (chlorite zone, with the occurrence of biotite in the deepest tectonic units of the nappe-pile).



1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 - 11 - 12 - 13 - 14 - 15 - 16 - 17 - 18 -

Fig. 3 - Nb/Y-Zr/TiO_2 diagram (after Winchester & Floyd, 1977) for the pre-Hercynian igneous products of Sardinia (from MEMMI *et al.*, 1983).
1: «Porfidi bianchi» and «Porfidi grigi» from Sarrabus; 2: Andesite-rhyodacitic metavolcanics from lower Flumendosa Valley (Gerrei); 3: «Porfiroidi» from Gerrei; 4: Andesite-rhyodacitic metavolcanics from Sarcidano-Salto di Quirra (Serra Tonnai Formation); 5: Metarhyolites from Sarcidano-Salto di Quirra (Monte Corte Cerbos Formation); 6: «Porfiroidi» from Sarcidano-Salto di Quirra; 7: «Porfiroidi» from Goceano; 8: Volcanic metagraywackes and metatuffites from Goceano; 9: «Porfiroidi» from Nurra; 10: Augen-gneisses (metarhyolites) from Gallura (441 ± 31 Ma.); 11: Granodioritic orthogneisses from Gallura (458 ± 31 Ma); 12: Metabasalts from Iglesiente; 13: Metabasalts and minor metagabbros from Sarcidano-Salto di Quirra; 14: Metabasites from Goceano; 15: Metabasalts and metagabbros from Nurra; 16: Amphibolites from Torpè; 17: Amphibolitized mafic granulites from Gallura; 18: Retrogressed eclogites from Gallura.

The first folding synmetamorphic phase produced almost ubiquitous penetrative schistosity and recumbent isoclinal folds. It was followed by regionally important overthrusts and «late» folding phases, without blastesis, which produced much smaller shortenings (CARMIGNANI & PERTUSATI, 1977; NAUD & TEMPIER, 1977).

The overthrusts make up the dominant structural character of this belt. The deepest Units (Gerrei, Castello di Quirra and Castello Medusa Units) crop out at the axial culmination of an antiform of nappes that extends from the Lower Flumendosa valley through the Mandas area, reaching as far as the Grighini Mountains (fig. 1).

The Gerrei Units are overlain to the south by the Genn'Argiolas Unit, including almost all the Sàrrabus, and to the north by Sarcidano-Salto di Quirra Units. The latter, together with the Arburese Unit may form a single allochthonous complex stepping over the Gerrei Units, and overthrusts the most external part of the chain (Arburese Unit) (fig. 1 and 2).

The innermost units are composed of the metamorphic complex of the Barbagia 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 metamorphic 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 Nurra, Goceano, Gennargentu Mountains) and those of the more external area (Sarcidano, Gerrei, Sàrrabus).

In the latter, the overthrusts cut the first-phase folds and produce 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 occurr 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, Goceano, Gennargentu Mountains) present a typical 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 (S_1).

In the whole of the «central belt», first-phase folds 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 culminations of the antiforms (where the upper and deeper tectonic units, respectively, crop out).

3. *Axial Zone (Northern Sardinia)*

The highest-grade metamorphites and the largest late - Hercynian intrusions crop out in Northern Sardinia.

From the tectono-metamorphic point of view «Northern Sardinia» means that part of the basement lying NE of the Stintino-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 (FRANCESCHELLI *et al.*, 1982 a e b).

The high-grade metamorphism and the complex structural setting lead to some difficulties in reconstructing the original stratigraphic sequences. However, the presence of metarhyolites, «Porfiroidi», rhyolitic augengneisses (441 ± 33 Ma), granodioritic orthogneisses (458 ± 31 Ma), within plate alkaline metabasites, graphitic phyllites and micaschists, calc-schists and marbles, suggest that this basement was at least partly constituted by sequences similar to those cropping out in Central-Southern Sardinia and dated paleontologically to the Ordovician and Silurian-Devonian age (CARMIGNANI *et al.*, 1982c).

On the other hand, the presence within the migmatites of the Sillimanite + K-feldspar zone of nodules and lenses of mafic rock, containing relics of eclogitic and/or granulitic parageneses, suggests the possible existence of an old basement (MILLER *et al.*, 1976; GHEZZO *et al.*, 1979, 1982).

Without excluding the presence of an old basement, the gradual and continuous passage in the Nurra region (as regards both structure and metamorphism) between the low-grade zone (dated paleontologically) and the medium-grade one, and the radiometric dating of a banded migmatite (344 ± 7 Ma) suggest that the basic character of this basement was determined by the Hercynian tectono-metamorphic event (CARMIGNANI *et al.*, 1979a; FERRARA *et al.*, 1978).

Three main folding phases (D_1, D_2, D_3), accompanied and followed by mineral growth, may be distinguished and chronologically correlated with the Hercynian phases of deformation of Central-Southern Sardinia (CARMIGNANI & PERTUSATI, 1977).

The relation between deformation and metamorphism studied in detail in Nurra can be taken as an example of the tectono-metamorphic evolution of North-Eastern Sardinia, since preliminary results indicate similar evolution in all the other areas (CARMIGNANI *et al.*, 1979a; FRANCESCHELLI *et al.*, 1982a).

The first, most intense, tectonic phase led to large-scale crustal shortening, with isoclinal folds overturned SW, flow schistosity and syn- to postkinematic metamorphism increasing in grade in a northerly direction.

The second E-W trending phase of deformation produced folds that gradually become tighter northwards, indicating a progressive increase in deformational strength. Metamorphism linked with this tectonic phase is well developed in the higher grade zones only.

The third phase preserves a relatively constant style and trends throughout Sardinia, producing only kinks and open folds with N-S axes.

Metamorphism in the «Axial zone» consists of an episode of prograde metamorphism (termed M_1) ranging northward from the Chlorite to the Sillimanite + K-feldspar zone, and a retrograde metamorphic episode.

The prograde metamorphic episode (M_1) took place during and after the first phase of deformation (D_1), the second (M_2) during and after the second phase (D_2), and they seem to reflect a continuous tectono-metamorphic evolution (FRANCESCHELLI *et al.*, 1982a).

The analysis of the mineralogical association encountered in the pelitic-psammitic schists, in relation to topologic variation in the simplified systems K_2O-Al_2O_3-FeO-MgO-SiO_2-H_2O and CaO-Al_2O_3-SiO_2-H_2O, has led to the definition of a prograde zoning that, moving northeastwards, includes the following metamorphic zones: Chlorite; Biotite; Garnet + Albite; Garnet

+ Albite + Oligoclase; Staurolite + Biotite; Kyanite + Biotite; Sillimanite + Muscovite and Sillimanite + K-feldspar (FRANCESCHELLI *et al.*, 1982a and b).

The mineralogical associations appear to be similar to those described for other areas affected by Barrovian-type metamorphism.

The diachroneity of development of metamorphism is noteworthy: in the low to medium grade zones mineral index as well as the most parageneses formed during the first tectono-metamorphic phase (D_1 + M_1); in the high grade zones the main parageneses grew during or after the second tectono-metamorphic phase (D_2 + M_2) (ELTER *et al.*, 1985).

Radiometric data indicate that the entire «polyphase» metamorphic evolution of the Hercynian metamorphism of North Sardinia probably took place in a time interval between 344 and 310-290 Ma (FERRARA *et al.*, 1978).

The structural and metamorphic characteristics support the view that considers northern Sardinia and its prolungation into central-southern Corsica as the «axial zone» of the Sardinian-Corsican segment of the Hercynian chain (CARMIGNANI *et al.*, 1979b).

LATE- TO POST-HERCYNIAN IGNEOUS ACTIVITY

1. *The Hercynian Batholith*

During or after the late Hercynian tectono-metamorphic events, the basement was extensively invaded by hundreds of plutons in more than 25 Ma (from at least 310 Ma to about 280 Ma). This plutonic complex constitutes the southern part (about 6.000 sq.km) of the Sardinian-Corsican batholith.

The intrusive sequence (DI SIMPLICIO *et al.*, 1974; ORSINI, 1980; BRALIA *et al.*, 1982) is composed as follows (GHEZZO & ORSINI, 1982):

— *syn-tectonic intrusions* (about 1-2% of the batholith) made up of small bodies and dikes of strongly foliated biotite or two-mica peraluminous granites, granodiorites and tonalites associated with the highest-grade metamorphites of the «Axial zone», or with the Mt. Grighini shear zone in the «Nappe zone» of the Hercynian chain (GHEZZO & ORSINI, 1982; CARMIGNANI *et al.*, 1985; DI PISA & OGGIANO, 1985).

— *Late-tectonic intrusions* (about 74% of the batholith). The older plutons (about 9%; 307 ± 6 Ma and $^{87}Sr/^{86}Sr_i$ = 0.7099) consist of tonalites and tonalitic granodiorites with marked flow structures. These intrusions, often with a foliated fabric, contain abundant mafic microgranular igneous inclusions and show contacts sometimes concordant with the metamorphic rocks.

The younger plutons (302 ± 5 Ma and $^{87}Sr/^{86}Sr_i$ = 0.7107), clearly discordant in the metamorphic cover, are mainly composed of monzogranitic granodiorites, biotite-bearing monzogranites, and biotite-bearing leucocratic monzogranites. The mafic microgranular igneous inclusions are less abundant and their amount decreases with the increase in acidity.

Minor cordierite-bearing monzogranites and two-mica leucogranites of uncertain age are also present.

The granitoids of this group sometimes contain small gabbro-tonalitic bodies (generally amphibolic gabbros, more or less quartz-bearing). Both the mafic igneous inclusions and the mafic plutonic bodies are considered to be derived from subcrustal subalkaline mafic magmas that underwent interaction processes at various degrees with the acid ones of infracrustal anatectic origin (hydration, chemical interaction, mixing, commingling).

— *Post-tectonic intrusions* (about 25% of the batholith). These are made up of pinkish biotite-bearing leucogranites (289 ± 1 Ma; $^{87}Sr/^{86}Sr_i$ = 0.7085, DEL MORO *et al.*, 1975), definitely discordant and practically lacking in mafic igneous inclusions. Their chemical composition shows a «minimum melt» character. They are present both in the «Axial zone» and the «External» one, and were emplaced at high crustal levels and post-dated all the tectono-metamorphic events and the regional uplift of the crystalline basement. The widespread «porphyry type» Mo-W mineralizations are linked to these younger granites (GHEZZO *et al.*, 1982; GUASPARRI *et al.*, 1984).

— *Syenites* - In southern Sàrrabus some small stocks (max. a few sq. Km) of syenites crop out. Mineralogical and chemical features indicate sodic alkaline affinity (BROTZU *et al.*, 1978). These stocks are intruded into calc-alkaline granodiorites and are intersected by late-Hercynian dikes. Their radiometric age has not yet been defined.

The whole tectono-magmatic cycle is characterized by a clear evolution within an ensialic context from the syn- to late-tectonic tonalite-monzogranite intrusions (with a general calc-alkaline character and emplaced in a compressive environment during the late orogenic stages) to the younger post-tectonic leucogranites (emplaced under a tensional tectonic regime after the rapid regional uplift).

On the basis of field relations, petrographical, chemical and isotopic data, and volume ratios of the different granite types (most plutonites are granodiorites, monzogranites and leucogranites) it results that two main contrasting granite associations coexisted in time and space, the I- and S- types of CHAPPELL & WHITE (1974). The former corresponds to the tonalite-granodiorite-monzogranite association, and the latter to the two-mica and/or cordierite-bearing granites. But for the Sardinian batholith some data point out a marked difference in comparison to other European Hercynian plutonic complexes («Hercynotype» association; PITCHER, 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 PITCHER (1983).

A polygenic origin of the whole batholith is assumed, that is a sub-crustal origin for the mafic magmas; an anatectic intracrustal origin for the granitic ones (which underwent successive local differentiation processes through fractional crystallization); and a hybrid origin by interaction between sub-crustal and crustal magmas for the tonalitic-granodiorite rocks (ORSINI, 1980; BRALIA *et al.*, 1982; COCHERIE, 1984).

2. *The Dike Complex*

A dike swarm cuts the Hercynian basement and locally, its Permian cover. It is composed of acid dikes (aplites and granitic to granodioritic and tonalitic porphyries) mainly related to the Carboniferous plutonic complex and to the Permian calc-alkaline magmatism, and of basic dikes (diabases 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 (~ 280-286 Ma: LOMBARDI *et al.*, 1974; COZZUPOLI *et al.*, 1984; BECCALUVA *et al.*, 1985). As regards its composition this post-orogenic volcanism ranges from minor andesite to rhyolitic and rhyodacitic lavas and ignimbritic flows extending at present for 300 sq.km. The tectono-petrogenetic meaning of this magmatism is not yet clear (BONIN, 1983).

CONCLUDING REMARKS

The available data on the Caledonian events prove the occurence of tectonic deformation (Sardic phase) (BARCA *et al.*, 1984) followed by large-scale magmatism of post-orogenic type (MEMMI *et 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 to post-kinematic intrusions. Considering the tectono-metamorphic zoning along a SW-NE cross-section, it is noteworthy that the regular distribution of the tectonic style and metamorphic zones proceeding from the «External zone» through the «Nappe zone», to the «Axial zone» is quite similar to those of many other orogenic belts.

Similar «zoning» also occurs in many southern European Hercynian massifs, from Maures Massif to Iberian Meseta, where large-scale tangential tectonics have been described (ARTHAUD & MATTE, 1966; 1977; MATTE, 1968; ARTHAUD *et al.*, 1969; ARTHAUD, 1970; WESTPHAL *et al.*, 1976; etc.).

The lack of ophiolitic associations (RICCI & SABATINI, 1978; MEMMI *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 entirely ensialic 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 & MCQUILLAN, 1971; BIRD & TOKSOZ, 1975; LEFORT, 1975; PECHER, 1975; MATTAUER, 1975; AMODIO-MORELLI *et al.*, 1976; MILNES, 1978, etc.), as for some European Hercynian chains (MATTAUER, 1974; CARME, 1974; MATTAUER & ETCHECOPAR, 1976; BOURROUILH, 1980).

This geodynamic model is also supported by many minor structural elements (sub-horizontal penetrative schistosity, extensive lineations, style of folds, etc.) and many large-scale structural traits (regional overthrustings, basement remobilization, etc.). It also satisfactorily explains the relations between the deformation and the metamorphism of the «north-eastern belt» (see CARMIGNANI *et al.*, 1979a, b; FRANCESCHELLI *et al.*, 1982a).

In the author's opinion, the model of CAR-

MIGNANI *et al.* (1979b), which proposed substantially unitary evolution for the Sardinian Hercynian chain, developing across multiple shear zones between an «External zone» to the south-west and «Axial zone» to the north-east, is still valid.

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Guide-book to the Excursion on the Paleozoic basement of Sardinia IGCP project no. 5 - Newsletter 1986, special issue, 23-25

THE PALEOZOIC METALLOGENESIS OF SARDINIA IN RELATION TO ITS GEOLOGICAL EVOLUTION

I. Salvadori, I. Uras & 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 shelf known as the «Gonnesa Formation». In fact both this formation and the underlying «Punta Manna Member» are made up of alternating pelitic, siltitic and carbonatic rocks, and contain various galena, blende, pyrite, and barite concentrations of the «strata-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 Gonnesa Formation, prevalent diffuse blende («blendous limestone» as the miners say) in the central part and prevalent galena in the higher part of the latter 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 *Punta Candiazzus* for barite; *Campo Pisano* for blende and pyrite; *S. Giovanni, Nebida* and *Masua* for prevalent blende with galena; *Monteponi* for prevalent galena with blende. It has, however, to be pointed out that their present shapes and consistences result from subsequent re-concentration processes.

The Cambrian-Ordovician orogenesis caused some parts of the carbonatic shelf 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 connection with various types of underwater volcanic activity and with the frequent establishment of sedimentary environments of the «black shale» type, variously composed ores were generated; more precisely (i) mixed sulphide complexes; (ii) antimonite and scheelite; (iii) silver with blende and galena in fluorite gangue (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 (Fluminese area), the north-western corner of the Island (Nurra district). The most typical deposits are: Correboi and Funtana Raminosa (partim) for mixed sulfide complexes, Ballao and Villasalto for antimonite and scheelite; Monte Narba, Masaloni, Giovanni Bonu, Baccu Arrodas, Tuviois (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; Schneider, 1972.

The Hercynian orogenesis and related intrusion of the granitoidal 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-

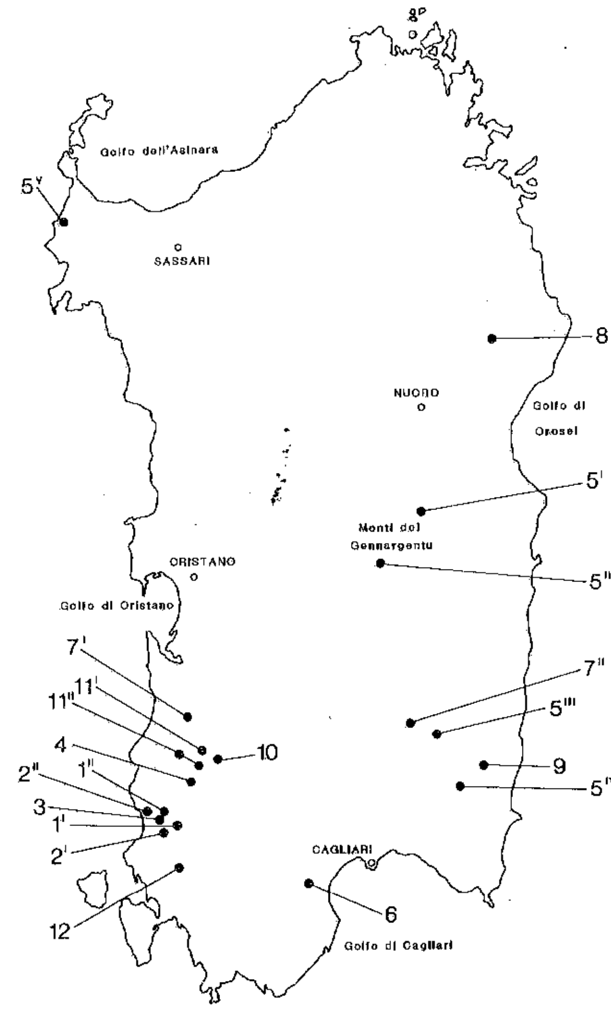

Fig. 1 - Main deposits in Sardinian Paleozoic.
1: Campo Pisano (1': FeS_2, ZnS), Punta Candiazzus (1'': $BaSO_4$); 2: San Giovanni (2': ZnS, PbS), Nebida, Masua (2'': ZnS, PbS); 3: Monteponi (PbS, ZnS); 4: Arenas partim (PbS, ZnS); 5: Correboi (5': mixed sulfides), Funtana Raminosa partim (5'': mixed sulfides), Ballao, Villasalto (5''': Sb_2S_3, $CaWO_4$); Monte Narba, Masaloni, Giovanni Bonu, Baccu Arrodas, Tuviois (5IV: Ag, ZnS, PbS, CaF_2), Canaglia della Nurba (5V: oolitic iron); 6: San Leone (Fe_3O_4); 7: Montevecchio, Ingurtosu, Gennamare (7': PbS, ZnS), Silius (7'': CaF_2, $BaSO_4$, PbS); 8: Monte Albo (ZnS, PbS) and — not located in the map of fig. 1 — Central-Eastern Sardinian laterites; 9: Baccu Locci partim (mixed sulfides); 10: Perda Lada (MoS_2); 11: Perda è Pipera (11': MoS_2), Monte Mannu and Perdu Cara (11'': SnO_2, ZnS, $CuFeS_2$); 12: Barega ($BaSO_4$).

ly useful pegmatites, and the genesis of ore bodies of the greisen, skarn and pneumatolitic-hydrothermal types (by remobilization, at least in some cases). The Hercynian metallogenic province covers all of East Sardinia, the South-Western and a small part of the North-Western sector.

The most typical examples are: for the skarn type ARENAS partim and S. LEONE DEL SULCIS (Fe_3O_4); for the greisen type, PERDA LADA (MoS_2); for the pneumatolytic - hydrotermal veins, PERDU CARA, MONTE MANNU (SnO_2, ZnS, $CuFeS_2$), PERDA È PIPERA MoS_2); for the hydrothermal veins, MONTEVECCHIO, INFURTOSU, GENNAMARE (PbS, ZnS), SILIUS (prevalent CaF_2 with $BaSO_4$, PbS, and some ZnS); for remobilizations, FUNTANA RAMINOSA, partim (mixed sulfides).

The emersion of the Paleozoic in consequence of the Hercynian orogenesis and its peneplation have had various metallogenic effects; more precisely:

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

(ii) formation of sulphide accumulations in the erosion channels of the post-Hercynic peneplane (MONTE ALBO and — partim — BACCU LOCCI);

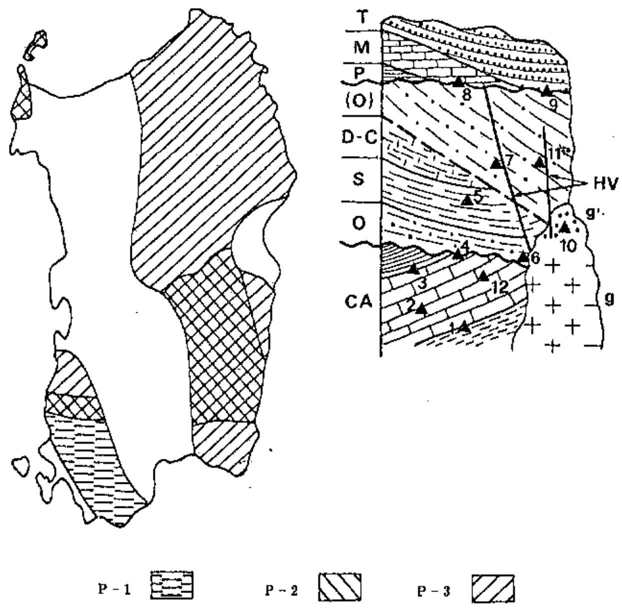

Fig. 2 - Paleozoic metallogenic epochs and provinces in Sardinia.
Simplified stratigraphic sequence: T = Tertiary; M = Mesozoic; P = Permian; (O) Overthrusted Lower Paleozoic (mainly Ordovician); D-C: Devonian - Carboniferous; S = Silurian (partly Devonian ?); O = Ordovician; CA = Cambrian; g = Hercynian granitoids and related metamorphic auteolas; g' = Hercynian greisens; HV = Hercynian vein type mineralizations.
Metallogenic provinces and related metallogenic epochs: P 1: A, B, D, E; P 2: C, E; P 3: D, E.
Metallogenic epochs and related metallogenic events: A = Cambrian: pre- and proto- concentrations of 1, 2, 3; B = Cambro-Ordovician: pre- and proto- concentrations of 4; C = Silurian (-Devonian ?): formation of 5; D = Hercynian Orogeny and Magmatism: formation of 6,7; also remobilization/reconcentration of pre-existing pre-/proto-concentrations (2, 3, 4, 5); E = Post-Hercynian Peneplanation: residual concentration (8); also supergene remobilization/reconcentration of pre-existing pre-/proto-concentrations (2, 3, 4, 5, 9).

(iii) formation of karstic barite accumulations with or without galena by remobilization of the pre-concentrations in the Gonnesa Formation. BAREGA 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 reconcentrations 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 reconcentration are still in progress. This is what caused the eluvial barite concentrations of industrial interest in the present soils around outcroppings of poor barite deposits; in some cases the mineralized harstic system are controlled by the present hydrostatic level (BAREGA).

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. Fig. n. 2 is a simplified scheme of the distribution in time of the metallogenic epochs and of the spatial distribution of the related provinces.

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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 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 Palezoic 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 - Sàrrabus
Day 3 - Gerrei
Day 4 - Barbagia
Day 5 - Northern Sardinia

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

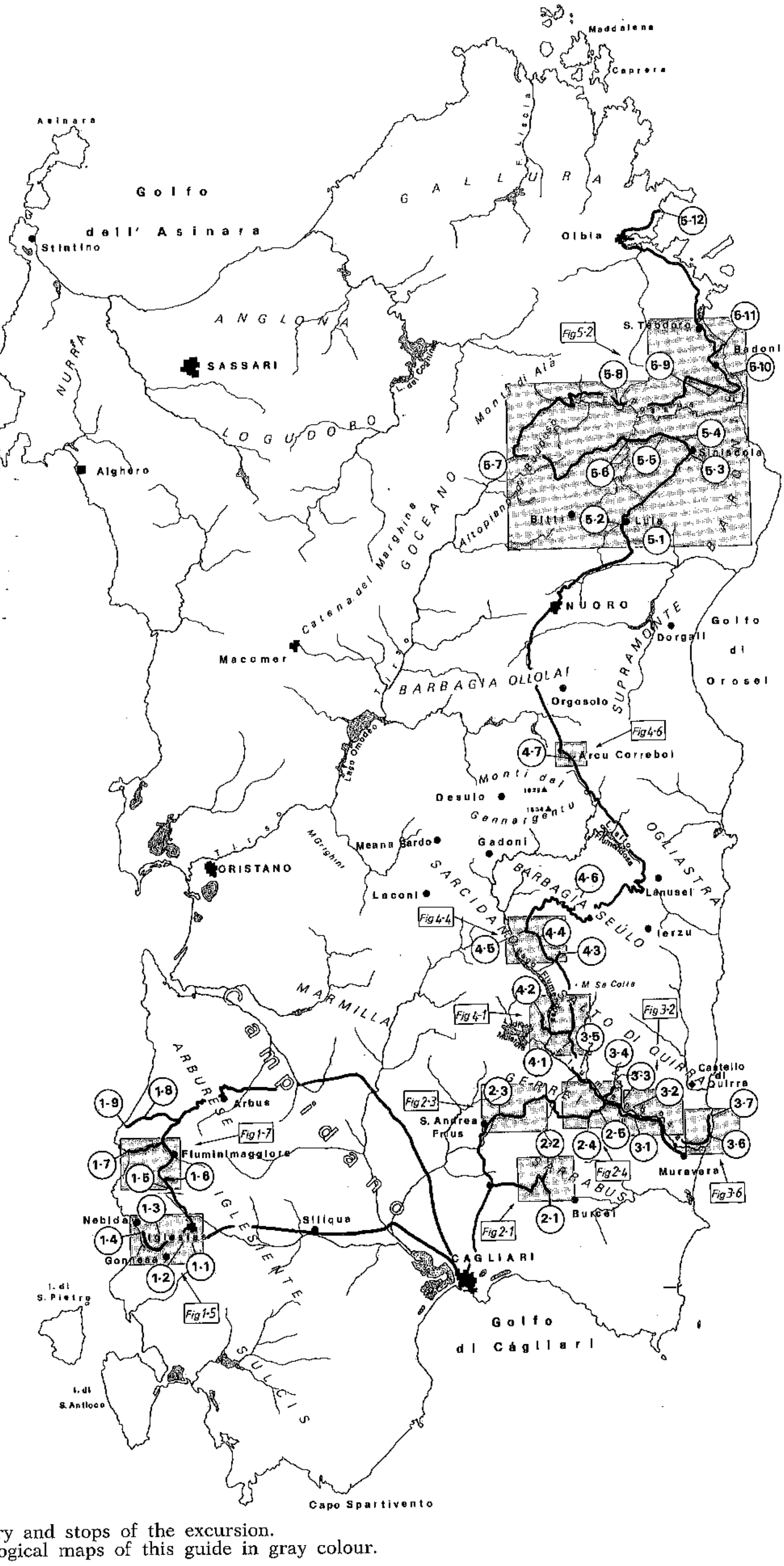

Plate 1 - Itinerary and stops of the excursion.
Location of geological maps of this guide in gray colour.

Guide-book to the Excursion on
the Paleozoic basement of Sardinia
IGCP project no. 5 - Newsletter 1986, special issue, 31-49

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

Theme of excursion of first day

THE GEOLOGY OF IGLESIENTE

by L. CARMIGNANI, T. COCOZZA, A. GANDIN, P.C. PERTUSATI

SUBJECTS: *Iglesiente Cambrian sequence - «Sardic unconformity» - Iglesiente Hercynian sequence - Arbus Unit.*

ITINERARY: *Cagliari - Iglesias - Nebida - Iglesias - Fluminimaggiore - Portixeddu - Arbus - Cagliari.*

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, Gonnesa, and Cabitza (RASETTI, 1972; COCOZZA, 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[1] 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 *Renalcis*) 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 Adtabanian (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 Manna 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 oncolitic 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).

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(1) 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.

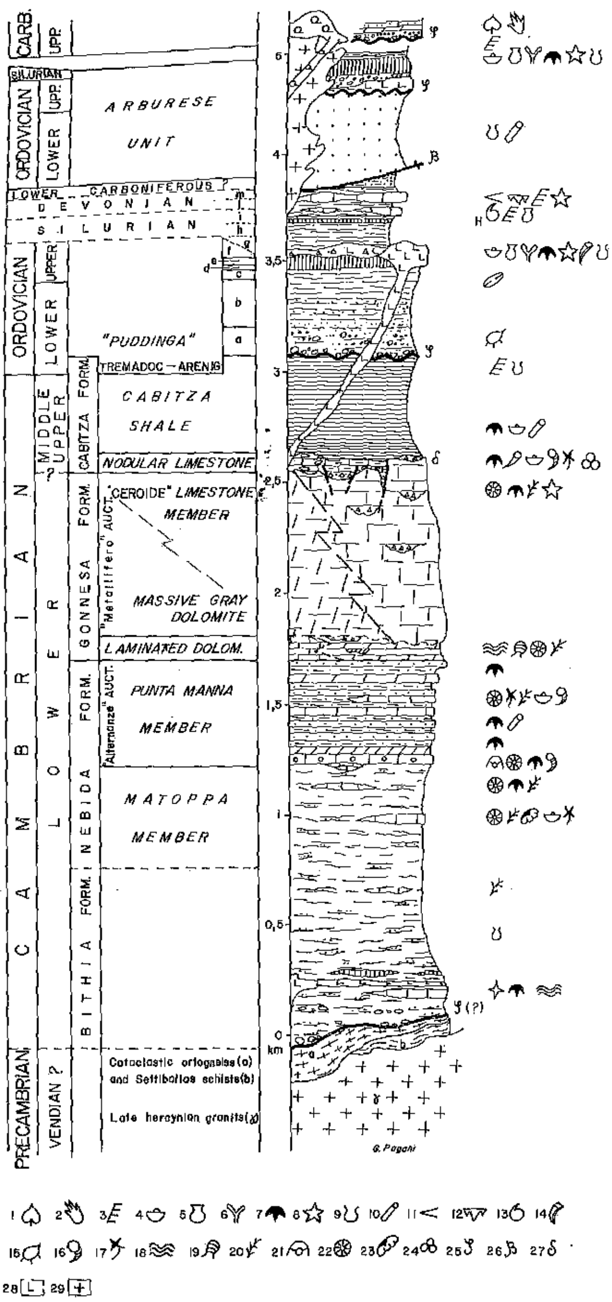

Fig. 1.1 - Paleozoic sequence of Iglesiente-Sulcis area. 1: Flora remnants; 2: Tetrapod traces; 3: Graptolites; 4: Brachiopods; 5: Pelecypods; 6: Bryozoa; 7: Trilobites; 8: Echinoderms; 9: Acritarchs; 10: Fossil traces; 11: Tentaculites; 12: Conodonts; 13: Cephalopods: Ammonoids; 15: Ostracods; 16: Carpoids; 17: *Chancelloria;* 18 and 19: Stromatolites; 20: Algae; 21: Oncolites; 22: Archeocyathids; 23: Stenotecoids; 24: Foraminifera; 25: Unconformity; 26: Tectonic contact; 27: Disconformity; 28: Rhyodacitic to andesitic volcanites of pre-Caradocian age; 29: Post-Hercynian granitoids; 30: Permo-Carboniferous volcanites (mainly acidic).
ORDOVICIAN: a) Polygenic conglomerates containing very scarce *Phyllocarida* (post-Arenigian-pre-Caradocian); b) Coarse sandstones with siltites and shales interbedded (same age of a); c) shales very rich in fossils and locally with glacial-marine deposits (Paratillite); d) Very coarse-grained mature sandstones (Caradocian); e) Bioclastic and fossiliferous shales (Caradocian-Ashgillian); f) Basic volcanics, breccia, with locally lacustrine and/or fluvial-lacustrine deposits, lateral and near the volcanic vent (Caradocian-Ludlovian).
UPPER ORDOVICIAN-LOWER SILURIAN: g) Siltites and shales, probably heteropic to «Scisti neri a *Rastrites peregrinus, Diplograptus, Climacograptus,* etc. of Lower-Silurian; h) black silica-rich shales with graptolites, black «liditi», fine-grained sandstones and lenticular dark limestones, which grade upward to i) black-limestones, sometimes lenticular, with *Orthoceras, Cardiola,* graptolites, conodonts, etc.
DEVONIAN: l) dark shaly siltstones with interbedded encrinite-limestones and mudstones; m) nodular shaly limestones with crinoids, tentaculites and trilobites, and dark siltstones and shales.

This unit is followed by a rhythmic alternation of sandstones (sometimes with high-angle cross-stratification, asymmetrical ripple marks and bioturbations) and limestones, more or less dolomitized, either oolitic with cross-lamination or rich in fragments of archeocyaths, trilobites, echinoderms and lingulids (ANGELUCCI, 1970). In the upper part of the sequence, the carbonate intercalations are composed of early dolomite, showing dessication structures, and algal mats, forecasting the features of the later Dolomia rigata member. Moreover, in the Iglesiente area, goethite-bearing horizons are frequent (FANNI *et al.,* 1982; DEBRENNE *et al.,* 1985). Average thickness of this members is 400 m.

The depositional setting of this member corresponds to a shoal-lagoon-sabkha system where the terrigenous siliciclastic input alternated with the marine carbonate deposition.

2. *The Gonnesa Formation («Metallifero» AUCT.)*

This formation begins with the Dolomia rigata member, generally marking the end of the terrigenous input on the epicontinental platform and the beginning of a pure-carbonate sedimentation.

The Dolomia rigata thickness varies from 20 to 250 m. It is mainly represented by early dolomite with algal mats and dessication structures evolving to «vadose pisolite» (sensu ESTEBAN, 1976). Thin oolitic or pelletoid layers and silica pseudomorphs after sulphate and halite are widespread, whereas only locally (Buggerru area) oncolites and archeocyaths have been found. In Eastern Sulcis, the stromatolithic facies consists exclusively of algal laminated limestone. The depositional setting has been interpreted as a tidal system in a hot arid environment (GANDIN *et al.*, 1973, 1974; CARANNANTE *et al.*, 1975). The occurrence of archeocyaths in the upper half of the sequence allows us to date the Dolomia rigata member to the Botomian age (DEBRENNE & GANDIN, 1985).

The transition between the Dolomia rigata member and the Calcare ceroide member is commonly marked by the occurrence of the «Dolomia grigia». This lithofacies also occurs as irregular patches at any level in the sequence and locally, for instance in the Cabitza area, replaces all the Calcare ceroide member (GANDIN, 1980). Sometimes traces of the algal-peloidal or vadose structures of the surrounding lithofacies remain. From petrographic analysis the gray dolomite 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 subsurface, occurring as a consequence of the block faulting and resulting from the Bahamian morphology of the carbonate platform (GANDIN, 1985).

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

Tha Calcare ceroide member shows four typical lithofacies (BONI *et al.*, 1981; FANNI *et al.*, 1982; DEBRENNE & GANDIN, 1985):

1 — «vadose pisolite», (*sensu*, ESTEBAN, 1976);

2 — mudstone-wackestone with bioclasts;

3 — grainstone with oolites and/or oncolites, echinoderms and trilobite remnants;

4 — cryptalgal boundstone, locally skeletal-algal (*Ephiphyton* and renalcids) boundstones with archeocyaths.

These facies indicate environments which vary from supratidal to subtidal. Their distribution reveals a «platform and basin» paleomorphology related to tensive synsedimentary tectonics (GANDIN, 1985). 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 Calcare ceroide member confirms a late Lower Cambrian age (Lower-Middle Toyonian: DEBRENNE & GANDIN, 1985).

3. *The Cabitza Formation*

The lower member of this formation (Calcare nodulare = «Calcescisti» *Auct.*) rests with a clear parallel unconformity on the Calcare ceroide member (fig. 1.1), and more rarely on the «Dolomia grigia» or on the lenticular breccia bodies (GANDIN, 1985). The Calcare nodulare member is composed of a tight alternation of thin beds of red, green, and more rarely black shales, which are more or less silty, and gray, pink or locally black limestones sometimes having a nodular structure. They result to be bioclastic wackestone-packstones containing trilobites, echinoderms, brachiopods, *Chancelloria*, sponge and *Hyolithes* remnants (GANDIN, 1980).

The depositional environment was clearly neritic, locally restricted and probably very shallow (GANDIN, 1980; GANDIN & PILLOLA, 1985).

The «Calcare nodulare» deposition marks the beginning of the «drowning» of the carbonate platform during the Middle Cambrian age. Its thickness varies greatly from 0 to 80-100 m, as a result of the extensional tectonics which was so active during this period (GANDIN, 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 shaly and silty laminae of 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 laminations and limestone nodules occur both in the silty and sandstone lithofacies (PALMERINI *et al.*, 1979; GANDIN & PILLOLA, 1985).

This member is closely folded and locally deeply eroded so that its maximum measurable thickness is about 400 m.

The lower part of the member has been attributed to the Middle Cambrian age on the basis of rich faunas with trilobites (*Paradoxides* cf. *mediterraneus*, *Ctenocefalus* (*Hortella*) sp. *Pardailhania hispida*, *Conocoryphe heberti*, *Conocoryphe levji*, *Jincella* sp.) which can be related to the B-F levels of the Montagne Noire (RASETTI, 1972; GANDIN & PILLOLA, 1985). The age of the middle and upper part was uncertain until the very recent findings of early Ordovician acritarchs and graptolites (*Dictyonema* *flabelliforme*) (GANDIN & PILLOLA, 1985; BARCA *et al.*, 1986).

The Cabitza Formation concludes the Caledonian depositional cycle. It is unconformably covered by the conglomerates («Puddinga» AUCT.) connected with the Sardic phase whose age, previously referred by STILLE (1924, 1939) to the Cambrian-Ordovician boundary, is now more precisely located between post-Arenig and pre-Caradoc on account of the discovery of the Tremadoc age of the upper preserved part of the Cabitza Formation (BARCA *et al.*, 1986) (fig. 1.1).

HERCYNIAN CYCLE

The Caledonian series is covered in a clear angular unconformity with a polygenic unsorted conglomerate having red-violet silty-shaly matrix, «Puddinga» AUCT. (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 Iglesiente, along the coast, a megabreccia consisting of Cambrian carbonate olistoliths occurs, which can be related to the synsedimentary activity of a normal fault still evident towards the east. Further up, with the disappearance of the conglomerates, alternations of sandstones (graywackes), siltites and shales, prevail marking a thick, fining, upward sequence (TEICHMÜLLER, 1931; COCOZZA & VALERA, 1966; COCOZZA & LEONE, 1977). In the middle part of this sequence only rare phyllocarid remnants have been found by TARICCO (1922), but they have never been studied. The first well-dated horizon, occurring in the upper part of the sequence, is composed of weakly-carbonate shales and siltites with abundant fossiliferous remnants (brachiopods, pelecipods, trilobites, bryozoans, cystoids, etc.) of Caradocian age (see bibliography in MACCAGNO, 1965; GIOVANNONI & ZANFRA, 1979; SERPAGLI, 1970a). Another fossiliferous horizon, immediately above the Caradocian, contains shaly biocalcarenites, often completely silicified, whose abundant fauna is very similar to the underlying one, although *Chasmatoporella* is lacking among the bryozoans and small Caradocian-Ashgillian trilobites are present (*Cyclopycidoa*). These Upper Ordovician fossil-rich horizons are also widespread in Central and South-Eastern 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 (BECCALUVA *et al.*, 1981; MEMMI *et al.*, 1982).

The transition to Silurian consists of regular alternations of grey or black sandstones, siltites and shales. The most complete sequence crops out above the cemetery of Fluminimaggiore: it is composed of black carbonaceous shales with graptolites of Llandoverian and lower Wenlockian age (20-25 m thick) overlain by about 30 m of black carbonaceous shales with limestone lenses containing late Wenlockian-Lundlovian *Orthoceras*, *Cardiola*, conodonts, ostracods, etc. (SERPAGLI, 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 GNOLI & SERPAGLI (1985) because of the occurrence of a large benthonic pelecipod such as *Slava*. According to these authors, the Silurian sequence begins here with two formations. The first corresponds to the upper part of the g-horizon of fig. 1.1, (considered by COCOZZA & LEONE (1977) as Ordovician in age), and the second to the «Scisti neri a *Rastrites peregrinus*, *Diplograptus*, etc.» (TARICCO, 1982; NOVARESE & TARICCO, 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 «griotte» — type limestone with *Tentaculites*, crinoids, cephalopods, conodonts and foraminifera. They are exposed in small scattered outcrops along a narrow belt running from the Fluminese area to eastern Sulcis, its thickness ranging from a few metres to 20 m in the Fluminese to more than 600 m at Mt. Padenteddu (eastern Sulcis). The presence at a conodont fauna of the *Icriodus woschmidti woschmidti* zone, ranging from the uppermost Silurian to the lowermost part of Lower Lochkovian, suggests that there is no sedimentary break between these two stages either (SERPAGLI & MASTANDREA, 1980; OLIVIERI *et al.*, 1981; SERPAGLI, 1983). However, the finding of a Pridolian conodont fauna of *ploekensis* and *eosteinhornensis* zones, but not of *crispa* and *snajdri-latialatus* ones does not resolve the problem of whether this part of Silurian is represented in south-western Sardinia by unfossiliferous or tectonized shales, or if it is completely missing (GNOLI & SERPAGLI, 1985). The presence of Upper Pragian-Early Zlichovian is confirmed by a conodont fauna found in a stromatactis-bearing carbonate mound at Mt. Padenteddu and at Su Nuragi near Domusnovas (OLIVIERI *et al.*, 1981; OLIVIERI, 1984).

In south-western Sardinia the Hercynian

depositional cycle ends with the Lower Fammenian; 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 (OLIVIERI, 1970). At any ràte, a terrigenous Lower Carboniferous has been repeatedly hypothesized although paleontological evidence is still lacking (VAI & COCOZZA, 1974; BARCA *et al.*, 1981b).

POST-HERCYNIAN DEPOSITS

In Iglesiente, the first sediments deposed after the Hercynian orogenesis consist of the Carboniferous continental deposits of San Giorgio, Iglesias (GAMBERA, 1897): a clastic fluvio-lacustrine sequence composed of conglomerate, coarse, quartzitic sandstone ad detritic dolomite (maximum thickness 30 m) This sequence has been attributed to the Stephanian by COCOZZA (1967) on the basis of a rich megaflora. Its Carboniferous age was later confirmed by microflora associations (DEL RIO, 1973). A more recent ichnological study (FONDI, 1980) suggests the Westphalian D for the oldest part of the sequence (fig. 1.1).

This continental phase, which persisted until the beginning of the Mesozoic age, led to the more or less evident peneplanation of extensive areas and to the intensive karstification of the Cambrian limestone, partly resulting from the Permian-Triassic climatic conditions (COCOZZA, 1967; MOORE, 1972; COCOZZA & GANDIN, 1977; BONI, 1980).

The Middle Triassic transgression caused an extensive epigenetic dolomization of the Cambrian limestone («Dolomia gialla» *Auct.*). The sediments of this period are the continental, evaporitic and shallow marine conglomeratic, dolomitic or calcareous deposits of Campumari (Iglesias; COCOZZA & GANDIN, 1977), Is Arenas (Capo Pecora), Sciria (Montevecchio), Cuccuru Zeppera (Guspini) (DAMIANI & GANDIN, 1974) and Sa Bagattu (Monte San Giovanni; BRUSCA *et al.*, 1967).

TECTONICS

In the structural zoning proposed by CARMIGNANI *et al.* (1979, 1981), Iglesiente is the outermost part of the Hercynian chain cropping out in Sardinia. It is characterized by very low to low-grade regional Hercynian metamorphism and by folding tectonics associated with strongly dipped 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 Iglesiente, than in other areas of the basement.

The first detailed structural analysis of part of Iglesiente was carried out by ARTHAUD (1963), who identified four deformation phases in the Cambrian rocks. A similar deformational sequence was also later described in northern Sulcis by POLL & ZWART (1964) and confirmed in subsequent works (POLL, 1966; DUNNET, 1969; DUNNET & MOORE, 1969; ARTHAUD, 1970).

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

1 — Sardic phase: minor folds with E-W axes, in the Arenig-Caradoc interval;
2 — First Hercynian phase: minor E-W trending folds, accentuating the former ones;
3 — Second Hercynian phase: main deformations with N-S trending folds accompanied by strongly dipped 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 of southern Iglesiente-northern Sulcis, the most evident structures are large E-W trending folds. Instead, the north-western Iglesiente area is mainly structured along N-S trending folds varying in size, involving also the post-Sardic sequences. The quadrilateral shape of the large outcrop of Lower Cambrian «Arenarie» (Nebida Formation), extending for the whole area north of Iglesias, is often quoted as a typical example of the interference of two fold systems with strongly dipped axial planes and approximately orthogonal axial directions.

1. *E-W trending deformation*

The presence of large structures[2] with E-W axes is certain (fig. 1.2), but the age of this deformation remains very debatable.

The existence of Arenig-Caradoc deformations is supported by the unconformity at the base of the Ordovician conglomerate («Puddinga»). This unconformity is well-exposed in various places (Masua, Nebida, Domusnovas, etc.) and seems to be of regional importance. Both in the Iglesiente (VARDABASSO, 1940, 1956; BRUSCA & DESSAU, 1968; DUNNET, 1969) and in the Sulcis region (POLL & ZWART, 1964; POLL, 1966),

(2) Abbreviations such as N-S schistosity, N-S or E-W axes, etc. will be used to indicate the elements of the two main structural directions although these directions may vary considerably.

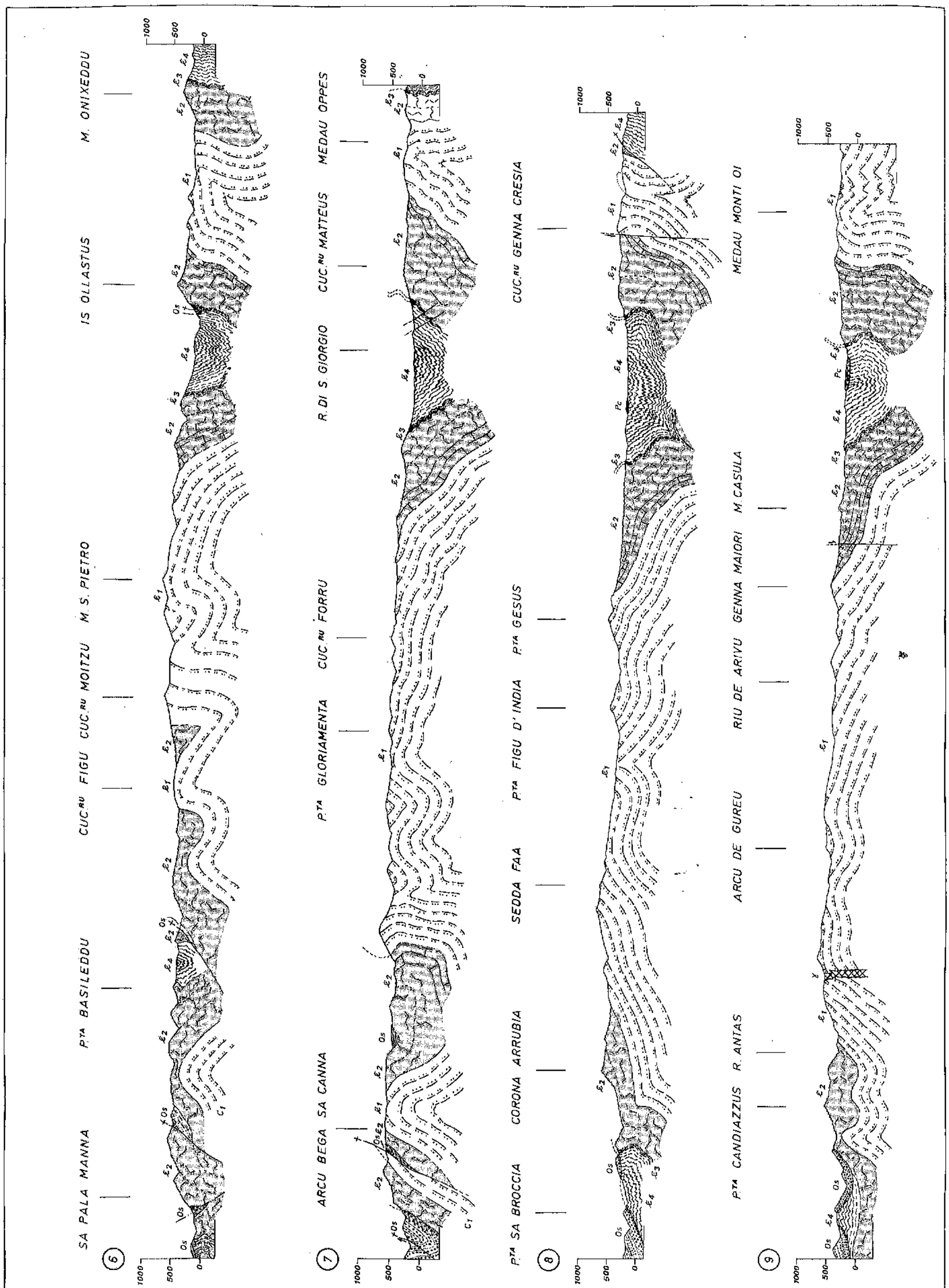

Fig. 1.2 - N-S sections across Iglesiente. Their orientation points out folds of Sardic phase. $\mathcal{C}_1$: Nebida Formation; $\mathcal{C}_2$: Gonnesa Formation; $\mathcal{C}_3$: Nodular limestone member; $\mathcal{C}_4$: Cabitza shale Member; Os: Ordovician and Silurian sediments; Pc: Upper Carboniferous sediments; Tr: Triassic sediments. These cross-sections are outlined on the bottom right of the fig. 1.3.

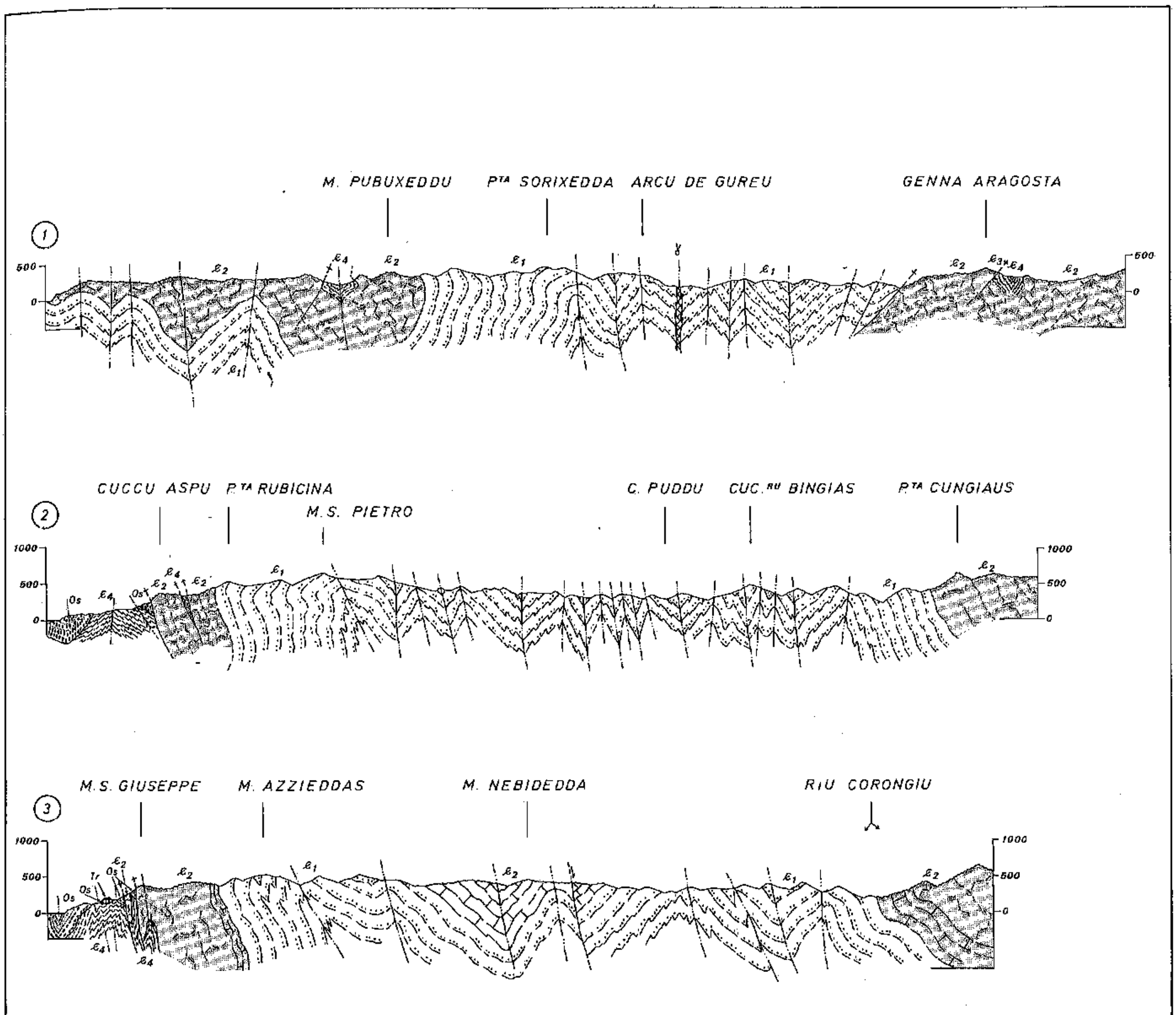

Fig. 1.3 - WSW-ENE sections across Iglesiente. Their orientation points out Hercynian folds.
Ꞓ_1: Nebida Formation; Ꞓ_2: Gonnesa Formation; Ꞓ_3: Nodular limestone member; Ꞓ_4: Cabitza shale Member; Os: Ordovician and Silurian sediments; γ: Quartz porphyries; Tr: Triassic sediments; Pc: Upper Carboniferous 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; ARTHAUD, 1970), south of Gonnesa, and in many other areas in Iglesiente (MAXIA, pers. comm.). Most authors therefore agree in believing that both the Sardic phase and one of the Hercynian phases have roughly 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 Iglesias sinclyne, the Canalgrande area, the Gonnesa 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 wavelenghts (POLL, 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. 1.3 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 most 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 «Metallifero» limestone and Cabitza Formation. The characteristic «cups-and-lobe» shape of these structures is shown in sections n. 4 and n. 5 of fig. 1.3 and in fig. 1.4. The shales 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, Acquaresi and Buggerru, whose core is made by Cabitza shale and Ordovician «Puddinga», 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 activated from Cambrian to Tertiary. In some cases, the movements may be reconstructed by means of families of subsequent striations. 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 kinks with variable trending axes. Extensive and transcurrent movements are post-Hercynian and Alpine in ages.

ARBUS AREA

Both in Iglesiente and Eastern Sulcis the Paleozoic 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 (VAI & COCOZZA, 1974; BARCA *et al.*, 1981b).

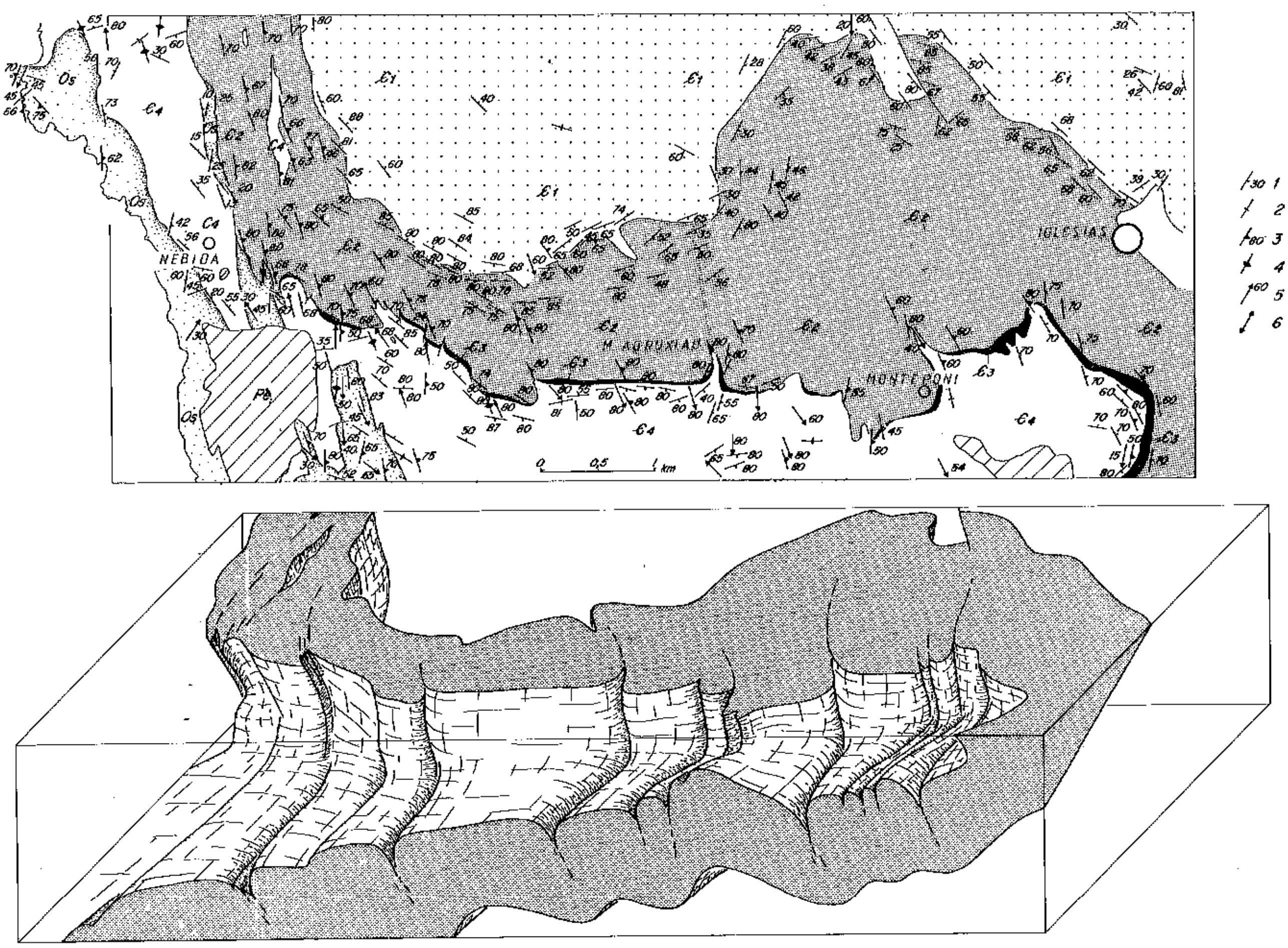

Fig. 1.4 - Geological map and block-diagram of the northern limb of Iglesias syncline.
Є$_1$: Nebida Formation; Є$_2$: Gonnesa Formation; Є$_3$: Nodular limestone Member; Є$_4$: Cabitza shale Member; Os: Ordovician and Silurian sediments; Pe: Post-Hercynian deposits. 1: Strike and dip of beds; 2: Vertical beds; 3: Strike and dip of N-S phase; 4: Vertical cleavage; 5: Minor fold axes and intersection lineations of N-S phase; 6: Minor fold axes and horizontal intersection lineations.

This complex, which unconformably covers the Ordovician, Silurian and Devonian formations, is known in literature as «Postgotlandiano» (TARICCO, 1922) and was long considered to be Upper Devonian-Lower Carboniferous in age (VAI & COCOZZA, 1974).

However, the recent discovery of abundant acritarch associations (*Stelliferidium, Cymatiogalea, Vulcanisphaera, Acanthodiacrodium, Striatotheca*) 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 overthrusted on the Iglesiente and Eastern Sulcis formations (Arbus Unit: BARCA *et al.*, 1981b). Moreover, the lithological affinities of the «Postgotlandiano» (AUCT.) of the Arbus Unit, with the «Arenarie di San Vito», indicate that the Arbus Unit may be correlated with the Genn' Argiolas Unit that exposed in Sàrrabus (BARCA *et al.*, 1981a, b). The Arbus Unit therefore represents the extreme south-western edge of the nappes of Central Sardinia (CARMIGNANI *et al.*, 1979, 1981) overthrusting the outermost zone of the Hercynian chain.

The affinity of the Arbus Unit with the Genn'Argiolas one (Sàrrabus) is also confirmed by the few outcrops of post-Lower Ordovician sequences in the Arbus Unit, north of Montevecchio 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 siltstone rich in benthonic fauna of Caradocian-Ashgillian age, schists, «liditi», and lenses of dark limestone with *Orthoceras* and graptolites (BARCA & SALVADORI, 1974).

However, although this complex (referred to in the past as Upper Devonian-Lower Carboniferous) turns out to be much older, the occurrence of a terrigenous Lower Carboniferous in south-western Sardinia cannot be completely excluded, since under the overthrust surface of the Arbus Unit, fine-grained, detritic, locally conglomeratic sequences crop out in several points of the Fluminese area, and thus may represent laminated wedges of a Carboniferous synorogenetic formation (VAI & COCOZZA, 1974).

This unit, like all the underlying Paleozoic formations, is crossed by plutons and stocks of post-tectonic granitoid, mainly represented by biotite leucogranite and, restricted to the Arbus area, by biotite or biotite-amphibole tonalites-granodiorites and two-mica or cordierite-bearing leucogranites.

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DESCRIPTION OF STOPS OF THE IGLESIENTE 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 Cixerri 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.

— STOP 1.1 - *Near the Campo Pisano mine: The upper part of Gonnesa 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 («Calcescisti» AUCT.) at its base;

— Gonnesa Formation («Metallifero» 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 beginning of the drowning of the pericontinental platform system («Calcare ceroide» member), after a short period of emersion, and the continuation of the marine sedimentation influenced by terrigenous input.

To the west, there is the Iglesias syncline, a large E-W trending structure (Sardic 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 Gonnesa Formation forms the abrupt reliefs bordering its flanks north and south.

— STOP 1.2 - *Opposite the Monteponi mine: Upper-Carboniferous sediments are unconformably lain on Cambrian (fig. 1.5).*

The angular unconformity between the Cabitza Formation and the Upper Carboniferous detritic sediments are 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 megaflora with *Pecopteris arborescens* SCHLOTH, *Callipteridium pteridium* (SCHLOTH), *Neuropteris planchardi* ZEILLER, *Dicksonite plukeneti* (SCHLOTH) *sterzeli* ZEILLER and some others have been found in them. The Upper Carboniferous age (Westphalian-Stephanian) is also confirmed by the palynological data and by an ichnofauna with *Salichnium heringi* (GEINITZ).

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

— STOP 1.3 - *Monte Agruxiau: Transition between the Gonnesa and Cabitza Formations (fig. 1.5).*

In spite of the occurrence of the typical epidiagenetic «yellow dolomite», the transition between the «Ceroide» limestone (Lower Cambrian: Gonnesa Fm) and the Nodular limestone (Middle Cambrian : Cabitza Fm) is clearly exposed in an old quarry. The last few metres of the «Ceroide» limestone are cut by fractures and cavities filled with calcite or reddish hematitic material. At the summit, the «Monte Agruxiau breccia» occurs. It is composed of angular clasts of «Ceroide» limestone represented by the fossiliferous facies, with trilobites and echinoderms, grainstone and cryptalgal boundstone.

The matrix of the breccia, locally very abundant, is not only composed of hematitic red material (paleosoil?) but also of yellow-pink marles 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 synsedimentary extensional tectonics, had previously undergone local emersions and karstifications.

Continuing further into the Cabitza shales and passing the San Giovanni mine we cross the «Sardic unconformity» and thus reach the Lower Ordovician (?Llanvirnian-Llandellian) transgressive conglomerate («Puddinga»). Along the Funtanamare coast, the Paleozoic succession reaches the Silurian and is overlain in clear angular unconformity by the subhorizontal con-

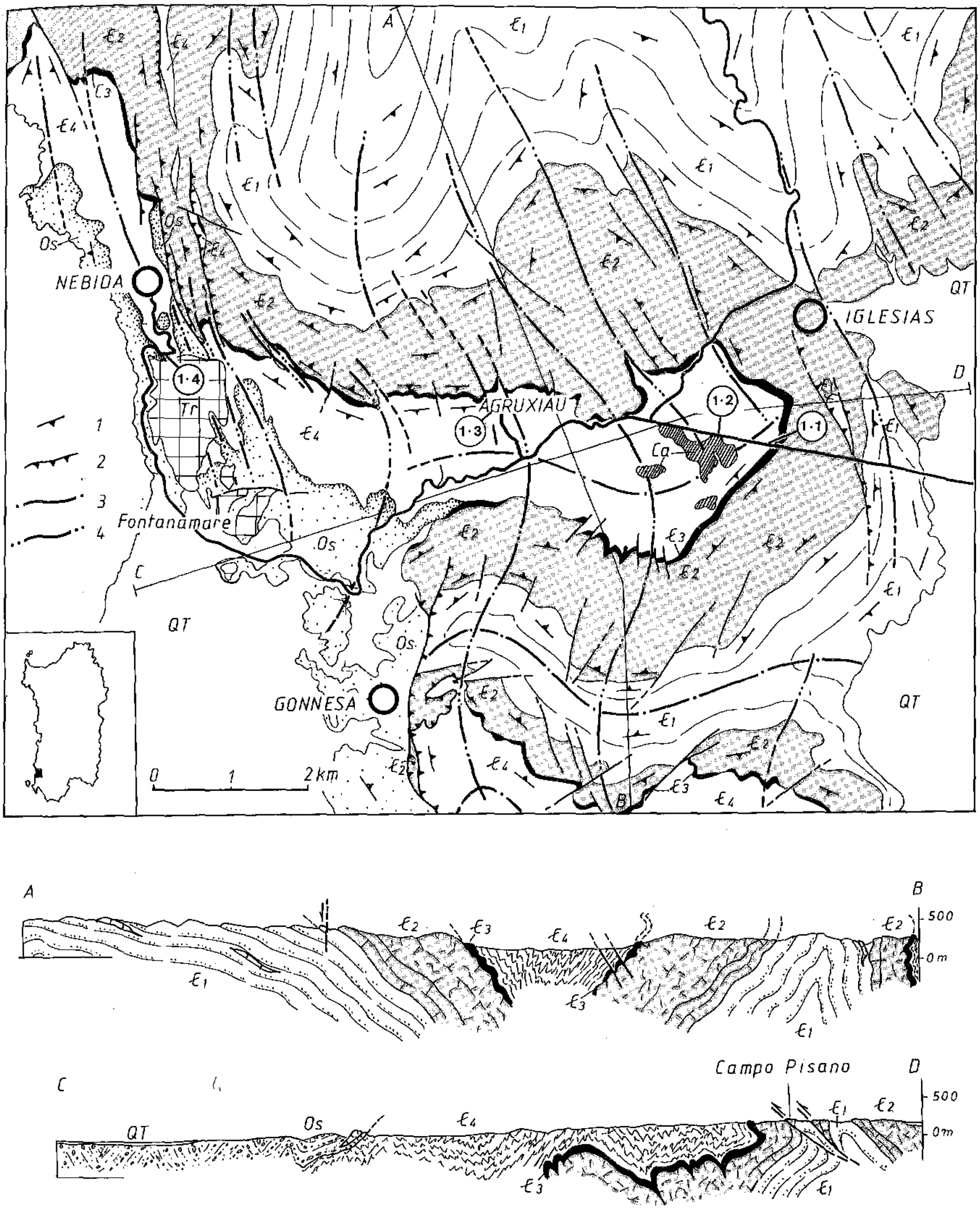

Fig. 1.5 - Schematic geological map and cross-sections of Iglesias area with location of stops (After Carmignani, Cocozza & Pertusati, 1983).
QT: Quaternary and Tertiary sediments and volcanites; Tr: Conglomerates and dolostones (Middle Triassic); Os: Carbonaceous slates with «*Orthoceras* limestone» lenses near Funtanamare; sandstones and siltstones brachiopoda, bryozoa, etc.; transgressive conglomerates with blocks of Cambrian limestones (Silurian-Ordovician); Є$_4$: Cabitza shale Member (Upper Cambrian - Early Ordovician); Є$_3$: Nodular limestone member (Middle Cambrian); Є$_2$: «Ceroide» limestone member and Grey; Є$_1$: Nebida Formation - sandstones with archeochyaths limestone and dolostone lenses (Lower Cambrian); 1: Strike and dip of beds; 2: Reverse faults and overthrusts; 3: Axial plane traces of major folds related to the Sardic phase; 4: Axial plane traces of main Hercynian phase.

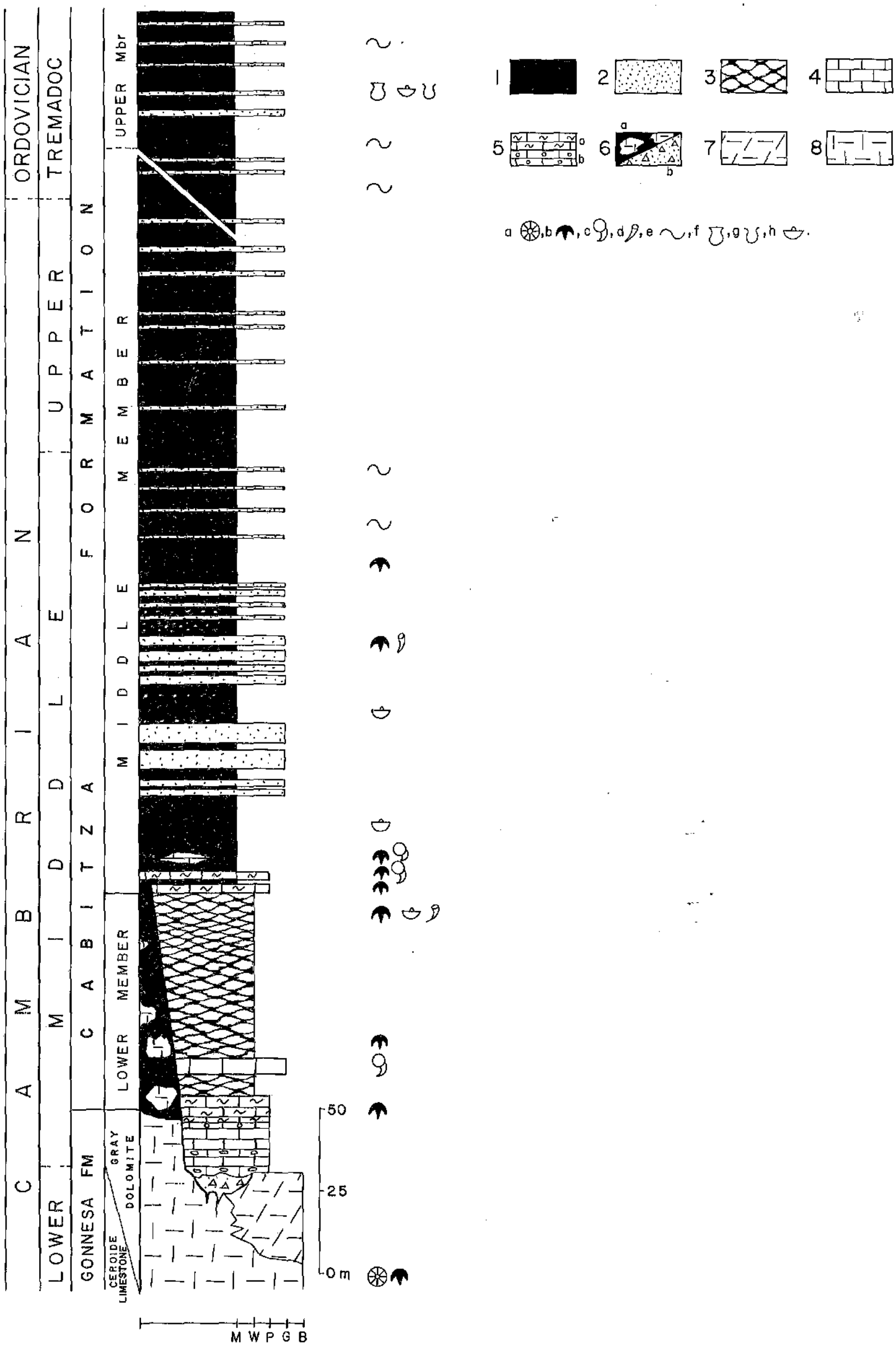

Fig. 1.6 - Upper part of Gonnesa Formation and Cabitza Formation.
1: Shales and silts; 2: Sandstones; 3: Marly limestones with small nodules; 4: Layered limestones; 5a: Shaly and silts; 5b: Marly limestones with large nodules. 6a: Breccia with shaly matrix; 6b: Breccia with red-silty matrix; 7: Grey dolomite; 8: Massive limestones; a) Archeocyaths; b) Trilobites; c) Echinoderms; d) Hyolithids; e) Trace fossils; f) *Dictyonema*; g) Acritarchs; h) Brachiopods.

glomerate and dolomite of the Middle Triassic Campumari plateau. These are post-orogenic alluvial and lagoon evaporitic deposits.

— STOP 1.4 - *Road to Nebida: «Sardic unconformity» (fig. 1.5).*

The Cabitza Formation and the Ordovician conglomerate («Puddinga») 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 «Ceroide» limestone and grey dolomite which are embedded into the Ordovician «Puddinga». 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 Gennarta Lake, we can see the carbonate intercalations characterizing the Punta Manna Member, and the passage to Gonnesa Formation («Metallifero» 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 archeocyathan fauna, however, gives us an Upper Atdabanian-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.

— STOP 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.

— STOP 1.6 - *Temple of Antas: Transition between the Punta Manna Member (Nebida Fm) and the «Dolomia rigata» member (Gonnesa 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 conglomerate («Puddinga») of the Ordovician transgression (Sardic phase) and then the finer Upper Ordovician detritic deposits. Near the cemetery of Fluminimaggiore these deposits pass to the Silurian sequence, exposed on the northern 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 Portixeddu, the Upper Ordovician fossiliferous siltite and shale are well exposed.

— STOP 1.7 - *Portixeddu: Upper Ordovician fossiliferous beds (fig. 1.7)*

The most important reliefs south of the bay are made up of the Cambrian limestone of Buggerru (another mining locality) which dip northwards under the unconformably overlying Ordovician sequences (see cross-section of fig. 1.7). The Portixeddu coastline is composed of Upper Ordovician (Caradocian-Ashgillian) fossiliferous shales and siltites.

It is one of the most famous fossiliferous localities of the Sardinian Paleozoic, and has been studied since the middle of the last cen-

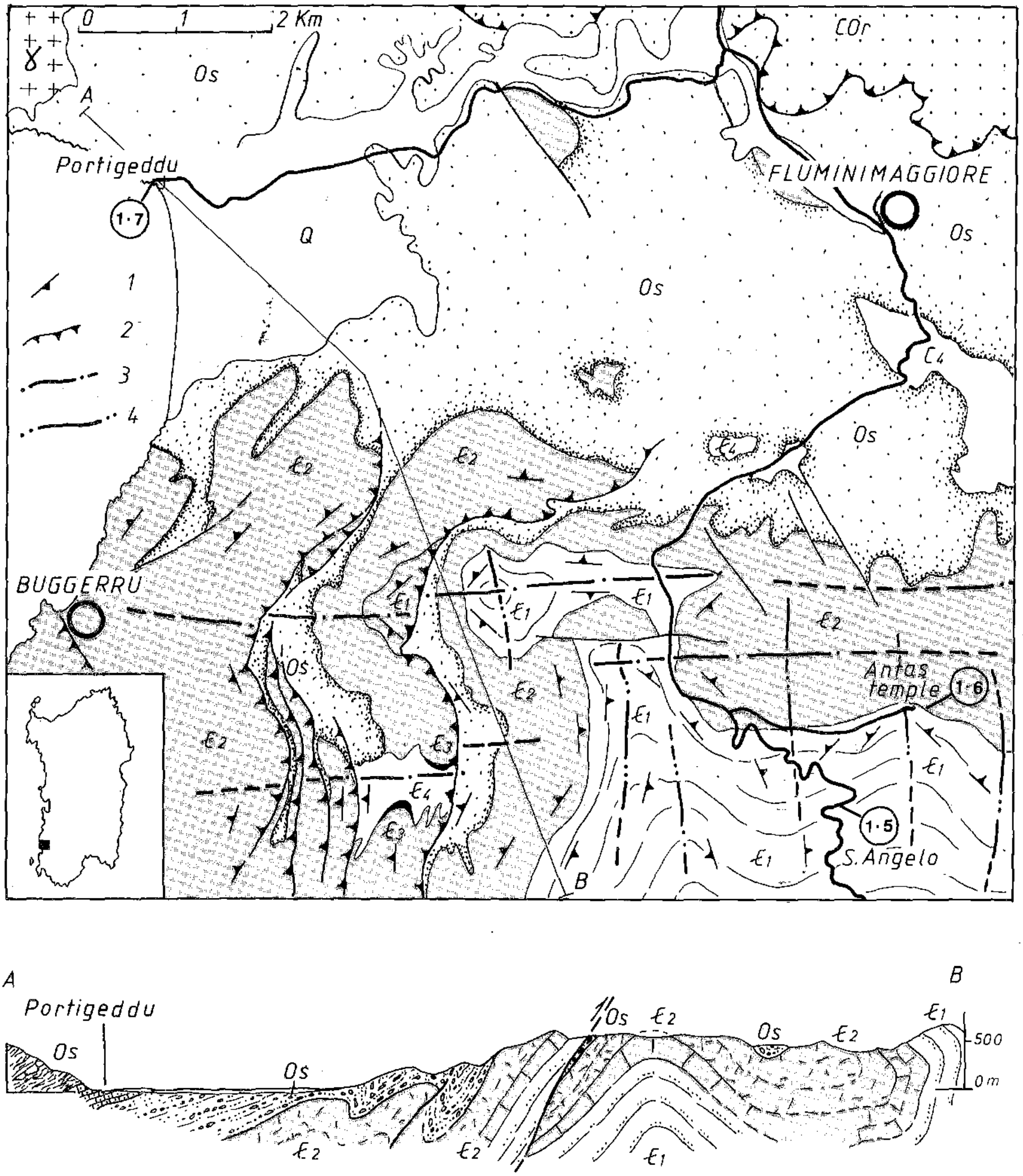

Fig. 1.7 - Schematic geological map and cross-section of Fluminimaggiore - Buggerru area with location of stops (After L. Carmignani, T. Cocozza & P.C. Pertusati, 1983).
Q: Quaternary deposits.
Arburese Unit: COr: Sandstones and shales (Cambrian-Early Ordovician). *Iglesiente Autochthonous:* Os: Carbonaceous shales, quartzites («Scisti a Graptoliti» and «Liditi» AUCT.), limestones («Calcari and *Orthoceras* AUCT.), sandstones and siltstones with Brachiopoda, Bryozoa, etc., transgressive conglomerates (Devonian-Ordovician); $Є_4$: Cabitza shale Member (Upper Cambrian - Early Ordovician); $Є_3$: Nodular limestone member (Middle Cambrian); $Є_2$: «Ceroide» limestone member and grey $Є_1$: Nebida Formation: metasandstones with archeocyathan limestones and dolostones lenses (Lower Cambrian); 1: Strike and dip of beds; 2: Reverse faults and thrusts; 3: Axial plane traces of major folds related to the Sardic phase; 4: Axial plane traces of major folds connected to the main Hercynian phase.

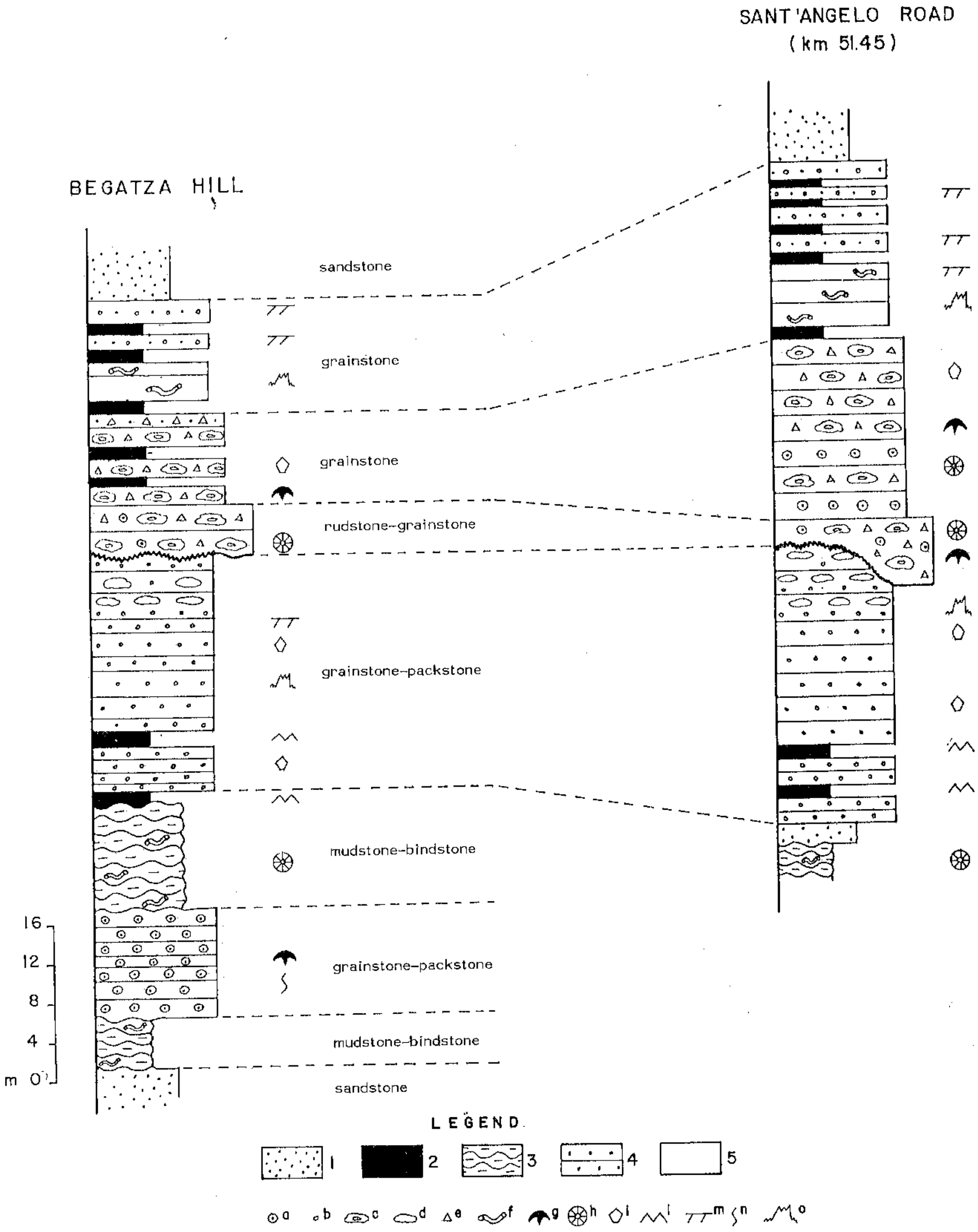

Fig. 1.8 - Lower part of the Punta Manna Member: Oolitic Unit.
1: Sandstones; 2: Slates; 3: Shaly limestones; 4: Sandy limestones; 5: Limestones; a: Ooids; b: Peloids; c; Oncoids; d: Fenestrae; e; Intraclasts/bioclasts; f: *Girvanella*; g: Trilobites; h: Archeocyaths; i: Echinoderms; l: Ripple marks; m: Cross laminations; n: Vertical burrows; o: Stylolites.

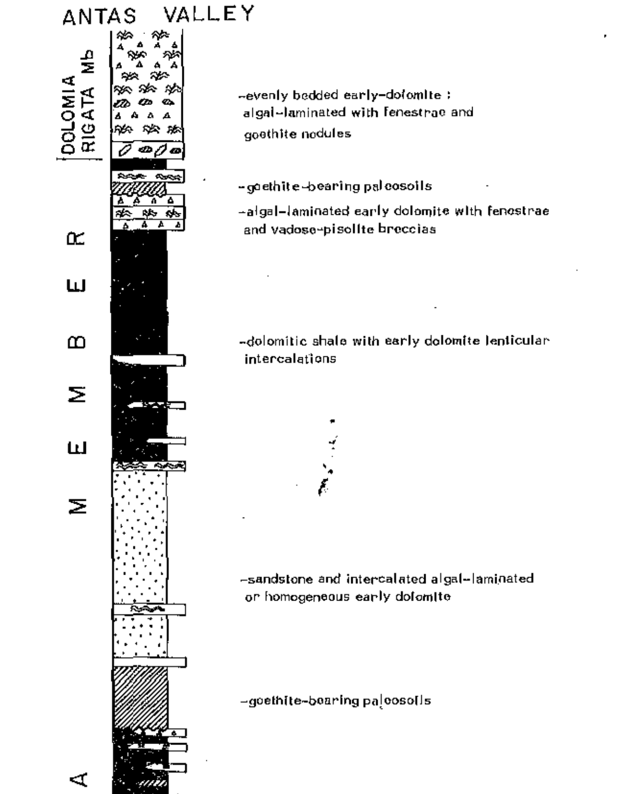

Fig. 1.9 - Upper part of Punta Manna Member.
1: Goethite; 2: Shales; 3: Sandstones; 4: Early dolomites; a; Intraclasts; b: Sulphate pseudomorphs; c: Goethite nodules; d: Algal mats; e: LLH structures; f: Fenestral algal mats; g: Chert nodules; h: Mud cracks; i: Vadose pisolites; l: Load deformations; m: Planar laminations; n: Cross laminations.

tury. Bryozoa, brachiopods and cystoids are abundant, although trilobites, molluscs, coelenterates, tabulates, etc. have also been found.

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 terrigenous suite of the Arburese Unit («Postgotlandiano» AUCT.). This is the outermost area of the Hercynian chain in which the allochthonous Arburese Unit has paleontologically 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 Arbus Unit can easily be observed.

— STOP 1.8 - *Road to Is Arenas: Arburese Cambrian-Ordovician suite*

Typical lithologies of the Arbus Unit («Postgotlandiano» AUCT.) along the road are exposed. They consist of micaceous sandstones, grey quartzites, siltites 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 Arburese 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 stop (Scivu), the Paleozoic basement is unconformably overlain by the Triassic conglomerate and dolomite forming typical flat-topped hills like that of Campumari (see Stop 1.4).

— STOP 1.9 - *Scivu: Tectonic contact between the Arburese Unit and the autochthonous Silurian-Devonian formations.*

The Cambro-Ordovician complex of the Arburese Unit tectonically overlies the typical Lower and Middle Devonian black shales with nodular dark limestone. The contact is clearly visible along the road, where it is marked by cataclasites.

In the next few days, we shall be able to follow this allochthonous complex, first in the Sàrrabus and then further north, as far as Sarcidano.

Returning to Cagliari, we cross the Arbus late-Hercynian intrusive massif, composed of two mica and/or cordierite-bearing leucogranites and monzogranites and of biotite or biotite-amphibole tonalites-granodiorites, and then the plain of the Tertiary Campidano graben.

Guide-book to the Excursion on the Paleozoic basement of Sardinia
IGCP project no. 5 - Newsletter 1986, special issue, 51-60

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

Theme of excursion of second day

THE GEOLOGY OF SARRABUS

by S. BARCA, L. CARMIGNANI, 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 - Silius - Villasalto - Muravera.*

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 carbonatic 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 metaconglomerates 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 (CARMIGNANI & 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»: CARMIGNANI & PERTUSATI, 1977).

In the structural scheme shown in fig. 1 of CARMIGNANI *et al.* this volume, this unit is correlated with the Arburese Unit (see 1.8 and 1.9 stops) and with the Meana Sardo Unit (see 4.3 stop). These three units show a great deal of affinities ragarding 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 «post-nappe» 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 («Sàrrabus Unconformity»: CALVINO, 1961). The age and importance of this unconformity was debated (SCHNEIDER, 1974; HELMCKE, 1973; CARMIGNANI & PERTUSATI, 1977; CARMIGNANI *et al.*, 1978; BARCA & DI GREGORIO, 1979; NAUD, 1981) until the recent paleontological findings in the Cambrian-Ordovician formations on the two sides of the Campidano (BARCA *et al.*, 1981 a, b) which linked the «Sàrrabus Unconformity» to the «Sardic Unconformity» of Iglesiente and thus established the extent of the Caledonian deformations (Fig. 2 in CARMIGNANI *et al.* this volume).

The succession 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. *Arenarie di San Vito Formation*

This formation, paleontologically dated, is the oldest of the entire Sàrrabus. It includes a succession of more or less quartzitic sandstones in decimetric or metric layers alternating with greenish-grey or blackish-grey metasiltites and slates. Kilometric recumbent folds occur in this succession (CARMIGNANI & PERTUSATI, 1977) so that its original thickness is uncertain 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 metaconglomerates. We frequently find laminated levels of siltitic metasandstones and meta-argillites with undulating 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 the formation.

On the basis of acritarch fauna dating, BARCA *et al.* (1981a) have shown the presence of Middle and Upper Cambrian. The formation probably also reaches Early Ordovician, since Tremadoc-Arenigian acritarchs have been found in formations which may be correlated with the «Arenarie di San Vito» both in the Fluminese (BARCA *et al.*, 1981b; PITTAU DEMELIA, 1985) and Sarcidano region (TONGIORGI *et al.*, 1982a, b).

2. *Ordovician Metavolcanic Complex*

This metavolcanic complex is composed of originally rhyolitic lavas, ignimbrites or tuffs. According to CALVINO (1961) and NAUD (1981), the metavolcanites are separated from the «Arenarie di San Vito» by a remarkable angular unconformity and the contact is sometimes marked by coarse-grained metaconglomerates.

The metamorphism of the entire Sàrrabus succession was of very low grade, so that the original structural features of the volcanites may still be recognized. Especially in the more massive types, deformations are limited to slight clastesis of the original phenocrysts, and microstructural lineaments due to penetrative schistosity are generally not present.

The lower part of the metavolcanic complex is often composed of original rhyolitic flows: white or greenish-white rocks, nearly aphanitic, with rare small «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 silicization processes of still undefined origin. Associated with the metarhyolites, and more frequently above them, there are thin layers of volcanic metasandstones and probably original tuffs, tuffites, and metaconglomerates with well-rounded pebbles of the above-described rhyolites and, more rarely, of quartzites.

The greater part of the metavolcanic complex is composed of the so-called «Porfidi grigi» (CALVINO, 1956). They consist of an ensemble of original lava-domes, lava-flows, and probable ignimbrites of rhyodacitic and subordinately dacitic composition. They are grey or sometimes blackish massive rocks without evident porphyritic structure. The abundant «phenocrysts» are represented by quartz, feldspars (microcline partially replaced by albite and albitic 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 «Arenarie di San Vito» (BARCA *et al.*, 1981a), and Caradocian, proven in the overlying formation.

3. *Punta Serpeddì 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 metarkoses, metasandstones and metaconglomerates. In the upper part, fine-grained metasandstones and grey-metasiltites, about 100 m thick, prevail. They contain rich benthonic faunas (brachiopods, bryozoa, crinoids, gasteropods, etc.) of Upper Ordovician age (BARCA & DI GREGORIO, 1979; GIOVANNONI & ZANFRÀ, 1979). The depositional environment varied from continental and littoral at the base to neritic platform upwards.

4. *Tuviois Formation*

This formation is composed of metasiltites and meta-argillites alternating with metalimestones, in general completely silicified, still containing Upper Ordovician (Ashgillian) benthonic faunas. It has a maximum thickness of several dozen metres and is a characteristic stratigraphic marker in all southern Sardinia.

Caradoc-Ashgillian fossiliferous formations are widespread over the entire low-grade Paleozoic basement and prove that, at the end of Ordovician, a marine environment had been re-established almost everywhere after the Caledonian deformations and magmatism.

5. *Serra S'Ilixi Group*

Composed of blackish, more or less carbonaceous metasandstones, metasiltites and meta-argillites, this group is intercalated with layers of «liditi» and basic metavolcanites.

Upper Llandoverian graptolites have been reported in the lower part of this group (TEICHMÜLLER, 1931; HELMCKE, 1973; JAEGER, 1977).

The upper part contains lenses of grey metalimestones with orthoceratites, 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 metasiltites with layers of brecciola, sometimes with black «liditi», 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 lense containing eo-Devonian conodonts and it also seems to be affected by the main Hercynian folds.

TECTONICS

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 Central Sardinia the main structural features are determined by a first deformation phase producing E-W trending isoclinal folds (BARCA & MAXIA, 1982) which were joined and followed by overthrusts.

Late folding phases refold 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 & MAXIA, 1982).

The overthrusts represent the most typical structural features of the region: the most important lies at the base of the Genn'Argiolas Unit («Villasalto Overthrust»: CARMIGNANI & PERTUSATI, 1977), whereas others of less importance are described either in western (BARCA & MAXIA, 1982) or in eastern Sarrabus (CARMIGNANI *et al.*, 1982).

The presence of cataclasites, containing rock-fragments belonging to the entire Paleozoic succession along almost the whole length of the tectonic contact, confirms ever more the regional importance of the «Villasalto Overthrust». In some zones, 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 Genn'Argiolas Unit, where below the Cambrian-Ordovician metasandstones the Silurian fossiliferous formations of the Gerrei crop out, should have convinced even the most tenacious autochthonists (CARMIGNANI *et al.*, 1982; BARCA & ARGIOLAS, 1985).

Regional considerations and the study of the stretched elements in the cataclasite indicate a direction of tectonic transport of the allochthonous units towards SW (CARMIGNANI & PERTUSATI, 1977; CARMIGNANI *et al.*, 1982; NAUD, 1982).

The following features provide a better definition of the chronological relations existing between folding phases and overthrusts:

— the overthrust surfaces are folded by the «late folding tectonics»;

— the rock-elements of the cataclasite show a schistosity which predate the cataclasis, and the first-phase folds are abrutly cut by the overthrusts.

The tectonic overthrusts were thus developed before the «late folding tectonics» and the units continued to move even after the «first phase».

Clast flattening and the fissility of the cataclasite groundmass suggest that the units were emplaced in a deformative regime similar to that of the first tectonic phase.

The simplest hypothesis is that the overthrusts represent the late evolution of the first phase: the deformation history would have started with folding deformations, then continued by developing shear-zones, which in turn, ended by absorbing most of the shortenings.

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DESCRIPTION OF STOPS OF THE SARRABUS EXCURSION

From Cagliari to Punta Serpeddì we will go up to Dolianova first crossing the Lower Miocene transgressive sediments and then the various terrains of the Paleozoic successions belonging to the Genn'Argiolas Unit.

— Stop 2.1 - *Punta Serpeddì: Ordovician succession of the Genn'Argiolas Unit and, in particular, the sedimentary transgression on the late Caledonian volcanic complex («Caradocian Transgression» AUCT.)* (Fig. 2.1).

The whole area between Punta Serpeddì and the Mt. Genis granite is a monocline dipping SE. From bottom to top it is composed of:

1) «Arenarie di San Vito» (Middle Cambrian-Early Ordovician);
2) Ordovician metavolcanic complex;
3) Caradocian detritic deposits (Punta Serpeddì Formation);
4) Ashgillian silicified limestones (Tuviois Formation);
5) Lower Silurian-Upper Devonian slates and metasandstones with rare metalimestones (Serra S'Ilixi Group);
6) Metasandstones, metasiltites with brecciola, probably of Lower Carboniferous age (Pala Manna Formation).

As the map and cross-sections of fig. 2.1 show, to the southwest a series of small Hercynian overthrusts produced several tectonic repetitions.

During a short walk, we will observe the Punta Serpeddì Formation lying on the volcanic complex. We start from the top of Punta Serpeddì, where a slightly metamorphic succession of conglomerate and grey, more or less micaceous sandstones with benthonic Caradocian fossils (crinoids, brachiopods, bryozoa, gasteropods, etc.) crops out.

Continuing along the NW flank of Punta Serpeddì, the contact with the underlying «Porfidi grigi» is found just under the summit. We then descend to the valley, crossing a monotonous sequence of Ordovician «porfidi» with minor metamorphic textural modification. During the day, we will be able to verify how similar and coeval lithotypes in the underlying units (Gerrei) have undergone very clear internal deformation.

Ashgillian silicified limestones crop out along the road at the bottom of the descent, where we may be lucky enough to find good specimens of brachiopods.

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 Ceraxa, we observe the typical lithologies of the «Arenarie di San Vito»: grey micaceous metasandstones, quartzites, greenish-grey, blackish or sometimes reddish-violet metasiltites and slates, with frequent parallel, undulating and convoluted laminations. This area has supplied Upper Cambrian acritarchs and *Medusa* trails.

— Stop 2.2 - *Rio Ceraxa: Contact between «Arenarie di San Vito» and «Porfidi grigi» and «Sarrabus Unconformity» conglomerates* (Fig. 2.1).

Along Rio Ceraxa, near the sheepfold at 714 m, the contact between the «Arenarie di San Vito» and the overlying pre-Caradocian volcanites («Porfidi bianchi» and «Porfidi grigi») is well exposed. It is marked by conglomerates with coarse, rounded pebbles of sandstones and quartzites of the «Arenarie di San Vito» and volcanites. Slightly east of this outcrop, marked angular unconformities between the «Arenarie di San Vito» and the volcanites have been described by Naud (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 Serpeddì, 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 steps of the eastern margin of the Sardic 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 biotite-bearing leucogranites overlain by the Miocene covers of Donori. After the ascent, along which we find dikes of pink porphyries and lamprophyres cutting the granite, we come

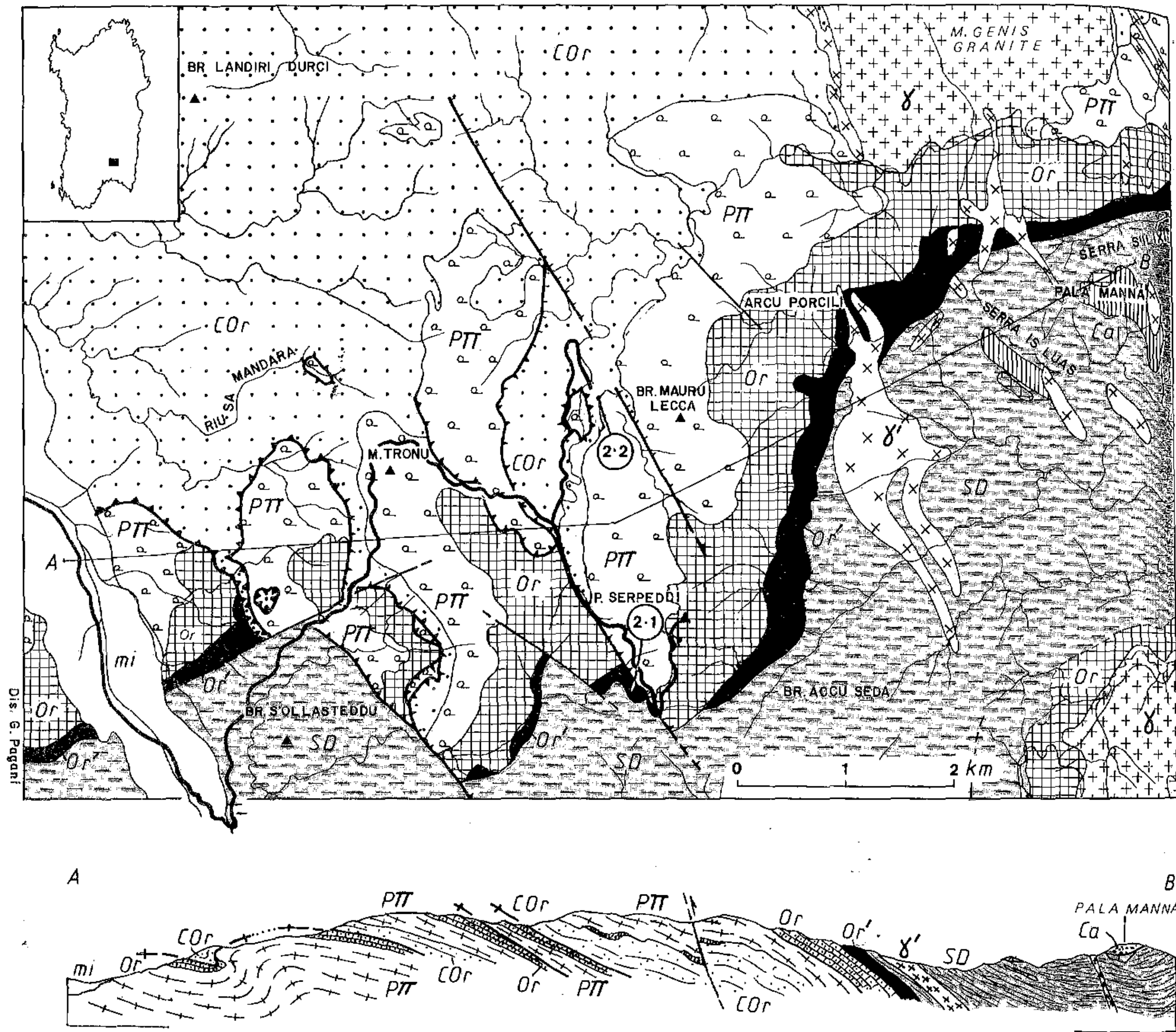

Fig. 2.1 - Schematic geological map and cross-sections of the Punta Serpeddì area with location of stops (after BARCA & MASCIA, 1982).
mi: Miocene continental deposits; γ': Granite porphyry (Carboniferous); γ: Leucogranite (Carboniferous).
Ca: Pala Manna Formation: Metasandstones and metaconglomerates (Lower Carboniferous); SD: Serra S'Ilixi Group: Metasandstones, slates with lenses of metalimestones and black quartzites (Silurian-Middle Devonian); Or': Tuviois Formation: Silicified limestones with brachiopods, bryozoa, crinoids, etc. (Ashgillian); Or: Punta Serpeddì Formation: Metaconglomerates, metasandstones and metasiltstones, with brachiopods, bryozoa, crinoids, etc. (Caradocian-Ashgillian); $P\pi$: Rhyolitic and rhyodacitic metavolcanites («Porfidi bianchi» and «Porfidi grigi» AUCT.); coarse-grained metaconglomerates are often present near the bottom («Conglomerati di Rio Ceraxa» AUCT., Ordovician); COr: «Arenarie di San Vito» (Cambrian-Early Ordovician).

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 «Arenarie di San Vito» (Cambrian-Ordovician). Beyond the village of S. Andrea Frius, the Planu Sanguini plateau stands out: a relic of the post-Hercynian peneplain, only slightly modified by Eocene transgression.

After S. Andrea Frius, along the climb to the plateau, only the Cambrian-Ordovician metasandstones of the Genn'Argiolas Unit crop out.

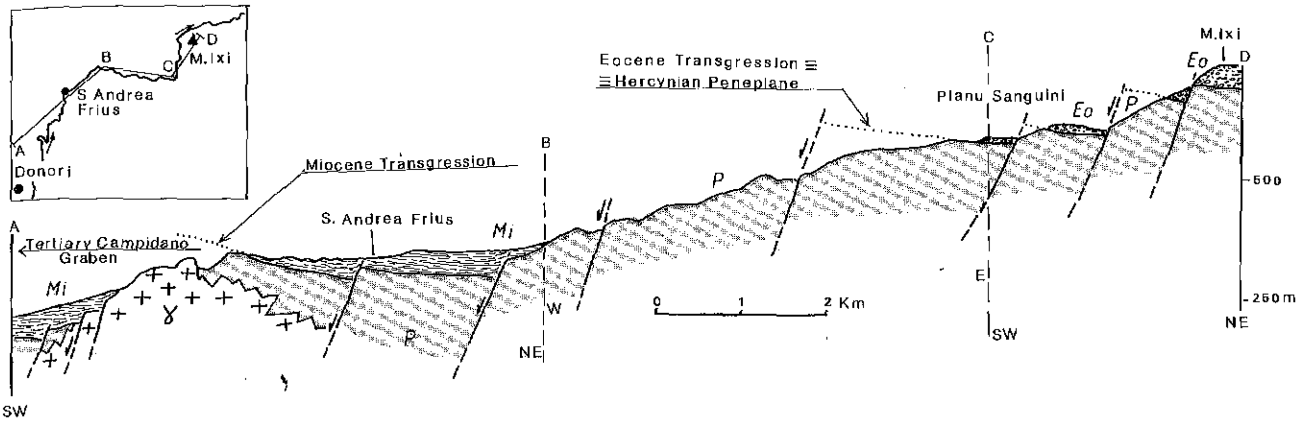

Fig. 2.2 - Cross-section of the western margin of Campidano graben (vertical exageration x 4). The Miocene and Eocene (coinciding to the post-Hercynian peneplane) transgressions are emphasized.
P: Paleozoic metamorphites; γ: Leucogranites with porphyry dikes; Mi: Miocene; Eo: Eocene.
In the insert the itinerary and the trace of the cross-section are shown.

— Stop 2.3 - *S. Andrea Frius-S. Nicolò Gerrei: A tectonic window in the Genn'Argiolas 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 tectonic window under the Cambrian-Ordovician metasandstones. Along a path near the road the basal tectonic contact of the Genn'Argiolas 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 metalimestones 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, Genn'Argiolas 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 Sanguini plateau, partially covered with Lower Eocene quartz-rich conglomerates dislocated by faults parallel to the Oligo-Miocene Rift. Continuing towards Silius, we enter the Gerrei Units; the contact with the Genn'Argiolas Unit is covered by the Eocene terrains. We then climb the spring of Is Alinos, where the «Porfiroidi» and their cover of metarkoses and metasandstones crop out («Caradocian Transgression», AUCT.). To the north the view extends to the entire valley of the Flumendosa river as far as the Gennargentu massif.

Lunch at Is Alinos spring.

Continuing towards Silius, we cross the sequence from the «Porfiroidi» to the dark schists with tentaculite-bearing nodular metalimestones which are also exposed beyond Silius as far as the junction for Villasalto. Beyond the crossroad, we again enter the «Arenarie 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 fluvial 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 metalimestones dipping under the Cambrian-Ordovician sandstones.

— Stop 2.4 - *Villasalto: The basal tectonic contact of Genn'Argiolas Unit («Villasalto Overthrust»)* (Fig. 2.4).

The overthrust between the Genn'Argiolas 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 Sàrrabus region is allochthonous above the Gerrei. Near Villasalto we will observe in detail the tectonic contact between the «Arenarie di San Vito» and the underlying nodular metalimestones containing Upper Devonian and Lower Carboniferous (Tournaisian) faunas by means of the cataclastic 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-nappe» tectonic phases (Fig. 2.4).

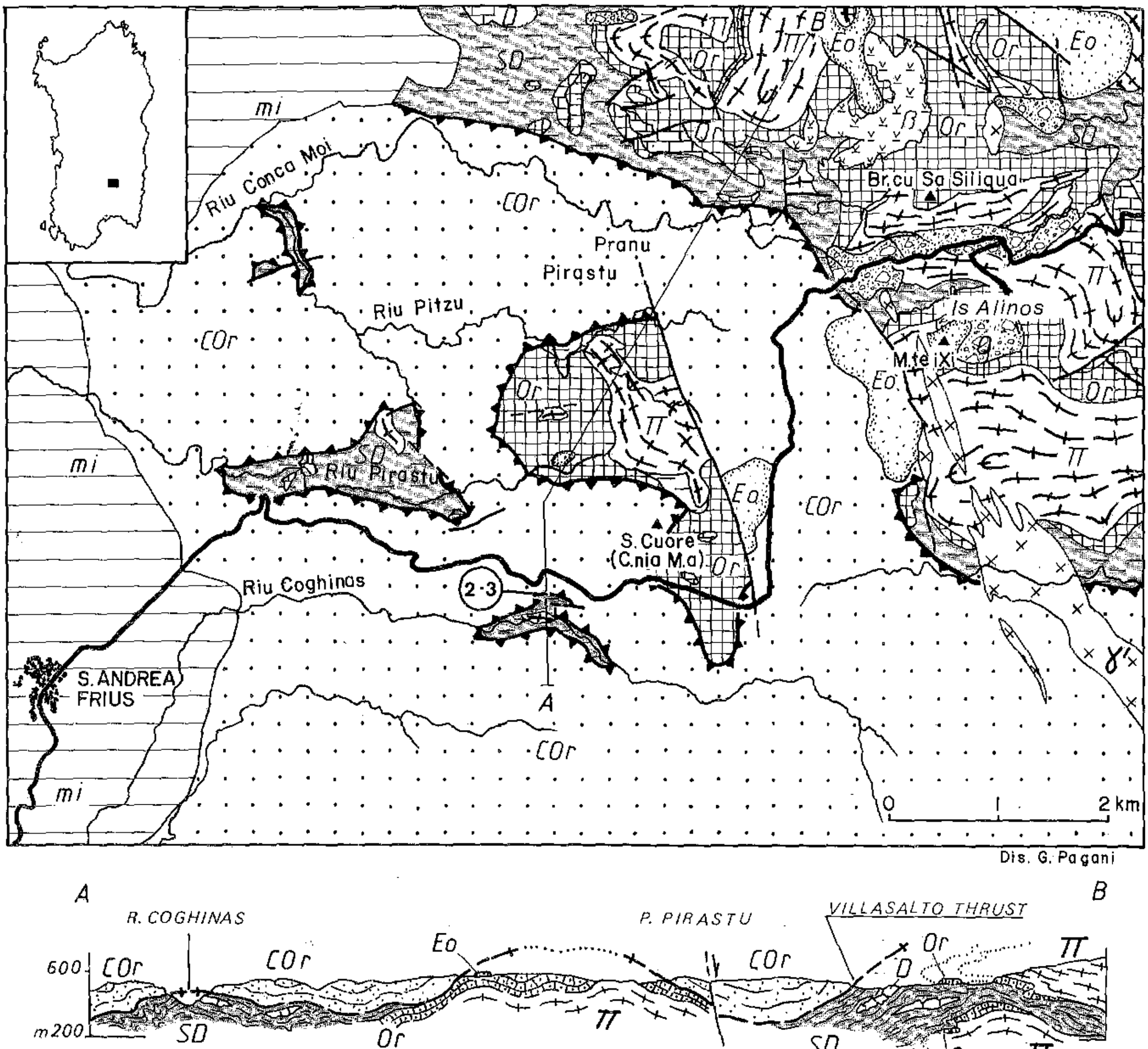

Fig. 2.3 - Schematic geological map and cross-section of the S. Andrea Frius area with location of stops.
Q: Quaternary deposits; mi: Miocene deposits; Eo: Quartzites (Eocene); γ': Granite porphyry (Carboniferous).
Genn'Argiolas Unit: COr: «Arenarie di San Vito» (Cambrian-Early Ordovician).
Gerrei Units: D: Biggest metalimestone lenses included in the Lower and Middle Devonian marly slates; SD: Marly slates with metalimestone intercalations (Lower and Middle Devonian), Graptolitic carbonaceous slates, with intercalations of dark metalimestones, black quartzites («Scisti a graptoliti» e «Liditi» AUCT., Silurian); Or: Metarkoses and metasandstones, metasiltstones and metalimestones with brachiopods, bryozoa, etc. (Upper Ordovician); β: Metavolcanites with basic and intermediate chemical characters (Ordovician); π: Metarhyolites with «augen texture» («Porfiroidi» AUCT., Ordovician).
This map is based on published and unpublished survey by M. ARGIOLAS, S. BARCA, L. CARMIGNANI, R. CAROSI, M. MORACCHIOLI & P.C. PERTUSATI.

After Villasalto, we again cross the cataclasite and descend towards the Flumendosa river.

— STOP 2.5 - *Villasalto: Mt. Atzeri, a large tectonic slice within the tectonic breccia of the «Villasalto Overthrust»* (Fig. 2.4).

Intensely foliated, Devonian metalimestones crop out half-way 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 Bruncu Siliqua and Mt. Sarbanedda, the Genn'Argiolas Unit is separated from the Gerrei Unit («Monte Lora Unit») by hundreds of metres of cataclasites and tectonic slices. Mt. Atzeri is a large tectonic slice of metasandstones

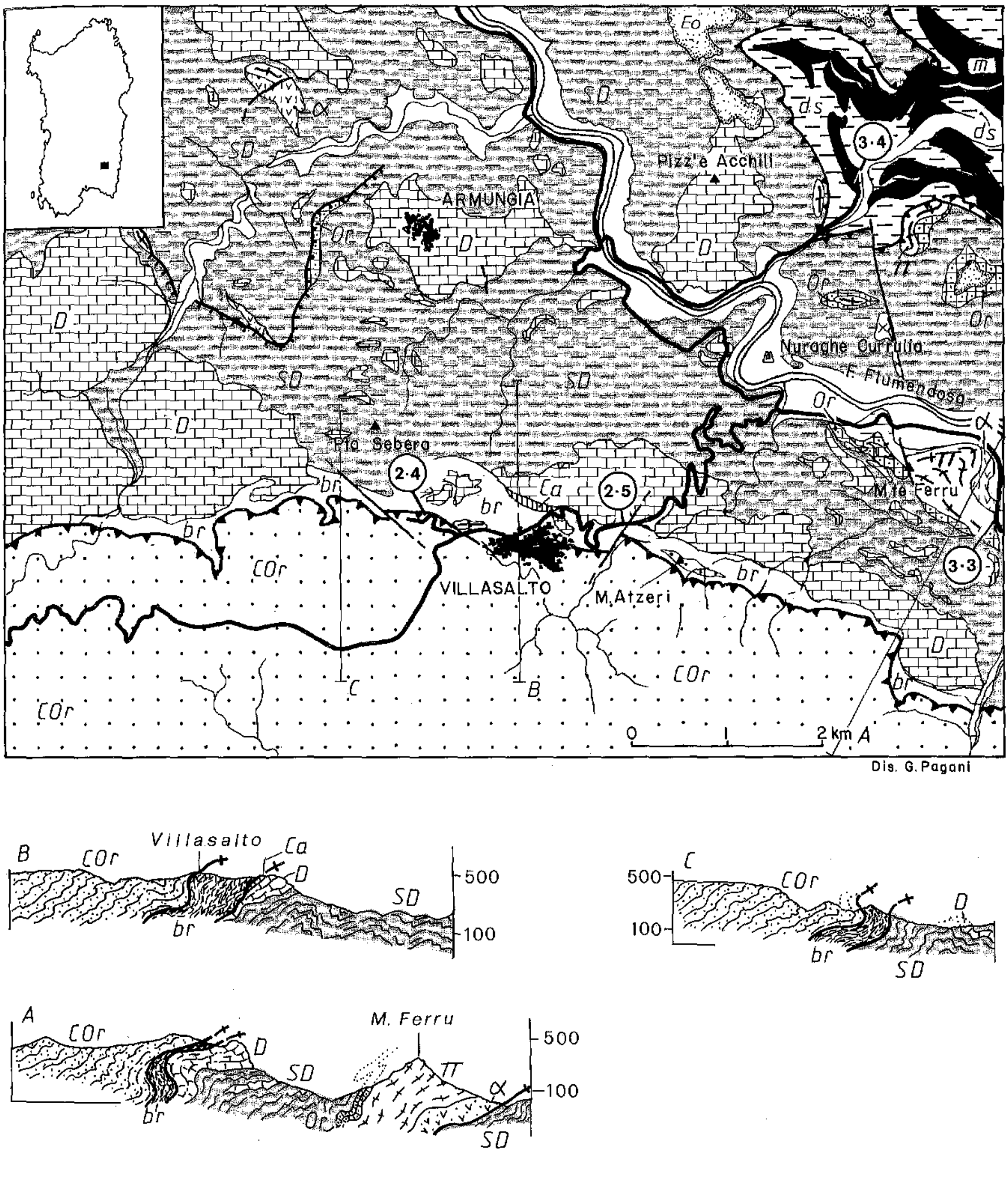

Fig. 2.4 - Schematic geological map and cross-sections of the Villasalto area with location of stops.
Eo: Eocene deposits.
Genn'Argiolas Unit: COr: «Arenarie di San Vito» (Cambrian-Early Ordovician); br: Polygenic tectonic breccias constituted mainly by Silurian black slates.
Gerrei Units: Ca: Metaconglomerates (Lower Carboniferous); D: Metalimestones (Upper Devonian-Lower Carboniferous), this symbol means also the largest limestone lenses included in the Lower and Middle Devonian marly slates; SD: Marly slates with intercalations of metalimestones (Lower and Middle Devonian), Graptolitic carbonaceous slates with intercalations of dark metalimestones, black quartzites («Scisti a Graptoliti» e «Liditi» AUCT.) (Silurian); Or: Metasilstones with brachiopods, bryozoa etc., metarkoses and metasandstones (Upper Ordovician); π: Metarhyolites with «augen texture» («Porfiroidi» AUCT.) (Ordovician); α: Metamorphic products of reworked volcanites and intermediate to acid metavolcanites (Ordovician).
Castello di Quirra Unit: m: Marbles and calc-schists (Devonian?); ds: Phyllites and metasandstones (Upper Ordovician-Devonian?).
This map is based on published and unpublished surveys by L. CARMIGNANI, G. OGGIANO, P.C. PERTUSATI.

and «Porfiroidi» embedded within the cataclasites.

Descending to the Flumendosa river, we cross an huge outcrop of phyllites and metalimestones: the Siluro-Devonian sequence was probably tectonically repeated several times.

We continue without further stops down the course of the lower Flumendosa river to Muravera.

Guide-book to the Excursion on the Paleozoic basement of Sardinia
IGCP project no. 5 - Newsletter 1986, special issue, 61-71

Theme of excursion of third day

THE GEOLOGY OF GERREI

by L. CARMIGNANI, M. GATTIGLIO, M. MAXIA, G. OGGIANO & P.C. PERTUSATI

SUBJECTS: *Paleozoic series and Gerrei tectonic Units. The innermost Units in central Sardinia: «Castello di Quirra» Unit.*

ITINERARY: *Muravera, San Vito, Lower Flumendosa valley, Rio Gruppa valley, Ballao, San Vito, Villaputzu, Muravera.*

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 Grighini. The units implied in the antiform are covered by the Genn'Argiolas 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 culminations 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 NAUD (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 NAUD (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 crinoid remnants in marbles 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 Metasandstones*

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 (NAUD & PITTAU DEMELIA, 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 metasandstones underlying the Ordovician metavolcanic complex, and often separated from it by levels of metaconglomerates, have been referred to as Cambrian-Ordovician (CARMIGNANI *et al.*, 1982). It deals with more or less quartzitic micaceous metasandstones, alternating with slates and metasiltites similar (in sedimentary structure too) to the Cambrian-Ordovician «Arenarie di San Vito» or to the «Arenarie di Solanas».

Owing to the scarcity of biostratigraphic data and the lithological similarity to an Upper Ordovician formation, the actual boundary of the Caledonian series in the Gerrei is still probably very approximate.

However, even if all the metasandstones of «incertae sedis» were attributed to Cambrian-Ordovician, the extent of the Caledonian outcrops remains very limited, clearly inferior to that of the Cambrian-Ordovician formations in the Genn'Argiolas or Meana Sardo Units. This subject will be discussed again in the part dedicated to tectonics.

2. *Ordovician Metavolcanic Complex*

The base of this complex is mainly volcano-sedimentary and consists of volcanic metasandstones and metaconglomerates with intercalations of grey porphyritic metavolcanites ranging in composition from rhyodacite to andesite.

Above this complex, separated by a metasedimentary sequence composed of metaconglomerates, quartzites, arkosic metasandstones and black metasiltites, lie massive silicic metavolcanites, up to 200 m thick with evident augen fabric («porphyroids with small phenocrysts»: CALVINO, 1961) derived from both lava flows and lava domes.

The metavolcanics are generally covered by feldspathic metasandstones clearly derived from the underlying volcanites, and followed by the Caradocian metasediments.

Although this succession could be defined the most frequent, slight differences are found in some units. For example, in the Arcu de Su Bentu Unit (CARMIGNANI *et al.*, 1982), under the Upper Ordovician levels, we first find meta-arkoses and then massive «Porfiroidi» with augen texture, determined by the presence of large «phenocrysts» (1-20 cm.) of potassic feldspar («porphyroids with large phenocrysts»). This type of porphyroids occurs in the Lower Flumendosa valley near S. Basilio and further North as far as Sarcidano. They correspond to original rhyolites, probably in the form of large domes or perhaps subvolcanic bodies. They are frequently associated with «porphyroids with small phenocrysts» (original lavas and partly arkosic sandstones).

Most of these metavolcanites show marked clastesis of the phenocrysts and strong recrystallizations of both quartz and feldspar (currently composed of albite + microcline), of which only pseudomorphic flakes of sericite sometimes remain; mafic minerals are in general completely transformed.

The more recent metavolcanites of the entire volcanic Ordovician complex are intercalated in the Upper Ordovician fossiliferous metasediments. They are fine-grained, greenish-grey intermediated and mafic metavolcanites associated with volcanic metagraywackes. These volcanites appear discontinuously over the whole Gerrei, although rare intercalations are also found in the Upper Ordovician of the Iglesiente. 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 plagioclasic phenocrysts and chloritic-epidote flakes, probably referable to original mafic crystals. The quite common presence of rounded aggregates of quartz, calcite or even chlorite, which are easily visible to the naked eye, suggests derivation from basalts with vescicular texture. Probably, some of the compositional features of these metabasalts also derived from their original spilitic character (LEHMANN, 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 dismantling of the volcanoes, and an upper part composed of finer metasediments, still of shallow marine type but less coastal, characterized by rich benthonic fauna indicating re-establishment of a marine environment after the Caledonian 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 metaconglomerates.

2 - Greenish or reddish, silty or sandy, carbonatic phyllites, sometimes with a typically vacuolar aspect due to the dissolution of fossils. They contain benthonic fauna with bryozoa, crinoids, brachiopods, etc. Bodies of reddish metalimestones are locally intercalated, composed almost entirely of crinoid remains (encrinites); when they are partially or totally silicified, they are identical in aspect to those of the Tuviois Formation of the Sarrabus. Also metabasites are characteristic intercalations.

4. *Silurian-Devonian Metasediments*

Mainly incompetent rocks, these are often found as «imprisoned» along the overthrusts, 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 expecially in Lower Devonian, rather uniform sedimentation conditions involved huge areas: biofacies and lithofacies indicated that the mainly coastal conditions of Upper Ordovician became more pelagic in a basin which was oxigenated on the surface and reduced at the bottom (GNOLI *et al.*, 1979).

The base of the sequence, generally attributed to Silurian, is composed of black quartzites («liditi») alternating with carbonaceous phyllites with graptolites and rare lenses of *Orthoceras*-bearing metalimestones.

Certain successions contain sequences with an apparent thickness of about 100 m composed of dark quartz-rich metasandstones.

This succession passes continuously to Lower and Middle Devonian and is composed of an alternation of dark or black phyllites and nodular metalimestones with tentaculites. In the Lower Flumendosa valley, the apparent thickness of these formations reaches several hundreds metres, although it is very probable that they are tectonically repeated at the base of the Genn'Argiolas Unit.

Between Mt. Lora and S. Nicolò Gerrei, this succession continues with a thick layer of nodular metalimestones (Upper Devonian-Tournaisian: LOVISATO, 1894; OLIVIERI, 1970). Apparent thickness may reach hundreds of metres, although repetitions probably also exist in this formation.

Near Villasalto, above the Upper Devonian-Tournaisian metalimestones, several dozen metres of metasandstones and metaconglomerates have been reported, representing the «passage to the terrigenous domain» of the Devonian-Lower Carboniferous carbonatic platform (TEICHMÜLLER, 1931; SPALLETTA & VAI, 1982; BARCA & SPALLETTA, 1984).

TECTONICS

The Hercynian structuring is more intense in the Gerrei Units than in the Genn'Argiolas one. For instance, the acid metavolcanics, which preserve much of their original fabric in the Genn'Argiolas Unit, almost always show a markedly augen texture in the Gerrei Units («Porfiroidi»).

Except for this higher «strain», probably due to their innermost position in nappes-pile, the entire structural framework is similar to that above-described for the Genn'Argiolas Unit. Also in the Gerrei Units, the Hercynian tectonics consists of:

a) a synmetamorphic 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 overturned towards S, SW or W. This variability results both 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 Flumendosa valley (CARMIGNANI *et al.*, 1982) and near San Basilio (NAUD, 1982). Slickensides on tectonic contacts and also research studies on the elongated elements in the cataclasites suggest that the tectonic transport occurred from NNE towards SSW.

The tectonic elements of the first phase deformation and the overthrusts are overturned by two fold systems with NNE-SSW and NW-SE trending axes. The main «post-nappe» structure trending NW-SE is the complex antiform of the Flumendosa valley which refolds all the allochthonous units and makes the innermost units crop out in correspondence to the main axial culminations: Castello di Medusa Unit and Castello di Quirra Unit. Although the metamorphic grade of these units still remains within the greenschists facies, they show a slightly higher grade which is clearly visible above all in the carbonatic formations 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 Gennargentu 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 Genn'Argiolas 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 large recumbent folds with more or less preserved inverse limbs, rooted to the north-eastern limb of the

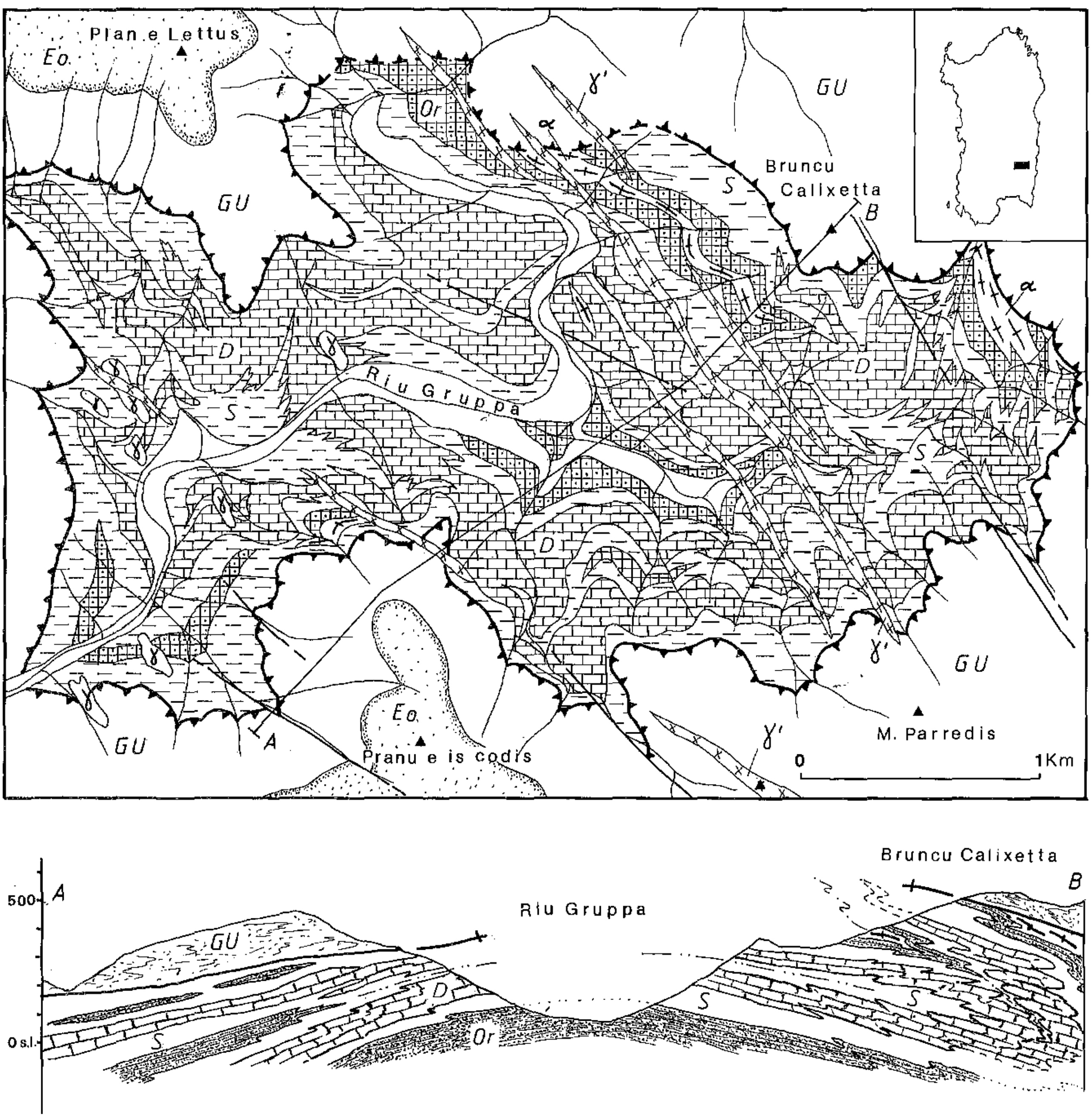

Fig. 3.1 - Schematic geological map and cross-section of the Rio Gruppa area.
Eo: Eocene deposits; γ': Most thick acid porphyry dikes; γ: Basic porphyrites. GU: Gerrei Units.
Castello di Quirra Unit: D: Marbles and calc-schists (Devonian?); S: Black phyllites (Silurian?); Or: Quartzites and metasandstones (Upper Ordovician); α: Metamorphic products of reworked volcanics and acid metavolcanics (Ordovician).
This map is based on published and unpublished surveys made by B. CAPPELLI & A. MORETTI.

Flumendosa valley antiform and ending as «tête 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 lamination 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 costituted by the Genn'Argiolas-Arburese-Meana Sardo Units.

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DESCRIPTION OF STOPS OF THE GERREI 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 Genn'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 metavolcanites and metavolcanoclastites 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 - *Cantoniera Mt. Lora: View of the overthrust 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 Cantoniera 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.

Naud & Pittau Demelia (1985) have reported acritarch-dated Middle and Upper Cambrian metasandstones associated with the porphyroids, and maintain that these porphyroids are therefore older than Middle Cambrian.

The Early Ordovician metasandstones (Tremadoc-Arenigian; Naud & Pittau Demelia, 1985) overlie this unit with tectonic contact; the metasandstones are covered in turn by the metavolcanites and metavolcanoclastites: they constitute the Mt. Rocca de Nuxi (Fig. 3.2).

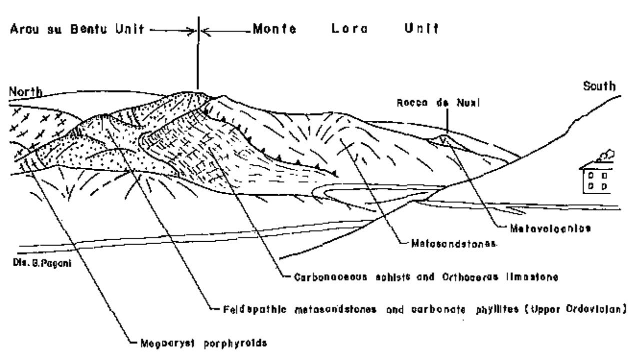


Fig. 3.2 - View of the tectonic contact between the Mt. Lora and Arcu de su Bentu Units.

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 laminated and the Mt. Lora Unit lies almost directly on «Porfiroidi» with megacrysts (see next stop).

— Stop 3.2 - *East of Mt. Ferro: pre-Caradoc succession of Mt. Lora Unit and tectonic contact with 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) Feldspathic quartzites and metasandstones immediately underlying the Upper Ordovician fossiliferous layers;

2) «Porfiroidi»;

3) Acid to, more rarely, intermediate metavolcanites and abundant metamorphic rocks deriving from the sedimentary reworing of volcanic materials.

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

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 constituted by:

1) «Porfiroidi»;
2) Meta-arkoses;
3) Upper Ordovician fossiliferous metasiltites;
4) Silurian «liditi» and graptolite carbonaceous schists;
5) Grey or carbonaceous phyllites with Lower and Middle Devonian nodular metalimestones.

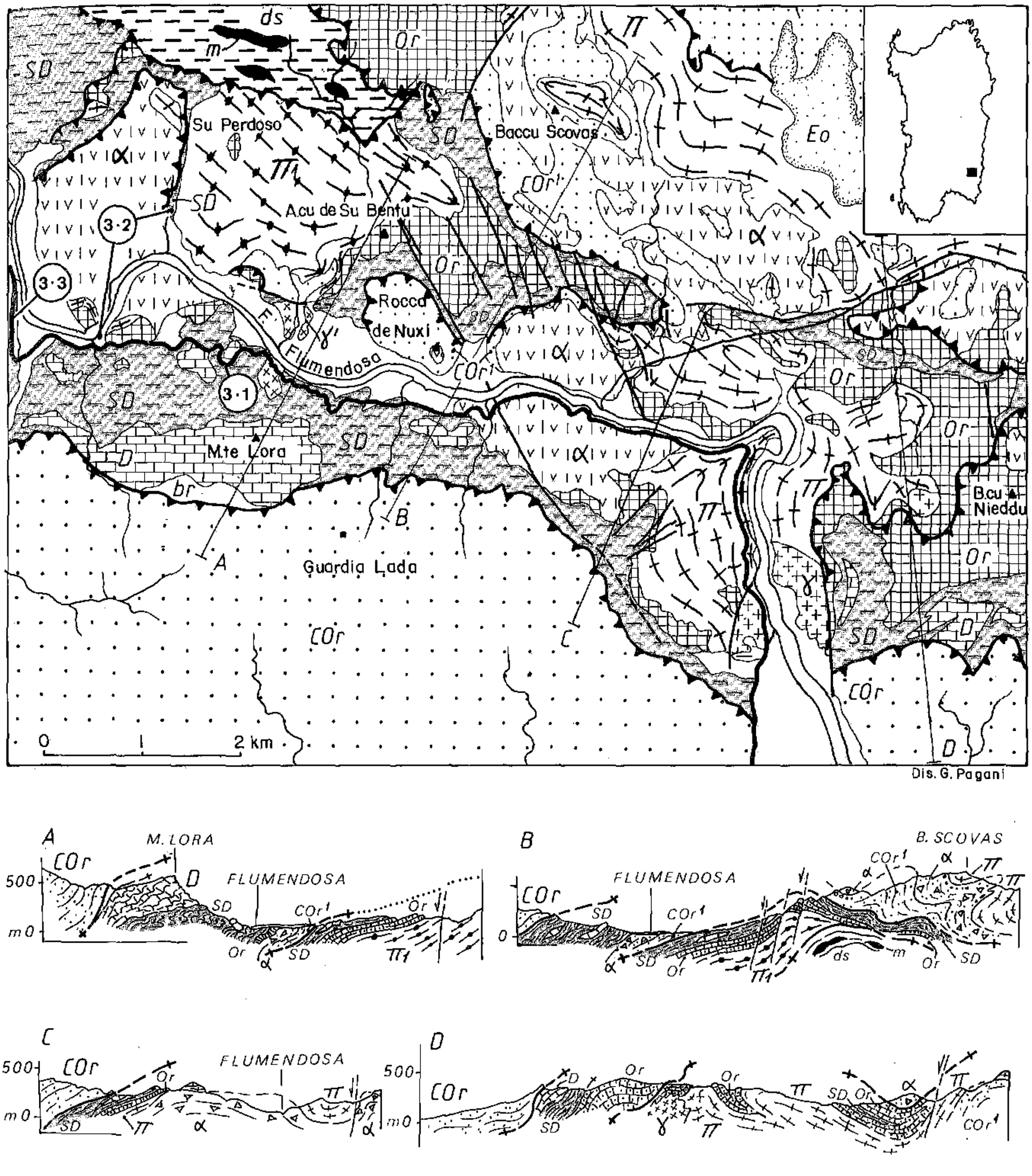


Fig. 3.3 - Schematic geological map and cross sections of the Mt. Lora area with location of stops.
Eo: Quartzites (Eocene); γ': Most thick acid porphyry; γ: Leucocrate microgranite.
Genn'Argiolas Unit: COr: «Arenarie di S. Vito» (Cambrian-Early Ordovician); br: Polygenic tectonic breccias, mainly constituted by Silurian black slates.
Gerrei Units: D: Metalimestones (Upper Devonian-Lower Carboniferous), this symbol also means the largest carbonatic lenses included in the Lower and Middle Devonian marly slates; SD: Marly slates, with metalimestone intercalations (Lower and Middle Devonian), Graptolitic carbonaceous slates, with intercalations of dark metalimestones, black quartzites («Scisti a Graptoliti» and «Liditi» Auct.) (Silurian); Or: Metarkoses and metasandstones, metasiltstones and metalimestones with brachiopods, bryozoa, etc. (Upper Ordovician); π: Metarhyolites with «augen texture» («Porfiroidi» Auct.) (Ordovician); π_1: Metarhyolites with large «phenocrysts» of K-feldspar (Ordovician); α: Metamorphic products of reworked volcanics and intermediate to acid metavolcanics (Ordovician); COr_1: Metasandstones (Cambrian-Early Ordovician).
This map is based on published and unpublished surveys by L. Carmignani, M. Gattiglio, G. Oggiano, M. Mascia, G. Naud, P.C. Pertusati & E. Sarria.

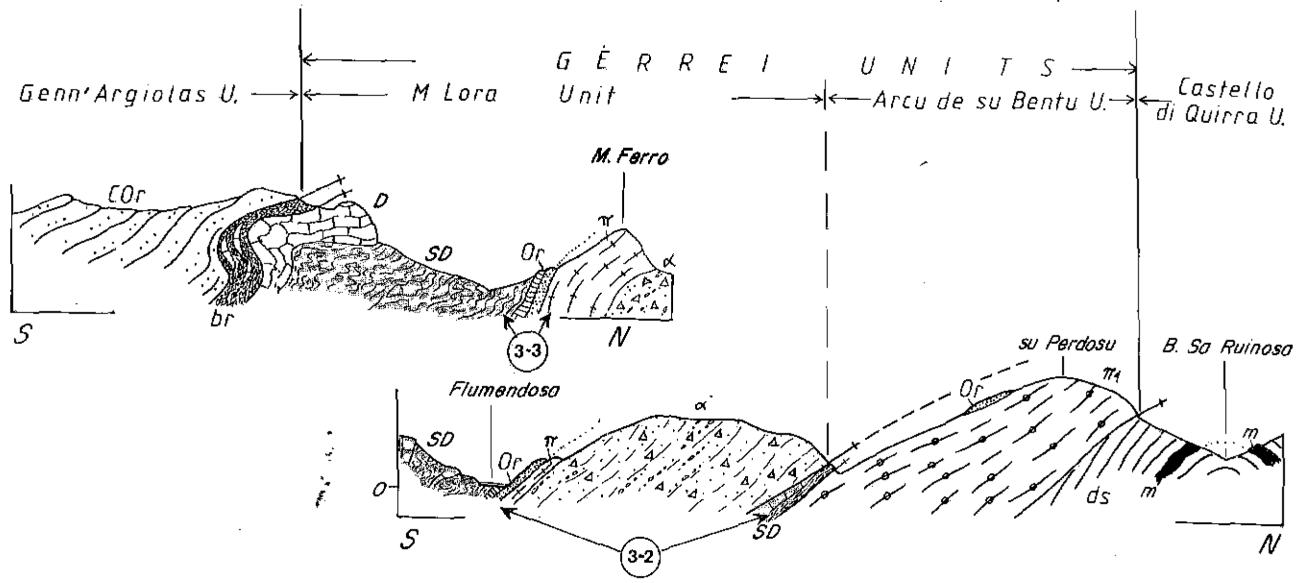


Fig. 3.4 - Section across lower Flumendosa valley with location of stop 3.2 and 3.3 (from CARMIGNANI *et al.*, 1982).
Genn'Argiolas Unit: Cor: «Arenarie di San Vito» (Cambrian-Early Ordovician); br: Polygenic tectonic breccias constituted mainly by Silurian black slates.
Gerrei Units: D: Metalimestones (Upper Devonian-Lower Carboniferous); SD: Marly slates with metalimestones intercalations (Lower and Middle Devonian), graptolitic carbonaceous slates, with intercalations of dark metalimestones, black quartzites («Scisti a Graptoliti» e «Liditi» AUCT.) (Silurian); Or: Metasiltstones with brachiopods, bryozoa, etc., metarkoses (Upper Ordovician); π: Metarhyolites with «augen texture» («Porfiroidi» AUCT.) (Ordovician); π_1: Metarhyolites with large «phenocrysts» of K-feldspar (Ordovician); α: Metamorphic products of reworked volcanites and intermediate to acid metavolcanites (Ordovician).
Castello di Quirra Unit: m: Marbles and calc-schists (Devonian?); ds: Phyllites and metasandstones (Upper Ordovician-Devonian?).

Towards the south, the succession is completed with Upper Devonian-Tournaisian metalimestones composing the limestone cliff of Mt. Lora, overthrusted by the «Arenarie di San Vito» to the south.

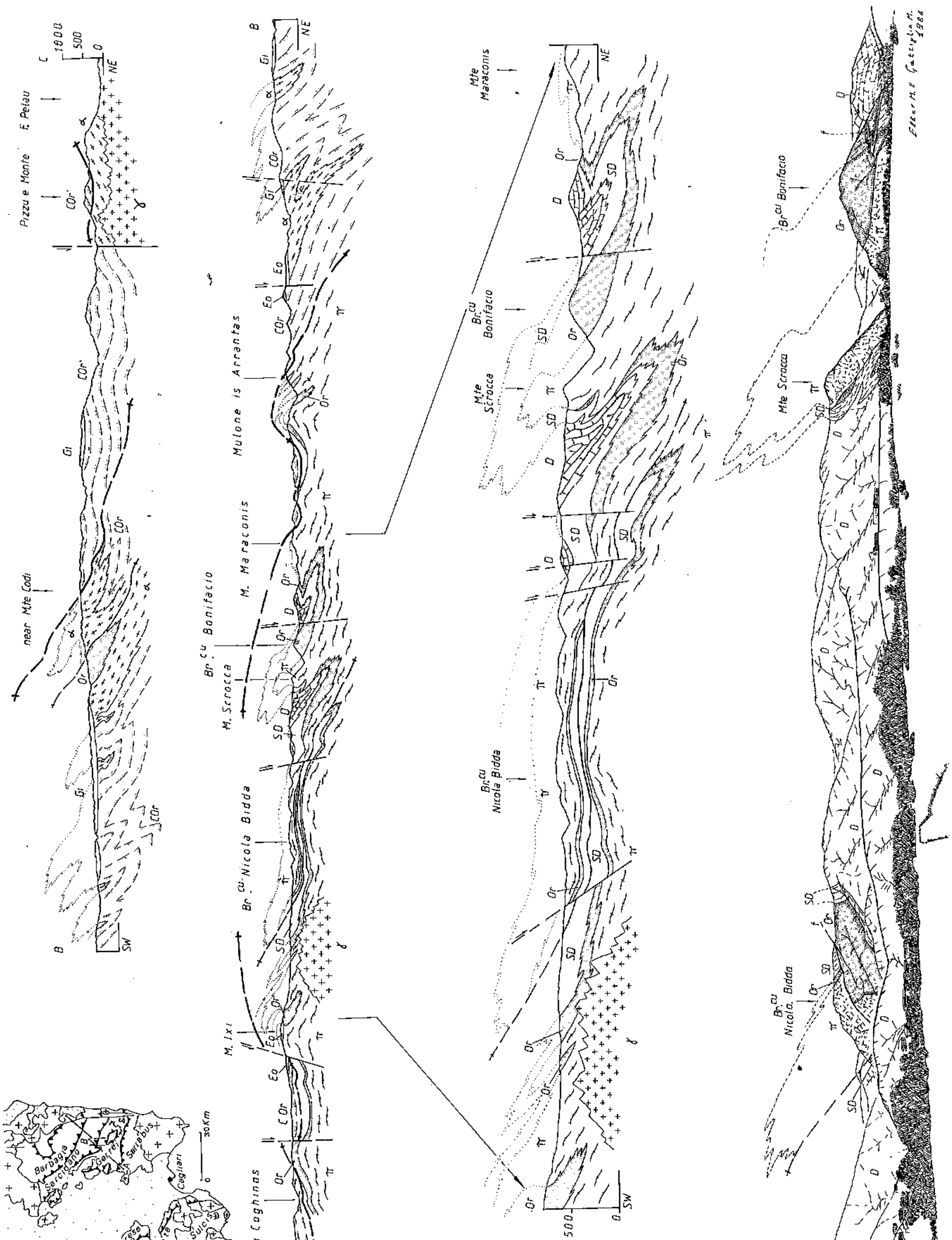
We climb the valley of the Flumendosa river, remaining among the Silurian-Devonian phyllites and metalimestones, and enter the valley of the Rio Gruppa as far as the core of the nappe antiform of the lower Flumendosa valley where the deepest unit of the nappe zone of Central and Central-Southern Sardinia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

— STOP 3.4 - *Rio Gruppa 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.

Fig. 3.5 - In the lower part view of the mountains near Ballao from the stop 3.5; geological section of the above-mentioned view. In the higher part sections A-B and B-C the allochthonous units of Central Sardinia.
Eo: Quartzites (Eocene); Gi: Jurassic limestones and dolostones; γ: Hercynian granitoids.
Low grade metamorphic complex of Barbagia: COr': Metasandstones and phyllites («Postgotlandiano» AUCT.) (Cambrian-Lower Ordovician?).
Meana Sardo Unit: Or: Metarkoses and metasandstones, metasiltstones with brachiopods, bryozoa etc. (Upper Ordovician); α: Mt. Corte Cerbos, Manixeddu, Serra Tonnai Formations: metarhyolites, metamorphic products of reworked volcanites, metavolcanites with intermediate chemical characters (metandesites) (Ordovician); COr: «Arenarie di Solanas» (Cambrian-Lower Ordovician).
Genn'Argiolas Unit: COr: «Arenarie di San Vito» (Cambrian-Early Ordovician).
Gerrei Units: D: Metalimestones (Middle Silurian-Upper Devonian); SD: Marly slates, metalimestone intercalations, graptolitic carbonaceous slates, with intercalations of dark metalimestones, black quartzites («Scisti a graptoliti» e «Liditi» AUCT.) (Lower Silurian-Middle Silurian). Or: Metarkoses quartzites and metasandstones, metasiltstones and metalimestones with brachiopods, bryozoa, etc. (Upper Ordovician). π: Metarhyolites with «augen texture» («Porfiroidi» AUCT.) and metarhyolites with large «phenocrysts» of K-feldspar (Ordovician). Near Mt. Maraconis this simbol) also means metamorphic product of reworked acid volcanites (Ordovician).


Pizzu e Monte
F. Pelau
near Mte Codi
Riu Coghinas
M. Ixi
Br. cu Nicola Bidda
M. Scrocca
Br. cu Bonifacio
M. Maraconis
Mulone is Arrantas
Mte Maraconis
Mte Scrocca
Battao
Barbagia
Sarcidano
Gerrei
Sarrabus
Arburese
Iglesiente
Sulcis
Cagliari
30Km
SW
NE
1000
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Ettore M.E. Cottiglio M. 1986

Fig. 3.5

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 Flumendosa along the Gerrei road to Ballao. Silurian-Devonian formations of the Gerrei Units crop out all along the road.

— STOP 3.5 - *Road to Rio Stanali: view of a section of recumbent folds of the Gerrei Units.*

The view and profile show in fig. 3.5 the structural style of isoclinal folds overturned towards S to SW, refolded into antiforms and synforms together with the overlying units.

Cross section A-B of fig. 3.5 shows that, slightly north of Ballao, the series of «Gerrei type» are tectonically overlain by the Cambrian-

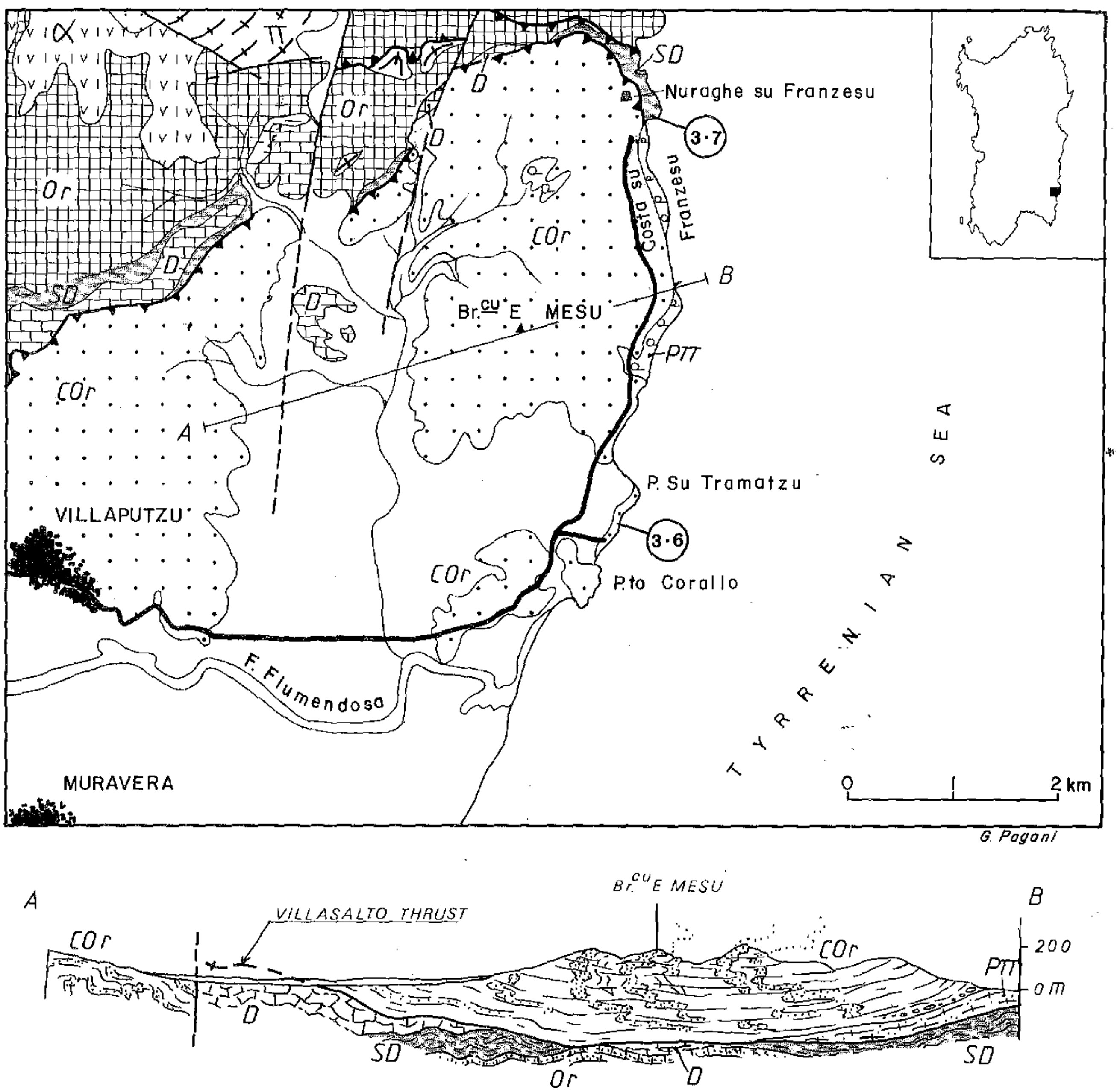

Fig. 3.6 - Schematic geological map and cross section of the Villaputzu area with location of stops.
Genn'Argiolas Unit: Pπ: Metarhyolites and metamorphic products of reworked volcanites (Ordovician); COr: «Arenarie di San Vito» (Cambrian-Early Ordovician).
Gerrei Units: D: Metalimestones (Devonian); SD: Marly slates with metalimestones intercalations (Lower and Middle Devonian), graptolitic carbonaceous slates with intercalations of dark metalimestones, black quartzites («Scisti a graptoliti» e «Liditi» AUCT.) (Silurian); Or: Metasandstones and metarkoses (Upper Ordovician); α: Acid to intermediate metavolcanites (Ordovician); π: Metarhyolites with «augen texture» («Porfiroidi» AUCT.) (Ordovician).
This map is based on published and unpublished surveys by L. CARMIGNANI, M. GATTIGLIO, M. MAXIA & P.C. PERTUSATI.

Ordovician metasandstones known in literature as «Arenarie di Solanas», constituting the base of the Meana Sardo Unit. According to the authors, the Meana Sardo Unit is to be correlated directly with the Genn'Argiolas 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' Argiolas Unit.

— STOP 3.6 - *Porto Corallo: sedimentary structures in «Arenarie di San Vito» and the vergence of folds of first Hercynian deformation phase* (Fig. 3.6).

The outcrops along the narrow strip of coastline from Porto Corallo to Punta su Tramatzu show sedimentary structures, such as cross-bedding and well-developed flute-casts, showing that stratification was overturned for at least 800 m.

The geometry of the folds and the relations between stratification and schistosity, both in overturned and normal flanks (outcropping on the higher land to the NW: Bruncu e Mesu), indicate that the structures are overturned towards the west (see cross-section of fig. 3.6).

— STOP 3.7 - *Nuraghe su Franzesu: overthrust of Genn'Argiolas Unit on Gerrei Units and mesoscopic polyphase tectonics* (Fig. 3.6).

Along the coast from Torre Motta to Costa su Franzesu, a thin strip of Ordovician metavolcanites, metavolcanoclastites and metaconglomerates crops out under the «Arenarie di San Vito».

At the Nuraghe Su Franzesu, the Genn'Argiolas Unit overthrusts one of the Gerrei Units. Just passed the overthrust surface, stressed by a cataclastic belt, we enter the sequence of sometimes carbonaceous schists and thin alternations of marly slates and metalimestones 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.

Guide-book to the Excursion on
the Paleozoic basement of Sardinia
IGCP project no. 5 - Newsletter 1986, special issue, 73-85

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. PERTUSATI

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

ITINERARY: *Muravera - Ballao - Escaplano - Monte S. Vittoria - Esterzili - Seui - Cantoniera Arquerì - Lanusei - Arcu Correboi - Nuoro.*

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 Genn'Argiolas Unit out cropping to the south-west of the Flumendosa antiform; the latter crops out in correspondence to the Gennargentu massif and corresponds to the low grade metamorphic complex of Barbagia, Goceano 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» (metarhyolites and metarhyodacites) underlying the Cambrian-Early Ordovician metasandstones («Arenarie di Solanas») and thus considered pre-Cambrian;

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

Recent research (CARMIGNANI *et al.*, 1985) indicate that the Cambrian-Ordovician «Arenarie 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 nappe zone units, begins with the Cambrian-Ordovician metasandstones («Arenarie di San Vito», «Arenarie di Solanas» etc.) (Fig. 2 of CARMIGNANI *et al.* this volume).

1. *«Arenarie di Solanas» Formation*

The «Arenarie di Solanas» Formation consists of a metric to decimetric alternation of more or less quartz-rich metasandstones, metasiltites and grey-olive 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 metaconglomerates is reported in the middle part whereas the top is characterized by red metasiltitic levels.

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

In the Sarrabus region, the formation can be correlated with the «Arenarie di San Vito» and, to the south-west of the Campidano plain, with the Cambrian-Ordovician metasandstones of the Arburese Unit. They all have to be related to similar depositional environments.

2. *The Ordovician Metavolcanic Complex*

As in the Sarrabus region, the contact between the Cambrian-Early Ordovician metasandstones and the overlying Middle Ordovician metavolcanic-sedimentary complex is often marked by metaconglomerates with elements of metasandstones and acid metavolcanites.

The lower part of the volcanic complex is constituted by white metarhyolites with rare and small-sized quartz and K-feldspar «phenocrysts» enclosed in a microcrystalline more or less sericitic groundmass sometimes hardly silicified («Mt. Corte Cerbos Formation»: BOSELLINI & OGNIBEN, 1968).

Towards the upper part of the complex, there is a prevalence of usually coarse-grained metavolcanoclastites (volcanic metasandstones and metaconglomerates) in which typical white rhyolitic fragments are very frequent («Manixeddu Formation»: BOSELLINI & OGNIBEN, 1968).

Those volcanoclastic facies, often with remarkable thickness, mainly derive from the erosion of original volcanoes composed of acid porphyritic lithologic types and phenocryst-poor rhyolitic lavas similar to those at the bottom of the complex.

Towards the top of the metavolcanic-sedimentary complex, levels of chloritic-epidotic schists appear increasingly frequent. They are more or less rich in plagioclase and sometimes, quartz «phenoclasts» and «phenocrysts», considered to derive from original tuffites or volcanic graywackes and minor horizons of andesitic to basaltic volcanites. The latter are characterized by microporphyritic structures, which can often be recognized in spite of the widespread schistosity. These structures are delineated by remnants of plagioclase phenocrysts (now albite) and by the usual chloritic and/or epidotic pseudomorphic aggregates on original mafic minerals («Serra Tonnai Formation»: BOSELLINI & OGNIBEN, 1968).

The age of the metavolcanic-sedimentary complex is included in both Arenigian (age of the upper part of the «Arenarie di Solanas Fm.»), and Caradocian (age of the overlying fossiliferous metasediments). The thickness in the whole metavolcanic-sedimentary complex in the Sarcidano region reaches 400-500 m.

3. *The Upper Ordovician Metasediments*

The Upper Ordovician succession in the Sarcidano region is similar to the succession either in Gerrei or Sàrrabus. Sometimes this formation in Sarcidano is characterized by much higher thickness.

Also here the Middle Ordovician metavolcanites are covered by more or less arkosic metasandstones and quartzites («Orroeledu Fm.»: BOSELLINI & OGNIBEN, 1968) with a variable thickness (from some to 150-200 m). Greenish metasiltites, slates and metasandstones set above («Bruncu su Pizzu Fm.»: BOSELLINI & OGNIBEN, 1968).

Even this formation presents a most variable thickness (from a few to hundreds of metres). Upper Ordovician fossils have also been found (NAUD, 1979).

4. *The Silurian-Devonian Metasediments*

Representing the youngest formations of the Unit, these constitute a more or less laminated horizon, which crops out from the village of Meana Sardo to the Tyrrhenian coast.

Except for the slightly higher recrystallization, this sequence has much in common with the coeval one in the Iglesiente, Sàrrabus and Gerrei regions. It is composed of black quartzites («liditi» AUCT.), carbonaceous phyllites and nodular metalimestones. In some places, the presence of basic metavolcanites levels, referable to original alkaline basalts of continental rift environments (RICCI & SABATINI, 1978; MEMMI *et al.*, 1982, 1983), have been pointed out. The whole succession varies in thickness because of the frequent tectonic laminations, it may even reach 400 m.

Although no paleontological research still exists, such succession might include at least the Devonian age.

5. *The Problem of «Postgotlandiano» AUCT)*

A mainly terrigenous complex known as «Postgotlandiano» lies above the Silurian-Devonian formations of the Meana Sardo Unit. For a long time, it has been thought to be in stratigraphic succession over the Silurian-Devonian formations (therefore the «Postgotlandiano» name) and also to be referred to the Carboniferous. Some authors (BOSELLINI & OGNIBEN, 1968; NAUD, 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 consideration that the «Postgotlandiano» AUCT. 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 reported in the 1:500.000 map «Structural Model of the Hercynian Basement of Sardinia» 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 (DESSAU *et al.*, 1982). As the surveys are completed structural framework will probably result more complicated.

THE GENNARGENTU UNIT

This unit is mainly constituted by a monotonous alternation of metasandstones, metasiltites and phyllites which crop out widely in the southern flank of the Gennargentu massif. From a stratigraphic viewpoint, no fossils have never been found out in this formation. It could be referable to the Cambrian-Early Ordovician age for the following reasons:

a) lithologic affinity with the Cambrian-Ordovician metasandstones found in the rest of Sardinia («Arenarie di S. Vito», «Arenarie di Solanas»);

b) presence of a succession constituted by acid metavolcanites, metarkoses and quartzites, carbonaceous phyllites and marbles with conodonta of Devonian age (PILI & SABA, 1975) in the north-eastern flank of Mt. Gennargentu. It probably represents a Middle Ordovician-Devonian stratigraphic cover of the «Postgotlandiano» of Gennargentu.

THE FONTANA BONA UNIT

A recent study carried out on the Arcu Correboi zone by DESSAU *et al.* (1982) allowed to distinguish at least an other unit overlying the Gennargentu one.

At Arcu Correboi, the Devonian marbles of the Gennargentu Units are overlain by the Fontana Bona Unit through an evident tectonic contact.

The Fontana Bona Unit is constituted by metasandstones, metavolcanites, 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 Sardo Unit has much in common with the tectonics of the «Nappe zone». The axial orientations of the folds of the first deformation phase vary from N120 to N180. In the metavolcanoclastites, the lineations of extension are clearly visible; their orientation ranges from N20 to N90 therefore, they are almost orthogonal 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 second deformation phase shows very dipping axial planes accompanied by a fracture cleavage or a strain-slip cleavage; the axial orientation trends E-W to N140. An interference between structures of first and of second deformation phase is shown in fig. 4.1 and 4.2.

The third folding phase causes slight deformations with N170 to N20 trending axes which produce axial culmination and depression of the second phase structures.

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 metasandstones of the Gennargentu Unit lie on different formations of the underlying unit: from the Devonian metalimestones to the Middle Ordovician metavolcanites.

The main 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 NE of sinkinematic metamorphism. That determines either a higher recrystallization or a higher ductility of the rocks during the deformation with development of a very penetrative flow schistosity implying a deep internal reorganization of fabric. A more complex structural evolution represents a further difference. In the low grade metamorphic complex of the Barbagia, the isoclinal folds that can be recognized at the mesoscopic scale refold an older foliation also related to another isoclinal fold system. The isoclinal folds are subsequently 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 Sardinia. However, it is well known that orogenetic belts like the Hercynian one generally imply shear zones which progressively involve in a rippling effect, the outer zones of the chain in the course of time.

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DESCRIPTION OF STOPS OF THE BARBAGIA EXCURSION

We climb the Flumendosa valley along the Gerrei road up to Ballao. Excluding few exceptions, like Mt. Ferro, 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 Bruncu Bonifacio and Mt. Maraconis (Fig. 3.5 of Day 3). Then, along the climb leading to the Mt. Maraconis pass, we cross the Ordovician metavolcanites cropping out at the core of the anticline, the northernmost of Gerrei Units along this transversal.

Beyond the Mt. Maraconis 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 Permian deposits which crop out extensively up to Escalaplano and even further on.

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

— Stop 4.1 - *Escalaplano: The Escalaplano Permian-Triassic Basin* (Fig. 4.1).

Along the road's bank near Escalaplano 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 Seui, Seulo, Perdasdefogu, Mulargia 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 Escalaplano, we go down again to the Flumendosa valley. Sediments and Permian volcanites (rhyolitic ignimbrites and rhyolitic lavas) crop out extensively along the road. The «Arenarie di Solanas» are the metamorphites cropping out beneath the Permian.

Passed the Flumendosa river we then go up to the other flank dominated by a wall of Plio-Quaternary alkaline basalts. The «Arenarie di Solanas» and the Ordovician metavolcanites of the Meana Sardo Unit crop out in overturned succession along the road; almost at the top of the climb, near Arcu S. Stefano they tectonically overlap the Silurian black schists of the «Gerrei type» series.

— Stop 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 an huge post-nappe antiform 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 «tête plongeante» anticlines with «Porfiroidi» of the Gerrei Units at the core, overlapped by the Meana Sardo Unit consisting of the «Arenarie di Solanas» and of Ordovician metavolcanites. The former crops out near the bridge of the Flumendosa river and also towards east beneath the Escalaplano Permian deposits, that we have seen for some kilometres.

The tectonic contact between the metavolcanites 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 Escalaplano and carry on towards Esterzili.

Leaving the village of Escalaplano, conglomerates and coarse Eocene sandstones crop out along the road. They lay in unconformity over the Medium Jurassic dolomites which crop out further on along the road up to Mt. Sa Colla (Fig. 4.1).

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

We now cross the south-western slope of Mt. S. Vittoria finding Cambrian-Ordovician metasandstones which are isoclinally folded together with the Ordovician metavolcanites (Fig. 4.3). The Upper Ordovician and Silurian-Devonian metasedimentary cover crops out on the north-eastern slope of the mountain where it is tectonically overlain by the low grade metamorphic complex of the Barbagia region («Postgotlandiano» AUCT.).

— STOP 4.3 - *Road leading to Mt. Santa Vittoria: Contact between the «Arenarie di Solanas», Ordovician metavolcanic complex and the interposed metaconglomerates* (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 metaconglomerate, here composed essentially of coarse volcanic elements. The succession then continues with white metarhyolites bearing small rare «phenocrysts» of quartz and K-feldspar within a microcrystalline more or less sericitic groundmass, which is sometimes hardly silicified («Mt. Corte Cerbos Formation»). In the Meana 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 metaconglomerates were interposed between the «Arenarie di San Vito» and the Ordovician metavolcanites. 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 way up and inverted. Along the road we find: «Arenarie di San Vito», metaconglomerates of the Caledonian unconformity, and different types of metavolcanites and Ordovician metavolcanoclastites.

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 metalimestones with phyllites of Silurian-Devonian age. At the top of the opposite slope of the valley, the unconformity between the Middle Jurassic dolomites of the «Tacco di Sadali» and the basement is well exposed.

— STOP 4.4 - *Along the climb to the Esterzili station: A typical fossiliferous Upper Ordovician outcrop of the Meana Sardo Unit.*

Along the bank of a country-road, fossiliferous metasiltites and metasandstones of Upper Ordovician age can well be observed.

Some levels are very rich in crinoids, brachiopods, bryozoa.

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

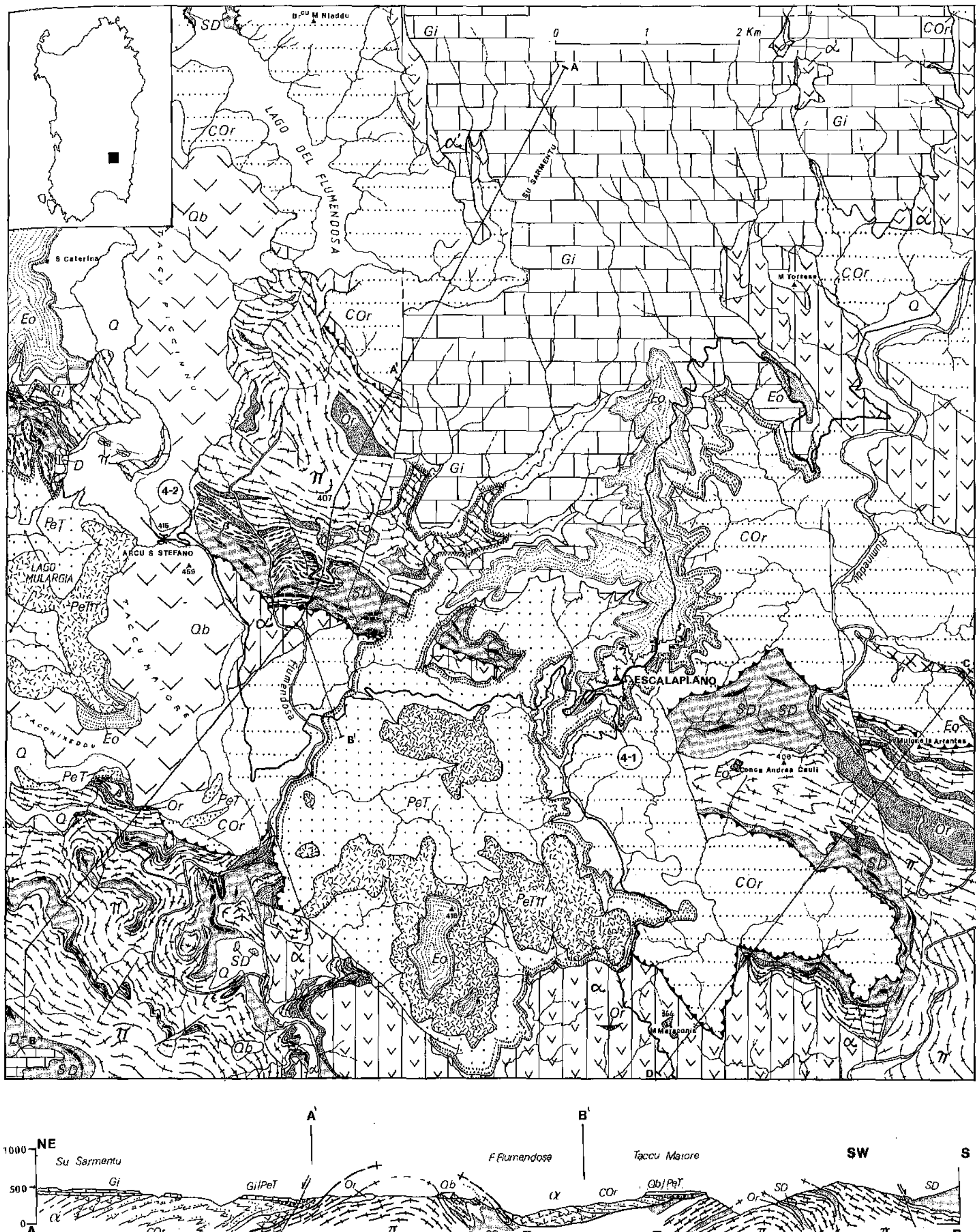
We now go up to the Esterzili station, the hairpin bends of the road cross the Ordovician-Upper Silurian boundary over and over again.

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

For about one kilometre, we can observe the following sequence along the bank: first the terrigenous deposits transgressive on the Ordovician metavolcanites («Caradocian Transgression» AUCT.), then the pelagic Silurian-Devonian facies, and last the metasandstones of the basal formation of the low grade metamorphic complex of the Barbagia region overthrusting the Meana Sardo Unit («Postgotlandiano» AUCT.).

Just before the station, there is an outcrop of the Ordovician metavolcanic complex represented both by metavolcanites with intermediate chemical composition and volcanic

Fig. 4.1 - Schematic geological map and cross-sections of Escalaplano and Flumendosa Lake area with location of stops. Q: Quaternary loose deposits; Qb: Alkaline Plio-Pleistocenic basalts; Eo: Quartzitic sandstones and conglomerates (Eocene); Gi: Dolomitic limestones and marly limestones with basal quartzose conglomerates (Jurassic); PeTπ: Permo-Triassic dacites, trachites and their tuffs; PeT: Conglomerates, sandstones, siltites with thin evaporitic levels (Permo-Trias); γ': Porphyries. *Meana Sardo Unit:* α': Mt. Corte Cerbos, Manixeddu, Serra Tonnai Formations. Metarhyolites, metamorphic products of reworked volcanites, metavolcanites with intermediate chemical character (metandesites) (Ordovician); COr: «Arenarie di Solanas» (Cambrian-Early Ordovician); SDl: *Orthoceras*-metalimestone lenses.
Gerrei Units: D: Main lenses of Devonian limestones; SD: Marly slates, graptolitic carbonaceous slates and black quartzites («Scisti a graptoliti» and «Liditi» AUCT., Silurian); Or: Metarkoses and metasandstones, metasiltstones and metalimestones with brachiopoda, bryozoa, etc. (Upper Ordovician); β: Metavolcanites with basic and intermediate chemical characters (Ordovician); π: Metarhyolites with «augen texture» («Porfiroidi» AUCT.) (Ordovician); α: Acidic metavolcanites and metamorphic products of reworked volcanites (Ordovician).
This map is based on published and unpublished surveys by L. CARMIGNANI, R. CAROSI, F.M. ELTER, M. GATTIGLIO & P.C. PERTUSATI.



0
1
2 Km
LAGO DEL FLUMENDOSA
Su Sarmentu
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TACCU MAIORE
LAGO MULARGIA
ARCU S STEFANO
TACCHIXEDDU
Flumendosa
ESCALAPLANO
M Torrese
Mulone Is Arrantas
Conca Andrea Cauli
M Maraconis
4-1
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A
A'
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Mulone Is Arrantas
Mte Maraconis

Fig. 4.1

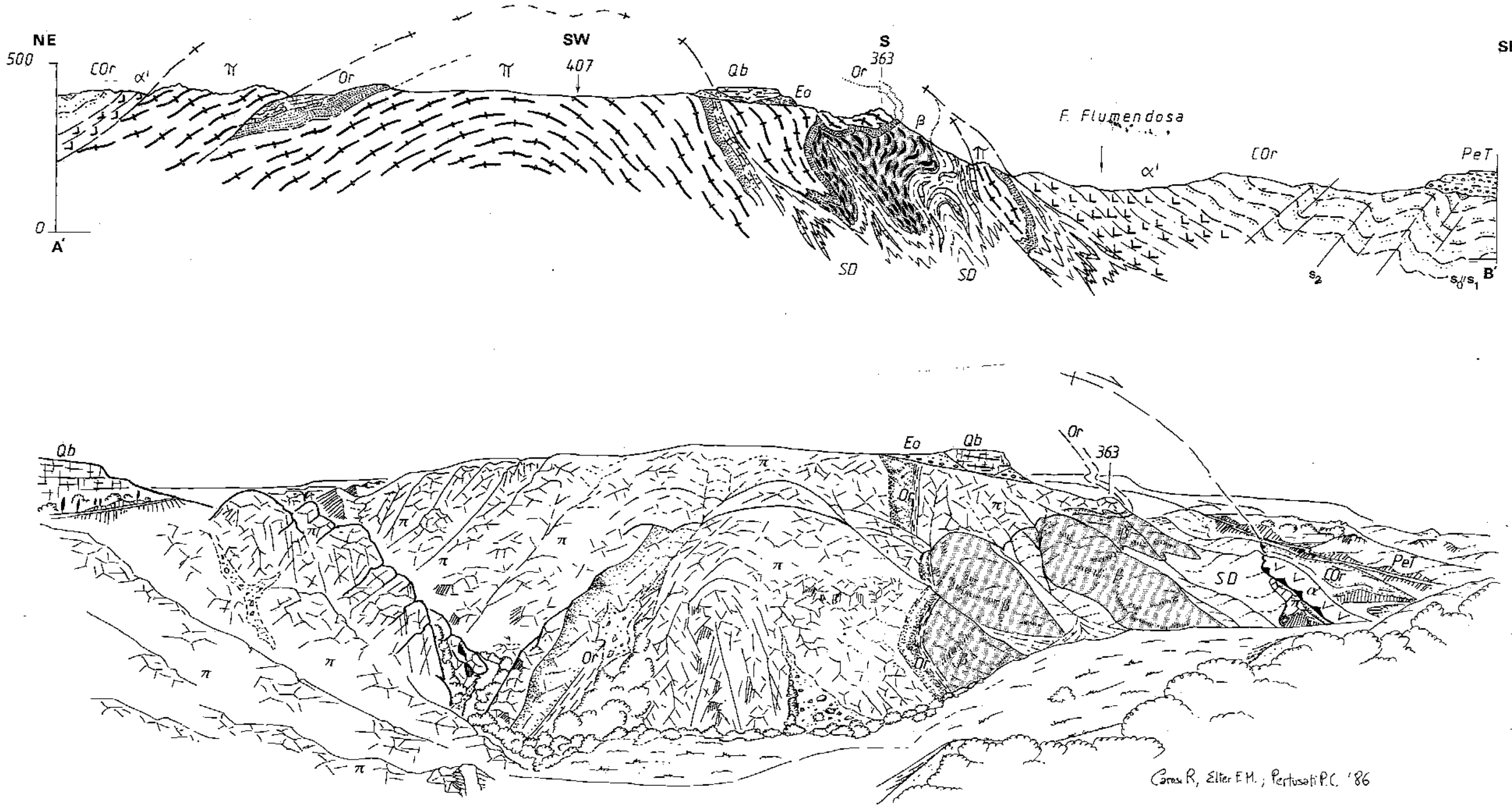


Fig. 4.2 - In the lower part view of the first phase recumbent folds in the area of the dam of Middle Flumendosa lake; in the higher part geological section of the above-mentioned slope (same symbols as in fig. 4.1).

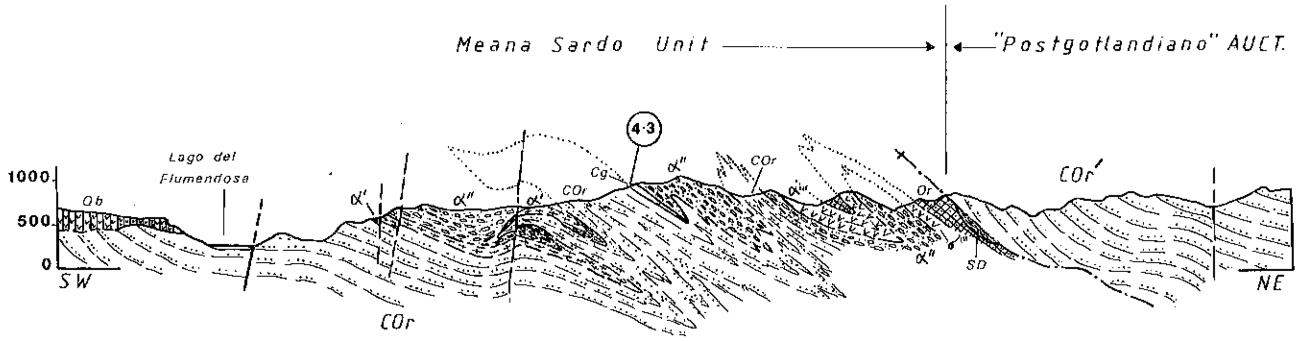


Fig. 4.3 - Sections across Mt. S. Vittoria ridge near stop 4.3.
Qb: Plio-Quaternary basalts.
Low grade metamorphic complex of Barbagia: COr: Metasandstones and phyllites («Postgotlandiano» AUCT.) (Cambrian-Early Ordovician?).
Meana Sardo Unit: SD: Carbonaceous slates (Silurian); Or: Metarkoses and metasandstones, metasiltstones with barchiopods, bryozoa, etc. (Upper Ordovician); α''': Serra Tonnai Formation. Metavolcanites with intermediate chemical characters (metandesites) (Ordovician); α'': Manixeddu Formation. Metamorphic products of reworked volcanites (Ordovician); α': Mt. Corte Cerbos Formation: metarhyolites (Ordovician); COr: «Arenarie di Solanas» (Cambrian-Early Ordovician).
From unpublished data collected by F.M. ELTER, M. GATTIGLIO, M. LAI, M. MAXIA, A. SANNA, E. SARRIA & R. SERRI.

metagraywacks; it is the Serra Tonnai Formation. In the Meana Sardo Unit, such formation usually constitutes the youngest term of the metavolcanic complex. The metavolcanites are covered by metarkoses and coarse-grained metasandstones which characterize the beginning of the transgression on the volcanites. At the station, we find Upper Ordovician fossiliferous metasiltites, metasandstones and phyllites. Beyond the station, carbonaceous phyllites with «lidite» referred to the Silurian and also strongly laminated metalimestones crop out. The original nodular structure, typical of Lower-Middle Devonian tentaculite-bearing metalimestones is still easily recognizable.

The Devonian is overlain by metasandstones («Postgotlandiano» AUCT.) alternated to phyllites cropping out for a short stretch of road before the cover of Middle Jurassic dolomites of «Tacco di Sadali».

According to the authors, the metasandstones are correlated to the Cambrian-Ordovician metasandstones of the Arburese, Sarrabus, Sarcidano, 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 «Postgotlandiano» 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 «Tacco di Sadali» we go towards Ussassai and cross a long stretch of road composed only of the «Postgotlandiano» metasandstones.

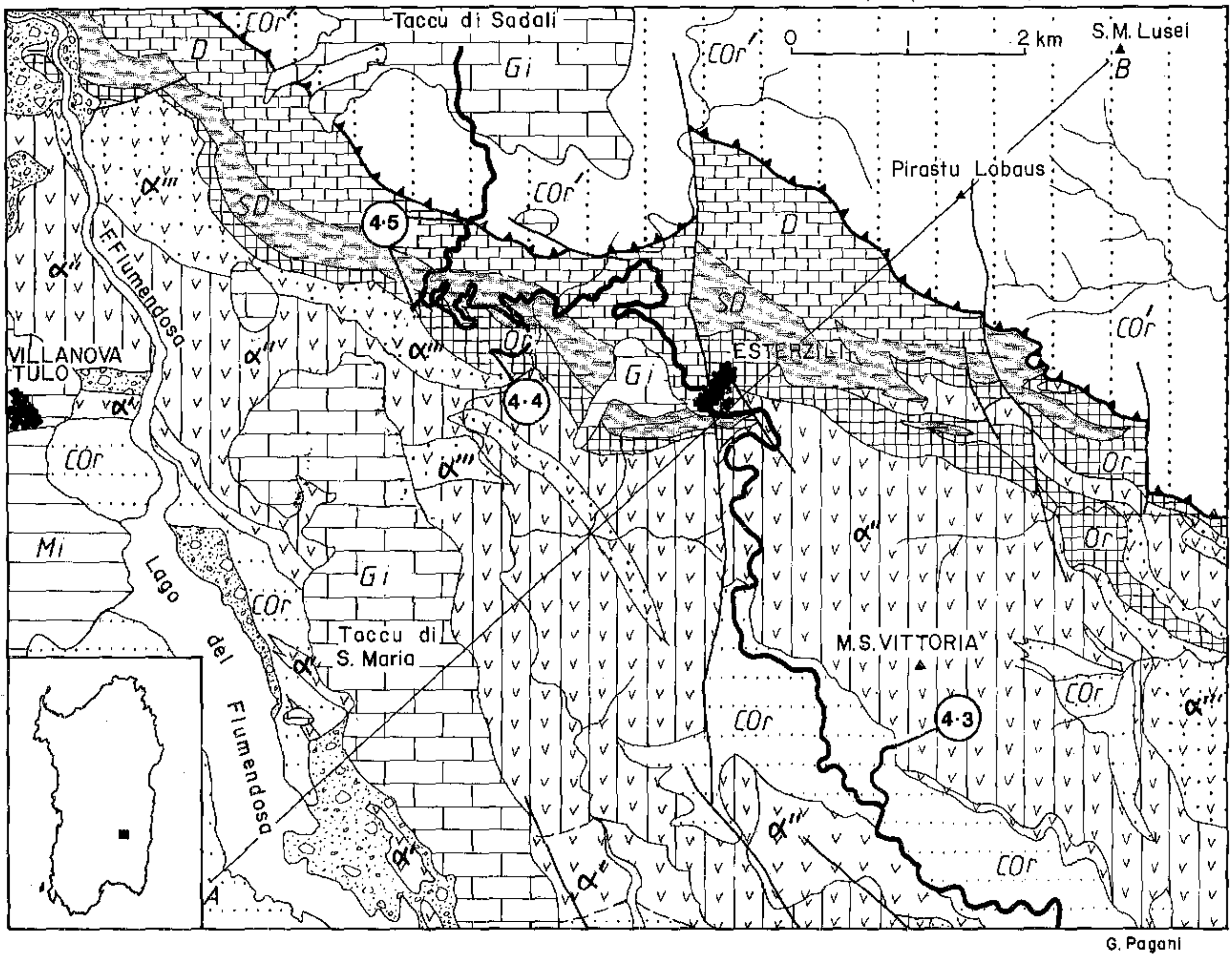
— STOP 4.6 - *Cantoniera Arquerì: Lithological types of «Postgotlandiano».*

The typical «Postgotlandiano» lithologies may be seen along the road: they consist of mature metasandstones alternated with green-grey phyllites, etc. Synschistose recumbent folds crop out just above the road. Such structures refold an older schistosity and vary in axial orientations, probably due to the reorientation of the fold axes trend according to the direction of maximum extension. Small-sized «sheat folds» are visible just above the road.

Going on, we cross the Mesozoic terrains of «Tacco di Jerzu», a few kilometres later, the «Postgotlandiano» metasandstones crop out again. Just leaving the village of Gairo, highly thermometamorphic terrains of the Meana Sardo Unit are exposed again in tectonic windows. In fact, shortly before the crossing to Lanusei tonalitic granodiorites as well as the biotite monzogranitic granodiorites are present for a long stretch of the way.

We leave the High Lake of Flumendosa on the left and then we go up to the Rio Correboi valley. Late Hercynian granodiorites appear and then Paleozoic low grade metamorphites. Along the first stretch of road, the latter are highly thermometamorphic; however, they should still be part of the highest part of «Postgotlandiano» sequence.

We go on towards NW and we cross different lithological types. They can be easily referred to as Upper Ordovician (green quartzites and metasiltites, «Porfiroidi», metarkoses).



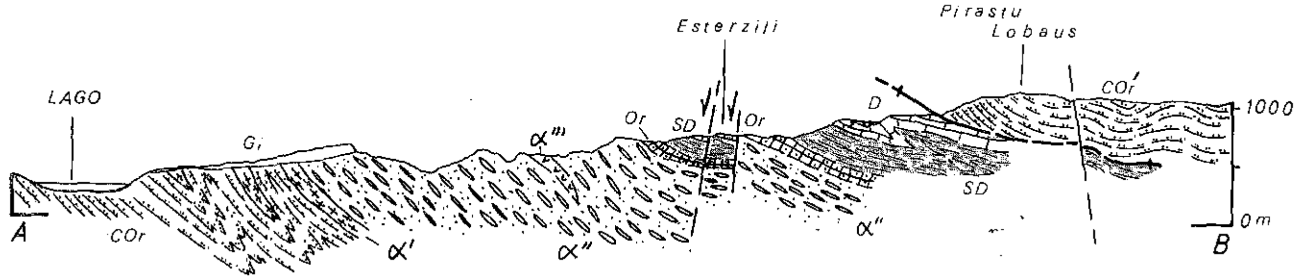
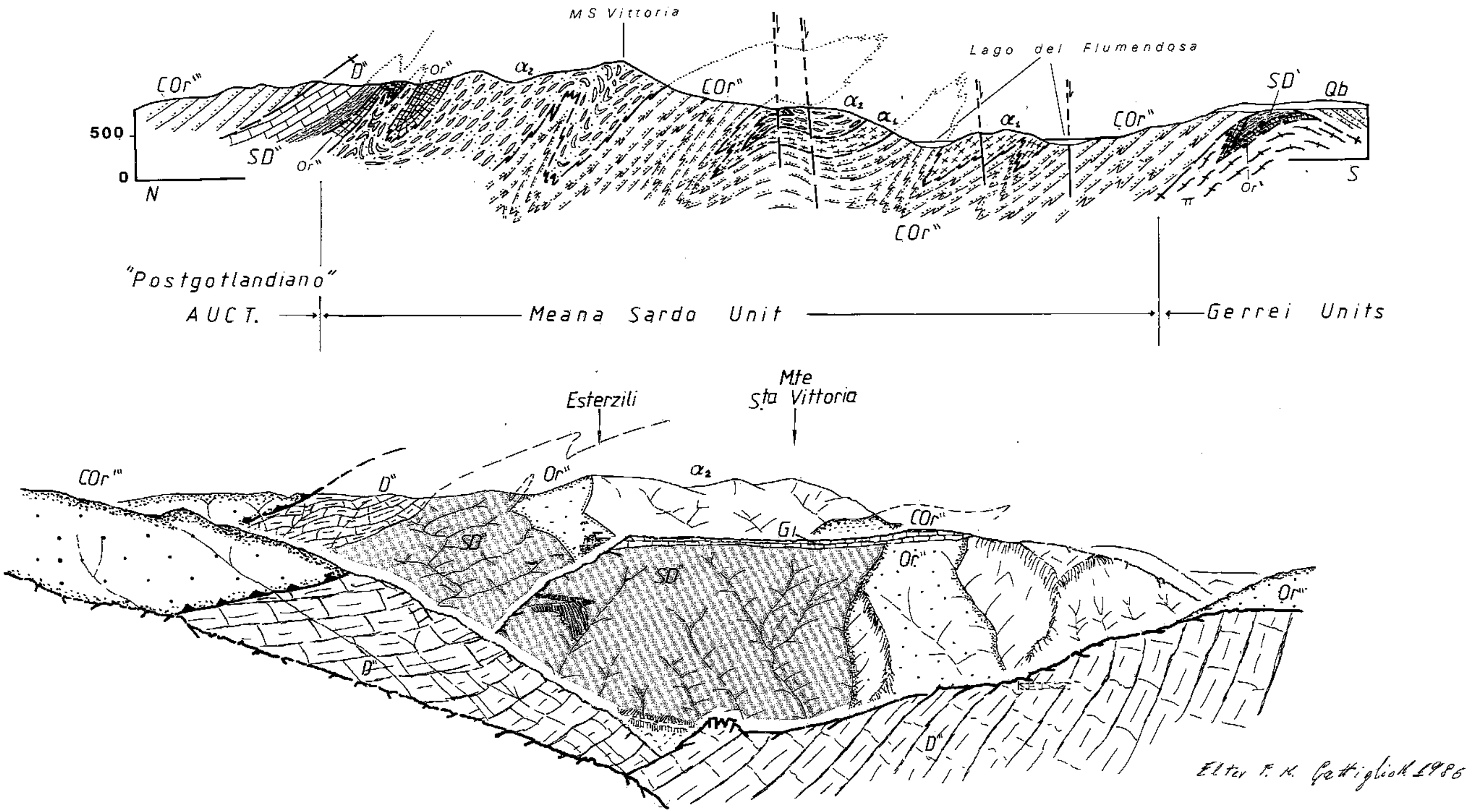


Fig. 4.4 - Schematic geological map of Mt. S. Vittoria area with location of stops.
Mi: Miocene deposits; Gi: Jurassic limestones and dolostones.
Low-grade metamorphic complex of Barbagia: COr': Metasandstones and phyllites («Postgotlandiano» Auct.) (Cambrian ?- Lower Ordovician?).
Meana Sardo Unit: D: Metalimestones (Devonian); SD: Carbonaceous slates, black quartzites («Scisti a Graptoliti» and «Liditi» Auct.) (Silurian); Or: Metarkoses and metasandstones, metasiltstones with brachiopods, bryozoa, etc. (Upper Ordovician); α''': Serra Tonnai Formation - Metavolcanites with intermediate chemical characters (metandesites) (Ordovician); α'': Manixeddu Formation - Metamorphic products of reworked volcanites (Ordovician); α': Mt. Corte Cerbos Formation - Metarhyolites (Ordovician); COr: «Arenarie di Solanas» (Cambrian-Early Ordovician).
This map is based on published and unpublished maps surveys by: F.M. Elter, M. Gattiglio, M. Lai, M. Maxia, A. Sanna, E. Sarria & R. Serri.

Fig. 4.5 - At the bottom view of Mt. S. Vittoria, showing relationships between the Meana Sardo Unit and «Postgotlandiano» Auct. At the top geological section of some area.
Qb: Plio-Quaternary basalts; Gi: Jurassic limestones and dolostones.
Low grade metamorphic complex of Barbagia: COr''': Metasandstones and phyllites («Postgotlandiano» Auct.) (Cambrian ?- Early Ordovician?).
Meana Sardo Unit: D'': Metalimestones (Devonian); SD'': Carbonaceous slates, black quartzites («Scisti a graptoliti» and «Liditi» Auct.) (Silurian); Or'': Metarkoses and metasandstones, metasilstones with brachipods, bryozoa, etc. (Upper Ordovician); α_2: Manixeddu Formation - Metamorphic products of reworked volcanites (Ordovician); α_1: Mt. Corte Cerbos Formation - Metarhyolites (Ordovician); COr'': «Arenarie di Solanas» (Cambrian-Early Ordovician).
Gerrei Units: SD': Marly slates, with metalimestone intercalations (Lower and Middle Devonian), graptolitic carbonaceous slates, with intercalations of dark metalimestones, black quartzites («Scisti a graptoliti» and «Liditi» Auct., Silurian); Or': Metarkoses and metasandstones, metasilstones and metalimestones with brachiopods, bryozoa etc. (Upper Ordovician); π: Metarhyolites with «augen texture» («Porfiroidi» Auct.) (Ordovician).
From unpublished data by F.M. Elter, M. Gattiglio.


MS Vittoria
Lago del Flumendosa
COr'''
D''
Or''
α_2
COr''
α_1
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Qb
500
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S
"Postgotlandiano"
AUCT.
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Gerrei Units
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Sta Vittoria
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Fig. 4.5

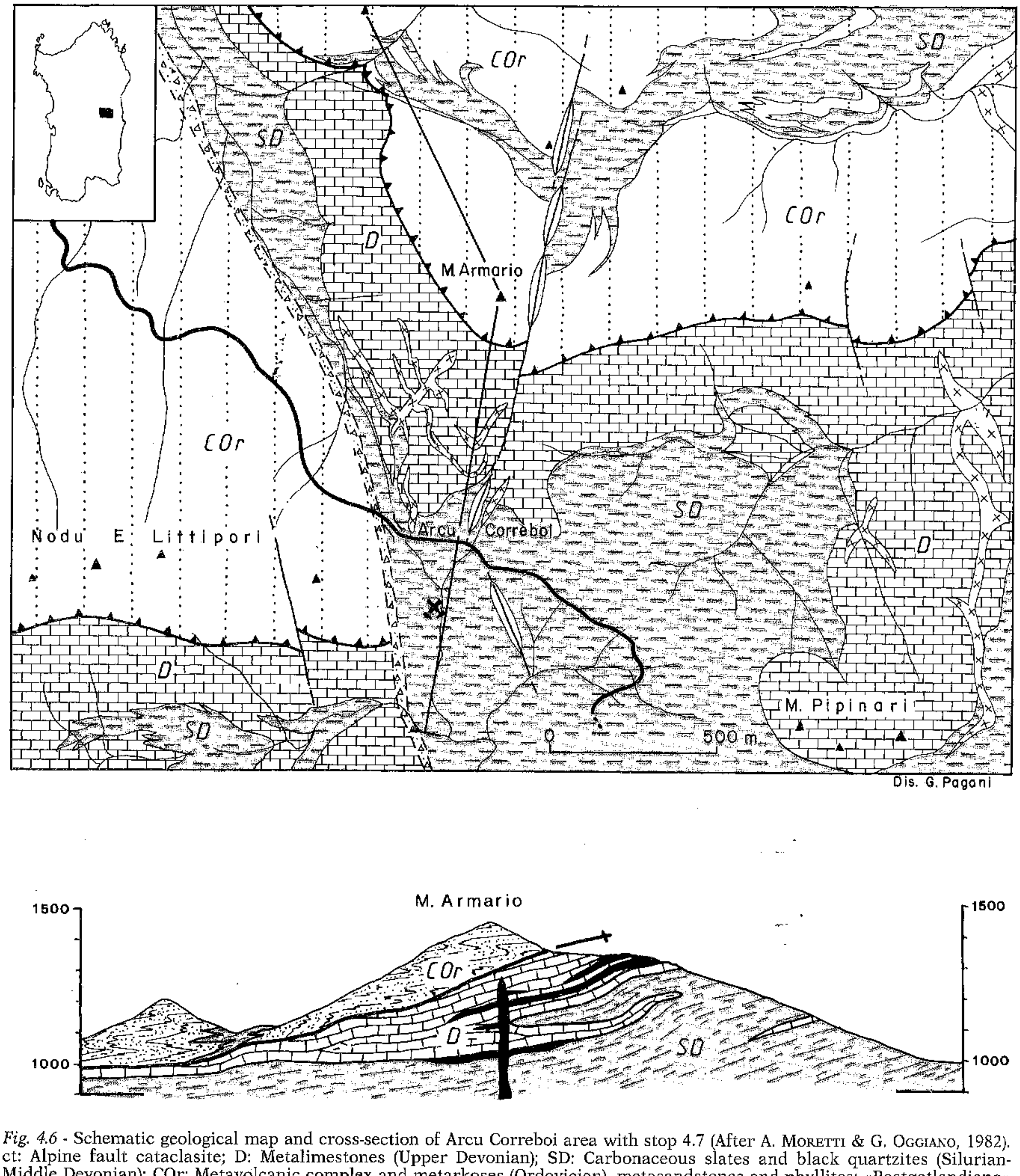

Fig. 4.6 - Schematic geological map and cross-section of Arcu Correboi area with stop 4.7 (After A. MORETTI & G. OGGIANO, 1982). ct: Alpine fault cataclasite; D: Metalimestones (Upper Devonian); SD: Carbonaceous slates and black quartzites (Silurian-Middle Devonian); COr: Metavolcanic complex and metarkoses (Ordovician), metasandstones and phyllites: «Postgotlandiano» AUCT. (Cambrian ?-Early Ordovician ?).
Most thick acid porphyry dikes are also shown (crosses in the map and black in the cross section).

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. Arbu and Punta Sa Birritta, 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 metasandstones which can probably be referred to as Ordovician, overthrust the Devonian marbles of «Postgotlandiano» sequence, precisely at Arcu Correboi. A few kilometres towards NE, outside our itinerary, the Ordovician formations of the Funtana Bona Unit show their Silurian-Devonian cover.

— STOP 4.7 - *Arcu Corrèboi: The overthrust between Cambrian-Ordovician metasandstones 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 conodonta 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-Hercynian porphyry dike with very fine sub-horizontal slickensides 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 metasandstones of the Funtana Bona Unit are visible on the bank of the road.

Beyond the Garavai pass, we go down to the rio Vavori 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-Gallura Batholith, which we will cross in the excursion of Day 5. These plutonic rocks accompany us along the entire road to Nuoro.

Guide-book to the Excursion on the Paleozoic basement of Sardinia
IGCP project no. 5 - Newsletter 1986, special issue, 87-102

Theme of excursion of fifth day

THE GEOLOGY OF NORTHERN SARDINIA

by F.M. ELTER, M. FRANCESCHELLI, C. GHEZZO, I. MEMMI & C.A. RICCI

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

ITINERARY: *Nuoro - Lula - Cantoniera S. Anna - Lodé - Buddusò - Torpé - Brunella - Punta Batteria - Punta de li Tulchi - Olbia - Golfo Aranci - Olbia.*

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 to post-tectonic Hercynian granitoids.

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

The style of deformation and the degree of metamorphism vary widely between the southern (Baronie, Goceano 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 OUTLINES

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) «Porfiroidi», volcanic metagraywackes and metabasites;

2) Metasiltites and black phyllites with levels of «oolitic ironstone»;

3) «Lidite», black phyllites with metabasites and rare intercalations of Orthoceras-bearing calcschists;

4) Black phyllites and metasiltites with metaconglomerates and quarzites;

5) Metasandstones, pinkish quartzites and phyllites.

Only the third term contains fossils which consent a founded attribution to Silurian and Devonian (CIAMPI, 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 & OGGIANO (1984) also found carbonatic levels and proposed a correlation between these levels and the calcareous levels attributed to the Caradoc-Ashgill in central Sardinia.

In northern Nurra, micaschists, paragneisses, porphyroblastic paragneisses 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 Goceano region, a stratigraphic reconstruction has not yet been made. However, the following rock types have been found out: «Porfiroidi», black schists, calc-schists, marbles, metabasites and volcanic metagraywackes (GHEZZO & RICCI & 1970; RICCI & SABATINI, 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 + (albite ± oligoclase);

c) Granodioritic orthogneisses and augen gneisses;

d) Micaschists and paragneisses with staurolite + biotite and kyanite + biotite;

e) Amphibolites with relics of granulite facies parageneses and rarely eclogites partially retrogressed;

f) 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 Rb/Sr ages of 458 ± 31 Ma for the granodioritic orthogneisses and 441 ± 33 Ma for the rhyolitic augen gneisses, which have been interpreted as the age of the emplacement of magmatic bodies (FERRARA *et al.*, 1978).

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

Granulites and eclogites occur as small bodies within the migmatitic rocks. They may represent the relics of a pre-Hercynian basement (GHEZZO *et al.*, 1979, 1982).

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

1) Granodioritic orthogneisses and rhyolitic augen gneisses of Baronie-Gallura, «Porfiroidi» of Nurra and Goceano with the Middle Ordovician acid igneous activity of Sarcidano, Gerrei and Sàrrabus (MEMMI *et al.*, 1982, 1983; fig. 2 of CARMIGNANI *et al.*, this volume).

2) Volcanic metagraywackes and subalkaline metabasites of Nurra and Goceano with the Ordovician subalkaline volcano-sedimentary complexes of Sarcidano and Gerrei (MEMMI *et al.*, 1982, 1983).

3) Alkaline metabasites of Nurra, Goceano and Baronie with those attributed to Silurian in Sarcidano and Barbagia regions (MEMMI *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 graptolites-bearing slates and orthoceras-bearing metalimestones of Silurian-Devonian age of central-southern Sardinia (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 (D_1, D_2, D_3).

Using several criteria (including orientation of axes, style and sequence of folding in time), three groups of folds may easily 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 phases and associated axial plane schistosity from southern to northern area is summarized in fig. 5.1 (after CARMIGNANI *et al.*, 1982b).

D_1 DEFORMATION PHASE

D_1 structures are the early, at 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 (S_1), striking about N120, are also related to D_1. 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 phyllosilicates and quartz-rich layers. Moving towards the zones of higher metamorphic grade, the S_1 surface is progressively transposed and obliterated by the S_2 schistosity. In the low grade rocks, the main minerals grew during the development of S_1 schistosity. An extensive growth of plagioclase and biotite porphyroblasts, enveloping trails of S_1 schistosity occurred in low and medium grade rocks (CARMIGNANI *et al.*, 1979; FRANCESCHELLI *et al.*, 1982a).

D_2 DEFORMATION PHASE

This phase refolds all D_1 structures and produces folds striking E-W which are the most evident 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 megastructures originated during this phase have been mapped in the Nurra and Baronie regions. In the Nurra region, the most remarkable D_2 structure is a kilometric syn-

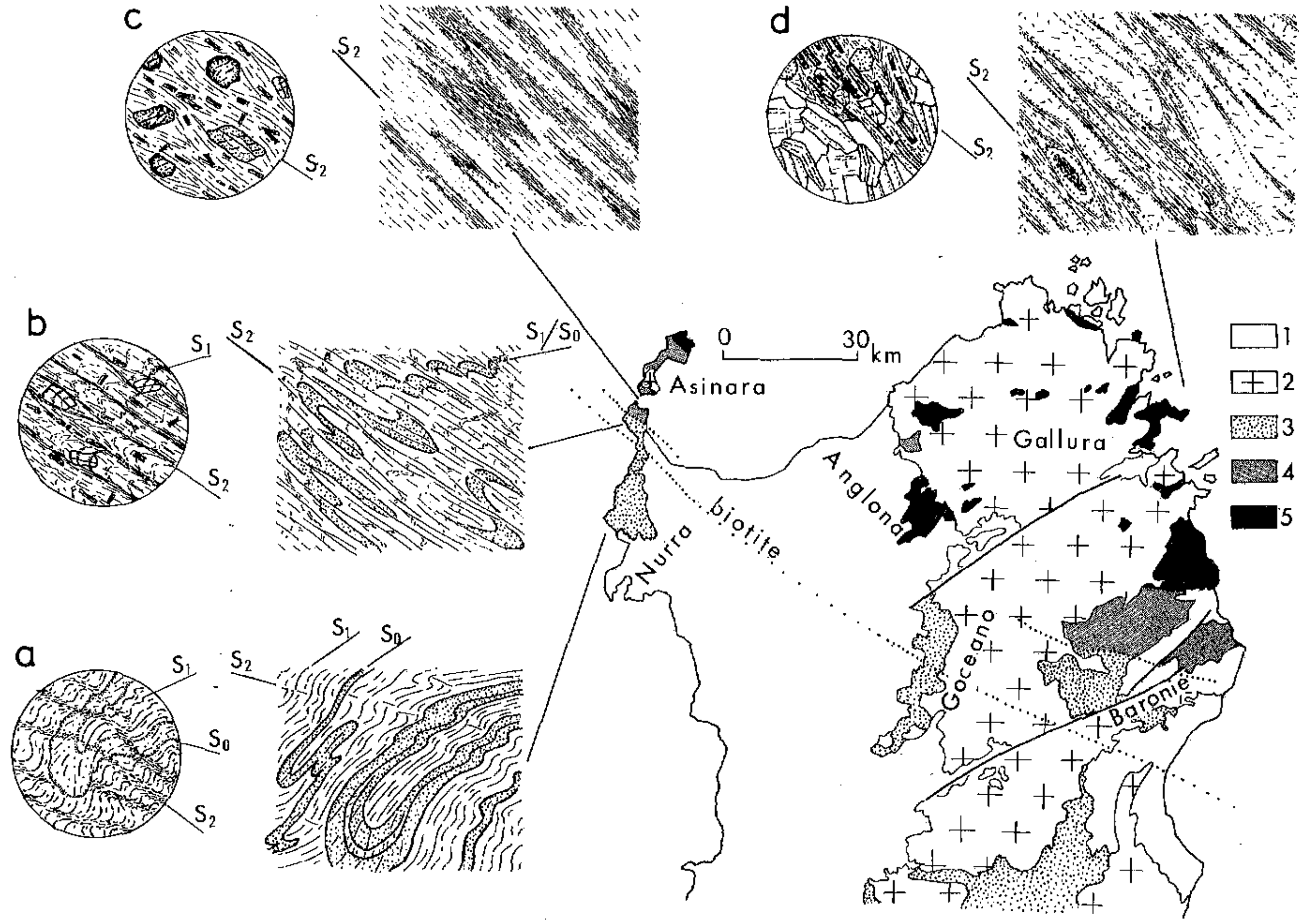

Fig. 5.1 - Schematic relationships (at mesoscopic and microscopic scale), between deformation and metamorphism in Northern Sardinia (after CARMIGNANI *et al.*, 1982 partly modified).
1: Post-Hercynian volcanics and sediments; 2: Granitoids; 3: Greenschist facies; 4: Amphibolite facies; 5: Migmatites and calc-silicate nodules and masses with relics of granulite and/or eclogite facies parageneses;
S_0: sedimentary layering; S_1: First schistosity; S_2: Second schistosity;
a: Chlorite zone - First phase folds, refolded by second phase open folds. Mineral essentially grew during D_1 (M_1 episode);
b: Biotite zone - Second phase isoclinal folds which refold both S_0 and S_1: minerals grown during D_1 are preserved as solid inclusions within porphyroblasts of albite, biotite, chlorite which grew post-D_1 e pre-D_2.S_2, defined by syn-D_2 muscovite, chlorite and rare biotite wrap around porphyroblasts;
c: Garnet+Albite+Oligoclase zone. Second phase isoclinal folds. S_1 is fairly completely transposed along S_2. At microscopic scale syn S_1 (?) minerals like muscovite, biotite, chlorite and sometimes garnet form helicitic inclusions within plagioclase porphyroblasts (albite core and oligoclase rim). Other post-D_1 e pre-D_2 minerals are biotite and garnet. S_2 is constituted by muscovite, chlorite and biotite. (In the Staurolite + Biotite and Kyanite + Biotite zone the key minerals constitute post-D_1 and pre-D_2 porphyroblasts, again related to M_1 episode).
d: Sillimanite + K-feldspar zone. Second (?) phase isoclinal folds which sometimes refold the migmatitic layering. Centimetric quartz-fibrolite rods are sometimes enveloped by S_2. At microscopic scale no clear pre-S_2 microstructure was observed. The only evidence of pre-M_2 mineral growth may be represented by rounded relics of kyanite and garnet (preserved as solid inclusions in plagioclase) and by the anhydrous mineral association found in the core of calc-silicate nodules.

form with the axes striking about E-W and plunging eastwards. In the Baronie, a kilometric antiform, with axes trending E-W and plunging eastwards has been mapped in the Siniscola-Mamone area (fig. 5.2). The S_2 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 grown parallel to the S_2 schistosity increases and the textures of the rocks are dominated by pre-S_2 porphyroblasts and syn-S_2 minerals. In the high grade zone, the migmatic layers are disposed parallel to the S_2 schistosity and no trace of pre-S_2 porphyroblasts remains (CARMIGNANI *et al.*, 1979; FRANCESCHELLI *et al.*, 1982a).

D_3 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 (CARMIGNANI *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 (ELTER, 1985). This shear zone trends E-W and affects a 10 km wide area from the Staurolite + Biotite to the Sillimanite grade. Microscopic studies reveal the presence of a variety of mylonitic rock types as cataclasite, protomylonite, mylonite and ultramylonite in a quite regular order moving northwards. These rock-types appear to be the product of a heterogeneous deformation in a suite of similar lithology. In the various mylonitic rock-types, we can distinguish two well developed foliations (S and C planes) which turn progressively into parallelism in the north margin of the shear zone.

The shear deformation in the Gallura region is overprinted to the regional D_2 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 time of minerals, two main episodes of crystallization (M_1 episode and M_2 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_1 EPISODE

The M_1 episode of crystallization includes minerals formed before the S_2 schistosity. During this episode, the key minerals in their own zone are synkinematic compared to S_1 in the low grade zones, and postkinematic in the low medium grade ones. The M_1 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-psammitic schists, predating the S_2, seven metamorphic zones are defined reflecting the change in the configuration of AKFM 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, Goceano and Baronie regions. Quartz, muscovite, albite and paragonite 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), Goceano and Baronie 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 Baronie-Gallura regions. The Garnet isograd is based on the first incoming of garnet in psammitic rocks, while the spaciousness of the garnet zone is defined by the persistence of the assemblage grt+chl+bt (mineral abbreviation as KRETZ, 1983). The AFM assemblages observed in this zone are shown

Fig. 5.2 - 1: Detrital deposits (Holocene); 2: Continental and beach deposits (Pliocene-Quaternary); 3: Platform carbonate sediments, continental and lagoonal sediments and evaporites (Triassic-Jurassic-Cretaceous); 4: Camptonite lamprophyre dikes (238 ± 10 Ma) (Permian-Triassic); 5: Acid pink porphyritic dikes; 6: Pinkish garnet-bearing leucogranites (Concas massif) (289 ± 1 Ma; $^{87}Sr/^{86}Sr$ = 0,7085); 7: Biotite leucogranites (Mt. Lerno massif); 8: Equigranular biotite monzogranitic granodiorites (Alà dei Sardi massif); 9: Inequigranular biotite-monzogranites and granodiorites (Benetutti-Orune Massif); 10: Whitish equigranular leucogranites, monzogranites and granodiorites (Buddusò massif); 11: Tonalites and tonalitic granodiorites (307 ± 6 Ma; $^{87}Sr/^{86}Sr$ = 0.7099) (Bitti massif); 12: Migmatitic complex of Sillimanite + Muscovite and Sillimanite K-feldspar zones (344 ± 7 Ma); 13: Eclogites partially retrogressed; 14: Micaschists and paragneisses of Staurolite + Biotite and Kyanite + Biotite zones. This area is affected by blastomylonitic shear zone of late Hercynian age; 15: Amphibolites with relics of granulite facies parageneses; 16: Rhyolitic augen gneiss (441 ± 33 Ma); 17: Granodioritic orthogneisses (458 ± 31 Ma); 18: Micaschists and paragneisses of garnet + Albite and Garnet + Albite + Oligoclase zones; phyllites and metasandstones of Biotite zone; 19: Main AKFM isograds; 20: Alpine faults; 21: Traces of cross-sections. (Location of stops is also shown).

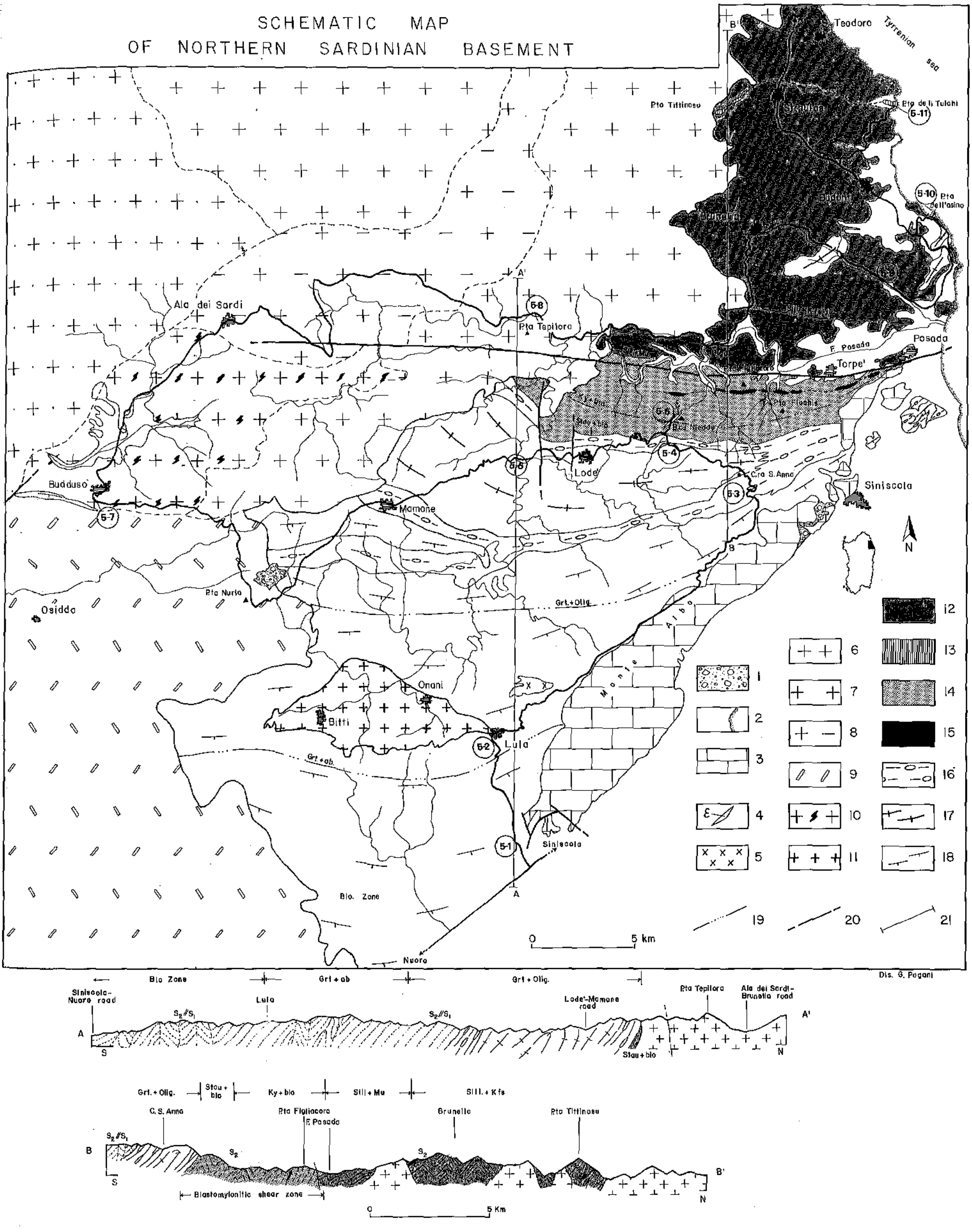
SCHEMATIC MAP
OF NORTHERN SARDINIAN BASEMENT
Teodoro
Tyrrenian sea
Pta Tittinosu
Pta de li Tulchi
Pta dell'asino
Ala dei Sardi
Pta Tepilora
Posada
F. Posada
Torpe'
Budduso
Lode'
C.ra S.Anna
Siniscola
Mamone
Pta Nurla
Osidda
Grt.+Olig.
Monte Albo
Onani
Bitti
Lula
Grt+ab.
Siniscola
Blo. Zone
Nuoro
0 5 km
N
5-1
5-2
5-3
5-4
5-5
5-6
5-7
5-8
5-10
5-11
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Dis. G. Pagani
Blo Zone
Grt + ab
Grt + Olig.
Siniscola-Nuoro road
Lula
Lode'-Mamone road
Pta Tepilora
Ala dei Sardi-Brunella road
A
A'
S
N
Stau+blo
Grt.+Olig.
Stau+blo
Ky+blo
Sill+Mu
Sill.+Kfs
C.S. Anna
Pta Figliacoro
F. Posada
Brunella
Pta Tittinosu
B
B'
Blastomylonitic shear zone
0 5 Km

Fig. 5.2

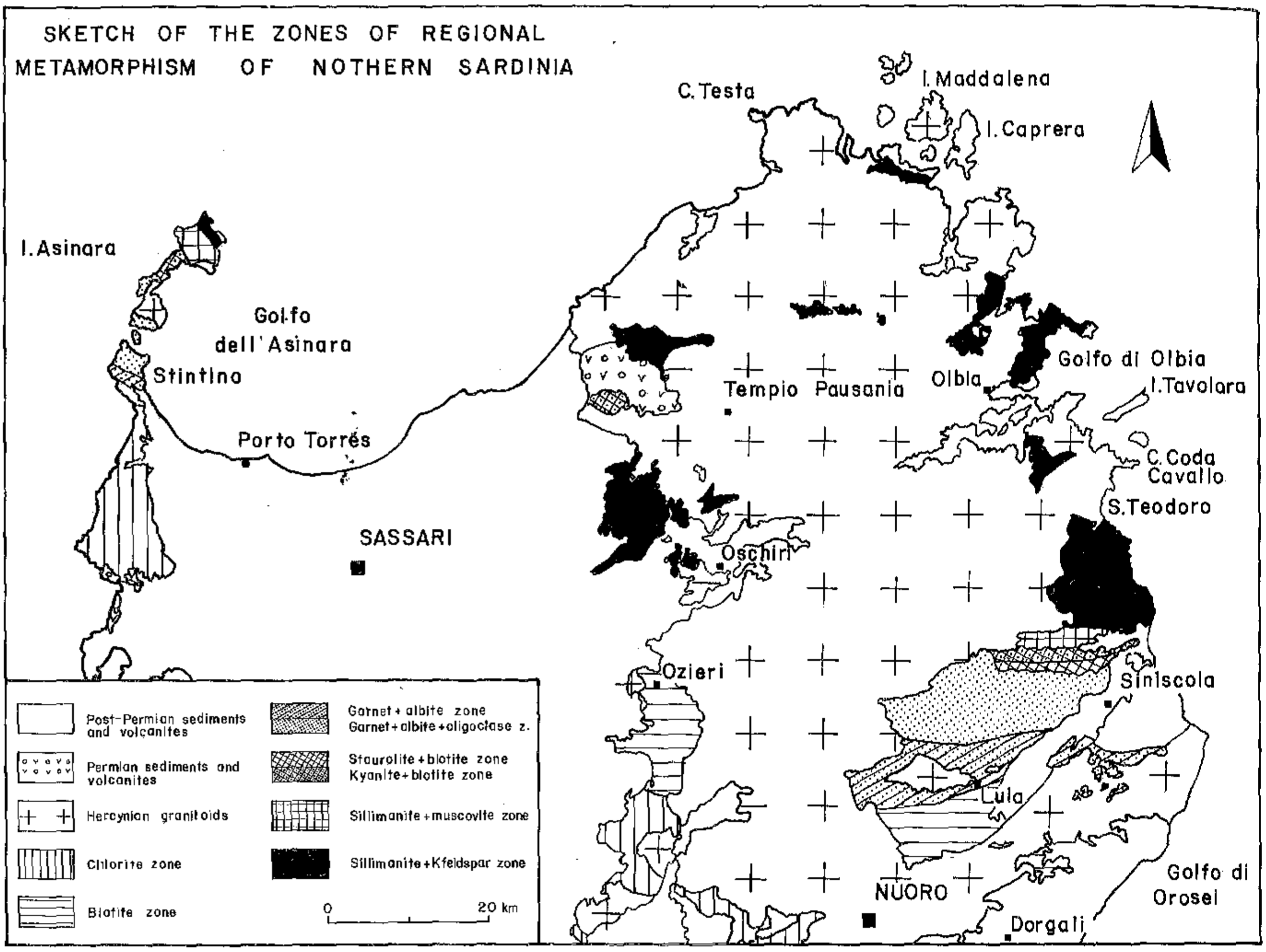

Fig. 5.3 - Sketch of the zones of regional metamorphism of Northern Sardinia.

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 Baronie-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 Kyanite + Biotite Zone*

This zone has been mapped in the Anglona and Gallura regions. The Kyanite + Biotite isograd is defined by the incoming 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 polymorphic 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

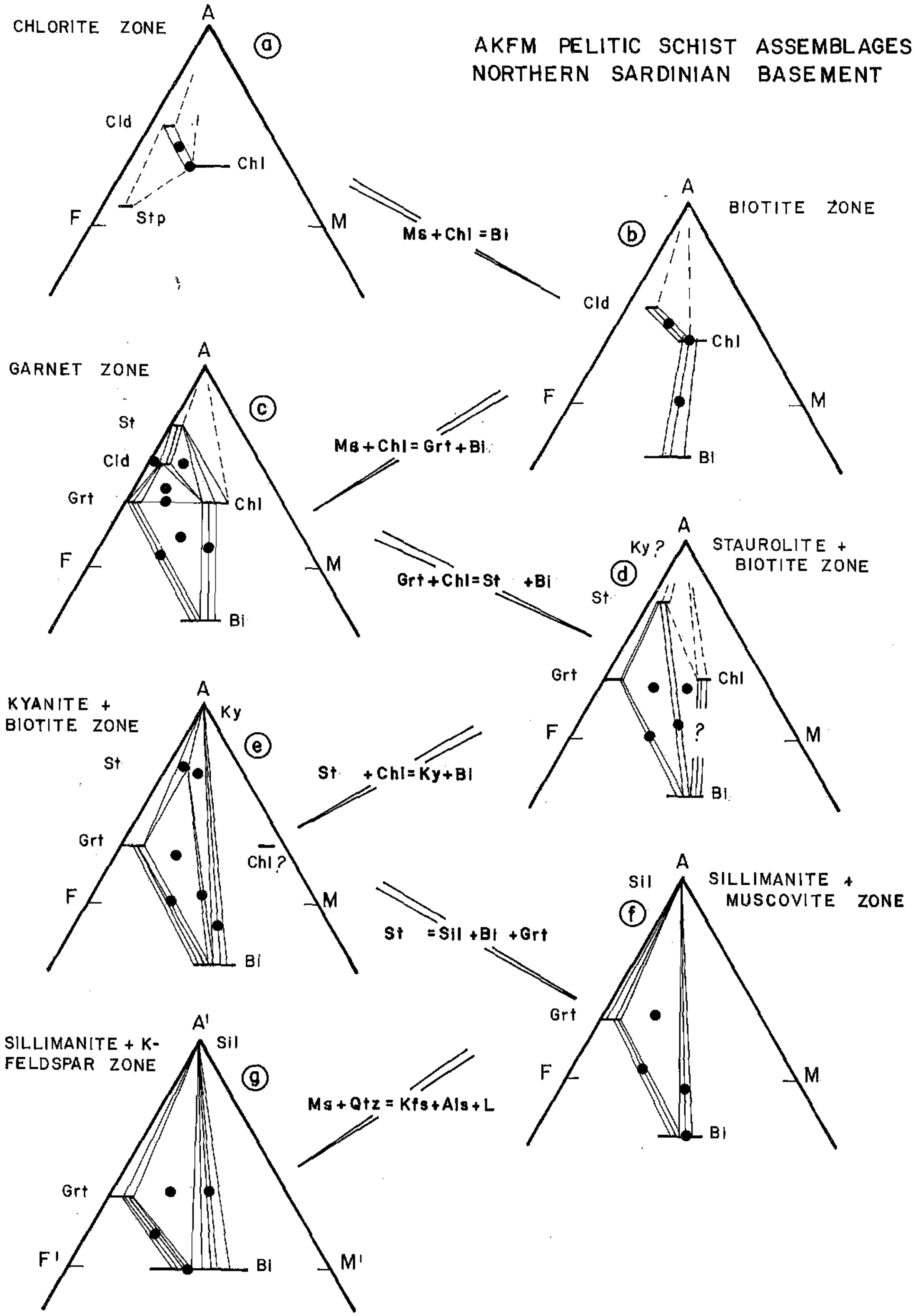

Fig. 5.4 - Generalized AKFM facies series for the metamorphism of pelitic schists of northern Sardinia basement. Full circles indicate observed assemblages. Dashed lines indicate assemblages not observed, but inferred to have been stable (facies a, b, c, d, e, f are projected from qtz, ms and H_2O; facies g from qtz, kfs and H_2O).

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 isograd. The observed AFM 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: throndhjemitic migmatite and granitic migmatite.

The compositional layering of the throndhjemitic migmatite is folded and transposed by the S_2 schistosity. This migmatitic compositional layering is supposed to have been formed during or after the D_1 deformation phase. The throdhjemitic migmatites occur at the beginning of the Sillimanite zone and also persist in the Sillimanite + K-feldspar zone. Qtz + pl + bt + sil is the constant and simple composition of leucosomes, and qtz + pl + bt + ms + grt ± sil that of mesosomes. For these types of rocks an anatectic origin cannot be documented.

The granitic migmatites appear just at the Sillimanite + K-feldspar isograd. The migmatitic rock-types include stromatite, flebite, nebulite, agmatite and layered migmatites. The leucosomes are essentially composed of qtz + pl + kfs in modal proportion quite similar to the minimum melt composition. Other minerals are muscovite, garnet, biotite and sillimanite in varying combinations. This suggests an anatectic origin and that the leucosomes' generating reactions involved dehydratation-melting of muscovite.

THE M_2 EPISODE

The M_2 episode includes a mineral growth during or after the development of S_2 schistosity.

In the lower part of the Chlorite zone, no mineralogical crystallization has been observed along the S_2 schistosity. In the upper part of the Chlorite zone, we observed an incipient crystallization of muscovite, chlorite and Fe-oxides.

In the Biotite zone, also some biotite flakes are orientated along the S_2 but, as previously reported, the first appearance of this key mineral is related to the M_1 episode.

In the Garnet zone, the S_2 schistosity is coupled with the growth of muscovite, chlorite, biotite, quartz and Fe-oxides. The other minerals such as plagioclase and quartz are rotated and reorientated. Garnet is corroded and replaced around margins and along cracks by biotite. There is no textural evidence of the growth of garnet during the S_2 development. Indeed, the inverse zoning (increase of the Mn content in the rim) is considered evidence of retrograde metamorphism.

The amount of syn-S_2 minerals notably increases in the Staurolite + Biotite and Kyanite + Biotite zones; kyanite, staurolite and garnet porphyroblasts are unstable. Garnet presents the same type of transformation as shown in the Garnet zone; staurolite is replaced by a muscovite + chlorite + biotite (?) association. The minerals grown along the S_2 (muscovite, chlorite, biotite) increase notably in their grain size.

In the Sillimanite + Muscovite and Sillimanite + K-feldspar zones, the minerals are disposed as S_2 schistosity. The leucosomes of the migmatite are sometimes refolded by the D_2 deformation phase, but some thick leucosome are discordant compared to S_2 axial plane schistosity. We interpreted this geometrical relation as the evidence that some leucosomes were generated or emplaced during or after the D_2 + M_2 tectono-metamorphic episode.

ECLOGITES, AMPHIBOLITES WITH RELICS OF GRANULITE PARAGENESES AND CALC-SILICATE NODULES

Up to now, eclogites, amphibolites with relics of granulite parageneses and calc-silicate nodules have been found only in the high grade metamorphic rocks of Gallura. However, we cannot exclude that these rock-types are present in other parts of northern Sardinia.

Miller *et al.* (1976) described eclogitic rocks highly re-equilibrated in amphibolite facies around Punta de Li Tulchi. The eclogitic rocks consist of relics of omphacitic pyroxene in garnet porphyroblasts enclosed in a symplectitic matrix composed of hornblende, albite, salitic clinopyroxene, hyperstene, quartz, ilmenite and apatite.

Ghezzo *et al.* (1979, 1982) described different mafic bodies (M. giu Nieddu, Posada Valley) that are fragments of original basic layered complexes. The ultramafic amphibolites consist of hornblende, chlorite, epidote, sphene and relics of a previous granulite paragenesis: olivine, clinopyroxene, orthopyroxene, garnet (mostly enclosed in the hornblende). The plagioclase amphibolites are composed of hornblende, plagioclase, garnet and/or clinopyroxene. Clinopyroxene and garnet are relics of the granulitic paragenesis.

Calc-silicate rocks are widespread in all the migmatitic complex and they form nodules with a size ranging from a few centimetres 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 amphibole, counterbalanced by a decrease of clinopyroxene and garnet.

According to MILLER *et al.* (1976) and GHEZZO *et al.* (1982) the eclogitic rocks experienced an early metamorphic history partially independent of that of migmatites, whereas the amphibolites of Torpè and Golfo Aranci and the calc-silicate nodules show a metamorphic evolution not contrasting with that of migmatites. The anhydrous assemblages could have been formed during M_1, while the successive retrogression and hydratation during and after the M_2 episode.

It is noteworthy that the development of the significative 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 parageneses formed during the first tectono-metamorphic phase (D_1 + M_1); in the high grade zones, the main parageneses grew during or after the second tectono-metamorphic phase (D_2 + M_2).

Microtextural data, together with those on mineral zoning and geothermometry and geobarometry, suggest that the rocks (or mineral pairs) of the different metamorphic zones record different path-ways in the P-T plane, in the course of time:

— prograde path-way for the rocks of the low to medium grade zones, possibly developed during the tectogenetic stage (thickening + heating);

— retrograde, eventually decompressive for the rocks of high grade zone, possibly developed during the exhumation of the basement (ELTER *et al.*, 1985).

Radiometric data indicate that the entire polyphase metamorphic evolution of the Hercynian metamorphism of northern Sardinia probably 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-time paths for tectonically thickened continental crust, recently elaborated by ENGLAND & THOMPSON 1984 and THOMPSON & ENGLAND 1984.

PLUTONISM

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 composite batholith extends southwards cross-cutting the low-grade metamorphic cover in the «Nappe zone» of central Sardinia.

The rocks range in composition from tonalites to leucogranites with minor gabbro-dioritic bodies.

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

These first magmatic events were followed by the emplacement of several plutons of biotite ± amphibole medium-grained tonalites and granodiorites, rich in melanocratic xenoliths of dioritic to tonalitic composition. Their emplacement 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 border zone of the batholith (Trinità d'Agultu, Pattada, Goceano, Sarule-Lanusei) or constitutes some satellitic intrusive massifs (Bitti, Sorgono) mainly cross-cutting low to medium grade metamorphites with strong thermal effects that postdate the regional metamorphism. These plutonic rocks often show a planar flow foliation and field relation that suggest a syn- to late-tectonic 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 plutonites frequently show a flow foliation and bear basic to intermediate xenoliths of magmatic origin.

Among this sequence of intrusions, at least three main groups of granitoid can be recognized:

a) pinkish inequigranular, coarse-grained monzogranites cropping out in the northern part of the region (Gallura; «Calangianus» type ad «Arzachena» type in BRALIA *et al.*, 1982);

b) gray inequigranular or equigranular, coarse-grained monzogranites and monzogranitic granodiorites cropping out in the southern part of the region (Barbagia, Ogliastra;

«Benetutti», «Alà dei Sardi» types in BRALIA *et al.*, 1982);

c) equigranular, massive, coarse-grained leucocratic monzogranites. These granites form medium-sized plutons cross-cutting the above mentioned a and b types of plutons (S. Pantaleo massif; Mt. Pinu massif; Buddusò massif; Borta Melone massif; «Buddusò» type in BRALIA *et al.*, 1982).

The first two groups form elongated parallel belts with NW-SE direction. Their emplacement is late-tectonic and coeval with the main regional up-lift; the third group is younger and cross-cut the structural units.

The radiometric data (DEL MORO *et al.*, 1975) suggest an age of about 300 Ma for the granodioritic to monzogranitic plutons and of 281 ± 5 Ma for the Buddusò massif (COCHERIE, 1984).

The two-mica and the cordierite-bearing granites, cropping out in the Mt. Senes massif (East from Nuoro), are probably contemporaneous with this sequence of late-tectonic intrusions.

— The post-tectonic intrusive cycle is composed exclusively of pinkish or whitish equigranular, massive, biotite leucogranites that form several large composite plutons (Costa Smeralda - Mt. Limbara - Mt. Pulchiana, 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 veins, dikes and stock of microleucogranites and aplites; miarolitic cavities), by an extensive post-magmatic hydrothermal alteration, and by practically the lack of microgranular magmatic xenoliths. On this type of intrusions the ages of 289 ± 1 Ma (DEL 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-dioritic bodies crop out; Punta Falcone, Olbia, Bortigiadas, Osidda, etc. These bodies have often field relations that suggest a mega-inclusions nature. They always show a complex pattern of chemical and mineralogical features connected with interaction processes between subcrustal basic and crustal anatectic acidic magmas (ORSINI, 1979, 1980; BRALIA *et al.*, 1982).

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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 Isatta 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 Baronie-Gallura region are well exposed along the road.

— STOP 5.1 *About one kilometre after the crossroad to Lula: metamorphites 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 «Postgotlandiano» AUCT. of Barbagia. The most evident structural element on a mesoscopic scale are D_2 isoclinal folds. The S_1 schistosity parallel to the compositional layering (S_o) is still clearly visible.

At microscopic scale, these rocks are characterized by a basic paragenesis consisting of quartz, muscovite, albite, chlorite ± biotite to which epidotes, carbonates and ilmenite are sometimes associated.

The biotite, the index mineral of this zone, is synkinematic with D_1 and is preserved in microlithons bounded by S_2.

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

— STOP 5.2 - *Lula: Micaschists and paragneisses of the Garnet + Albite zone.*

Near the village of Lula, it is possible to observe the metamorphic rocks of the Garnet + Albite zone. They are paragneisses (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 S_2, which wraps around microlithons and/or albite porphyroblasts carrying microscopic evidence of the S_1 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 paragneisses and the micaschists, sometimes carbonaceous, of the Garnet + Albite zone.

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

— STOP 5.3 - *Road from Lula to Cantoniera S. Anna: Metamorphites of the Garnet + (Albite + Oligoclase) zone. Micaschists, porphyroblastic paragneisses and augen gneisses (metarhyolites).*

Along a short stretch of road, the contact between the basal levels of the porphyroblastic paragneiss and the augen gneiss is visible. It is the southern limb of the overturned Mamone-Siniscola antiform, developed during the second deformation phase with axis trending E-W and plunging towards E. The porphyroblastic paragneisses are characterized by the presence of plagioclase porphyroblasts with albitic core and oligoclasic rim. They are rotated and flattened according to S_2, 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 remains of a pre-S_2 foliation.

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

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

Moving towards Lodè, we enter the granodioritic orthogneiss, constituting the core of the antiform, and then we pass to the northern limb, also constituted by augen gneisses (here strongly laminated) and northwards, by micaschists.

— STOP 5.4 - *Road Cant. S. Anna - Lodé: Metamorphites of the Staurolite + 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-D_2 static event, were rotated, flattened, and sometimes reduced in grain sized during the second deformation phase responsible of the S_2 foliation.

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

— STOP 5.5 - *Bruncu Nieddu: Metamorphites of the Kyanite + Biotite zone. Garnet - staurolite - kyanite - micaschists. Dikes of camptonitic 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 dike of camptonitic porphyritic lamprophyres of Permian-Triassic age. Northwards (at the bottom of the Rio Posada valley) there is the Sillimanite + Muscovite isograd that coincides roughly with the first appearance of migmatitic facies (quartz - plagioclase - muscovite-bearing leucosomes).

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

— STOP 5.6 - *Rio Mannu: Lodè granodioritic orthogneisses.*

Along the Rio Mannu there are good exposures of the granodioritic orthogneisses of Lodè 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 an amphibolite facies metamorphism during the Hercynian orogenic 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 melanocratic inclusions which have the same schistosity's orientation.

The road to Mamone crosses first granodioritic orthogneisses, locally intruded by metaplites and then, the northern limb of the antiform. Augen gneisses and micaschists often show remarkable thermometamorphic effects linked to the Hercynian plutonites (mainly granodiorites).

Lunch at Nuraghe Loelle.

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

— STOP 5.7 - *Quarry near Buddusò: Monzogranites.*

The Buddusò massif is one of the youngest intrusion belonging to the late-tectonic calcalkaline 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 leucogranitic plutons, belonging to the Mt. Lerno and Concas massifs.

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

— STOP 5.8 - *Punta Tepilora: Stock of garnet-bearing leucogranite.*

The road cross-cuts the Concas 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 migmatitic rocks of the Sillimanite + Muscovite zone.

On the right, southwards, there is a broad blastomylonitic belt trending E-W. Within the blastomylonitic belt, which essentially affected paragneisses and micaschists of the Kyanite +

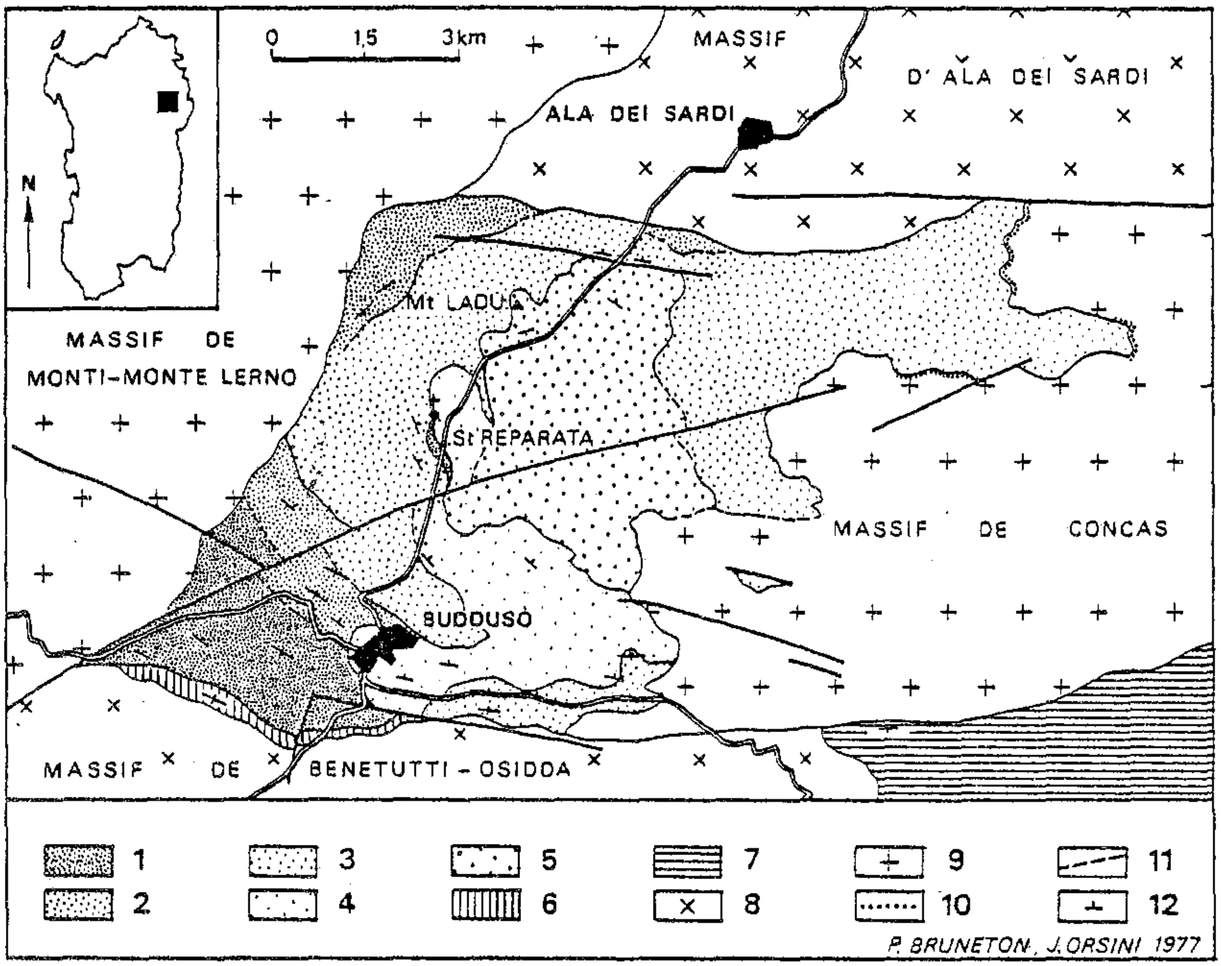

Fig. 5.5 - Geological map of Buddusò massif. (After ORSINI, 1980).
1: Amphibole-bearing tonalites and granodiorites; 2: Amphibole-bearing monzogranites; 3: Biotite-rich monzogranites; 4: Coarse-grained leucocratic monzogranites; 5: Fine-grained leucocratic monzogranites; 6: Metamorphic *septa* 7: Metamorphites of the Lodè-Mamone area; 8: Other granitoids of G2 group; 9: Granitoids of G3 group; 10: «Bordures figées» of the Concas massif; 11: Supposed geological boundaries; 12: Igneous planar fluidality.
(G_2 group of ORSINI (1980) belongs to the late tectonic plutonites of this paper, whereas G_3 group corresponds to the post-tectonic plutonites).

Biotite zone, there are lenticular, stretched and retrogressed bodies of amphibolite, eclogite (?) and augen gneiss.

Further on, we pass the village of Torpè and continue on the Posada plain, up to the crossroad with «Orientale Sarda».

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. Albo group, that are here transgressive just on the hinge of the Siniscola-Mamone antiform.

Going towards Olbia, we take the crossroad to Brunella.

— STOP 5.9 - *Crossroad to S. Lorenzo-Brunella: Metamorphites of Sillimanite + K-feldspar zone. Banded migmatites.*

Along the bank of the road to S. Lorenzo-Brunella, 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 Brunella, 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 gray-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 (S_2) trending about E-W and dipping towards the south. Mesoscopic evidence of pre-S_2 foliations are scanty; 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 can 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. Ruju, mesocratic gneisses are partially lacking in leucosomes, but contain abundant Ca-silicates nodules. These nodules have a sferoid to ellipsoidal shape and are fine-grained and lack in any foliation. 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 orthogneiss crops 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 ground, it is quite similar to the granodioritic orthogneisses of Lodè (see stop 5.6) and plot on the same Rb/Sr whole rock isochron of 458 ± 31 Ma.

We return to the «Orientale Sarda» 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 li Tulchi: 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 alternated 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 gray-green nodules and pods (5-30 cm) as we have seen during the previous stop.

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

Such eclogite roks, probably constituted by an early omphacite-garnet association, appear to have been greatly retrogressed through a successive recrystallization, under amphibolite facies conditions, which caused the development of coronitic and symplectitic structures (hornblende-salitic clinopyroxene-hypersthene-sodic plagioclase).

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

— STOP 5.12 - *M.giu Nieddu - Golfo Aranci: Migmatites and metabasites 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 migmatites, microstructural evidence indicates that the widespread Hercynian recrystallization in amphibolite facies affected rocks already containing high grade anhydrous minerals (kyanite, orthoclase, garnet).

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