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The Late Ordovician (Hirnantian) deposits in the Domusnovas area (SW Sardinia)

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LOCALITY	Perda Muzza, 4 km north-east of Domusnovas village, at geographic coordinates 39°20’45" N, 8°41’05"E
LITHOSTRATIGRAPHIC UNITS	Punta S’Argiola Member of the Domusnovas Formation; Punta Arenas Member, Cuccuruneddu Member, Serra Corroga Member and Girisi Member of the Rio San Marco Formation.
AGE	Katian and Hirnantian.
WHAT TO SEE	Cyclopygid bed, graptolite horizon, manganese rich deposits, offshore storm deposits, glaciomarine deposits, *Hirnantia* fauna.

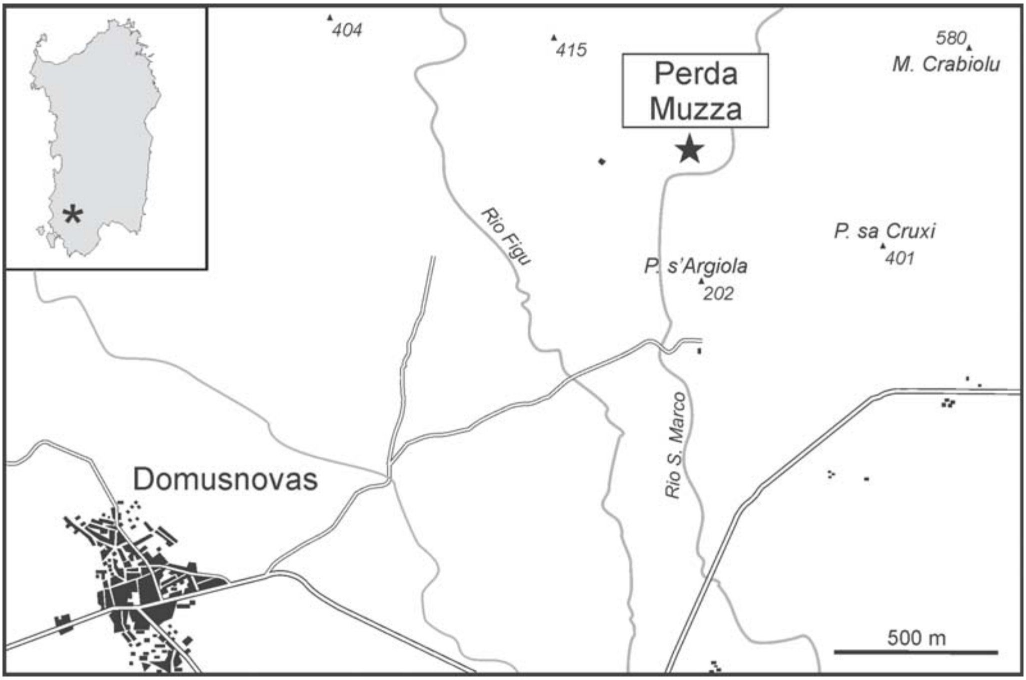

Fig. 1- Location map of the Perda Muzza Ordovician succession.

How to get there

The Perda Muzza outcrops are located 4 km north east of Domusnovas village, F° 556 IV I.G.M.I., inside a reforestation protected area (A.F.D.R.S.) so that a permission is needed for access. You enter going along the municipal road to San Marco valley up to the gates of the A.F.D.R.S. located at various point. Inside you can easily go along many service roads.

Historical outline

The lithostratigraphic units of the uppermost part of Ordovician succession have been formally defined in this area; a detailed description is given in Leone et al. (1991). Cocozza & Leone (1977) have been the first authors to report the outcrops of this member in this site, underlying the essential lithologic features and the occurrence of fossils among which cyclopygid trilobites. These outcrops are also quoted by Giovannoni & Zanfrà (1979) for the brachiopod fauna.

Introduction on the Upper Ordovician of SW Sardinia

The upper Ordovician of the Iglesiente-Sulcis region of southwestern Sardinia (Fig.2) has been studied intensively during the last 30 years by Leone (1973), Cocozza & Leone (1977), Havlícek et al. (1987), Leone et al. (1991, 1995, 1998, 2002), Laske et al. (1994), Hammann & Leone (1997, 2007), Hammann & Serpagli (2003), Storch & Leone (2003) and Botquelen et al. (2006).

Several lithostratigraphical units have been distinguished in the sequence; five formations and nine members have been formally described by Leone et al. (1991) and by Laske et al. (1994) (Fig. 2). The richly fossiliferous levels (Leone et al. 1995) provide an important biostratigraphical and palaeoecological framework for palaeoenvironmental reconstructions and age assignment of the Ordovician succession of southwestern Sardinia.

From the lowermost Monte Argentu Formation, which rests unconformably upon the Cambro-Tremadocian Cabitza Formation, up to the top of the Rio San Marco Formation, the sequence is composed largely of siliciclastic rocks. An exception occurs in the middle Ashgill (Katian) with sedimentation of carbonates in the Punta S'Argiola Member of the Domusnovas Formation (Fig. 2).

The age of the entire post-Tremadocian sequence spans from tentatively defined Caradoc (Sandbian?-Katian) up to the Hirnantian and is principally based on trilobite and brachiopod associations. Near the top of the Punta Arenas Mb. of the Rio San Marco Fm., common graptolites, assigned to the important age-diagnostic species *Normalograptus ojsuensis* (Koren & Mikhaylova), have been described (Storch & Leone 2003). Two horizons with trilobites and brachiopods of the *Hirnantia* fauna are also present in the uppermost part of the succession.

Several transgressive-regressive sedimentary packages have been identified (Fig. 2). The main three sea-level fluctuations can be interpreted as glacio-eustatic changes (Leone et al., 1991, 1995, 1998, 2002; Loi, 1993a, b; Ghienne et al 2000). The other less important sea-level changes could be linked to various phenomena such as subsidence increase, tectonic and probably minor glacio eustatic pulsations.

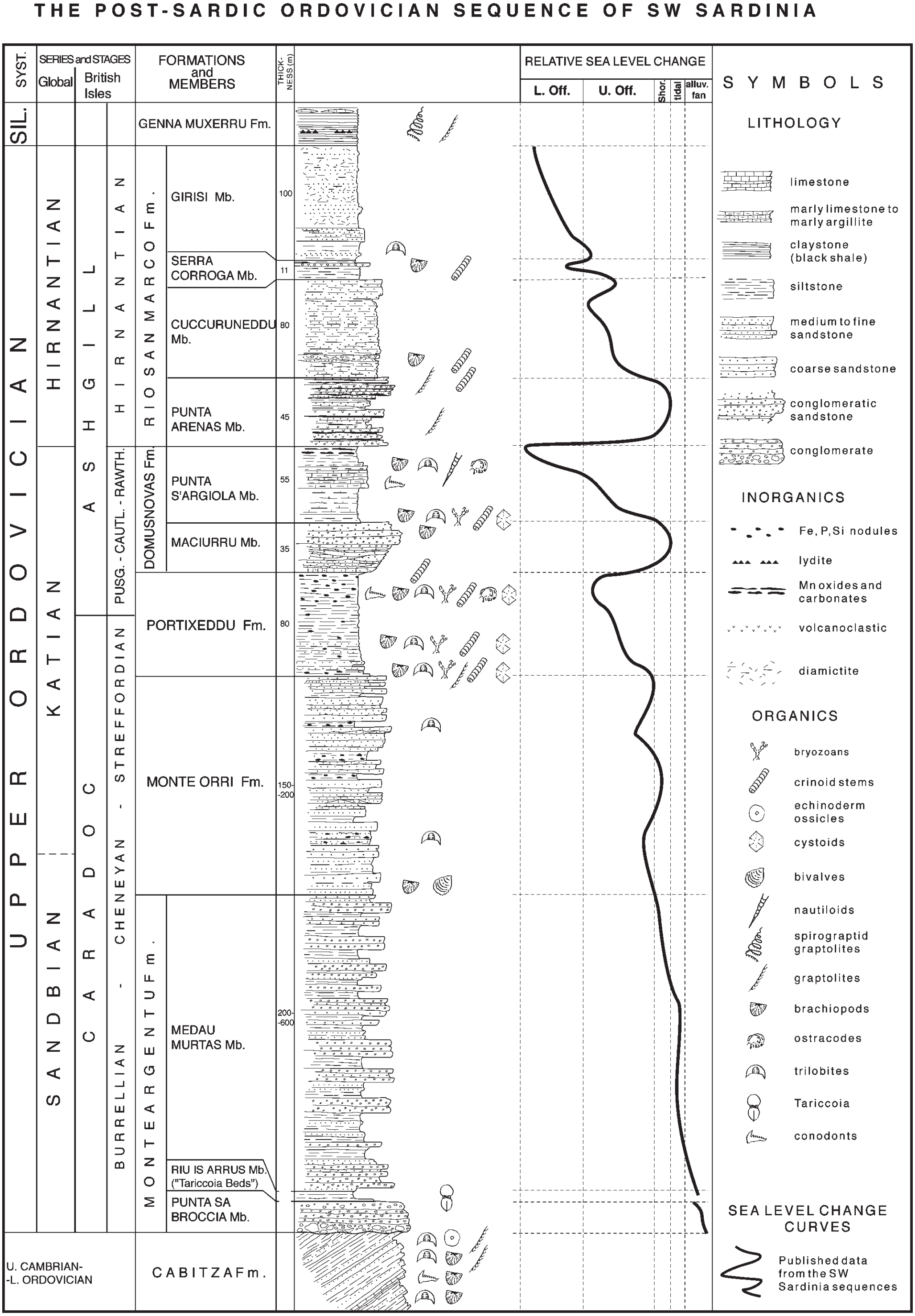

Fig. 2 - The post-sardic Ordovician sequence of southwestern Sardinia (after Leone et al., 1991, 1995, 1998, 2002; Loi, 1993a, b).

The Perda Muzza Ordovician succession

In this locality we can see the uppermost part of the Ordovician succession: the Punta S'Argiola Mb. (part) of the Domusnovas Fm.; the Punta Arenas Mb., Cuccuruneddu Mb., Serra Corroga Mb. and Girisi Mb. of the Rio San Marco Fm. (Fig. 3). Because of logistical problems it is not possible to visit the fomations in the ascending order.

The Punta S'Argiola Member

Location

Inside the A.F.D.R.S. area, along the service road and along a firebreak belt.

Lithology and fossil content

The general lithology consists of red, fossiliferous siltstones/claystones, with a variable content of calcium carbonate.

In the type area of Punta S' Argiola Mb. a 55 metres thick sequence starts with a few metres of grey to light green massive siltstone, barren of fossils in the lower part but with scattered brachiopods and bryozoans in the upper one, followed by slightly calcareous siltstones, grey to light green in colour, with abundant bryozoans and brachiopods and rare trilobites.

The lower-middle part consists of more or less calcareous red shales, very rich in bryozoans, brachiopods (BH4) and echinoderms particularly in the first 15-20 metres. Towards the top, barren horizons of variable thickness alternate with fossiliferous ones. Bioturbation occurs at several levels.

The following part consists of a thin-bedded sequence of weak red marly shales alternating with dusky red calcareous shales, which yield a fairly abundant fauna of orthoconic cephalopods, small brachiopods, bryozoans and crinoids.

At the top of this bedded sequence a dark, reddish grey, slightly calcareous silty shale, very rich in fossils is present; the fauna is characterised by trilobites ("Cyclopygid Bed", TH4), small brachiopods (BH5), ostracodes and rare cephalopods.

The uppermost part consists mostly of unfossiliferous, dusky red to very dusky red shales. Towards the top of the sequence, narrow horizons or nodules, very rich in Fe and Mn oxides, mark the gradual transition to the overlying Punta Arenas Member of the Rio San Marco Formation.

The trilobite fauna (Hammann & Leone, 1997, 2007) is dominated by *Cyclopyge (Phylacops) marginata* Hawle & Corda, but also contains many other typical Ashgillian species, e.g. *Symphysops armata* (Barrande), *Ovalocephalus tetrasulcatus* Kielan, *Arthrorhachis tarda* (Barrande), *Ulugtella angelini* (Holm,), *Shumardia extensa* Weir, *Nankinolithus granulatus* (Wahlenberg), *Paraphillipsinella* aff. *nanjiangensis* Lu, *in* Lu & Chang, *Stubblefieldia* sp., *Staurocephalus clavifrons* Angelin, *Deloites maiderensis* Destombes, *Dreyfussina struvei* (Destombes), *Dicranopeltis* cf. *polytoma* (Angelin), *Calipernus* cf. *immanis* Hammann. The exact age of the fauna within the Ashgill (late Katian) remains uncertain.

The brachiopod assemblage contains distinct elements of the cosmopolite *Foliomena* Fauna and the Bohemian *Proboscisambon* Community (Villas et al., 2002). The *Foliomena* Fauna is known from Pusgillian to middle Rawtheyan, even if a few older records are from late Caradoc. The occurrence of members of the *Proboscisambon* Community,

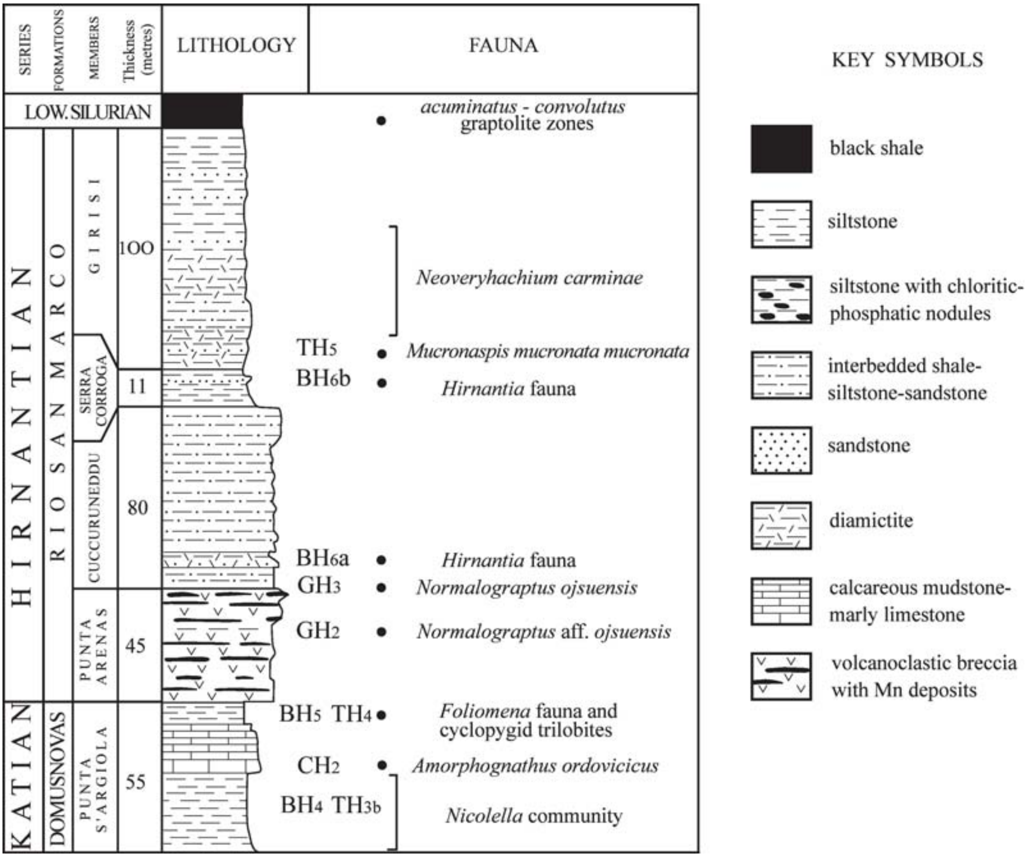

Fig. 3 - Compiled stratigraphy of the Hirnantian deposits of southwestern Sardinia (after Storch & Leone, 2003, modified).

present in Bohemia in the uppermost part of the Kraluv Dvur Formation, may allow the attribution of a more detailed age to this horizon.

Diffractometrical and chemical analyses reveal a Fe content slightly more than 4%. Fe is present as diagenetic hematite, which is responsible for the characteristic red colour of the member. The original Fe components were probably chamosite-goethite. The more common clay minerals are chlorite and illite; very fine quartz crystals were also detected.

In the Punta S'Argiola Member sequence is therefore well detectable a gradual dipping of the sedimentary environment which from inner shelf becomes outer shelf-upper slope. This trend is mainly suggested by the bathymetric meaning of the brachiopod and trilobite assemblages, while the wide range of bathymetric distribution of the cyclopygid trilobites (200-700 metres) does not allow to specify the real variation of sea level which must have exceded 150 metres.

The Punta Arenas Member: manganese rich deposits

Location

Along the service road. The whole section will be crossed from base to top.

Lithology and fossil content

This member is mostly made up of thin (5-10 cm) “brecciated” and conglomeratic layers, green in colour, the dominant pebbles of which are of mainly heterometric and unsorted basic volcanic rocks (Beccaluva et al., 1981), alternating with Mn bearing carbonates and oxides, black siltstones and shales. Towards the base of the sequence some beds, which can reach 50 cm in thickness, bear pebbles up to 3-4 cm in diameter.

The Punta Arenas Member shows strong lateral variations both in the thickness (0-50 metres) and in the distribution of the different lithologies.

A conformable contact exits with the overlying Cuccuruneddu Member, which starts where the sandy horizons do not bear any more volcanic material.

Very rare reworked fragments of bryozoa have been discovered at several levels in the shales. Two fragmentary specimens of graptolites (GH2), previously assigned to *Glyptograptus* sp. and *Glyptograptus* sp. ex gr. *persculptus* (?), have been found. A graptolite bearing-level (GH3) located in the uppermost beds of the Punta Arenas Member contains *Normalograptus ojsuensis* (Koren & Mikhaylova) and possibly also *Normalograptus extraordinarius* (Sobolevskaya) (Fig. 4a), which indicates the lower part of the Hirnantian (Storch & Leone, 2003).

Depositional environment

Nearshore environments have been suggested by Loi (1993b) on the basis of manganese geochemistry. The deposition of manganese is strictly controlled by the eustatic and climatic variations and these processes are particularly important during glacioeustatic transgressions and regressions (Frakes & Bolton, 1984, 1992). The most important sedimentary ores of Mn in the world (Nikopol, Chiatura, Vama, Imini, Urucum, Abuzemina e Polounotch) have originated in littoral or tidal environment.

In Sardinia, Mn-bearing sediments are only present during the glaciation (Loi, 1993a, b; Ghienne et al., 2000). Physiographic modifications on the platform can thus be supposed, such as the occurrence of small isolated sub-basins after a rapid glacio-eustatic fall. During a global low glacio-eustatic sea level episode, glacioeustatically-driven fluctuations control the basinal redox dynamics. During very low sea-level, a large supply of fresh water is responsible for oxydizing conditions and Mn-oxide concretions can form, while during relatively higher sea-levels, sea water inflows result in water stratification and reducing conditions. Mn-carbonate can form by the reduction of Mn-oxydes and dissolved Mn in water can concentrate in sea-water.

The levels of manganese oxides and of manganesiferous carbonates developed from direct precipitation as indicated by bioturbation *(Skolithos* facies), which crosses those levels; the important manganese supply being derived from contemporaneous volcanic activity. The location of the source area of the volcanic materials is, at present, uncertain.

The transition from the Punta S’Argiola Member (outer shelf) to the Punta Arenas Member (nearshore) thus corresponds to an important marine regression.

However, the variation of the sea-level (more than 200 metres) seems too important to be regarded as resulting exclusively from eustatic processes.

The Cuccuruneddu Member

Location

The base of the Member will be observed along the service road.

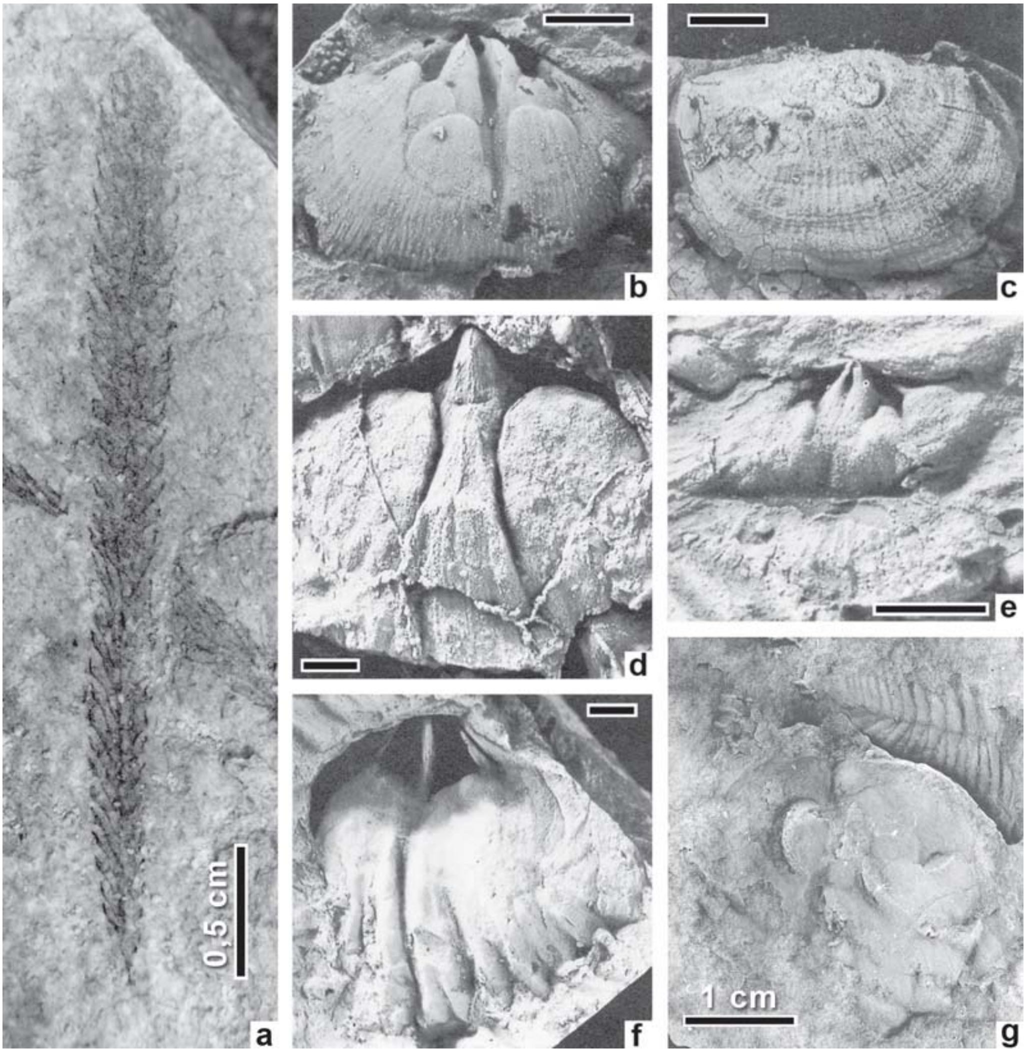

Fig. 4 - Fossils found in Hirnantian deposits. a) *Normalograptus ?extraordinarius* (Sobolevskaya); b) *Kinnella kielanae* (Temple), internal mould of brachial valve; c) *Kinnella kielanae* (Temple), latex cast of ventral exterior; d) *Hindella crassa incipiens* (Williams), internal mould of pedicle valve; e) *Mirorthis* cf. *mira* Zeng, internal mould of brachial valve; f) *Plectothyrella crassicosta* (Dalman), internal mould of brachial valve; g) *Mucronaspis mucronata mucronata* (Brongniart). Bar scale of b, c, d, e and f is 0.25mm. (a refigured after Storch & Leone, 2003; b, c, d, e and f after Leone et al., 1991; g after Hammann & Leone, 2007)

Lithology and fossil content

The general lithology consists of a rhythmical repetition of grey to light grey arenaceous-pelitic beds.

The member is conformable with the underlying Punta Arenas Member and with the overlying Serra Corroga Member. The lower boundary is below the first level of micaceous sandstone barren of volcanoclastic material.

The unit is apparently barren of macrofossils, while several kinds of ichnofossils are preserved on bedding planes but they are practically unstudied. Poorly preserved acritarchs and chitinozoans have been found in several clayey horizons (Del Rio et al., 1979).

More or less 15 metres above the base of the unit, a several metres thick level of massive arenaceous siltstone, interpreted as glaciomarine deposits (diamictite), occurs. South of the Cixerri valley the same level contains *Hindella crassa incipiens* (Williams) (Fig. 4d) and other unassigned articulate brachiopods (BH6a). The occurrence of this typical Hirnantian species supports the Hirnantian age of this member.

Sedimentology and depositional environment

The Cuccuruneddu Member is characterised by typical rhythmic deposits of sandy-clayey heterolithic sequences, representing offshore storm facies frequently of turbidite-like type (Loi, 1993b). The main sedimentary structures are HCS, 2D and 3D ripples, placers, flute-casts, prod-marks and tool-marks (Leone et al., 1991; Loi, 1993b) and the various associations of structures indicate several distinct offshore environments and a new transgressive pulse. The level that has yielded *Hindella* gives evidence (unsorted pebbles of various lithologies within an abundant pelitic matrix) of a sedimentation influenced, in some way, by processes most probably related with the Late Ordovician glaciation.

The Serra Corroga Member

Location

Inside the A.F.D.R.S. area, along a firebreak belt (fire safety belt).

Lithology and fossil content

The most typical lithology consists of a dark-grey and dark-green very fine siltstone with an extremely thin and closely-spaced parallel, varve-like lamination; rare small starved ripples are locally present. This lithology follows grey-greenish siltstones with narrow levels of fine sandstones and grey-greenish siltstones with well out-distanced parallel laminae.

A graded coarse siltstone and sandstone fossiliferous horizon is constantly present in all localities of the Domusnovas area between 26.50 and 50 cm below the top of the member.

This fossiliferous horizon (BH6b) has yielded mainly bryozoans and crinoid ossicles and brachiopods (Fig. 4) such as *Dalmanella* sp., *Mirorthis* cf. *mira* (Zheng), *Hirnantia* sp., *Kinnella kielanae* (Temple) and *Plectothyrella crassicosta* (Dalman), typical elements of the widely spread *Hirnantia* fauna, that occurred in a fairly wide range of depth in the shelf during the Hirnantian Stage (Brenchley & Cocks, 1982).
The thickness of the Serra Corroga Member ranges from 4.50 to 11.50 metres (whereas the typical lithology varies between 3.40 and 7.00 metres).

Sedimentology and depositional environment

The typical varvitic sediments of the Serra Corroga Member consist of an alternation of light and dark coloured laminae of infra-millimetric thickness (about 50 laminae in 1 centimetre). They consist of sequences made of (a) a fine grained silt level (average grain size 40 µm, with some rutile, zircon, tourmaline), (b) a thin film of clay minerals, and (c) a film of spheroidal pyrite (25 sequences per centimetre) (Loi,1993b). These sediments are regarded as distal storm generated deposits.

In the distal upper offshore and in the proximal lower offshore the erosive character of storms disappears; the deposits show a laminar aspect with graded sequences separated by non deposition hiatuses, with characteristics similar to those of the distal turbiditic facies. The fine-grained sandy beds and graded coarse sandstones that constitute intercalations in the typical facies might be related either with bathymetric variations or with exceptional storm events. The typical facies of this member can be interpreted as a turbidite-like storm facies deposited in the distal upper offshore and the proximal lower offshore, meanwhile the coarser intercalations have more affinities with the deposits of the middle part of the upper offshore.

The Girisi Member

Location

Outside the A.F.D.R.S. area, along a dirt path, a few hundred meters to the East from the previous stop.

Lithology and fossil content

The lower part (about 40 metres) consists of dark grey siltstones and claystones with interbedded thin levels of fine and very-fine sandstones with horizontal and crossed lamination. Bioturbated horizons with horizontal trails are present in the lower part whereas in the upper part a 3 m thick rhythmical repetition of pelites and fine sandstones occurs in very thin beds.

The upper part (about 60 metres) consists of highly micaceous and mostly massive siltstones and claystones, dark-grey to green-grey in colour with occasionally intercalated thin beds of fine sandstones. Scattered quartz grains dispersed inside the micaceous siltstone have been observed at several levels.

For this member, even if not directly measurable, a thickness of 70-100 metres is inferred because in all localities it is strongly influenced tectonically by an overthrust of the Arburese Unit.

A single specimen of the trilobite *Mucronaspis mucronata mucronata* (Brongniart) (Fig. 4g) has been found a few metres above the base and a discontinuous level, occurring about 15 m above the base, bears a poorly preserved reworked fauna consisting of small and fragmentary moulds of articulate brachiopods, fragments and ossicles of crinoids, all surrounded by a blackish pelitic matrix. In addition, pelitic levels, interbedded in the first 50 metres of the Salto di San Marco Section, yelds acritarchs of the *Neoveryhachium carminae* Assemblage (Del Rio et al*.*, 1979). The late Llandovery-early Wenlock age of this acritarch assemblage proposed by these authors is in disagreement with the early Llandovery age of the overlying black shales of the Genna Muxerru Formation stated on the base of well preserved graptolites, including *P. acuminatus* Zone (Gnoli et al*.*, 1990; Storch & Serpagli, 1993).

The most reliable age of the member is, therefore, late Hirnantian.

Depositional environment

Horizons bearing uniformly dispersed pebbles within the rich micaceous-pelitic matrix are more common between 40 and 80 metres above the base in the Serra Giomaria hills,

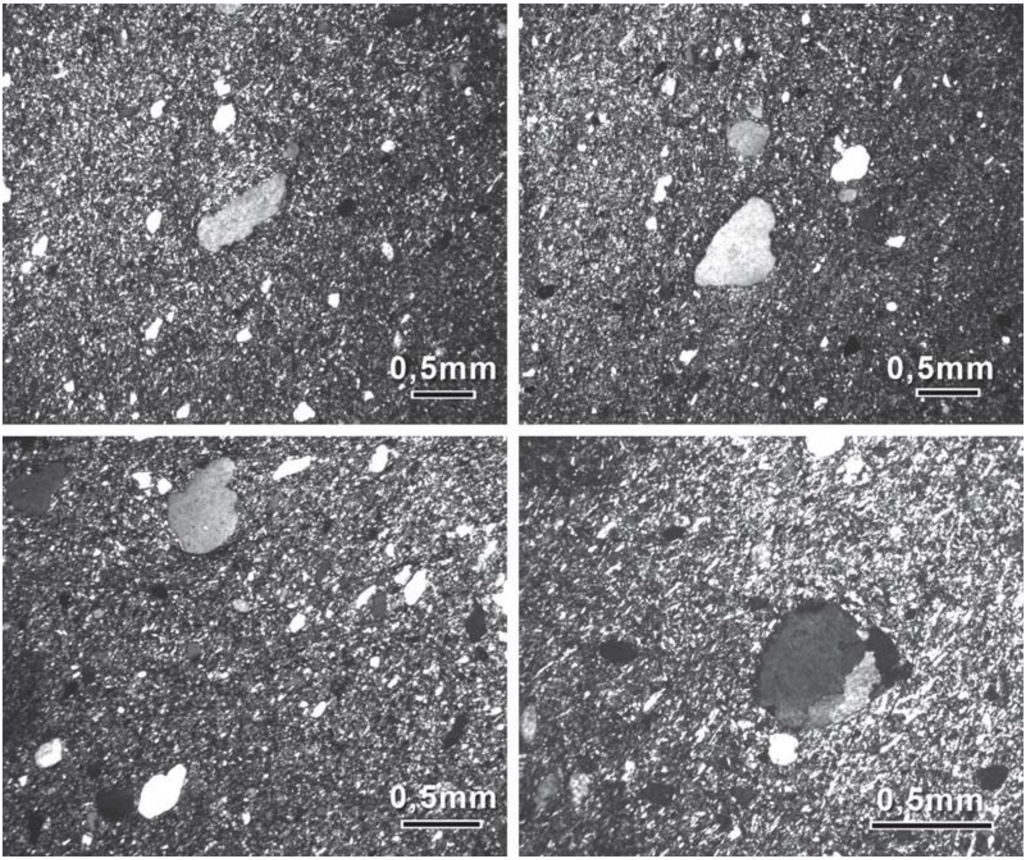

Fig. 5 - Textures and patterns of macro-grains of quartz (dropstone) in the pelitic deposits of Girisi Member.

south of the Cixerri Valley. The largest pebbles are mostly well-rounded quartz grains ranging from 0,4 to 3.0 mm in diameter and mica lamellae up to 1.5 mm (Fig. 5). Such pebbles occur on the rock surface as 2-3 in number per square centimetre. Very rare pebbles of siltstone and micaceous shale, up to 1 cm across, also occur. In thin section the grain percentage is higher (from 7 to 15 %), their size is extremely variable and shape range from well rounded to very angular. These sediments have many features in common with the well-known glaciomarine facies of the uppermost part of the European Ordovician succession, (the "pèlites grèseuses" of Normandy and Spain, the "microconglomeratic argillites" of North Africa or "diamictites" of the Prague Basin). Consequently the sediments of this member are interpreted as glaciomarine deposits. Because many pebbles are well rounded, we suppose that they were dropstones included in the ice starting from almost contemporaneous littoral sediments. The glaciomarine origin inferred for such deposits is in full agreement with the late Hirnantian age of the Girisi Member.

References

Beccaluva L., Leone F., Maccioni L. & Macciotta G. (1981). Petrology and tectonic setting of the Paleozoic basic rocks from Iglesiente-Sulcis (Sardinia, Italy). *Neues Jahrbuch für Mineralogie Abhandlungen*, 140, 2: 184-201.

Botquelen A., Gourvennec R., Loi A., Pillola G.L. & Leone F. (2006). Replacements of benthic associations in a sequence stratigraphic framework, examples from Upper Ordovician of Sardinia and Lower Devonian of the Massif Armoricain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 239: 286-310.

Brenchley P. J. & Cocks L. R. M. (1982). Ecological associations in a regressive sequence: the latest Ordovician of the Oslo-Asker District, Norway. *Palaeontology*, 25: 783-815.

Cocozza T. & Leone F. (1977). Sintesi della successione stratigrafica paleozoica della Sardegna sud-occidentale. *In* Escursione in Sardegna 1977: risultati e commenti (a cura di G. B.Vai), GLP, 2, supplemento, 15-23.

Del Rio M., Leone F. & Pittau P. (1979). Acritarchi Siluriani della successione Paleozoica di Domusnovas (Sardegna sudoccidentale). *Memorie della Società Geologica Italiana*, 20: 289-299.

Frakes L.A. & Bolton B.R. (1984). Origin of manganese giants; Sea level change and anoxic-oxic history. *Geology*, 12, 83-86.

Frakes L.A. & Bolton B.R. (1992). Effects of ocean chemistry, sea level, and climate on the formation of primary sedimentary manganese ore deposits. *Economic Geology*, 87, 5: 1207-1217.

Ghienne J.-F., Bartier D., Leone F. & Loi A. (2000). Caractérisation des horizons manganésifères de l'Ordovicien supérieur de Sardaigne : relation avec la glaciation fini-ordovicienne. Comptes Rendus de l'Académie des Sciences Paris, 331: 257-264.

Giovannoni M.A. & Zanfrà S. (1979). Studio di brachiopodi ordoviciani della Sardegna meridionale. *Bollettino del Servizio Geologico d'Italia*, 99, 85-232.

Gnoli M., Kriz J., Leone F., Olivieri R., Serpagli E. & Storch P. (1990). Lithostratigraphic units and biostratigraphy of the Silurian and early Devonian of Southwest Sardinia. *Bollettino della Società Paleontologica Italiana*, 29, 1: 11-23.

Hammann W. & Leone F. (1997). Trilobites of the "post-Sardic" (Upper Ordovician) sequence of southern Sardinia. Part 1. *Beringeria*, 20 (1997): 217pp.

Hammann W. & Leone F. (2007). Trilobites of the 'post-Sardic' (Upper Ordovician) sequence of southern Sardinia. Part II. *Beringeria*, 38: 160pp.

Hammann W. & Serpagli E. (2003). The algal genera *Ischadites* Murchison, 1839 and *Cyclocrinites* Eichwald, 1840 from the Upper Ordovician Portixeddu Formation of SW-Sardinia. *Bollettino della Società Paleontologica Italiana*, 42: 1-29,

Havlicek V., Kríz J. & Serpagli E. (1987) Upper Ordovician brachiopod assemblages of the Carnic Alps, middle Carinthia and Sardinia. *Bollettino della Società Paleontologica Italiana*, 25, 3: 277-311.

Laske R., Bechstädt T. & Boni M. (1994) The post-Sardic Ordovician series. *In* Mem. Descr. Carta Geol. d'It., Bechstädt T. and Boni M. eds., 48: 115-146.

Leone F. (1973) La serie paleozoica del settore di Orbai-Monte Maori (valle del Cixerri, Sardegna SW). *Bollettino della Società Geologica Italiana*, 92: 621-633.

Leone F., Ferretti A., Hammann W., Loi A., Pillola G.L. & Serpagli E. (1998). Outline of the post-Sardic Ordovician sequence in South-western Sardinia. *In* Serpagli E. (Ed.), Sardinia Field-trip Guide-book, ECOS VII. *Giornale di Geologia*, 60, Spec. Issue: 39-56.

Leone F., Ferretti A., Hammann W., Loi A., Pillola G.L. & Serpagli E. (2002). A general view on the post-Sardic Ordovician sequence from SW Sardinia. *Rendiconti della Società Paleontologica Italiana*, 1: 51-68.

Leone F., Hammann W., Laske R., Serpagli E. & Villas E. (1991). Lithostratigraphic units and biostratigraphy of the post-sardic Ordovician sequence in south-west Sardinia. *Bollettino della Società Paleontologica Italiana*, 30, 2: 201-235.

Leone F., Loi A. & Pillola G.L. (1995). The post-sardic Ordovician sequence in south-western Sardinia. *In*: Cherchi A. (Ed.), Sardinia 95, 6th Paleobenthos International Symposium, October, 25-31, 1995. *Rendiconti del Seminario della Facoltà di Scienze dell'Università di Cagliari*, suppl. vol. 65: 81-106.

Loi A. (1993a). Sedimentological-Petrographical study and paleogeographical approach of the Upper Ordovician of the central southern Sardinia. *European Journal of Mineralogy "Plinius"*, 9 81-86.

Loi A. (1993b). Studio sedimentologico - petrografico e considerazioni paleogeografiche dell'Ordoviciano superiore della Sardegna centro meridionale. Doctoral Thesis, Cagliari University, 204pp.

Storch P. & Leone F. (2003). Occurrence of the late Ordovician (Hirnantian) graptolite *Normalograptus ojsuensis* (Koren' & Mikhaylova, 1980) in south-western Sardinia, Italy. *Bollettino della Società Paleontologica Italiana*, 42 (1-2): 31-38.

Storch P. & Serpagli E. (1993). Lower Silurian Graptolites from Sardinia. *Bollettino della Società Paleontologica Italiana*, 32(1): 3-57.

Villas E., Hammann W. & Harper D.A.T. (2002). *Foliomena* fauna (brachiopoda) from the Upper Ordovician of Sardinia. *Palaeontology*, 45 (2): 267-295