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Silurian and its surroundings in the inner nappes of Sardinian Variscides: lithostratigraphical evidence from metamorphosed deposits

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ABSTRACT - In the tectonic units of the Inner Nappe Zone of the Sardinian Variscides, due to metamorphism and deformation, the Silurian System and its lower and upper boundaries are badly defined. Apart the occurrence of black, graphite bearing phyllites and schists, no sedimentary and fossil record survived. Only in Nurra (northwestern Sardinia) a unique finding of *Orthoceras*-made black coquina allows attributing, even broadly, the thick, monotonous black phyllites outcrops to the Silurian System. Here, in addition, the metasediments lying at the Ordovician-Silurian transition exhibit high variability both in composition and texture: they include glaciomarine diamictite, oolitic ironstones, phosphorites, sub-aerial conglomerate and epiclastite. This succession is also characterized by the occurrence of alkaline metabasites. Different Variscan blocks, from Maures to eastern Alps, share similar litho-stratigraphic features possibly testifying glacial environment, emergence and rifting at northern Gondwana between Late Ordovician and early Silurian.

KEY WORDS - Ordovician/Silurian Boundary, Inner Nappe Zone, Silurian, Sardinia

The Silurian exhibits only weak variability among the different tectonic units of the Sardinian Variscides. Differences concern the abundance of calcareous beds as well as – although limited to the very base of this System – the occurrence of alkaline volcanics. The latter can be considered the prosecution of Late Ordovician volcanic activity as confirmed by a recent U/Pb datation (440 ± 1.7 My; Buzzi et al., 2007) on coarse alkaline epiclastic rocks in the external (Gerrei Unit) nappes.

As for the Silurian of the Inner Nappe Zone, some differences rise between the units of eastern Sardinia, from Gennargentu Mountain up to the Posada valley, and the units of northwestern Sardinia. In the former units the only evidence of Silurian deposit is restricted to the occurrence of black phyllites. Approaching to the Posada-Asinara Line, metalimestones tend to disappear and only rare, thin beds of marble occur within dark micaschists, which but supposedly can be referred to a protolith of Silurian age. Moreover, no alkaline metavolcanics are associated to the black metapelites and surrounding schists in this area. Over all, the increased metamorphic grade between green schist and amphibolite facies, along with strong deformation, prevent any stratigraphical distinction on the transition between Ordovician and Silurian systems. On the other hand this boundary, otherwise worthy of detailed investigation, is badly exposed even in the external nappes, as Upper Ordovician deposits and Silurian metargillites are generally juxtaposed along tectonic contacts.

Despite green-schist facies metamorphism and high strain, which affect most of the rocks, litho-stratigraphical correlations are still possible in some tectonic units of the Inner Nappe Zone. In fact, some metasediments retain primary meso- and micro-textures, which along with chemical bulk composition and mineralogy, represent distinctive features useful both as stratigraphical markers and palaeoenvironmental proxies. This is the case of the metasediments, which characterize the uppermost Ordovician and the lower Silurian in the Nurra region (northwestern Sardinia) (Fig. 1). Here black phyllites are exposed on the overturned limb of a SW verging anticline, which in turn is refolded in a wide E-W trending synform (Carmignani et al., 1979). Despite metamorphism erased any trace of

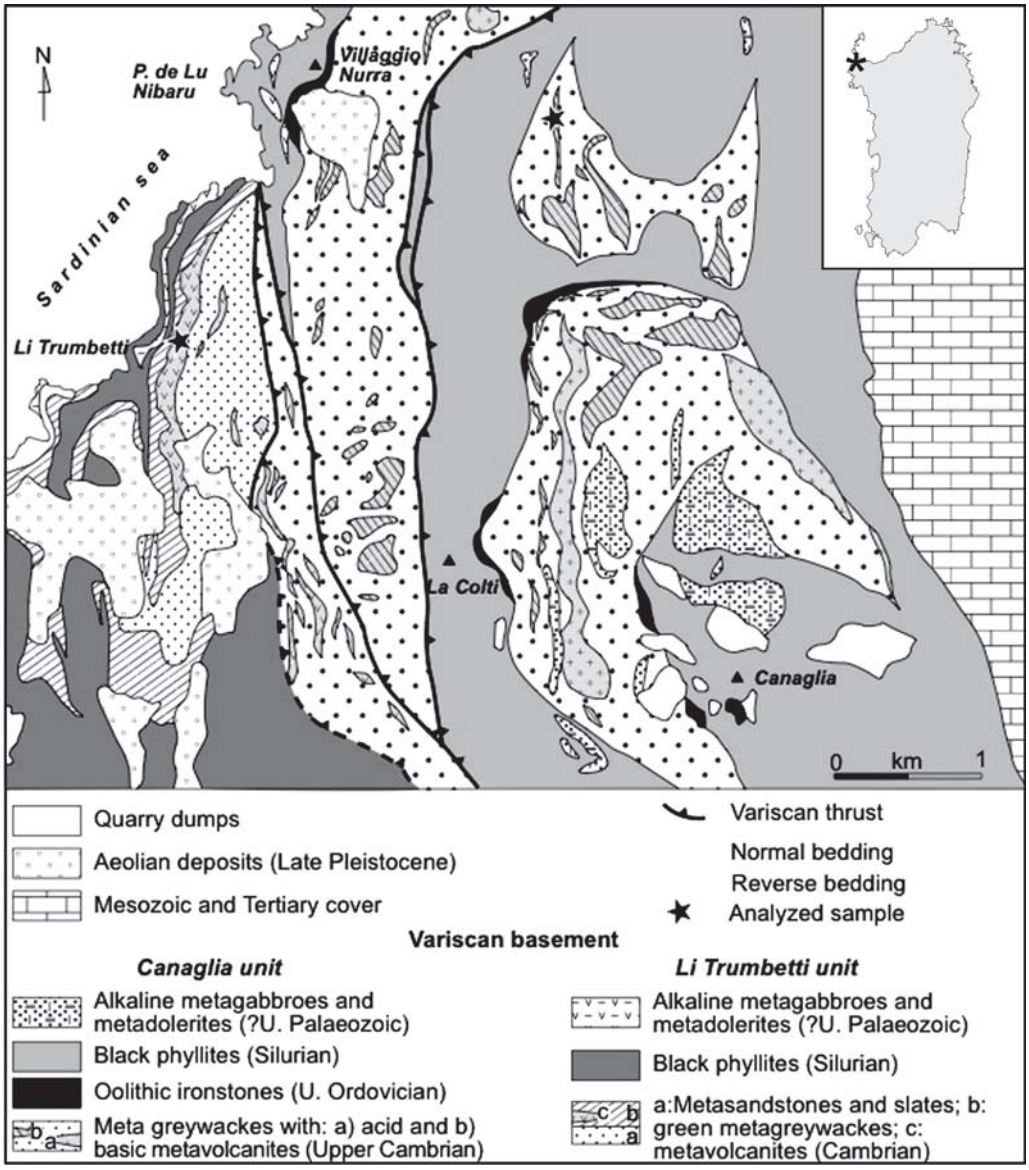

Fig. 1 - Geological sketch map of central Nurra.

graptolites, a broadly Silurian age of these metargillites is confirmed by the finding of rare *Orthoceras*-bearing black limestone (Venerandi, 1965) - which differs from the typical Ockerkalk limestone anyway - at La Colti mine.

In Nurra, black limestones associated with black metapelite are restricted to rare metric lenses. Devonian shelf limestones, widespread elsewhere in the external nappes, are missing in Nurra. On the other hand, the thickness of the black metargillites is higher than in the external nappes as it exceeds 200 meters.

Glaciomarine deposits, oolitic ironstone, phosphorus-rich and iron-rich (chamosite) mudstones characterize the Ordovician-Silurian boundary; moreover conglomerates reworking oolitic ironstones and sub aerial volcanoclastites give evidence for an emergence episode.

High facies variability between units and even, over short distance, within the same unit, is another clue that an emergence occurred at the end of the Ordovician, followed by transgression in the Silurian. How wide the gap linked to the continental period was is hard to establish lacking any biostratigraphical data. In the same way there is no evidence to establish whether the sea withdraw was driven only by glacioeustasy or if tectonics played also a role.

Similar associations, at different metamorphic grade, are decipherable from Maures Massif (Collobrieres, Le Murettes units), to the Carnic Alps (Rauchkofel) (Ferretti, 2005).

An overview of the Ordovician-Silurian boundary in Nurra can refer to three areas that probably correspond to different tectonic units (Fig. 2).

These units are all affected by green schist facies metamorphic overprint and by pervasive axial planar cleavage linked to the F1 olding phase of Carmignani et al. (1979). Locally, close to shears zone, a second pervasive cleavage could appear, but weak or no cleavage characterize the wide F3 upright, open folds with E-W trending axes and eastward axial immersion.

The structural arrangement issued from the Variscan collision, along with the eastward Cainozoic tilting of this basement block, brought Silurian and Upper Ordovician rocks to the surface in the central part of the coastal Nurra, just in the core of a regional F3 post-nappe synform.

Three tectonic units separated by tectonic contact have been distinguished (Oggiano & Mameli, 2006). Within each of these, beyond the Variscan deformation which generally makes the polarity reversed, it is possible to reconstruct with good approximation the stratigraphy at the Upper Ordovician-Silurian boundary (Fig. 2).

In the Canaglia Unit, at La Colti mine and in the excavations near Villaggio Nurra where oolitic ironstone was mined, the following succession can be reconstructed:

- Silurian black phyllite with pyrite crystals in the basal beds;
- 5-10 m thick black metargillite with thin, light-coloured, varve-like laminations;
- 1 m thick metamorphosed mudstone, chamositic in composition, in which thin clast-bearing layers alternate with a layer rich of clayey ooids;
- a discontinuous horizon of matrix-supported conglomerate with rounded, millimetric to metric, clasts mostly made of magnetite (hard ironstone). This rock is detectable only in an old adit, so that to assess its thickness is not easy, in any case it should not exceed a couple of meters;
- a few meters of a metamorphic diamictite consisting of chamosite matrix supporting chamosite ooids, nodules and clasts of phosporites;
- at least 50 meters of greenish metagraywacke hosting alkaline metabasite.

Metadolerite sills and metagabbroic bodies are scattered within this succession.

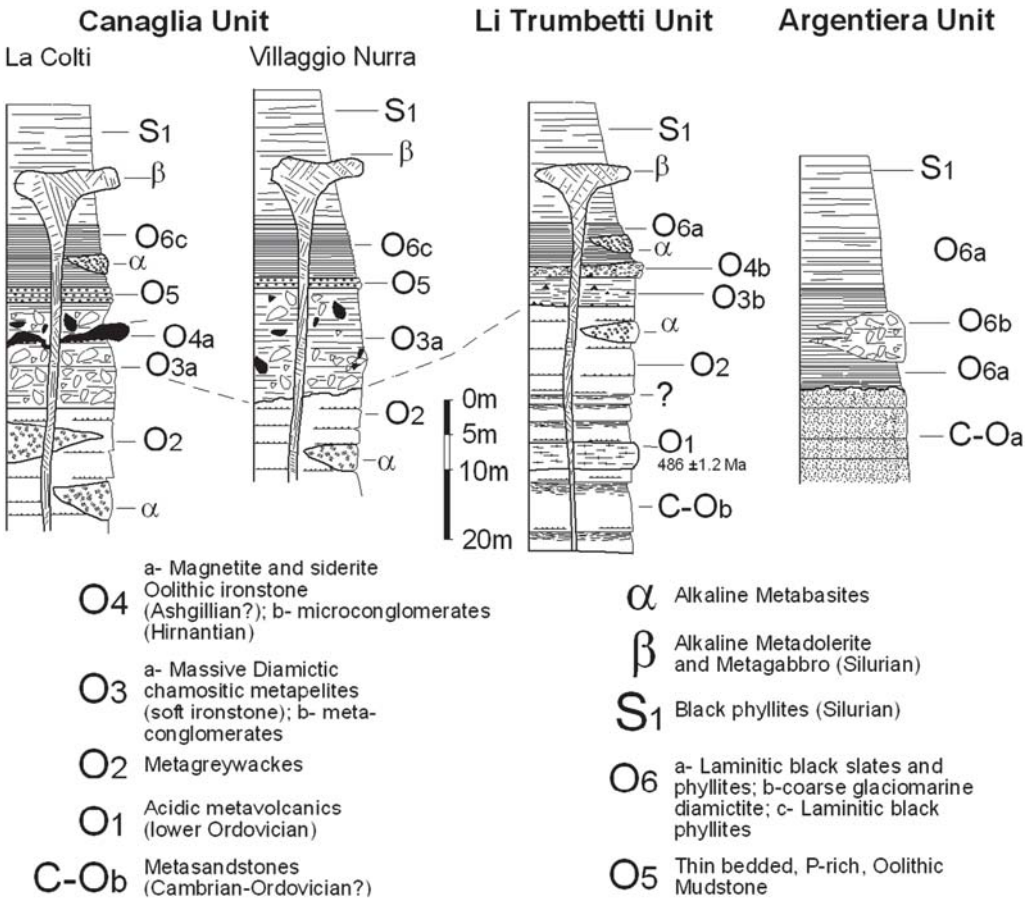

Fig. 2 - Litho-stratigraphical logs of the tectonic Units cropping out in Nurra (northwestern Sardinia), across the Ordovician-Silurian boundary

In the Li Trumbetti Unit a similar succession crops out but oolithic ironstones are absent and the older rocks are metasandstones and slates hosting metarhyolite bodies that yielded an age of 486 ± 1.2 My (U/Pb age on zircon; Buzzi et al., 2007), these metasediments are capped by:

· 30 meters of metagreywacke with metabasite bodies, coarse epiclastite and rare metalimestone or marble lenses;
· 1-2 meters of a fine, quartzitic, metamicroconglomerate with pyrite;
· a few meters of black metargillite with thin, light-coloured, varve-like laminations;
· At least 150 meters of black phyllites hosting rare level of black cherts (lydites). At places some metric lenses of black limestone were observed.

A different stratigraphical succession characterizes the Argentiera Unit (Fig 2). In fact here the metavolcanic products, the oolitic ironstone and the chamosite-bearing mudstone, which characterize the supposed Upper Ordovician in the previous units, are missing and the black metargillite with thin, light-coloured, varve-like laminations rests on pinkish quartzite with sericite and ankerite. Worthy of note is the discontinuous occurrence of angular, possibly rafted debris, embedded within the dark laminites. Despite deformation

and metamorphism the characteristic of glaciomarine diamicton is still preserved. Oggiano & Mameli (2006) referred this metadiamictite to the Hirnantian glaciation.

In conclusion a number of noticeable features characterize the Silurian and, in particular, the Ordovician-Silurian transition in the inner nappe of Nurra:

i) The huge thickness of black phyllites in comparison with other sectors of the Sardinia and Corsica Variscides and the lack of meaningful amount of carbonate rocks, including the Devonian limestones;
ii) The occurrence of within-plate alkaline volcanism (Di Pisa et al., 1992);
iii) The occurrence of chamosite oolitic ironstone and phosphorus-rich sediments;
iv) The occurrence of an emergence just before the Silurian transgression;
v) Glaciomarine deposits and chlorite/chamosite-rich nearshore diamictic mudstones.

These stratigraphical features reflect a scenario characterized by the onset of rifting in the North Gondwana margin (alkaline metabasalt). The rifting stage embraced the time span during which Hirnantian glaciation occurred. This glacial event, along with a possible break up in the rift centre, enhanced the sea retreat from the shelf leading to an unconformity driven by break-up and eustatic minimum with stratigraphical gap embracing part of Hirnantian and part of Llandovery.

During the following early Silurian transgression this realm has got located in the outer shelf-upper slope settings on the Gondwanan passive margin pertaining to the broadened rift that allowed the drifting of the peri-Gondwanan terranes. This location could explain the lack of both Silurian and Devonian shelf limestones. Moreover the occurrence of glacial deposits in Armorica (Robardet & Doré, 1988; Picarra et al., 2002) in this time span, suggests that the "Armorican Terranes Assemblage" (Franke, 2000) or Hun Superterrane (von Raumer, 2003) - if ever detached from the Northern Gondwana margin - were still close to it in the early Silurian.

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