

Occurrence of the late Ordovician (Hirnantian) graptolite *Normalograptus ojsuensis* (Koren' & Mikhaylova, 1980) in south-western Sardinia, Italy

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ABSTRACT – Common graptolite rhabdosomes assigned to the late Ordovician zonal index species *Normalograptus ojsuensis* (Koren' & Mikhaylova, 1980) are recorded from the upper part of the Punta Arenas Member of the Rio San Marco Formation (Iglesiente-Sulcis region, south-western Sardinia). They provide biostratigraphical evidence for the previous assumption that at least the upper part of the Punta Arenas Member is Rawtheyan/Hirnantian or early Hirnantian in age. The present graptolite material refers the upper part of the Punta Arenas Member to the early Hirnantian extraordinarius – ojsuensis Biozone. The Hirnantian age of the succeeding Cuccuruneddu Member has already been established by the presence of an Hirnantia Fauna and glacio-marine diamictites.

RIASSUNTO – [Graptoliti dell'Ashgill superiore (Ordoviciano terminale) nella Sardegna sud-occidentale, Italia] – Nella parte superiore del Membro di Punta Arenas della Formazione di Rio San Marco (Iglesiente-Sulcis, Sardegna sud-occidentale) è stato rinvenuto un livello con abbondanti rhabdosomi di graptoliti, attribuibili alla specie guida *Normalograptus ojsuensis* (Koren' & Mikhaylova, 1980). Ciò rappresenta una conferma di quanto precedentemente supposto e cioè che almeno la parte superiore del Membro di Punta Arenas ricadesse o a cavallo del limite Rawtheyano/Hirnantiano o nell'Hirnantiano inferiore. Il materiale ritrovato permette di attribuire la parte alta del membro di Punta Arenas alla biozona a extraordinarius-ojsuensis dell'Hirnantiano. L'età Hirnantiana del successivo Membro di Cuccuruneddu è già stata documentata dalla presenza della Fauna a Hirnantia e da depositi glacio-marini.

INTRODUCTION

The upper Ordovician of the Iglesias-Sulcis region of south-western Sardinia (Text-fig. 1) during the last 25 years has been studied intensively by Leone (1973), Coccozza & Leone (1977), Havlíček *et al.* (1987), Leone *et al.* (1991), Laske *et al.* (1994), and Leone *et al.* (1995).

Several lithostratigraphic units have been distinguished in the sequence and five formations and nine members have been described formally by Leone *et al.* (1991) and Laske *et al.* (1994). The many fossiliferous levels (Leone *et al.*, 1995) provide an important biostratigraphical and palaeoecological framework for palaeoenvironmental reconstructions and precise age assignment of the Ordovician succession of south-western Sardinia.

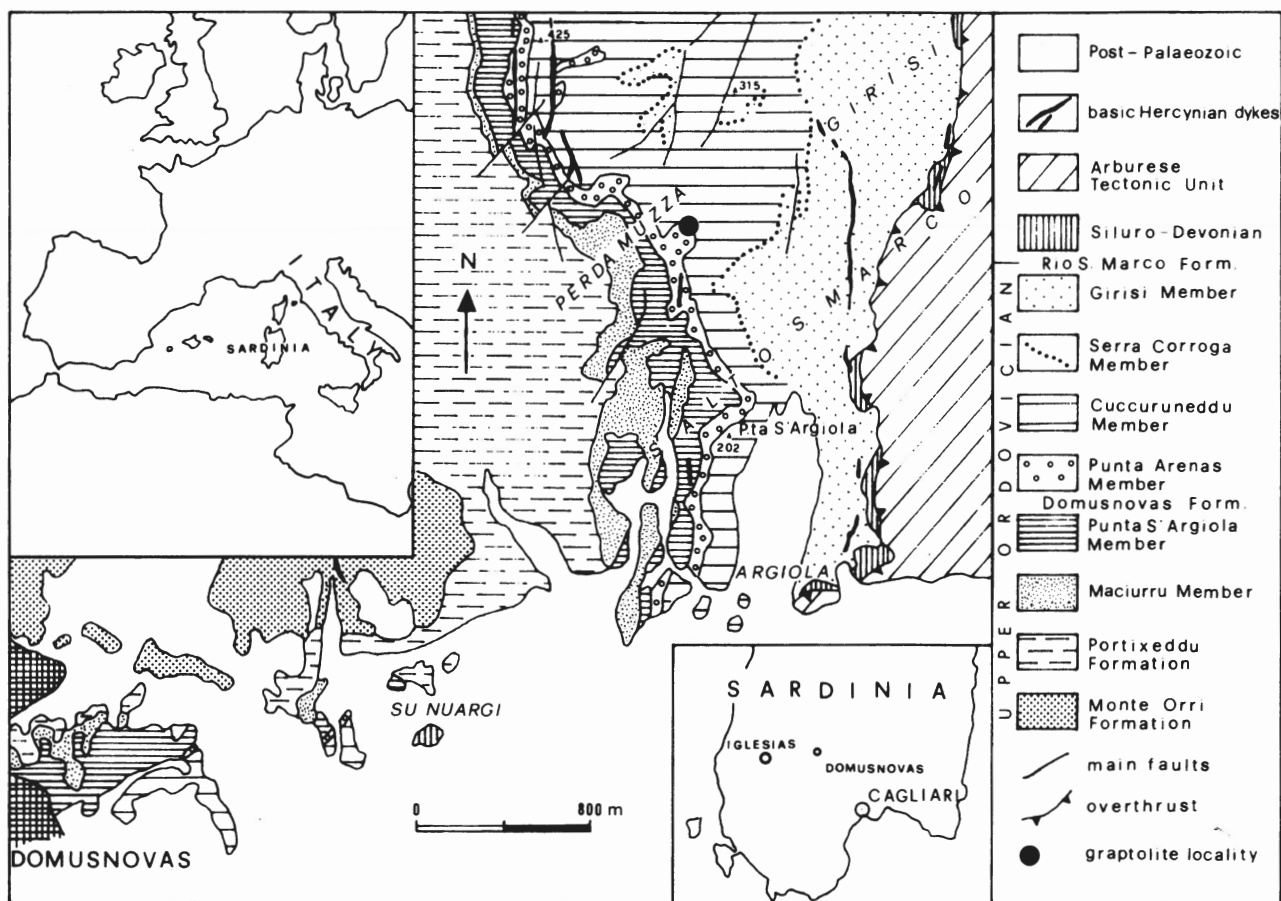
From the lowermost Monte Argentu Formation, which rests unconformably upon the folded Cambro-Tremadoc formations, up to the top of the Rio San Marco Formation, the sequence is composed largely of siliciclastic rocks. An exception occurs in the middle Ashgill (Text-fig. 2A), when the Punta S'Argiola Member of the Domusnovas Formation contains carbonates. This is not surprising as significant carbonate deposition occurred across Peri-Gondwanan Europe in about the mid-Ashgill (various types of cystoid and bryozoan limestones and calcareous mudstones are known from the Iberian Peninsula, Bohemia and the Carnic Alps).

The age of the entire post-Tremadoc sequence spans from tentatively defined Caradoc (Soudleyan) up to the uppermost Ashgill. It is dated principally by trilobite and brachiopod associations because among the graptolites so far recovered (Leone *et al.*, 1993) no zonal diagnostic species were found. The Ashgill strata, for instance, have so far yielded twelve fossiliferous levels. Near the supposed base of the upper Ashgill (Hirnantian) sequence, common graptolites, herein assigned to the important age-diagnostic species *Normalograptus ojsuensis* (Koren' & Mikhaylova), have been found by one of us (F.L.).

The upper Ordovician succession also records several sea-level fluctuations, the most prominent of which were during the Ashgill (Text-fig. 2B, after Loi, 1993 and Leone *et al.*, 1995). These oscillations have been mainly, but not exclusively, attributed to glacio-eustatic influences (Leone *et al.*, 1995, and references cited therein).

GEOLOGICAL SETTING

The upper Ashgill Rio San Marco Formation begins with the interbedded conglomerates, volcanoclastic breccias, siltstones and shales of Punta Arenas Member. The average thickness of the individual layers of conglomerate is 0.3-0.5 metres, clasts may reach 30-40 mm in diameter. The bulk of clasts are alkali-basalts (Beccaluva *et al.*, 1981) derived from contemporaneous volcanic activity; a minor amount is siltstones and sandstones.



Text-fig. 1- Geological map showing location of the graptolite-bearing level in the Punta Arenas Member.

These clastic beds alternate with black siltstones, dark-green shales and quartz-poor arenites. Frequent intercalations of manganese oxides, up to 0.1 m thick, are also present in the sedimentary succession of the Punta Arenas Member.

No significant fossils were found in this succession, apart from rare bioturbation, a few bryozoan fragments and two levels with a monospecific assemblage of biserial graptolites.

The *Normalograptus ojsuensis* described in this paper come from the uppermost part of the Punta Arenas Member, a few metres below the base of the succeeding Cuccuruneddu Member (both members belong to the Rio San Marco Formation), i.e. a few metres below glacio-marine diamictites and beds which yield *Hirnantia* Fauna.

The graptolite-bearing greywacke, 0.3 m thick (Text-fig. 2A), is composed of small argillified volcanic clasts included in a fillosilicatic matrix. The rock is rather soft, cleaved and extremely friable. Its primary colour (dark-green or black) has altered to light-grey due to intense weathering. Some Mn and Fe patinas are present. Apart from the common rhabdosomes of *N. ojsuensis*, one undeterminable brachio-

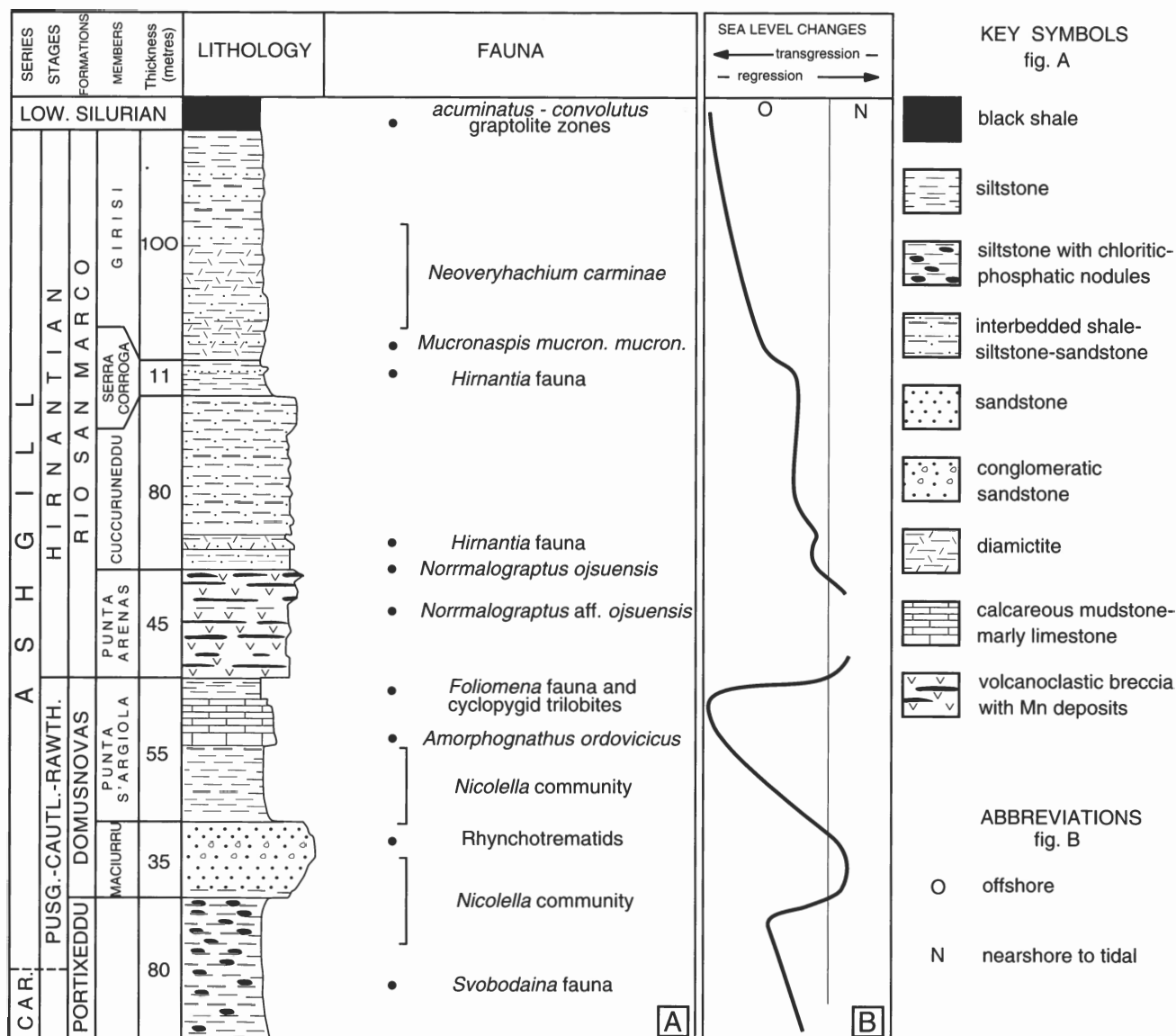
pod was recorded. Above this level rare graptolites occur in some dark grey shales. These shales, however, are so badly cleaved that no fossils can be identified (because of the tectonic deformation).

The fossiliferous bed crops out at Perda Muzza, about 4 km north-east of Domusnovas (I.G.M.I., F 556 IV), along a service road inside the Monti Mannu A.F.D.R.S. protected reforestation area (Text-fig. 1). This exposure was investigated during the field trip of the 6th Paleobenthos Symposium (Leone *et al.*, 1995, Stop 5 on fig. 32), when the graptolites were attributed provisionally to "*C. extraordinarius*."

SEDIMENTARY ENVIRONMENT OF THE PUNTA ARENAS MEMBER

At some outcrops of the Punta Arenas Member, particularly near the base of the unit, the occurrence of Ta-e Bouma sequences suggests that sedimentation was probably controlled by proximal turbiditic processes (Leone *et al.*, 1991).

Petrological and sedimentological studies by Loi (1993) emphasized the anomalous abundance of Mn minerals and made possible the more precise assess-



Text-fig. 2 - Compiled stratigraphy of the Ashgill deposits of south-western Sardinia (A) and sea-level curve (B) after Leone *et al.* (1995), modified.

ment of the sedimentary environment of the unit, based on the geochemical behaviour of Mn.

The dissolution/precipitation processes of Mn compounds are strongly controlled by eustatic and climatic variations in platform marine sediments. These processes become more prominent during transgressive-regressive cycles, especially those, related to glacio-eustatic sea-level fluctuations (Frakes & Bolton, 1992). The manganese is soluble as a colloidal form in anoxic conditions but precipitates in the form of an oxide (in well oxygenated nearshore environments) or carbonate (in well oxygenated offshore environments). During sea-level high-stand periods, the dissolved manganese is concentrated in

oxygen-depleted (or poorly oxygenated) deep waters. In regressive periods, the sea-level drops, the shoreline retreats and the littoral dynamics trigger Mn precipitation in the highly oxygenated nearshore environments (Frakes & Bolton, 1992 - "Broom and Veil Effects").

The common manganese accumulations suggest a nearshore to transitional marine, locally even lagoonal environment for the Punta Arenas Member.

The graptolite-bearing bed of the upper part of the Punta Arenas Member, however, originated under normal, shallow marine (offshore) conditions. A similar environment can be envisaged for the sandy conglomeratic levels with crinoid columnals, about two

metres higher up the sequence, just below the base of the succeeding Cuccuruneddu Member.

A prominent regressive-transgressive cycle starts with the outer shelf deposits of the Punta S'Argiola Member. Deep-water brachiopod and trilobite faunas have been listed by Villas *et al.* (2002) and Leone *et al.* (2002). Brachiopods were referred to *Foliomena* Fauna and closely related to Rawtheyan *Proboscisambon* Community of Bohemia. Regression culminates in the nearshore conglomerates and breccias of the Punta Arenas Member, and the new transgression is demonstrated by the offshore, storm-influenced deposition of the Cuccuruneddu Member.

The Cuccuruneddu Member is characterized by the appearance of quartzose-micaceous beds with high-energy structures (such as HCS, cross lamination, etc.) indicating storm-influenced deposition. The recent discovery of the *Hirnantia* fauna (Leone *et al.*, 1991) provides direct evidence of the Hirnantian (late Ashgill) age of this unit.

In the lower part of the Cuccuruneddu Member, 15-20 metres thick sub-greywackes are present. They are regarded as glaciomarine diamictites reflecting the latest Ordovician (late Ashgill) glaciation of the Southern Hemisphere.

SYSTEMATIC SECTION

Genus NORMALOGRAPTUS Legrand, 1987

Type species (by original designation) – *Diplograptus persculptus* Elles & Wood, 1907; from the upper Ordovician of Pumpsaint, Wales.

Diagnosis – After Štorch & Loydell (1996).

Remark – Štorch & Loydell (1996) assigned *Glyptograptus persculptus* Elles & Wood to *Normalograptus* Legrand. The same time *Gl. persculptus* was designated the type species of the new genus *Persculptograptus* by Koren' & Rickards (1996). With respect to recent examinations of *P. persculptus* and related species *P. ojsuensis* we retain the two species in *Normalograptus* Legrand according to their pattern H astogeny (*sensu* Mitchell, 1987) combined with geniculated, glyptograptid thecae. More or less geniculate thecae, extended throughout the rhabdosome, are common among the species of broadly defined *Normalograptus*. Geniculate appearance of the thecae may be either enhanced or suppressed according to preservation and compression of each rhabdosome.

NORMALOGRAPTUS OJSUENSIS (Koren' & Mikhaylova, 1980) Text-figs. 3 A-F, 4 a-d

- 1973 *Diplograptus tariti* (Legrand) - MIKHAYLOVA, pp.16-17, pl. 3, figs. 7-8.
? 1976 *Fenhsiangograptus extraordinarius* (Sobolevskaya) - SENNIKOV, p.121, pl.3, fig. 9.

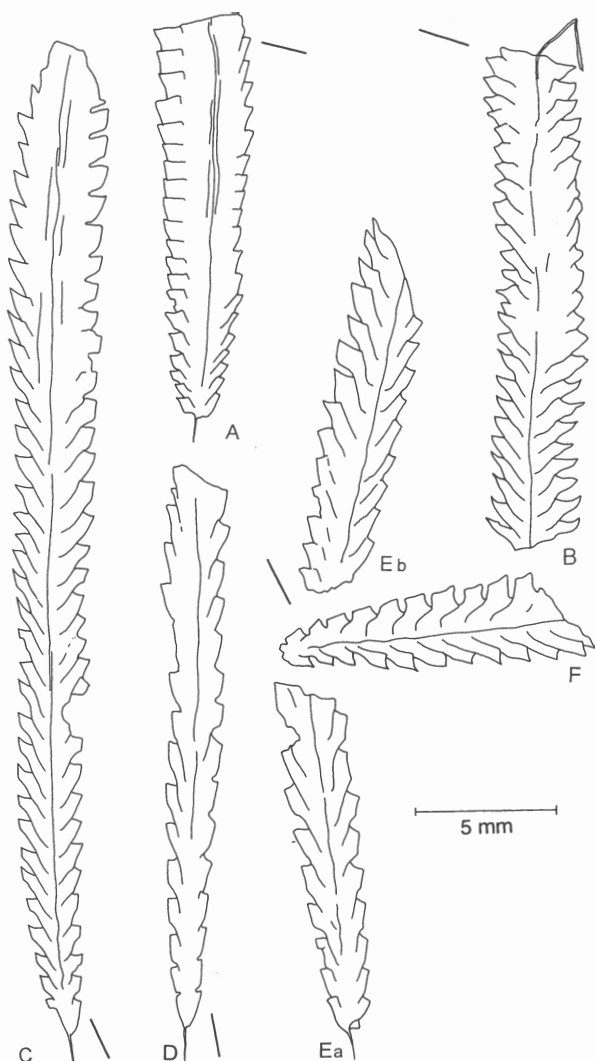
- 1977 *Diplograptus* sp. KOREN' & SOBOLEVSKAYA, fig. 2/3.
1979 *Glyptograptus* ? *ojsuensis* Koren' & Mikhaylova - KOREN' *et al.*, pl. 21, figs. 4-9 (*nomen nudum*).
1980 *Glyptograptus* ? *ojsuensis* Koren' & Mikhaylova, sp. nov. - KOREN' *et al.*, pp.143-145, pl. 41, figs 1-8, pl. 42, figs 1-2, text-fig. 43 a-e.
1983 *Glyptograptus* ? *ojsuensis* Koren' & Mikhaylova - KOREN' & SOBOLEVSKAYA, pp. 142-144, pl. 41, figs 7-12, pl. 42, figs 1-3, text-fig. 53 a-l.
? 1983 *Diplograptus ojsuensis* (Koren' & Mikhaylova) - MU & NI, pp.165-166., pl. 1, figs. 1-4.
1984 *Diplograptus ojsuensis* (Koren' & Mikhaylova) - LI, p. 338, pl. 10, figs 5-6, 9-12.
1984 *Diplograptus ojsuensis* (Koren' & Mikhaylova) - GE, pp. 417-418, pl. 1, figs 19-21, 23; pl. 3, fig. 9; pl. 5, figs 14-15.
1984 *Diplograptus ojsuensis* (Koren' & Mikhaylova) - NI, p. 323, pl. 1, figs 13-14; pl. 2, figs. 17-18.
1989 *Glyptograptus teres* (Perner) - ŠTORCH & MERGL, pl. 4, fig. 2.
1989 *Glyptograptus* cf. *ojsuensis* Koren' & Mikhaylova - ŠTORCH, pp. 181-182, pl. 2, figs 1-2, 6-7; text-fig. 2 A-D.
1993 *Glyptograptus* (*Glyptograptus* ?) *ojsuensis* Koren' & Mikhaylova - LEGRAND, pp. 437-438, pl. 1, figs a-e; text-fig. 2 a-g.
2000 *Normalograptus ojsuensis* (Koren' & Mikhaylova, 1980) - CHEN *et al.*, text-fig. 7u.

Holotype – Original designation: specimen No 11568/96 (housed in VSEGEI Museum in St. Petersburg) from the uppermost part of the *Cl. supernus* Biozone (*Par. pacificus* Subzone), Chokpar Formation, locality No F-1053 near Ojsu, Chu-Ili Mountains, WNW of Alma Ata, Kazakhstan. Figured by Koren' and Mikhaylova (1980) on pl. 41, fig. 1.

Material – About fifty flattened specimens affected by moderate to severe tectonic deformation. When cleavage lineation is at right angles to a flattened rhabdosome, the dorso-ventral width and thecal inclination are increased, and the thecae are more closely packed and are strongly geniculate. When the lineation is parallel to the length of the rhabdosome, the thecal count and inclination are decreased, and the rhabdosome may appear narrower. Many specimens, however, have been affected only by moderate oblique deformation which altered the original proportions of the rhabdosome only slightly. The oblique lineation, however, has caused differences in thecal and apertural inclinations between the two thecal series of the biserial rhabdosome.

All specimens are from the same horizon in the uppermost part of the Punta Arenas Member of Rio San Marco Formation, exposed at Perda Muzza, 4 km NE of Domusnovas.

Description – The rhabdosome is over 40 mm long, with a 1-2 mm long virgella and slender, several mm long nema. The rhabdosome widens from 1.2-1.4 mm at the aperture of th 1¹ to 1.8-2.4 mm at the level of the fifth thecal pair. A width of 2.3-2.6 mm is attained within 10 mm of the proximal end of the rhabdosome. The maximum width of 2.7-3.1 mm is attained about 15 mm from the proximal end.



Text-fig. 3 A-F - *Normalograptus ojsuensis* (Koren' & Mikhaylova) from Perda Muzza near Domusnovas. A) DSTCL.302; B) DSTCL.301; C) DSTCL.305; D) DSTCL.303; Ea, Eb, and F) DSTCL.304. All specimens $\times 4$, cleavage lineation indicated by respective black bar.

In specimens where the cleavage lineation is parallel to the length of the rhabdosome, the dorso-ventral width increases from the initial 0.85-1.3 mm to 1.9-2.0 mm within the initial 10 mm of the rhabdosome's length. The maximum width of 2.2-2.5 mm is attained about 15 mm from the proximal end.

Where the lineation is perpendicular to the length of the rhabdosome, the width increases from the initial 1.5-1.8 mm to the maximum of 3.0-3.6 mm which is attained within 10-15 mm of the proximal end.

The sicula is visible for about 0.8 mm in obverse view. The sicular aperture has a diameter of about 0.3 mm; the sicular apex has not been observed. Th 1^1 grows downwards and then, below the sicular aper-

ture, turns upwards. Th 1^2 grows upwards for its entire length. The proximal development gives a distinctive asymmetrical normalograptid appearance to the proximal end (pattern H proximal development *sensu* Mitchell, 1987).

The appearance of the thecae depends upon the orientation of the rhabdosome with respect to the cleavage lineation. Sigmoidally curved thecae with sharp genicula are typical of flattened rhabdosomes perpendicular to the lineation. Those rhabdosomes oblique to the lineation or preserved in subscleriform view have one thecal row strongly geniculate whilst the second displays almost straight ("orthograptid") thecae. Less deformed specimens show almost glyptograptid, moderately geniculate thecae. Thecal excavations occupy c. one-fifth of the dorso-ventral width of the rhabdosome. Thecae number 5-5.5 in proximal 5 mm. They number 4.5 in the proximal 5 mm in tectonically elongated rhabdosomes and up to 7 in the proximal 5 mm in tectonically broadened rhabdosomes. Distally the thecae number 9.5-10.5 in 10 mm. In strongly deformed rhabdosomes the distal thecal count varies between 7.5 and 14 thecae in 10 mm. The median septum is probably complete and is slightly undulating in the proximal part of the rhabdosome.

Remarks – The present material is too tectonically deformed to ascertain precisely the former gross parameters of the rhabdosome and the details of thecal morphology. Geniculation, thecal count and morphology, all vary greatly due to the tectonic deformation. With the exception of the rhabdosomes preserved parallel to the lineation, the Sardinian specimens differ from both the type material of *N. ojsuensis* (Koren' *et al.*, 1980) and from *N. persculptus* reviewed by Storch & Loydell (1996), in being considerably wider, presumably due to the tectonic deformation. The thecae are of glyptograptid appearance although the proximal thecae have stronger genicula.

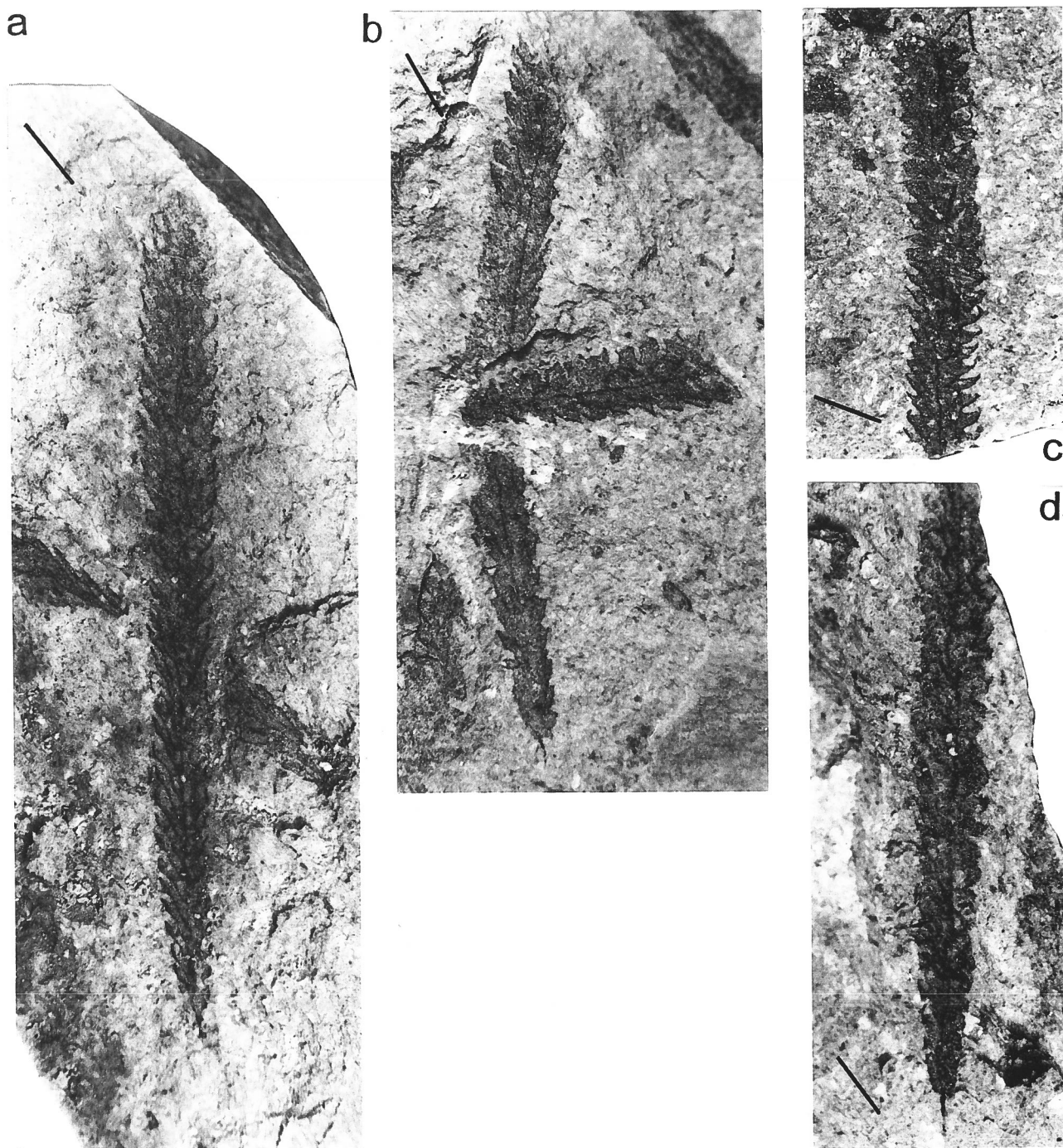
There are two graptolite taxa similar to *Normalograptus ojsuensis* reported from roughly coeval strata:

Normalograptus extraordinarius (Sobolevskaya, 1974), a zonal-index species of early Hirnantian age, is wider and differs in having strongly geniculate, more tightly packed thecae with prominent genicular flanges, shorter, parallel-sided supragenicular walls and smaller apertural excavations.

N. persculptus, a zonal-index graptolite of late Hirnantian age and a likely descendant of *N. ojsuensis* (see also Rickards & Koren', 1996), differs in having less geniculate and more greatly overlapping thecae with shallower thecal excavations and more inclined supragenicular walls.

STRATIGRAPHICAL SIGNIFICANCE

Normalograptus ojsuensis has been found in many richly fossiliferous and biostratigraphically well dated sections of Kazakhstan, NE Russia and China. Chen



Text-fig. 4 a-d - *Normalograptus ojsuensis* (Koreň & Mikhaylova) from Perda Muzza near Domusnovas. a) DSTCL.305; b) DSTCL.304; c) DSTCL.301; d) DSTCL.307. All specimens x 4, cleavage lineation indicated by respective black bar.

et al. (2000) introduced a combined *N. extraordinarius* – *N. ojsuensis* Biozone, defined in Yangtze region sections in South China and correlated worldwide. In Kazakhstan the first appearances of *N. ojsuensis* overlap with the last occurrences of *Parorthograptus pacificus*. First appearance of *N. extraordinarius* is located

a little higher. The same biostratigraphic succession has been described from NE Russia (Koreň & Sobolevskaya, 1983). There *N. ojsuensis* has been associated with *Normalograptus angustus*, *N. pogrebovi*, *N. normalis* and highest occurrences of *Par. pacificus*. *N. extraordinarius* appeared immediately above.

In Bohemia the specimens assigned herein to *N. ojsuensis* were described by Štorch (1989) from the top of the Králův Dvůr Formation. The graptolite-bearing bed is underlain by the so-called Pernik Bed, a distinct muddy limestone with a rich Rawtheyan shelly fauna (*Proboscisambon* Community), and is succeeded by the first glaciomarine diamictites and shales with uncommon mucronaspid trilobites (Štorch & Mergl, 1989; Štorch, 1990).

One of the most recent records of *Normalograptus ojsuensis* comes from Niger, central Africa (Legrand, 1993). The possibly preHirnantian or, at maximum, early Hirnantian age of the local graptolite-bearing beds (Chirfa Formation) is supported by the presence of associated trinucleid trilobite species.

In south-western Sardinia all specimens of *N. ojsuensis* were found in a thin horizon close beneath the lowest glaciomarine diamictites of the Cuccuruneddu Member, well above the Rawtheyan *Foliomena* Fauna of the Punta S'Argiola Member and a few metres below the *Hirnantia* Fauna (see Text-fig. 2).

Here and elsewhere in the otherwise graptolite-poor Gondwanan (Niger) and peri-Gondwanan (Bohemia) upper Ordovician, *N. ojsuensis* characterizes the beds immediately beneath glacially influenced Hirnantian sequence with occasional *Hirnantia* fauna. On the basis of the records reviewed above, we support Chen Xu *et al.* (2000) and consider *Normalograptus ojsuensis* (Koreň & Mikhaylova) to be an important age-diagnostic species indicative of the early Hirnantian *N. extraordinarius* – *N. ojsuensis* Biozone. In according to the records listed above, however, the base of recently introduced *extraordinarius* – *ojsuensis* Biozone is placed slightly below the base of the formerly used *extraordinarius* Biozone (as already stated by Rong *et al.*, 1999).

The graptolites recorded herein indicate that the uppermost beds of the Punta Arenas Member of south-western Sardinia belong in the lower Hirnantian *extraordinarius* – *ojsuensis* Biozone. This assignment supports the preliminary but biostratigraphically unsupported dating of the Ashgill strata by Leone *et al.* (1991, 1995).

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