

Conodont content and stratigraphy of the Llessui Formation from the south central Pyrenees.

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ABSTRACT

A synthetic stratigraphic succession of the Upper Silurian Llessui Formation is established according to partial sections and conodont sampling. The lower part of the formation is considered Ludlow, while the uppermost Přídolí conodont *O. e. detortus* Zone is recognised at the top. Above, the shales, with some limestones of the Aneto Formation, range from the Přídolí to the middle Lochkovian *L. omoalpha-A. trigonicus* Zone, where the limestones of the Rueda Formation begin. The carbonate facies of the Llessui Fm are similar to the Ockerkalk facies from the Northern Gondwana. The succession is compared with other Pyrenean sequences and related with some Mediterranean neighbouring areas.

Key words: conodonts, Ockerkalk facies, Pyrenees, stratigraphy, Upper Silurian.

RESUMEN

Una sucesión estratigráfica sintética de la Formación Llessui (Silúrico Superior) es establecida a partir de la realización de secciones parciales y el estudio del contenido en conodontos de algunas capas. La parte inferior de la formación es considerada del Ludlow, mientras que el techo contiene conodontos del Přídolí más alto, en particular de la Zona de *O. e. detortus*. Encima, las pizarras con algunas capas de caliza de la Formación Aneto abarcan desde la parte más alta del Přídolí al Lochkoviense medio (Devónico), con conodontos de la Zona de *L. omoalpha-A. trigonicus* Zone, y donde se inicia la Formación Rueda. Las facies carbonatadas de la Formación Llessui son similares a las conocidas como facies Ockerkalk en el Norte de

Gondwana. La sucesión estratigráfica se compara con otras de los Pirineos y se relaciona con las descritas en áreas próximas del Mediterráneo.

Palabras clave: conodontos, facies Ockerkalk, Pirineos, estratigrafía, Silúrico Superior.

INTRODUCTION

Silurian black argillaceous limestones, bearing cephalopods and cardioids are commonly intercalated among black shales in the Pyrenees. These limestones are particularly abundant between the upper Wenlock and the Lower Lochkovian (see synthesis in García-López *et al.*, 1996). The Llessui Limestones (Poblet and Casas, 1993) denomination, is applied to a particular Silurian unit composed of shales and limestones outcropping between the Flamisell and the Noguera Pallaresa rivers (south central Pyrenean Axial zone). The Llessui Limestones are included in the Durro-Llessui tectonic unit (Poblet and Casas, 1983) and in the eastern part of the Baliera-Flamisell unit (Mey, 1967).

The Silurian of the Llessui-Durro unit has an important basal detachment level, which placed the Silurian succession on different levels of the Cambro-Ordovician series. Therefore, the relationship with the underlying Cambro-Ordovician Orri unit is produced through a subtractive contact (Poblet and Casas, 1993) that has been folded and reactivated as a thrust in the successive Variscan and Alpine deformations (Gil-Peña and Barnolas, 2001). According to these authors, the internal structure of the Durro-Llessui unit is really complicated, with the superposition of two non-coaxial multi-kilometric fold systems with thrusts associated. The deformation produces frequently stratigraphic repetitions, which make difficult the understanding of the Silurian succession.

The first attempt to study the Silurian succession in the Llessui area was made by Schmidt (1931) based on the fossils identified by von Gaertner (1930). He interpreted tentatively an original thin Silurian succession that was strongly thickened by the intense Variscan deformation. Later, Dégardin (1988) studied some faunas of graptolites, conodonts and trilobites.

The present paper describes the stratigraphic succession for the Llessui Limestones based on observations on some localities and the study of the conodont content. The description of the Llessui Limestones contributes to a better knowledge of the Silurian sedimentation in the Pyrenees and allows a comparison to other Pyrenean or North Spain Iberian successions.

STRATIGRAPHY OF THE LLESSUI LIMESTONES

The Llessui Limestones or Formation is applied to a unit composed by darkish grey nodular limestones with shale inter-beds. It is located between the 'Lower Graptolitic shales' of Schmidt (1931) and the shales of the Aneto Formation or also the Devonian shales and limestones of the Rueda Formation, both after Mey (1967). The 'Lower Graptolitic shales' are black carbonaceous shales bearing graptolites that Dalloni (1930) and mainly Dégardin (1988), considered from the upper Telychian (Llandovery) to the Gorstian (Ludlow) in the Llessui area. The shales included carbonate thin beds and nodules in the uppermost 15 m of the unit. Limestones are black carbonaceous and often laminated, containing many orthoconic nautiloids, bivalves, ostracods and some trilobites, some of them cited in and von Gaertner (1930) and Schmidt (1931). Some nodules are rich in pyrite filling fossil moulds.

Above the 'Lower Graptolitic shales', the Llessui Fm is divided in a lower and an upper members. The lower one begins at the first beds of darkish grey nodular limestones. They are bioturbated mudstones and show flaser beds, typical of the Thuringian 'Ockerkalk' facies of Jaeger (1977). This first beds are several metres thick (4-7 m) and are followed by another shale prevailing unit, with marls and some limestone beds, and where layers with trilobites and crinoid remains are found.

The upper member of the Llessui Fm is composed of approximately 18 m of limestones with the 'Ockerkalk' facies. They are mudstone to wackestone of cephalopods and ostracods with bioturbated beds. The burrows are brown to yellow in colour and evident in the grey blue carbonates. Some black shale beds are inter-bedded. At the top, there are 3-3.5 m of crinoidal wackestone disposed in levels, with rare tests and scarce cephalopods. The top of the Llessui Fm is locally an irregular and sharp surface under marls and shales. However, marls and some thin carbonate nodules or layers can be observed in the base of the overlying Aneto Fm. The upper member of the Llessui Fm has provided '*Cardiola interrupta*', '*C. gibbosa*', '*Maminka comata*', '*Pentamerus optatus*', '*Atrypa ovata*' and '*Scyphocrinus elegans*' (Roussel in Dalloni, 1930).

The Aneto Fm is less thick in the Llessui area, 8-12 m, than in the typical west Baliera-Flamisell unit, where 50-200 m have been described (Mey, 1967). It is grey and greenish altered shales with rare carbonate nodules. We have also included in this formation to an upper part of 8-10 m thick, where shales include nodular carbonate beds or nodule levels among marls. The lower part of the Aneto Fm has yield steams of crinoids. Schmidt (1931) found marls with *Scyphocrinus* and *Phacops* cf. *bronni* of Lochkovian age at the northern border of the Coma de

Montros, under blue shales with *Uncinulus* cf. *subwilsoni* and a platycrinoid. He described tests of probably *Scyphocrinus subonartus* Barrande at Capdella, revised later by Haude (1992) as *Marhoumacrinus* n. sp.?, and *Camarocrinus* cf. *subornatus* from a probable Přídolí age.

The Rueda Fm begins in a predominantly carbonate lower member with some 20 m of thickness. It is composed of nodular limestone beds or nodules among marls and bluish black shales, which are not often differentiated of the Llessui Limestones. The typical Rueda Fm is developed above this member, where the shales increase its content on pelitic greywackes and siltstones. In the Llarvent area, Schmidt (1931) determined a 'lower Cobletzian' age for a bed with '*Orthoceras*' sp., '*Athyris*' *undata*, *Merista* sp., *Petraja* sp., *Striatopora* sp., *Cladochonus striatus*, *Dalmanites* sp., *Phacopidella misera* and '*Chonetes* cf. *plebeia*'.

BIOSTRATIGRAPHY

Carbonate beds from the upper part of the 'Lower Graptolitic shales' and the lower member of the Llessui Fm have provided low diverse and scarce conodont faunas with *Ozarkodina excavata*, elements of *Oulodus* (samples Altron Sorre 1 and Sopena). *Ozarkodina excavata* was cited by Dégardin (1988, samples F351 and F386) and Sanz López (1995, sample 826 from Dr. Poblet). Dégardin and Pillet (1983) determined *Leonaspis* (*Kettneraspis*) *leridae* Dégardin and Pillet above upper Wenlock graptolites, and Dégardin (1988) indicated the presence of graptolites of the *P. nilssoni* Zone (Gorstian) in the 'Lower Graptolitic shales'. The lower beds in the upper member of the Llessui Fm are considered Gorstian according to the presence of the conodont *Kockelella variabilis variabilis* (sample 135). This subspecies is referred from the *K. crassa* Zone to the *A. ploeckensis* Zone after Corradini and Serpagli (1999). It agrees with the finding of ostracode *Bolbozoe bohémica* by Schmidt (1931) under the upper member in shales with siliceous nodules and the trilobite '*Phacopidella*' sp. and '*Cheiurus*' sp. The ostracode has a range from upper Gorstian to the Lutfordian (Ludlow) in Bohemia. The Gorstian age disagrees with the trilobite findings from the so-called 'marly horizon' of Schmidt (1931). He considered a lower Ludlow age, but the fauna, according to the discussions in Rábano *et al.* (1993), can be correlated with middle Lutfordian bohemian faunas. '*Encrinurus*' *rialpensis* von Gaertner, '*Ceratocephala minuta*' Barrande (= *Acantholomina minuta*), *Phacopidella grimburgi* Frech, '*Phacops fecundus minor*' Barrande (= *Ananaspis fecunda*) occur.

Dégardin (1988) assigned samples of the Llessui Fm to the *O. eosteinhornensis* Zone (Přídolí), although elements of '*Ozarkodina eosteinhornensis*' were only obtained in one of them (F378). However, *Ozarkodina crispa* is cited in his sample F405 collected from dark

limestones with thin interlayered black shales. It is indicative of the upper Lutfordian (Ludlow) and basal Přídolí *O. crispa* Zone.

Ozarkodina aff. *eosteinhornensis* is yielded in the uppermost beds with abundant crinoids (samples 136-4, 137 and Bordes de Enviny-1), together with *Ozarkodina confluens* (late morphs), *Ozarkodina excavata*, , *Oulodus elegans*, *Oulodus* cf. *siluricus*. The samples are correlated with the *O. eosteinhornensis* s.l. Zone (Přídolí). The uppermost beds contain elements of *Oulodus elegans detortus* (sample 136-1), some of them with two small teeth between big ones (sample 136-3). This taxon is indicative of the *O. e. detortus* Zone, in the uppermost Přídolí.

The Aneto Fm had provided only a lower Lochkovian conodont fauna (*Icriodus angustoides* and *Ozarkodina eladioi* Valenzuela-Ríos) but it came from a far section of the Llessui area (Baliera section of Valenzuela-Ríos, 1994). At the studied area, a nodular carbonate level near the base of the Aneto Fm has provided elements with morphologies of *Ozarkodina canadensis*, species referred in the upper Přídolí, below and with the findings of *O. e. detortus* in the East Baltic (Viira, 1999). Consequently, the base of the Aneto Fm is still Přídolí-in age.

The carbonate nodule levels in the top of the Aneto Fm have provided elements of *Ozarkodina remscheidensis*, *O. eladioi*, *O. planilingua*, *Lanea* cf. *omoalpha* (samples EN-2, EN-3, Solana de Enviny and 133), indicatives of a probably lower Lockhovian to the basal middle Lochkovian age, *L. omoalpha-A. trigonicus* Zone.

The lower member of the Rueda Fm indicates a middle Lochkovian age, with taxa as *Icriodus angustoides alcoleae* and *Pelekysgnathus serratus elongatus* and *Flajsella shulzei*, from the *L. omoalpha-A. trigonicus* to the *A. trigonicus-O. pandora* β zones (samples EN4 to EN-6).

DISCUSSION

Limestones of the 'Lower Graptolitic shales' correspond to the cardiolid cephalopod-bearing black argillaceous limestone facies. However, the Llessui Fm corresponds to the 'Ockerkalk' facies type. This second facies is known in Thuringia, southeastern Sardinia and West Sudeten Mountains (Jaeger, 1977), Catalan coastal ranges (Walliser, 1964) and now in an area of the south central Pyrenees. This facies was interpreted as a condensed deposit, poor in various fossils, and deposited in a quiet pelagic environment below wave-base (Barca *et al.*, 1995). The wide development of the bioturbation in many beds can be in relation to oxygenated sediment beyond some centimetres under the bottom-sea.

The age deduced for the Llessui Fm, Gorstian to uppermost Přídolí, is approximately similar to the other areas with 'Ockerkalk' facies. The Aneto Fm is aged from the uppermost Přídolí to the lower Lochkovian or base of middle Lochkovian, considering this age for the first beds of the Rueda Fm.

In the Pyrenees, only the Toloriu-Bar area (Segre unit, southeastern Pyrenees) shows comparable carbonate facies to the Llessui Limestones. The so-called Toloriu Limestone there (Boersma, 1973) is composed of greyish black nodular limestone intercalated among black shale beds with a thickness of 20 to 30 m (Dégardin, 1988). The limestones are micrite and similar to 'Ockerkalk' facies, but the shales are clearly more abundant than in the Llessui area. It could be interpreted as a deeper water depositional environment than the inferred for the Llessui Fm. The Přídolí conodont *Ozarkodina eastehornensis* occurs (Boerma, 1973; Dégardin, 1988; Valenzuela-Ríos in García-López *et al.*, 1966). Furthermore, 10 m below the Toloriu Limestone, Dégardin and Pillet (1984) found graptolites from the *P. nilssoni* Zone (Gorstian) with trilobite determinations discussed in Rábano *et al.* (1993).

The recognition of the 'Ockerkalk' facies in the south central Pyrenees (Llessui Fm and Toloriu Limestone), as well as in the Catalonian coastal ranges (La Creu Fm of Julivert *et al.*, 1985), seems to suggest a probable occurrence of this carbonate facies in the intermediate area, the subsoil of the Ebro basin. The deep carbonate pelagic platform developed from the Gorstian to the Přídolí, should be bordered by anoxic black shale sedimentation with episodes of black rich cephalopod carbonates in the Pyrenees. This platform can have a continuity with the Gerrei and Sarrabus outcrops in the south-east of Sardinia, if we are to take into consideration the Miocene rotation of the island and its almost adjacent position to Catalonia and the south of France until the late Oligocene (Arthaud and Matte, 1966; Olivet *et al.*, 1996).

Stop 1: Upper Silurian limestones at Altron-Sorre, the succession of the Llessui Fm.

Location: We will arrive to Sort (meaning 'luck' in Catalan language) from Lleida, passing by la Pobla de Segur along the road N-260. We take a secondary road at the north end of Sort, towards Llessui village. The stop is just before the entry of the small Sorre village, along the left bank of the road.

Stratigraphic units: Llessui and Aneto formations.

Age: Upper Silurian

Figure: 2.

What to see: Nodular limestones with bioturbations and crinoidal wackestones.

What to collect: Samples from the uppermost meter of the Llessui Formation.

CAI: 5.5

The outcrop corresponds to the inverted limb of a faulted fold. The stop has an easy access, although studied conodont samples were collected from different outcrops, a long way from this locality.

The limestones show ochre bioturbated beds typical of the 'Ockerkalk facies' and shales with carbonate beds, lower part of the Llessui Fm, can be observed towards the Sorre village. The lower black-coloured part of the formation is also outcropping towards the Altrón village, where a sample (Altrón-Sorre1) has yielded elements of *Ozarkodina excavata*, *Oulodus* cf. *elegans* and *Pseudooneotodus* sp.

The top of the Llessui Formation is to the south, moving us away from the Sorre village. The grey limestones contain stems and ossicles of crinoids. The sample Sorre1 from carbonate nodules in marls above the limestones is fruitless, so far. Conodonts correlated with the *Oulodus elegans detortus* Zone (uppermost Přídolí) were obtained in others localities.

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FIGURE CAPTIONS

Figure 1. Sketch- map of the south central and eastern Pyrenees with the location of the Llessui and Toloriu Limestones outcropping area.

Figure 2. Synthetic columnar section of the Llessui Formation and the Aneto Formation based on some studied outcrops. Therefore, numbers on the left of the column come from many localities.

Figure 3. Distribution of the Ockerkalk type facies in Pyrenees, Catalonian coastal ranges and Sardinia with respect to cephalopod and cardiolid black limestones. Siliciclastic coarse grained are located in the Cantabrian and Iberian Mountains, while fine grained are described in the Basque Pyrenees. The sketch- map comes from an interpretation about the position of the Iberian peninsula, Sardinia-Corsica block with respect to Europe and Africa, in the lower Jurassic after Olivet *et al.* (1996).

Table 1. 1A) Conodonts obtained from carbonate beds in the ‘Lower Graptolitic shales’ (sample Sopena) and the lower part of the Llessui Formation. 1B) Conodonts obtained from the upper part of the Llessui Formation.

Table 2. Conodonts classified in limestone beds in the Aneto Formation and the lower member of the Rueda Formation in the Llessui area.

Figure 1

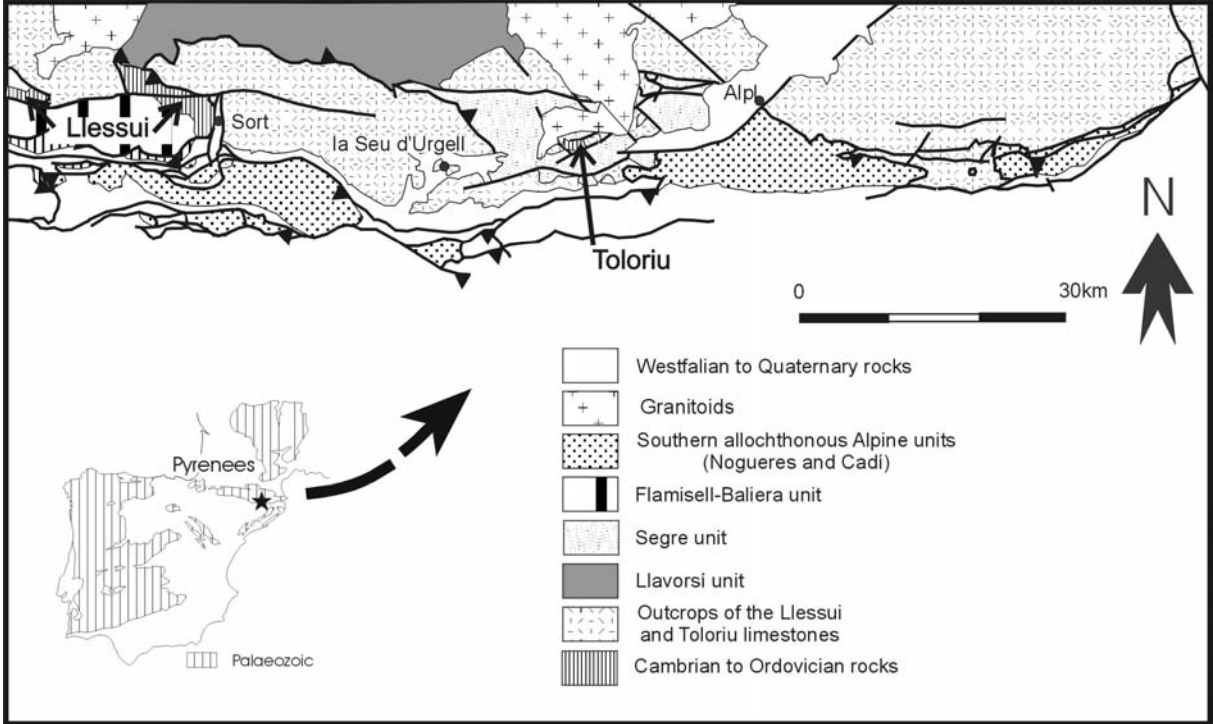


Figure 2

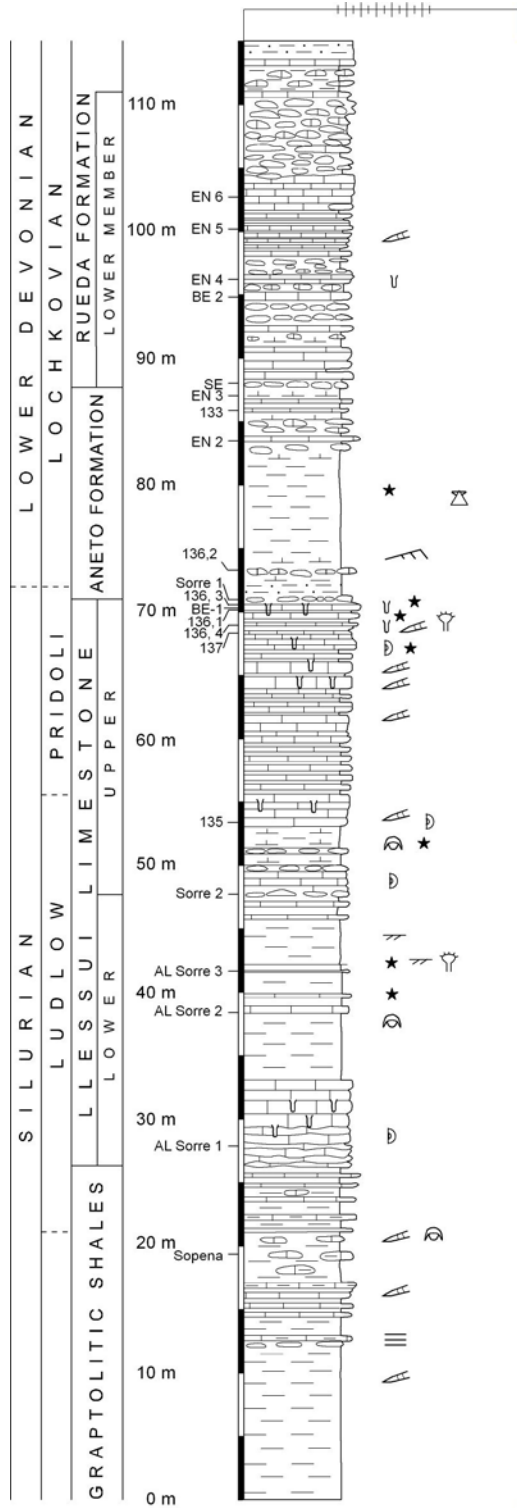
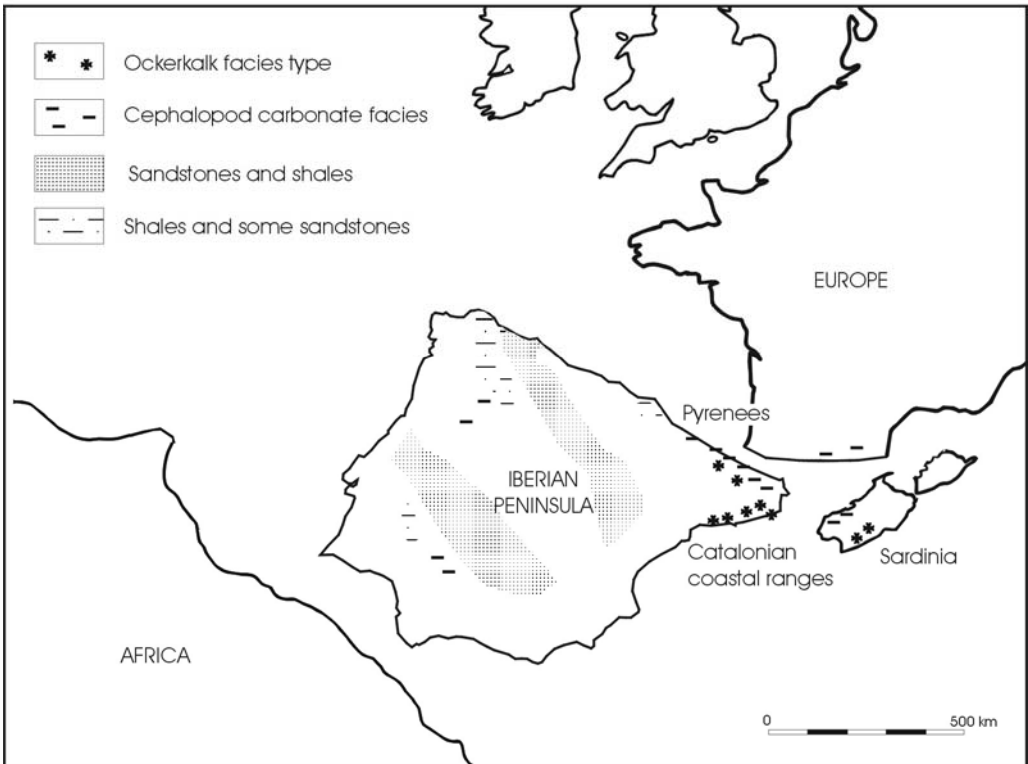


Figure 3



1A	Shales	Llessui Limestones		
		lower member		
samples	Sopena	Al-Sor1	Al-Sor2	Al-Sor3
kg	1.38	2.54	1.9	0.2
<i>Oulodus</i> sp.	+			
<i>Oulodus</i> cf. <i>elegans</i> (Walliser)		+		
<i>Ozarkodina excavata</i> (Branson & Mehl)	+	+		
<i>Pseudooneotodus</i> sp.		+		

1B	upper member of the Llessui Formation								
samples	Sorre2	135	EN1	137	136-4	136-1	Bordes Enviny1	136-3	Sorre1
kg	0.92	3,25	1.1	1,85	2.27	2.5	2.05	4.37	1.25
<i>Oulodus</i> cf. <i>elegans</i> (Walliser)				+					
<i>Oulodus siluricus</i> (Branson & Mehl)		+							
<i>Oulodus elegans</i> (Walliser)					+				
<i>Oulodus</i> cf. <i>siluricus</i> (Branson & Mehl)					+		+		
<i>Oulodus elegans detortus</i> (Walliser)						+		+	
<i>Ozarkodina excavata</i> (Branson & Mehl)		+		+		+	+	+	
<i>Oz.</i> aff. <i>eosteinhornensis</i> (Walliser)						+	+	+	
<i>Ps. beckmanni</i> (Bischoff & Sannemann)						+	+		
<i>Kockelella variabilis variabilis</i> Walliser		+							

