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Un assemblage à Radiolaires du Silurien inférieur (Aéronien) extrait de jaspes noirs du Massif Armoricain (France)

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Abstract

The Chalonnes-sur-Loire outcrop is the most complete Llandovery section in the Ligerian domain (Armorican Massif, NW France); it displays a ca. 10 m-thick sequence of organic-rich black bedded cherts alternating with black graptolitic shales, which were deposited above glaciomarine diamictites of the Hirnantian glaciation. It is likely the black cherts accumulated under eutrophic waters, on the outer shelf part (distal offshore) of a Gondwanan margin, situated at intermediate to high latitudes of the Southern hemisphere. Hydrofluoric acid processing allowed for the extraction of radiolarians; seven species are identified in the best preserved sample discovered so far. All seven are common species in tropical assemblages known from Alaska and Nevada, which are characteristic of the *Orbiculopylorum* assemblage, of Aeronian to early Telychian age. This age is in good agreement with independent age control from graptolites in the Chalonnes section, suggestive of an Aeronian age to the radiolarian-yielding level.

Key-words: Radiolaria, black cherts, Lower Silurian, Aeronian, Armorican massif, France

Résumé

L'affleurement de Chalonnes-sur-Loire représente la série la plus complète du Llandoverien du Domaine Ligérien (Massif Armoricain, France nord-occidentale), avec environ 10 mètres de phtanites (jaspes lités, riches en matière organique) alternant avec des argilites noires à Graptolites, déposées au-dessus de diamictites glaciomarines de la glaciation hirnantienne. La série jaspeuse s’est accumulée probablement sous des eaux eutrophiques, sur la plateforme externe (offshore distal) d’une marge continentale gondwanienne, située dans les moyennes-hautes latitudes de l'hémisphère Sud. Des extractions à l'acide fluorhydrique ont permis la détermination de sept espèces de radiolaires dans l'échantillon le plus prometteur. Ces sept espèces sont communes avec les assemblages tropicaux connus d’Alaska et du Nevada ; cette faune est caractéristique de la zone d'assemblage à *Orbiculopylorum* qui s'étend de l'Aéronien au Télychien inférieur. Cet âge est en bon accord avec l’âge Aéronien établi indépendamment par des graptolites pour ce niveau à Radiolaires de la coupe de Chalonnes.

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Mots-clefs: Radiolaires, phtanites, jaspes, Silurien inférieur, Aéronien, Massif Armoricain, France

1. Introduction

Radiolaria live today in all modern oceans, at all depths of the water column. The delicate siliceous skeleton of polycystine Radiolaria is known since the Early Cambrian (Botomian; Pouille et al., 2011; Korovnikov et al., 2013); they have contributed to the accumulation of siliceous sediments in the oceans since the Late Cambrian (Tolmacheva et al., 2001) and possibly since even the Early Cambrian (Zhang et al., 2013). Given their lengthy fossil record Radiolaria have the potential to provide valuable insights into the biotic response of heterotrophic plankton to paleoclimatic or biogeochemical events during the entire Phanerozoic. However, our current knowledge of Lower Palaeozoic radiolarian assemblages is still fragmentary, especially for the high paleolatitudinal realm (Danelian et al., 2013).

The present contribution aims at documenting “north-Gondwana” radiolarian assemblages from Lower Silurian organic-rich black bedded cherts, known in French as “phtanites”. According to Cayeux (1929), "phtanites" are siliceous deposits that have undergone secondary silicification. This term is used both for the palaeozoic radiolarites (present study) and for the proterozoic silicified rocks (Dabard, 2000). Intercalated graptolitic black shales offer good biostratigraphic control for this particular succession (Piçarra et al., 2002, 2009), and directly underlying glaciomarine diamictites testify of a Lower Silurian post-glacial climatic framework, following the Hirnantian glaciation. The black cherts were deposited in an intermediate to high southern paleolatitudinal setting of the southern Hemisphere (Ghienne et al., 2007; Robardet and Doré, 1988). Although mentioned initially from thin sections (Piçarra et al., 2009), radiolarians were not specifically studied and identified. Rhuddanian and Aeronian radiolarians are still poorly known, especially from the high latitudes, which makes the study of this section significant in terms of its age range and paleogeographic position.

New sampling and specific laboratory preparation were undertaken in order to extract radiolarians and identify them to the species level. Comparison of our assemblage with other Llandoverian assemblages worldwide will improve our understanding of Lower Silurian radiolarian biogeographic distribution and diversity. This is a preliminary report focusing specifically on the radiolarian fauna identified in the sample with the best preservation of radiolarian skeletons.

2. Geological and stratigraphical settings

2.1. Depositional setting

In the Armorican Massif, the Proterozoic basement and its Lower Palaeozoic cover were deformed during the Variscan orogeny. A number of tectonically juxtaposed domains bounded by major shear zones (e.g. North Armorican, northern and southern South Armorican Shear Zones; Fig. 1) are characterized by distinct depositional and metamorphic histories. In the southeastern Armorican Massif, most of the suggested reconstructions acknowledge a suture zone separating an Armorica microplate and the northern margin of the Gondwana supercontinent, although the exact location of the terrane limits, as well as the importance and age of the subducted oceanic crust(s) is still under discussion (Ballèvre et al., 2009 and references therein).

The study area is located in the Ligerian domain that is characterized by an imbrication of fault-bounded tectonic units in which some pre-Carboniferous series are interpreted by Dubreuil (1980, 1986) as olisthostromes and olistolithes, redeposited within Lower Carboniferous basins. However, a Lower Palaeozoic stratigraphy is reconstructed based on currently dismembered stratigraphic sedimentary sequences (Cavet et al., 1971; Ducassou et al., 2009; Lardeux, 1980; Lardeux and Cavet, 1994; Strullu-Derrien et al., 2010). On top of a Brioverian (Neoproterozoic) metamorphosed basement, the Lower Palaeozoic strata include (i) an Ordovician succession (basal conglomerates, sandstones and siltstones and locally end-Ordovician diamictites), overlain conformably by (ii) Lower Silurian black cherts grading upwards into (iii) Middle to Upper Silurian shales. Lowermost Devonian strata are not palaeontologically characterized, the oldest deposits being limestones assigned to the Pragian/Emsian.

This succession is in general understood as being initially deposited either at the southern margin of the Armorica microplate, or over a distal segment of the northern continental margin of Gondwana (Ballèvre et al., 2009). Given that the depositional setting of the sampled Silurian black cherts lies immediately south of the Nort-sur-Erdre Fault, which is thought to represent a Variscan suture zone (see discussion in Ballèvre et al., 2009), the latter reconstruction is preferred. Palaeogeographic relationships relative to the structure of the Gondwana margin are however still unclear (outer shelf setting, extensional allochton or drifted continental block?).

2.2. The Chalonnes-sur-Loire outcrop

The outcrop is located along the southern boundary of the Ancenis basin in the Tombeau Leclerc Unit, 700 m to the SE of Chalonnes-sur-Loire (near Angers, WGS84 coordinates : 47°20'44.29"N, 0°45'35.83"O) and close to the historical “Les Fresnaies” section. This unit is interpreted as a continuous stratigraphical sequence (Ducassou et al., 2011) comprising five formations (Fm) successively: the “Pélites à fragments” Fm (Late Ordovician), the *Monograptus* Black Chert Fm (Llandovery), the Graptolites Siltstone Fm (Wenlock to Ludlow), the Tentaculites Limestones

(Pragian) and the “La Grange” Limestones (Emsien). The section exhibits an end-Ordovician to lowermost Silurian succession (Piçarra et al., 2002). The end-Ordovician interval includes a ca. 30 m-thick, poorly bedded argillaceous diamictite with subordinate sandstone beds (interval **a** on Fig. 2), which is overlain by ~ 2m-thick shales and subordinate diamictite lenses (interval **b**). Both of these two intervals are assigned to the Hirnantian *Tanuchitina elongata* chitinozan biozone (Bourahrouh, 2002); they reflect the Hirnantian glacial event and the latest Ordovician deglaciation, respectively. The Lower Silurian organic-rich chert succession (interval **c**) overlies conformably the uppermost Ordovician sediments. It consists of an up to 10 m-thick pile of cm- to dm-thick, commonly laminated, grey to black chert beds alternating with thin (< 2cm), pyrite-rich, black-shale interlayers. A Llandovery age has been acknowledged for a long time for this sequence, based on a graptolite fauna (Barrois, 1892; Philippot, 1950); however, it is only recently that the lowermost Silurian was confirmed, using both chitinozoan and graptolite assemblages. In addition, the Rhuddanian and Aeronian stages have been formally recognized in this sequence (Piçarra et al., 2009). According to the latter authors, this outcrop displays the most complete Llandovery succession of the Ligerian domain of the Armorican Massif. Finally, the upper horizons of the studied section are tectonized (interval **d** on Fig. 2) and thought to be early Telychian in age (Piçarra et al., 2009); however they were not sampled due to the difficulties in accessing this part of the section.

3. Material and methods

The sequence of black cherts was sampled at regular intervals (27 samples from the interval **c**, Fig. 2). Thin sections were prepared in order to select samples with observable radiolaria for laboratory processing with hydrofluoric acid. Thin sections were observed under a polarizing microscope in order to better understand the lithological composition of the studied samples and their depositional setting. In addition, RAMAN spectroscopy (Jobin Yvon, LabRam HR 800 UV) observations were also conducted occasionally on thin sections to confirm the composition of some elements.

In order to extract radiolarians, samples were washed, oven-dried and crushed into small pieces before being left in a plastic beaker in which diluted (ca. 5% HF) hydrofluoric acid was added. After 24 hours, the contents were sieved and rinsed. The fraction between 63µm and 630µm was picked while the fraction larger than 630µm was left again in a renewed ca. 5% HF dilution during 24 hours and the whole process was repeated 6 times. The residues were examined and picked under a binocular microscope; the radiolarians collected were mounted on carbon stubs, metal coated, scanned and magnified with a Scanning Electron Microscope (FEI, Quanta 200).

4. Results

Although all 27 collected samples were processed in the laboratory, this preliminary report focuses specifically on sample MT18, from which over 200 moderately well-preserved radiolarian specimens were recovered. In most other samples the extracted radiolarians are relatively poorly preserved. In thin section preparations, the main microfacies is characterized by a finely laminated microquartzitic and clayey matrix in which intervals full of radiolarian relics (spheres less than 0.5 mm in diameter) may be recognized; they appear to have rather clear boundaries with the intervals devoid of radiolaria (Plate 1, fig. 10). All beds are rich in organic matter and pyrite crystals.

Seven species were identified from sample MT18 and all are illustrated in Plate 1. Four of them belong to the Archaeospicularian family Secuicollactidae (*Secuicollacta bipola* Won et al., 2002, *S. hexactinia* Won et al., 2002, *S. multispinosa* Won et al., 2002 and *S. parvitesta* Won et al., 2002). The three other species identified belong to the Spumellarian family Haplotaeniatidae (*Haplotaeniatum aperturatum* Noble et al., 1998, *Orbiculopylorum marginatum* Noble et al., 1998 and *O. spendens* Noble et al., 1998).

The radiolarian fauna extracted from sample MT18 can be assigned to the Early Silurian *Orbiculopylorum* assemblage zone of MacDonald (2006), characterized essentially by the first and the last occurrence of genus *Orbiculopylorum*. According to latter author, the *Orbculopylorum* zone may be correlated with the earliest Aeronian to early Telychian interval, as it extends from the base of the *Campograptus curtus* to the middle of the *Spirograptus turriculatus* graptolite zones.

5. Discussion

Piçarra et al. (2009) published a very detailed and revised biostratigraphic report of the occurrence of graptolite species throughout the Chalonnes-sur-Loire outcrop. Based on their figure 3, it is rather straightforward to assign our radiolarian-bearing sample MT18 to the middle Aeronian *Lituigraptus convolutus* graptolite biozone (Figure 2), which is in good agreement with the known age of the *Orbiculopylorum* Radiolarian assemblage.

The assemblage we obtained from sample MT18 shares six common species with the Upper Aeronian to Lower/Mid Telychian radiolarian fauna of Won et al. (2002) from Alaska. It is also fairly similar to the Upper Rhuddanian assemblage described by Noble et al. (1998) from Nevada. These similarities are interesting indeed, as paleogeographically the Alaskan and Nevadan radiolarian localities were situated during the Early Silurian in the tropical realm (15°N and 10°S, respectively), while Armorica was situated in an intermediate-high latitudinal region of the southern hemisphere.

Black cherts appear only in the Ligerian domain of the Armorican Massif; the Chalonnes-sur-Loire outcrop is the thickest and most representative for this paleogeographic realm (Piçarra et al., 2009). According to these authors, the absence of coarse terrigenous material in this Llandovery sequence contrasts with other coeval sequences of the Armorican Massif. It is also worth mentioning that based on the study of Ordovician Trilobites Henry (1989) found differences between the northern and central Armoricain realm on one hand, and with the south Armoricain realm on the other. Moreover, the Trilobites found in the latter realm reflect a deeper environment and appear to show some Bohemian affinities. As mentioned earlier, our preferred paleogeographic location of the sedimentary sequence at Chalonnes-sur-Loire is along the northern margin of Gondwana, possibly in a distal offshore (outer shelf) depositional environment, starved of any coarse siliciclastic and carbonate input.

In today's oceans, Radiolaria are abundant in eutrophic waters, such the upwelling areas, where nutrients and tiny prey are abundant (De Wever et al., 1994, 2001). Although an actualistic approach may have its limitations for pre-Cretaceous oceans (see discussion in Racki and Cordey, 2000), abundant and well-preserved radiolaria are often found in fine-grained and organic rich deposits and considered as the result of elevated plankton productivity (Danelian and Baudin, 1990; De Wever and Baudin, 1996). The sedimentary facies of the studied black chert sequence at Chalonnes-sur-Loire, namely the abundance of organic matter, radiolarian biogenic silica and pyrite crystals, could reflect accumulation of fine grained pelagic sediments under eutrophic waters and associated reducing conditions on the sea-floor.

6. Conclusion

The 10 m-thick black chert outcrop of the Chalonnes-sur-Loire section is the most representative Llandovery sequence of the Ligerian domaine of the Armorican Massif. It consists of an argillaceous-siliceous sedimentary sequence, rich in organic matter and pyrite. It is likely that it accumulated in an outer offshore depositional environment, along an intermediate-high latitudinal Gondwanan margin of the Southern Hemisphere, in which graptolites and radiolarians proliferated under eutrophic conditions. An assemblage of seven Radiolarian species is recognized in a promising sample, which shares many similarities with coeval tropical assemblages known from Alaska and Nevada. The fauna can be assigned to the *Orbiculopylorum* assemblage established in

North America and correlated with the Aeronian to early Telychian. This Radiolarian age is in good agreement with the middle Aeronian age assigned previously based on graptolites, more specifically of the *Lituigraptus convolutus* zone.

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CAPTIONS

Figure 1 : Distribution of Paleozoic outcrops (grey areas) and of the main tectonic zones of the Armorican Massif. The locality of the studied section is indicated with a star.

Figure 1 : Carte de la distribution des terrains paléozoïques et des diverses zones tectoniques majeures du Massif Armoricain. La localité de la coupe étudiée est indiquée avec une étoile.

Figure 2 : Lithostratigraphy of the studied Chalonnes-sur-Loire outcrop, including the graptolite

biozones identified by Piçarra et al. (2009) and the stratigraphic position of the radiolarian-yielding sample MT18.

Figure 2. Lithostratigraphie de l'affleurement étudiée à Chalonnes-sur-Loire, y compris les biozones à graptolites déterminées par Piçarra et al. (2009) et la position de l'échantillon à radiolaires MT18.

Plate 1 : Identified Radiolaria and microfacies of sample MT18.

1, *Secuicollacta bipola* (Won et al., 2002), MT18. ***2***, *Secuicollacta hexactinia* (Won et al., 2002), MT18. ***3***, *Secuicollacta multispinosa* (Won et al., 2002), MT18. ***4,*** *Secuicollacta parvitesta* Won et al., 2002, Morphotype 1, MT18. ***5***, *Secuicollacta parvitesta* Won et al., 2002, Morphotype 2, MT18. ***6***, *Haplotaeniatum aperturatum* Noble et al., 1998, MT18. ***7***, *Orbiculopylorum marginatum* Noble et al., 1998, MT18. ***8***, *Orbiculopylorum spendens* Noble et al., 1998, MT18. Scale bar 100 µm for figures 1-8

9, Close-up view of a well-preserved radiolarian (probably *Orbiculopylorum* sp.) and of a sponge spicule in a dark siliceous-clayey matrix, MT18. ***10***, Overall view of the two main microfacies observed in sample MT18; 500 µm for figures 9-10.

Planche 1 : Radiolaires déterminés et microfaciés de l'échantillon MT18.

9, *Vue rapprochée d'un radiolaire bien préservé, probablement du genre* Orbiculopylorum, *d'un spicule d'éponge, et de la matrice très sombre, MT18.* ***10***, *Vue d'ensemble des deux faciès, avec et sans sphère, MT18. Barres d'échelle 100 µm pour les figures 1-8 ; 500 µm pour les figures 9-10.*