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Lower Cambrian (Botomian) polycystine Radiolaria from the Altai Mountains (southern Siberia, Russia)

Radiolaires polycystines du Cambrien inférieur (Botomien) des montagnes de l'Altaï (Sibérie méridionale, Russie)

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ABSTRACT

Relatively well-preserved polycystine Radiolaria are here described from Lower Cambrian (Botomian) strata of the Shashkunar Formation, Altai Mountains in southern Siberia (Russia). These radiolarians display a test formed of a disorderly and three-dimensionally interwoven meshwork of numerous straight and curved bars branching from a five-rayed point-centered spicule located within the inner shell surface. The shell structure allows their assignment to the family Archeoentactiniidae, thus extending the known age range of the family down to the Lower Cambrian. The Botomian age is based essentially on trilobites (*Parapagetia–Serrodiscus* zone), but also on archaeocyathids identified in earlier publications. The study of the radiolarian-bearing sedimentary sequence confirms the presence of polycystine radiolaria in the external platform environments of Lower Cambrian ecosystems.

RÉSUMÉ

Nous décrivons ici des radiolaires polycystines provenant des niveaux du Cambrien inférieur (Botomien) de la Formation de Shashkunar des Montagnes de l'Altaï en Russie méridionale. Ces radiolaires montrent un test construit par un réseau tridimensionnel constitué de nombreuses barres droites ou courbées, entrecroisées de manière désordonnée. Ces barres se développent à partir d'un spicule formé de cinq épines centrées sur un point situé à l'intérieur de la coque. Cette structure particulière suggère leur appartenance à la famille des Archeoentactiniidae. L'âge Botomien de ces niveaux est contraint par des Trilobites (*Parapagetia–Serrodiscus* zone) et des Archéocyathes déterminés dans des travaux antérieurs. L'étude de la série sédimentaire comprenant les radiolaires confirme la présence des Radiolaires polycystines dans des environnements de plate-forme externe des écosystèmes du Cambrien inférieur.

1. Introduction

The earliest radiolarian record is difficult to decipher (see Maletz, in press, for a recent review) and until recently

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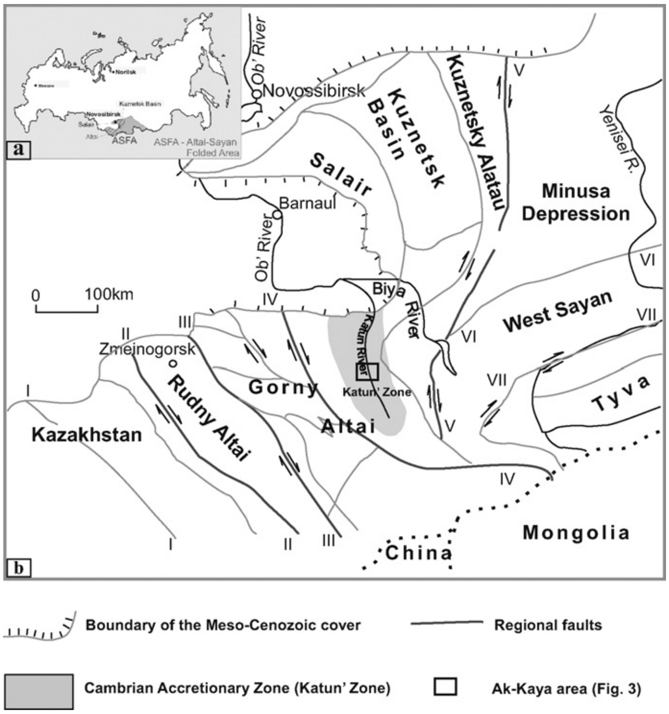

Fig. 1. a: geographic map of Russia with the Altai Sayan Folded Area (in grey), including the area detailed in Fig. 1 b (stripped); b: simplified tectonic map of the Altai-Sayan Folded Area. Major Pz-Mz shear-zones and shear overthrusts, showing directions of block movements: I: Chara; II: Irtysh; III: Northeastern; IV: Charysh-Terekta; V: Kuznetsk-Altai; VI: West Sayan; VII: Kurtushiba.

Fig. 1. a : carte géographique de la Russie avec la région de l'Altai Sayan Folded Area (en gris), incluant la région détaillée dans la figure Fig. 1 b) (hachuré) ; b : carte tectonique simplifiée de la région de l'Altai-Sayan Folded Area. Les zones de cisaillement majeures du Pz-Mz et de chevauchement montrent les directions de mouvement des blocs. I : Chara ; II : Irtysh ; III : Northeastern ; IV : Charysh-Terekta ; V : Kuznetsk-Altai ; VI : West Sayan ; VII : Kurtushiba.

Modified from Yolkin et al., 1994.

the presence of the clade in the Cambrian was still questionable (Lipps, 1992). The discovery of a well-preserved and diverse fauna from Templetonian strata of Australia (Won and Below, 1999) established the undisputable presence of this plankton group in Middle Cambrian marine ecosystems. In spite of a number of morphological similarities of this primitive fauna with sponge spicules (i.e., interlocked point-centered spicules; skeletal elements consisting of hollow tubes; Won and Below, 1999) molecular arguments suggest that siliceous biomineralisation took place independently in the two eukaryote lineages (Danelian and Morreira, 2004). In addition, molecular phylogenies indicate that polycystine radiolarians are one of the deepest lineages of the Rhizaria supergroup (Bass et al., 2005). Therefore, knowledge of the earliest radiolarian fossil record is of prime importance to calibrate the Rhizarian phylogenetic tree, but also to understand their early evolutionary history.

An early controversial report on Cambrian radiolarians from Russia was published by Nazarov (1973), based on Lower Cambrian (Atdabanian) material from the Batenev Ridge, West Siberia (Russia). However, subsequent efforts to replicate or to confirm the presence of unambiguous radiolarians from these strata remained without any successful result (Obut and Iwata, 2000). More recent investigations by Obut and Iwata (2000) unveiled the presence of spherical Radiolaria with a porous cortical shell from the Lower Cambrian Shashkunar Formation of the Altai Mountains, south of West Siberia. However, the internal structure was not able to be observed in any of the described material and their unambiguous assignment to polycystine radiolarians was questioned in a recent review of the Cambro-Ordovician radiolarian record (Maletz, in press).

In the framework of a recent French-Russian collaborative project, we undertook new field and laboratory work in the Altai Mountains with the objective to improve the fossil record of Cambrian radiolarians. We have discovered additional material from the same locality reported by Obut and Iwata (2000), which allows to observe new morphological and structural details of the test. We here report on preliminary results that improve our understanding of the skeleton structure of these radiolarians. We also stress on the available biostratigraphic constraints for the age of the radiolarian-bearing strata and on the depositional environnements in which they were found.

2. Geological and stratigraphic framework

The Gorny Altai region is situated in the southern part of West Siberia and is part of a complicated tectonic structure of the Altai-Sayan Folded Area (ASFA) (Fig. 1). The Katun' zone of Gorny Altai stretches over 120 km along the Katun' River (Fig. 1; Dobretsov et al., 2004). It is formed of an ancient accretionary complex composed of several Upper Neo-Proterozoic–Lower Palaeozoic island arcs and oceanic island fragments (Dobretsov et al., 2004). During the Vendian–Early Cambrian, a complex system of island arcs (Kuznetsk-Altay island arc system) was situated at the margin of the Siberian continent (Dobretsov et al., 2004; Safonova et al., 2011). Early Cambrian hot spot activity was responsible for the formation of a number of oceanic seamounts situated between the Palaeo-Asian Ocean and the Siberian continent (Safonova et al., 2011). The Katun' accretionary complex was formed following the subduction of the Palaeo-Asian oceanic crust beneath the Siberian craton and the accretion of existing paleo-islands (seamounts) to the Kuznetsk-Altay island arc (Buslov et al., 1993; Buslov et al., 2001; Dobretsov et al., 2004).

The Vendian-Cambrian sequence that crops out along the Katun' River (northern Gorny Altai, Katun' zone) is mainly composed of a thick sequence of biogenic carbonate sedimentary rocks that accumulated on shallow marine depositional environments of a basaltic plateau. They belong to two laterally coeval formations, which may reach 1000 m in thickness: the Baratal Formation, made essentially of thick-bedded partly stromatolitc limestones, underlain by black shales, and the Eskongo Formation, made of dark colored dolomites and limestones with some intercalations of chert (Fig. 2). These oldest parts of the Katun sedimentary sequence are considered as Vendian to Early Cambrian (Tommotian) in age; the Baratal Formation contains microphytolites of a Vendian age (Buslov et al., 1993; Zybin and Sergeev, 1978). The Eskongo Formation contains microphytolites, calcareous algae and shelly microfauna characteristic of a Vendian-Early Cambrian age (Terleev, 1991). A lot of sponge spicules (*Protospongia* sp. and *Chancelloria* sp. and specimens of Monaxonellida, Hexactinellida and Tetraxonida) were also identified in the siliceous levels of this Formation (Zybin et al., 2000). The Manzherok Formation is essentially a thick (up to 1,250 m) sequence of Lower Cambrian basaltic lavas that overly unconformably the Baratal Formation. Blocks of brecciated silicified carbonate rocks which reflect accumulation in a slope depositional environment are present in places. They contain algae, microphytoliths and sponge spicules (Safonova et al., 2011; Zybin et al., 2000). The Shashkunar Formation, a 500 m thick Lower Cambrian sequence of essentially carbonate rocks, overlies unconformably the Manzherok Formation and displays at its base a thick sequence of conglomerates. It is composed essentially of thin-bedded grey to dark grey limestones with interbedded nodular chert levels which become more frequent towards the top of the Formation. Trilobites of the Botomian *Parapagetia*–*Serrodiscus* zone were identified in the 1970s (Repina and Romanenko, 1978; see Zybin et al., 2000 for further details). In addition to the trilobites, archaeocyathids and algae of an Early Cambrian age were also found in these limestones. Moreover, sponge spicules and protoconodonts, characteristic of the Upper Atdabanian and Botomian stages, as well as radiolarians were found in the siliceous mudstone lenses of this formation (Obut and Iwata, 2000; Zybin et al., 2000).

The up to 700-m-thick Cheposh Formation, composed of massive limestones made of archaeocyathid biohermes, overlies conformably the Shashkunar Formation. Trilobite associations found in this Formation belong to the

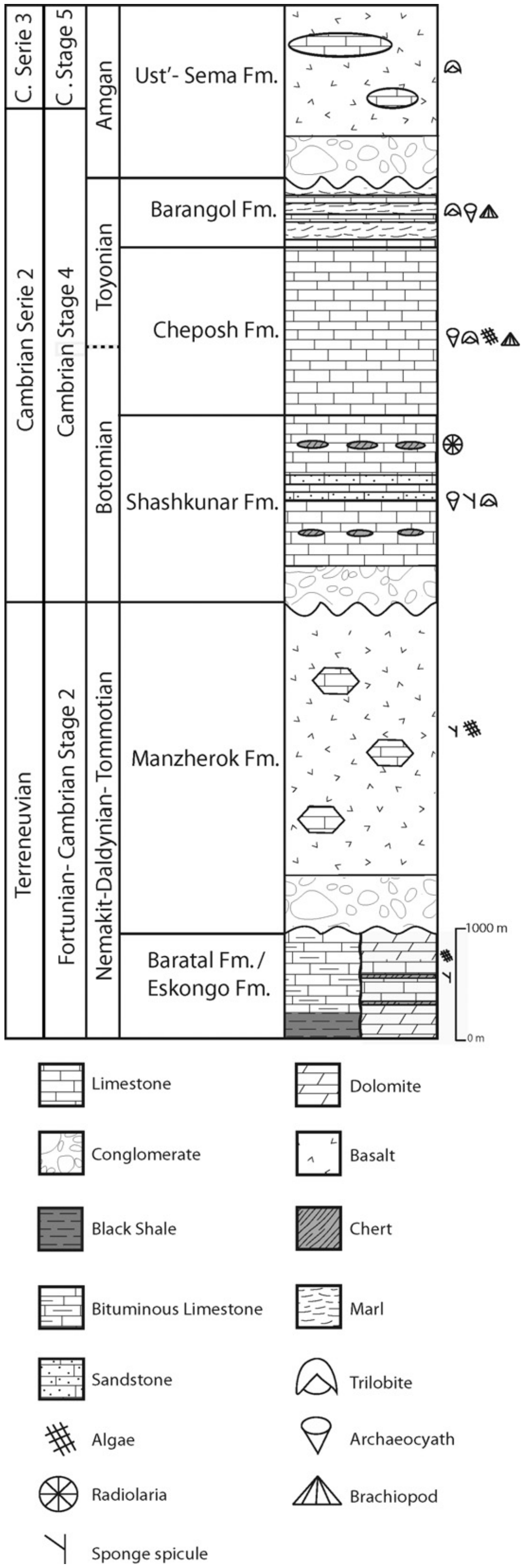

Fig. 2. Generalised stratigraphic column of the Vendian-Cambrian Katun' Zone, Gorny Altai, southern Siberia.

Fig. 2. Colonne stratigraphique générale de la « Katun' Zone » au Vendien-Cambrien, Gorny Altaï, Sibérie méridionale.

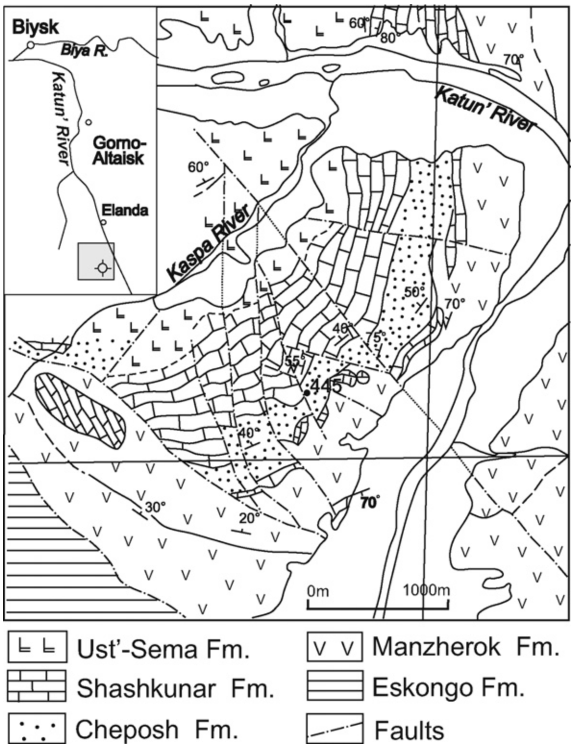

Fig. 3. Geological sketch-map of the Katun'-Kaspa interfluvial area (northern Gorny Altai).

Fig. 3. Carte géologique de la région interfluviale de Katun'-Kaspa (au nord de Gorny Altaï).

Lower Toyonian *Parapoliella–Onchocefalina* zone. Archaeocyathids and brachiopods found in this formation suggest a wider, but compatible, Botomian to Toyonian age (Zybin et al., 2000). The Lower Cambrian carbonate sequence ends with the 160-m-thick Upper Toyonian Barangol Formation, the age which is based on calcareous algae, archaeocyatids and trilobites (Zybin et al., 2000). It is uncorformably overlain by the Ust'-Sema Formation, a 1,000-m-thick basaltic sequence displaying thick conglomerates at its base, containing blocks of limestones with a similar fauna to the one identified in the Cheposh Formation (Zybin et al., 2000).

All these carbonate sequences were probably accumulated on the slope of a mid-oceanic basaltic seamount, formed by a mantle plume event (Safonova et al., 2011); they were later incorporated in the Katun' accretionary complex (Dobretsov et al., 2004; Uchio et al., 2004).

3. Material and methods

The studied "Kaspa" section is situated in the Ak-Kaya Gorge, in the middle reaches of the Katun' River (left bank), northern Gorny Altai, 60 km south from Ust'-Sema Village (Fig. 3). A full description of the studied section is provided by Zybin et al. (2000; Fig. 3). Our samples were collected from the top of the Shashkunar Formation, around locality 445 (N51° 08′ 20, 1″ E086° 09′ 21, 7″), from member 7 of the subsection, about 159 m above the base of the Formation. Grey, greenish or reddish thin-bedded centimetric nodular siliceous beds crop out along with bedded nodu-

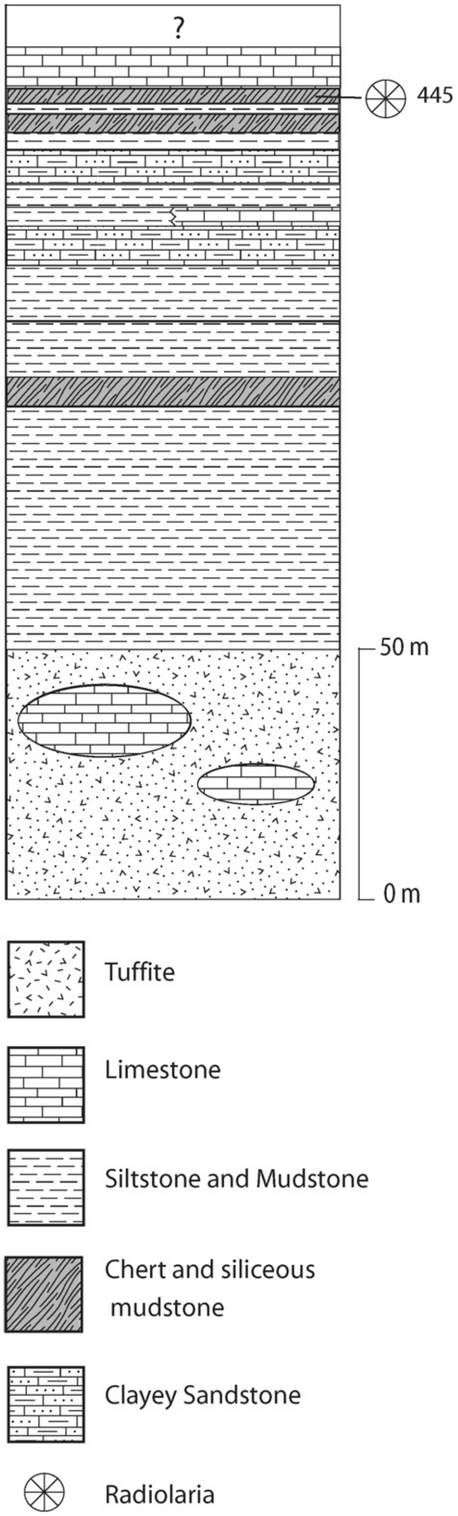

Fig. 4. Detailed stratigraphic column of the Lower Cambrian Shashkunar Formation in the studied "Kaspa" section, Ak-Kaya area, northern Gorny Altai.

Fig. 4. Colonne stratigraphique détaillée du Cambrien inférieur de la formation de Shashkunar dans la section « Kaspa » située dans la région de Ak-Kaya au nord de Gorny Altaï.

Modified from Zybin et al., 2000.

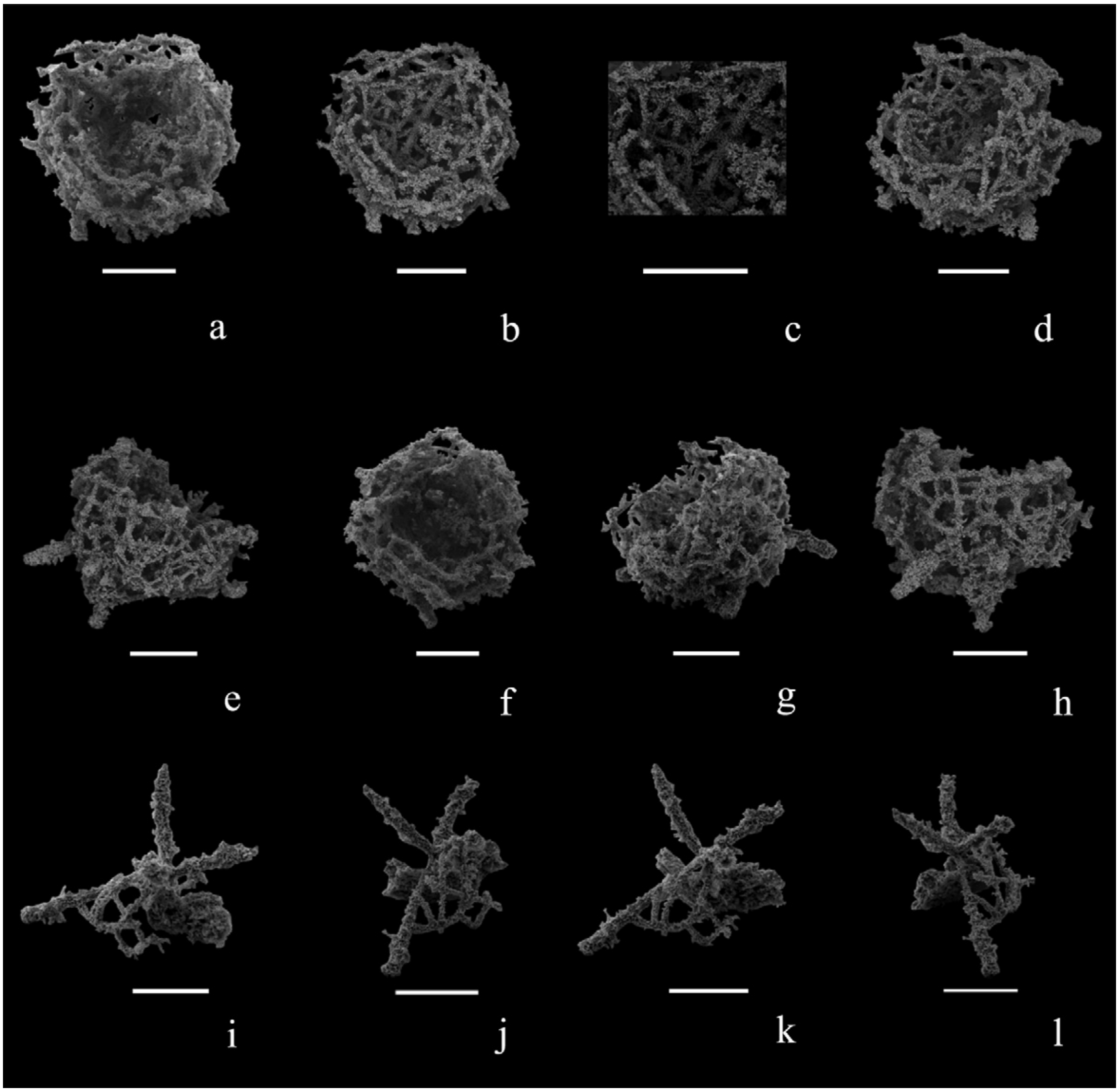

Fig. 5. Scanning Electron Micrographs of the two radiolarian specimens yielded from locality 445, Shashkunar Formation, "Kaspa" section. Bar scale corresponds to 100 μm on all figures. **a–l** *Archeoentactinia?* sp.A.; **a-e**: well-preserved specimen; **a, f**: secondary electron images allowing to observe a single double-layered shell; **b-e**: backscattered electron images allowing to observe the internal structure of the shell, the primary spicule (see detail on the magnified Fig. 5, c) and a number of spines on the external part of the shell; **i-l**: very incomplete specimen (juvenile?), displaying the primary spicule and the innermost part of a three-dimensional shell with the emergence of curved bars branching from the primary spicule.

Fig. 5. Photographies prises en microscopie électronique à balayage des deux spécimens de radiolaires provenant de la localité 445 dans la formation de Shashkunar sur la section « Kaspa ». La barre d'échelle correspond à 100 μm sur toutes les images. **a–l** : *Archeoentactinia* ? sp. A. ; **a–e** : spécimen bien préservé; **a, f** : images prises sous faisceau d'électrons secondaires permettant d'observer une coque à double couche; **b-e** : images prises sous faisceau d'électrons rétrodiffusés permettant d'observer la structure interne de la coque, un spicule initial (voir détails sur la figure agrandie Fig. 5, c) et des épines sur la surface externe de la coque; **i-l** : spécimen très incomplet (juvénile ?), montrant un spicule initial et l'ébauche de la partie la plus interne d'une coque en trois dimensions avec l'émergence de barres courbées ramifiées à partir du spicule initial.

lar limestones (Fig. 4). Radiolarians were extracted from greenish-grey laminated cherts level, the same bed as the one described by Obut and Iwata (2000). Five samples were studied from this bed. Microfossils were removed from the samples by using a standard hydrofluoric acid treatment: samples were crushed into 1 to 3 cm fragments and processed in a plastic beaker filled with 4% diluted hydrofluoric acid. The sample was washed every 8 to 12 h and the residue was then sieved and dried. Only two radiolarian specimens were found so far in the examined residue.

4. Systematic palaeontology

Superorder POLYCYSTINA Ehrenberg, 1838

Family ARCHEOENTACTINIIDAE Won and Below, 1999

Genus ***Archeoentactinia*** Won and Below, 1999

Type species: *Archeoentactinia incaensis* Won and Below, 1999

Archeoentactinia? sp. A

Fig. 5, a-l

***Description**:* The skeleton consists of an irregularly sub-spherical shell made of a three-dimensionally and disorderly interwoven meshwork formed by numerous straight or curved bars. The central part of the shell is a hollow cavity and the surface of the shell is uneven and angular. The three-dimensional arrangement of the bars is organised in two distinctive layers that gives the impression of a two-shelled skeleton. However, the two shell-layers are so closely interconnected that it is more appropriate to describe them as a single two-layered shell. The curved bars emerge from a prominent structure composed of five massive rays originating from a central point (Fig. 5, b-c). This five-rayed spicule is located eccentrically within the inner surface of the shell wall. It is the most robust and thickest element of the shell skeleton. Therefore it can be considered as the primary spicule *sensu* Maletz and Bruton (2007). Seven spines emerge from the shell surface. Since nearly half of the skeleton is broken, it is likely that the total number of spines emerging from the shell is in fact more important. Five of these spines protrude from the primary spicule

***Measurements* (in μm)**:

Diameter of shell: 290–260; length of primary rays: 90–170; thickness of primary rays: ca. 20–25.

Material: Two specimens

Remarks:

Our material differs from the genera *Archaeocenosphaera* and *Altaiesphaera* described by Obut and Iwata (2000) by its bigger skeleton size (260–290 μm, as opposed to 80–160 μm) and by the presence of a large polygonal pore frame (as opposed to small rounded pores). Further comparison with the material of Obut and Iwata (2000) is hampered because their internal structure is unknown. Our material is also characterised by the presence of a main pentactine spicule that is grown attached to the internal side of the cortical shell and which appears to have been formed at an early stage of the shell development.

Occurrence: Lower Cambrian (Botomian) of the Shashkunar Formation, Sanashtykgol Horizon, Ak-Kaya section, near locality 445 mentioned by Zybin et al., 2000. Left bank of Katun' river, 60 km from Ust'-Sema Village, northern Gorny Altai, SW Siberia

5. Discussion

Our specimens display strong affinities with representatives of the Archeoentactiniids known from Middle Cambrian strata of Australia (Won and Below, 1999), which are characterized by a skeleton made of a disorderly, three-dimensionally interwoven meshwork with one or more four to six-rayed point-centered spicules (Won and Below, 1999). More particularly, our specimens are morphologically close to the genus *Archeoentactinia* which is characterized by a large empty space in the central cavity of the shell and only one (or two) point-centered primary spicules positioned very close to the shell wall. Moreover, the type-species *Archeoentactinia incaensis* displays also some rare individuals with a five-rayed spicule, the intersection point of which is positioned very close to the inner surface of the shell wall. Therefore, the material obtained from Altai attests that the earliest representatives of the family Archeoentactiniidae originated during or before the Botomian. Cambrian Radiolaria are best known from Middle Cambrian shallow-water carbonate environments (i.e., the Middle Cambrian strata; Won and Below, 1999), but they are also known Upper Cambrian in deep-sea deposits (Tolmacheva et al., 2001). The facies of the siliceous limestones of the Shashkunar Formation, in which radiolarians were found, reflect an upper slope depositional environment which was present at the flank of an oceanic plateau. This is of particular importance because it establishes the presence of polycystine Radiolaria in the open marine environments of Lower Cambrian ecosystems.

6. Conclusions

New microfossil material from nodular cherts of Botomian slope carbonates of the Shashkunar Formation can be assigned to the Archeoentactiniid family. The previously known age range of the family Archeoentactiniidae can be therefore extended to the Lower Cambrian (Botomian). Our new discovery establishes firmly the presence of polycystine Radiolaria in outer shelf environments of the Early Cambrian marine ecosystems.

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