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First Early Cambrian Radiolaria

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Abstract: Radiolarian skeletons are known from a limestone concretion collected from a black shale succession and from black cherts of the Yangtze Platform, China. Both occurrences are of earliest Cambrian age. The findings, reported in this paper, represent the oldest known fossil Radiolaria. Their spherical skeletons display a morphology typical of spherical radiolarians from Ordovician and younger faunas. This occurrence of radiolarians with radial symmetry and, most probably, a planktonic lifestyle can now be traced back into the earliest Cambrian. Thus, radiolarians have been part of the early oceanic plankton and likely played a significant role in the silica cycle of the oceans along with siliceous sponges.

Apart from their natural beauty, radiolarians are an important constituent of today's oceanic plankton and one of the major groups of organisms utilizing opaline silica to form their skeletons (Anderson 1983). They significantly influence the oceanic silica cycle, and their skeletons contributed to oceanic sediments and siliceous sedimentary rocks since, at least, the Ordovician (Grunau 1965; Danelian 1999). The last decades have seen a significant increase in the practical value of radiolarians for biostratigraphy and palaeoceanography for all periods from the Cambrian onwards (Vishnevskaya *et al.* 2000; De Wever *et al.* 2001).

Although it has frequently been postulated that radiolarians are a very old group of protists (Campbell 1954), extending back into the Precambrian, very little is known about their origin and early history during Precambrian and Cambrian times. Finds of skeletons in rocks of 'Precambrian' age have been reported (Cayeux 1894; David *et al.* 1896), but have either been disputed or revised in terms of age or are not fully accepted as radiolarian remains because of poor preservation (Deflandre 1949). From the biological side, and based mostly on softpart characteristics and cytology, several contradictory statements as to the origin and ancestry of the radiolarians have been made (Chatton 1934; Dogel 1950; Hollande *et al.* 1970; Strelkov *et al.* 1974; Petrushevskaya 1977). In addition, molecular data are currently being obtained specifically for radiolarian groups (Amaral-Zettler *et al.* 1997). Considerations on the timing of eukaryote groups based on molecular data point to an origin of the Radiolaria approximately 1 billion years ago (Knoll 1992; Blair Hedges *et al.* 2001); these data are currently not supported by fossil evidence. The fossil record of well-preserved radiolarian skeletons goes back reliably only to the Middle Cambrian (Won *et al.* 1999). A report of Early Cambrian radiolarians from the Altai-Sayan region (Nazarov 1973) was based on spherical bodies in thin section, the radiolarian nature of which remains disputable. Late Cambrian and Early Ordovician faunas have been described by Kozur *et al.* (1996) and Dong *et al.* (1997).

The well-preserved skeletons from the earliest Cambrian of China described herein, therefore, are of importance both with respect to existing data on early radiolarian evolution, and with regard to the more general discussion on the development of faunal communities around the Precambrian–Cambrian boundary.

Localities

Hetang Formation, Xintangwu, Jianshan County, W. Zhejiang Province

A few radiolarian skeletons have been recovered from large carbonate concretions occurring within a black shale succession (the 'Hetang' Formation; see Zhu *et al.* 2000; cf. Fig. 1b). Spicules of siliceous sponges, small shelly fossils (SSF) and indeterminate bivalved arthropod shields have been found in the residues associated with radiolarian fragments

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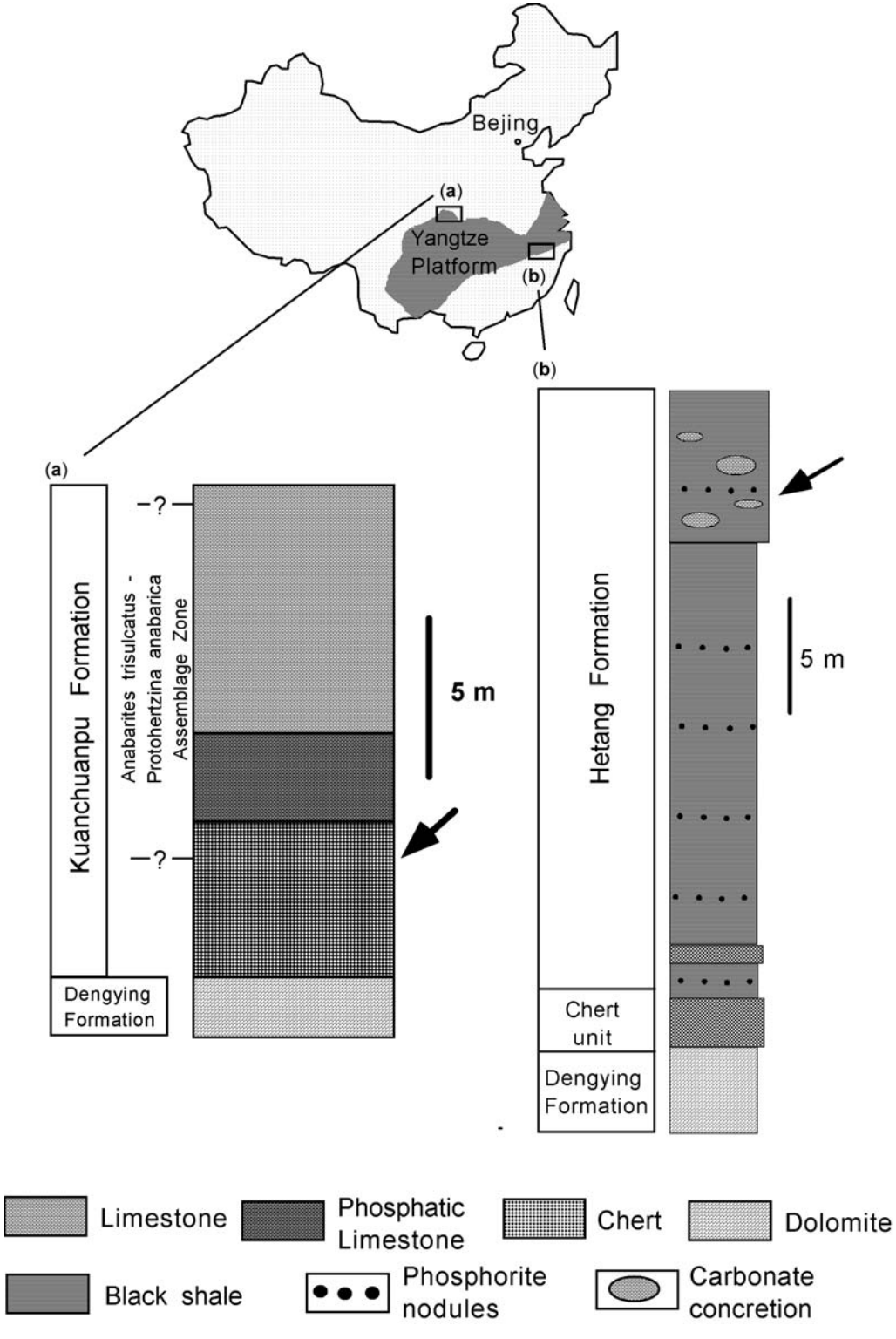

Fig. 1. Sample location areas on the Yangtze Plate, China and stratigraphic columns. Arrows point to radiolarian-bearing horizons. (**a**) Stratigraphic column of the Kuanchuanpu Formation at Shizonggou, near Kuanchuanpu, Ningqian County (Shaanxi Province). (**b**) Stratigraphic column of the Hetang Formation at Xintangwu, Jianshan County, W. Zhejiang Province.

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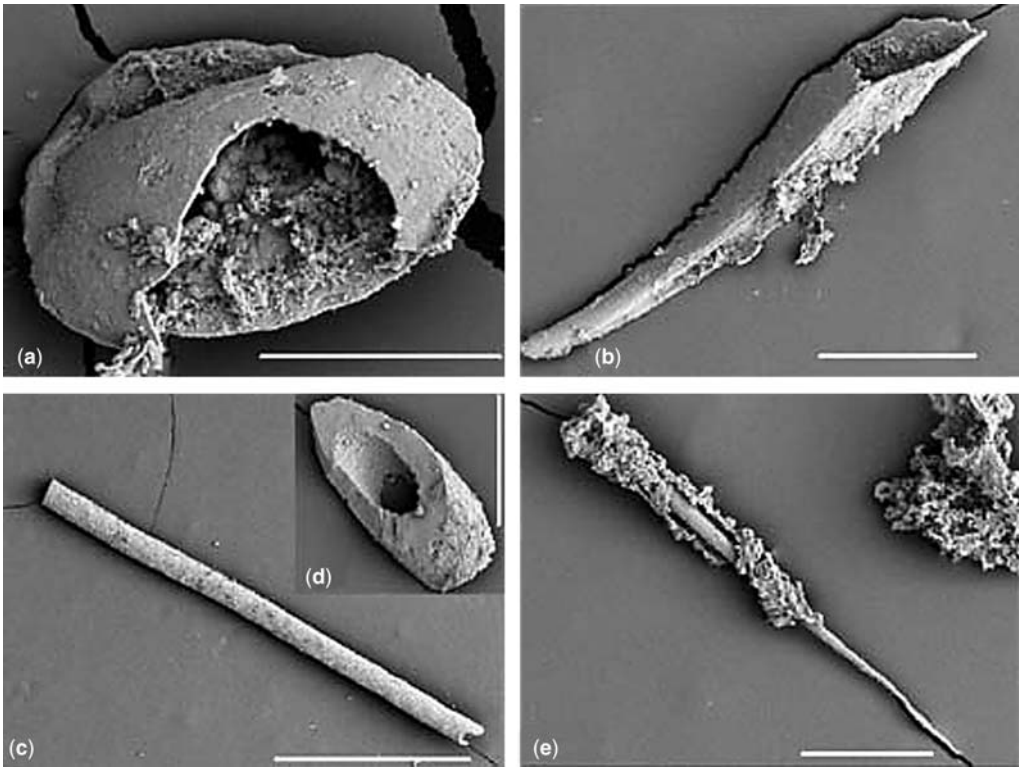

Fig. 2. Microfossils from the radiolarian-bearing residue of the Xintangwu carbonate concretion. (**a**) undetermined bivalved arthropod shield. (**b**) *Protohertzina* sp. (**c**, **d**, **e**) Spicules of siliceous sponges, with open (d) and diagenetically filled (e) central canal. Lower Cambrian, Meishucunian Stage, *Anabarites-Protohertzina* zone, Xintangwu, western Zhejiang, China. Length of the scale bars: 100 μm.

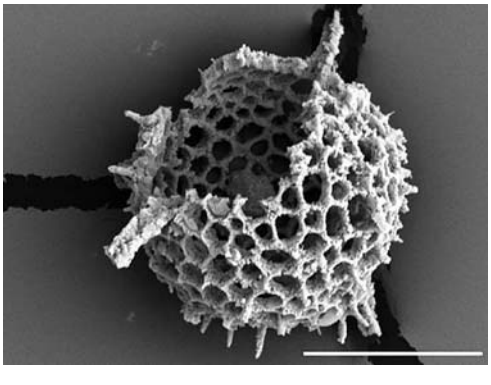

Fig. 3. Spherical radiolarian skeleton possessing a lattice sphere and spines of different orders of magnitude. Lower Cambrian, Meishucunian Stage, *Anabarites-Protohertzina* zone, Xintangwu, western Zhejiang, China. Length of the scale bar: 100 μm.

(cf. Fig. 2a–e). Compared to the sponge spicules, radiolarians are very rare.

The age of the occurrence is provided by the small shelly fossils *Anabarites trisulcatus* and *Protohertzina* sp. (=*Anabarites-Protohertzina* Zone, Meishucunian stage; earliest Cambrian, cf. Zhu *et al.* 2000). The lithological association in the area is interpreted as basinal and oceanic. However, compared to the widespread, completely carbonate-free shales of the Hetang Formation, the rock sequence at Xintangwu appears to have been deposited in a shallower environment, probably in a slope or marginal platform setting. This is evidenced by the immediately-underlying stromatolitic succession and the higher carbonate content in concretions and layers of the Hetang Formation itself. Besides dark, bituminous carbonates, the black shales at Xintangwu contain small amounts of black cherts and phosphatic concretions. Cherts, as well as phosphatic concretions, have been sampled for radiolarians but, as yet, without success.

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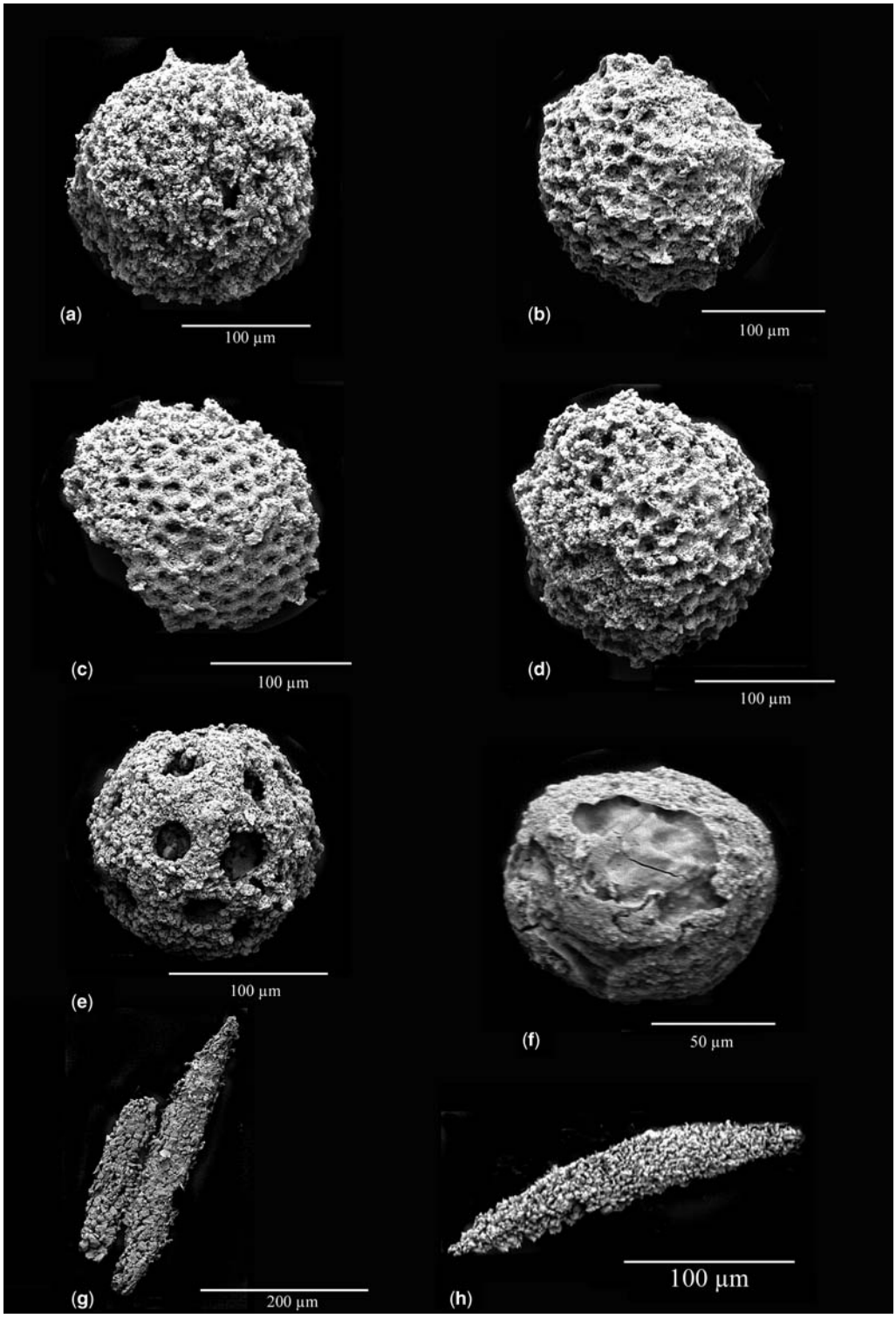

Fig. 4. Siliceous microfossils from HF acid residues of black cherts, locality Ninqiang, S. Shaanxi, Kuanchuanpu Formation. (**a**, **b**, **c**, **d**) Spherical radiolarian skeletons with lattice spheres (b, c, d) and short, triangular spines (a). Residue and matrix of the rock is strongly dominated by monaxon sponge spicules (**g**, **h**), along with silica spherules, probably representing radiolarian Steinkerns (**e**, **f**).

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Kuanchuanpu Formation, Ningqian, S. Shaanxi Province

Radiolarian skeletons have been recovered from a sequence of black cherts underlying phosphatic carbonate beds, the latter containing *Olivooides* and the embryonic series described by Zhao & Bengtson (1999). The area is situated near the northern rim of the Yangtze Platform (cf. Fig. 1a). Its lithologies are generally interpreted as being of shallow shelf origin. However, the lithologies at Ningqian lack any sediments and structures indicative of such shallow water origin. Black cherts and phosphatic limestones, lacking autochthonous fauna, seem to indicate a deeper water setting, at least at this locality. Details of lithology and the bathymetry of Ningqian are currently being investigated by the authors. The chert samples did not yet yield any microfossils other than sponge spicules and radiolarians. As the first Early Cambrian small shelly fossils (*Anabarites trisulcatus* and *Protohertzina*) occur in the lowermost bed of phosphatic carbonate above the sample horizon (see profile in Zhao & Bengtson 1999), it cannot be stated with certainty whether the radiolarians are of latest Precambrian or earliest Cambrian age.

Material and methods

Xintangwu concretion

Besides several lattice fragments, one well preserved and fairly complete specimen has been found in a sample of 1 kg of carbonate rock after digestion in 10% acetic acid (cf. Fig. 3). Preservation of radiolarians in calcareous concretions within clay-dominated sediments has been repeatedly recovered from sedimentary successions of different ages (Blome & Albert 1985). Early carbonate precipitation protected the radiolarian skeletons from early diagenetic dissolution, which is otherwise common in clay-rich sediments (Riedel 1959). Co-existence of radiolarians and sponge spicules has been observed in many other radiolarian occurrences, and the preservation of radiolarians has been attributed to the presence of sponge spicules (Fortey & Holdsworth 1972).

Because of the significance of the finds, special attention has been paid to the question of whether or not the skeleton fragments are original to the rocks dissolved. The following observations suggest that the resulting fossils are original:

(1) the sorted material contains not only a fairly complete skeleton, but also several fragments of lattice spheres;
(2) the external appearance and crystallinity of the siliceous remnants of the limestone sample is the same between sponge spicules and radiolarians;
(3) the lithology and fossil content of the sample (bituminous carbonate concretion in a black shale containing abundant siliceous sponge spicules) is exactly the kind of lithological and diagenetic facies commonly containing radiolarians from other periods, especially in the Palaeozoic (e.g. Holdsworth 1966).

The material was processed and the residue sieved and picked by an experienced laboratory technician in clean and new sieves, which had not been used in any kind of radiolarian preparation before.

Ningqian chert

Four lattice spheres (cf. Fig. 4a–d) that were preserved well-enough to permit further investigations have been found in addition to monaxon siliceous sponge spicules (cf. Fig. 4g, h) and spherical bodies, most probably representing siliceous Steinkerns of Radiolaria (cf. Fig. 4e–f). Pieces of the black chert have been etched with diluted (10%) HF acid, as described for younger radiolarian-bearing rocks by Pessagno and Newport (1972) and Braun (1990). Abundance of siliceous microfossils (predominantly sponge spicules) and the regular, dm-scale bedding suggests that the cherts are biosiliceous sediments, much like the bedded radiolarian cherts of the Palaeozoic age.

Morphological characteristics of the Radiolaria

The skeletons from the two localities are very similar to each other in external aspect. They possess a lattice sphere with a diameter of slightly more than 150 μm. The Xingtangwu specimen displays two sets of spines, the larger seemingly bladed, the smaller needle-like. Only one specimen from the Ningqiang cherts has fragmentary, small spines of equal size left on the surface of the lattice sphere. The lattice pores are similar in size and rounded polygonal in outline. We found no internal structures, such as an internal spicule or additional internal spheres in our material, but this may well be attributed to the diagenetic silica filling and does not suggest original absence of internal structures. We have avoided treating the specimens systematically, because the few specimens found are too incompletely preserved for closer systematic assignment. A systematic study must await additional material.

Discussion

Spherical shape and the regular, two-dimensional lattice of our radiolarian skeletons are unlike the irregular spongy framework, present in well-preserved radiolarian faunas from the Middle and Late Cambrian of Australia and China, which have

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been found in carbonate lithologies of shallower water environments. (Dong *et al.* 1997; Won *et al.* 1999). They show neither a needle-like morphology nor a spicular construction mode postulated to be characteristic for ancestral radiolarians (Archaeospicularia, cf. Petrushevskaya 1977; Dumitrica *et al.* 2000). In addition, there is no sign of polarity. Polarity in the architecture of many Palaeozoic radiolarians has been interpreted as a morphological expression of a sessile life habit before a benthos-plankton transition. All such presumed or predicted ancestral characteristics are completely missing in the Early Cambrian skeletons described here. Instead, the overall morphology is decidedly more similar to that of younger Palaeozoic radiolarians from the Ordovician (Dunham *et al.* 1976) or younger faunas dominated by spherical entactinids, which commonly occur in a similar kind of oceanic sedimentary environment (black shales with carbonate and/or phosphatic concretions).

Our finds indicate that by the Early Cambrian, radiolarians living in an oceanic setting had already developed advanced skeletal architecture with several sets of spines, a lattice sphere and radial symmetry. Lattice sphere, spines and radial symmetry are adaptations to a planktonic mode of life in radiolarians and so even this early, radiolarians seem to have been adapted morphologically to a planktonic mode of life in the oceans. Our finds support the idea that spherical radiolarians are a very ancient morphology among radiolarians (Kling 1978).

Early development and composition of plankton communities

Radiolarians are now known to be constituents of zooplankton communities and as part of the oceanic food chain in the earliest Cambrian. The composition and biodiversity of oceanic plankton, at the time of the Early Cambrian 'bioradiation' (Butterfield 1997), is usually considered to be dominated by acritarchs (Vidal *et al.* 1983). To that group we can now add the radiolarians. The occurrence of radiolarians in rocks of black shale and black bedded chert lithologies as early as earliest Cambrian corresponds well with the connection of radiolarian occurrences and anoxic to dysoxic oceanographic conditions ('events') observed during later time periods (Thurow 1988; Erbacher & Thurow 1997). At Xintangwu, anoxic/dysoxic conditions followed blooms of phytoplankton, as indicated by the carbonaceous and highly bituminous black shale lithology and by biodiverse phytoplankton discovered in thin sections of phosphorite concretions and cherts (Braun *et al.* 2003). The hypothesis of an origin of a planktic mode of life as a kind of 'evasive action' during times of poor bottom oxygenation during such anoxic events (Tappan & Loeblich 1973; Leckie 1989) gains further support from this ancient co-occurrence.

Geological implications

Of the siliceous planktonic organisms known to play an important role in the silica cycle of the oceans, at least since the Cretaceous (Heath 1974), radiolarians are currently the only major group recognized from fossils at the beginning of the Cambrian. Based on the rare skeleton findings reported herein, however, nothing can be said about how important their role was in biomass and silica cycling. However, our findings do indicate, that by the Early Cambrian siliceous zooplankton were contributing to the oceanic silica balance in addition to the siliceous sponges (Bengtson 1986). The latter are common and sometimes present in rock forming amounts within chert sequences spanning the Precambrian/Cambrian boundary (Braun *et al.* 2004). Should the Neoproterozoic series of siliceous shales and bedded cherts, underlying the Cambrian in many places of the Yangtze Platform, turn out to be radiolarian-rich sedimentary rocks (in the field, they are indistinguishable from bedded radiolarian cherts) this would introduce significant constraints for the palaeogeochemistry of the oceans. We did not find traces of radiolarian skeletons during our processing in a first test series of these siliceous rocks, but this could be due to the strong recrystallization of the chert matrix in the area sampled (southern Shaanxi Province). Exploration for more evidence of Radiolaria and biosiliceous sedimentation will be conducted in the basinal facies of the Neoproterozoic of the Yangtze Platform.

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References

Amaral-Zettler, L. A., Sogin, M. L. & Caron, D. A. 1997. Phylogenetic relationships between the Acantharea and the Polycystinea: a molecular perspective on Haeckels Radiolaria. *Proceedings of the National Academy of Sciences*, **94**, 11411–11416.

Anderson, O. R. 1983. *Radiolaria*. Springer, New York.

Bengtson, S. 1986. Siliceous microfossils from the Upper Cambrian of Queensland. *Alcheringa*, **10**, 195–216.

Blair Hedges, S., Chen, H., Kumar, S., Wang, D. Y. C., Thompson, A. S. & Watanabe, H. 2001. A genomic timescale for the origin of eukaryotes. *BMC Evolutionary Biology*, **1**, 4.

Blome, C. D. & Albert, N. R. 1985. Carbonate concretions: an ideal sedimentary host for microfossils. *Geology*, **13**, 121–215.

Braun, A. 1990. Radiolarien aus dem Unter-Karbon Deutschlands. *Courier Forschungsinstitut Senckenberg*, **133**, 1–177.

Downloaded from http://sp.lyellcollection.org/ at Massachusetts Institute of Technology on November 22, 2019

BRAUN, A. & CHEN, J. 2003. Plankton from Early Cambrian black shale series on the Yangtze Platform, and its influences on lithologies. *Progress in Natural Sciences*, **13**, 777–782.

BRAUN, A., CHEN, J., WALOSZEK, D. & MAAS, A. 2004. Siliceous microfossils and biosiliceous sedimentation in the Lowermost Cambrian of China. Monash Science Centre, Melbourne (extended abstract).

BUTTERFIELD, N. J. 1997. Plankton ecology and the Proterozoic–Phanerozoic transition: *Paleobiology*, **23**, 247–262.

CAMPBELL, A. S. 1954. Radiolaria. *In*: MOORE, R. C. (ed.) *Treatise on Invertebrate Paleontology. Part D—Protista 3*, Geology Society of America and The University of Kansas, D11–D163.

CAYEUX, L. 1894. Les preuves de l'existence d'organismes dans le terrain précambrien. Première note sur les Radiolaires précambriens. *Société Géologique de France, Bulletin*. Séries **3**, 197–228.

CHATTON, E. 1934. L'origine péridinienne des Radiolaires et l'interprétation parasitaire de l'anisosporogenèse. *Comptes Rendus de l'Académie des Sciences*, **198**, 309–312.

DANELIAN, T. 1999. Taxonomic study of Ordovician (Llanvirn-Caradoc) Radiolaria from the Southern Uplands (Scotland, UK). *Geodiversitas*, **21**, 625–635.

DAVID, T. W. & HOWCHIN, W. 1896. Note on the occurrence of casts of Radiolaria in Pre-Cambrian (?) rocks, South Australia. *Proceedings of the Linnean Society of New South Wales*, **XXI**, 571–583.

DEFLANDRE, G. 1949. Les soi-disant radiolaires du Précambrien de Bretagne et la question de l'existence de radiolaires embryonnaires fossils. *Bulletin de la Société Zoologique de France*, **74**, 351–352.

DE WEVER, P., DUMITRICA, P., CAULET, J.-P., NIGRINI, C. & CARIDROIT, M. 2001. *Radiolarians in the Sedimentary Record.* Gordon & Breach, London.

DOGEL, V. A. 1950. New data on the phylogeny of Radiolaria. *Zoologitschjeskii Zhournal*, **29**, 562–565.

DONG, X., KNOLL, A. H. & LIPPS, J. H. 1997. Late Cambrian Radiolaria from Hunan China. *Journal of Paleontology*, **71**, 753–758.

DUMITRICA, P., CARIDROIT, M. & DE WEVER, P. 2000. Archaeospicularia, ordre nouveau de radiolaires: une nouvelle étape pour la classification des radiolaires du Paléozoique inférieur. *Comptes Rendus de l'Académie des Sciences (Paris)*, Série II, **330**, 563–569.

DUNHAM, J. B. & MURPHY, M. A. 1976. An occurrence of well preserved Radiolaria from the Upper Ordovician (Caradocian), Eureka county, Nevada. *Journal of Paleontology*, **50**, 882–887.

ERBACHER, J. & THUROW, J. 1997. Influence of anoxic events on the evolution of mid-Cretaceous Radiolaria in the North Atlantic and western Tethys. *Marine Micropaleontology*, **30**, 139–158.

FORTEY, R. A. & HOLDSWORTH, B. K. 1972. The oldest known well preserved Radiolaria. *Bolletino della Societa Paleontologica Italiana*, **10**, 35–41.

GRUNAU, H. R. 1965. Radiolarian cherts and associated rocks in space and time. *Eclogae Geologicae Helvetiae*, **58**, 157–208.

HEATH, G. R. 1974. Dissolved silica and deep-sea sediments. *In*: HAY, W. W. (ed.) *Studies in Paleo-Oceanography*. Society of Economic Paleontology and Mineralogy Special Publication, **20**, 77–93.

HOLDSWORTH, B. K. 1966. Radiolaria from the Namurian of Derbyshire. *Paleontology*, **9**, 319–329.

HOLLANDE, A., CACHON, J. & CACHON, M. 1970. La signification de la membrane capsulaire des Radiolaires et ses rapports avec le plasmalemme et les membranes de reticulum endoplasmique. Affinités Radiolaires, Heliozoaires et Peridiniens. *Protistologica*, **6**, 311–318.

KLING, S. A. 1978. Radiolaria. *In*: HAQ, B. U. & BOERSMA, A. (eds) *Introduction to Marine Micropaleontology*. Elsevier, New York, 203–244.

KNOLL, A. 1992. The early evolution of eucaryotes: a geological perspective. *Science*, **256**, 622–627.

KOZUR, H. W., MOSTLER, H. & REPETSKI, J. E. 1996. Well preserved Tremadocian primitive radiolarian from the Windfall Formation of the Antelope range, Eureka County, Nevada, USA. *Geologisch-Paläontologische Mitteilungen der Universität Innsbruck*, **21**, 245–271.

LECKIE, R. M. 1989. An oceanographic model for the early history of planktonic Foraminifera. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **73**, 107–138.

NAZAROV, B. B. 1973. Radiolaria from Lower Cambrian horizons. Trudi Instituta Geologii, Akademia Nauk SSSR, **49**, 5–13.

PESSAGNO, E. A. & NEWPORT, R. L. 1972. A technique for extracting Radiolaria from Radiolarian cherts. *Micropaleontology*, **18**, 231–234.

PETRUSHEVSKAYA, M. 1977. On the origin of Radiolaria. *Zoologitschjeskii Zhournal*, **56**, 1448–1458.

RIEDEL, W. R. 1959. Siliceous organic remains in pelagic sediments. *In*: IRELAND, H. A. (ed.) *Silica in Sediments.* Society of Economic Paleontologists and Mineralogists, Special Publication, **7**, 80–91.

STRELKOV, A. A. & RESHETNYAK, V. V. 1974. Radiolaria Acantharia. *In*: *Chemicoradioecology of Pelagics and Benthics*. Naukova Dumka, Kiev, 95–188.

TAPPAN, H. & LOEBLICH, A. R. 1973. Evolution of the oceanic plankton. *Earth Science Reviews*, **9**, 207–240.

THUROW, J. 1988. Radiolarians of Turonian bituminous carbonates (transgressive sequences of Northwest African Coastal Basins). *In*: SCHMIDT-EFFING, R. & BRAUN, A. (eds) First International Conference on Radiolaria (Eurorad V), Abstracts: *Geologica et Palaeontologica*, **22**, 210.

VIDAL, G. A. H. & KNOLL, A. H. 1983. Proterozoic plankton. *Geological Society of America, Memoir*, **161**, 265–277.

VISHNEVSKAYA, V. S. & KOSTYUCHENKO, A. S. 2000. The evolution of radiolarian biodiversity. *Paleontologitscheskii Journal*, **34**, 124–130.

WON, M.-Z. & BELOW, R. 1999. Cambrian Radiolaria from the Georgina basin, Queensland, Australia. *Micropaleontology*, **45**, 325–363.

ZHAO, Y. & BENGSTON, S. 1999. Embryonic and post-embryonic development of the early Cambrian cnidarian *Olivooides*. *Lethaia*, **32**, 181–195.

ZHU, M., ZHANG, J., STEINER, M., LI, G. & YANG, A. 2000. *Sino-German Cooperative Program. Programme and Excursion Guide*. Nanjing Institute of Geology and Paleontology, Academia Sinica.