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Occurrences of Permian radiolarians in central and eastern Nei Mongol (Inner Mongolia) and their geological significance to the Northern China Orogen

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Abstract **The Zhesi (Jisu) Formation of the Middle Permian in Nei Mongol (Inner Mongolia) was commonly considered to be a shallow marine sequence. Here I report the radiolarians found in the argillite bed of that formation in Zhesi and Xilinhot areas. This fact indicates a deep marine sedimentary facies persisted during the Middle Permian, and suggests that the ocean between the North China Block and Siberian Craton was not closed until the Late Guadalupian. The suture of this two blocks is probably extends along the Linxi ophiolite belt, south of the Hegenshan ophiolite belt.**

Keywords: radiolarian, Middle Permian, Inner Mongolia.

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The Northern China Orogen corresponding to the collision zone between the North China Blocks (NCB) and Siberian Craton represents the southeastern part of the Central Asian Orogenic Belt (CAOB) in eastern China. It is one of the key regions for understanding the tectonic evolution of CAOB. However, developmental history of the North China Orogen remains poorly understood due to the superposition of late deformations. The position of the suture, the geometry of the orogen, the geodynamic evolution model, and the time of collision are still disputed[1—8]. In general, the ophiolite of the Linxi area was deduced to be the suture zone of the final collision zone from the views of tectonics, sedimentology and paleobiogeography[1,8—10]. Because ultramafic rocks and volcanic rocks of arc and MORB (Mid-ocean Ridge Basalts) type were observed in the Hegenshan area, some workers suggested that the final suture of North China Orogen was along the Hegenshan ophiolite[4,7,11,12] or even further north along the mélange zone of South Mongolia[13—15]. The time of collision has been inconsistently regarded to be either the Middle Devonian[2,5], Late Devonian, Early Carboniferous[3,16], interval between the Permian and Triassic[1,4,6,8,17—19], or the Mesozoic time[7].

Because outcrops are poor and restricted, many of these interpretations were drawn on the basis of data from local areas which were studied following various approaches. For instance, the collision time was mostly determined by radiometric data, but evidences of paleontology and paleogeography are rather rare[20,21]. This paper presents some results of detailed paleontology work on radiolarians collected from the Middle Permian in central and eastern Inner Mongolia and discusses their significance in interpreting the timing and location of the collision between the NCB and Siberian block.

1 Geological backgrounds

In the central and eastern parts of Inner Mongolia, outcrops of Permian rocks are distributed dispersively and exclusively fault-bounded. Most of these strata were located, from west to east, at the northern part of Darhan Muminggan Lianheqi, the northern part of Sonid Zuoqi, the eastern part of Xilinhot, the Xi-Ujimqinqi and Linxi areas (Fig. 1). As a set of Permian strata commonly seen in the North China Orogen, the Middle Permian Zhesi (Jisu) Formation is characterized by fine-grained sandstone, siltstone and shale with limestone lenses.

The Zhesi Obo (the Obo means Heap of Stores in Mongolian) section, which is located to the north of Darhan Muminggan Lianheqi, is the type locality of the Zhesi Formation and consists of medium- to fine-grained sandy-clay sediments and limestone up to hundreds of meters in thickness (about 277 m thick). The limestone is rich in reef-building fossils, such as brachiopods, corals, fusulinids, and bryozoans. In the previous works, the abundance of benthic fossils was taken as an evidence for shallow marine facies for those Middle Permian deposits[22—28]. In fact, up to now, most of the fossils used to determine the age of the Zhesi formation come from the limestone, which crop out as lenses-shaped blocks in sandstone, thin bedded limestone or calcareous sandstone interbedded within the sandy-clayey sequence. Only few fossils were reported from the argillites[20,22], which account for a large proportion of the Zhesi Formation. The radiolarian fossils I found in the argillite provide the additional evidence for age and depositional environment of the Zhesi Formation.

(i) Stratigraphy of central Inner Mongolia. The Zhesi Obo section is composed of sandy-clayey sequence and limestone. The limestone formed the Zhesi Obo ridge and contains diverse marine fossils. These marine invertebrates have been described since Grabau in 1930s[23]. During the 1970s and 1980s, this set of clastic Permian deposits and layers were comprehensively studied by several Chinese geologists[24,27,28]. Even now, the sequence characteristics, the environmental and paleogeographical aspects have also been discussed[25,26,29]. Different studies have resulted in several substantially different interpretations due to the intricate deformation, fault contract be-

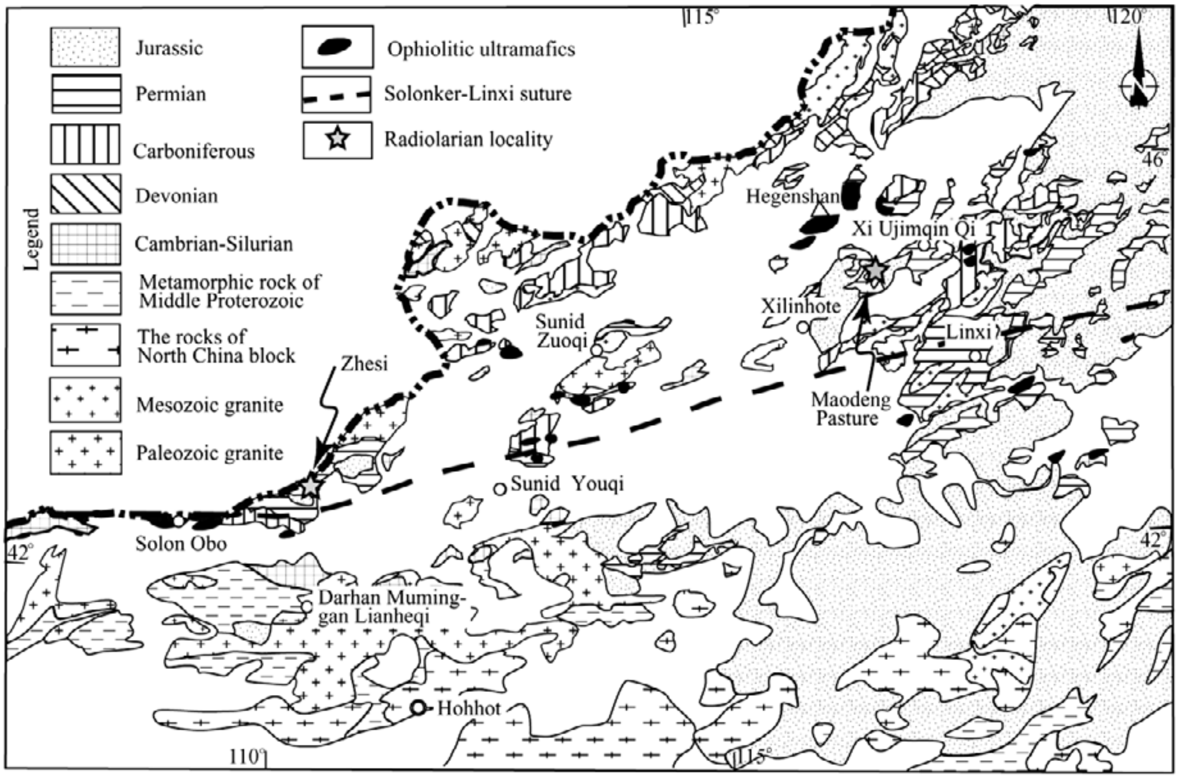

Fig. 1. A simplified geological map of SE part of North China Orogen[1,8,22] and the sampling sites of the Permian radiolarians.

tween different units and the Quaternary sedimentary cover. The diverse opinions concerning structure and deposit sequence are also reflected in different interpretations of defined stratigraphic units, such as their names and sedimentary environments. For instance, the sandstone-shale beds of our research target, which crop out north of Zhesi Obo limestone ridge, have been called as the Upper Jisu Formation[23,30,31], Sanmianjing Formation[27], Yihewusu Formation[24] or Bulege Formation[29]. The sedimentary environments were considered as near shore shallow marine[25,26] or rapid compensated subsidence[29].

The samples were collected from Zhesi Honguer lowland (E: 110°18′33″; N: 42°39′50″), approximately 1000 m north of Zhesi Obo ridge. Although this area is overlain by a thick cover of the Quaternary sediments and abundant steppe vegetation, the rhythmically alternating argillite and sandstone are well exposed in some gullies in the middle part of the lowland. These rocks dip northward at high angles, and small-scale folds and faults are locally observed. In the study area, the exposures consist of argillaceous rocks with scarce organic remains. Fossils are found in the limestone lenses and blocks irregularly distributed within the main rock mass. Reef-building organisms such as solitary corals, brachiopods, crinoids, bryozoans, bivalves and foraminifers indicate a Middle Permian age[24,29].

(ii) Stratigraphy of eastern Inner Mongolia. The second research area is located in the Maodeng Pasture, northeast of Xilinhot City, Inner Mongolia (E: 116°33′49″; N: 44°09′03″). The clayey-sandy sequence of the Zhesi Formation exposed within volcanic rocks. The relationship between this sequence and volcanic rock is quite difficult to recognize. These clastic layers have been referred to as intercalated bed of volcanic unit of the Dalinuoer Formation. In a recent summary of the lithostratigraphic units of the Inner Mongolia, this argillaceous sequence was referred to as an independent unit, the Zhesi Formation[31].

The entire section is dominated by clayey rock and interpreted as an overturned monocline with southward dipping. From the lower part to upper part, the lithology changed from clayey deposit to sandstone-clayey rocks gradually. The uppermost strata are coarse-grained sandstone. Argillite nodules are mainly confined to the lower and middle parts of the sequence and decrease upward. The well-developed cleavage and quartz vein affect the entire sequence, which is approximately 200 m thick. From the argillite nodules ammonites, such as *Daubichites* sp. and other species, are yielded. The features of these fossils were similar to that occurring in the Zhesi Formation of the Honggormiao area of Abag Qi, and indicate a Middle Permian age[22]. During our fieldwork, we found that not only many ammonite fossils, but also abundant radiolarians, are preserved in these argillite nodules.

2 Occurrence and age of the radiolarian fauna

(i) Radiolarians from central Inner Mongolia. Radiolarians from Zhesi area of Darhan Muminggan Lianheqi are extracted from the argillite masses in thin-bedded bioclastic sandstone (or sandy-detrital limestone), and the argillite nodules in shale of the Zhesi Formation. During the field survey, more than ten rhythms which composed of bioclastic sandstone with siltstone and shale alternations were observed. This bioclastic sandstone, which is about 10—30 cm thick and located in lower part of each subsequence of these rhythmic sedimentary, looks like a single bedding and sharply changes to the fine-grained siltstone and shale upwardly; usually it cannot be distinguished from sandy-detrital limestone. In the weathering surface, the coarse-grained detrital fractions are composed of the fragments of spines and valves of Brachiopods and other fossils. The argillite masses, which are enclosed in the matrix of bioclastic sandstone, have a variable size (the maximum dimension can be 15 cm long), shape and irregular distribution. Radiolarian and sponge spicule were recovered from these argillite masses. Within the shale beds of the upper part of the section, similar micro-fauna have also been found in argillite nodules. Nevertheless, no fossil has been obtained from the shale.

After processing by hydrofluoric acid (HF) in laboratory, radiolarians, sponge spicules and some foraminifers were extracted from the argillite masses and nodules. These radiolarian skeletons are poorly preserved and dominated by spherical forms. This fauna consists of *Hegleria mammilla* (Sheng et Wang), *Hegleria* sp., *Entactinosphaera*? sp., *Staurolonche*? sp., *Ishigaum*? sp., and *Pseudoalbaillella*? sp. (Fig. 2).

Among the radiolarians listed above, *Hegleria mammilla* (Sheng et Wang) is widely distributed in the Late Guadalupian deposits, including the Guadalupian in Texas and Oregon, USA, Sicilia of Italy, and southeast Thailand, and was considered as a typical taxon of the radiolarian fauna from the Kuhfeng Formation, South China. This species is also an important form of the Middle Permian radiolarian fauna identified in the ophiolite belt near the Xira-Moron River[21]. Other genera and species mostly belong to the wide stratigraphic ranging and

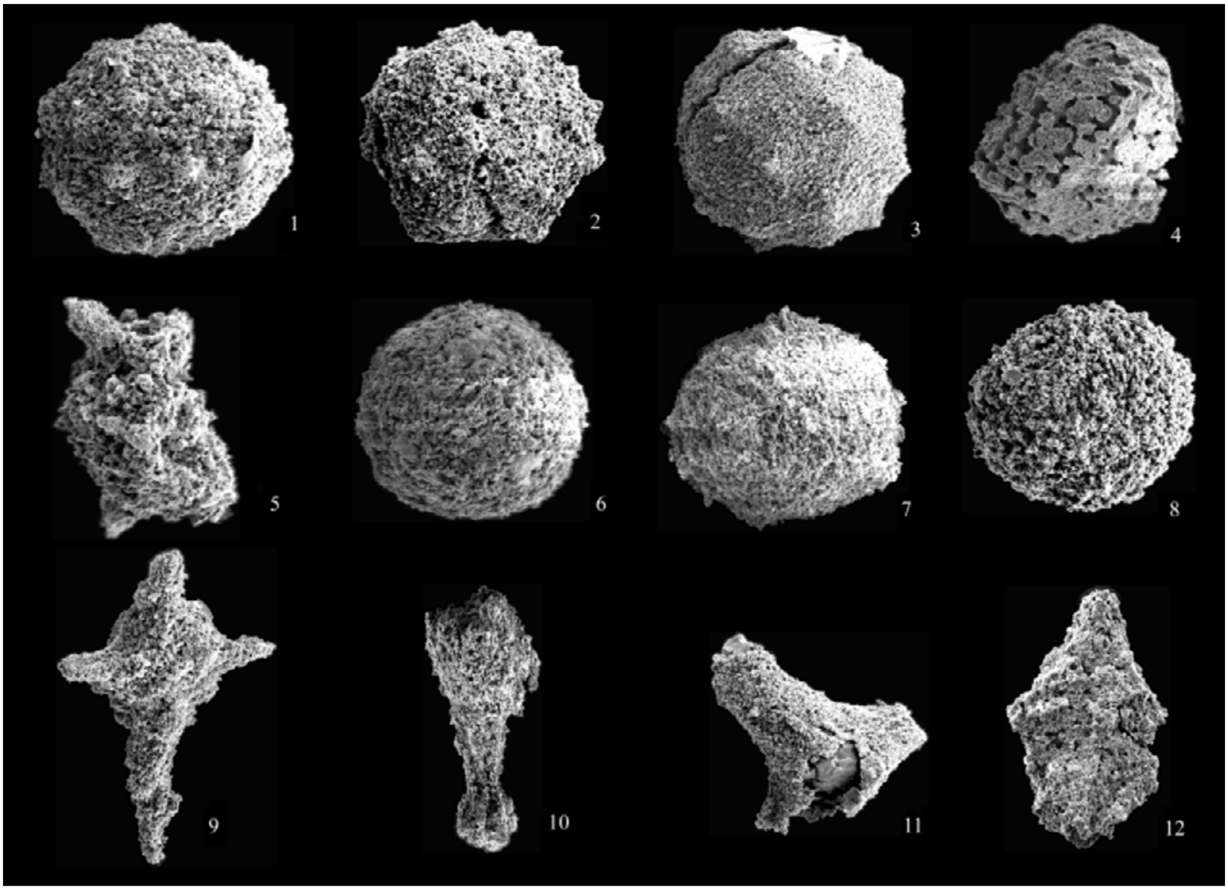

Fig. 2. Radiolairans from the Zhesi Formation in the northern Zhesi Obo of Darhan Muminggan Lianheqi, Inner Mongolia. 1, *Hegleria mammilla* (Sheng et Wang), ×120; 2 and 3, *Hegleria*? sp. (2, ×120; 3, ×100); 4, 6—8, Radiolarians incertae sedis (4, ×210; 6, ×180; 7, ×170; 8, ×200); 5, *Entactinosphaera*? sp., ×160; 9, *Staurolonche*? sp., ×200; 10 and 11, *Ishigaum*? sp. (10, ×240; 11, ×220); 12, *Pseudoalbaillella*? sp., ×170.

common forms of the Permian. On the basis of our work and the associated bryozoans, brachiopods and fusulinids of the Guadalupian from the sandy limestone and limestone lenses[24,29], it should be ascertained that these radiolarian-bearing strata belong to the Late Guadalupian.

(ii) Radiolarians from eastern Inner Mongolia. Fine-grained clastic rock of the Zhesi Formation in the Maodeng Pasture area, northeastern Xilinhot City yields radiolarians and other microfossils. All radiolarian fossils are extracted from argillite nodules enclosed in shale beds. They are very abundant though most of them are poorly preserved. This is probably because the fossil-bearing strata have been severely deformed. All samples were treated with 5% diluted hydrofluoric acid in the laboratory. A large amount of spherical forms lack ornaments and thus, are very difficult to identify precisely. A few species, such as *Copiellintra*? sp., *Copicyntra*? sp., and two species of *Pseudoalbaillella* can be recognised (Fig. 3). Observation under the microscope shows that a majority of the radiolarians had been dissolved and recrystallized, and is represented by broken external shell only. The same phenomena were observed in other microfossils like the sponge spicule and foraminifers. This makes identification of these forms very difficult. The radiolarian *Pesudoalbaillella* is widespread in the world during the Early and Middle Permian period; according to other symbiosis fossils, these shales could be considered as older than the latest Middle Permian epoch. Together with the associated ammonite, the Zhesi Formation in this area belongs to the Guadalupian.

3 Discussion

(i) Depositional environment of the Zhesi Formation. Since the first work of Grabau in 1930s, it was considered that the Middle Permian sediments in the Inner Mongolia accumulated in shallow marine environment. The new discovery of radiolarian fauna of the Zhesi Formation in central and eastern Inner Mongolia provides some new evidence to discuss the sedimentary setting of the Middle Permian period.

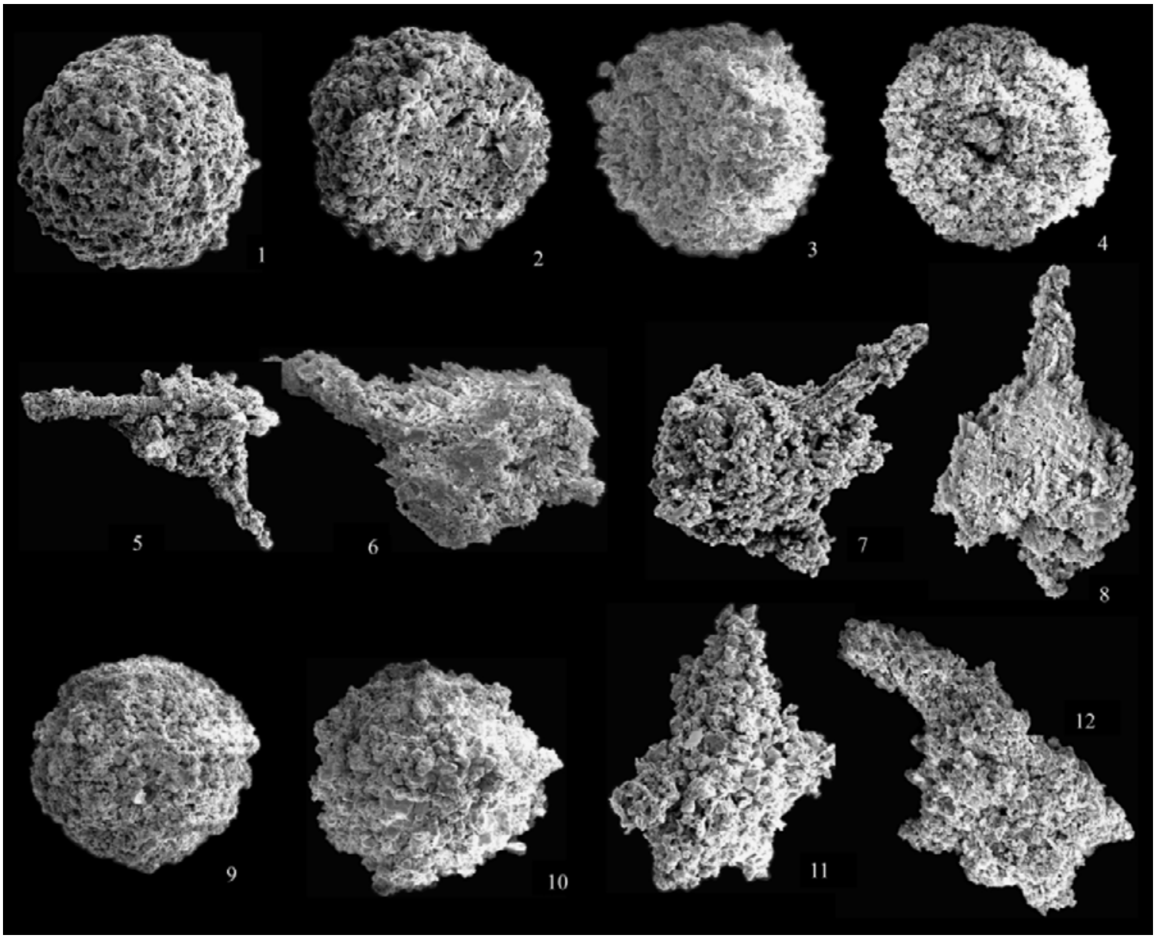

Fig. 3. Radiolarians from the Zhesi Formation in the Maodeng Pasture of Xilinhot City, Inner Mongolia. 1—5, 9 and 10, Radiolarians incertae sedis (1, ×180 ; 2, ×150; 3, ×180; 4, ×250; 5, ×280; 9, ×150; 10, ×230); 6, *Copiellintra*? sp., ×300; 7 and 8, *Copicyntra*? sp. (7, ×250; 8, ×300); 11 and 12, *Pseudoalbaillella* sp. (11, ×240; 12, ×230).

There are many controversy arguments about the depositional conditions of radiolarian bearing rocks[32,33]. These siliceous sediments might be lain down in shallow coastal basins, in depressions of continental slopes, on continental margins, and in shallow water and deep oceanic basins. Although these siliceous sediments accumulated not always in very deep oceanic basins (>3000 m), on the basis of the modern analogue, it is usually thought that radiolarites deposited in various oceanic environments deeper than 300—500 m. This sedimentary setting reflects both productivity in the overlying water and carbonate dissolution on the sea floor.

The radiolarians reported in this paper are preserved in argillite nodules enclosed in shale and sandstone. The fossils associated with radiolarian are sponge spicule, foraminifera and ammonite. All these chaperonage animals are natant classes and might appear in different marine facies from shallow to deep water. In contrast, no radiolarian has been reported from the limestone lenses that yield rich shallow marine species. Therefore, the sandy-clayey sequence of the Zhesi Formation probably represents deep basin or continental slope deposits.

Their geographic location may also explain many sedimentologic characteristics of the radiolarian bearing rock of the Zhesi Formation. At the Zhesi Honguer lowland, the Zhesi Formation consists of rhythmic alternation of shale and thin-bedded bioclastic sandstone with well developed graded bedding. Under the microscope, organic remains in bioclastic sandstone were broken into pieces and mostly represented by sponges, bryozoans, spines and valves of brachiopods, which account for 40%—50% of the volume of framework grain. The chamber of some organic fragments is filled with muddy sediments. In addition to organic remains, the terrigeneous component of the sediments consist of quartz (both monocrystalline and polycrystalline), feldspar, and a few of calcite and volcanic clasts. These grains are sub-angular and poorly sorted. The structure of rock is mostly grain-supported and with partially contains clay cement. Argillite mass is enclosed in a bioclastic sandstone matrix with a variable size, shape and irregular distribution, which consists of the clay mineral with microcrystalline and volcanic ash with crypto-crystalline, and yield scattered radiolarians and sponge spicules.

The juxtaposition of these different groups of bioclastic sandstone and argillite indicate that these sediments come from different sources both continental and oceanic. They may have been accumulated very quickly being transferred from their original site, and have resulted in turbiditic redistribution of littoral and slope sediments. The organic remains of sponge, bryozoa and brachiopoda may have been derived from the reef of shallow marine, the quartz, feldspar, volcanic detritus grain from continent or island arc, and the radiolarian bearing argillite rocks from deep marine deposits.

According to our field survey, the limestone bodies exposed to the north of Zhesi Obo limestone ridge are allochthonous blocks. They are mostly composed of massive bioclastic limestone or bedded sandy-detrital limestones, which contains very rich corals, bryozoans, brachiopods and other fossils, and has a variable size and configuration. The bedding in blocks is truncated by surrounding rock. Composite blocks consisting of closely joined different rock types (sandstone, detrital and biomorphic limestone) also exist in this area[29]. Blocks are frequently bounded by pebbly mudstone. All the sedimentological observations indicate that the isolated rock blocks and fragments are re-deposited. The thick sequence of shales and sandstones exposed Zhesi Honguer lowland is coeval with the embedded limestone blocks and the carbonate section of the Zhesi Obo, because they contain similar fossil assemblages. It can be assumed that they accumulated synchronously, but in different environments. They are presently juxtaposed due to tectonics.

In the Zhesi Formation of the Maodeng Pasture area, neither carbonate interbeds, nor limestone lenses were preserved. Rhythmical alternations of siltstone and shale have been observed in all sections. Graded bedding is well developed. Apart from radiolarians, there are also ammonites, foraminifers and sponge spicules. Although more detailed chemical composition and lithofacies researches are needed; in general, based on the faunal content this set of formation indicates relatively deep-water sedimentation. In addition, during the field work in the west of Xi-Ujim-qin-Qi, I found that all of the thin-bedded chert beds within the Zhesi Formation are sponge-spicule rocks, which generally occur more extensively in the shelf margin or continental slopes and indicate slight shallower depth than radiolarites.

According to my field survey in middle and east parts of Inner Mongolia, the analysis of lithofacies and the discovery of radiolarians, I believe that the argillaceous Zhesi Formation represents deep-water sedimentation. However, detailed palaeoceanographic reconstructions about the radiolarian fauna are not yet available, and composition is also difficult to understand due to its poor preservation.

(ii) Tectonic interpretation. Generally, the Middle Permian strata in nothern China region were considerred as shallow marine or paralic and continental sedimentation before; the discovery of the Middle Permian deep water sedimentation provides a very important evidence for the tectonic evolution of North China Orogen. The Middle, Upper Permian and its lower Late Paleozoic strata were considered as postcollisional shallow water sedimentation or molasse[2,3,5,34,35]. For instance, in the east of Xilinhot region, the sandstone, shale, limestone and volcanic rocks of Carboniferous to Permian age were interpreted as molasse deposits, and thought to be the earliest sediments deposited in a post collisional foreland basin[15]. On the basis of this deduction, the collision between the Sonid Zuoqi arc and the NCB was assumed to occur during the Late Devonian to Early Carboniferous. Wang et al.[1] considered that Solonker-Linxi ophiolitic belt was the final suture of the Late Permiam, but they deemed that these Middle Permian strata were molasse of marine facies in the west part of suture and overlaid the Middle-Upper Carboniferous discontinuty. At the eastern part of the suture, these Middle Permian strata were considerred to be a flysch series[1]. All the work was based on the understanding of the sedimentary environment of the Middle Permian rocks, which is the key to understand the tectonic evolution of the southeast parts of the Central Asian Orogenic Belt.

Based on the discovery of these deep marine strata of the Zhesi Formation, it can be proposed that the Paleo-Asia ocean still existed during the Guadalupian period, and at least, during this period, some deep basinal sedimentation still existed. Hence, the collision between the NCB and the Siberian Craton may have stopped at the end of the Guadalupian, which is confirmed by work of structure geology, petrology, geochemistry and geochronology[1,4,6,17—19]. Based on the distribution of Andean-type magmatism, Xiao et al.[8] considered that the Central Asian Ocean still existed during the Late Permian.

Although the faunas of the Zhesi Formation have mixed features of Boreal and Tethyan Provinces[24], based on the statistic of species in Zhesi section most forms belong to the Boreal realm. From the view of paleogeography, they should be situated at the southern margin of the Siberian Craton, thus distributing to the northern part of the Solonker-Xilinhot zone. From Solonker, via Sunid Zuoqi to Xilinhot, the Solonker zone was considered as the final suture between the NCB and Siberian Craton by most of geologists[2,4,18]. In the eastern part, the prolongation of this suture is widely disputed as to along the Hegenshan ophiolites belt or the Linxi ophiolites belt. From the result of our work and the discovery of the Middle Permian radiolarian in the ophiolites of Xira-Moron river of Linxi[21], which can be considered as the youngest deposits in the Central Asian Ocean, it can be deduced that the eastern part of this suture zone seems situated at the south of Xilinhot-Linxi area. This conclusion can explain why there are no mixed floras between the Angaran Realm and Cathaysian Realm at the north of Xira-Moron River during Early and Middle Permian[36,37].

4 Conclusion

Our work in the central and eastern parts of Inner Mongolia suggests that the oceanic depositional environment between the NCB and Siberian Craton persisted till the Late Guadalupian and that the Central Asian Ocean was closed after the Guadalupian. The position of this oceanic depositional environment shows that the suture extends along the Solonker-Linxi belt.

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