Vol. 85 No. 2 pp. 421–436 ACTA GEOLOGICA SINICA (English Edition) April 2011

Stratigraphy of the Triassic–Jurassic Boundary Successions of the Southern Margin of the Junggar Basin, Northwestern China

SHA Jingeng[1, *], Vivi VAJDA[2, **], PAN Yanhong[1], Linda LARSSON[2], YAO Xiaogang[1], ZHANG Xiaolin[1], WANG Yaqiong[1], CHENG Xiansheng[3], JIANG Baoyu[4], DENG Shenghui[5], CHEN Siwei[1] and PENG Bo[1]

1 *State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, the Chinese Academy of Sciences, Nanjing 210008, China*

2 *Department of Earth and Ecosystem Sciences, Lund University, 22362 Lund, Sweden*

3 *PetroChina Xinjiang Oil Field Company, Keramay 834000, China*

4 *School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China*

5 *Research Institute of Petroleum of Exploration and Development, PetroChina, Beijing 100083, China*

Abstract: The Triassic–Jurassic (Tr–J) boundary marks a major extinction event, which (~200 Ma) resulted in global extinctions of fauna and flora both in the marine and terrestrial realms. There prevail great challenges in determining the exact location of the terrestrial Tr–J boundary, because of endemism of taxa and the scarcity of fossils in terrestrial settings leading to difficulties in linking marine and terrestrial sedimentary successions. Investigation based on palynology and bivalves has been carried out over a 1113 m thick section, which is subdivided into 132 beds, along the Haojiagou valley on the southern margin of the Junggar Basin of the northern Xinjiang, northwestern China. The terrestrial Lower Jurassic is conformably resting on the Upper Triassic strata. The Upper Triassic covers the Huangshanjie Formation overlaid by the Haojiagou Formation, while the Lower Jurassic comprises the Badaowan Formation followed by the Sangonghe Formation. Fifty six pollen and spore taxa and one algal taxon were identified from the sediments. Based on the key-species and abundance of spores and pollen, three zones were erected: the Late Triassic (Rhaetian) *Aratrisporites–Alisporites* Assemblage, the Early Jurassic (Hettangian) *Perinopollenites–Pinuspollenites* Assemblage, and the Sinemurian *Perinopollenites–Cycadopites* Assemblage. The Tr–J boundary is placed between bed 44 and 45 coincident with the boundary between the Haojiagou and Badaowan formations. Beds with *Ferganoconcha* (?), *Unio–Ferganoconcha* and *Waagenoperna–Yananoconcha* bivalve assemblages are recognized. The *Ferganoconcha* (?) bed is limited to the upper Haojiagou Formation, *Unio–Ferganoconcha* and *Waagenoperna–Yananoconcha* assemblages are present in the middle and upper members of the Badaowan Formation. The sedimentary succession is interpreted as terrestrial with two mainly lake deposit intervals within Haojiagou and Badaowan formations, yielding fresh water algae and bivalves. However, the presence of brackish water algae *Tasmanites* and the marine–littoral facies bivalve *Waagenoperna* from the Badaowan Formation indicate that the Junggar Basin was influenced by sea water caused by transgressions from the northern Tethys, during the Sinemurian.

Key words: Biostratigrapy, Triassic–Jurassic, Hettangian–Sinemurian, palynology, bivalve, Haojiagou of Junggar Basin, northwestern China

1 Introduction

The turnover coincident with the Triassic–Jurassic (Tr–J) boundary c. 200 Ma is considered as one of the five major extinction events in the history of life (Raup and Sepkoski, 1982) with a loss of over 50% of the biota at genus level in both marine and continental realms. Land plants were among the most severely affected groups (Burgoyne et al., 2005) with an extinction level reaching

* Corresponding author. E-mail: jgsha@nigpas.ac.cn
vivi.vajda@geol.lu.se

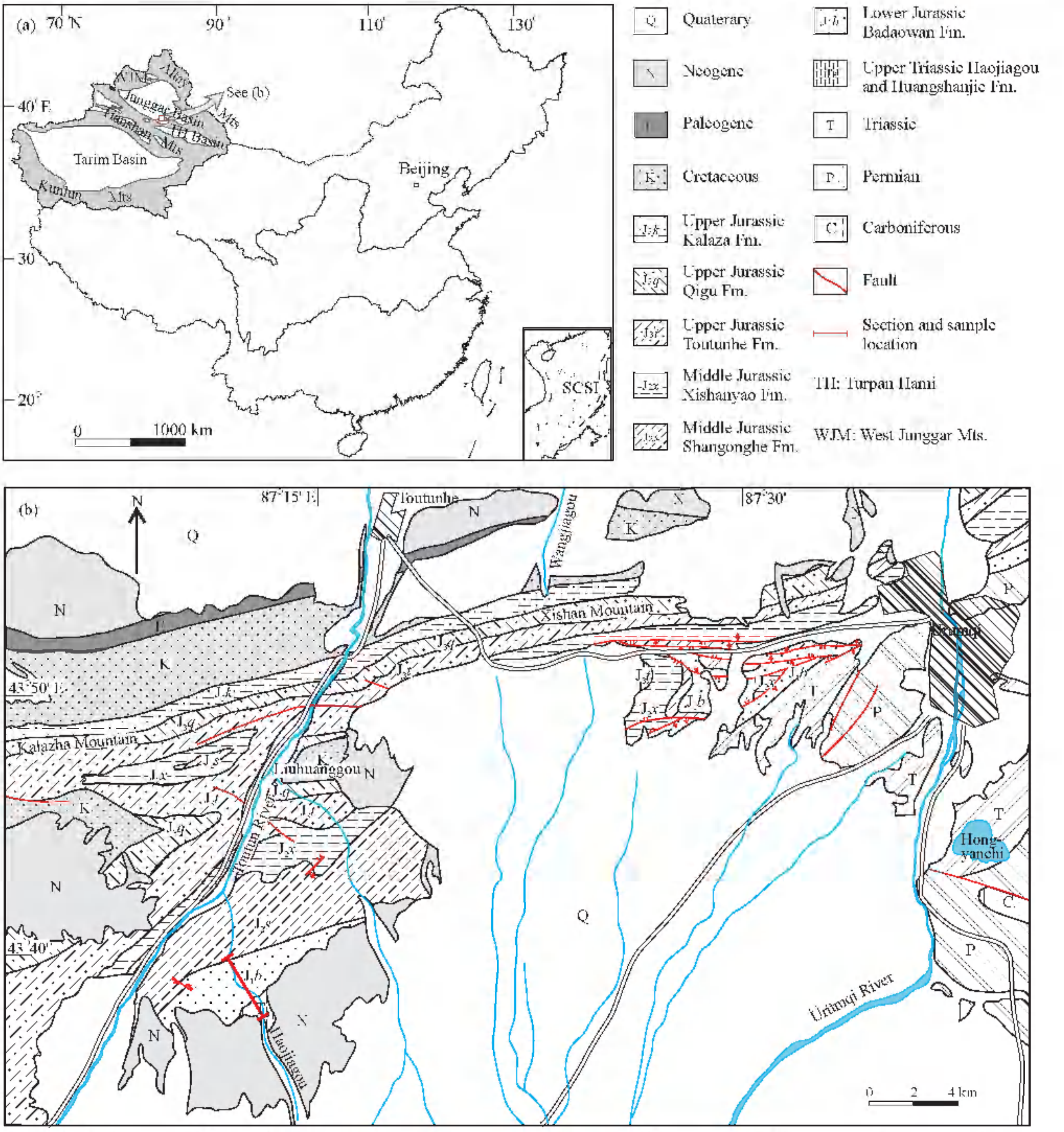

Fig. 1. Geological map of the Haojiagou area in the southern margin of Junggar Basin, northern Xinjiang Uygur Autonomous Region, northwestern China. Modified from 2nd Regional Geology Survey Team of Geology Bureau of Xinjiang Uygur Autonomous Region of the Ministry of Geology and Mineral Resources, 1965. Geology Map of Ürümqi of The People's Republic of China (K–45–IV) (1:200 000).

60% of species documented from North American sections but possibly up to 95% turnover within the plant assemblages in the North Atlantic region (Beerling and Berner, 2002).

A large number of studies have been carried out in mainly northern hemisphere Tr–J boundary sequences in Europe (e.g., Warrington and Ivimey-Cook, 1995; McRoberts et al., 1997; Marzoli et al., 1999; Wignall, 2001; Hesselbo et al., 2002, 2004, 2007; Hesselbo, 2008; Bonis et al., 2009; Larsson 2009; Ruhl et al., 2009, 2010; Vajda and Wigforss-Lange, 2009), North America (e.g., Hallam and Wignall, 2000; Ward et al., 2001; Olsen et al., 2002; Guex et al., 2003; Lucas and Tanner, 2007, 2008; Lucas et al., 2007), South America (e.g., Hillebrandt, 1994), Asia (e.g., Hallam et al., 2000; Hautmann et al., 2008; Yin and Fürsich, 2009) and Africa (Deenen et al., 2010). However, scientific results from terrestrial Tr–J boundary sequences in general (e.g., Lucas and Tanner, 2007) and from China in particular are few, thus this event still provides many unanswered questions (Vajda and Turner, 2009). Along the Haojiagou (Haojia valley) on the southern margin of the Junggar Basin of northern Xinjiang Uygur (Uighur) Autonomous Region, northwestern China (Fig. 1a), a continuous section covering the Tr–J boundary interval is completely exposed (Fig. 1b), yielding macro- and microfossils. The exact location of the Tr-J boundary has been discussed by previous authors (e.g., Hendrix et al. 1992; Sha and Jiang, 2004; Lu and Deng, 2005; Huang, 2006; Shi et al., 2006) without reaching a consensus. The aim of this paper is to make an age assessment based on palynology and to link the palynological data with the occurrence of macrofossils, mainly bivalves in order to contribute to the stratigraphic understanding of the area.

2 Geological Setting

The Junggar Basin is located in the northern part of the Xinjiang Uygur (Uighur) Autonomous Region, northwestern China. The basin, associated with several small to medium sized basins including Hefeng, Yining, Youerdusi, Chaiwobao, Tuha and Santanghu basins, is a large subtriangle-shaped continental basin (Fig. 1a). The area is bordered by three mountain ranges; the Tianshan Mountains in the southwest, the Altai Mountains in the northeast and the West Junggar Mountains in the northwest. The largest continental basin in China, the Tarim Basin, is situated to the south, separated from the Junggar Basin by the Tianshan Mountains (McKnight et al., 1990; Hendrix et al., 1992; Deng et al., 2003; Wang et al., 2005; Chen et al., 2010) (Fig. 1a). These two basins both yield major quantities of coal, oil and gas.

The geology of the Junggar Basin is composed of Paleozoic–Quaternary rocks, except for the southernmost part of the basin where the Lower Paleozoic is missing. The Lower Paleozoic comprises mainly metamorphic, volcanic and volcaniclastic rocks, and clastic deposits intercalated with carbonatite, indicating that marine volcanoes were very active during the Early Paleozoic. The Upper Paleozoic is more complex where Devonian and Carboniferous rocks are developed both as marine and non-marine deposits, in which the marine volcanic and volcaniclastic rocks are very common, but continental volcanic rocks are locally well represented. The Lower Permian is dominated by continental volcanic rocks, locally composed of alternative marine and non-marine deposits, while the Upper Permian is mainly composed of continental deposits, locally associated with terrestrial volcanic and volcaniclastic rocks. The Paleozoic fossil fauna is mainly represented by Boreal taxa and the Carboniferous–Permian macro plant fossils belong to the Angara Flora (Bureau of Geology and Mineral Resources of Xingjiang Uygur Autonomous Region, 1999).

The Mesozoic and Cenozoic successions are entirely represented by inland basin deposits. The Lower Triassic comprises red conglomerates intercalated with mudstone, but also limestones occur, but the Middle–Upper Triassic consists of gray, grayish-yellow, green and black sandstone, siltstone, mudstone intercalated with conglomerates, and thin-bedded limestone, coal streaks, siderite and cone-in-cone limestone.

The Lower and Middle Jurassic successions are dominated by sandstone, siltstone and mudstone, and characterized by extensive coal deposits. The Upper Jurassic comprises grayish-green and purplish red mudstone intercalated with sandstones.

The Mesozoic fossil biota is mainly represented by plants, sporopollen, mollusks, ostracods, conchostracans and by vertebrate remains such as *Lystrosaurus* and pterosaur (Bureau of Geology and Mineral Resources of Xingjiang Uygur Autonomous Region, 1999).

The Cenozoic rocks are dominated by red beds, but locally green mudstones occur in the southern Junggar basin (Bureau of Geology and Mineral Resources of Xingjiang Uygur Autonomous Region, 1999). The Junggar Basin was cut off from the sea during the Carboniferous–Early Permian when the Tianshan was formed, as a response to the collision of the Tarim Craton with the southern margin of central Asia, within the Hercynian orogenic event (McKnight et al., 1990; Wang et al., 2005). During the Late Permian, the southern Junggar Basin became a foreland basin, an asymmetric, flexurally subsiding trough adjacent to active fold and thrust belts in the Tianshan (Hendrix et al., 1992). Late Triassic and Jurassic rocks are well exposed in the southern margin of the Junggar Basin (Fig. 1).

In ascending order, the Upper Triassic is represented by Huangshanjie and Haojiagou formations of middle–upper Xiaoquangou Group, conformably resting on the Middle Triassic Kelamayi Formation of the lower Xiaoquangou Group. The Lower Jurassic is divided into the lower and middle Shuixigou Group, i.e., Badaowan and Sangonghe formations; Middle Jurassic comprises the Xishanyao Formation of the upper Shuixigou Group and the Toutunhe Formation of lower Aiweiergou/Shishugou Group. The Upper Jurassic is part of the middle and upper Aiweiergou/Shishugou Group divided into Qigu and Kalaza formations, unconformably underlying the Cretaceous Tugulu Group. The Xiaoquangou Group and Shuixigou Group are respectively the important oil-bearing beds in the northern Xinjiang Uygur (Uighur) Autonomous Region and the most important coal-bearing measures in Xinjiang Uygur (Uighur) Autonomous Region (cf. Bureau of Geology and

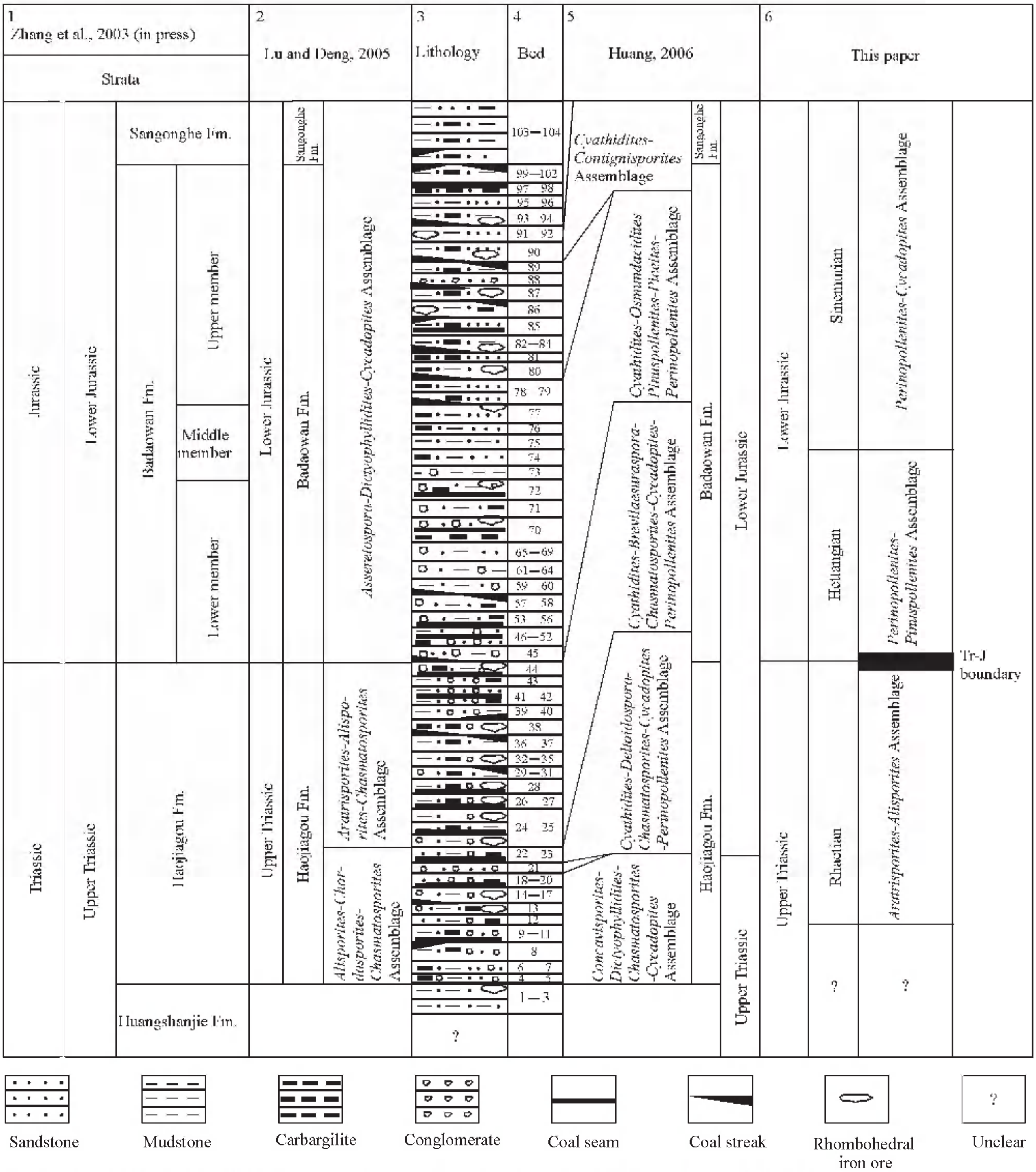

Fig. 2. Simplified stratigraphical log over the investigated section (modified from Huang (2006, fig. 2) with a summary of previously recorded palynological zonation compared with the zonation of this study.

Mineral Resources of Xingjiang Uygur Autonomous Region (ed.), 1999; Zhang et al., 2003). Except for the sediments of the uppermost Jurassic Kalza Formation, the sediments of all the formations contain various fossils, including macro- and micro plant fossils, bivalves, gastropods, ostracods, spinicaudatan clam shrimps (conchostracans), insects and vertebrates. In the Haojiagou area in the southern margin of the Junggar Basin, the Upper Triassic and Jurassic deposits are represented by continuous, fossiliferous successions that are completely exposed (Fig. 1b). Herein we focus on the sedimentary successions spanning the Tr–J boundary and thus, only the lower and upper Haojiagou Formation, the entire Badaowan Formation and the lower Sangonghe Formation are studied in detail (Figs. 2–4; Appendix 1).

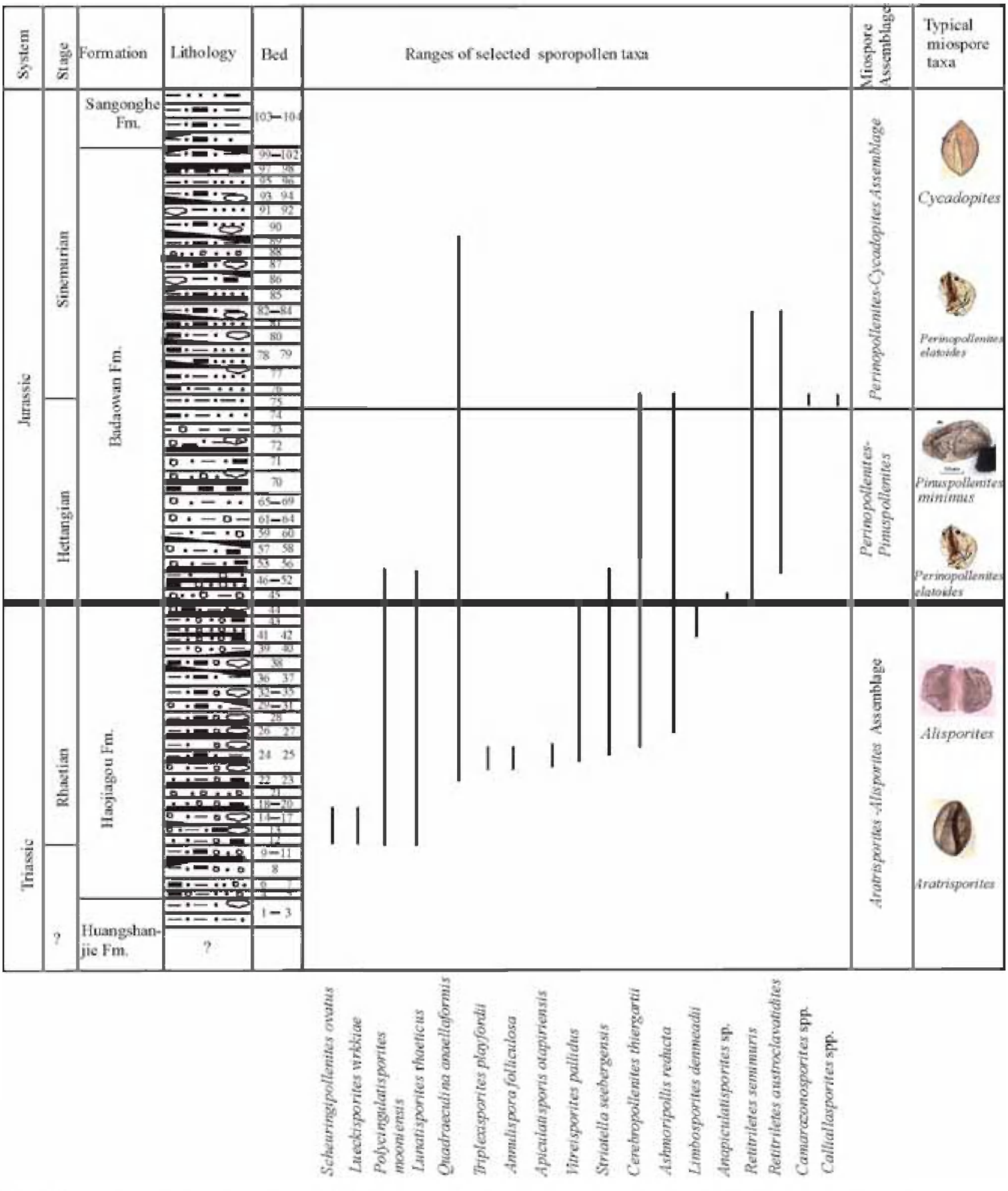

Fig. 3. Range chart of selected taxa from the Haojiangou and Badaowan formations showing the distribution of pollen and spores, and suggested palynological zonation.

3 Materials and Methods of Palynology

A sedimentary succession spanning approximately 1535 m was investigated sedimentologically and 210 samples were collected for biostratigraphical purposed encompassing beds 1–122. The sampled interval includes the Huangshanjie Formation to the base of the Sangonghe Formation (Fig. 2, col. 3). Samples from beds 12–102 were selected for palynology and spanning approximately 1113 m from the lower Haojiagou Formation to the top of Badaowan Formation (Fig. 3). Out of the 51 samples processed, 21 samples showed to be productive and were

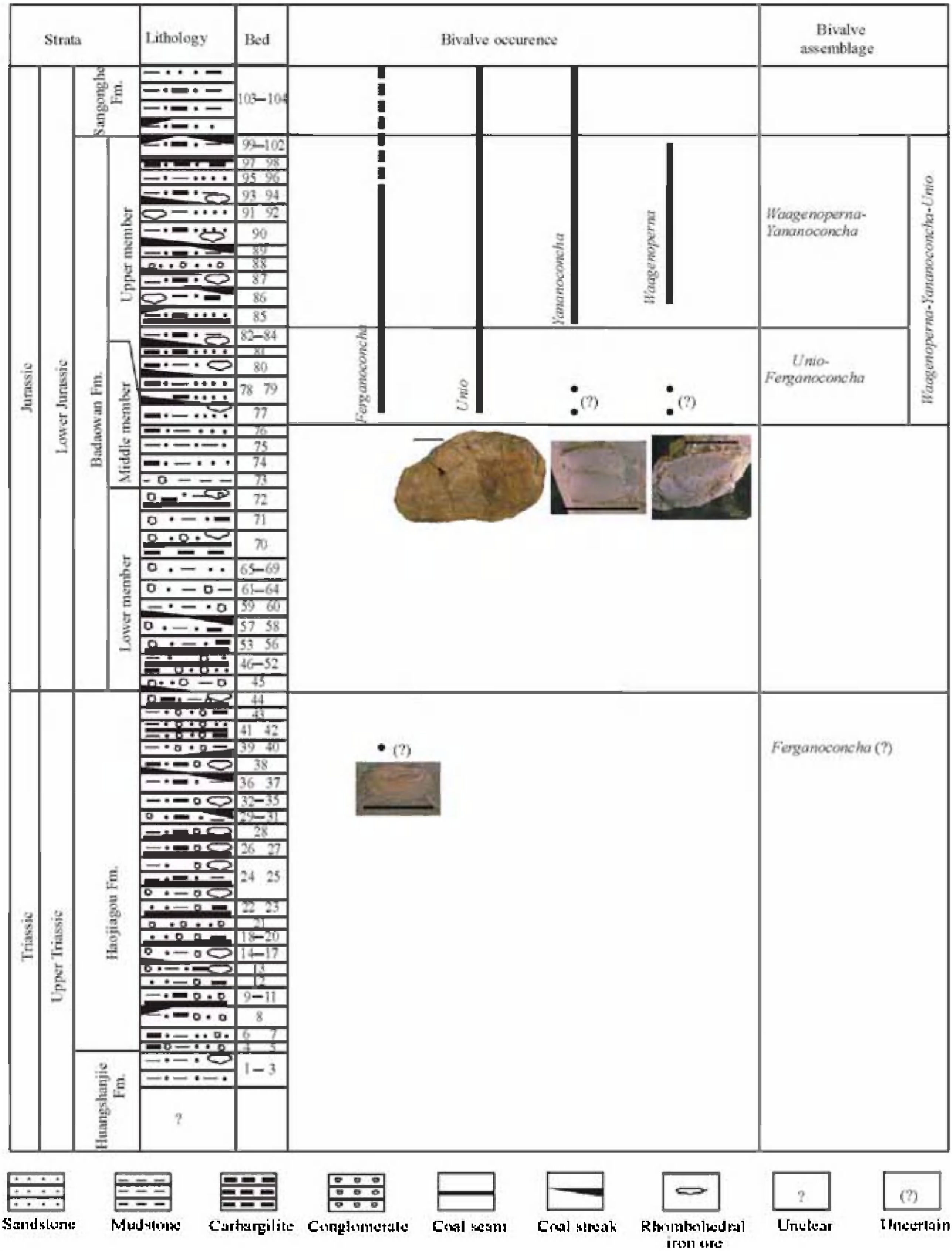

Fig. 4. Range chart of bivalve assemblage/bed of the Haojiangou and Badaowan formations. Scale bars = 5 mm.

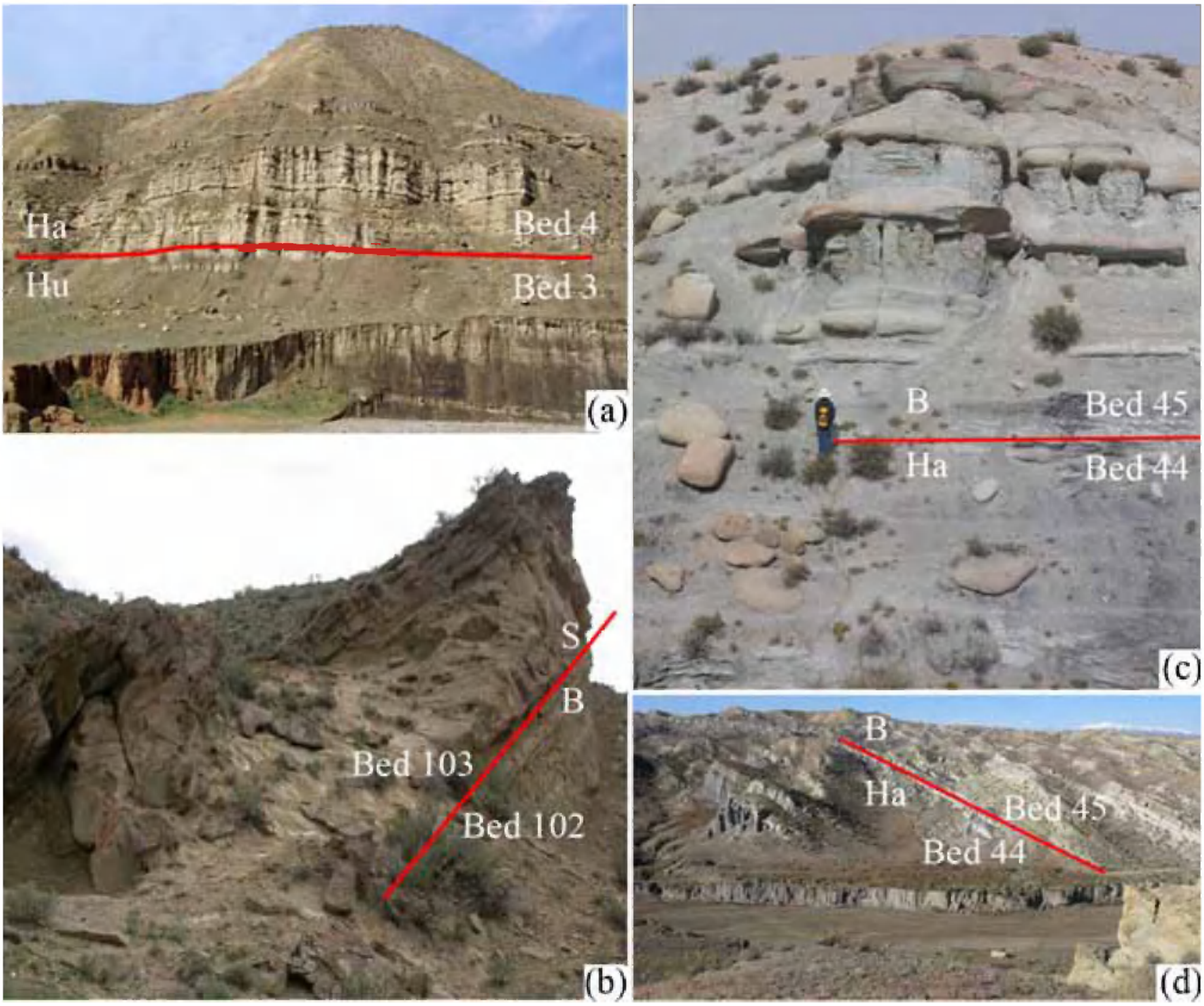

Fig. 5. Photos from the studied outcrop showing the boundaries of Huangshanjie–Haojiagou Formation (a), Haojiagou–Badaowan Formation (c, d) and Badaowan–Sangonghe Formation (b).

investigated quantitatively. Palynological processing followed standard methods: 10–20 g of each sample were treated by hydrochloric acid (HCl) to remove carbonate, hydrofluoric acid (HF) to remove siliclastic material, and finally Schulze reagent to disaggregate the organic material. The organic matter residue was sieved and retained on 12 μm screen, and finally mounted on slides in epoxy for examination under a transmitted light microscope. Percentages of spores and pollen were calculated from a total counted population of at least 300 miospores/sample. The palynological slides and residues are stored at the Department of Earth and Ecosystem Sciences, Lund University, Sweden.

4 Sedimentology and Biostratigraphy

On the basis of Zhang et al. (2003) and based on our biostratigraphic investigations of the Haojiagou section, the Tr–J boundary is placed at the boundary between the Haojiagou Formation and the Badaowan Formation, herein dated to Triassic and Jurassic, respectively (Fig. 2, col. 3). Three pollen assemblages were identified in the investigated succession spanning 1113 m.

4.1 Sedimentology

4.1.1 Haojiagou Formation

The Haojiagou Formation is approximately 527 m thick and part of the upper Xiaoquangou Group. The sediments are chiefly composed of yellowish-green, grayish-green, greenish-gray, black gray conglomerates, siltstone, sandstones, sandy mudstone and carbonaceous mudstone, forming litho-cycles in the upper part of the formation. These rocks are intercalated with thin coal streaks, coal beds and siderite. This formation is conformably resting on the Huangshanjie Formation (Fig. 5a) of which the upper part (~ 23 m) is exposed in the investigated Haojiagou section. The sediments of the Huangshanjie Formation are composed of grayish-green fine-grained sandstone to dark mudstone, intercalated with yellowish-green fine-grained sandstone–siltstone, yielding plant fossils and occasional insects.

4.1.2 Badaowan Formation

This formation, approximately 797 m in thickness, comprises three members. The Lower member (299 m thick) is composed of several lithological rhythms mainly characterized by grayish-white and grayish-green conglomerates, slightly yellow, yellowish-green and grayish-green sandstones, siltstone and dark gray carbonaceous mudstone. These sediments are intercalated with coal seams and brown thin-bedded barringerite and ferruginous sandstone.

The sediments of the middle member (~122 m thick) is composed of grayish-green, yellowish-green muddy siltstone, fine-grained sandstone, dark gray silty mudstone. The middle member is different from the other two members within this formation in that it does not contain coal seams. The succession of the upper member (~381 m thick), is again composed mainly of multicolored sandstones and mudstones intercalated with coal beds or coal steaks, and brown thin-bedded barringerite or ferruginous sandstone and clay-rich limestone.

The Badaowan Formation is conformably resting on the Haojiagou Formation (Fig. 5c, d) and underlying the Sangonghe Formation (Fig. 5b).

4.1.3 Sangonghe Formation

Sangonghe Formation consists of two members. The lower member of the Sangonghe Formation (~258 m thick) and the upper member (~225 m thick). These successions are mainly composed of yellowish-green, grayish-green, dark gray thick-bedded or massive medium-grained sandstones (sometimes calcareous) with conglomerates, silty sandstone, silty mudstone, carbonaceous mudstone, additionally it contains coal seams or coal streaks. The sediments of the Shangonghe Formation yield fossils of flora, sporopollen, non-marine bivalves, conchostracan, and occasional gastropods, insects, ostracods and fish scales.

4.2 Biostratigraphy of palynofloras and bivalves

4.2.1 Palynology

Out of the 51 samples processed for palynology, 21 yielded assemblages of fossil pollen and spores. The preservation of the palynofloras is generally excellent revealing a relatively diverse palynoflora and fifty six miospore taxa were identified representing fifty one genera. Additionally the brackish water alga *Tasmanites* sp. was identified. All identified taxa are presented in Appendix 1 while a range of selected taxa are presented in Fig. 3, and selected specimens are illustrated in Figs. 6, 7 and the presence of all taxa are shown in Appendix 1. The paleoenvironment of the investigated sediments is interpreted as mainly terrestrial, fluviatile but interval with still-standing waters, possibly lake deposits are recognized, based on the presence of fresh-water algae in the middle part of the Haojiagou Formation (beds 26 and 29). Algal assemblages are further evident in the Sinemurian interval of the Badaowan Formation (beds 75, 77 and 78) (Figs. 2, 3) and these algae may reflect brackish conditions. Three palynofloral assemblages were distinguished by their quantitative contents; the Triassic (Rhaetian) *Aratrisporites–Alisporites* Assemblage, the Early Jurassic (Hettangian) *Perinopollenites–Pinuspollenites* Assemblage, and the Sinemurian *Perinopollenites–Cycadopites* Assemblage (Fig. 2, col. 6; Fig. 3). Several key-species of stratigraphic importance were identified contributing to the following palynostratigraphical interpretation.

Beds 12 to 44 of the Haojiagou Formation is referred to as the *Aratrisporites–Alisporites* Assemblage. This part of the succession is interpreted as Triassic, Rhaetian in age based on the presence of Triassic taxa such as the bisaccate pollen *Vitreisporites pallidus*, and the common occurrence of taeniate bisaccate pollen grains such as *Lunatisporites rhaeticus* and *Distriatites insolitus*. Other Triassic characteristics are the presence of trilete spores such as *Limbosporites denmeadii, Dictyophyllidites mortonii, Polycingulatisporites mooniensis*, *Foveogleicheniidites avatus*, *Apiculatisporis otapiriensis, Annulispora folliculosa, Neoraistrickia ramosus.* and *Camarozonosporites rudis.* In addition to the key taxa, the palynological assemblages of these beds are dominated by gymnospermous taxa such as *Alisporites* spp. and *Perinopollenites elatoides,* which together make up as much as 80% of the recorded taxa. Indicative for this part of the section are high amounts of species belonging to the genus *Aratrisporites* and frequently occurring *Araucariacites australis, Podocarpidites* spp. and species belonging to the genus *Chasmatosporites.*

Beds 45–74 of the Lower and Middle members of the Badaowan Formation are referred to the *Perinopollenites–Pinuspollenites* Assemblage (Figs. 2, 3) based on the common occurrence of *Perinopollenites elatoides* and *Pinuspollenites minimus.* This part of the succession is interpreted as Early Jurassic, Hettangian in age based on the first occurrence of the typical Jurassic spore *Retitriletes semimuris* in bed 45. In addition, the assemblage is relatively abundant in other typical Jurassic elements such as the gymnosperms *Ashmoripollis reducta,*

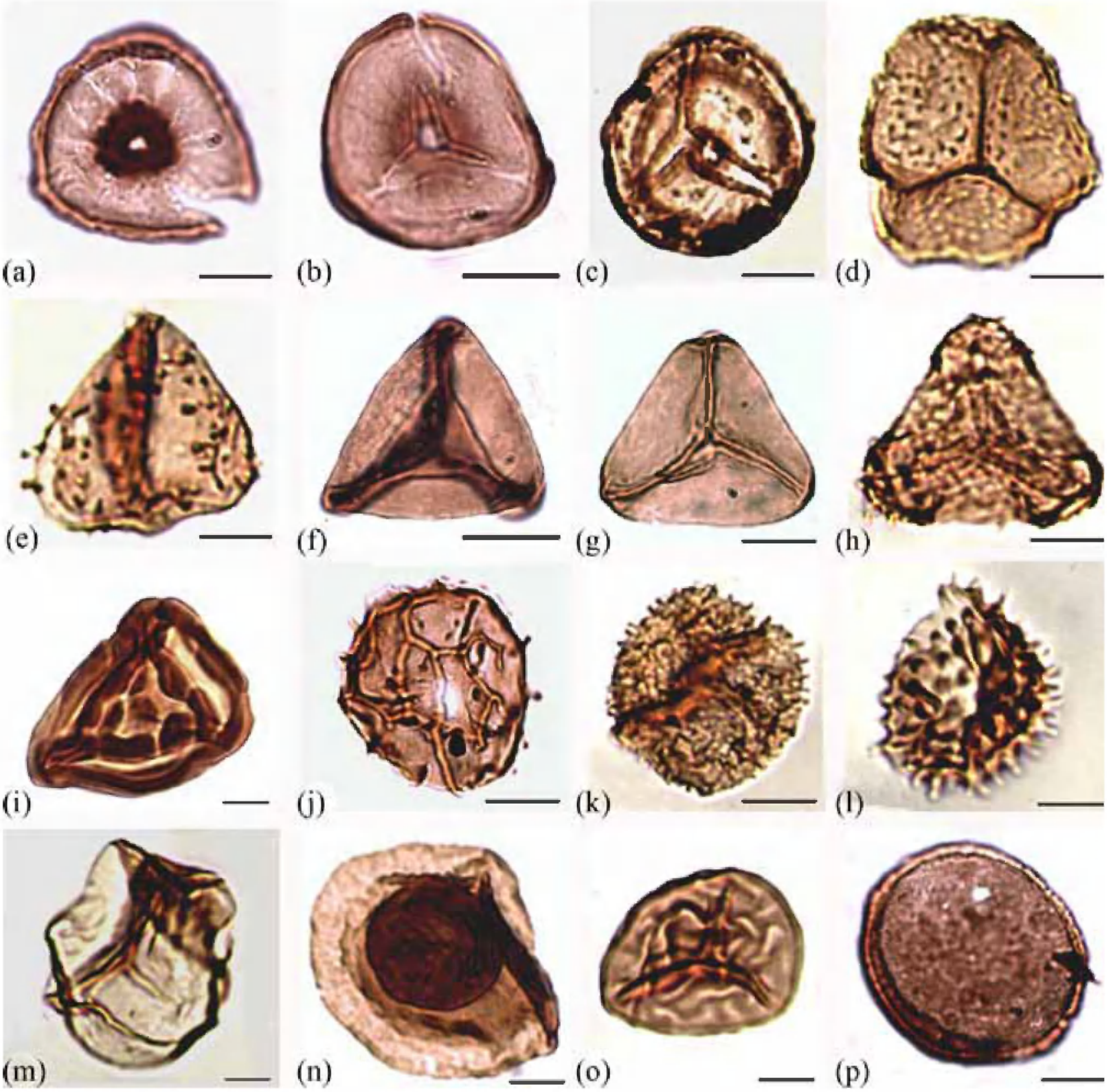

Fig. 6. Light micrographs of selected spore taxa from the studied succession. Scale bars = 10 μm.
(a), *Annulispora folliculosa*; (b), *Annulispora folliculosa*; (c), *Polycingulatisporites mooniensis*; (d), *Apiculatisporis otapiriensis*; (e), *Neoraistickia* sp.; (f), *Dictyophyllidites mortonii*; (g), *Deltoidospora toralis*; (h), *Foveogleicheniidites avatus*.; (i), *Striatella seebergensis*; (j), *Retitriletes semimuris*; (k), *Aratrisporites* sp.; (l), *Apiculatisporis otapiriensis*; (m), *Calamospora tener*; (n), *Playfordiaspora velata*; (o), *Camarozonosporites rudis*; (p), *Tasmanites* sp.

Cerebropollenites thiergartii and *Quadraeculina anellaeformis* and, the assemblage lacks typical Triassic taxa. The trilete spores, *Striatella seebergensis* and *Acanthotriletes* sp. are also recorded. Additionally, *Deltoidospora toralis, Cycadopites* sp. and *Cycadopites follicularis* are also markedly more common than in the older Triassic assemblage.

Beds 75–102 of the Badaowan Formation (upper part of Middle member and entire Upper member) are herein referred to as the *Perinopollenites–Cycadopites* Assemblage (Figs. 2, 3) and is dated to Sinemurian based on the first occurrence of the gymnosperm pollen genus *Calliallasporites* and the spore genus *Camarozonosporites* together with the high abundances of *Corollina torosa* (Fig. 3), signatures that are also seen in coeval assemblages from other parts of the world (Jansson et al., 2008a,b; Mehlqvist et al., 2009; Akikuni et al., 2010). The most common taxa in this assemblage are *Pinuspollenites minimus*, *Perinopollenites elatoides* and pollen belonging to the genus *Cycadopites*. This assemblage in this present study is named the *Perinopollenite–Cycadopites* Assemblage (Figs. 2, 3).

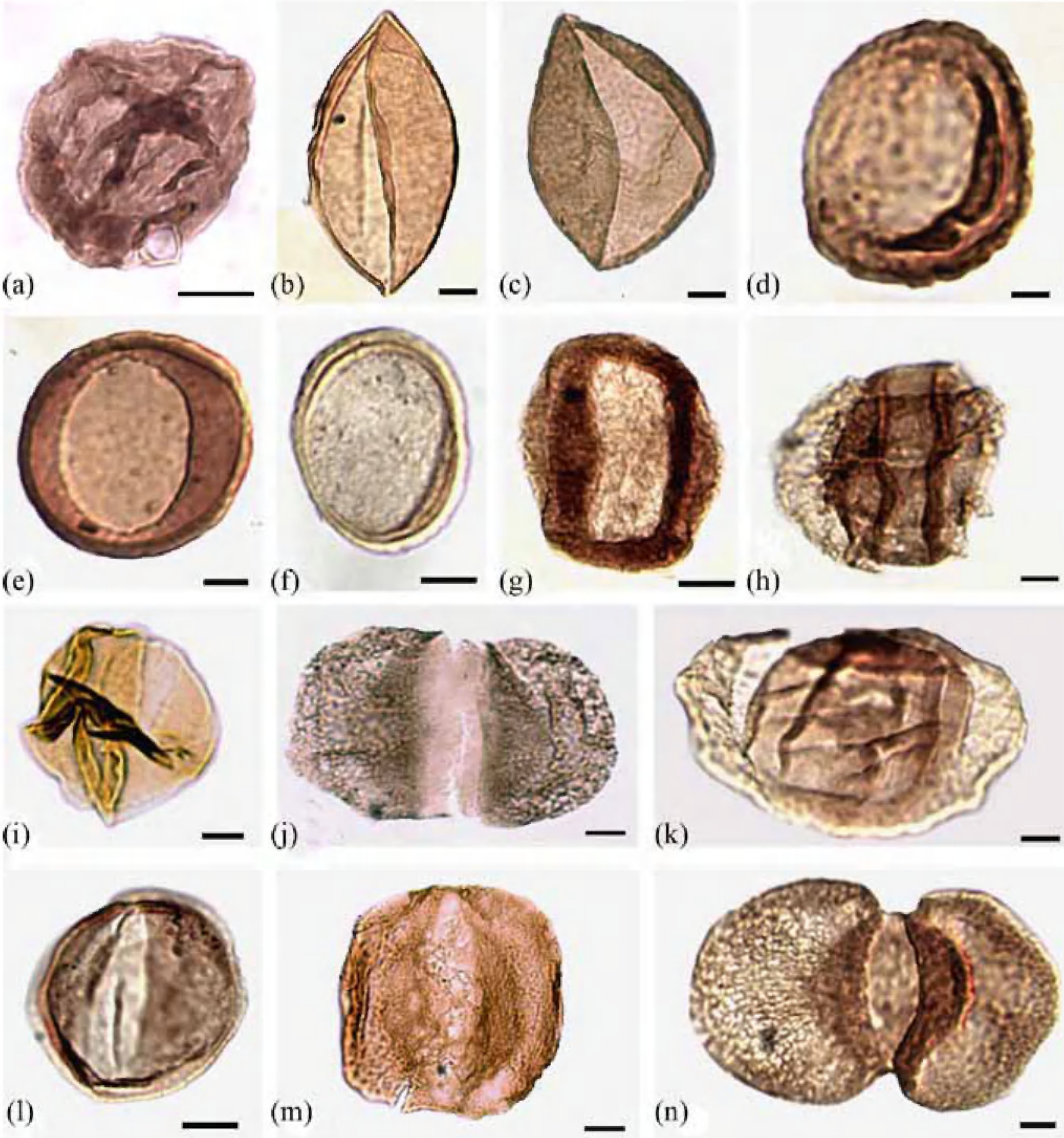

Fig. 7. Light micrographs of selected pollen taxa from the studied succession. Scale bars = 10 μm.
(a), *Araucariacites australis*; (b), *Cycadopites follicularis*; (c), *Cycadopites nitidus*; (d), *Cerebropollenites thiergartii*; (e), *Chasmatosporites apertus*; (f), *Tasmanites* sp.; (g), *Quadraeculina anellaeformis*; (h), *Lunatisporites rhaeticus*; (i), *Perinopollenites elatoides*; (j), *Alisporites robustus*; (k), *Distriatites insolitus*; (l), *Ashmoripollis reducta*; (m), *Alisporites* spp.; (n), *Podocarpidites* sp.

The Triassic *Aratrisporites–Alisporites* Assemblage (Fig. 3) agrees in composition and age assessment with a study made by Lu and Deng (2005) where the authors recognized the Tr–J boundary (Fig. 2, col. 2) in the same bed as in this present study (beds 44–45) (Fig. 2, col. 6; Fig. 3). However, in a paper by Huang (2006) on the Haojiagou section of Xinjiang the zonation and age assessment (Fig. 2, col. 5) differs from the one outlined in this present study (Fig. 2, col. 6; Fig. 3). Huang (2006) place the Tr–J boundary in bed 22 and 23. However, our interpretation differs based on the presence of important Triassic indicators in the samples below beds 44–45, such as *Distratites insolitus* (Fig. 7, K) and *Limbosporites denmeadii*. Nevertheless Huang (2006) recognized the similar quantitative changes in the palynoflora (Fig. 2, col. 5) as in this present study within beds 44–45 (Fig. 2, col. 6; Fig. 3), which we herein have interpreted as the Tr–J boundary. Huang (2006) also noted important changes between bed 79 and 80 (Fig. 2, col. 5), which is herein interpreted as the boundary between the early Hettangian and Sinemurian stages (Fig. 2, col. 6; Fig. 3).

4.2.2 Bivalves

Nearly 1000 bivalve specimens were collected during 2006–2008. They are mainly non-marine, and 12 species (see Appendix 2) belonging to eight genera of bivalves were temporarily distinguished from the formations of Huangshanjie and Haojiagou, Badaowan.

It is difficult to use the non-marine bivalve taxa of this study to exactly date the strata and/or for global biostratigraphical correlation as they are mainly endemic and have rather long ranges and thus, these are correlated to the palynostratigraphy. However, the bivalves of the Haojiagou and Badaowan formations were distinctly grouped into one bed and two assemblages (Fig. 4), on the basis of their occurrences.

Ferganoconcha (?) bed. *Ferganoconcha* occurs in Upper Haojiagou and middle and upper Badaowan formations, and extends up into the Sangonghe Formation. Below bed 45 of the Upper Triassic Haojiagou Formation (Fig. 4), such bivalve is only represented by questionable *Ferganoconcha,* which is recorded from bed 40, associated with some forms resembling *Shananxiconcha*. It is characterized by ill-preserved specimens, small-sized, thin and compressed shell, ellipse-shaped, smooth except for the feeble commarginal growth lines on the shell surface. It has a sub-straight hinge line, but almost no hinge is observed on the specimens. As the Genus *Ferganoconcha* is the only bivalve taxon recovered from the interval below bed 45, this interval is referred to as the *Ferganococha* (?) bed. *Ferganoconcha* is a non-marine Jurassic (Cox, 1969a, N410) or Late Triassic(?)–Jurassic (Gu et al., 1976, p. 292) bivalve genus, and *Shananxiconcha* has been recorded from the Triassic and is particularly common in Late Triassic Yanchang Formation (e.g., Institute of Geology, Chinese Academy of Geological Sciences, 1980, pp. 6-21). Therefore the concurrent-range-zone of the two genera is Late Triassic. Furthermore, considering the Hettagian palynofloral *Aratrisporites–Alisporites* assemblage spanning beds 12–44, the *Ferganoconcha* (?) bed (bed 40) was dated as Late Triassic. The following interval from bed 41 of Haojiangou Formation to bed 76 of middle Badaowan Formation are devoid of bivalves (Fig. 4).

Unio–Ferganoconcha Assemblage. Beds 77–80 spanning the upper middle member and basal upper member of the Badaowan Formation are herein referred to as the *Unio–Feraganoconcha* Assemblage (Fig. 4). This interval contains abundant *Unio* fossils, including *Unio lucaogouensis*, and *Ferganoconcha*, including *Ferganoconcha subcentralis*, associated rare and poor-preserved specimens resembling *Yananoconcha* and probably *Waagenoperna* in beds 77 (Zhang et al., 2003) and 78.

This interval is further characterized by the first occurrence of the genus *Unio*. *Unio* is a medium to large, ellipse-shaped bivalve. The shell is smooth except for the feeble commarginal growth lines on the shell surface, sub-straight hinge line, and having distinct anterior and posterior lamellar teeth and anterior adductor scars.

In this assemblage, all of the forms of *Unio* such as *Unio miquanensis* (= *Unio manasensis*) and *Unio lucaogouensis*, are endemic taxa for the Junggar Basin. *Ferganoconcha subcentralis* is a Jurassic taxon and is widely distributed in northern, China (e.g., Tianjing Institute of Geology and Mineral Resources, 1984, p. 34; Shengyang Institute of Geology and Mineral Resources, 1980, p. 13; Geological Examination Department of Petroleum Administration Bureau and Regional Survey Party of Geological Bureau of Xingjiang Uygur Autonomous Region, 1984, p. 4; Compiling Group of Fossil Lamellibrachiata of China, 1976, p. 239), Transbaikalia and Far East frontiers (Chernyshev, 1939), all indicating a Jurassic age of the assemblage spanning beds 77–80 (Fig. 4).

Waagenoperna–Yananoconcha Assemblage. This assemblage ranges from bed 85 to bed 100 in the upper Badaowan Formation. This assemblage is characterized by the first occurrence of the first two confirmable index genera (both are fairly abundant), and the disappearance of the first index genus *Waagenoperna* after bed 100 and the corresponding bed in the southern margin of the Junggar Basin.

This assemblage is composed of different species belonging to the genus *Waagenoperna*, including the *Waagenoperna lilingensis* group composed of *Waagenoperna lilingensis*, *Waagenoperna mytiloides* and *Waagenoperna pernoformis*. It further includes species belonging to the genus *Yananoconcha*, including *Yananoconcha henshanensis*, *Ferganoconcha* including *Ferganoconcha subcentralis*, associated with many *Unio*, including *Unio lucaogouensis*, some *Margaritifera isfarensis* (= *Margaritifera delunshanensis*), and probably *Sibericoncha* and *Pseudocardinia*.

Waagenoperna is a marine to littoral facies ptero-like bivalve with resilifers along interior dorsal hinge plates and commarginal growth lines on the shell surface. It has previously been considered to indicate a Late Permian–Late Triassic age (e.g., Cox, 1969b, N326; Gu et al., 1976; Gu et al., 1980; Chen and Zhang, 2000; Deng et al., 2003).

Apart from the Junggar Basin, this genus has a wide distribution in China, e.g., the Anyuan Formation, Paijiachong Member of the Guanyintan Formation and Tabakou Member of the Fengjiachong Formation of the Hunan Province, "Middle Coal Formation" of the Xiangxi Group of Hubei Province, central-south China; the Xiaoping Formation of Guandong Province, southern China (Hubei Institute of Geology et al., 1977, pp. 48–49; Gu et al., 1980), the Anyuan Formation and Zaoshan Member of the Menkoushan Formation of Jiangxi Province, and probably the Fanjiatang Formation of Jiangsu Province, eastern China (Gu et al., 1980; Nanjing Institute of Geology and Mineral Resources, 1982, pp. 33–34). The *Waagenoperna lilingensis* group including *Waagenoperna mytiloides* and *Waagenoperna pernoformis* also occurs in the Xujiahe Formation of Sichuan, southwestern China, but they were described under different specific names such as *Waagenoperna? sichuanensis*, *Waagenoperna sichuanensis producta* and *Waagenoperna aurita* (Compiling Group of continental Mesozoic stratigraphy and paleontology in Sichuan Basin of China 1984, pp. 522–526). All of the formations yielding *Waagenoperna* above have been interpreted as Late Triassic by the previous authors except Deng et al. (2003, P. 71) who interpreted the presence of the *Waagenoperna lilingensis* group including *Waagenoperna mytiloides* and *Waagenoperna pernoformis* to indicate an Early Jurassic Sinemurian age. The similar forms of the group, such as *Naiadites mentougouensis* and probably some *Naiadites* cf. *krasnojarkiensis* are also recorded from the Middle Jurassic Xiayaopo Member of the Mentougou Formation of Beijing, northern China (Tianjing Institute of Geology and Mineral Resources, 1984, pp. 64–65).

Yananoconcha is a non-marine bivalve, which is elliptical, rounded quadrate to oval in outline and smooth except the commarginal growth lines and rugae on the shell surface, and has smooth lamellar teeth (two in both anterior and posterior of the right valve, but two in anterior and one in the posterior of the left valve) in hinge plates subparallel to the dorsal line.

Ma (1989) and Jiang et al. (2005) merged *Yananoconcha* (Yu and Zhang) into the genus *Kija* (Lebedev) due to the similarity in hinges, but the genus name *Yananoconcha* is herein temporarily kept as the authors have not studied the holotype of the type species of *Kija* from Central Asia in detail.

Outside the Junggar Basin, *Yananoconcha* has been recorded from the Lower–lower Middle Jurassic in northern, northwestern and northeastern China, such as the Middle Jurassic Heifeng Formation of the Shanxi Province, northern China (Tianjing Institute of Geology and Mineral Resources, 1984, pp. 53–55), the Lower (?)–Middle Jurassic Yanan Formation of the Shanxi-Gansu-Ningxia basin of northwestern China (Institute of Geology, Chinese Academy of Geological Sciences, 1980, pp. 39–42; Xi'an Institute of Geology and Mineral Resources, 1982, pp. 20–21), the Lower Jurassic Wafangdian Formation of Liaoning Province, northeastern China (Shengyang Institute of Geology and Mineral Resources, 1980, pp. 16–17), the Middle Jurassic Kapushaliang and Kezilenuer formations of Kuche Depression of Xinjiang Uygur (Uighur) Autonomous Region, northwestern China (Jiang et al., 2005).

Consequently, the *Waagenoperna–Yananoconcha* Assemblage spanning beds 85–100 (Fig. 4) is probably Early Jurassic in age. The base of the Sangonghe Formation is characterized by the presence of *Unio* and *Yananoconcha,* whereas the genus *Waagenopern* is totally absent.

Bivalve assemblages of *Unio–Ferganoconcha* and *Waagenoperna–Yananoconcha* probably should be merged into one assemblage, the *Waagenoperna–Yananoconcha–Unio* Assemblage, because the index species of the 2nd assemblage also rarely extend lower into *Unio–Ferganoconcha* Assemblage, and *Unio* and *Ferganoconcha* are common in *Waagenoperna–Yananoconcha* Assemblage (Fig. 4).

It is Early Jurassic and most probably Sinemurian in age, as the palynoflora of the *Perinopollenites–Cycadopites* assemblage spanning beds 75–102 indicated.

5 Conclusion

The Triassic to Jurassic palynomorph assemblages in the present investigation varies from taxonomically restricted to extremely diverse, and contain a limited number of taxa of biostratigraphical value. Nevertheless, some palynomorphs with long stratigraphical ranges show interesting quantitative variations over time, which is the effect of several elements, such as climatic conditions including depositional environment, but also the sedimentology. When we combine these variations with the appearances and disappearances of certain key taxa, three palynofloral assemblages, defining two potential biostratigraphical boundaries, i.e., Tr–J (Rhaetian–Hettangian) and Hettangian–Sinemurian boundaries, were recognized from the Haojiagou section of the southern margin of the Junggar Basin, which has made it possible to date and correlate our results with other investigations in the area.

Based on palynological analyses, the Tr–J boundary of the Haojiagou section of the southern margin of the Junggar Basin has been bracketed within a 10 m interval of mainly silty sandstones of terrestrial origin. The Tr–J (Rhaetian–Hettangian) boundary is located between the *Aratrisporites–Alisporites* Assemblage and *Perinopollenites–Pinuspollenites* Assemblage, and the Hettangian–Sinemurian boundary is located between the *Perinopollenites–Pinuspollenites* Assemblage and *Perinopollenites–Cycadopites* Assemblage (Figs. 2, 3). Although the bivalves, particularly the non-marine forms are generally long ranging, they basically support the boundary based on the palynofloral assemblages.

The bivalves in the Haojiagou section are assigned to three assemblages. One from bed 40 of the Haojiagou Formation (Fig. 4) is tentatively attributed to *Ferganoconcha* but it is long ranging so the Late Triassic age attributed to the bed is based on the palynostratigraphy outlined above. The *Unio–Ferganoconcha* and *Waagenoperna–Yananoconcha* assemblages (Fig. 4) are consistent with an Early Jurassic (Sinemurian) age as outlined in the palynostratigraphy. Many names have been used for non-marine Mesozoic bivalves of the Junggar Basin, but a comprehensive taxonomic revision is required in order to resolve the species relationships and distribution.

The composition of the fossil palynofloras together with the bivalve assemblages identified in this over 1000 m thick section have furthermore contributed to the paleoenvironmental interpretations. The flora identified mainly represents seed-ferns such as Corystosperms (represented by the pollen genus *Alisporites*) mainly in the Late Triassic part of the succession. According to a study by Zan et al. (2008) corystospermales were present in China (Laurasia) as early as the Late Triassic further supporting the interpretations. Other elements in the palynoflora includes Cycadophytes/ginkgos and a broad range of pteridophytes (including marattia species) as previously outlined also by the macroflora in coeval strata all over China (Wang, 1999).

In general, the occurrence of bivalves coincides with intervals representing fresh water lake deposits, and the Sinemurian part of the studied succession generally represents wetter conditions. Interestingly, the presence of brackish water algae such as *Tasmanites* (Figs. 6p; 7f) and the marine–littoral facies bivalve *Waagenoperna* within the same interval indicate brackish water conditions which may signify a Sinemurian sea-level rise, causing transgressions from northern Tethys, which influenced the Junggar Basin (Chen and Zhang, 2000; Deng et al., 2003). Further studies are required to elucidate the causes and magnitude of this event.

Acknowledgements

This work is supported by Special Basic Research Program of Ministry of Science and Technology of China (Grant No. 2006FY120300) and National Committee of Stratigraphy of China. V. Vajda acknowledges the financial support provided by Swedish Research Council (VR, Grant No. 2007–4509). V. Vajda is a Swedish Royal Academy of Sciences Research Fellow founded through the Knut and Alice Wallenbergs Foundation. It is also a contribution to UNESCO–IUGS IGCP Project 506.

Manuscript received May 4, 2010
accepted Sept. 15, 2010
edited by Jiang Shaoqing

References

2nd Regional Geology Survey Team of Geology Bureau of Xinjiang Uygur Autonomous Region of the Ministry of Geology and Mineral Resouces, 1965. *Geology Map of Urumqi of The People's Republic of China (K–45–IV) (1:200000), with explanation text*. State-operated 543 Printing House (Press) (in Chinese).

Akikuni, K., Hori, R., Vajda, V., Grant-Mackie, J., and Ikehara, M., 2010. Stratigraphy of Triassic-Jurassic boundary sequences from the Kawhia coast and Awakino gorge, Murihiku Terrane, New Zealand. *Stratigraphy*, 7: 7–24.

Beerling, D.J., and Berner, R.A., 2002. Biogeochemical constraints on the Triassic-Jurassic boundary carbon cycle event. *Global Biogeochemical Cycles*, 16(3): 1–13.

Bonis, N.B., Kurschner, W.M., and Krystyn, L., 2009. A detailed palynological study of the Triassic–Jurassic transition in key sections of Eiberg Basin (Northern Calcareous Alps, Austria. *Review of Palaeobotany and Palynology*, 136(3–4): 376–400.

Bureau of Geology and Mineral Resources of Xingjiang Uygur Autonomous Region (ed.), 1999. *Multiple classification and correlation of the stratigraphy of China. Stratigraphy (lithostratigraphic) of Xingjiang Uygur Autonomous Region.* Beijing: China Geology University Press, 430 (in Chinese).

Burgoyne, P.M., van Wyk, A.E., Anderson J.M., and Schrire, B. D., 2005. Phanerozoic evolution of plants on the African plate. *Journal of African Earth Sciences*, 43: 13–52.

Chen Dongxia, Pang Xiongqi, Kuang Jun, Kang Dejiang, Lei Lei and Deng Yougen, 2010. Control of Facies and Potential on Jurassic Hydrocarbon Accumulation and Prediction of Favorable Targets in the Hinterland Region of the Junggar Basin. *Acta Geologica Sinica* (English edition), 84 (5): 1256–1272.

Chen Jinhua and Zhang Yijie, 2000. Marine bivalve found in Lower Jurassic of continental Junggar Basin of west China. *Xinjiang Geology*, 18(1): 28–31 (in Chinese with English abstract).

Chenyshev, B.I., 1939. On some pelecypods from Transbaikalia and Far East frontiers. *Trudy All-Union Inst. of Min. Res.* 143: 61–68 (in Russian with English abstract).

Compiling Group of continental Mesozoic stratigraphy and palaeontology in Sichuan Basin of China 1984. *Some brackish-water Lamellibrachea from Xujiahe Formation of Upper Triassic in Hulukou of Weiyuan, Sichuan. Part II. Palaeontological professional papers*. Chengdu: People's Publishing House of Sichuan, 622 (in Chinese).

Compiling Group of Fossil Lamellibrachiata of China, 1976.

Fossil Lamellibranchiata of China. Beijing: Science Press, 522 (in Chinese).

Cox, L.R., 1969a. Ferganoconchidae. In: Moore, R.C. (ed.), *Treatise on Invertebrate Paleontology, Pt. N, Mollusca, 6, Bivalvia 1, Systematic Description*. Bo, Co. and Lawrence, Ka.: The Geological Society of America and the University of Kansas Press, N410.

Cox, L.R., 1969b. Isognomonidae. In: Moore, R.C. (ed.), *Treatise on Invertebrate Paleontology, Pt. N, Mollusca, 6, Bivalvia 1, Systematic Description*. Bo, Co. and Lawrence, Ka: The Geological Society of America and the University of Kansas Press, N321–326.

Deenen, M.H.L., Ruhl, M., Bonis, N.R., Krijgsman, W., Kuerschner, W.M., Reitsma, M., and Van Bergen, M.J., 2010. A new chronology for the end-Triassic mass extinction. *Earth and Planetary Science Letters*, 291: 113–125.

Deng Shenghui, Yao Yimin, Ye Dequan, Chen Piji, Jin Fan, Zhang Yijie, Xü Kun, Zhao Yingcheng, Yuan Xiaoqi, Zhang Shiben et al., 2003. *Jurassic System in the north of China. Vol. I. Stratum Introduction*. Beijing: Petroleum Industry Press, 399 (in Chinese with English abstract).

Geological Examination Department of Petroleum Administration Bureau and Regional Survey Party of Geology Bureau of Xingjiang Uygur Autonomous Region (ed.), 1984. *Palaeontological atlas of northwest China. Xingjiang Uygur Autonomous Region Fascicle. III. Mesozoic and Cenozoic Part*. Beijing: Geological Publishing House, 211 (in Chinese).

Gu Zhiwei, Chen Chuzhen, Li Jinhua, Ding Baoliang and Cheng Zhengxiu, 1980. *Waagenoperna* (*Wagenoperna*) and its Distribution in the "Lower Jurassic" of south China. *Acta Palaeontologica Sinica*, 19(6): 445–459 (in Chinese with English abstract).

Gu Zhiwei, Huang Baoyu, Chen Chuzhen, Wen Shixuan, Ma Qihong, Lan Xiu, Xu Juntao, Liu Lu, Wang Deyou, Qiu Ranzhong, Huang Zhaoqi, Zhang Zuoming, Chen Jinhua and Wu Peili, 1976. Fossil Lamellibranchiata of China, Beijing: Science Press, 522 (in Chinese).

Guex, J., Bartolini, A., Atudorei, V., and Taylor, D., 2003. Two negative $\delta^{13}C_{org}$ excursions near the Triassic–Jurassic boundary in the New York Canyon area (Gabbs Valley Range, Neveda. *Bulletin de Géology, Lausanne*, 360 (Special Issue): 1–4.

Hallam, A., and Wignall, P.B., 2000. Facies changes across the Triassic–Jurassic boundary in Nevada, USA. *Journal of the Geological Society, London*, 157: 49–54.

Hallam, A., Wignall, P.B., Yin Jiarun and Riding, J.B., 2000. An investigation into possible changes across the Triassic–Jurassic boundary in southern Tibet. *Sedimentary Geology*, 137: 101–106.

Hautmann, M., Stiller, F., Cai Huawei and Sha Jingeng, 2008. Extinction-recovery pattern of level-bottom faunas across the Triassic–Jurassic boundary in Tibet: Implications for potential killing mechanisms. *Palaios*, 23: 711–718.

Hendrix, M.S., Graham, S.A., Sobel, E.R., McKnight, C.L., and Wang Zuoxun, 1992. Sedimentary record and climatic implications of recurrent deformation in the Tian Shan: Evidence from Mesozoic strata of the north Tarim, south Junggar, and Turpan basins. *Geological Society of American Bulletin*, 104: 53–79.

Hesselbo, S.P., 2008. Sequence stratigraphy and inferred relative sea-level change from the onshore British Jurassic. *Proceedings of the Geologists' Association*, 119: 19–34.

Hesselbo, S.P., Robinson, S. A., Surlyk, F., and Piasecki, S., 2002. Terrestrial and marine extinction at the Triassic–Jurassic boundary synchronized with major carbon-cycle perturbation: A link to initiation of massive volcanism? *Geology*, 30(3): 251–254.

Hesselbo, S.P., Robinson, S.A., Surlyk, F., and Piasecki, S., 2004. Sea-level change and facies development across potential Triassic–Jurassic boundary horizons, SW Britain. *Journal of the Geological Society, London*, 161: 365–379.

Hesselbo, S.P., McRoberts, C.A., and Palfy, J., 2007. Triassic–Jurassic boundary events: Problems, progress, possibilities. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 244: 1–10.

Hillebrandt, A.V., 1994. The Triassic/Jurassic boundary and Hettangian biostratigraphy in the area of the Utcubamba Valley (northern Peru). *Geobios*, 17: 297–307.

Huang Pin, 2006. Sporopollen assemblages from the Haojiangou and Badaowan formations at the Haojiagou section of Urümqi, Xinjiang and their stratigraphical significance. *Acta Micropalaeontologica Sinica*, 23(3): 235–275 (in Chinese with English abstract).

Hubei Institute of Geology, Bureau of Geology of Hubei Province, Bureau of Geology of Guangdong Province, Bureau of Geology of Henan Province, Bureau of Geology of Hunan Province and Guangxi Zhuang (Chuang) Autonomous (eds.), 1977. *Palaeontological atlas of central-south China. III. Mesozoic and Cenozoic Part*. Beijing: Geological Publishing House, 332 (in Chinese).

Institute of Geology, Chinese Academy of Geological Sciences (ed.), 1980. *Mesozoic stratigraphy and palaeontology of Shanxi-Gansu-Ningxia basin*. Beijing: Geological Publishing House, 188 (in Chinese).

Jansson, I-M., McLoughlin, S., and Vajda, V., 2008a. Early Jurassic annelid cocoons from eastern Australia. *Alcheringa*, 32: 285–296.

Jansson, I-M., McLoughlin, S., Vajda, V., and Pole, M., 2008b. An Early Jurassic flora from the Clarence-Moreton Basin, Australia. *Review of Palaeobotany and Palynolog*, 150: 5–21.

Jiang Baoyu, Cai Huawei and Chen Siwei, 2005. Some Middle Jurassic Bivalves from the Kuche Depression of the Tarim Basin, northwestern China. *Acta Palaeontologica Sinica*, 44 (2): 296–305 (in Chinese with English abstract).

Larsson, L.M., 2009. Palynostratigraphy of the Triassic–Jurassic transition in southern Sweden. *GFF*, 131: 147–161.

Lucas, S.G., and Tanner, L.H., 2007. The non-marine Triassic–Jurassic boundary in the Newark Supergroup of eastern North America. *Earth-Science Reviews*, 84: 1–20.

Lucas, S.G., and Tanner, L.H., 2008. Reexamination of the end-Triassic mass extinction. In: *Mass extinction* (*Elewa, A. M., ed.*). Berlin: Springer Verlag, 66–103.

Lucas, S.G., Taylor, D., Guex, J., Tanner, L.H., and Krainer, K., 2007. The proposed global stratotype section and point for the base of the Jurassic system in the New York Canyon area, Nevada, USA. In: *Triassic of the American West*. (*Lucas, S.G. and Spielmann, J.A., eds.*). *New Mexico Museum of Natural History and Science Bulletin*, 40: 139–167.

Lu Yuanzheng and Deng Shenghui, 2005. Triassic–Jurassic sporopollen assemblages on the southern margin of the Junggar Basin, Xinjiang and the T–J boundary. *Acta Geologica Sinica*, 79(1): 15–27 (in Chinese with English abstract).

Ma Qihong, 1989. A new recognition of (Pseudocardiniidae" (Lamellibranchia). *Acta Palaeontologica Sinica*, 28(5): 604—616 (in Chinese with English abstract).

Marzoli, A., Renne, P.R., Piccirillo, E.M., Ernesto, M., Bellieni, G., and De Min, A., 1999. Extesive 200-million-year-old continental flood basalts of the Central Atlantic magmatic province. *Science*, 284: 616–618.

McKnight, C.L., Graham, S.A., Carroll, A.R., Gan, Q., Dilcher, D.L., Zhao Min and Liang Yunhai, 1990. Fluvial sedimentology of an Upper Jurassic petrified forest assemblage, Shishu Formation, Junggar Basin, Xinjiang, China. *Palaeogeography, Palaeoclimatology, Palaeoecolgy*, 79: 1–9.

McRoberts, C.A., Furrer, H., and Jones, D.S., 1997. Interpretation of a Triassic–Jurassic boundary section from western Austria based on palaeoecology and geochemistry. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 136 (1–4): 79–95.

Mehlqvist, K., Vajda, V., and Larsson, L., 2009. An assemblage of a Middle Jurassic flora from Bornholm, Denmark – a study of a historic collection at Lund University, Sweden. *GFF*, 131: 137–146.

Nanjing Institute of Geology and Mineral Resources, 1982. *Palaeontological atlas of eastern China*. Beijing: Geological Publishing House, 405 (in Chinese).

Olsen, P.E., Koeberl, C., Huber, H., Montanari, A., Fower, S.J., Et-Touhami, M., and Kent, D.V., 2002. The continental Triassic–Jurassic boundary in Central Pangea: Recent progress and preliminary report of an Ir anomaly. *Special Paper–Geological Society of America*, 356: 505–522.

Ruhl, M., Kürschner, W.M., and Krystyn, L., 2009. Triassic-Jurassic organic carbon isotope stratigraphy of key sections in the western Tethys realm (Austria). *Earth and Planetary Science Letters*, 281: 169–187.

Ruhl, M., Veld, H., and Kürschner, W.M., 2010 Sedimentary organic matter characterization of the Triassic–Jurassic boundary GSSP at Kuhjoch (Austria). *Earth and Planetary Science Letters* 292: 17–26.

Raup, D.M., and Sepkoski, J.J., 1982. Mass extinctions in the marine fossil record: testing for periodicity of extinction. *Science*, 215: 1501–1503.

Sha Jingeng and Jiang Baoyu, 2004. Characteristics of the Lower and Middle Jurassic stages in Zhungeer basin, northwestern China. *Journal of Heilongjiang Institute of Science* and *Technology*, 14(3): 137–139, 144 (in Chinese with English abstract).

Shengyang Institute of Geology and Mineral Resources, 1980. *Paleontological atlas of northeast China. II. Mesozoic and Cenozoic Volume*. Beijing: China Geology University Press, 403 (in Chinese).

Shi Xiaoyin, Sha Jingeng and Deng Shenhui, 2006. The Jurassic system of China–Main characteristics and recent advances in research. *Progress in Natural Science*, 16 (Special Issue): 90–107.

Tianjing Institute of Geology and Mineral Resources, 1984. *Palaeontological atlas of north China. II. Mesozoic Fascicle*. Beijing: Geological Publishing House, 384 (in Chinese with English abstract).

Vajda, V., and Turner, S., 2009. The Jurassic: In the forefront of science outreach. *GFF*, 131: 1–3.

Vajda, V., and Wigforss-Lange, J., 2009. Onshore Jurassic Scandinavia and related areas. *GFF*, 131(1–2): 5–24.

Wang, H., Zhang, S., and He, G., 2005. China and Mongolia. In: *Encycropedia of geology* (*Richard C. Selley, L. Robin M. C. Cocks and Ian R. Plimer, eds*). Oxford: Elsevier, Vol. 1: 345–348.

Wang, Y., 1999. Fertile organs and *in situ* spores of *Marattia asiatica* (Kawasaki) Harris (Marattiales) from the Lower Jurassic Hsiangchi Formation in Hubei, China. *Review of Palaeobotany and Palynology*, 107: 125–144.

Ward, P.D., Haggart, J.W., Carter, E.S., Wilbur, D., Tipper, H.W., and Evans, T., 2001. Sudden productivity collapse associated with the Triassic–Jurassic boundary mass extinction. *Science*, 292: 1148–1151.

Warrington, G., and Ivimey-Cook, H.C., 1995. The Late Triassic and Early Jurassic of coastal sections in west Somerset and South and Mid-Glamorgan. In: *Field Geology of the British Jurassic* (*Taylor, P. D., ed.*). *Geological Society, London*, 9–30.

Wignall, P.B., 2001. Sedimentology of the Triassic–Jurassic boundary beds in Pinhay Bay (Devon, SW England). *Proceedings of the Geologists' Association*, 112: 349–360.

Xi'an Institute of Geology and Mineral Resouces (ed.), 1982, *Palaeontological atlas of northwest China. Shanxi, Gansu and Ningxia Volume. Part III. Mesozoic and Cenozoic*. Beijing: China Geology University Press, 181 (in Chinese).

Yin Jiarun and Fürsich, F.T., 2009. Dispersal events of Triassic–Jurassic boundary faunas, and paleoenvironment of Tibetan Himalayas. *Science in China* (*Series D*), 52(12): 1993–2000.

Zan, S., Axsmith B.J., Fraser, N.C., Liu Fengxiang and Xing Dehe, 2008. New evidence for laurasian corystosperms: Umkomasia from the Upper Triassic of Northern China. *Review of Palaeobotany and Palynology*, 149: 202–207.

Zhang Yijie, Qi Xuanfeng, Fu Guobin, Wang Zhi, Kong Fanjun, Cheng Xiansheng, Hou Quanzheng, Li Meng et al., 2003. *Jurassic System in the north of China. Vol. III. Xinjiang Stratigraphic Region*. Beijing: Petroleum Industry Press, 399 (in Chinese with English abstract) (in press).

Appendix 1 List of palynomorph taxa identified in this study

Acanthotriletes sp.
Alisporites robustus Nilsson 1958
Alisporites warepanus (Raine in de Jersey and Raine 1990)
Alisporites spp.
Annulispora folliculosa (Rogalska 1954) de Jersey 1959
Apiculatisporis otapiriensis (de Jersey and Raine 1990)
Aratrisporites sp. (Zhang and Grant-Mackie 1997)
Araucariacites australis (Cookson 1947)
Ashmoripollis reducta (Helby 1987)
Baculatisporites comaumensis (Cookson 1953) Potonie 1956
Calamospora tener (Couper 1958)
Callialasporites dampieri (Balme 1957) Dev 1961
Callialasporites trilobatus (Balme 1957) Dev 1961
Camarozonosporites rudis (Leschik 1955) Klaus 1960
Cerebropollenites thiergartii Schulz, 1967
Chasmatosporites sp. (Nilsson 1958)
Chordasporites australiensis (de Jersey 1962)
Cibotiumspora juriensis (Balme, 1957) Filatoff 1975
Cordaitina sp. (de Jersey and Raine 1990)
Corollina torosa (Reissinger) Klaus 2007
Craterisporites rotundus (de Jersey 1970)
Cycadopites follicularis (Wilson and Webster 1946)

Cycadopites granulatus (de Jersey 1962) de Jersey 1964
Cycadopites stonei (Helby et al., 1987)
Deltoidospora toralis (Leschik 1955)
Dictyophyllidites mortonii (de Jersey 1959) Playford and Dettmann 1965
Dictyosporites tirumalacharii (Ramanujam and Ramachar 1991)
Distriatites insolitus (Bharadwaj and Salujha 1964)
Foveogleicheniidites atavus (Raine in de Jersey and Raine 1990)
Gleicheniidites senonicus (Ross 1949)
Limbosporites denmeadii (de Jersey 1962) de Jersey and Raine 1990
Lueckisporites virkkiae (Potonie and Klaus 1954)
Lunatisporites rhaeticus (Schulz 1954) Warrington
Marattisporites scabratus (Couper 1958)
Neoraistrickia ramosus (Balme and Hennelly 1956) Hart 1960
Nevesisporites vallatus (de Jersey and Paten 1964)
Perinopollenites elatoides (Couper 1958)
Pinuspollenites minimus (Couper 1958)
Playfordiaspora crenulata (Wilson 1962) Foster 1979
Playfordiaspora velata (Leschik 1955) Stevens 1981
Podocarpidites marwickii (Couper 1953)
Podocarpidites spp.
Podosporites variabilis (Dev 1961)
Polycingulatisporites mooniensis (de Jersey and Paten 1964)
Punctatosporites walkomii (de Jersey 1962)
Quadraeculina anellaeformis (Maliavkina 1949)
Retitriletes austroclavatidites (Cookson 1953) Pocock 1962
Retitriletes semimuris (Danze-Corsin and Laveine 1963) McKellar 1974
Rugaletes awakinoensis (Raine in de Jersey and Raine 1990)
Scheuringipollenites ovatus (Balme and Hennelly 1955) Foster 1979
Stereisporites steroides (Potonié and. Venitz) Pflug 1953
Striatella seebergensis (Madler 1964)
Striatoabieites multistriatus (Balme and Hennelly 1955) Hart 1964
Trachysporites asper (Nilsson 1958)
Triplexisporites playfordii (de Jersey and Hamilton 1967) Foster 1979
Vitriesporites pallidus (Reissinger 1938) Nilsson 1958
Tasmanites sp.

Appendix 2 Bivalve taxa preliminarily identified in this study

Waagenoperna lilingensis Zhang 1977
Waagenoperna mytiloides Zhang 1977
Waagenoperna pernoformis Zhang 1977
Ferganoconcha subcentralis Chernyshev 1939
Ferganoconcha? sp.
Shananxiconcha? sp.
Yananoconcha henshanensis Yu and Zhang 1980
Unio lucaogouensis Wei 1984
Unio miquanensis Wei 1984 (= *Unio manasensis* Wei 1984)
Sibericoncha sp.
Margaritifera isfarensis (Chenyshev 1937) (= *Margaritifera delunshanensis* Wei 1984)
Pseudocardinia sp.