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

SHA Jingeng¹, *, Vivi VAJDA²**, PAN Yanhong¹, Linda LARSSON², YAO Xiaogang¹, ZHANG Xiulin¹, WANG Yaqiong¹, CHENG Xiansheng³, JIANG Baoyu⁴, DENG Shenghui⁵, CHEN Siwei¹ and PENG Bo¹

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: Biostratigraphy, 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...
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 in the southwest, the Altai Mountains in the northeast and the West Junggar Mountains in the northwest. The 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 were 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 Oigu 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
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, 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 Triassic-Jurassic 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).

### Figure 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.)

<table>
<thead>
<tr>
<th>Formation</th>
<th>Lower Jurassic</th>
<th>Upper Jurassic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haojiagou Fm.</td>
<td>Lower member</td>
<td>Middle member</td>
</tr>
<tr>
<td></td>
<td>Upper member</td>
<td>Badaowan Fm.</td>
</tr>
<tr>
<td>Sangonghe Fm.</td>
<td>Lower</td>
<td></td>
</tr>
<tr>
<td>Upper Triassic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Triassic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 1: Summary of the palynological zonation

<table>
<thead>
<tr>
<th>Age</th>
<th>Assemblage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triassic</td>
<td>Conchostracans-Chaetognaths-Assilinids Assemblage</td>
</tr>
<tr>
<td>Jurassic</td>
<td>Cynhsidion-Chaetognaths-Assilinids-Peripatellidae Assemblage</td>
</tr>
</tbody>
</table>

### Time Pies

- Triassic
- Jurassic

- Conchostracans-Assilinids-Chaetognaths Assemblage
### Materials and Methods of Palynology

A sedimentary succession spanning approximately 1535 m was investigated sedimentologically and 210 samples were collected for biostratigraphical purposes 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 Haojiangou Formation to the top of Badaowan Formation (Fig. 3). Out of the 51 samples processed, 21 samples showed to be productive and were

---

**Fig. 3.** Range chart of selected taxa from the Haojiangou and Badaowan formations showing the distribution of pollen and spores, and suggested palynological zonation.
Fig. 4. Range chart of bivalve assemblage/bed of the Haojiangou and Badaowan formations. Scale bars = 5 mm.
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 Xiaquangou 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 bairingerite 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 bairingerite 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 spore 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, fluvial 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 demeadii, Dicytophyllidites mortonii, Polycingulatisporites mooniensis, Foveolestichidites avatus, Apiculatisporis otapiriensis, Annulispora folliculosa, Neoraistrickia ramosus and Camarozonosporites rudus. 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) and 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), Apiculatispora otapiriensis; (e), Neoriatichia sp.; (f), Dicyophyllidites mortoni; (g), Deltoidospora toralis; (h), Foveogleicheniidites ovatus; (i), Striatella seebergensis; (j), Retitriites semimuris; (k), Anarisporites sp.; (l), Apiculatispora 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 Calliallassporites 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), Chasmatopollenites apertus; (f), Tasmanites sp.; (g), Quadraeculina anelliformis; (h), Lunatisporites rhaeicicus; (i), Perinopollenites elatoides; (j), Alisporites robustus; (k), Distriatites insolitus; (l), Ashmoripollis reducta; (m), Alisporites spp.; (n), Podocarpidites sp.

The Triassic Artrisporites–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 Haojiaogou 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 Distriatites 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 Haojiangou, 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 Haojiangou 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 Haojiangou and middle and upper Badaowan formations, and extends up into the Sangonghe Formation. Below bed 45 of the Upper Triassic Haojiangou Formation (Fig. 4), such bivalve is only represented by questionable Ferganoconcha, which is recorded from bed 40, associated with some forms resembling Shanxiconcha. 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 Ferganoconcha (?) bed. Ferganoconcha is a non-marine Jurassic (Cox, 1969a, N410) or Late Triassic(?)–Jurassic (Gu et al., 1976, p. 292) bivalve genus, and Shanxiconcha 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 Hettagain palynoflora Artrisporites–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–Ferganoconcha 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 Lamellibranchiata 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 Waagenoperna liilingensis group composed of Waagenoperna liilingensis, 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 isfarenensis (= 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
Apart from the Junggar Basin, this genus has a wide distribution in China, e.g., the Anyuan Formation, Pajiajachong Member of the Guanyinian 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 Guangdong 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 lilengensis 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 lilengensis 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 Uygar (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 Waagenoperna 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
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 Wallenberg Foundation. It is also a contribution to UNESCO–IUGS IGCP Project 506.

References


Appendix 1 List of palynomorph taxa identified in this study

<table>
<thead>
<tr>
<th>Taxon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthotriletes spp.</td>
</tr>
<tr>
<td>Alisporites robustus Nilsson 1958</td>
</tr>
<tr>
<td>Alisporites warepanus (Raine in de Jersey and Raine 1990)</td>
</tr>
<tr>
<td>Annulispora folliculosa (Rogalska 1954) de Jersey 1959</td>
</tr>
<tr>
<td>Apiculatisporis otapiriensis</td>
</tr>
<tr>
<td>appendix 1</td>
</tr>
<tr>
<td>Bactulisporites comamensis (Cookson 1947)</td>
</tr>
<tr>
<td>Ashmoripollis reducta (Helby 1987)</td>
</tr>
<tr>
<td>Baculatisporites comamensis (Cookson 1953)</td>
</tr>
<tr>
<td>Calamospora tener (Couper 1958)</td>
</tr>
<tr>
<td>Calliasporites dampilerti (Balme 1957) Dev 1961</td>
</tr>
<tr>
<td>Calliasporites trilobatus (Balme 1957) Dev 1961</td>
</tr>
<tr>
<td>Camaroconosporites radis (Leschik 1955) Klaus 1960</td>
</tr>
<tr>
<td>Cerebropollenites thiergartii Schulz, 1967</td>
</tr>
<tr>
<td>Chasmatosporites sp. (Nilsson 1958)</td>
</tr>
<tr>
<td>Chordaspores australiensis (de Jersey 1962)</td>
</tr>
<tr>
<td>Cibotiumspora juriensis (Balme, 1957) Filato 1975</td>
</tr>
<tr>
<td>Cordaitina sp. (de Jersey and Raine 1990)</td>
</tr>
<tr>
<td>Cordilina torosa (Reissinger) Klaus 2007</td>
</tr>
<tr>
<td>Craterisporites rotundus (de Jersey 1970)</td>
</tr>
<tr>
<td>Cycadopites follicularis (Wilson and Webster 1946)</td>
</tr>
</tbody>
</table>
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 Saluja 1964)
Foveogleicheniidsites atavus (Raine in de Jersey and Raine 1990)
Gleicheniidsites senonicus (Ross 1949)
Limbosporites demeadii (de Jersey 1962) de Jersey and Raine 1990
Lueckisporites virkhiiae (Potonie and Klaus 1954)
Lunatisporites rhaeticus (Schulz 1954) Warrington
Marattisporites scabatus (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 anellaformis (Maliavkina 1949)
Retitriletes australis (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 Heninelly 1955) Foster 1979
Stereisporites steroides (Potonie and Venitz) Pfug 1953
Striatella seebergensis (Madler 1964)
Striatobisporites mullistriatus (Balme and Heninelly 1955) Hart 1964
Trachysporites asper (Nilsson 1958)
Triplesisporites playfordii (de Jersey and Hamilton 1967) Foster 1979
Vitriscoplates pallidus (Reissinger 1938) Nilsson 1958
Tazmanites 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.
Yanaonocona henshanensis Yu and Zhang 1980
Unio lucaogouensis Wei 1984
Unio miquanensis Wei 1984 (= Unio manasensis Wei 1984)
Sibericoncha sp.
Margaritifera isfarensis (Chernyshev 1937) (= Margaritifera delunshanensis Wei 1984)
Pseudocardina sp.