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Jurassic clam shrimp ("conchostracan") faunas in China

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Abstract

Jurassic deposits in China are mainly of continental origin and contain an abundance of clam shrimps, whose rapid evolution and radiation make them biostratigraphically useful in subdividing and classifying non-marine strata in China. In this paper we summarize nine Jurassic clam shrimp faunas in China. Although the early Middle Jurassic *Shizhuestheria* fauna has been encountered in geographically small areas in Chongqing, the early Early Jurassic *Palaeolimnadia baitianbaensis* fauna, the late Early Jurassic *Eosolimnadiopsis* fauna and the Middle Jurassic *Euestheria ziliujingensis* fauna are widely distributed in southern and northern China. Since late Middle Jurassic because of the climate change and the geographical barrier clam shrimps began to differentiate into two geographical provinces, e.g. the *Paleoleptestheria*? *chinensis* fauna in southwestern China and the *Sinokontikia* fauna in northern China. During Late Jurassic warm, extremely arid climate in China made clam shrimps differentiated into three faunas, e.g. the Oxfordian *Pseudograpta* fauna of the northern province, the Oxfordian-Kimmeridgian *Eosestheriopsis* fauna and the *Qinghaiestheria-Mangyalimnadia* fauna of the southern province, the latter fauna is only recovered in one locality in the Qaidam Basin.

Key words: fossil clam shrimps, biostratigraphy, Jurassic, China, palaeobiogeography, palaeoclimate.

Introduction

Clam shrimps ("conchostracans") are small, bivalved branchiopod crustaceans with a chitinous carapace that have a long geological history extending back to the Devonian period. Extant clam shrimps normally inhabit quiet, alkaline freshwater pools, and often

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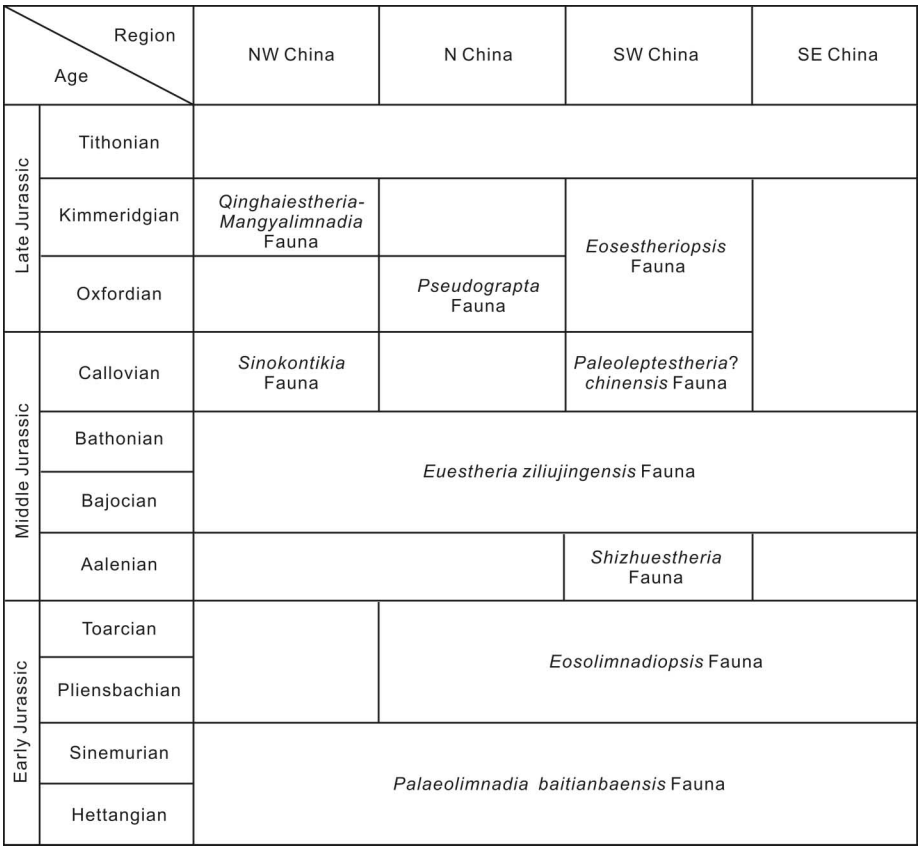

Fig. 1. Jurassic clam shrimp faunas in China.

occur in temporary water bodies like rice field and even rain pools. Although today only 16 genera in three families remain (Zhang et al., 1976; Brtek, 1997), they were much more prosperous during the Mesozoic Era, and were commonly abundant and widely distributed in lacustrine deposits. As a result, they are useful for biostratigraphic subdivision and correlation of non-marine successions. Variations in the composition of assemblages associated with changes of facies within a single section are seldom expressed. However, other taxa may occur in deposits of the same age in different drainage basins, reflecting local geographic and climatic variations and/or differences in the physical and chemical conditions within the water (Chen and Shen 1982; Chen and Hudson 1991; Chen et al., 2007).

Jurassic deposits in China are mainly of continental origin and contain an abundance of fossil clam shrimps (Chen, 2003). The first taxonomic research on Chinese Jurassic clam shrimps was carried out in early 20th century, although these taxa were originally assigned to Early Cretaceous (Chi, 1931). At the beginning of the second half of 20th century, Japanese and Russian scientists published some taxonomic data on Jurassic clam shrimp material from China (Kobayashi, 1951; Novojilov, 1958). Later on, through extensive geological mapping and mineral resources exploration many clam shrimp specimens have

been recovered and described from the Jurassic lacustrine deposits in China, resulting in the accumulation of a large amount of new taxonomic and biostratigraphic data on fossil clam shrimps of China, either in separately published papers of academic journals or in palaeontological atlases (Wang, 1976, 1980; Shen et al., 1982; Wang et al., 1984) and monographs (Zhang et al., 1976; Chen and Shen, 1985; Shen, 2003). In these publications, the abundant and diverse clam shrimp *Nestoria-Keratestheria* and *Eosestheria* faunas of the Jehol Biota have been assigned to a Late Jurassic age (Zhang et al., 1976; Wang, 1981; Wang, 1987; Chen, 1988). Since late 1990s the extensive recoveries of evolutionarily important, excellently preserved fossils like feathered dinosaurs (Ji and Ji, 1996; Chen et al., 1998), early birds (Zhou et al., 1992; Hou et al., 1995), primary mammals (Ji et al., 1999), and early angiosperm (Sun et al., 1998) of the Jehol Biota have inspired the great interests to re-measure the geological age of the fossil bearing beds and their underlying deposits through various radiometric dating methods (Swisher III et al., 1999; Wang et al., 2001; Liu et al., 2003; Davis, 2005; He et al., 2006). These new, more precise radiometric age data result in the assignment of the Jehol Biota to an Early Cretaceous age and the lowering of the non-marine Jurassic/Cretaceous boundary in China (Ji et al., 2006; Zhou et al., 2009).

This paper summarizes Jurassic clam shrimp faunas in China, revaluating the components of these faunas and discusses their geographic distribution and palaeo-climatic conditions.

Jurassic clam shrimp faunas

Here we summarize nine Jurassic clam shrimp faunas and describe them in ascending order (Fig. 1).

1. Early Early Jurassic (Hettangian-Sinemurian) Palaeolimnadia baitianbaensis fauna

The fauna is dominated by species of the genus *Palaeolimnadia* Raymond, 1946 and contains a minor component species of nine other genera, i.e. *Bulbilimnadia* Shen in Zhang et al., 1976, *Eueshteria* Deperet and Mazeran, 1912, *Iliestheria* Li and Shen, 1995, *Lioestheria* Deperet and Mazeran, 1912, *Loxomegaglypta* Novojilov, 1958, *Loxomicroglypta* Novojilov and Varentsov, 1956, *Ovjurium* Novojilov and Varentsov, 1956, *Pseudestheria* Raymond, 1946, and *Pseudolimnadia* Novojilov, 1954.

Paleolimnadia is characterized by a large umbo and smooth growth bands, which was first reported in the Triassic Wianamata Series in Australia. Later studies have shown that the genus ranges from Carboniferous to Middle Jurassic. *Palaeolimnadia* had a small carapace (1–3 mm long), and was a subordinate component before Jurassic. During Early Jurassic, it became larger, the carapace size reached 4–6 mm long, and it got flourished in China, Siberia and Kazakhstan (Zaspelova, 1961; Novojilov and Kapelka, 1968; Zhang et al., 1976), later on it has got a sharp decline in abundance and diversity.

Bulbilimnadia has a big umbo with an elongated protuberance and smooth growth bands. *Pseudolimnadia*, with large punctuate reticulations on growth band, was originally described from the Early Jurassic of Mongolia (Novojilov, 1954), and later has also been reported from Lower Jurassic of Siberia (Stepanov, 1966). The Chinese specimens have only large reticulations on growth bands with no punctae within reticulations and they are now doubtfully assigned to *Pseudolimnadia*.

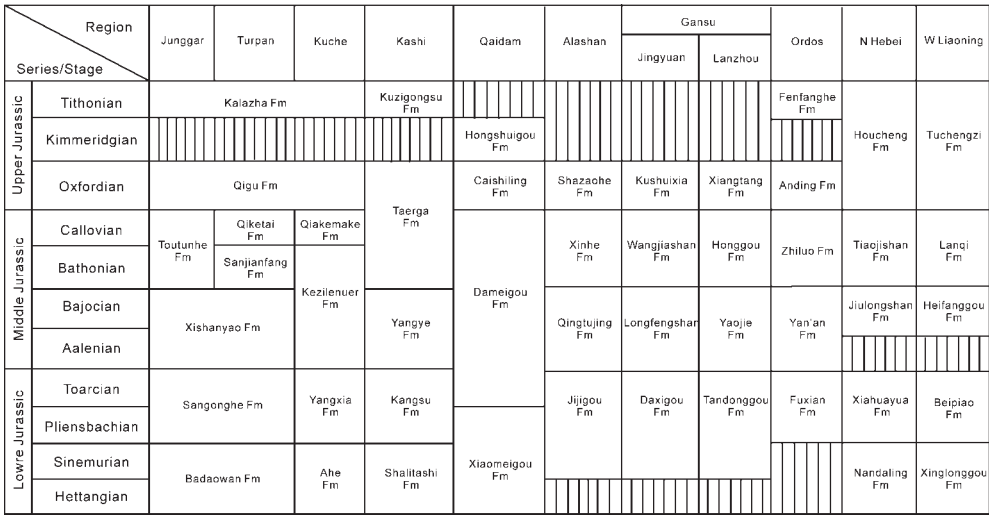

Fig. 2. Correlation chart for Jurassic clam shrimp bearing sequences in northern China (revised after Chen, 2003).

The *Palaeolimnadia baitianbaensis* fauna is represented by *P. baitianbaensis* Chen, 1974 and *Euestheria taniiformis* (Zaspelova, 1961), and comprises other 52 species, including *Bulbilimnadia bullata* Shen in Zhang et al., 1976, *B. wanxianensis* Shen in Zhang et al., 1976, *Euestheria changtanensis* Shen in Zhang et al., 1976, *E. elegans* Shen in Zhang et al., 1976, *E.*? *elongata* Chen in Zhang et al., 1976, *E. khinganensis* (Kobayashi, 1951), *E. orientalis* Shen in Zhang et al., 1976, *E. shandanensis* Chen in Zhang et al., 1976, *E. shandongensis* Chen, 1982, *Iliestheria nilkaensis* Li and Shen, 1995, *I. xinjiangensis* Li and Shen, 1995, *Lioestheria shimamurai* (Kobayashi, 1951), *Loxomegaglypta dafangensis* Shen and Chen, 1982, *Loxomicroglypta laohugouensis* Wang, 1980, *L.* cf. *laohugouensis*, *L. liaoxiensis* Liu, 1987, *L. kirgizica* Novojilov and Varentsov, 1956, *Ovjurium* cf. *ubsanuri* Novojilov and Varentsov, 1956, *O. yixianensis* Liu, 1987, *Palaeolimnadia acuta* Shen in Zhang et al., 1976, *P. baoxingensis* Shen in Zhang et al., 1976, *P. chuanbeiensis* Shen in Zhang et al., 1976, *P. dachaidanensis* Wang, 1983, *P. diannanensis* Chen, 1974, *P.* aff. *dundugobica* Novojilov, 1954, *P. exiensis* Shen in Zhang et al., 1976, *P. grandis* Shen in Zhang et al., 1976, *P. guangyuanensis* Chen, 1974, *P. houjieensis* Shen in Zhang et al., 1976, *P. hubeiensis* Shen in Zhang et al., 1976, *P. intermedia* Shen in Zhang et al., 1976, *P.* cf. *intermedia*, *P. kangnaiensis* Chen, 1974, *P. lingguanensis* Shen in Zhang et al., 1976, *P.* cf. *lingguanensis*, *P. longmenshanensis* Shen in Zhang et al., 1976, *P. longyinensis* Chen in Zhang et al., 1976, *P. menglaensis* Chen in Zhang et al., 1976, *P.* cf. *parva* Zaspelova, 1961, *P. pengxianensis* Chen in Zhang et al., 1976, *P. rhombica* Chen, 1974, *P. semicircularis* Shen in Zhang et al., 1976, *P. sichuanensis* Shen in Zhang et al., 1976, *P. subcircularis* Shen in Zhang et al., 1976, *P. subtriangularis* Shen in Zhang et al., 1976, *P.* cf. *venusta* Zaspelova, 1961, *P. xiaomeigouensis* Wang, 1983, *P. yangziensis* Shen in Zhang et al., 1976, *Pseudestheria* cf. *subovata* Zaspelova, 1961, *Pse. tanii* (Kobayashi, 1951), *Pseudolimnadia*? *reticulata* Chen in Zhang et al., 1976, and *Ps.*? *weixinensis* Shen

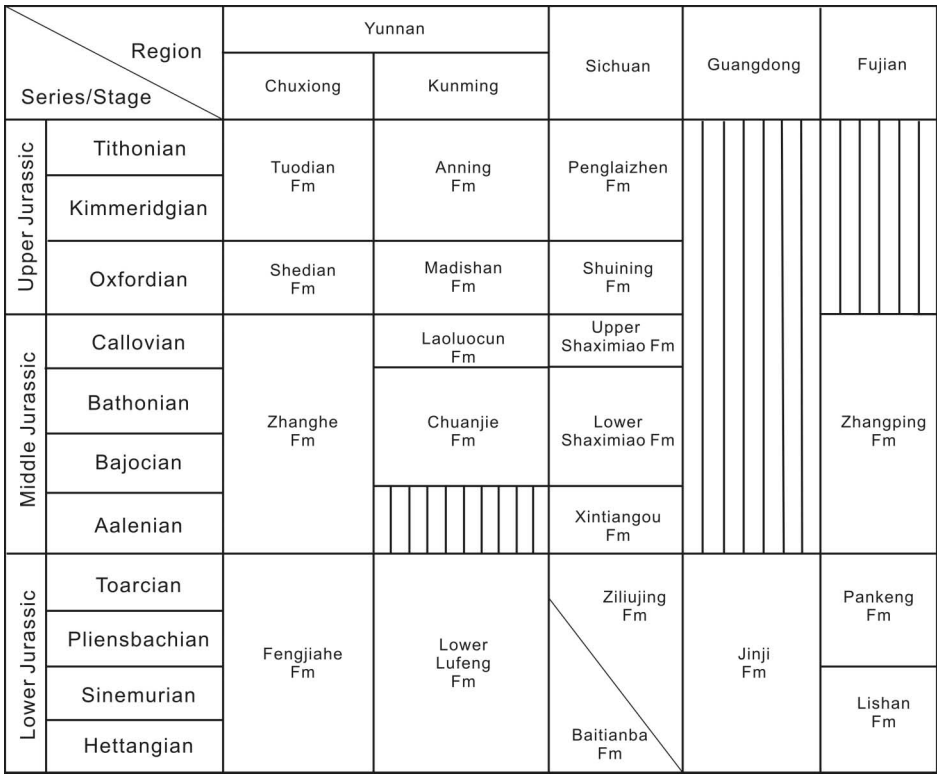

Fig. 3. Correlation chart for Jurassic clam shrimp bearing sequences in southern China.

and Chen, 1982. It is likely that the species number will be reduced considerably once the assemblage is re-examined using Scanning Electronic Microscope (SEM) and the degree of sexual dimorphism is taken into account.

The *Palaeolimnadia baitianbaensis* fauna was originally described from the middle part of the Lower Jurassic Baitianba Formation in the Guangyuan area, northern Sichuan Province, and also widely occurs in the Lower Jurassic sequences in southern China; e.g. in the lower Ziliujing Formation, central and eastern Sichuan, northern Guizhou and western Hubei; the Tiankou Formation, western Yunnan; the upper Dakeng Formation, Zhangping, Fujian; and the Lower Jurassic, Aidian, Ningming, Guangxi Province (Fig. 2). In northern China, it has been recovered from the Lower Jurassic sequences, like the Badaowan and Sangonghe formations of the Junggar Basin (Fig. 3); the Tariqik Formation in the Tarim Basin; the lower Dameigou Formation in the northern margin of the Qaidam Basin in Qinghai Province; the Nandaling Formation of Chengde in northern Hebei; the Wennan Formation of Mengyin, Shandong; the upper Laohugou Formation, Lingyuan (Wang, 1980); and the upper Yangcaogou Formation in western Liaoning (Liu, 1987).

2. Late Early Jurassic (Pliensbachian-Toarcian) Eosolimnadiopsis fauna

The late Early Jurassic *Eosolimnadiopsis* fauna was first described from the Lower

Jurassic Fuxian Formation in the Gushan area of Fugu County, northern Shaanxi Province, and later it has been encountered from the Lower Jurassic squences in widely scattered areas in China, namely in the Fuxian Formation of Zhungeer Qi of Ordos, Inner Mongolia (Wang and Liu, 1980), the Lower Jurassic of Tongxin, Haiyuan and Guyuan in the Ningxia Hui Autonomous Region (Shen, 2003), the Xinchun Formation in the Huili area of Xichang, southwestern Sichuan Province (Duan, 1978), the Qianfoyan Formation at the Yuelong village of Liuyang, Hunan Province (BGMRH, 1997), the Pankeng Formation in the Tangpu area of Yongding County, southwestern Fujian Province (Cao, 1986), the upper part of the Jinji Formation of Wuhua County, Heyuan and Huiyang, eastern Guangdong Province (Liu, 1982). The occurrence of ammonites *Arietites* and *Hongkongites* from the lower part of the Jinji Formation indicates that the upper part of the formation containing *Eosolimnadiopsis* fauna should be post-Sinemurian in age (Liu, 1982). The fauna is dominated by species of *Eosolimnadiopsis* (=*Fuxianlimnadiopsis* Liu, 1982) and *Asiolimnadiopsis* Liu, 1982 (=*Biglimnadiopsis* Liu, 1982; *Guangdonglimnadiopsis* Liu, 1982), with minor associates of *Euestheria*, *Neimongollimnadiopsis* Liu, 1982, and *Pseudolimnadia*. The genus *Eosolimnadiopsis* has growth lines that are slightly recurved near the posterior end of the dorsal margin. Its carapace has ornamentation that changes gradually from irregular middle-sized reticulation on dorsal and anterior parts to radial lirae on ventral and posterior parts. *Asiolimnadiopsis* differs from *Eosolimnadiopsis* in having growth lines that are thickened and markedly recurved near the posterior end of the dorsal margin, and projecting above the dorsal margin, which makes the dorsal margin showing serrated structure. *Neimongollimnadiopsis* is characterized by having small-sized reticulation on the lower part of each growth band, and changing to bold reticulation in the upper part.

The fauna contains 20 species in five genera including *Asiolimnadiopsis buccinia* (Liu, 1982), *A. heyuanensis* Liu, 1982, *A. huiyangensis* Liu, 1982, *A. lantangensis* Liu, 1982, *A. para* (Liu, 1982), *A. wuhuaensis* (Liu, 1982), *A. zhoujiangensis* (Liu, 1982), *Eosolimnadiopsis dachanghangouensis* (Liu in Wang and Liu, 1980), *Eo. fuanensis* Chen in Zhang et al., 1976, *Eo. gushanensis* (Liu in Wang and Liu, 1980), *Eo.* aff. *gushanensis*, *Eo. haqinggouensis* (Liu in Wang and Liu, 1980), *Eo. shanbeiensis* Chen in Zhang et al., 1976, *Eo. staminis* (Liu in Wang and Liu, 1980), *Eo. wuziwanensis* (Liu in Wang and Liu, 1980), *Euestheria*? *yaoshanensis* Shen and Chen, *Neimongollimnadiopsis fuxianensis* Liu, 1982, *N. subquadrata* Liu, 1982, *Pseudolimnadia*? *guyuanensis* Chen in Zhang et al., 1976, *Ps.*? *ningxiaensis* Chen in Zhang et al., 1976, and *Ps.*? *tanshanensis* Chen in Zhang et al., 1976.

3. Early Middle Jurassic (Aalenian?) Shizhuestheria fauna

The *Shizhuestheria* fauna occurs in the lower Middle Jurassic Xintiangou Formation of Chongqing, and consists of *S. truncata* Shen and Chen, 1982, *Pseudolimnadia*? *shaxiensis* Shen and Chen, 1982 and *Euestheria complanata* Chen in Zhang et al., 1976. The fauna is dominated by the first species and the latter two taxa are extremely rare. *Pseudolimnadia*? *shaxiensis* was described based on only one poorly preserved specimen (Shen and Chen, 1982). *Shizhuestheria* has relatively wider growth bands in the infancy stage, on which there are medium-sized reticulation, and several small-sized reticulation (or puncta) occur within each lumina; the growth bands become narrower since the adult stage, and the

reticulation becomes faint or disappeared, and only small-sized reticulation (or puncta) remains (Li et al., 2009).

4. Middle Jurassic (Bajocian-Bathonian) Euestheria ziliujingensis Fauna

In China the Middle Jurassic *Euestheria ziliujingensis* Fauna is widely distributed in lacustrine deposits, such as in the Xishanyao Formation and the lower part of the Toutunhe Formation in the Junggar Basin, the Sanjianfang and Qiketai formations in the Turpan Basin, the Kezilenuer and Yangye formations in the Tarim Basin, the upper part of the Dameigou Formation in the Qaidam Basin, the Yaojie, Wangjiashan and the lower and middle Xinhe formations in Gansu, the Ma'ao Formation in Henan, the Jiulongshan Formation in northern Hebei and Inner Mongolia, the Haifanggou Formation in western Liaoning, the Lower Shaximiao Formation in Sichuan and Guizhou, the Hepingxiang, Zhanghe and Upper Lufeng formations in Yunnan, the Zhangping Formation in Fujian (Zhang et al., 1976; Chen and Shen, 1983; Cao, 1986; Shen, 2003; Shen et al., 2003). *Euestheria* has a small carapace that is ornamented by delicate reticulations with a mesh diameter about 0.02 mm. By using SEM the taxa *Qaidamestheria* Wang, 1983 and *Triglypta* Wang, 1984 have been described from the fauna, in which the small-sized puncta are radially arranged on the ventral and posteroventral parts of the carapace. *Euestheria trotternishensis* Chen and Hudson, 1991, the only euestheriid of the Middle Jurassic (Bajocian-Bathonian) *Skyestheria* fauna from the Great Estuarine Group of Skye in northern Scotland, resembles *Qaidamestheria* in having a punctuate carapace ornamentation.

The common species of the fauna are *Euestheria ziliujingensis* Chen in Zhang et al., 1976, *E. haifanggouensis* Chen in Zhang et al., 1976, *E. complanata* Chen in Zhang et al., 1976, *Qaidamestheria dameigouensis* Wang, 1983, *Triglypta pingquanensis* Wang, 1984, in addition the fauna includes *E. changhangouensis* Wu, 1980, *E. datongensis* Zhang in Zhang et al., 1976, *E. exilis* Chen in Zhang et al., 1976, *E. fabiformis* Chen in Zhang et al., 1976, *E. jingyuanensis* Chen in Zhang et al., 1976, *E. luanpingensis* Shen and Niu in Zhang et al., 1987, *E. manzhuangensis* Chen in Zhang et al., 1976, *E. rotunda* Zhang in Zhang et al., 1976, *E. shandanensis* Chen in Zhang et al., 1976, *E. shiguaiziensis* Wu, 1980, *E. sinkiangensis* (Chi, 1931), *E.*? *subquadrata* Chen in Zhang et al., 1976, *E. xiazhuangensis* Chen in Zhang et al., 1976, *E. yanjiawanensis* Chen in Zhang et al., 1976, *E.*? *yangbiensis* Chen in Zhang et al., 1976, *Qaidamestheria shanshanensis* Wang, 1985, *Triglypta manasica* Wang, 1985, *T. ovata* Wang, 1985, and *T. Tianshanensis* Wang, 1985.

5. Late Middle Jurassic (Callovian) Sinokontikia fauna

Sinokontikia Novojilov, 1958 has a relatively large carapace, a few wide growth bands with tubercular ornamentation and is easy to be identified. The original description of *Sinokontikia* just mentioned that the material was from the Turpan Basin but without detailed locality information. The *Sinokontikia* fauna was originally attributed to the late *Euestheria ziliujingensis* fauna (Chen et al., 2007). Recent years the fauna has been recovered from various localities in the upper part of the Middle Jurassic strata in northwestern China, such as in the upper Qiketai Formation at Lianmuqin of the Turpan Basin, the upper Xinhe Formation in the Alashan area, the top Wangjiashan Formation of Jingyuan, the Honggou Formation of Tianzhu in Gansu Province, northwestern China (Shen, 2003). It contains 18 species in seven genera, including *Qaidamestheria*

shanshanensis Wang, 1985, *Sinokontikia chaoi* (Novojilov, 1958), *S. lianmuqinensis* Wang, 1985, *S. szei* Novojilov, 1958, *S. clinorbita* Wang, 1985, *S. youngi* Novojilov, 1958, *Tianzhuestheria gansuensis* Shen et al., 2002, *Triglypta ovata* Wang, 1985, *T.* cf. *pingquanensis* Wang, 1984, *T. tianshanensis* Wang, 1985, *T. yingzueishigouensis* Wang, 1985, *Turfanograpta chankei* Novojilov, 1958, *T. chowmincheni* Novojilov, 1958, *T. elongata* Wang, 1985, *T.*? *huoyanshanensis* Wang, 1985, *T. hongshanensis* Wang, 1985, *Paleoleptestheria*? *chinensis* Chen in Zhang et al., 1976, and *Mesolimnadia* sp. *Paleoleptestheria*? *chinensis* has been found in association with *Sinokontikia* in the top Wangjiashan Formation of Jingyuan in Gansu.

6. Late Middle Jurassic (Callovian) Paleoleptestheria? chinensis Fauna

This fauna occurs in the Middle Jurassic Upper Shaximiao Formation of Chongqing and northern Guizhou, and in the Second Member of the Guangyuan Group of northern Sichuan. It is also reported from the Middle Jurassic of peninsular Thailand (Chonglakmani et al., 1990; Duan and Chen, 2000). *Paleoleptestheria*? *chinensis* has a small- or medium-sized carapace, with medium-sized cavernous reticulation, which shows as isolated rounded or elliptical nodules on external mould.

7. Early Late Jurassic (Oxfordian) Pseudograpta fauna

Pseudograpta murchisoniae (Jones, 1862), the type species of *Pseudograpta* (Novojilov, 1954) (=*Diplograpta* Wang, 1980), was originally described from the late Middle Jurassic (Callovian) Skudiburgh Formation of the Great Estuarine Group of Skye in northern Scotland (Chen et al., 2007). Extensive marine transgressions in Europe, beginning in the Callovian, led to the eastward migration of the European *Pseudograpta* fauna. They arrived in East Asia during the Oxfordian, and have been recovered from the lower Tuchengzi Formation in western Liaoning, the Houcheng Formation in northern Hebei and the Xiangtang Formation of Gansu (Wang, 1984; Shen, 2003). Three species that originated in western Europe, i.e. *P. murchisoniae*, *P. orbita* Chen in Zhang et al., 1976 and *P.*? *mirabilis* Shen and Chen, 1984 (=*P. jonesi* Chen and Hudson, 1991), continue to thrive, and six other species evolved: *P. brevis* Shen and Chen, 1984, *P.*? *inconstantis* Shen and Chen, 1984, *P. liaoningensis* Shen and Chen, 1984, *P. paucilineata* Shen and Chen, 1984, *P. subquadrata* Shen and Chen, 1984, and *P. yuzhongensis* Chen in Shen et al., 1982. In addition, *Monilestheria* Shen and Chen, 1984 (=*Prosentestheria* Wang, 1987) and *Nestoria* Krasinetz, 1963, including *N. reticulata* (Chernyshev, 1930) and *N. pissovi* Krasinetz, 1963, were descended from *Pseudograpta*. The monilestheriids, consisting of *M. caijiagouensis* Shen and Chen, 1984, *M. oblonga* Shen and Chen, 1984, *M. ovata* Shen and Chen, 1984, and *M. subcircularis* Shen and Chen, 1984, have the same ornamentation on their growth bands as species of *Pseudograpta*, but they differ in having a row of tubercles on the growth lines. The earliest form of *Nestoria*, *N. reticulata*, has a small carapace, and a few broad growth bands ornamented by a bold polygonal reticulation, but the very fine, densely distributed, radial lirae on growth bands near the venter of the carapace in *Pseudograpta* have disappeared (Chen et al., 2007).

In addition to the nestoriids, the fauna also includes two species in the superfamily Lioestherioidea Raymond, 1946 (suborder Spinicaudata Linder, 1945), *Mesolimnadia jinlingsiensis* Chen, 1975 and *M. recta* Chen in Zhang et al., 1976, and two attributable to

the superfamily Paleolynceioidea Tasch, 1956 (suborder Laevicaudata Linder, 1945), *Prolynceus beipiaoensis* Shen and Chen, 1984, and *P. lineatus* Shen and Chen, 1984. All of the four species have muscle and shell gland marks on the carapace. The mesolimnadiids have a large umbo, several to more than 10 growth bands ornamented by a delicate reticulation, and radial lirae. The prolynceids have a large umbo with only one growth line, and its carapace is smooth.

8. Late Jurassic (Oxfordian-Kimmeridgian) Eosestheriopsis fauna

The *Eosestheriopsis* fauna, a Late Jurassic Tethyan realm fauna in southwestern China, was first described from the Upper Jurassic Tuodian Formation of Chuxiong, Shuangbai, Xiangyun and Yongren Counties in Yunnan, including *Eosestheriopsis dianzhongensis* (Chen in Zhang et al., 1976), *E. subovata* (Chen in Zhang et al., 1976), *E. semiorbita* (Chen in Zhang et al., 1976), *E. subquadrata* (Chen in Zhang et al., 1976), and *Diestheria yunnanensis* Chen in Zhang et al., 1976. All of these taxa have a row of tubercles along the lower margin of each growth band in the middle and ventral parts of the carapace (Chen, 1977). Later the fauna was also recovered from the Upper Jurassic Suining and Penglaizhen formations in the Sichuan Basin (Shen and Chen, 1982). In addition, more taxa have been described, including *Huilongestheria rotunda* Shen and Chen, 1982, *H.* sp., and fushunograptids *Orthestheria* sp., *Suiningestheria minor* Shen and Chen, 1982, *Qinghaiestheria chuangzhongensis* (Shen and Chen, 1982), *Q. sichuanensis* (Shen and Chen, 1982), and *Q. suboblonga* (Shen and Chen, 1982). *Qinghaiestheria* has a small carapace ornamented by puncta, reticulation, radial lirae and cross bars, and its growth lines are serrated along its lower margins (Li, 2004).

Recently, Niu et al. (2005) described 13 new species in four genera, including two new genera, i.e. *Chuanjieestheria* Niu and *Yunnanograpta* Niu from the Upper Jurassic Tuodian, Madishan and Anning formations of Yunnan. The new taxa are *Chuanjieestheria ampulliformis* Niu, *C. elliptica* Niu, *C. orbita* Niu, *C. ovata* Niu, *C. suborbita* Niu, *Diestheria jishanpoensis* Niu, *Eosestheriopsis anningensis* Niu, *E. chuanjieensis* Niu, *E. elliptica* Niu, *E. intermedia* Niu, *Yunnanogropta latiovata* Niu, *Y. linearis* Niu, and *Y. longa* Niu. At present the *Eosestheriopsis* fauna includes 25 species in eight genera. According to the fossil records, *Eosestheriopsis* is relatively rare in the Suining Formation of Sichuan and the Madishan Formation of Yunnan, but it became common and abundant in the overlaying Penglaizhen Formation in Sichuan, and the Tuodian and Anning formations in Yunnan. The genus *Eosestheriopsis* migrated to the Palaeo-Heilongjiang drainage system that was occupied by the *Eosestheria* Fauna of the Jehol Biota during the Early Cretaceous, and was recovered in the Jianshangou beds of the Yixian Formation in western Liaoning (Chen, 1999).

9. Middle Late Jurassic (Kimmeridgian) Qinghaiestheria-Mangyalimnadia Fauna

The fauna is characterized by the label genera, and only recovered from the Hongshuigou Formation of the Qaidam Basin, Qinghai Province. The fauna contains six species in three genera including *Qinghaiestheria hungshuikouensis* (Chang, 1957), *Q. asmussiformis* (Chang, 1957), *Q. erisopsiformis* (Chang, 1957), *Mangyalimnadia quadrata* (Chang, 1957), *M. subovata* (Chang, 1957), and *Sinoestheria tsaidamensis* Chang, 1957. The association of the fauna with Kimmeridgian bivalve *Danlengiconcha* and ostracode

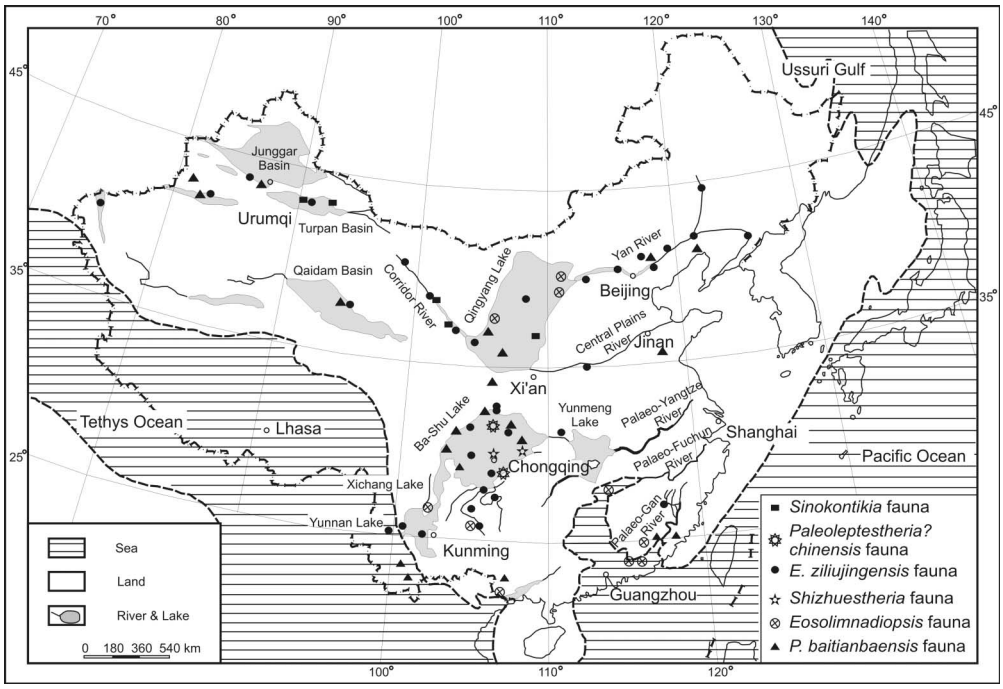

Fig. 4. Distribution of Early and Middle Jurassic clam shrimp faunas in China (revised after Chen, 1979; Chen and Shen, 1983).

Cetacella indicates that the *Qinghaiestheria-Mangyalimnadia* fauna could be Kimmeridgian in age (Shen, 2003).

The occurrence of *Qinghaiestheria* in the upper most part of the 2nd member of the Penglaizhen Formation in the Sichuan Basin represents the highest horizon of the *Eosestheriopsis* fauna. Thus, the *Eosestheriopsis* fauna seems to be not younger than Kimmeridgian, and should be older than the Early Cretaceous *Eosestheria* fauna (Li, 2004; Li and Batten, 2004).

Jurassic clam shrimp biogeographic provinces

During Early Jurassic, the East Tethys occupied Tibet and southwestern Yunnan Province, the Guangdong-Jiangxi Gulf separated the southeast costal region from mainland China, and the Ussuri Gulf reached the eastern Heilongjiang region (Chen, 1979). In northern China the biggest Qingyang Lake occupied the Ordos Basin area, and the water replenishment was supplied by three big rivers, e.g. the Yan and Central Plains Rivers in the east, and the Corridor River in the west. In southern China, the palaeo-Yangtze River, starting from the east, ran westwards along the Yunmeng, Ba-Shu and Yunnan Lakes into the Tethys in southwestern Yunnan. The Early and Middle Jurassic warm and humid climate made clam shrimp fauna evenly distributed both in north and south China. The Early Jurassic *Palaeolimnadia baitianbaensis* fauna and the Middle Jurassic *Euestheria*

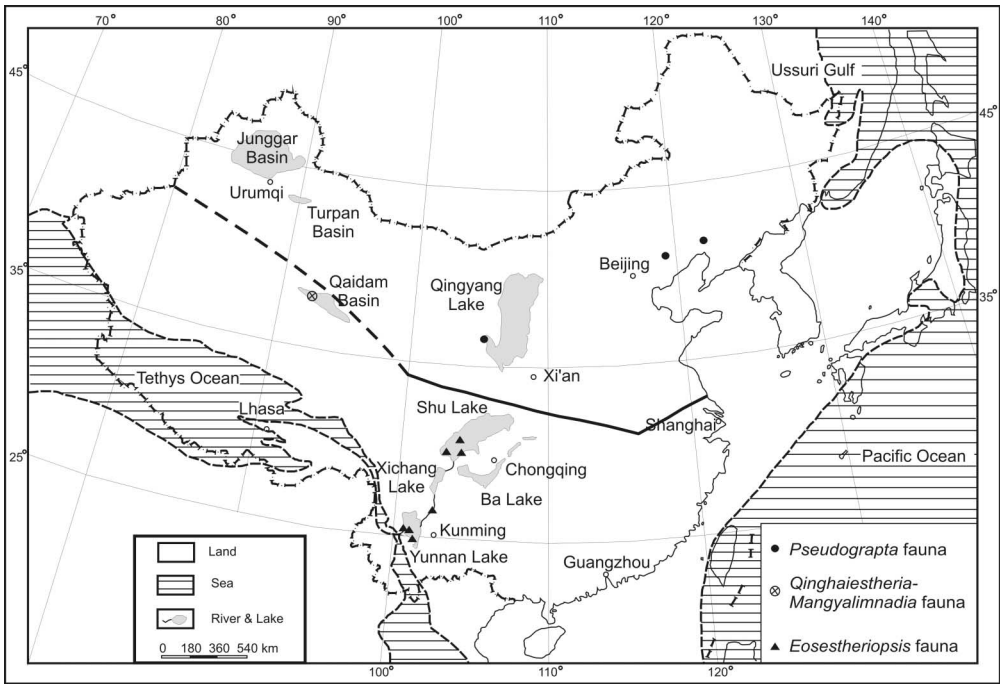

Fig. 5. Distribution of Late Jurassic clam shrimp faunas in China (revised after Chen, 1979; Chen and Shen, 1983).

ziliujingensis fauna flourished not only in the palaeo-Yangtze drainage system, but also in the Qingyang Lake drainage system. They were recovered even in Junggar, Turpan and Qaidam Basins, and also occurred in the southeast costal region. The late Early Jurassic *Eosolimnadiopsis* fauna was distributed mainly in the southeast coast region and the Qingyang Lake area, and was very scarcely recovered from the palaeo-Yangtze drainage system (Fig. 4).

Since late Middle Jurassic because of geographic barrier and climate change, clam shrimps began to differentiate into two faunas, e.g. the *Paleoleptestheria*? *chinensis* fauna in Ba-Shu Lake and the *Sinokontikia* fauna in Qingyang Lake and the Turpan Basin. With the gradual break-up of the Eurasian continent during the late Middle-early Late Jurassic, the distribution of land and sea changed significantly. At the same time the warm, humid climate of the Early-Middle Jurassic period gave way to a warm, extremely arid climate in East Asia during the Late Jurassic (Chen and Norling 2002; Chen et al., 2007). Clam shrimps differentiated into two biogeographic provinces containing three faunas, e.g. the Oxfordian *Pseudograta* fauna of the northern clam shrimp province, the Kimmeridgian *Qinghaiestheria-Mangyalimnadia* fauna and the Oxfordian-Kimmeridgian *Eosestheriopsis* fauna of the southern clam shrimp province in China (Fig. 5). The latter two faunas have the common component genus *Qihaiestheria*, which is only recovered in the Qaidam Basin and Yunnan and Sichuan Provinces.

Conclusion

The Early-Middle Jurassic warm and humid climate made clam shrimps flourished in China. Three clam shrimp faunas, the early Early Jurassic *Palaeolimnadia baitianbaensis* fauna, the late Early Jurassic *Eosolimnadiopsis* fauna, and the Middle Jurassic *Euestheria ziliujingensis* fauna are widely distributed both in northern and southern China. The limited distribution area of the *Shizhuestheria* fauna in Chongqing may reflect a climate disturbance during early Middle Jurassic. Since late Middle Jurassic clam shrimps began to differentiate into two geographic provinces, e.g. the *Sinokontikia* fauna in Qingyang Lake and the Turpan Basin of northern China, and the *Paleoleptestheria*? *chinensis* fauna in Ba-Shu Lake in southwestern China. The Late Jurassic warm, extremely arid climate and geographic barrier made clam shrimps differentiated into two geographic provinces, e.g. the Oxfordian Pseudograta fauna of the northern province occurring in Liaoning, Hebei and Gansu, the Oxfordian-Kimmeridgian *Eosestheriopsis* fauna and the Kimmeridgian *Qinghaiestheria-Mangyalimnadia* fauna of the southern province.

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