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Permian coral faunas of the eastern Cimmerian Continent and their biogeographical implications

X.D. Wang[a,*], T. Sugiyama[b]

[a]*Nanjing Institute of Geology and Palaeontology, Chinese Academy of Science, Nanjing 210008, People's Republic of China*
[b]*Department of Earth System Science, Fukuoka University, Fukuoka 814-0180, Japan*

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Abstract

Because of a depositional hiatus, Late Carboniferous corals are unknown from the eastern Cimmerian Continent. Early Permian (Asselian to Artinskian) corals are characterized by non-dissepimented solitary forms, and the absence of Kepingophyllidae and Waagenophyllidae, forms common in the Cathaysian biotic province. Roadian faunas in most areas of the eastern Cimmerian Continent are dominated by small solitary corals. These faunas are quite different from those of the Cathaysian area, where abundant large solitary and compound corals occur. By the Wordian, and into the Capitanian, large solitary and massive Waagenophyllidae, with a Cathaysian aspect, were well developed and widespread in the Cimmerian Continent. However, some endemic taxa, like *Thomasiphyllum*, also occur. Late Permian corals consist only of Cathaysian elements. Therefore, paleobiogeographically, the coral faunas in the eastern Cimmerian Continent reveal the following changes: (1) a Peri-Gondwanan affinity during the Early Permian to early Middle Permian, (2) an endemic Cimmerian–Cathaysian affinity during the late Middle Permian, and (3) a true Cathaysian fauna during the Late Permian. These changes may be related to the rifting of the Cimmerian Continent from Gondwanaland in the Late Early Permian and its subsequent northward drift. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Coral faunas; Eastern Cimmerian Continent; Biogeographic framework

1. Introduction

The Cimmerian Continent consists of several allochthonous blocks (or terranes) located between Gondwana and Eurasia (Sengor, 1979, 1984) that have a similar Late Paleozoic evolutionary history. They were separated from Gondwana during the Early Permian, drifted northward in the Paleo-Tethys ocean during the Middle and Late Permian, and amalgamated with southern Eurasia during the Triassic (Metcalfe, 1991, 1999; Archbold and Shi, 1996; Grunt and Shi, 1997; Shi and Archbold, 1998). To better understand the historical processes of the dispersion of northern Gondwana and its accretion to Asia, it is essential to reconstruct the paleobiogeographic framework of these blocks, based on shallow marine benthos.

The Cimmerian Continent can be divided, geographically, into a western and eastern part (e.g. Shi and Archbold, 1998). According to Sengor's (1984) definition, the former includes the Mediterranean and Ghaznian (Southwest Asian) Cimmerides, and the latter, the Chinese and Indochinese (Southeast Asian) Cimmerides. Using the paleobiogeographical classification of Permian global marine provinces of Grunt and Shi (1997), the Cimmerian, a biogeographical region belonging to the Palaeo-Equatorial realm, can be subdivided into four provinces: the Sibumasu Province, the Himalayan Province, the Pamiran Province, and the Iranian Province. The former two cover the eastern Cimmerian Continent of this paper, and include the following blocks or terranes: Shan-Thai Block in SE Asia; Baoshan and Tengchong blocks in West Yunnan, China; and the Lhasa and western Qiangtang blocks in Xizang (Tibet), China (Fig. 1).

This paper reviews new collections of fossil corals and a compilation of published data related to the east Cimmerian Continent. These data will provide further paleobiogeographical constraints on the dynamic tectonic evolution during the Permian.

2. Permian stratigraphy in the eastern Cimmerian Continent

The Sibumasu Block was defined by Metcalfe (1984) as bounded by the Shan Boundary Fault on the west, and by the Nan-Uttaradit Fault and the Bentong–Raub Fault in

* Corresponding author.
E-mail address: xdwang@nigpas.ac.cn (X.D. Wang).

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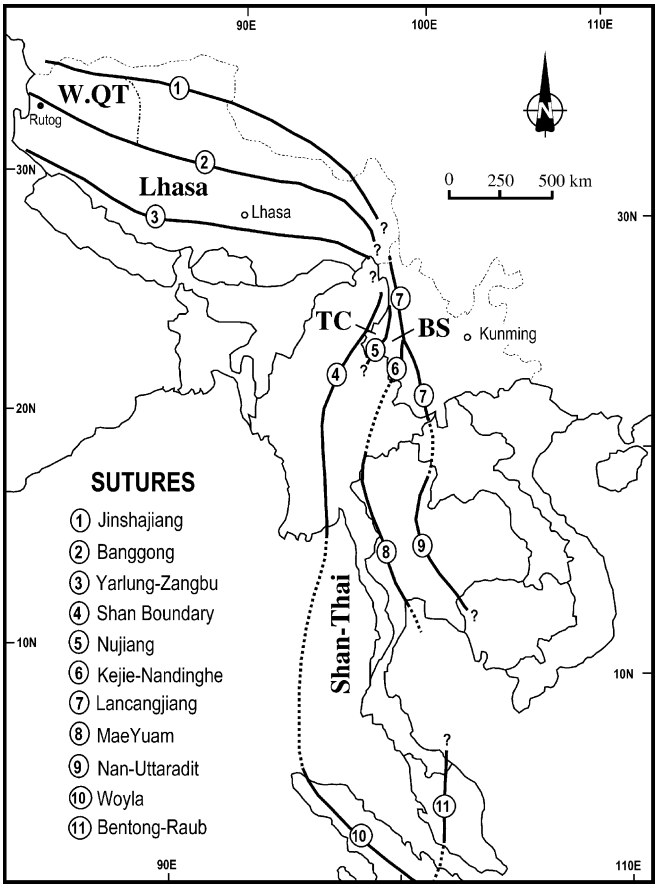

Fig. 1. Map of continental blocks (terranes) referred in this paper and their tectonic boundaries; W.QT: western Qiangtang Block; TC: Tengchong Block; BS: Baoshan Block.

Thailand and Malaysia on the east. This definition was debated by Jin (1996), and Ueno and Igo (1997), and recent paleontological evidence indicates that the eastern boundary of Sibumasu corresponds to the Mae Yuam (or Mae Sariang) Fault Zone, which is oriented north–south along the border between Thailand and Myanmar (Ueno and Igo, 1997). Here, the name Sibumasu is not used and instead we recognize Chinese blocks called Tengchong and Baoshan, separated from the Shan-Thai block in Myanmar, Thailand, Malaysia, and Sumatra (Fig. 1).

The threefold Lower Permian sequence of diamictites, pebbly mudstones, and dark-colored fine clastics (which may also include some Upper Carboniferous beds), occurs in the Shan-Thai Block. This threefold sequence, 1600–2000 m thick, is called the Lebyin Group and the Mergui Group in central Myanmar and Peninsular Myanmar, the Kaeng Krachen Group and the Phuket Group in southwestern Thailand and Peninsular Thailand, and the Singa Formation in the Langkawi Islands, Malaysia (Jin, 1996). These siliciclastic deposits contain few fossils, but include cool-water brachiopod fauna, a few solitary corals, and some bryozoans. The overlying limestone is known as the Ratburi Limestone in Peninsular Thailand (Fig. 2), the Plateau Limestone in the Shan States of Myanmar, and the Chuping Formation in northwestern Malaysia. The lowest part is composed of bedded black wackestones containing bryozoans, brachiopods, and some solitary corals (Fontaine et al., 1994a). The main part of the limestone contains a foraminiferal assemblage of low diversity and some massive corals that indicate a Wordian to Wuchiapingian age (Fontaine and Suteethorn, 1988; Ueno et al., 1996). However, Waterhouse (1981) stated that brachiopods from the lower part of the Ratburi Limestone indicate a Kubergandian (Roadian?) age. Strata overlying the Ratburi Limestone, or equivalent units, have, until now, been poorly known.

The Permian of the Baoshan Block has been extensively studied during the past twenty years. The northern part of the block contains a relatively complete stratigraphic sequence: the Lower Permian, represented by the Dingjiazhai Formation, is composed of diamictites and siliciclastic rocks with thin bedded carbonate intercalations and the Woniusi Formation consisting of basalts and basaltic clastics; the Middle Permian Bingma Formation (= Yongde Formation in the southern part of the block) contains shales, sandstones, and mudstones, and the Daaozi Formation is mostly shelf carbonates (Wang et al., 1999). A distinctive feature of this block is the absence of Upper

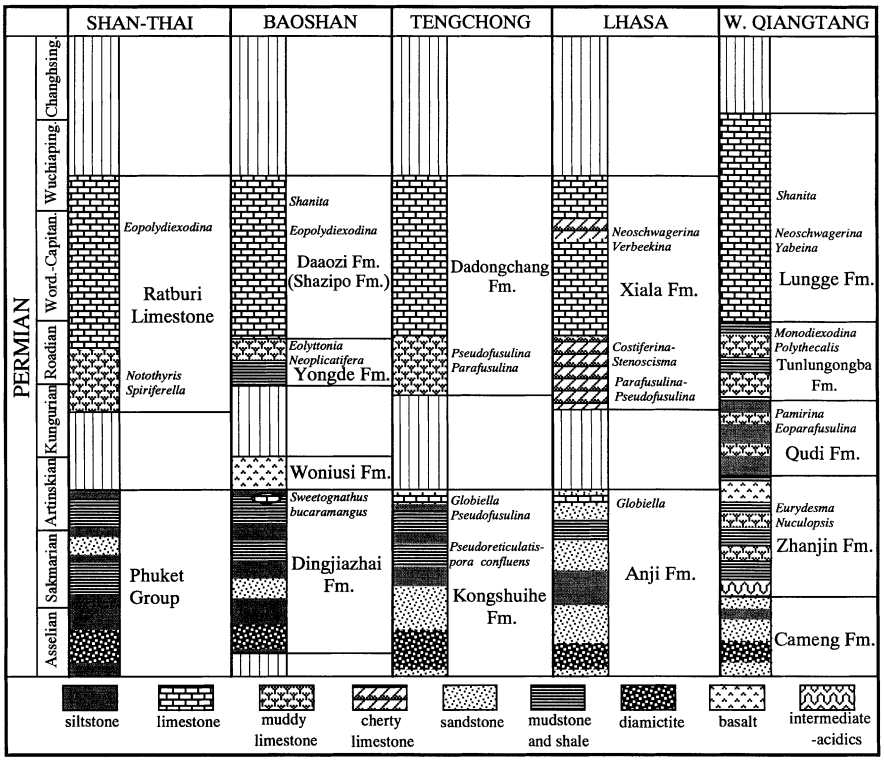

Fig. 2. Schematic correlation chart of the Permian in the eastern Cimmerian Continent.

Carboniferous rocks. An Asselian to early Artinskian age for the Dingjiazhai Formation is indicated by the conodont *Sweetognathus bucaramangus*, the fusulinid *Pseudofusulina-Eoparafusulina*, the brachiopod *Stenoscisma-Elivina*, and coral *Cyathaxonia* faunas (Shi et al., 1996; Wang et al., 1999). Brachiopod and coral faunas from the muddy limestones of the Yongde Formation and coral and fusulinid faunas from the limestones of the Daaozi (or Shazipo) Formation indicate a Middle Permian age. The presence of the small foraminifer *Shanita* in the upper part of the limestones suggests that Upper Permian rocks may occur in the Baoshan Block. The Lower Triassic Hewajie Formation overlies the Daaozi (or Shazipo) limestones disconformably.

The Permo-Carboniferous of the Tengchong Block, the westernmost block in West Yunnan, consists of a lower clastic interval and an upper carbonate interval. Two formations, the Zizhi Formation and the Kongshuihe Formation, are recognized in the clastic part and the upper carbonate part is the Dadongchang Formation (Jin, 1994). The Zizhi Formation is mainly sandstones and its age is still unclear because of the absence of fossils. The Kongshuihe Formation is composed of dark and black siltstones and mudstones, with irregular limestone intercalations. It contains Asselian and partially Sakmarian Gondwana-type spores and pollen (Yang, 1999), the *Globiella* (*Stepanoviella*) brachiopod fauna (Fang and Fan, 1994), and the *Pseudofusulina* fusulinid fauna (Nie et al., 1993). These all indicate an Asselian to Artinskian age. The Dadongchang Formation, overlying the Kongshuihe Formation unconformably, is characterized by black bryozoan limestones in the lower part, dark gray wackestones in the middle part, and dolomitic limestones in the upper part. The fairly diversified coral fauna in this formation indicates a Middle to early Late Permian age.

In the Lhasa Block, the Lower Permian consists of siliciclastics with pebbly mudstones which have been given many different names. Yin (1997) clarified these names, and only accepted the Anji Formation, which included Asselian to lower Artinskian siliciclastic deposits. As in the Dingjiazhai Formation of the Baoshan Block, the upper part of the Anji Formation contains several limestone intercalations. The brachiopod fauna from the Anji Formation is characterized by Gondwana-type forms including *Trigonotreta*, *Globiella*, *Bandoproductus*, and *Peruvispira,* associated with non-dissepimented solitary corals, bivalves, and bryozoans. The overlying Xiala Formation can be divided into three parts: lower cherty and bioclastic limestones; thick-bedded and dolomitic limestones in the middle; upper massive, cherty, and bioclastic limestones. The lower and middle parts contain the: *Costiferina-Stenoscisma* brachiopod Assemblage, the *Lytvolasma-Ufimia* non-dissepimented coral fauna, and the fusulinids *Parafusulina*, *Nankinella* and *Pseudofusulina*. These all indicate a Roadian (late Chihsian) age. The upper part of the Xiala Formation contains a highly diverse benthic fauna. The coral fauna is dominated by reef-type and large solitary taxa with dissepiments, that was named the *Iranophyllum-Ipciphyllum* Assemblage by Wu et al. (1982). The fusulinid

fauna is characterized by typically Cathaysian *Neoschwagerina* and *Verbeekina*. These fossils support a Wordian to Capitanian age.

The Qiangtang Block can be divided into western, central and eastern regions. The western region is also referred to as the Southeast Karakorum Block and had Cimmerian characteristics during the Late Paleozoic. The Lower Permian, consisting of siliciclastics, was named the Huoerbacuo Group and was subdivided into three units by Xia and Liu (1997) (Fig. 2). The Cameng Formation, the lower unit, consists mainly of non-fossiliferous sandy pebbly slates, interbedded with pebbly siltstones and sandstones. The middle unit, the Zhanjin Formation, is characterized by intermediate to acidic volcanics and basalts. Gondwanan bivalves *Eurydesma* and *Nuculopsis* occur in the calcareous sandstones and sandy limestones of the Zhanjin Formation. This formation also contains a non-dissepimented solitary coral fauna. The upper unit of the Huoerbacuo Group, the Qudi Formation, consists of silty slates and argillaceous limestone intercalations. The *Eoparafusulina-Pamirina* fauna of the Qudi Formation indicates an Artinskian to Kungurian age. The overlying Tunlunggongba Formation is dominated by alternating beds of fine clastics and argillaceous limestones. It contains *Monodiexodina* and *Polythecalis-Chusenophyllum* faunas, and therefore can be considered Roadian in age. A Wordian to Capitanian age is suggested for the massive limestones of the Lungge Formation, based on the fusulinids *Neoschwagerina* and *Yabeina* and the small foraminifer *Shanita*. The uppermost Permian consists of dolomitic limestones and sandstones containing the Lopingian corals *Waagenophyllum* and *Huayunophyllum*.

3. Coral faunas of the eastern Cimmerian Continent

3.1. Shan-Thai Block

Only one non-dissepimented solitary coral, *Euryphyllum* sp., has been recorded in the Lower Permian Phuket Group, Peninsular Thailand (Waterhouse, 1982). Corals occur relatively abundantly in the overlying Ratburi or Plateau limestones. These coral faunas include non-dissepimented solitary, large dissepimented solitary, fasciculate compound, massive compound, and tabulate corals. Based on the foraminifers and corals a Wordian to Capitanian age can be given (Fontaine et al., 1994b).

Five non-dissepimented coral species: *Amplexocarinia* sp., *Paracaninia* sp., *Lophophyllidium pendulum* Grabau, *Pleramplexus* sp., and *Ufimia* sp., were reported from the Ratburi Limestone of Peninsular Thailand (Fontaine et al., 1994b). They usually occur in bedded black wackestones and are associated with abundant bryozoans and brachiopods (Fontaine et al., 1994a). This fauna in similar to that from the Yongde Formation in the Baoshan Block. A non-dissepimented solitary coral, *Lophophyllidium orientale*, also occurs in the Plateau Limestone in the southern Shan States of Myanmar (Smith, 1941).

All large solitary and compound corals belong to the typical Middle Permian family Waagenophyllidae. In Peninsular Thailand, the coral faunas from the Ratburi Limestone contain solitary types including *Pavastehphyllum (Thomasiphyllum) yanagidai*, *P. (Sakamotosawanella) meesooki*, *P. (Pavastehphyllum)* sp., *P. (Pseudocarniaphyllum)* sp., and *Iranophyllum* sp., and compound types: *Paraipciphyllum thailandicum*, *P. kulvanichi*, *P.* sp., *Chombungia ratburian*, *Wentzelella megastomata*, *Polythecalis* (?) sp., and *Wentzelloides* (?) sp. Tabulate corals include *Sinopora asiatica*, *Pseudofavosites* sp., '*Michelinia*' (?) sp., and *Protomichelinia* sp. (Fontaine et al., 1979; Fontaine and Suteethorn, 1988; Fontaine and Jungyusuk, 1995; Sugiyama in Ueno et al., 1996). Some specimens assigned to *Paraipciphyllum kulvanichi* from the northern part of Peninsular Thailand (plate 13, figures 1 and 2; Fontaine and Suteethorn, 1988) probable belong to *Wentzellophyllum*. The well-developed vesicular septa, nearly complete wall, and local occurrence of tertiary septa are suggestive of *Wentzellophyllum shidianense* (Sung), a species from the Baoshan Block. A specimen of *Paraipciphyllum kulvanichi* from the Chom Bung area, Peninsular Thailand (Fontaine and Jungyusuk, 1995) is very similar to *Wentzellophyllum persicum* but the axial structure is slightly larger.

Smith (1941) described several Waagenophyllidae and tabulate corals from the Plateau Limestone of the southern Shan States. The rugose corals include *Pavastehphyllum* (*Thomasiphyllum*) *spongifolium* (Smith, 1941), *P.* (*Sakamotosawanella*) *carcinophylloides* (Douglas), *Waagenophyllum*? sp., *Wentzelella* cf. *timorica* (possibly *Wentzellophyllum*), and *Lonsdaleiastraea*? sp. Tabulate corals are *Pleurodictyum* (= *Protomichelina*) *siyangensis* and *Hayasakaia* (= *Multithecopora* or *Sinopora*) sp. The occurrence of *Waagenophyllum* indicates the possible existence of Wuchiapingian strata.

Of the three tabulate species discovered from the Shan-Thai Block, *Sinopora asiatica* Mansuy is the most common. This species also occurs widely in other areas of the Cimmerian Continent.

3.2. Baoshan Block

A *Cyathaxonia* fauna occurs in the upper part of the siliciclastic Dingjiazhai Formation. This coral fauna is Sakmarian to Artinskian in age, based on the associated conodonts *Sweetognathus bucaramangus* (Rabe) and *Sweetognathus inornatus* Ritter (Wang et al., 1999). The coral fauna includes four species: *Cyathaxonia* sp. A, *Claviphyllum*? sp., *Duplophyllum* sp., and *Paracaninia*? sp. Based on what is known of the Tethyan and adjacent regions, the only comparable faunas are these from the Qudi Formation in Rutog County, west Xizang (He and Weng, 1982), Anji Formation, Xainza, central Xizang (Yang and Fan, 1982; Zhao and Wu, 1986; Fan, 1988), and an unnamed Sakmarian

bed in South Afghanistan (Leven, 1997, p. 21). The South Afghanistan fauna includes *Paracaninia* sp., *Bradyphyllum* sp., *Amplexus* sp., and *Caninia* sp.

Middle Permian coral faunas were collected from two localities in the Baoshan Block. One is at Xiaoxinzhai Village, Gengma County in the southern part of the block. Only non-dissepimented solitary corals were obtained from the Yongde Formation at this site. They are *Lophophyllidium proliferum* (McChesney), *Lophophyllidium* sp., *Verbeekiella* sp., *Ufimia* sp., and an indeterminate species. The coral-bearing strata have been assigned to an interval from the late Kungurian to the Roadian, based on the brachiopods (Shi and Archbold, 1998). Another coral fauna characterized by Waagenophyllidae and tabulate corals also occurs at this locality. Recently, we collected abundant specimens of *Thomasiphyllum* from the lower part of the Shazipo Formation. *Thomasiphyllum* has a wide paleogeographical distribution, occurring in the Middle Permian of the Cimmerian Continent in West Sumatra (Fontaine, 1983, 1989), Peninsular Thailand (Fontaine, in Fontaine and Suteethorn, 1988; Ueno et al., 1996), Shan States of Myanmar (Smith, 1941), Central Xizang (Tibet) (Wu et al., 1982; Zhao and Wu, 1986), and Iran (Douglas, 1936, 1950). It should be noted that some corals from South China have also been identified as *Thomasiphyllum*, but these lack real vesicular septa and globose dissepiments and thus should be excluded from this genus. In addition, several massive colonies, including *Paraipciphyllum*, *Protolonsdaleiastraea*, an indeterminate Waagenophyllidae with vesicular septa and thick wall, and the tabulate *Sinopora*, also occur in the lower part of the Shazipo Formation.

Another locality yielding Middle Permian corals is at Jinji Village, near Baoshan City. This fauna is also characterized by a low diversity of corals containing two massive rugose species, both from the Daaozi Formation *Wentzellophyllum persicum* (Douglas), *Wentzellophyllum shidianense* (Sung), and the tabulate *Sinopora asiatica* (Mansuy). *Wentzellophyllm persicum* has also been reported from Iran (Douglas, 1936), Iraq (Hudson, 1958), and the Lhasa Block (He, in Yang et al., 1990) where it is associated with *Ipciphyllum ipci*, a typical Capitanian species in South China.

Song (Geological Bureau of Yunnan, 1974) described several species of *Ipciphyllum* from the Daaozi Formation, Shidian County, including *Ipciphyllum shidianense* Sung, *Ipciphyllum* aff. *subtimorica* (Huang), *Ipciphyllum vesiculosum* Sung, and *Ipciphyllum floriformis* Sung. The specimens of *Ipciphyllum shidianense* and *Ipciphyllum floriformis* figured by Song are probably a single species of *Wentzellophyllum*; they contain tertiary septa and lonsdaleoid dissepiments. Two other species illustrated by Song may also be synonymous, but comparisons are impossible because the figures are unclear.

Late Permian corals are unknown from this block.

3.3. Tengchong Block

A list of Early Permian corals from the Kongshuihe Formation is given by Nie et al.(1993) without any illustration or description. This coral fauna is composed of such non-dissepimented solitary types as *Pseudobradyphyllum* sp., *Lophophyllidium* sp., *Tachylasma* (= *Ufimia*) sp., *T. zhajeense*, and *Cyathaxonia*? sp. The coral-bearing strata are underlain by shales containing Sakmarian spores and pollen (Yang, 1999), which indicate possibly a Sakmarian or younger age for the coral fauna.

The overlying Dadongchang Formation contains the following corals: solitary *Lophophyllidium* sp., *Verbeekiella* sp. and *Iranophyllum* sp.; fasciculate *Waagenophyllum kueichowense* and *Praewentzelella* sp.; massive *Paraipciphyllum* sp., *Lonsdaleiastraea* sp. A and B; and the tabulate *Sinopora xainzaensis*. *Waagenophyllum kueichowense* is a common species from the upper Middle Permian to the lower Upper Permian in the Tethys area. *Paraipciphyllum* sp. is similar to *Paraipciphyllum thailandicum* from the Ratburi Limestone of Peninsular Thailand (Fontaine and Suteethorn, 1988; Ueno et al., 1996), but all specimens from Tengchong have fewer major septa. *Lonsdaleiastraea* sp. B resembles *Lonsdaleiastraea iranica* Ezaki from the Surmaq Formation of Central Iran (Ezaki, 1991). *Iranophyllum* sp. is very similar to *Iranophylloides* described by Lin (1983) from Xainza, Central Xizang and assigned to *Iranophyllum* by Lin et al. (1995). *Sinopora xainzaensis* is a species from Xainza, Central Xizang. *Praewentzelella* sp. is similar to *Xainzaphyllum longiseptatum* Wang from Xainza, Lhasa Block. The genus *Xainzaphyllum* was later included in *Praewentzelella* by Lin et al. (1995). Except for the two solitary corals *Lophophyllidium* and *Verbeekiella*, from lower part of the Dadongchang Formation, all compound corals and the one tabulate species were obtained from the middle of the formation. This compound coral fauna could be late Middle Permian (Wordian or Capitanian) to Early Wuchiapingian in age.

3.4. Lhasa Block

Early Permian (Sakmarian?) corals have been recovered from the Anji Formation (or equivalent strata), at Xainza, central Xizang (Tibet) (Yang and Fan, 1982; Zhao and Wu, 1986; Fan, 1988). The fauna contains only non-dissepimented solitary types, such as *Amplexus*? *romanovskyi* Fomitchev, *Cyathaxonia lomonosovi* Fomitchev, *Lophophyllidium sauridens* (White), *Lophophyllidium* sp., *Verbeekiella* sp., *Amplexocarinia* sp., *Ufimia* sp., *Meniscophyllum stereoseptatum* Fan, *Bradyphyllum bellicostatum* Grabau, and *Paracaninia* sp. This fauna is possibly correlative with the Dingjiazhai fauna of the Baoshan Block.

A Late Chihsian (Roadian) coral fauna occurs in the lower and middle parts of the Xiala Formation and equivalent strata at Xainza, Lhuzab, Shiquanhe, and Gegyai. This fauna is characterized by non-dissepimented solitary corals

and has been named the *Lytvolasma-Ufimia* assemblage (see Yin, 1997). This solitary coral fauna consists of up to 18 rugose and four tabulate genera, including rugosans: *Cyathaxonia*, *Cyathacarinia*, *Paralleynia*, *Amplexocarinia*, *Metriophyllum*, *Duplophyllum*, *Rotiphyllum*, *Lytvolasma*, *Amplexus*, *Calophyllum*, *Pentaphyllum*, *Ufimia*, *Lophophyllidium*, *Lophocarinophyllum*, *Timorphyllum*, *Verbeekiella*, and *Cravenia*, and the tabulate genera: *Pseudofavosites*, *Neomultithecopora*, *Sinopora*, and *Multithecopora* (Wang and Liu, 1982; Wu et al., 1982; Fan, 1988; Zhao, 1991; Lin, 1983). Associated groups are the *Costiferina-Stenoscisma gigantea* brachiopod Assemblage and fusulinids *Parafusulina* sp. and *Pseudofusulina* sp. No compound rugose corals were found in this interval.

The Maokouan (Wordian–Capitanian) coral fauna is dominated by Waagenophyllidae and was named the *Iranophyllum-Ipciphyllum* assemblage by Wu et al. (1982). Abundant massive corals with Cathaysian affinities occur in the upper part of the Xiala Formation at Xainza, Lhuzab, Gegyai, and other localities (He and Weng, 1982; Wu et al., 1982; Lin, 1983; Zhao and Wu, 1986; Zhao, 1991). This fauna is composed of 10 massive rugosan genera (37 species), four fasciculate genera (six species), seven dissepimented solitary genera (23 species), six small non-dissepimented solitary genera (12 species), and five tabulate genera (14 species). The dissepimented solitary and compound corals are: *Pavastehphyllum*, *Thomasiphyllum*, *Iranophyllum*, *Zhenganophyllum*, *Sakamotosawanella*, *Sarcinophyllum*, *Akagophyllum*, *Pseudohuangia*, *Praewentzelella*, *Xizangophyllum*, *Axopinnophyllum*, *Lonsdaleiastraea*, *Ophryphyllum*, *Wentzellophyllum*, *Ipciphyllum*, *Paraipciphyllum*, *Tibetophyllum*, *Wentzelella*, *Prowentzelellites*, *Wentzelellites*, *Wentzelloides*. Among them, *Sarcinophyllum*, *Xizangophyllum*, *Axopinnophyllum*, *Ophryphyllum*, and *Tibetophyllum* are endemic genera occurring only in this block. Some, such as *Thomasiphyllum*, and species of *Wentzellophyllum*, are typical Cimmerian elements. Other taxa are the main representatives of the upper Middle Permian in Cathaysian areas such as South China and Indochina. Associated fusulinids, which indicate a Maokouan age, include *Neoschwagerina*, *Rugososchwagerina*, *Verbeekina*, *Yangchienia*, *Yabeina*, *Chusenella*, and others (Zhu, 1982).

Lopingian corals of the block are represented by three indeterminate species of *Waagenophyllum* from Baxoi and Xainza (Wu et al., 1982) and *Huayunophyllum xiaganjanense* from Gaize (He, in Yang et al., 1990).

3.5. Western Qiangtang Block

The Zhanjin Formation of the Huoerbacuo Group contains a non-dissepimented solitary coral fauna. This fauna was named the *Amplexocarinia-Cyathaxonia* assemblage by He (in Yang and Nie, 1990), and includes *Amplexocarinia* cf. *muralis*, *Cyathaxonia* sp., *Lophophyllidium* sp., *Rotiphyllum* sp., and *Calophyllum* sp. Based on the association with the typical Gondwanan bivalve *Eurydesma,* these corals are probable Asselian to Sakmarian in age. The overlying Qudi Formation and lowest Tunlunggongba Formation contain an Artinskian to Kungurian *Eoparafusulina-Pamirina* fusulinid assemblage (Nie and Song, in Yang et al., 1990).

A Roadian coral fauna was named the *Polythecalis-Chusenophyllum* assemblage by He (in Yang and Nie, 1990). This assemblage is composed mainly of massive Waagenophyllidae: *Polythecalis*, *Chusenophyllum*, *Wentzellophyllum*, *Pseudopolythecalis*, *Parapolythecalis*, with a few solitary corals: *Ufimia* and *Paracaninia*. This assemblage was collected from the middle part of the Tunlunggongba Formation at Doumar, Rutog County, West Xizang (Tibet) and can be correlated with the *Polythecalis* zone of the Upper Chihsian in South China. The *Monodiexodina* fusulinid fauna also occurs in this interval.

Wordian coral fauna was collected from the upper part of the Tunlunggongba Formation and is composed of the non-dissepimented solitary corals: *Lytvolasma*, *Ufimia*, *Paracaninia*, *Pentaphyllum*, *Lophophyllidium*, and tabulate corals: *Tetraporinus*, *Protomichelinia*, *Sinopora*, and *Petraiella*. The fauna was named the *Lytvolasma-Tachylasma* assemblage (He and Weng, 1982; He, in Yang and Nie, 1990). The associated brachiopod assemblage is the *Stenoscisma ornata-Costiferina sinensis* assemblage (see also Yin, 1997).

The Lungge Formation at Doumar, Rutog County contains a Capitanian coral assemblage named the *Iranophyllum-Tibetophyllum* Assemblage by He (in Yang et al., 1990). It is associated with the fusulinids *Neoschwagerina* and *Yabeina* and contains *Iranophyllum splendens* Douglas, *I. tunicatum* Igo, *I. curvaseptatum* He and Weng, *I. zangeiense* He and Weng, *I. cylindricum* He, *Wentzelella katoi* Flugel, and *Tibetophyllum sinense* (He and Weng, 1982).

A fasciculate Waagenophyllidae *Huayunophyllum minor* He (in Yang et al., 1990) occurs at Doumar, Rutog, which indicates a possible presence of Lopingian strata in the area.

4. Discussion and conclusions

Late Carboniferous corals are unknown from the eastern Cimmerian Continent because of a depositional hiatus, as clearly recognized in the Baoshan Block (Wang et al., 1999). This absence of coral faunas was followed by Early Permian coral faunas characterized by non-dissepimented solitary types. Previously this was known as the *Cyathaxonia* fauna and was considered indicative of stressed environments. These possible Sakmarian non-dissepimented solitary coral faunas on different blocks can be, more or less, correlated with one another, using such common taxa as *Cyathaxonia* and *Ufimia*. These faunas themselves cannot supply sufficient paleogeographical information, because these genera are mainly cosmopolitan. The absence of Kepingophyllidae, Waagenophyllidae, and

		SHAN-THAI	BAOSHAN	TENGCHONG	LHASA	W. QIANGTANG	Paleogeographical change
PERMIAN	Lopingian	*Waagenophyllum*		*Waagenophyllum*	*Waagenophyllum* *Huayunophyllum*	*Huayunophyllum*	Cathaysian
	Wordian - Capitanian	*Thomasiphyllum, Sakamoto-sawanella, Pavastehphyllum, Pseudocarniaphyllum, Iranophyllum, Paraipciphyllum, Chombungia, Wentzelella, Polythecalis?, Wentzelloides?, Wentzellophyllum, Lonsdaleiastraea?, Sinopora, Pseudofavosites, Protomichelinia,*	*Thomasiphyllum* *Paraipciphyllum* *Wentzellophyllum* *Ipciphyllum?* *Sinopora*	*Iranophyllum* *Praewentzelella* *Paraipciphyllum* *Lonsdaleiastraea* *Sinopora*	*Thomasiphyllum, Pavastehphyllum, Iranophyllum, Zhenganophyllum, Sakamotosawanella, Sarcinophyllum, Akagophyllum, Pseudohuangia, Praewentzelella, Xizangophyllum, Axopinnophyllum, Lonsdaleiastraea, Ophryphyllum, Wentzellophyllum, Ipciphyllum, Paraipciphyllum, Tibetophyllum, Wentzelella, Prowentzelellites, Wentzelellites, Wentzelloides*	*Lytvolasma, Ufimia, Paracaninia, Pentaphyllum, Lophophyllidium, Iranophyllum, Wentzelella, Tibetophyllum, Tetraporinus, Protomichelinia, Sinopora, Petraiella*	Cimmerian
	Roadian	*Amplexocarinia* *Paracaninia* *Lophophyllidium* *Pleramplexus* *Ufimia*	*Lophophyllidium* *Verbeekiella* *Ufimia*	*Verbeekiella* *Lophophyllidium*	*Cyathaxonia, Cythacarinia, Paraleynia, Amplexocarinia, Metriophyllum, Duplophyllum, Rotiphyllum, Lytvolasma, Amplexus, Calophyllum, Pentaphyllum, Ufimia, Lophophyllidium, Lophocarinophyllum, Timorphyllum, Verbeekiella, Cravenia, Pseudofavosites, Neomultithecopora, Sinopora, Multithecopora*	*Polythecalis* *Chusenophyllum* *Wentzellophyllum* *Pseudopolythecalis* *Parapolythecalis* *Ufimia* *Paracaninia*	
	Kun.						
	Ass. - Art.	*Euryphyllum*	*Cyathaxonia* *Claviphyllum?* *Duplophyllum* *Paracaninia?*	*Pseudobrady-phyllum* *Lophophyllidium* *Ufimia* *Cyathaxonia?*	*Amplexus?, Cyathaxonia, Lophophyllidium, Verbeekiella, Amplexocarinia, Ufimia, Meniscophyllum, Bradyphyllum, Paracaninia*	*Amplexocarinia* *Cyathaxonia* *Lophophyllidium* *Rotiphyllum* *Calophyllum*	Peri-Gondwana

Fig. 3. Coral genera in the Permian of the eastern Cimmerian Continent and their paleobiogeographical occurrence.

other large dissepimented corals, all of which occur abundantly in South China and other Tethyan regions, allows differentiation between the eastern Cimmerian Continent and Tethyan regions. During the Early Permian, the eastern Cimmerian Continent was still located at the northern margin of Gondwana rather distant from the Cathaysian Continent. This conclusion is consistent with paleobiogeographical conclusions based on other fossil groups, e.g. brachiopods (Shi et al., 1996), and spores and pollen (Yang, 1999). The Early Permian *Cyathaxonia* faunas may reflect cold or cool water as mentioned for the Baoshan Block by other authors (e.g. Fang and Fan, 1994) as suggested by the underlying diamictites which are regarded as glacial in origin (Jin, 1994; Wopfner, 1996).

Roadian strata of the eastern Cimmerian Continent are also characterized by non-dissepimented solitary corals, with one exception, namely the western Qiangtang Block where massive Waagenophyllidae dominate. These Roadian non-dissepimented corals are usually associated with brachiopods and bryozoans and are usually preserved in mudstones, calcareous shales, and muddy limestones. They occur respectively in the lower part of the Ratburi Limestone in Peninsular Thailand; Yongde Formation in the southern part of the Baoshan Block; the lower part of the Dadongchang Formation in the Tengchong Block; and the lower and middle parts of the Xiala Formation in the Lhasa Block. The Lhasa Block contains the greatest diversity of corals. Predominant genera are *Lophophyllidium*, *Ufimia*, and *Lytvolasma* which are associated with the *Costiferina-Senoscisma* brachiopod assemblage and, in some place, the fusulinids *Parafusulina* and *Pseudofusulina*. Lack of the large solitary and compound corals, which are common in Cathaysia, indicates that the Cimmerian Continent was still an independent paleobiogeographical region. At this time, the Cimmerian Continent was probably detached from the northern Gondwana, and drifting northward, but was still some distance from the Cathaysian Continent.

Wordian and Capitanian coral faunas are dominated by both solitary and compound Waagenophyllidae, which are also common elements in Cathaysia, but there are several faunal differences. These include typical Cimmerian taxa, including *Thomasiphyllum* and *Wentzellophyllum persicum*, and the abundance of *Iranophyllum* and *Paraipciphyllum*. Only the Lhasa Block can be well dated from the Wordian to the Capitanian, using *Ipciphyllum* and the associated fusulinids *Neoschwagerina* and *Yabeina*. The blocks within the eastern Cimmerian Continent, however, can be correlated with one another by not only common corals, but also by common fusulinid taxa. These blocks were at different latitudes as shown by the diversity and abundance of corals. The Shan-Thai, Baoshan, and Tengchong blocks were located farther south than the Lhasa Block and the western Qiangtang Block (Wang et al., 2001) as indicated by the low

diversity of the Middle Permian corals in the former three blocks and the high diversity and abundance in the latter two blocks. This conclusion is also consistent with the paleogeographical reconstruction of the Cimmerian Continent by Metcalfe (1996), and Shi and Archbold (1998).

Lopingian corals, represented by fasciculate Waagenophyllidae, occur sporadically in the eastern Cimmerian Continent, and show typical Cathaysian affinity, even at the species level.

Therefore, the Permian coral faunas in the eastern Cimmerian Continent exhibit a characteristic transition from the Sakmarian to the Wuchiapingian (Fig. 3). During Sakmarian to Roadian time, non-dissepimented solitary coral faunas of the eastern Cimmerian Continent have Peri-Gondwanan affinities. From Wordian to Capitanian the abundance of Cathaysian corals occur together with some endemic taxa, but by the Wuchiapingian, Cathaysian coral species dominated.

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