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Darriwilian *Saucrorthis* Fauna: implications for the Great Ordovician Biodiversification Event (GOBE)

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Abstract. The *Saucrorthis* Fauna is a brachiopod-dominated shelly fauna developed in relatively deeper-water benthic regimes of a few peri-Gondwana terranes (e.g. northern Iran) and palaeoplates (South China and Sibumasu) during the Darriwilian (late Middle Ordovician). It has its longest geological range, widest palaeogeographic distribution, most abundant and diversified brachiopod taxonomic composition and most complex palaeoecological differentiation in South China, where it concentrated in the centre of the Upper Yangtze Platform. The generally low similarity coefficients (<0.3) between any two representatives of the *Saucrorthis* Fauna firmly support a statement about the Great Ordovician Biodiversification Event (GOBE) that strong endemism or provincialism made a great contribution to the second pulse of the Ordovician brachiopod radiation in South China, which might also be true for the international trend.

Key words: *Saucrorthis* Fauna, Darriwilian (Middle Ordovician), Great Ordovician Biodiversification Event, GOBE, South China.

INTRODUCTION

The Darriwilian (late Middle Ordovician) *Saucrorthis* Fauna is a brachiopod-dominated normal marine shelly fauna characterized by the small- to medium-shelled, costate eponymous genus and the predominance of some common orthides (e.g. *Orthambonites* and *Parisorthis*) and strophomenides (e.g. *Leptellina*, *Calyptolepta* and *Bellimurina*) (Fig. 1). The genus *Saucrorthis* of the subfamily Productorthinae was named 40 years ago from the calcareous mudstone of the Shihtzupu Formation (Darriwilian) at Shizipu of Zunyi, northern Guizhou Province, southwest China (Xu et al. 1974), but the *Saucrorthis* Fauna as a whole was first recognized by Zhan et al. (2007) as a unique benthic shelly fauna representing the second diversity acme of the Ordovician brachiopod radiation in South China. *Saucrorthis* is now known to be widely distributed on the Upper Yangtze Platform of the South China palaeoplate, and also at some localities in the Shan States (Myanmar, Sibumasu palaeoplate) and the Alborz Mountains (northern Iran, peri-Gondwana terrane), but the taxonomic composition of the *Saucrorthis* Fauna at different localities varies substantially. Another Darriwilian brachiopod fauna, the *Aporthophyla* Fauna, has a much wider distribution than the *Saucrorthis* Fauna but shows a similar or slightly lower latitudinal affinity. They rarely occur together in the rocks with just one exception at Wudang of Guiyang, central Guizhou, southwest China. This paper is to document the occurrences of the *Saucrorthis* Fauna and to investigate its implications for the Great Ordovician Biodiversification Event (GOBE) by comparing its taxonomic composition and palaeogeographic distribution with those of the *Aporthophyla* Fauna. The specimens studied are housed in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, with a prefix NIGP for each number.

STRATIGRAPHICAL AND GEOGRAPHICAL DISTRIBUTION OF THE *SAUCRORTHIS* FAUNA

Since its establishment in the 1970s (Xu et al. 1974, p. 150), *Saucrorthis* has been found at almost all localities of the Shihtzupu Formation on the Upper Yangtze Platform covering a large area in Guizhou, Yunnan, Sichuan and Hubei provinces and Chongqing Municipality (Zhan & Jin 2005b; Liang & Zhan 2012) (Fig. 2A). Besides, it is also known from the Dashaba Formation (Darriwilian) of Shuanghe, Changning County, southern Sichuan Province (Zhan & Jin 2005a), the upper Houping Formation (middle–upper Darriwilian) of Houping, Chengkou County, northern Chongqing Municipality (Zhu et al. 1977; Chen et al. 1995), and the Kuniutan Formation (Darriwilian) of Wudang, Guiyang,

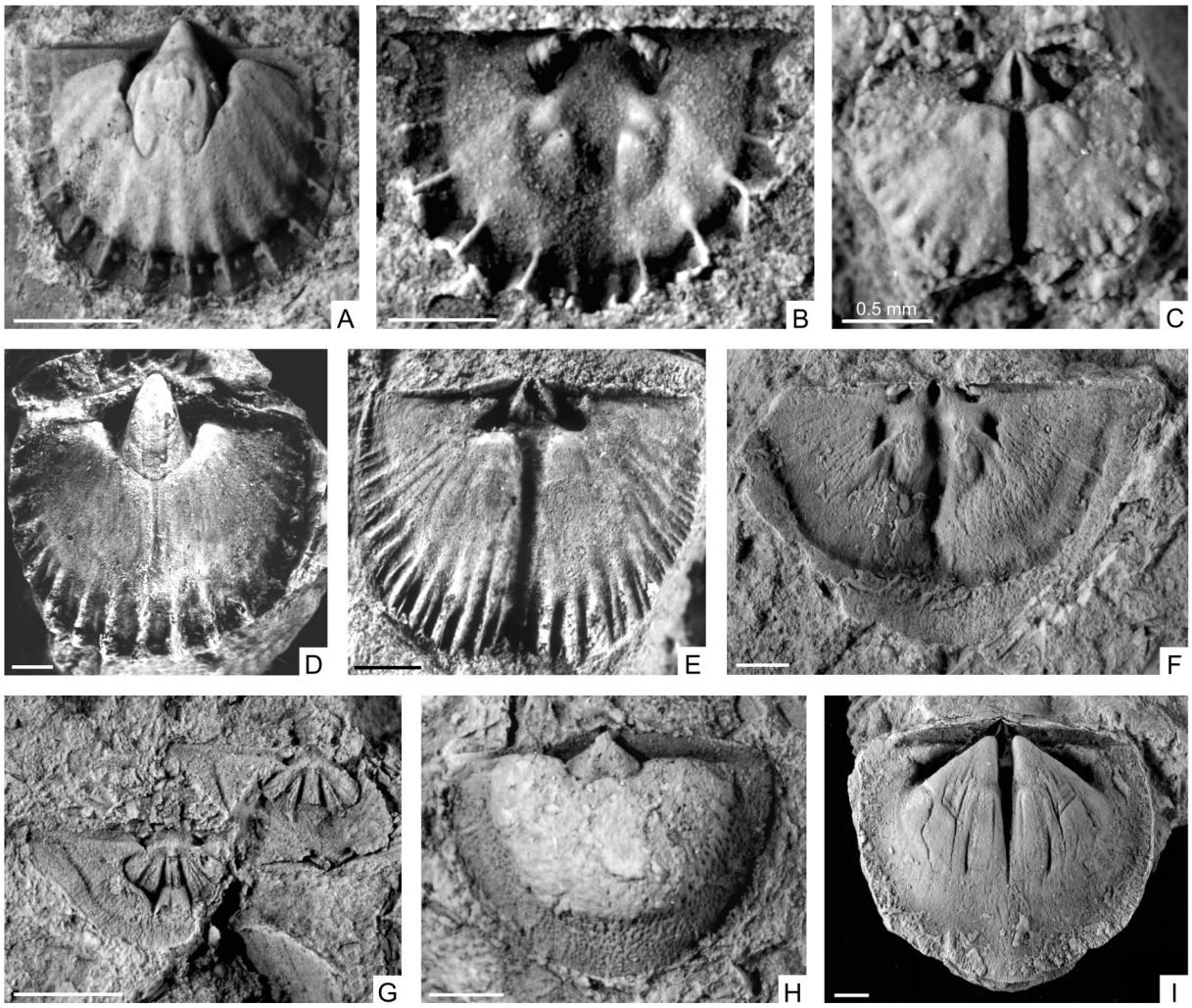

Fig. 1. Representative brachiopods of the *Saucrorthis* Fauna. **A**, **B**, *Saucrorthis minor*, A, NIGP136194, ventral internal mould; B, NIGP136369, dorsal internal mould. **C**, *Protoskenidioides weixinensis*, NIGP139097, dorsal internal mould. **D**, *Orthambonites delicata*, NIGP134299, ventral internal mould. **E**, *Parisorthis dischidanteris*, NIGP134347, dorsal internal mould. **F**, *Leptellina spatiosa*, NIGP139117, dorsal internal mould. **G**, *Calyptolepta huanghuaensis*, NIGP139142, dorsal internal moulds. **H**, *Leptestiina veturna*, NIGP139146, ventral internal mould. **I**, *Martellia ichangensis*, NIGP139158, dorsal internal mould. A, B, from the Shihtzupu Formation at Shizipu, Zunyi, northern Guizhou; C, F–I, from the upper Shihtzupu Formation at Shizigou, Weixin, northeastern Yunnan Province, southwest China; D, E, from the Dashaba Formation at Shuanghe, Changning County, southern Sichuan Province, southwest China. Scale bars = 1 mm unless otherwise noted.

central Guizhou (Rong et al. 2005), all of which were on the Upper Yangtze Platform. Although the Darriwilian rocks are also well developed and widespread on the Lower Yangtze Platform and even the Kuniutan Formation could extend to parts of the Lower Yangtze Platform (Chen et al. 1995; Liang & Zhan 2012), there are no documentations on the occurrences of *Saucrorthis* and the *Saucrorthis* Fauna yet. Such a phenomenon may have been caused by the local environment where the water depth was too great for *Saucrorthis* to survive in the Lower Yangtze Platform. On the regional scale, the *Saucrorthis* Fauna is most abundant in the central part of the Upper Yangtze Platform in the area of the Shihtzupu (e.g. CWX in Appendix) and the Dashaba (CCN in Appendix) formations and decreases sharply in diversity in nearshore and more offshore localities (Fig. 2A).

After careful taxonomic revision and redescription in the light of modern brachiopod studies conducted by Cocks & Zhan (1998), the brachiopod fauna from the Naungkangyi Group and its equivalents of southern Shan States, Myanmar, is proven to be very close to that

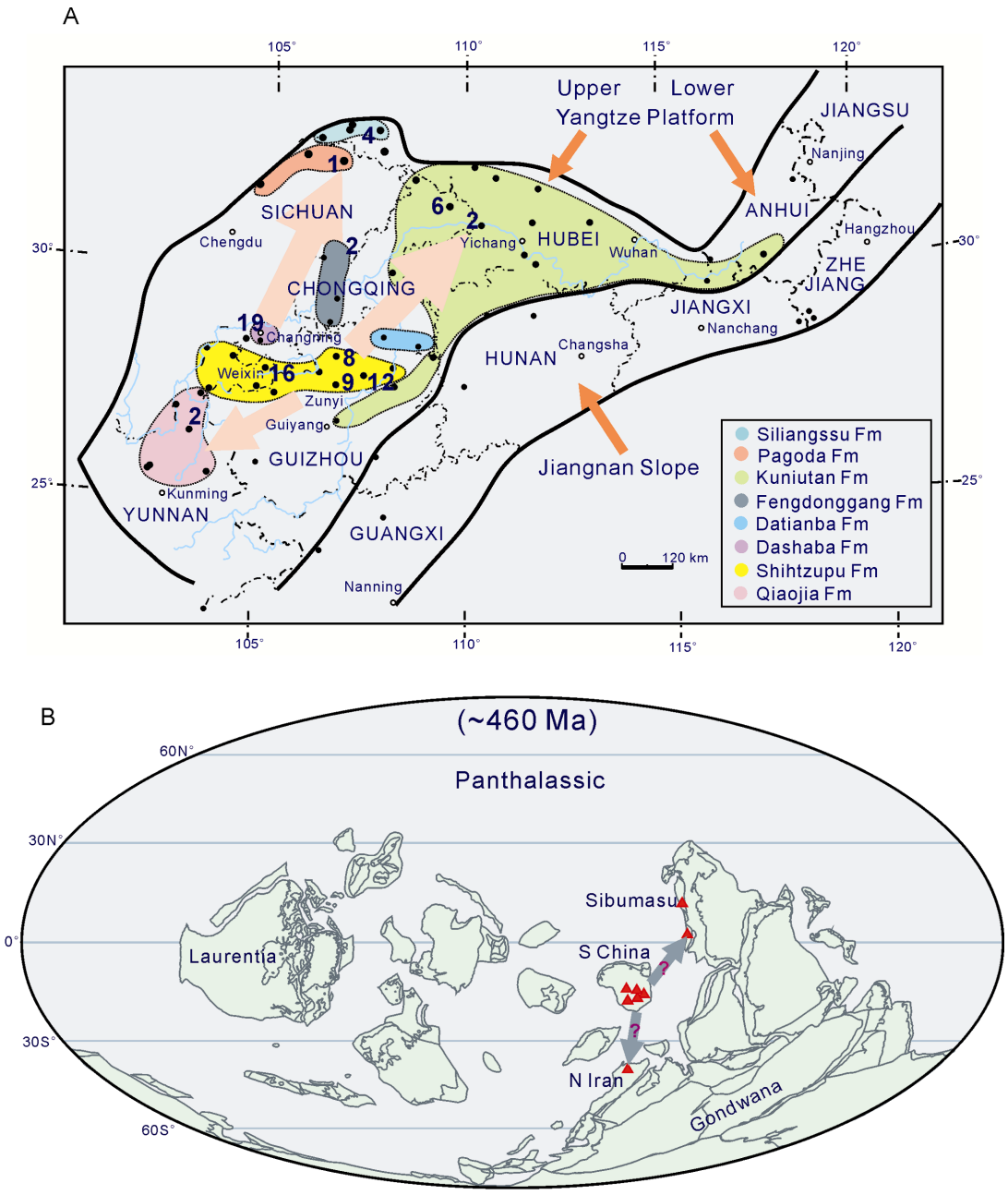

Fig. 2. Geographic and palaeogeographic distributions of the *Saucrorthis* Fauna. **A**, Darriwilian lithological units developed on the Upper and Lower Yangtze Platform of the South China palaeoplate, and the diversity change of the *Saucrorthis* Fauna from the Shihtzupu and Dashaba formations to the Kuniutan, Qiaojia, Fengdonggang and Siliangssu formations (modified from Liang & Zhan 2012). Numbers 1–19 in the map represent the number of brachiopod genera of the *Saucrorthis* Fauna at each particular locality on the Upper Yangtze Platform. Hollow circles indicate the cities and solid circles the section sites we investigated. **B**, regional distribution of the *Saucrorthis* Fauna (indicated by red solid triangles) showing its marginal Gondwanan affinity and possible migration routes (base map after Torsvik & Cocks 2013).

of the Shihtzupu Formation of South China (e.g. CWX in Appendix) and represents another occurrence of the *Saucrorthis* Fauna in the Sibumasu palaeoplate (detailed faunal list of BST in Appendix). It contains 31 genera and 37 species of brachiopods, representing one of the most diversified occurrences of the fauna. Unfortunately it was mistakenly thought to be of Late Ordovician age (Caradoc, i.e. Sandbian) when it was correlated with

that of the Shihtzupu Formation (Cocks & Zhan 1998). A new association of the *Saucrorthis* Fauna, the *Saucrorthis–Leptestiina* Association, has been reported in the Sibumasu palaeoplate from the Shihtien Formation (Darriwilian) in the Baoshan–Shidian area, western Yunnan, southwest China (Zhan et al. 2014a). It also has a pretty high brachiopod diversity including 27 genera such as *Antigonambonites*, *Atelelasmoidea*, *Baoshania*, *Calyptolepta*, *Dedzetina*, *Glyptomena*, *Glyptorthis*, *Horderleyella*, *Leptastichidia*, *Leptellina*, *Leptestiina*, lingulid indet., *Martellia*, *Nicolella*, *Nothorthis*, *Orthambonites*, *Paralenorthis*, *Peritritoechia*, *Plectorthis*, *Porambonites*, porambonitid indet., *Protoskenidioides*, *Pupiaoia*, rhynchonellid indet., *Saucrorthis*, *Strophomena* and *Sulcatorthis* (detailed systematic work on this fauna is going on). Similar to the other representatives of the *Saucrorthis* Fauna or any other Darriwilian non-*Saucrorthis* brachiopod communities or associations, this association is taxonomically composed of mainly orthides and strophomenides (particularly plectambonitoids).

Also marginal to the Gondwana supercontinents, the Alborz Mountains of northern Iran were reported to yield some brachiopods apparently attributable to the *Saucrorthis* Fauna from the lower Lashkarak Formation (middle Darriwilian) (detailed faunal list of IDM in Appendix) (Ghobadi Pour et al. 2011) (Fig. 2B). Based on both outdoor and indoor preliminary investigations, only five brachiopod genera are known to occur, dominated by two local endemics *Bastamorthis* and *Semnanostrophia* (Ghobadi Pour et al. 2011). Besides, some other groups of fossils also occur in the rocks, such as, e.g., echinoderms, trilobites and conodonts.

Up to now, South China is the region where the *Saucrorthis* Fauna has its longest geological range (extending for the entire Darriwilian), the widest geographic and palaeogeographic distribution (several hundreds of kilometres long and wide), the most abundant constituents (the amount of fossils) and the most complicated palaeoecological differentiation from nearshore shallow-water to offshore deeper-water benthic settings. There is another interesting phenomenon about the *Saucrorthis* Fauna. The trilobite *Neseuretus*, a cool and relatively deeper-water environment indicator (Ghobadi Pour et al. 2011), is found to occur together with the *Saucrorthis* Fauna in Myanmar and western Yunnan, southwest China (Sibumasu palaeoplate) and northern Iran (peri-Gondwana terrane), but never in South China where it was also widespread, flourished and highly diversified on the species level before the appearance of *Saucrorthis* during the late Floian and Dapingian (Zhou & Dean 1989; Zhou & Zhou 2008; Zhou Zhiyi pers. comm. 2014).

IMPLICATIONS FOR THE GOBE

In order to analyse the relationships between different representatives of the *Saucrorthis* Fauna, we selected six communities or associations plus one outgroup association from southern Tibet for comparison: four from different lithological units on the Upper Yangtze Platform of the South China palaeoplate and one from Myanmar of the Sibumasu palaeoplate and northern Iran of the peri-Gondwana terrane, respectively (see Appendix for detailed faunal lists).

Among 53 brachiopod genera involved in the numerical analyses, 37 (70%) are known from only one locality, 15 (28%) from two or three localities (amongst which most from localities of the South China palaeoplate), and only the eponymous genus is common to all localities. The cluster analysis (CA, Fig. 3) shows that the similarity coefficient between any two representatives of the *Saucrorthis* Fauna is always less than 0.3 although several similarity measures are tried under the algorithm 'paired group'. The association from the Lower Formation of the Chiatsun Group of southern Tibet (CTJ in Appendix) has a very low similarity coefficient (less than 0.1) with any other associations or communities with *Saucrorthis*, indicating the substantial difference between the *Aporthophyla* Fauna and the *Saucrorthis* Fauna.

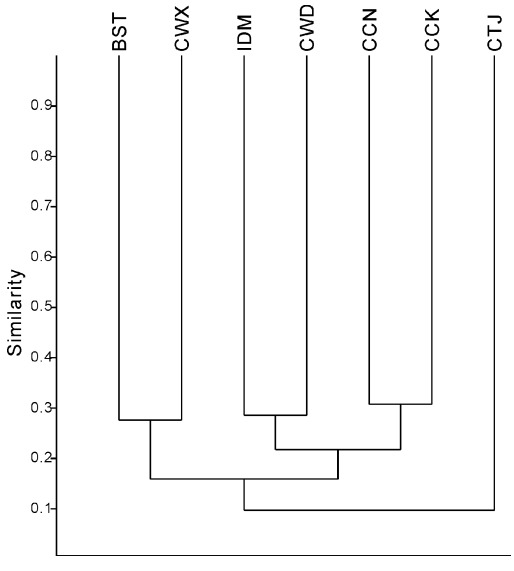

Fig. 3. Cluster analysis (CA) of six representatives of the *Saucrorthis* Fauna in the South China palaeoplate (4), Sibumasu palaeoplate (1) and peri-Gondwana terrane (northern Iran) (1) with the contemporaneous association from the Lower Formation of the Chiatsun Group of southern Tibet as an outgroup, showing the strong endemism and provincialism during late Middle Ordovician time.

The late Middle Ordovician has been shown to be an interval when strong endemism and provincialism occurred in marine shelly faunas (Williams 1973; Jaanusson 1979), and when the GOBE got its first diversity acme on a global scale for all marine organisms (Webby 2000), the brachiopods in particular (Harper et al. 2004). The case study conducted in South China further indicates that the appearance and flourishing of typical regional shelly faunas made an essential contribution to the GOBE in each particular palaeoplate or terrane, e.g. the *Saucrorthis* Fauna in the Sibumasu palaeoplate in South China and the peri-Gondwana terrane in northern Iran.

Compared with another widespread Darriwilian shelly fauna, the *Aporthophyla* Fauna (CTJ in Appendix) (Zhan et al. 2014a), the *Saucrorthis* Fauna is rather limited in its palaeogeographic distribution confined to peri-Gondwana. Both of them share very few common constituents of brachiopods (Zhan et al. 2014b). There is only one locality where *Saucrorthis* occurs together with *Aporthophyla* and some other shelly fossils constituting a unique brachiopod-dominated association, the *Yangtzeella–Orthambonites* Association from the Kuniutan Formation at Wudang of Guiyang, central Guizhou (South China palaeoplate) living in a shallow-water benthic environment corresponding to BA3 (Rong et al. 2005). The *Aporthophyla* Fauna was flourishing in nearshore shallow-water benthic regimes (corresponding to lower BA2 to BA3) of many palaeoplates or terranes during late Middle Ordovician time (Darriwilian), all of which were with a medium or low latitude affinity (Neuman & Harper 1992; Rong et al. 2005; Zhan et al. 2014a).

CONCLUSIONS

The Darriwilian (late Middle Ordovician) *Saucrorthis* Fauna, a brachiopod-dominated shelly fauna in normal marine (relatively deeper) benthic regimes with muddy or calcareous muddy substrates, was a typical regional fauna confined mainly to the South China palaeoplate, together with some sporadic occurrences in the Sibumasu palaeoplate and a peri-Gondwana terrane (i.e. northern Iran), all of which are of peri-Gondwana affinities. The fauna represents the second pulse of the brachiopod GOBE in South China, coinciding with the first diversity acme of the GOBE globally not only for the brachiopods but also for all fossil groups. The generally low similarity coefficients between different *Saucrorthis* Faunas of different localities and regions, and between all Darriwilian shelly faunas indicate that the diversity acmes of the GOBE were always manifested by (a) the flourishing of local or regional faunas and (b) strong endemism or provincialism in the epeiric seas during the Ordovician.

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APPENDIX

GENERIC FAUNAL LIST OF TYPICAL REPRESENTATIVES OF THE *SAUCRORTHIS* FAUNA AND ONE DARRIWILIAN BRACHIOPOD FAUNA FROM SOUTHERN TIBET USED FOR COMPARISON

CCN: Dashaba Formation (Darriwilian), Shuanghe, southern Changning, southern Sichuan, southwest China (South China palaeoplate) (Zhan & Jin 2005a); *Calyptolepta*, *Glyptomena*, *Heteromena*, *Horderleyella*?, indet. strophomenid sp. 1, indet. strophomenid sp. 2, *Leptastichidia*, *Longvillia*?, *Maydenella*, *Nothorthis*, *Orthambonites*, *Paralenorthis*, *Parisorthis*, *Pentagomena*, *Phragmorthis*, *Saucrorthis*, *Tarfaya*?, *Tritoechia*, *Yangtzeella*.

CWX: Shihtzupu Formation (Darriwilian), Shizigou, Weixin, northeastern Yunnan, southwest China (South China palaeoplate) (Zhan & Jin 2005b); *Calyptolepta*, *Glyptorthis*, *Halirhachis*, indet. strophomenid sp. 3, *Leptastichidia*, *Leptellina*, *Leptestiina*, *Martellia*, *Nothorthis*, *Onniella*, *Petritrioechia*, *Porambonites*, *Protoskenidioides*, *Saucrorthis*, *Sulevorthis*, *Tritoechia*.

CCK: Houping Formation (Darriwilian), Houping, Chengkou, northern Chongqing, central China (South China palaeoplate) (Zhu et al. 1977; Chen et al. 1995); *Calyptolepta*, *Eodiorthelasma*, *Parisorthis*, *Phragmorthis*, *Saucrorthis*, *Schedophyla*, *Virgoria*.

BST: Naungkangyi Group and its equivalents (Darriwilian), Shan States, northern Myanmar (Sibumasu palaeoplate) (Reed 1906, 1932; Cocks & Zhan 1998; Zhan & Jin 2005a); *Bekkerella*, *Bellimurina*, *Cyclospira*, *Dirafinesquina*, *Glyptomena*, indet. clitambonitid, indet. leptaenines, indet. syntrophopsid, *Ishimia*, *Leptellina*, *Nicolella*, *Onniella*, *Palaeoglossa*?, *Plaesiomys*, *Porambonites*, *Protozyga*?, *Ptychoglyptus*?, *Saucrorthis*, *Skenidioides*.

IDM: Middle part of the Lashkarak Formation (middle Darriwilian), Alborz Mountains, northern Iran (peri-Gondwana terrane) (Ghobadi Pour et al. 2011); *Bastamorthis*, *Martellia*, *Saucrorthis*, *Semnanostrophia*, *Yangtzeella*.

CWD: Kuniutan Formation (Darriwilian), Wudang, Guiyang, central Guizhou Province, southwest China (South China palaeoplate) (Rong et al. 2005); *Anomalorthis*, *Aporthophyla*, *Hemipronites*, *Leptellina*, *Leptestia*, *Orthambonites*, *Parisorthis*, *Saucrorthis*, *Yangtzeella*.

CTJ: Lower Formation of the Chiatsun Group, Jiacun, Nyalam, southern Tibet, southwest China (Tibet palaeoplate) (Liu 1976, 1979; Zhan et al. 2014a); *Aporthophyla*, *Aporthophylina*, *Diaphelasma*, *Glyptomena*, *Hemipronites*, *Nanambonites*, *Paralenorthis*, rafinesquinid gen. et sp. indet., *Tritoechia*, *Xizangostrophia*.

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