Ostracods and palaeobotany from the middle Permian of Oman: implications on Pangaea reconstruction

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ABSTRACT

Discovery of a middle Permian ostracod fauna in the marine Khuff Formation (Sultanate of Oman), combined with palaeobotanical data from the immediately underlying continental Gharif Formation, supports new interpretations of the palaeobiogeography of the Tethys during the late Palaeozoic. A mixed ostracod fauna existed on the Arabian platform. This new record of Permian ostracods, combined with recent data obtained in other Tethyan areas, emphasizes the close relationship between the south-western Tethys realm and South China. The macro- and microfloral assemblages of the continental Gharif Formation demonstrate that this palaeoflora represents a true mixed association in which Gondwanan, Cathaysian and Euramerian elements are intermingled. Two main models exist for the reconstruction of Pangaea during the late Palaeozoic. Both ostracods and palaeobotanical evidence favour the reduction of the oceanic area between South China and Arabian plate as in the B Pangaea model favoured by recent palaeomagnetic data.

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Introduction

The reconstruction of Permian Pangaea remains an important and controversial topic. Two main models have been proposed. The A Pangaea (the Wegenerian Pangaea) is the best known model. In the B Pangaea model based on palaeomagnetic data (Irving, 1977), the eastward location of Gondwana with respect to Laurussia reduces the Tethys extension considerably. Moreover, several new models, also based on palaeomagnetic data, differ markedly from the classic view of a Tethyan area widely open on Panthalassa. This is a consequence, on the one hand, of the location of Chinese blocks, which constitute a N–S barrier east of the Tethys, and, on the other, of the relative positions of Gondwana with respect to Laurussia, mentioned above. New data obtained in Oman on the continental flora and the marine ostracod fauna provide a new opportunity to assess Permian palaeobiogeography and palaeogeography.

The Huqf area is located at the south-eastern margin of the Arabian Plate in Central Oman (Fig. 1) and constitutes an anticlinal structure that exposed Palaeozoic rocks (Hughes-Clarke, 1988). Late Carboniferous to Permian units represent a N–S elongated strip exposed on the western edge of the uplifted Huqf massif (Le Métour *et al.*, 1993).

The outcropping succession contains two stacked megasequences (Dubreuilh *et al.*, 1992a,b; Roger *et al.*, 1992a,b). The first begins with the Westphalian–Sakmarian glacio-lacustrine deposits of the Al Khlata Formation, overlain by the transgressive marine sediments of the late Sakmarian (Angiolini *et al.*, 1997) Saiwan Formation marking the progressive deglaciation of the region. The unconformable second megasequence encompasses the basal, thick, fluvial, terrigenous Artinskian–early Wordian Gharif Formation (Broutin *et al.*, 1995). The sequence passes gradually up into the marine, marly carbonate deposits of the early Wordian (Angiolini *et al.*, 1996) Khuff Formation.

The present contribution examines the ostracod data of the Khuff Formation and the palaeobotanical data of the Gharif Formation.

Results and analysis

Ostracod data

Thirty-five ostracod species were discovered in the Khuff Formation: 18 are endemic species; 14 are new species (Crasquin-Soleau *et al.*, 1999).

Identification at species level is necessary in order to establish palaeobiogeographical links; for this purpose, the present analysis used the provincialism index (Johnson, 1971), denoted as PI ($PI = C/2E_1$, where C is the number of species common between two areas and E_1 the number of endemic species of the area where they are fewer). This index permits comparison of areas that have very different numbers of species.

PI is highest in South China (0.08 and 0.11 with affine species), Hungary (0.08), Israel and Tunisia (0.05), and Greece (0.02 and 0.05 with affine species). One species is compared with a Russian species. In addition, the middle Permian assemblage of the Khuff includes some species known in the late Carboniferous and/or early Permian of the North American platform (three common species and two affine species), the Russian Platform (four common species and three affine species), and one species affine from North China. These last species are younger in Oman than in their areas of origin.

Recent studies conducted in two other areas of the Tethys realm, Hydra Island (Greece) (Crasquin-Soleau and Baud, 1998) and Southern Tunisia (Said-Benzarti and Crasquin-Soleau, 1998), give results of the same order.

Studies of living fauna (Teeter, 1973; Cronin, 1988; Titterton and Whatley, 1988) prove that neritic ostracods are carried on floating algae by equatorial currents across the Pacific. Such algae existed before the Permian. Taking these results into account, Lethiers and Crasquin-

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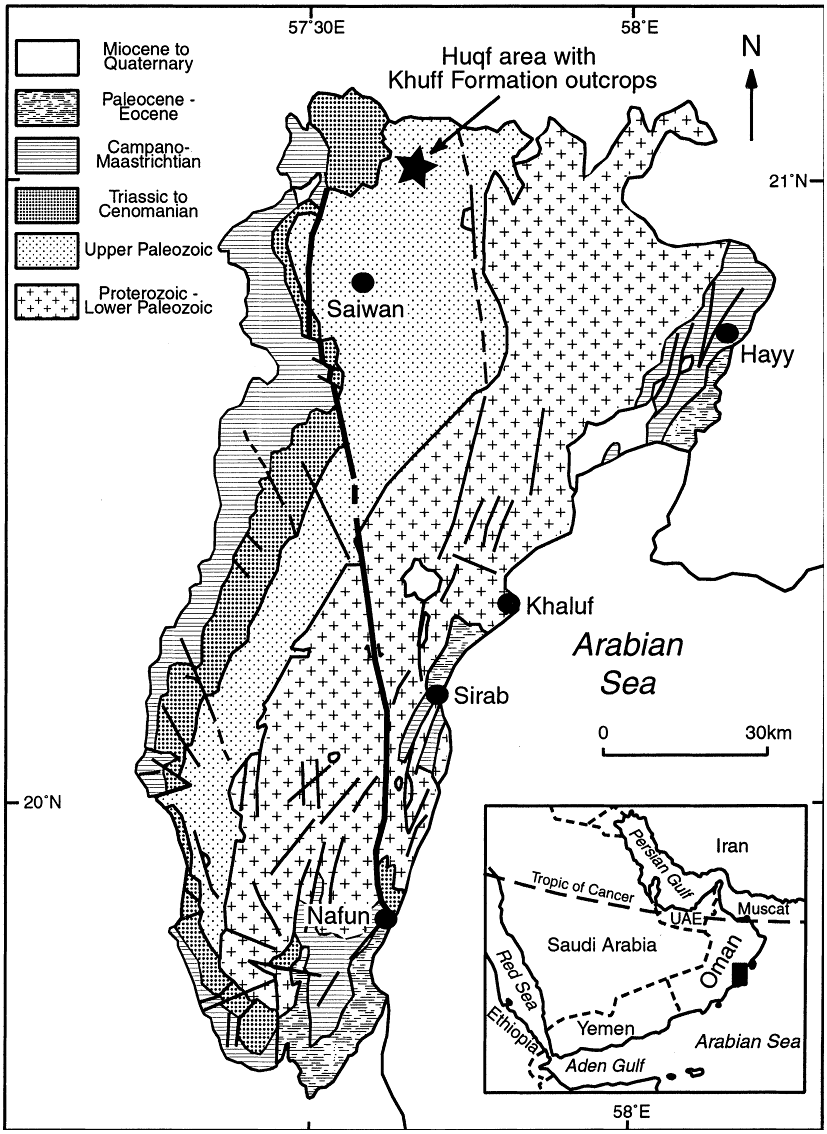

Fig. 1 Geological sketch map of Haushi–Huqf uplift in Oman (after Platel *et al.*, 1994).

Soleau (1995) proposed a global palaeocurrent scheme for the late Carboniferous – early Permian. Equatorial surface currents connected western Pangaea to Tethys, where they spread and seeded infralittoral areas. The species common with North American and Russian Platforms, and North China (only one affine species) are older (late Carboniferous to early Permian). Thus, the species from the North American shelves and, later, from the Russian platform could have been the ancestral forms which crossed the Palaeo-Pacific, dispersed during late Carboniferous – early Permian times, and then seeded the Tethys platforms where they grew up during the middle Permian.

All the species common to Hungary, South China, Israel, Tunisia and Greece have the same age (middle Permian).

The interesting thing to emphasize is the importance of the palaeobiogeographical relationships between south-western Tethys and South China during middle Permian times. Following the model proposed by Lethiers and Crasquin-Soleau (1995), the links between eastern and western areas could be explained by the equatorial currents but a significant reduction of the oceanic space between these two areas should also be considered. This hypothesis is supported strongly by the continental data obtained on the palaeoflora of the underlying Gharif Formation.

Palaeobotanical data: the Gharif palaeoflora

The Gharif palaeoflora integrates elements of three phytogeographic provinces (see Fig. 2).

1 *Cathaysian elements*. In addition to the numerous specimens assignable to *Tingia hamaguchi*-like leafy shoots (Broutin *et al.*, 1995), new discoveries include: a *Tingiostacha* strobilus, *Fascipteris hallei*; numerous representatives of the *Protoblechnum-Compsopteris* complex, many showing the typical asymmetrical paripennate apice; and Gigantopterid foliage.

2 *Gondwanan elements*. The diversity of the Glossopterids is now reasonably well established. The newly collected material has already been compared in detail with the standard material kept in São Paulo University. *Glossopteris occidentalis* was originally described from an almost entire leaf with a preserved characteristic epidermis (Broutin *et al.*, 1995), but is now based on many more specimens. *Glossopteris* sp. 1 (Broutin *et al.*, 1995) can now be identified, on the basis of additional compressions, to *G. angustifolia* var. *taeniopteroides*. *Glossopteris* cf. *clarimarginata* (Broutin *et al.*, 1995) and *Glossopteris* cf. *stricta* are still established only on a single specimen. Three leaflets, preserved up to 9 cm long, of a *Glossopteris* leafy whorl have been discovered, preserved in their original natural disposition.

Associated with this sterile, very characteristic foliage, numerous fertile leaves and dispersed ovuliferous organs, from specimens of *Plumstedia* genus, demonstrate the relationship of these Oman plant remains to the true Gondwanan Glossopterids.

3 *Euramerian elements*. In addition to the already recorded conifer remains of *Otovicia* (Al. *Walchia*) *hypnoides*, various leafy shoots can now be added, including main branches up to several decimetres long. Preserved medullar casts of the Sphenophyte *Calamites gigas* have also been recorded.

Independently of their taxonomic position, all of the transverse sections

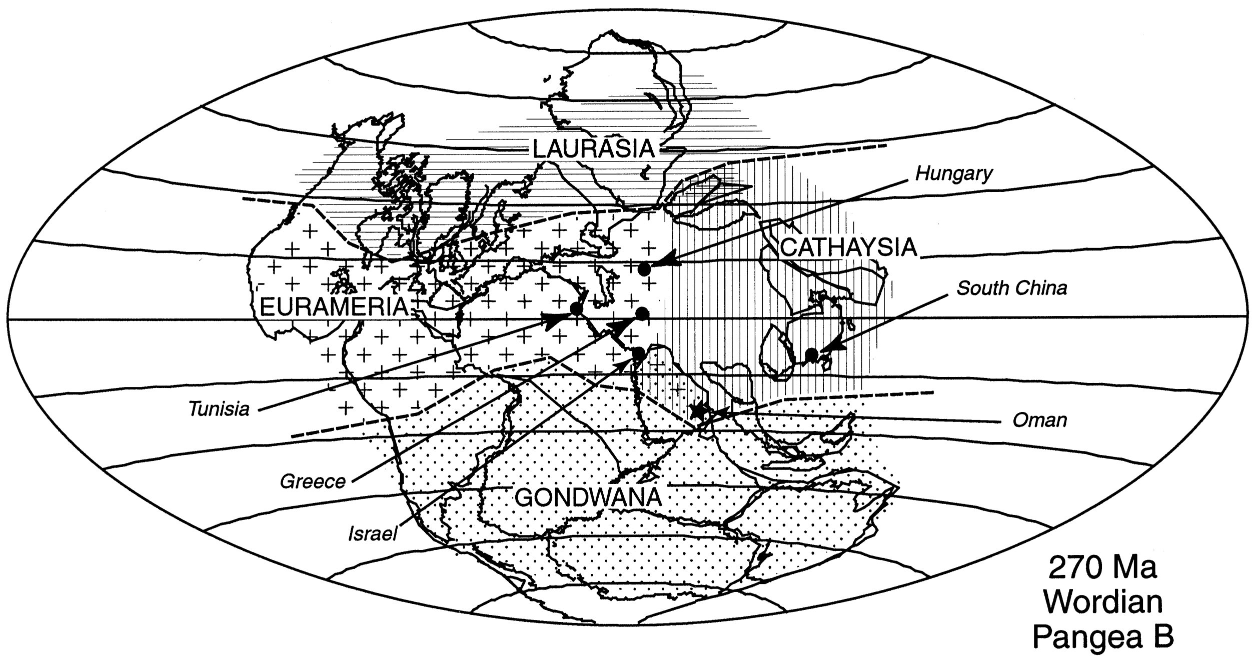

Fig. 2 Location of the main palaeobotanical province during the Permian.

of the fossil tree trunks exhibit irregularly distributed, inconspicuous or even no growth rings. Such characteristics suggest a warm and humid climate with weak drier periods (perhaps seasons), i.e. more or less Cathaysian climatic conditions.

The analysis of the Permian phytogeographic sequence in the Arabian peninsula domain clearly demonstrates that the configuration proposed by Chaloner and Creber (1978), closely linking Arabia and the South China block, became effective only during early middle Permian time (Metcalfe, 1998). Thus, the movement of the Arabian plate into tropical latitudes led to a closeness between this domain and the South China block during the middle Permian, regardless of the Carboniferous location of this block.

The Cathaysian flora became distinct in the late Carboniferous, differentiated first in North China and spread out westwards during the Permian (Li Xing Xue, 1986; Utting and Piasecki, 1995). A review by Ziegler (1990) concluded that the Cathaysian vegetation consisted of tropical rainforest populated, mainly, by arborescent lycopsids (now recorded as well in the Gharif Formation), sphenophytes and gigantopterids. Thus, South China was in very low latitudes during Permian times, a unanimous conclusion even in contradictory Permian reconstructions (Chaloner and Creber, 1978; Li *et al*., 1993; Ross, 1995; Scotese and Langford, 1995).

During the Roadian–Wordian period (i.e. middle Permian) climatic conditions were warm and humid both in the Haushi–Huqf area (the dark claystones become true thin coal seams at several levels) and in the Unayzah area (El Khayal *et al*., 1980).

Cathaysian floral elements started to occur in Oman at the Roadian–Wordian transition and developed fully during the late Wordian–early Wichiapingian at Unayzah (Saudi Arabia) and later on at Hazro (Turkey). Therefore, this area was gradually integrated into the Cathaysian domain during this period, coming from the Gondwana realm. Using such a dynamic approach, the occurrence of several Glossopterid Gondwanan elements in the Arabian domain (including Hazro in Turkey) can be analysed in terms of persistence as an inheritance of the former palaeogeographical location within the Gondwana floral realm. Thus, the Arabian Peninsula would have already drifted into lower latitudes than postulated by Scotese and Langford (1995), which accords with the successive late Carboniferous, early middle Permian reconstructions proposed by Li *et al*. (1993). This also implies a less pronounced latitudinal gradient between eastern and western ends of the Permian south Tethyan margin.

The incoming of the Arabian Peninsula into low tropical latitudes, in a drastically reduced marine domain would have made floral exchange possible between South China and Arabia. In this case, the occurrence of middle Permian advanced Cathaysian forms on the Arabian Plate would be the result of Permian westwards Cathaysian dispersal.

In the middle Permian epoch, all geodynamic and palaeontological events discussed above corroborate an important shortening of the Tethys clearly more in line with the Pangaea B reconstruction (Torcq *et al*., 1997), than with any other type of already proposed Pangaea A model.

Palaeomagnetism data

Palaeomagnetic data have been used to assess the evolution of continent position during the Permian. Three reconstructions are presented at Sakmarian (early Permian, Fig. 3a) and

Wordian (middle Permian, Fig. 3b,c) times. The palaeoposition of Laurussia (North America, Greenland and Europe) is accurate during this time period, with small uncertainties of less than 3°. Indeed, the late Palaeozoic apparent polar wandering path segment (APWP) is defined by a large number of well-determined poles (Van der Voo, 1993). Siberia was on the way to completing its collision with the Russian platform through the Urals Mountain belt. Its palaeoposition has been computed using the Siberian palaeomagnetic database of the Kramov compilation in Van der Voo (1993). Its position is more uncertain (10°) for the middle Permian, and has been pushed slightly northward, within error bars. A mosaic of accreted blocks that rifted away from Gondwanaland, and collided against its southern margin constitutes the southern part of Asia. Palaeomagnetic studies in Tarim (Gilder *et al.*, 1996) show the position of this block with respect to the Kazakhstan and Siberian plates, accreted shortly before. Studies on the South China block (SCB) demonstrate that it was situated in the southern hemisphere, close to the equator during Permian (for a review, see Enkin *et al.*, 1992; Zhao *et al.*, 1996). A continental bridge between this block and Tarim is via the North China block (NCB), rotated with respect to Siberia by more than 60°. At that time, NCB, SCB and Mongol–Central Asian blocks were still separated from Siberia by the Mongol–Okhosk Ocean, and collided with it only by the latest Jurassic (Yang *et al.*, 1992). Chinese data for the late Permian are now very well constrained.

Reconstructing the southern landmasses with respect to the northern one is more difficult and has caused controversy over 20 years. Using the palaeomagnetic data of Gondwana implies a Pangaea B scenario that differs markedly from the classic Jurassic Wegenerian Pangaea, where South America is facing North America into the late Permian (Irving, 1977). In Fig. 3(a), we the compilation made by Besse *et al.* (1996) is used to assess the Gondwanian position. The present data also imply a Pangaea B scenario; the Wordian reconstruction is consistent with the late Permian reconstructions of Torcq (1997), Torcq *et al.* (1997) and Besse *et al.* (1998), based on recent palaeomagnetic surveys of Permo-Triassic sediments in Saudi Arabia and a careful selection of South American, African, Madagascar, and Moroccan poles.

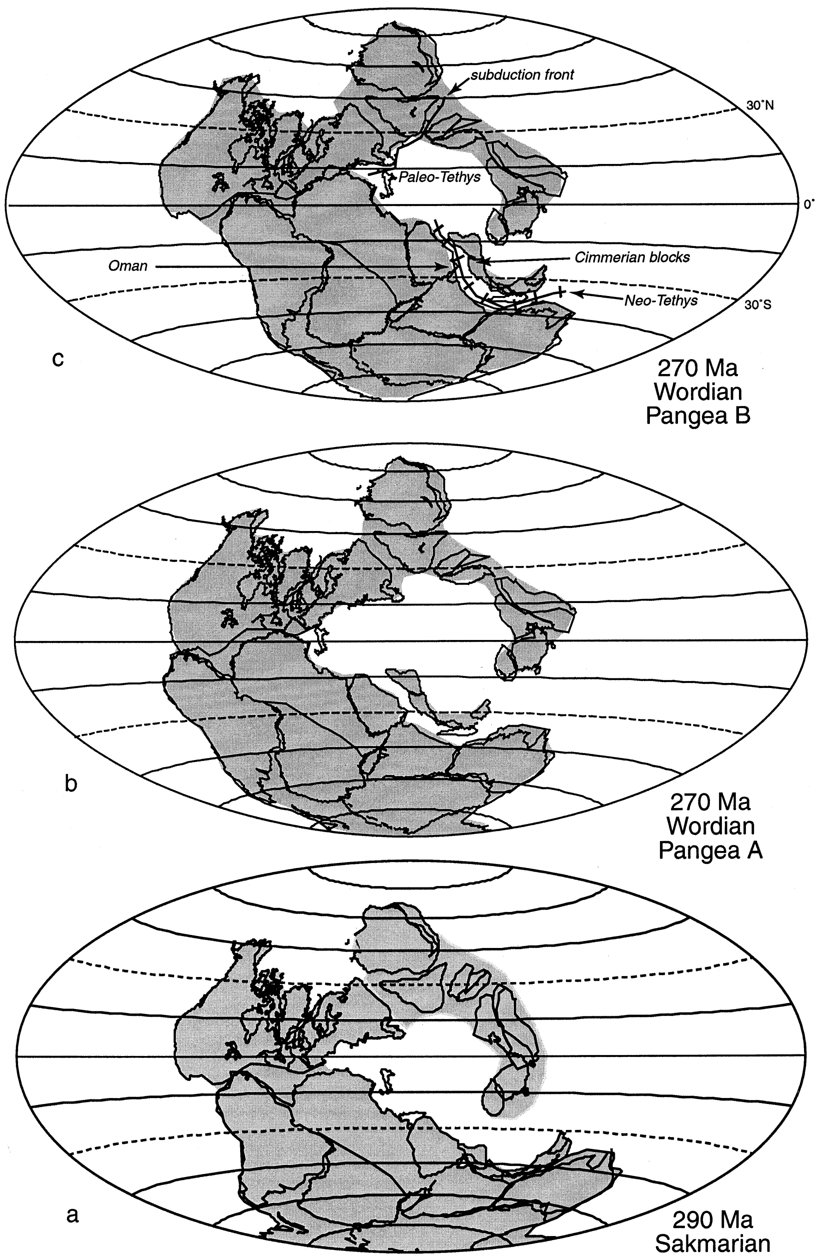

Fig. 3 Pangaea A reconstructions: (a) during the Sakmarian (290 Ma); (b) during the Wordian (270 Ma); (c) Pangaea B during the Wordian (270 Ma).

The Cimmerian continent, a nearly continuous belt of continental blocks including parts of Iran, Afghanistan, Tibet and western parts of Indochina, rifted away from Gondwana during Permian times, and was located in the southern hemisphere, between China and the northern periphery of Gondwana. The palaeoposition has been determined using reconstructions derived from new data in Iran (Besse *et al.*, 1998).

There is a clear northward motion of Arabia (and Gondwana) of more than 1500 km from Sakmarian to Wordian, in agreement with the passage to tropical climatic conditions inferred by palaeodata from the Wordian. The Mongol and Chinese blocks form a continental N–S alignment from the middle latitudes up to south of the Equator, which acts as a barrier. Gondwanaland in B position, and the northward motion of Iran during the Permian, lead to a strongly reduced area of Tethyan Ocean during late Permian. This situation may have allowed easy southern connections between China and Arabia, as supported by the palaeontological data mentioned above. Such a connection could have been made easier by the proximity of northward moving Cimmerian blocks rifted away from Gondwana since the early Permian. For comparison, Fig. 3(b) shows the Pangaea A scenario. The northern continents, central Asia, China and Indochina and south remain in exactly the same position as for Pangaea B of Fig. 3(c). Gondwana is fitted using Van der Voo's preferred solution (Van der Voo, 1993; solution 4, tables 5–10). The much larger oceanic space between Indochina and Gondwana may render the connections described above untenable, and thus Pangaea B is favoured.

Conclusion

New palaeontological data (palaeobotany and ostracods) obtained from middle Permian deposits in Oman reveal close relationships between this area and the South China block. Therefore, southern Arabia was located in tropical latitudes at that time. These data are in good agreement with palaeomagnetic reconstructions and provide a more plausible explanation of the coexistence between the late Palaeozoic biostratigraphic sequences and the mixed middle Permian flora and fauna in Oman. A confirmation of this hypothesis may be found in a revision of Arabian Plate palaeontological and sedimentological data, and should be sought in the palaeontological content of the Permian of Iranian and Indochinese blocks.

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