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# The Oman Gharif mixed paleoflora: a useful tool for testing Permian Pangea reconstructions

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## Abstract

The discovery of a Middle Permian fossil flora in the continental Gharif Formation (Huqf area, Sultanate of Oman), combined with an ostracod fauna in the overlying marine Khuff Formation, provides new data that further refine paleogeographical reconstructions of the Paleo-Tethys during the Late Paleozoic. The macro- and microfloral assemblages, originating from a single fossiliferous bed of the Gharif Formation, demonstrate that this paleoflora represents a true mixture of Gondwanan, Cathaysian and Euramerican elements. These data furthermore show that the Huqf area occupied a paleogeographical location favorable for floral exchange at this time. The composition of this flora and its dating are of significance with regard to the relative position of the Arabian Peninsula during the Permian. The presence of forms belonging to the tropical rain forest of the Permian Cathaysian paleokingdom emphasizes the close relationship of the southwestern Paleo-Tethys realm and South China, two regions that were then characterized by the same climatic conditions. For this period, our new data indicate for this period a lower latitude for the Arabian plate and a much more reduced oceanic space between the Cathaysian blocks and the Arabian Peninsula. Therefore, the new data are more in accordance with the recently actualized Pangea B model, than with other, previously proposed Permian Pangea models.

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**Keywords:** Permian; mixed paleoflora; Arabian Peninsula; Pangea reconstruction

## 1. Introduction

The study of Permian floras is strongly hampered by the incompleteness of the fossil record. Only the lowermost part of the Permian and the

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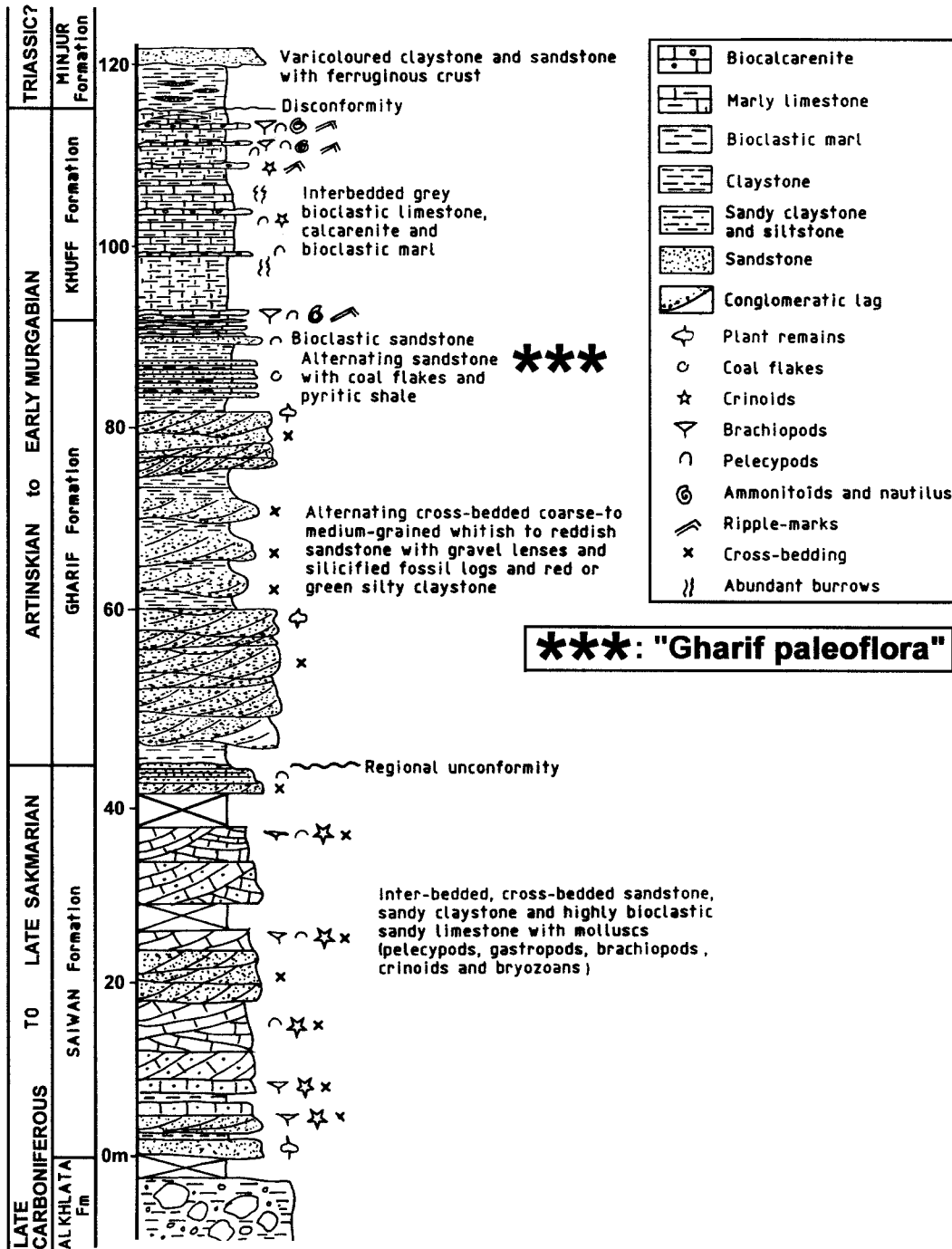


Fig. 1. Composite Log of the Permian succession in the Haushi-Huqf area (slightly modified after Roger et al., 1992b).

Upper Permian are reasonably well documented. Four main floral realms are recognized during the Permian: the Euramerican, the Gondwanan, the Angaran and the Cathaysian realms. Euramerica included North America, Eastern and Western Europe. Gondwana covered South America, mainly south of the Sahara, Arabia, Madagascar, India, South Tibet, New Guinea, Australia and Antarctica. Angara occupied the area east of the Urals extending through Siberia to the Pacific and from the Arctic Ocean south to outer Mongolia. Whereas the Cathaysian realm referred to the floras that grew in the present-day territories as China, Japan, Korea and other South-Eastern countries from the Late Carboniferous until the end of the Permian and perhaps the Early Triassic (Utting and Piasecki, 1995). A number of mixed floras including elements of two or more realms have been documented in past decades.

The ‘Gharif’ paleoflora discovered on the Southern Peri-Tethyan platform (Central Oman) is the third major mixed paleoflora from the Permian of the Arabian Peninsula. The Unayzah (El-Khayal et al., 1980; Lemoigne, 1981; El-Khayal and Wagner, 1985) and Jal Khartam floras (Hill and El-Khayal, 1983; Hill et al., 1985) found in the Saudi Arabian Khuff Formation are respectively dated as Late Wordian (Murgabian) and Early Changsingian (Dorashamian), whereas the new mixed ‘Gharif’ paleoflora is referred to an Early Wordian age (Kubergandian/Murgabian transition). It corresponds to the first occurrence of such a mixed flora in the Arabian plate.

The mixed paleoflora in Central Oman is of primary importance for the understanding of the phytogeographic history of the Arabian platform and vegetation dynamics during the Permian. Apart from being one of the very few well dated Middle Permian floras, this mixed flora provides important clues for the position of the Arabian plate during the Permian in particular and Permian paleobiogeography and paleogeography in general.

## 2. Locality and source data

The Huqf area, located in Central Oman, con-

stitutes an anticlinal structure in which Paleozoic rocks are exposed (Hughes-Clarke, 1988). Late Carboniferous to Permian units represent a North–South elongated strip exposed on the western edge of the uplifted Huqf massif (Le Métour et al., 1994). The complete biogeographic sequence of this area is now well established from the early late Westphalian–early Stephanian to the early Late Permian (i.e. early Guadalupian, Dubreuilh et al., 1992a,b; Roger et al., 1992a,b; Besems and Schuurman, 1987; Love, 1994). The Late Paleozoic succession is composed of four formations: the Al Khlata, Saiwan, Gharif and Khuff formations.

Well bracketed by the Saiwan and the Khuff,

	TIME	STAGES	TETHYS
Lopingian		CHANGHSINGIAN (251.4)	Dorashamian
		WUCHIAPINGIAN (253.4)	255 Dzhulfian
Guadalupian	260	CAPITANIAN	259 Midian
		WORDIAN (265)	264 Murgabian
		ROADIAN	269
	270	KUNGURIAN	Kubergandian 273 Bolorian 275
Cisuralian	280	ARTINSKIAN	ARTINSKIAN
		SAKMARIAN (283)	
	290	ASSELIAN (290.6)	

Fig. 2. Standard and Tethys time-scales (modified after Permpohiles 36, p. 2).

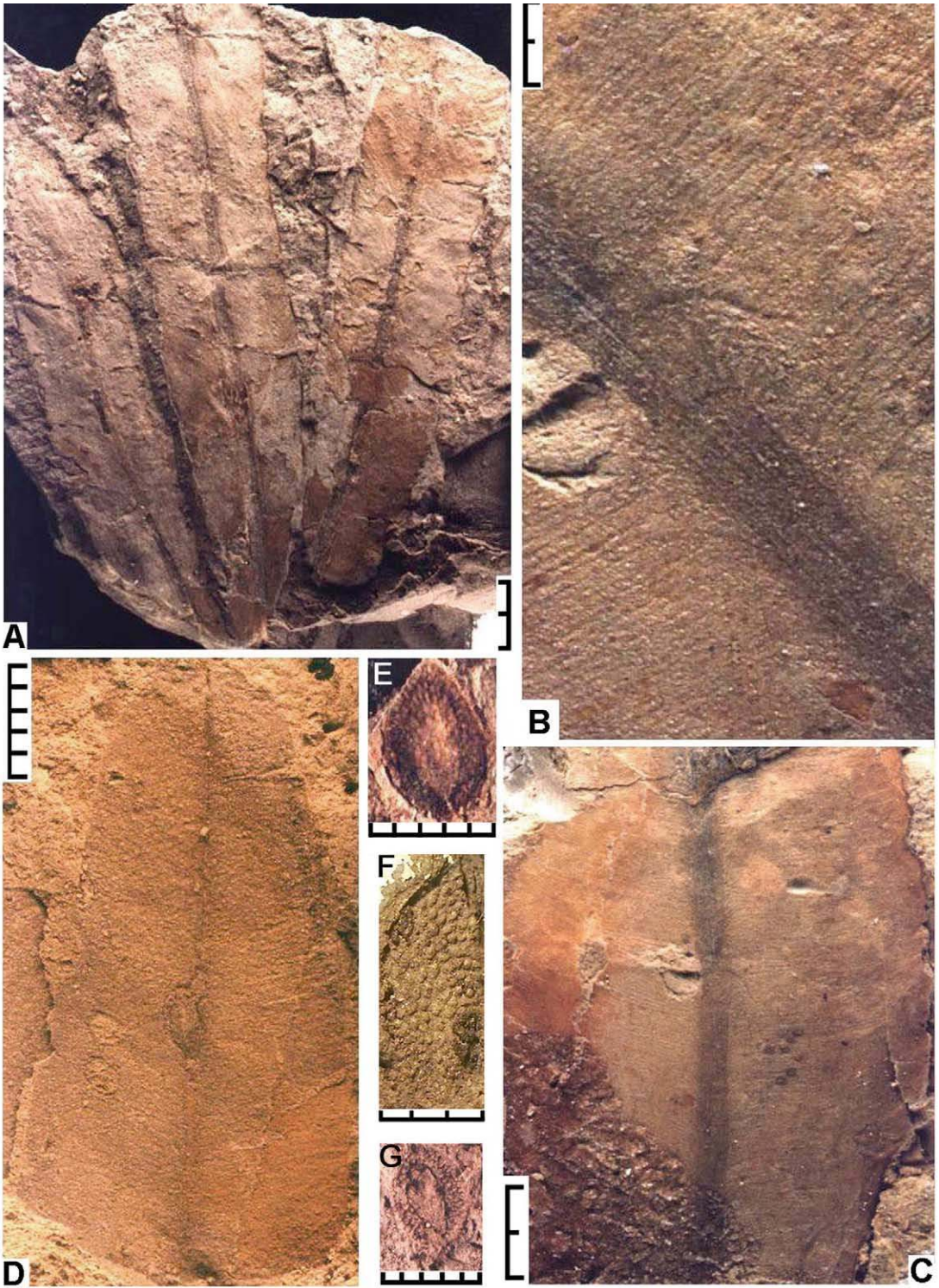


Table 1  
Table of the main paleofloristic elements of the Gharif paleoflora

Cosmopolitan taxa	Gondwanan taxa	Cathaysian taxa	Euramerican taxa
<i>Sphenophyllum speciosum</i>	<i>Glossopteris occidentalis</i>	<i>Cathaysiopteris whitei</i>	<i>Otovicia (Walchia) hypnoides</i>
<i>Sigillaria brardii</i>	<i>Glossopteris taeniopteroides</i>	<i>Gigantonoclea lagrelii</i>	<i>Calamites gigas</i>
	<i>Glossopteris angustifolia</i>	<i>Gigantonoclea</i> sp.	<i>Calamostachys dumasii</i>
	<i>Glossopteris claramarginata</i>	<i>Gigantopteris</i> sp.	<i>Baieroxylon implexum</i>
	<i>Glossopteris browniana</i>	<i>Lepidodendron acutangula</i>	
	<i>Glossopteris damudica</i>	<i>Sphenophyllum sino-coreanum</i>	
	<i>Plumsteadia</i> sp.	<i>Tingia</i> sp.	
	<i>Arberia</i> sp.	<i>Tingiostachya</i> sp.	
	<i>Arberioopsis</i> sp.	<i>Comia</i> sp.	
	<i>Lidgettonia</i> sp.		
	<i>Lanceolatus</i> sp.		
	<i>Dadoxylon (Eristophyton)</i> nov. sp.		
	<i>Prototaxoxylon</i> nov sp.		
	<i>Trigonomyelon</i> nov sp.		
	<i>Cyclodendron leslii</i>		

fossiliferous marine formations, respectively dated as late Sakmarian (Angiolini et al., 1997) and Early Wordian (Angiolini et al., 1996), the age of the terrestrial flora is well constrained (Fig. 1). This flora, discovered in the uppermost dark pelitic horizons of the Gharif Formation (Broutin et al., 1995), is late Roadian/Early Wordian in age (i.e. Kubergandian/Murgabian transition with respect to the Tethys time-scale, Fig. 2).

### 3. Main paleofloristic elements of the Gharif paleoflora

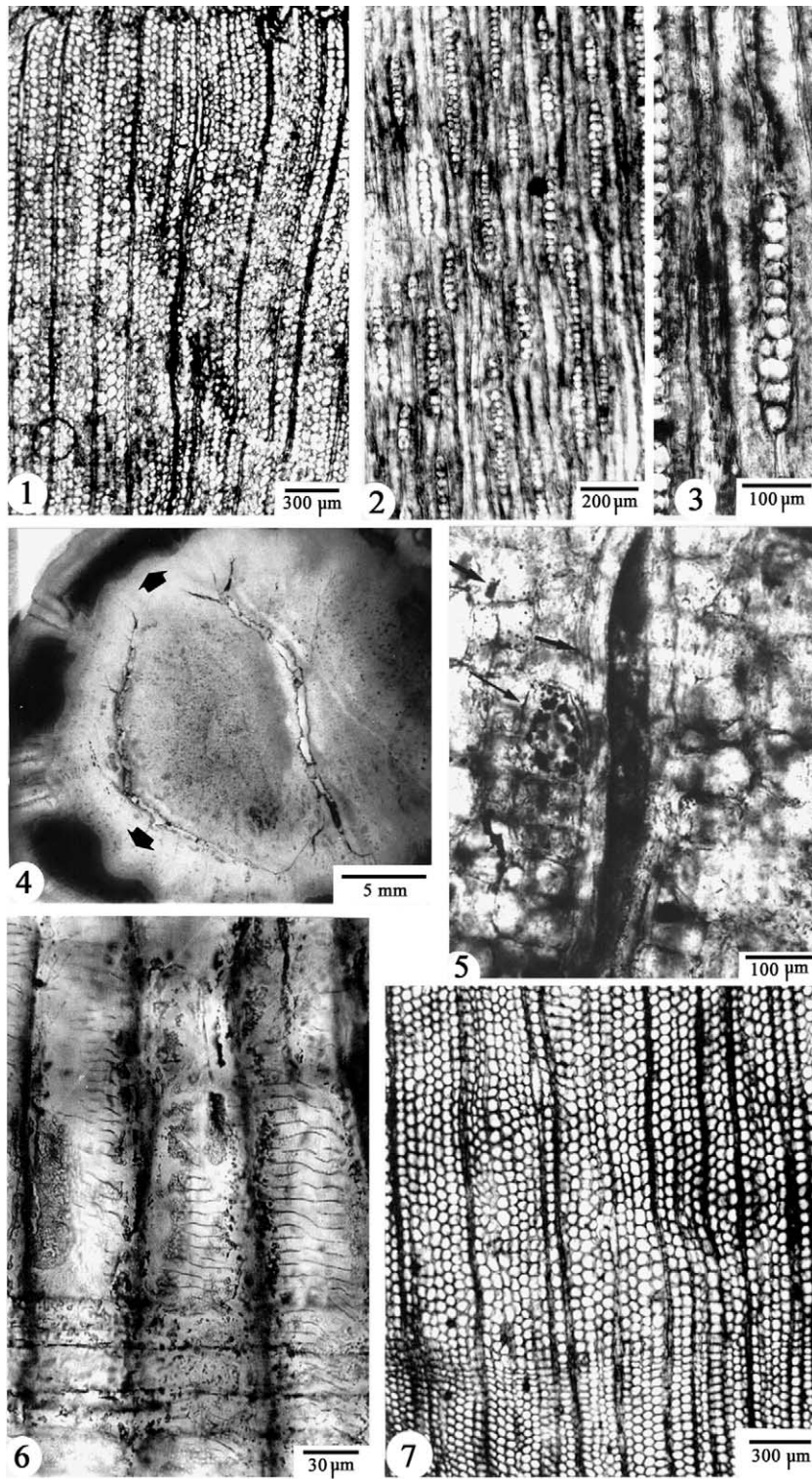
The floral assemblage includes excellently preserved impressions–compressions (cf. Table 1), permineralized remains (silicified woods) and palynomorphs. The palynological assemblage is dominated by anemophilous mono- and bisaccate pollen grains (Broutin et al., 1995). The abundance and variety of striate bisaccate pollen grains belonging to *Protohaploxypinus* could be compared with the ‘*Protohaploxypinus microcorpus* Zone’ defined in Australia (Foster, 1979; Backhouse, 1991).

#### 3.1. Gondwanan taxa

The Gharif flora contains several Glossopteridales. Six species have been identified to date, *Glossopteris occidentalis* White 1908 (with very well preserved cuticles), *G. damudica* Feistmantel 1879 (Fig. 3B,C), *G. taeniopteroides* Feistmantel 1878 (Fig. 6b), *G. angustifolia* Brongniart 1830, *G. claramarginata* Anderson and Anderson 1985 and *G. browniana* Brongniart 1828 (Fig. 8, 1). Many *Glossopteris* leaves still bearing female organs (*Plumsteadia* Rigby 1962; *Lanceolatus* Plumstead, 1952, Fig. 3D) and isolated fertile structures (e.g. *Arberia* White 1908, *Arberioopsis* Bernardes de Oliveira 1977, *Plumsteadia* and *Lidgettonia* Thomas 1958) have been found (Fig. 3E–G). They are frequently associated with *Glossopteris* leaves of the *G. indica–angustifolia* type (Fig. 3A), an association very similar to that of the Permian paleoflora of Southern Africa (Anderson and Anderson, 1985).

Among the permineralized gymnosperm woods *Dadoxylon (Eristophyton)* nov. sp. (work in progress) and *Prototaxoxylon* nov. sp. have been identified. *Dadoxylon ibericum* Vozenin-Serra 1991

Fig. 3. Glossopteridean Gondwanan elements from the Gharif paleoflora. A–C: sterile foliage (A, *Glossopteris indica–angustifolia* complex; B and C, *G. damudica* Feistmantel); D, fertile leaf with *Lanceolatus*-type fructifications; E–G, isolated glossopteridean fructifications (*Plumsteadia–Scutum* complex).



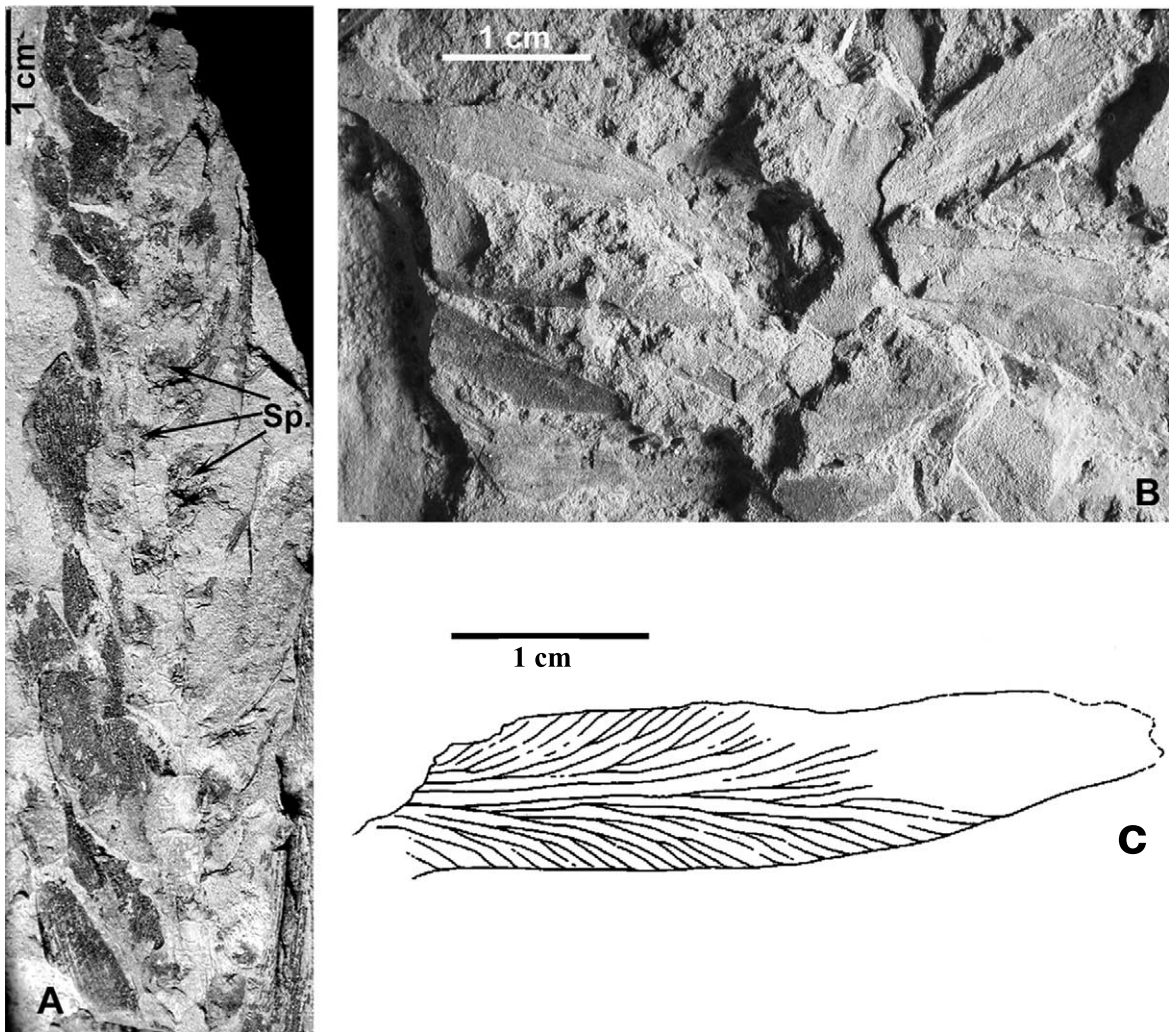


Fig. 5. A, *Tingiostachya* sp. Arrows: location of the sporangia; B, incomplete and fragmented leaf whorl of *Sphenophyllum sino-coreanum* Yabe; C, drawing of isolated leaf of *S. sino-coreanum*, showing the crowded venation, ending at lateral margins.

from the Early Permian of Spain and some fossil gymnosperm trunks of the Carboniferous complex of Tazekka (Morocco) are similar to *Dadoxylon* (*Eristophyton*) of Oman. The growth rings of these woods are similar to those of the trees living

in an equatorial to humid tropical climate. The pycnoxylic wood and the lack of real growth rings in *Prototaxoxylon* of Oman (Fig. 4, 6 and 7) also suggest such climatic conditions. This fossil trunk is similar to *Parataxopitys americana* (Milanez

Fig. 4. 1, cross section of *Baieroxylon implexum* (Zimmerman) Greguss, devoid of growth ring; 2, general view of tangential section of *B. implexum*; 3, rays of *B. implexum* (higher magnification); 4, cross section of *Trigonomyelon* nov. sp. showing pith, more or less rounded with numerous small lobes (arrow); 5, longitudinal section of *Trigonomyelon*, showing heterogeneous pith with three kinds of cells, prosenchyma cells, thick walled secretory cells with numerous globular bodies and normal parenchyma cells; 6, delicate tracheid walls ornamentation of *Prototaxoxylon* nov. sp.; 7, cross section of *Prototaxoxylon* showing indistinct growth ring.

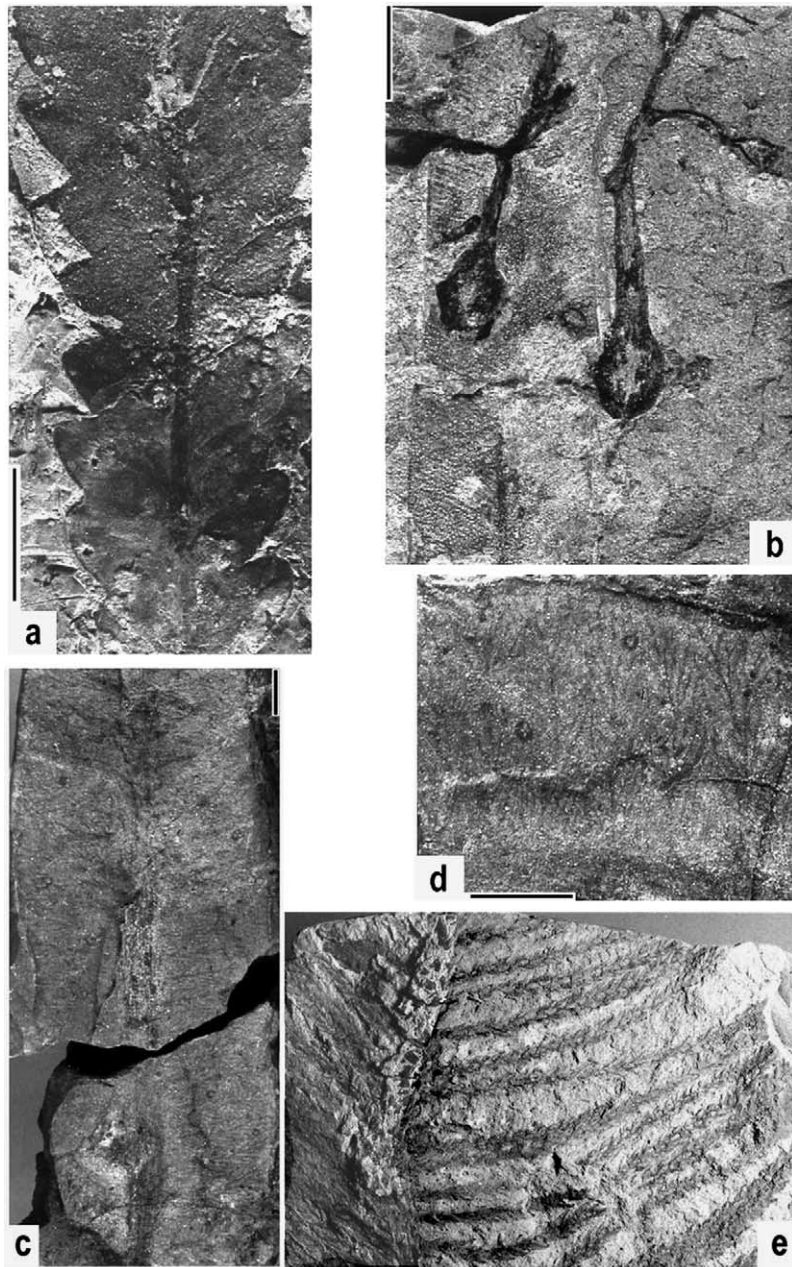


Fig. 6. a, *Gigantonoclea lagrelii* (Halle) Koidzumi; b, female organ, *Arberioopsis* sp., associated with *Glossopteris taeniopteroides* Feistmantel; c, *Cathaysiopteris whitei* (Halle) Koidzumi; d, detail of the Gigantopterid-type venation; e, *Otovicia (Walchia) hypnoides* (Brongniart) Kerp et al.

and Dolianiti, 1950) Krausel and Dolianiti 1958 from the Early Permian of Brazil. Another silicified wood, *Trigonomylon* nov. sp., is also similar to Gondwanan species. This last specimen shows

scalariform thickenings on primary xylem (Fig. 4, 4 and 5).

Numerous stems of arborescent lycopsids have been found in Oman. Some of them are similar to



forms from Southern Africa (e.g. *Cyclodendron leslii* (Seward 1903) Kraüsel 1928), others to forms of Europe and America (e.g. *Sigillaria brardii* Brongniart, 1828).

Other lycopsid stems found in the Gharif Formation show some affinity with Cathaysian taxa such as *Lepidodendron acutangula* (Halle 1927) Stockmans and Mathieu 1957. This latter taxon, which is often regarded as a synonym of *L. oculus-felis* (Abbado 1900) Zeiller 1901, is considered to be a typical element of the late Early Permian (Artinskian and Kungurian) of Cathaysia. Arbor-escient lycopsids were the major components of coal-swamp forests in the Cathaysian realm during the Late Carboniferous and Early Permian. They flourished under warm and humid climatic conditions.

The sphenopsid macrofossils include *Sphenophyllum speciosum* (Royle, 1839) Mc Clelland 1851. This taxon is well distributed in the Gondwanan realm, but it is also recorded from the Stephanian to the Permian in China, Korea. Another *Sphenophyllum* species reported from Oman is *S. sino-coreanum* Yabe 1920 (Fig. 5B,C). This taxon occurs both in Cathaysia and in Gondwana in Permo-Carboniferous times.

### 3.2. Cathaysian taxa

*Gigantopteris*-like leaves identified as *Giganto-*

*pteris* sp., *Gigantonoclea lagrelii* (Halle 1927) Koidzumi 1936 (Fig. 6a) and *Cathaysiopteris whitei* (Halle 1927) Koidzumi 1936 (Fig. 6c,d; Fig. 7) are known to have been endemic in North and South China during the Permian. The main characters of the *Gigantopteris*-like foliage are the undivided leaves and the existence of a delicate reticulate venation.

Herbaceous Noeggerathiopsids (Tingiales) identified as *Tingia* sp. cf. *T. hamaguchi* Kon'no 1929 and fertile cones *Tingiostachya* sp. (Fig. 5A), have been recorded from Oman. These taxa are typical Permian–Triassic Cathaysian genera but the botanical affinities of Noeggerathiales remain uncertain.

*Comia* sp. is a cathaysian–angaran and euramerican taxa, which has been discovered in Oman (Fig. 8, 2). The leaves are pinnate and show a lateral venation forming distinct bundles corresponding to folds or to lobes. These leaves are similar to the diagnosis of the genus *Comia* Zalesky, 1934 first discovered in the Petchora basin.

### 3.3. Euramerican taxa

The presence of the Euramerican conifer *Otoviccia* (*Walchia*) *hypnoides* (Brongniart 1828) Kerp et al., 1990 (Fig. 6e) (Walchiaceae) is noteworthy; this taxon was only known from Europe and

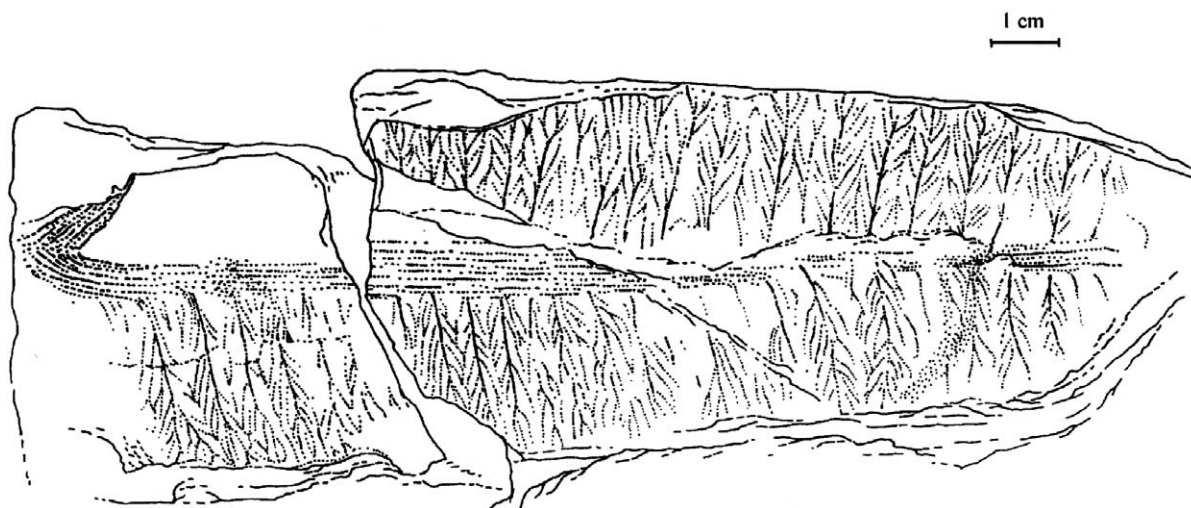


Fig. 7. Drawing of *Cathaysiopteris whitei* (specimen no. 112/3).



Fig. 8. Drawing of *Glossopteris browniana* Brongniart (1); *Comia* sp. (2).

North America from Late Carboniferous to Early Permian (Kerp et al., 1990).

The ginkgophyte *Baieroxylon implexum* (Zimmermann 1953) Greguss 1961 is a type of permineralized woods that occurs in the assemblage (Fig. 4, 1–3). To date this taxon is only known from the uppermost Carboniferous and Permian of western Europe.

Medullar casts of the sphenophyte *Calamites gigas* Brongniart 1828 and its strobilus *Calamostachys dumasii* (Zeiller 1892) Jongmans 1911 have been recorded. This species (the stems were originally described by Brongniart from the copper sandstone of Orenburg, Russia) was only known from the Stephanian and Lower Permian of Western Europe, North America, and Russia.

#### 4. Phytogeographic and paleoenvironmental analysis

The paleofloristic data of the Gharif Formation clearly demonstrate that during the Middle Permian, plants migrated from three different floral provinces to the Arabian Peninsula. Consequently Euramerican and Cathaysian elements are mixed with Gondwanan taxa. Several typical Euramerican species make their last appearance during the Middle Permian in the Huqf area. These taxa normally occur in the upper Stephanian and Lower Permian. These paleobotanical data suggest that the Arabian plate may have been a refuge for these species, as their geographic range contrasted. The composition of this mixed floristic assemblage points to an intertropical to subequatorial latitude for Oman during the Middle–Late Permian. A warm and humid tropical climate without marked seasonality (attested by the inconspicuous growth rings of the permineralized woods) prevailed at that time. The distribution of floral elements suggests that the Arabian plate and China were lying at the same latitude and were characterized by a similar climate.

The northward drift of Pangea brought the Arabian platform into a tropical to subequatorial latitude during the Permian and thus allowed the southeastward extension of Euramerican floral elements. The occurrence of *Walchia* and *Calamites* in Oman and occurrences of these and other typical Euramerican taxa in Spain, Morocco and Nigeria (Broutin et al., 1995) document the extension of equatorial elements into subequatorial latitudes. Permian plant distribution patterns indicate that paleobiogeographic relationships between the southwestern Paleo-Tethys and South China were closer than previously assumed. Because of the controversial relative position of Gondwana to Laurussia, several Permian Pangea models have been proposed. Some of them have major consequences for the Paleo-Tethyan area, e.g. by the location of the Chinese blocks and paleobiogeographic relationships with the southwestern Paleo-Tethys. New data on the land flora and the marine ostracod fauna of Oman give us a better opportunity to assess the paleogeography of the Permian.

## 5. Paleogeographical implication for the Arabian Peninsula

The ancient territories of the Cathaysian realm consisted of a number of paleoblocks having different sizes and locations at different geological periods. These paleoblocks were scattered as a group of islands around the paleoequator in the eastern Paleo-Tethys. Although the blocks were separated from each other, biological interchange took place between North and South China as is shown by the island distribution pattern of the Permian Cathaysian flora (Jun et al., 1998). In addition, it is interesting to note that recent plate tectonic studies and terrane analyses of southeastern Asia have shown that the region is a puzzle of allochthonous continental blocks or fragments, and other terranes of an island arc (Metcalf, 1993, 1998). Recent integrated studies using stratigraphic, paleontological and paleomagnetic data indicate that most, and probably all of SE-Asia was derived directly or indirectly from Gondwanaland. A major rifting phase occurred on the margin of NE-Gondwanaland in the Early to Middle Permian indicating that a substantial continental fragment or several fragments separated from Gondwanaland at that time. Metcalfe (1998) argued that the rifting terranes were Sibumasu, Lhasa and Chiantang, along with other terranes constituting the Cimmerian continent (Sengör, 1984). Bidirectionality of floral (and faunal) exchange between Gondwanan and Cathaysian elements certainly occurred on these terranes during the Permian. Similarly, floral exchange could be envisaged between South China and the Arabian Peninsula through an island arc belonging to the South Cathaysian realm after the deglaciation and the warming in the southern hemisphere in the late Early Permian. That could explain the presence of evolved Cathaysian floral elements in Oman as well as in Saudi Arabia (work in progress).

Not only does the Gharif paleoflora document relationships between the Gondwanan and Cathaysian terranes, also ostracod faunas from the overlying Khuff Formation show affinities with those of South China, Israel, Tunisia and Greece; South China having the highest provincialism in-

dex (Crasquin-Soleau et al., 2001). Biostratigraphic analysis of the conglomerates and the sandstones in the Batain plain (NE-Oman) has revealed that the Permian fusulinid assemblages are much more similar to those known from several formations of the Lopingian of South China and the Akiyoshi group in Japan, than to those from Iran and Turkey (Hauser et al., 2000). Thus, both paleobotanical and marine paleontological data on fusulinids, ostracods and brachiopods from South China and the Oman area (and the entire Arabian plate) necessitate a reconsideration of the paleogeographical location of the Arabian plate during the Permian. South China was positioned at very low latitudes during Permian times, as is unanimously assumed by various authors, even when their paleogeographical reconstructions for the Permian are conflicting (Chaloner and Creber, 1978; Li et al., 1993; Ross, 1995; Scotese and McKerrow, 1990; Scotese and Langford, 1995; Torcq et al., 1997). However, the new paleobotanical and paleontological data do not support the position of the Arabian plate suggested by Scotese and McKerrow (1990), who favor another paleogeographical reconstruction.

## 6. Conclusions

The new paleobotanical, ostracod, brachiopod and fusulinid data (Angiolini, 1995; Angiolini et al., 1996, 1997; Broutin et al., 1995; Crasquin-Soleau et al., 1999, 2001; Hauser et al., 2000) clearly demonstrate that Southern Arabia was located at a tropical paleolatitude during the Artinskian–Early Wordian, which implies a much more reduced oceanic space than is assumed by various authors but is in agreement with the paleomagnetic data and the paleogeographical reconstruction of Besse (1998). This means that the Arabian platform would have drifted into a lower latitude earlier than previously assumed by Scotese and Langford (1995). The subduction of the Paleo-Tethys, related to the opening of the Neo-Tethys, leads to the decrease of the Paleo-Tethyan oceanic space. The movement of the Arabian Peninsula into low tropical latitudes, in this drastically reduced marine domain, would have made floral

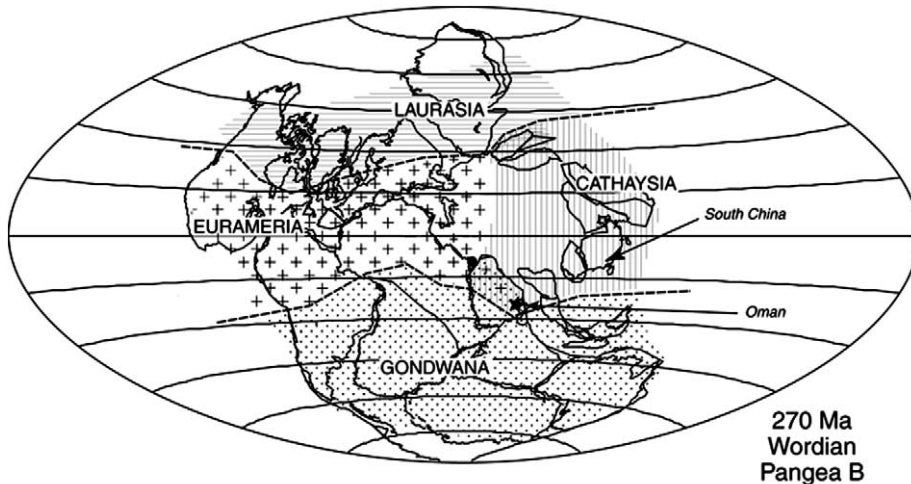


Fig. 9. Paleogeographical reconstruction of Pangea during Wordian Time (slightly modified after [Crasquin-Soleau et al., 2001](#)).

exchange between South China and Arabia possible. Floral exchange may have taken place easily via the southern connections of the above mentioned island arc.

Gigantopterids found in Oman and Arabia ([Broutin et al., 1995](#)) closely resemble advanced forms characteristic of the mid-Permian East Asia Cathaysian flora (and particularly South China). The Cathaysian flora differentiated first in South China during the Late Carboniferous and expanded in a westward direction during the Permian. However, the middle Asian mixed Cathaysian–Euramerican floras appear to be younger than both the Early–Late Permian Spanish–Moroccan floras ([Broutin, 1982](#)) which are positioned paleogeographically more towards the west, and the Venezuelan floras ([Hill et al., 1985](#)). Therefore, a first Early Permian westward floral extension from China to Western Europe–North America occurred along the northern shores of the Paleo-Tethys by the same route as *Paripteris* ([Laveine et al., 1992](#)) during the Visean to Westphalian times. Afterwards, during the Middle Permian, the dispersal of the advanced Cathaysian floral elements can be traced along the southern margin of the Paleo-Tethys from the South China province westward through the Middle and South Tibetan Blocks to the Arabian platform ([Broutin et al., 1995](#)).

The model with a reduced oceanic space for the Paleo-Tethys and a lower latitude for the Arabian plate ([Fig. 9](#)) is better in accordance with the Pangea B reconstruction of [Irving \(1977\)](#) and [Torcq et al. \(1997\)](#) than with the previously proposed Pangea A model.

When considered in the context of the complete biostratigraphic sequence of the Huqf area, the Gharif paleoflora is of particularly relevant importance for biostratigraphic correlations. As its age is very well constrained, this fossil flora may serve as a reference for comparing other mid- and late Permian paleofloras of the eastern Peri-Tethyan area. As a matter of fact, few of the known continental mixed floras are chronologically constrained. Although more data and research on the Arabian plate and the Iranian and Indochinese blocks will be necessary to further refine the picture, the paleontological data already considerably contribute towards a better paleogeographical reconstruction for the Peri-Tethyan realm.

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