On the first appearance of some gymnospermous pollen and GSPD assemblages in the sub-Angara, Euramerian and Cathaysia provinces

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In this paper the appearance of some gymnospermous pollen and GSPD assemblages in the sub-Angara, Euramerian and Cathaysia provinces has been discussed.

Key-words—Palynology, Gymnosperm, Angara, Euramerian, Cathaysia.

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साराँश

उप-अंगारा, यूरामेरियन एवं कैथेसिआ प्रदेशों में कुछ अनावृतबीजी परागकणों तथा जी.एस.पी.डी. समुच्चयों की पहली बार उपस्थिति

ऊयाँग शु

प्रस्तुत शोध-पत्र में उप-अंगारा, यूरामेरियन एवं कैथेसिआ प्रदेशों में कुछ अनावृतबीजी परागकणों तथा जी-एस-पी-डी. समुच्चयों की पहली बार उपस्थिति पर विवेचना की गई है।

THE rise of the Mesophyte is one of the major plant evolutionary events in the global terrestrial floras. However, despite that the "Paleophytic" and "Mesophytic" boundary is a useful concept both in palaeobotany and in palynology, it is by no means indisputable as for how to define it among palaeobotanists (e.g., Dobruskina, 1982, 1987). Just for convenience in the present paper, in some cases, the informal term "Mesophyte" has been used as representing a period of advanced gymnosperms (conifers, higher pteridosperms, cycadophytes and ginkgophytes, etc.) and their pollen dominance following the traditional but somewhat improved definition (Meyen, 1987; Traverse, 1988; Wang, 1989). Considering that various factors (e.g., Neves Effect) may have important influence upon the concentration of pollen/spores and the complex nature of the Mesophyte problem, the purpose of this review is only to trace out the first appearance of some gymnosperm pollen and their dominance with main attention confined to some records known from the sub-Angara area, and the Euramerian/Cathaysia Province. Partly for practical reason, the latter will be treated separately as two provinces.

The mainland of China is one of the ideal areas for studying the vegetational changes and phytoprovincial relationships of Late Paleozoic because the three major phytoprovinces (Angara/sub-Angara, Euramerian/Cathaysia and Gondwana) meet one another at their region. Furthermore, for its formation is resulted from conjugation of several plates, or blocks, at a certain time; then existing seaways separating them, and subsequent mountain chains formed might have been the main barriers for migration of some Mesophytic plants. Thus, the time discrepancy of the rise of palynofloras with a Mesophyic aspect is remarkable (Text-figure 1; Table 1). Naturally, the palynological data may in turn provide valuable evidence for reconstructing the tectonic history. Unfortunately, palynomorphs of the Gondwana Province in China proper (mainly in Xizang = Tibet) have so far not been reported.

The term "Subangara Area", a unit of the Angara Province ('Kingdom'), is used here in Meyen's sense (1982, 1987). The composition, age and distribution of the Subangara floras are still insufficiently studied, and its southern boundary is unclear in particular, although some attempts have been made (Utting *in* Lenz *et al.*, 1993). Palynological evidence indicates that N. Xinjiang, the Urals region of Russia, Kazakhstan, Svalbard, NW Canada and possibly northern Greenland may belong to the Subangara as early as in the early Late Carboniferous.

Taking into account of the parent-plant affinity and stratigraphic use as well as the morphological overlap in routine identification for some striate (taeniate included) genera, Ouyang (1991) suggested to establish two Subinfraturmas under the Infraturma Straititi of R. Potoniés turmal system, namely, the Multistriatiti (including *Protohaploxypinus*, *Striatoabieites*, *Striatopodocarpites*, *Hamiapollenites* and *Vittatina*, etc.) and the Raristriatiti (*Chordasporites*, *Lueckisporites*, *Gardenasporites*, *Scutasporites* and *Lunatisporites*= *Taeniaesporites*, etc.). The latter seems mainly related to conifers based on some *in situ* pollen findings (e.g., *Pseudovoltzia* and *Majonica* — *Lueckisporites/Gardenasporites*; an 'unnamed' conifer — *Lunatisporites* Clement-Westerhof, 1974, 1988; Lebachiaceae, *Devinostrobus* — *Scutasporites*; *Ullmania* — *Jugasporites/Lueckisporites*; Meyen, 1987). Whilst the former is possibly largely derived from pteridosperms, as evidenced by the presence of *Protohaploxypinus* s.l. in some glossopterids (e.g., *Arberiella*; Gould, 1981) and *Protohaploxypinus* and *Vittatina* in Peltaspermaceae (*Peltaspermum* and *Tatarina*; Meyen, 1982, 1987). Although overlaps do exist occasionally both in morphology and affinity, for example, a Triassic conifer from the Southern Hemisphere, *Rissikia*, is said to produce *Protohaploxypinus*-type pollen (Anderson & Anderson, 1983), and *Pteruchus*, a pteridosperm, bears *Lunatisporites* (Townrow, 1962 see Traverse, 1988). Taxa of Multistriatiti, having generally longer vertical ranges than those of Raristriatiti, are mainly characteristic of the Subangara Area, while the Raristriatiti are more common in Europe.

In dealing with the Permian miospores, Meyen (1982) pointed out that "Presently we have enough grounds to state that the similarity between Angara and Gondwana miospore assemblages is essentially related to parallelism". With this view the present author in principle is quite in agreement. Balme (1980) has discussed the drastic rise of gymnosperm pollen in the Gondwana Province and its bearing on the delineation of Carboniferous and Permian. Palynologically, the rise of "Mesophyte" in the Angara Province (e.g., Kuznetsk and Tunguska) seems to start from the base of Kungurian or of the Upper Permian (Andreyeva, 1956; Faddeeva, 1990; Oshurkeva, 1990). The present paper aims at approaching the interesting diachronosity of the base of the "Mesophyte" between these two provinces and its possible backgrounds, hence the Late Paleozoic palynofloras of Angara and Gondwana will not be discussed.

Several abbreviations are used in this paper, namely, GPD = gymnosperm pollen dominance, used in the broad sense and often concerned with pollen or pre-pollen of some Paleophytic plants (e.g., Cordaitales = majority of *Florinites* and *Cordaitina*, and ancient pteridosperms, viz., Lyginopteridales, Medullosales and Callistophytales); AGPD advanced gymnosperm pollen dominance, denoting the pollen mostly derived from conifers, cycadophytes and ginkgophytes in addition to some striate forms; and GSPD = gymnospermous, especially striate pollen of advanced pteridosperms playing more important roles in a given assemblage.

I. EARLY RECORD OF SOME SACCATE POLLEN OF ADVANCE GYMNOSPERMS

The palynological data from the North Hemisphere indicate that saccate pollen or prepollen (not including radially symmetrical trilete 'pseudosaccate' forms, such as *Rhabdosporites*) already appeared in

Table 1—Broad correlation of Subangaran, Euramerian and Cathayslan Late Carboniferous and Permian stages (the asterisks indicating the approximate horizon of first appearance of GSPD or AGPD assemblage)

System	Chinese Stage	Internatl. Stage	Sub-Angara (N. Xinjiang)	Denetz Basin	Western Europe	U.S.A. Western Interior	Tarim Basin	N. China	S. China	SW China
Lower Triassic		Olenekian	Upper Cangfang-gou Group		Buntsandstein			Heshanggou Fm.	Chinglung Formation	Koyitou Formation
		Indian						Liujiagou Fm.		Hsuanwei Formation
Upper Permian	Changhsinggian	Changhsingian	Lower Cangfang-gou Group		Zechstein	Ochoan	Biyouleibao-guzi Group	Schhchiengfeng Formation	······· Changhsing Formation	Omeishan Formation
	Wujiapingian	Dzhulfian	Upper Jijicao Group		Saxonian	Guadalupian	Kalundaer Formation ······	······· Shihhetze Group	Lungtan Formation	Maokou Formation
	Maokouan	Kazanian							Yanqiao Formation	
Lower Permian		Kungurian	Lower Jijicao Group			Leonmidian			Maokou Formation	Chihsia Formation
	Chihsiaian	Chihsian			?		Balikelike Formation	Shansi Formation	Chihsia Formation	Kuangshan-chang Formation
		Artinskian								
		Sakmarian		Slavyanskian	Autunian	Upper Wolfcampian ········				
	Longyinian	Asselian	Liukeshu Formation	Nikitosvskian	······	Lower Wolfcampian	Kankelin Formation	Taiyuan Formation	Chuanshan Formation	Maping Formation
Upper Carboniferous	Mapingian	Gzhelian		•Katamyshkian•	Stephanian	Missourian				
				Araucaritan						
		Kasimovian		Avilovskian						
				Isaevskian	Westphalian D	Desmoinesian		Penchi Formation / Vanghukou Formation	Huanglung Formation	
	Weiningian	Moscovian		Krasnokutskian						
				Kamenskayan	Westphalian C					
				Belayaka-litevskian						
			Chepaizi Formation ·······	Katalskian	Westphalian B	Atokan				
					Westphalian A					
		Bashkirian	Batamayineishan Fm.		Namurian	Morrowan		Hongtuwa Formation		

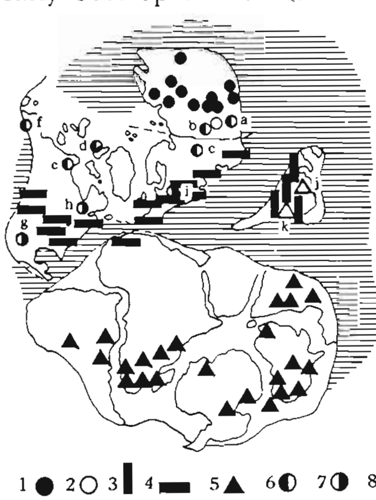
Visean, e.g., *Schulzospora*, possibly related to ancient pteridosperms (R. Potonié, 1962) of Europe, N. America and Russian Platform (Clayton *et. al.*, 1977; Fredereksen, 1972; Panova *et al.*, 1990) and this might be the ancestor of some other advance gymnospem pollen (Jansonius & Staplin, 1962).

The first appearance of some gymnosperm pollen has not been very clear. Meyen (1987, p. 257) listed the following succession: Mono- and quasi-saccate pollen— near the end of the Early Carboniferous; di-and quasi- saccate— in the first half of the "Middle Carboniferous"; quasi-saccate and striate forms — at the end of the "Middle Carboniferous" and *Vittatina* at the end of the "Middle Carboniferous". Meyen uses the term quasi-saccus instead of protosaccus because he thinks this kind of saccus is not necessarily primitive. He is right in this regard because the "eusaccate" forms seem also to have very early origin as known in the Early Bashikirian *Striatolebachiites junggarensis* Wang from N. Xinjiang, NW China. However, the sequence he suggested, or at least for the last three categories, is a equation at issue. According to the data available, the present author considers that three significant events in gymnosperm pollen evolution are worthy of notice.

1. The first appearance of large-sized monosaccate pollen represented by *Potonieisporites*, e.g., *P. elegans* (Wilson) and *P. grandis* (Luber), derived most likely from conifer and disaccate/mono-fissured pollen *Limitisporites* in the latest Early Carboniferous (E zone or E+H zones): The former (sometimes indistinguishable from large *Florinites* when its body is poorly preserved) has been known in northern England (Clayton *et al.*, 1977), in the Yukon-Mackenzie area (Utting in Bamber *et al.*, 1989), in Kazakhstan (Luber, 1955), probably in the Donetz Basin (Inosova *et al.*, 1976; Panova *et al.*, 1990) and in northern Xinjiang (Ouyang *et al.*, 1993). Both genera have been recorded in the coeval strata in Jinyuan, Gansu, N. China (Zhu, 1993). Besides, mono-disaccate transitional forms of unknown affinity, namely, *Lamellosaccites* and *Costatascyslus* were reported from the Visean Nanmingshui Formation in N. Xinjiang and the Springer Formation (C1/C2 boundary) in the United States (Felix & Burbridge, 1967), respectively.
2. The first appearance of striate and disaccate, non-striate and alete pollen in the Bashikirian.

Early Bashikirian (R zone)—The earliest *Remysporites varicus-Striatolebachiites junggarensis* Pro-GSPD assemblage of this age with abundant gymnosperm pollen is known from the Batamayineishan Formation outcropped in the eastern Junggar Basin, N. Xinjiang. The dating of this formation is based on fossil plants in the underlying formation and faunas in the overlying formation. In addition to the presence of large *Potonieisporites*, one of the most noticeable features is the first appearance of large-sized monosaccate Multistriatiti *Striatolebachiites* and morphological "primitive" *Protohaploxypinus*, both having similar intrareticulate structure (eusaccate?), and these striate pollen amount to 20 per cent of the total assemblage (Ouyang *et al.*, 1994).

Middle-Late Bashikirian (possibly R+G zones)—In the subsurface "Batamayineishan Formation" assemblages similar to that of the same formation in the nearly outcrop section (localities 1-3 in



Text-figure 1—Scheme of palaeofloristic zonation of Late Carboniferous-Early Permian (modified from Meyen, 1987) megafloristic areas: **1**. Angara Province; **2**. Kazakhstan area; **3**. Cathaysian Province; **4**. Euramerian Province; **5**. Gondwana Province. First appearance of GSPD/AGPD assemblages: **6**. Late Carboniferous (Late Bashikirian-Moscovian or Moscovian); **7**. Early Permian; **8**. Early Late Permian (N. China) and late Late Permian and Permian-Triassic boundary (S. and SW China). **a**. N. Xingiang; **b**. Kazakhstan in part; **c**. E. and W. slopes of mid-Urals; **d**. Ellesmere Island; **e**. Melville Island; **g**. Mid-Continent in USA; **h**. Canadian Maritime Provinces; **i**. some localities in W. Europe; **j**. North China; **k**. South and Southwest China.

Text-figure 1) have been found but they contain more abundant and diverse gymnosperm pollen with *Potonieisporites* amounting to 11 per cent, and disaccate Striatiti (*Protohaploxypinus* and *Striatopodocarpites*) to 12 per cent of the total on average. Pollen of the *Vittatina*-group (*Tiwariasporis*) is first seen. There are also disaccate non-Striatiti *Pityosporites* and *Platysaccus* as well as mono fissured *Limitisporites* (Ouyang *et al.*, 1994). *Platysaccus Klausipollenites, Alisporites* and *Gardenasporites* are also recorded from the classic Jinyuan section in Gansu of roughly the same age (Zhu, 1993, 1994). But striate pollen in the Corboniferous of N. China are very rare, and reliable occurrence appears first in the latest Carboniferous (Taiyuan Formation).

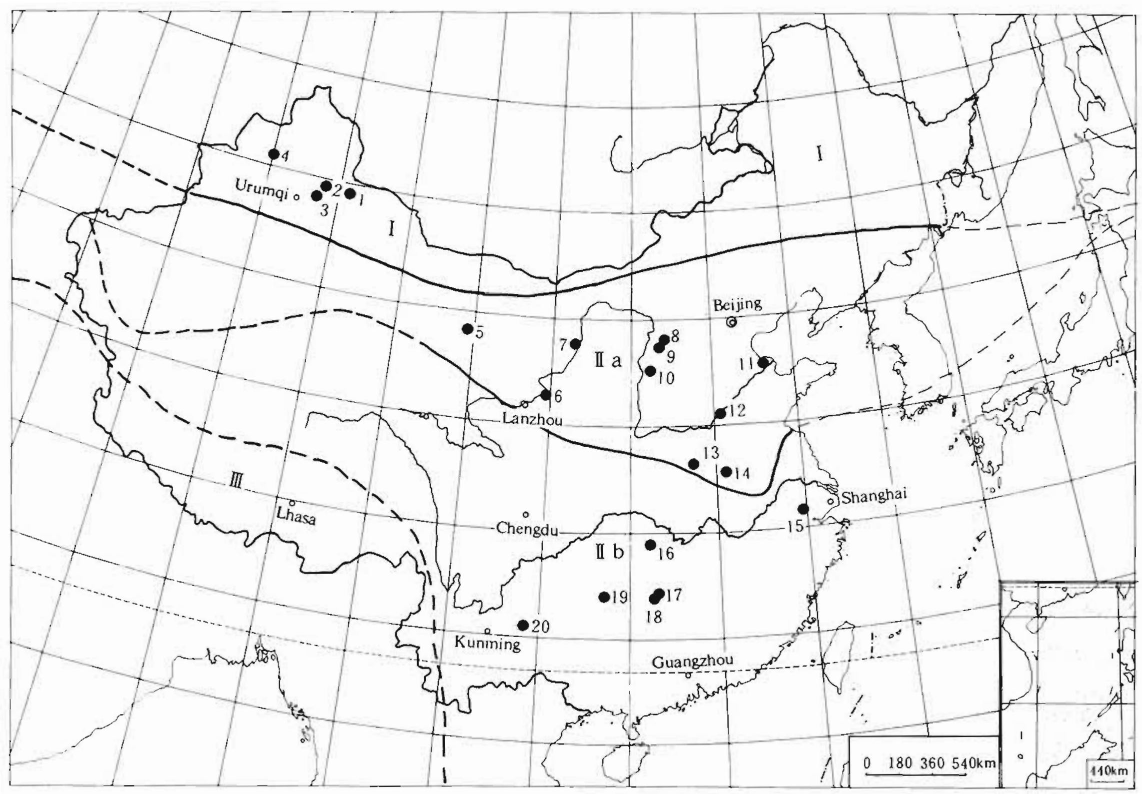
3. The first appearance of GSPD assemblages in Late Bashikirian- Moscovian or Moscovian in the northern Subangara area.

In the Late Bashikirian-Moscovian Chepaizi Formation from the Junggar Basin, N. Xinjiang an assemblage of gymnospermous, especially striate pollen dominance has been found. It is named as *Protohaploxypinus verrucosus-Hamiapollenites chepaiziensis* assemblage. The dating is based on the associated faunas and regional stratigraphic correlation (Ouyang *et al.*, 1994). The following are among those of advanced gymnosperm pollen: *Potonieisporites, Florinites*(pars), *Vesicaspora*(pars), *Pityosporites, Platysaccus Klausipollenites, Voltziaceaesporites, Falcisporites, Piceaepollenites, Abiespollenites* and *Limitisporites*, etc. and monosaccate Striatiti (*Striatolebachiites* and *Striamonosaccites*) as well as disaccate Striatiti (*Chordasporites, Gardenasporites, Illinites?, Protohaploxypinus, Striatoabieites, Striatopodocarpites, Hamiapollenites, Vittatina* and *Lunatisporites?*). Multistriatiti genera are especially diverse in species composition. The gymnosperm pollen amount to 77 per cent of the total assemblage in content with disaccate Striatiti to 44 per cent. So this is a real GSPD assemblage.

It deserves of mention that some elements with a Gondwanic aspect occur in this assemblage, they are: *Parasaccites obscurus* Tiwari, *Plicatipollenites indicus* Lele, P. cf. *P. densus* Srivastava, *Virkipollenites* cf. *V. triangularis* (Mehta), *Crucisaccites indicus* Srivastava and cf. *C. latisulcatus* Lele, etc. (Ouyang *et al.*, 1993). Of these, *Crucisaccites* is widely reported in the Permian (Talchir to Barakar) in Gondwana, the oldest occurrence of the other three genera have been known from Namurian in Australia and South America (Vijaya & Tiwari, 1992).

Similar GSPD assemblages also have been recorded from the Ettrain Formation of Late Bashikirian-Moscovian age in the Yukon Territory (Barss, 1967, 1972; Bamber *et al.*, 1989), and in the Otto Fiord Formation of Ellesmere Island of Arctic Canada (Utting, 1985); the unnamed strata of Moscovian in the eastern and western slopes of the Urals (Chuvashov *et al.*, 1979, 1984; Chuvashov & Djupina, 1973; Djupina, 1979) and possibly in central Kazakhstan (Chuvashov *et al.*, 1984) and in the Barents Sea (oral communication with Wood, G. D.). Thus, from N. Xinjiang through the Urals-central Kazakhstan-Arctic Canada to Yukon, i.e., the northern Subangara area in the present paper, vegetations composed mainly of conifers and advanced pteridosperms (e.g., Peltaspermaceae and its allies?) based on the palynological evidence would have existed during the Late Bashikirian Moscovian or Moscovian time, constituting a relatively independent ecozone (or ecotone of Meyen), or at least communities living in the xerophilous-mesophilous upland environments. These regions occupy a latitudinal extended belt south to the typical Angara Province and north to the Euramerian/Cathaysia Province (Text-figure 2).

It should be pointed out that although their first appearances are generally somewhat later than in the northern Subangara area, some of those pollen also have long history in the Eurameria. For instance, in the United States, *Potonieisporites* already appeared in the Bashikirian (Morrowan), and *Pityosporites, Platysaccus, Alisporites, Sahnisporites*, striate *Illinites* and *Rhizomaspora* first appear in the Desmoinesian (Moscovian). But they do not dominate the assemblage until in the latest Carboniferous — the Virginian GSPD assemblage found in marine shales in the Midcontinent (Jizba, 1962). Other striate pollen *Protohaploxypinus, Striatopodocarpites, Hamiapollenites* and *Vittatina* seem to start from the end of the Late Carboniferous (Frederecksen, 1972).



Text-figure 2—Showing palynological locations (black circles) in China and the Carboniferous-Permian floral provinces (after Li & Yao. 1979): **1**: Shuangzingzi, **2**. Zhangpenggou, **3**. Beisantai, **4**; Chepaizi in Xinjiang Province; **5**. Sunan and **6**. Jingyuan in Gansu Province;**7**. Yinchuan in Ningxia Province; **8**. Shuoxian, **9**. Ningwu **10**. Lishi in Shanxi Province; **11**. Zhanhua and **12**. Fanxian in Shandong Province; **13**. Pingdingshan in Henan Province; **14**. Jieshou in Anhui Province; **15**. Changxing in Zhejiang Province; **16**. Shimen, **17**. Shaodong and **18**. Shaoyang in Hunan Province; **19**. Kail in Guizhou Province; **20**. Fuyan in Yunnan Province. **I**. Angara/Subangara Floral Province; **IIa**. North China Cathaysian Floral Subprovince; **IIb**. South China Cathaysian Floral Subprovince: **III**. Gondwana Province.

In western Europe, besides the earlier appearance of *Potonieisporites* as mentioned before, *Illinites* began to occur in Bashikirian (Neves, 1964) and a few dissaccate Striatiti in Moscovian (Westphalian C): But these pollen do not occupy prominent position in the assemblage until the Early Permian (Autunian).

While in eastern Europe which was originally assigned to the Subangara area (Meyen, 1972), as in Poland, gymnosperm pollen had become fairly diverse in Westphalian D in the Mseno Basin, the assemblage contains higher proportion of Paleophytic spores in association with *Potonieisporites, Florinites, Vesicaspora, Alisporites, Limitisporites, Illinites, Protohaploxypinus?, Hamiapollenites, Tumorisporites* and *Vittatina*, etc. (Kalibova, 1989).

II. DIACHRONOUS CHARACTER OF THE FIRST APPEARANCE OF GSPD OR AGPD ASSEMBLAGES IN DIFFERENT PHYTOPROVINCES

1. Subangara area

The earliest appearance of GSPD/AGPD assemblages in the northern part of this area has been introduced before.

In the southern part of the Pre-Urals, GSPD assemblages containing *Vittatina*, disaccate Striatiti and *Potonieisporites*, etc. (about 60% in content, acritarchs excluded) are generally to start from the Early Asselian *(Schwagerina fusiformis-S. vulgaris* zone), and southwards to the Pri-Caspian Basin, GSPD assemblages first occur in the middle-upper parts of the Asselian. Sometimes, the Early Permian assemblages in these regions are characterized by abundant acritarchs due to transgression influence (Faddeeva, 1974; Faddeeva in Panova *et. al.*, 1990).

In the Donetz Basin of western Russia Platform, the Late Paleozoic palynofloras have more connection with those of Europe. In the Late Moscovian to Kasimovian (Kamenskkayan to Avilovskian) assemblages, monosaccate and disaccate non-Striatiti as well as Striatiti become progressively abundant; however, their content in total is generally less than 20 per cent. It is worth noting that the content of *Potonieisporites* reaches 10 per cent in the Late Carboniferous (C3), while in the Early Permian it may often reach 20-25 per cent and spores of Paleophytic pteridophytes loss their importance. Without faunal control, here the C/P boundary delineation is slightly different. It is placed between the lithological members P6/P5 within the Araucarilic Formation based on the widespread *Callipteris*; whilst the palynological boundary of the base of Permian marked by the first appearance of AGPD assemblage is somewhat higher between the member Q7/Q6 within the Kartamyshkian.

In the Tarim Basin, SW China, the macroflora found from the Upper Permian (the Biyouleibaoguzi Group) shows some features of the Angara Province, dominated by plants of Peltaspermaceae. But the palynological record indicates that GSPD or AGPD assemblage already existed in the late Early Permian (Kalundaer Formation). Pollen of advanced gymnosperms (e.g. *Potonieisporites* and *Striatolebachiites)* in the slightly younger Kaipaizileik Formation may reach up to more than 50 per cent in content of the total assemblage (Zhou & Chen, 1990).

During Late Carboniferous and Permian, Northern Xinjiang and Tarim Basin belong to the Angara Province, as opined by some palaeobotanists (Dou & Sun, 1985; Sun, 1992); however, judging from the palynological evidence, these basins should belong to the Subangara area because of the presence of abundant and diverse striate pollen in the known assemblages although they indeed bear some aspect of the Angara as evidenced by the occurrence of *Cordaitina* and *"Remysporites"* (strictly = *Noeggerathiopsidozonotriletes* Luber or *Psilohymena* Hart), etc. Meyen (1987) considered that some multistriate forms such as *Protohaploxypinus* s.1. *Vittatina* are characteristics of the Subangara just as fossil plants of Peltaspermaceae are assemblages from the Angara s.s. the striate pollen are usually much more rarer than in the Subangara area.

2. Euramerian Province

1. *Western Europe*—In Western Europe the lower Autunian assemblages as known in France, Germany (the middle part of the Kusel Group) and Spain (north to Madrid) are generally rich in *Potonieisporites, Cheiledonites* and *Vittatina*, named *Vittatina costabilis* zone, and their main expansion coincides with the base of the Upper Autunian which marks the lower boundary of the Disaccites Striatiti zone (Clayton *et al.*, 1977; Balme, 1980). Meyen (1987) also mentioned that assemblage dominated by conifers, *Callipteris*, *Potonieisporites* and *Vittatina*, typically from the Autunian, occasionally occurs in the 'barren-facies' of Stephanian in France. The upper Breitenbacher Schichten in Germany contains abundant or very common *Ptonieisporites, Illinites* and *Pityosporites*, sometimes their highest content reaching 51 per cent of the total (Helby, 1966).

The assemblage from the Carboniferous-Permian transition in the Iberian Peninsula, Guadalcanal, SW Spain is still dominated by Paleophytic spores. Onwards there is a break, lacking a part of Permian strata. In the Sakmarian-Kungurian assemblage therein, gymnosperm pollen became dominant (AGPD), including *Potonieisporites*, disaccate Striatiti and non-Striatiti and monocolpates: altogether reaches 80-88 per cent even some Gondwana forms excluded, they still occupy about 61 per cent on average (Broutin, 1986).

2. North America— In the Maritime Provinces of SE Canada the assemblage of the upper part of the Pictou Group (Stephanian) contains *Potonieisporites* and *Illinites unicus* Kosanke, etc. but many Carboniferous elements occur. The top of this group, dated as Wolfcampian in age, is characterized by GSPD assemblage with quite diverse disaccate Striatiti and *Vittatina* (Barss, 1967). In the Midcontinent of the United States, at the base of Wolfcampian monosaccate pollen and trilete spores predominate with only a few striate forms. The lower part contains a number of Paleophytic spores, and locally trilete spores are very common, but striate forms increased; and the upper part is marked by GSPD assemblage.

According to Gupta (1977), the base of the Wichita Group is marked by the appearance of an association of *Hamiapollenites*, *Vittatina*, *Striatoabieites*, *Platysaccus*, *Potonieisporites* and *Nuskoisporites*. Gupta regards the lower part of the group as Pennsylvanian, however, Balme (1980) is inclined to correlate the assemblage with that of the Orenburgian-Lower Asselian of Russia (lower and middle *Schwagerina* zone), i. e., equivalent to the Lower Permian in Balme's correlation scheme. In the Leonardian-Guadalupian strata, saccate pollen, especially *I. virkkiae* and monocolpates increase progressively (Wood *et al.*, 1991). The Wellington Formation (Artinsk) also bears GSPD assemblage (Wilson, 1987).

To sum up, the drastic rise of GSPD/ASPD assemblages may be within the Lower Autunian and nearly at that base of the Upper Wolfcampian in the hinterland of W. Europe and N. America (Table 1).

3. *Mid-East*— Holowicz (1972) suggests that the Late Permian assemblage of Israel (Zohar) is of Cathaysian type; this assumption, however, seems more apparent than real because the lack of many typical Cathaysian elements, such as *Patellisporites*, *Nixispora*, *Propterisispora*, *Bactrosporites*, *Yunnanospora* and, *Macrotorispora* and *Anticapipollis* in particular as well as numerous species (Ouynag, 1962, 1982, 1986; Chen, 1978). The Israel assemblage contains abundant trilete spores, including some relic forms of Carboniferous, and fairly diverse saccate pollen with low content. In this respect it has similarity to those of Late Permian of the Cathaysian, possibly reflecting a similar ecological background (warm and humid, as in S. China). On the other hand, the subsurface Permian assemblages of Israel (including Zohar) recently studied by Eshet (1990) display different features: In the "Autunian" seems already to be AGPD assemblage, in which Euramerian and Subangara forms *Potonieisporites*, *Nuskoisporites*, *Protohaploxypinus* and *Hamispollenites* are in association with Gondwanid *Plicatipollenites*. And the "Thuringian" yields an assemblage of GSPD, showing a stronger Euramerian aspect as represented by *L. virkkiae* and *K. schaubergeri*. Eshet concluded that " the Permo-Triassic palynozones of Israel show affinities to key sections in both Gondwana and Laurasia". Combining the data of Holowicz and Eshet, one can at least say that some horizons of the Upper Permian of Israel contain GSPD assemblages, possibly somewhat later than in the hinterland of W. Europe and N. America.

3. Cathaysia Province

1. *North China*—The early record of a few gymnosperm pollen in Visean and Bashikirian has been mentioned before. In the Yanghukou Formation of Jiniyuan, Gansu and Shanxi-Gansu-Ningxia Basin (Westphalian B-D), the Paleophytic spore-dominated assemblages contain *Pityosporites*, *Platysaccus*, *Klausipollenites*, *Limitisporites*, *Vestigisporites* and *Cycadopites* (Wang, 1982; Geng, 1985). The Penchi Formation (Westphalian C-D) from Shouxian, Shanxi (Ouyang & Li, 1980a) yields a similar assemblage with various disaccate non-Striatiti but in very low proportion (5%) *Cycadopites* of ginkgophytes and cycadophytes also has an early history in China, appearing in the early Late Carboniferous (Namurian R+G zones, e.g., the Hongtuwa Formation in Jinyuan) at the latest, but usually very rare in assemblages through Carboniferous and Lower Permian, partly may be due to its uneasy preservation.

A tendency of increase both in diversity and abundance of gymnosperm pollen may be traced up through the Carboniferous to Permian in China as they do in other parts of the world, however, they did not occupy dominant position until the early Late Permian in N. China. An exception is found in a GSPD or AGPD assemblage from the Shansi Formation (Sakmarian-Chihsian) at Sunar, Gansu Province, where is adjacent to the Subangara area (the author's unpublished data). In the Upper Shihetze Formation (roughly equivalent to the Lower Zechstein), an assemblage found in Ningwu, Shanxi, contains abundant (40-50%) disaccate forms, including the first appearance of *L. virkkiae* in addition to the Paleophytic *Cordaitina* and *Schopfipollenites*, etc. (Gao, 1984). In the same formation from Fanxian and Zhanhua, Shandong, a diagnostic feature of the assemblage is the common presence of the Cathaysia genus *Anticapipollis* (conifer?). In the upper part of the Upper Shihhetze Formation the content of AGP may reach to 37-56 per cent (47% on average) of the total assemblage, and the generic composition is very diverse, especially for disaccate non-Striatiti (may up to 40%). They are in association with some striate forms, such as *Protohaploxypinus*, *Striatoabieites*, *Costapollenites*, *Vittatina* and *Ephedripites* (Zhou, 1987). Therefore, in some places of N. China, AGPD assemblages first appeared in the early Late Permian. Similar tendency has also been observed in the macrofossil plant record (Wang, 1989).

However, the drastic modification of terrestrial floras in N. China only happened in the beginning of the Late Permian (Shihchiengfeng Formation s. s. = Sunjiagou Formation) for GSPD assemblages can be found in vast area of N. China, such as in Shanxi (Lishi) (Qu, 1980), Henan (Pingdingshan) (Ouyang & Wang, 1983) and Anhui (Jieshou) (Wang, 1987). The palynoflora is characterized by the presence of *L. virkkiae*, *Jugasporites*, *schaubergeroides* and *K. zapfei*. The assemblage of Anhui is more diverse with AGP reaching 60-77 per cent. In addition to individual *Potonieisporites*, disaccate non-Striatiti occupy 32 per cent, comprising *Pityosporites*, *Platysaccus*, *Alisporites*, *Vitreisporites*, *Cedripites*, *Protopinus*, *Piceapollenites* and *Pteruchipollenites*; disaccate Stratiti reach 17-30 per cent, including *Illinites*, *Chordasporites*, *Gardenasporites*, *Lueckisporites*, *Lunatisporites*, *Protohaploxypinus*, *Striatopodocarpites* and *Vittatina* as well as *Jugasporites* and *Limitisporites* in association with a few monocolpates. Paleophytic spores (e.g. *Lycospora*, *Densosporites*, *Crassispora* and *Thymospora*) are much rarer than preceeding assemblages.

2. *South China*—During the Late Carboniferous and Early Permian, South China was mostly covered by epicontinental sea, generally devoid of spores and pollen. Only in some places in the Early Permian occur terrestrial-marine alternated sediments known as the Liangshan Formation (or the Basal Chihsia Coal Series) which have been proved to be palyniferous. For example, a GPD assemblage of the formation known from Kaili, Guizhou has been reported (Gao, 1989). It is still characterized by Paleophytic spores, but contains a plentiful of gymnosperm pollen, amounting to 44-55 per cent in content, except for a majority of *Florinites* (30-50%) of largely Cordaitalean origin, there are *Vitreisporites*, *Sulcatisporites*, *Gardenasporites* and *Protohaploxypinus*. Another assemblage of this age from Shiman, Shaodong and Shaoyang, Hunan, is dominated by zonotriletes and monolete spores of Paleophytic pteridophytes, saccate pollen being very rare (Chen, 1978).

The assemblages from the early Late Permian Lungtan Formation (and its underlying Yanqiao Formation) which yields typically the Gigantopteris flora are exclusively dominated by Paleophytic spores, such as known from Changxing in Xhejiang and several localities in Hunan (Ouyang, 1962; Chen, 1978; Jiang, 1982). Gymnosperm pollen are low in frequency (5-10%) but may be quite diverse, including both disaccate non-Striatiti and Striatiti.

The assemblage from the Late Permian Chanshing Formation typically outcropped in Changxing, Zhejiang is often dominated by marine acritarchs. The overlying Lower Triassic, Lower Chinglung Formation contains *Vittatina-Protohaploxypinus* assemblage below and *Lunatisporites-Gnetaceaepollenites* assemblage above, both having *L. virkkiae* and *K. schaubergeri* (Ouyang & Utting, 1991). Recently, GSPD assemblages have been found in several horizons of the upper part of the Changhsing Formation (Ouyang & Hou, 1994, MS). In other words, the first appearance of GSPD assemblage has commenced within the Changhsingian time, i.e., somewhat later than that in N. China.

The assemblages from the Late Permian coal-bearing Xuanwej Formation in Fuyuan, Yunnan, SW China, are still dominated by pteridophytic spores, including quite a number of relic forms of Carboniferous: *Walzispora*, *Schopfites*, *Stellisporites*, *Triquitriletes*, *Tripartites*, *Lycospora*, *Crassispora*, *Torispora* and *Thymospora*, etc., These elements are thought to be indigenous, i.e., not reworked as discussed in some detail elsewhere (Ouyang, 1982, 1986). Gymnosperm pollen are low in content (5-6%) but fairly diverse, including *Protopinus*, *Vitreisporites*, *Abietineaepollenites*, *Cedripites*, *Pteruchipollenites*, *Platysaccus*, *Klausipollenites*, *Limitisporites*, *Gardenasporites* and *Anticapipollis* associated with individual *Protohaploxypinus*, *Striatopodocarpites*, *Vittatina* and *Cycadopites*. The assemblage from the overlying Early Triassic Kayitou Formation at the same locality displays a transitional character of Paleophyte and Mesophyte, especially in its lower part (27-35 m). It contains some relic forms persisted up from older ages on the one hand, and many Mesophytic forms, including *Aratrisporites-Lundbladispora* and spores of Leptosporangiate plants on the other. A dramatic change is seen from the middle part of the formation in which AGPD (60-80% in content) assemblage is found, mainly composed of disaccate non-Striatiti with similar generic composition as in the preceding Xuanwei Formation, and slightly increased disaccate Striatiti (Ouyang & Li, 1980b).

As manifested by the progressively increase of GSP or AGP both in diversity and abundance and the gradual decrease of spores of arborescent laycopsids, sphenophyllids and articulates as well as pollen of ancient pteridosperm and Euramerian cordaitaleans with time, the rise of the Cathaysia Mesophyte is a long-term process in association with the decline of Paleophytic vegetation which is mostly composed of lowland or coal-swamp communities, while the former reflects mainly of xerophilous-mesophilous vegetation in upland environments (Yao & Ouyang, 1980). Compared with the Cathaysia Province, the Subangarid N. Xinjiang is very peculiar where the Early Carboniferous palynoflora dominated by zonotriletes spores (reflecting the "Lepidophyte Flora", Dou & Sun, 1985) was almost suddenly replaced by the pro-GSPD and GSPD assemblages in the Early Bashikirian and Late Bashikirian-Moscovian, respectively. The early GSPD assemblage is also possibly derived from advanced pteridosperms and conifers. And worth mentioning is that this kind of assemblage runs through the Late Carboniferous and almost the whole Permian in N. Xinjiang, involving both marine (C2-P1) and terrestrial (P2) sediments.

Now, more and more palynological data about the first appearance of GSPD or AGPD assemblages from the Late Carboniferous to the Late Permian have been accumulated, which enables us to improve our knowledge in this regard. Thus the approximate horizons of the beginning of GSPD/AGPD assemblages in the Subangara area, the Euramerian and Cathaysia provinces are marked in the stratigraphic correlation table (Table 1) which is made on the basis of some references (Shen Guanglong, 1994, MS; Balme, 1980; Zhou & Chen, 1990; Sheng *et al.*, 1982; Hou & Wang, 1986; Liao *et al.*, 1990; Zhu, 1983; Ouyang *et al.*, 1994).

III. DISCUSSION

From the foregoing review and Table 1 one can clearly see that the first appearance of GSPD or AGPD assemblages, or in some cases, the base of Mesophyte, is dischronous in different phytoprovinces or subprovinces. Furthermore, it has a general southward tendency from north to south in the Laurasia (Angara Province s.s. excluded) from the early Late Carboniferous to the end of the Permian Period. It occurs during the Late Bashikirian-Moscovian in the northern Subangara area, nearly at the beginning of the Permian in the hinterland of Europe and N. America, in the late Early Permian in some peripheral places north to the Tethys Sea (e.g., S. Spain and Israel), within the Early Permian in the Tarim Basin, at the beginning of the late Late Permian or somewhat earlier in N. China, in the upper half of the Late Permian in S. China and nearly at the boundary of Permian/Triassic boundary in SW China (Text-figure 2).

This kind of tendency may have been related to several fundamental factors as follows:

1. Some parent plants of GSPD or AGPD assemblages (e.g., Peltaspermaceae and its allies) might have migrated southwards following the general tendency of the Laurasia's constant northward drift during the Carboniferous-Permian times. As Kremp (1977) first pointed out that "the constant northward movement of Pangaea which caused a constant southward shift of the climate zones, which, in turn, forced plant and animal communities into a continuing southward migration in order to stay in the same climate zone".
2. It may be partly explained by the time-differentiation of conjugation of some Eurasia blacks (Scotese & McKerrow, 1990; Zhou & Chen, 1990; Tu, 1993), for instance, the Junggar block (terrain) and the Kazakhstan block as well as the Siberia block (D3-C2), the Tarim block and Junggar block (C2-P1), the North China block and Siberia block (P2?), and the South China block and North China block (T3 or earlier) although there is much difference of opinion amongst the scientists as for the conjugation ages are concerned (as shown in the brackets). For example, the age of the main progeny of the Qinling Moun-

tain ranges—a collision-type mountain belt which finally connected the North and South China blocks — was supposed either Late Triassic (Sengor, 1985) or basically the Late Paleozoic (Li *et al.*, 1981). Anyway, the general tendency of the conjugation ages to become younger and younger southward, did exist and coincides in principle with the successive shift of the first appearance of GSPD or AGPD assemblages from north to south in China.

3. The indication of hot/warm and dry climate or drought belt expanded from north to south, or the progressive disappearance of coal-swamp conditions as typically seen in the Cathaysia Province.
4. In the vast expanse of the North Hemisphere caused by the constant increase of continentality during the Carboniferous and the effect of glaciations in Gondwana, the climate in Permian became more continental and drier in general than before, and the downwards of groundwater table related to the sea level promotes the drying up of lowland, and consequently, in accompanying with the southward migration of some plants living in comparatively higher latitude, some advanced gymnosperms originally growing in the upland habitats of low latitude might also move to the aggradational basins (Fredereksen, 1972).

These two migration events, viz., the latitudinal migration from north to south and the altitudinal migration from upland to lowland, may be used to explain better the palynologically drastic changes and the discrepancy of macro-and micro-floral records. Naturally, in the meantime, migration of some plants along other direction or even the reverse (from south to north) might also happen owing to the climatic fluctuation, the broad ecological adaptability of some plants, changes in geological and topographical conditions (e.g., seaways, land bridges) as well as warm current of ocean, etc. (Meyen, 1987; Wang, 1989).

CONCLUSIONS

1. Palynological evidence from the areas reviewed indicates that some monosaccate pollen forms of assumed conifers, as represented by large-sized *Potonieisporites* and *Limitisporites*, already evolved in the latest Early Carboniferous (E zone or E+H zones): *Lamellosaccites* and *Costatascyclus* of unknown affinity appeared in the Visean or C1/C2 boundary.
2. Among saccate Multistriatiti, *Striatolebachiites* and morphologically 'Primitive' *Protohaploxypinus* first appeared in the early Late Carboniferous (Early Bashikirian, R zone) of the Subangara area.
3. The first radiation of some disaccate non-Striatiti (*Pityosporites, Platysaccus, Klausipollenites* and *Alisporites*, etc.) and disaccate Striatiti (*Illinites, Gardeniasporites, Striatopodocarpites*) happened during the middle-late Bashikirian (R+G zones) and a representative of the *Vittatina* group (*Tiwariasporis*) first appeared in the same age.
4. The first and earliest GSPD assemblages containing abundant and diverse disaccate non-Striatiti and Striatiti (*Chordasporites, Striatoabietes, Hamiapollenites, Vittatina* and *Lunatisporites*, etc.) in addition to monosaccate Striatiti and non-Striatiti were originated in the Late Bashikirian-Moscovian and Moscovian in the northern part of the Subangara area.
5. Unlike the sudden rise of angiosperms in the Late Cretaceous in a world-wide scale, the first appearance of GSPD or AGPD assemblages is diachronous in different phytoprovinces and subprovinces, thus in principle it can not be used as a clue to correlate the strata of inter-provincial areas.
6. There is a tendency that the horizon of the first appearance of GSPD or AGPD assemblages becomes higher and higher from north (the northern Subangara area) to south (north to the Tethys), possibly related to several causal factors, such as the northward drift of the Laurasia which caused southward migration of their parent plants and the drier climate in the Permian caused downward migration of some plants originally living in the upland environments in low latitude, i.e., from upland to lowland aggradational basins. These two major migration events may be used better to explain the drastic changes of the palynofloras of the Late Carboniferous to the end of the Permian Period and the age discrepancy of macro- and microfossil records.

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