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FOURTEENTH BIRBAL SAHNI MEMORIAL LECTURE

The mixed Permian Cathaysia-Gondwana flora

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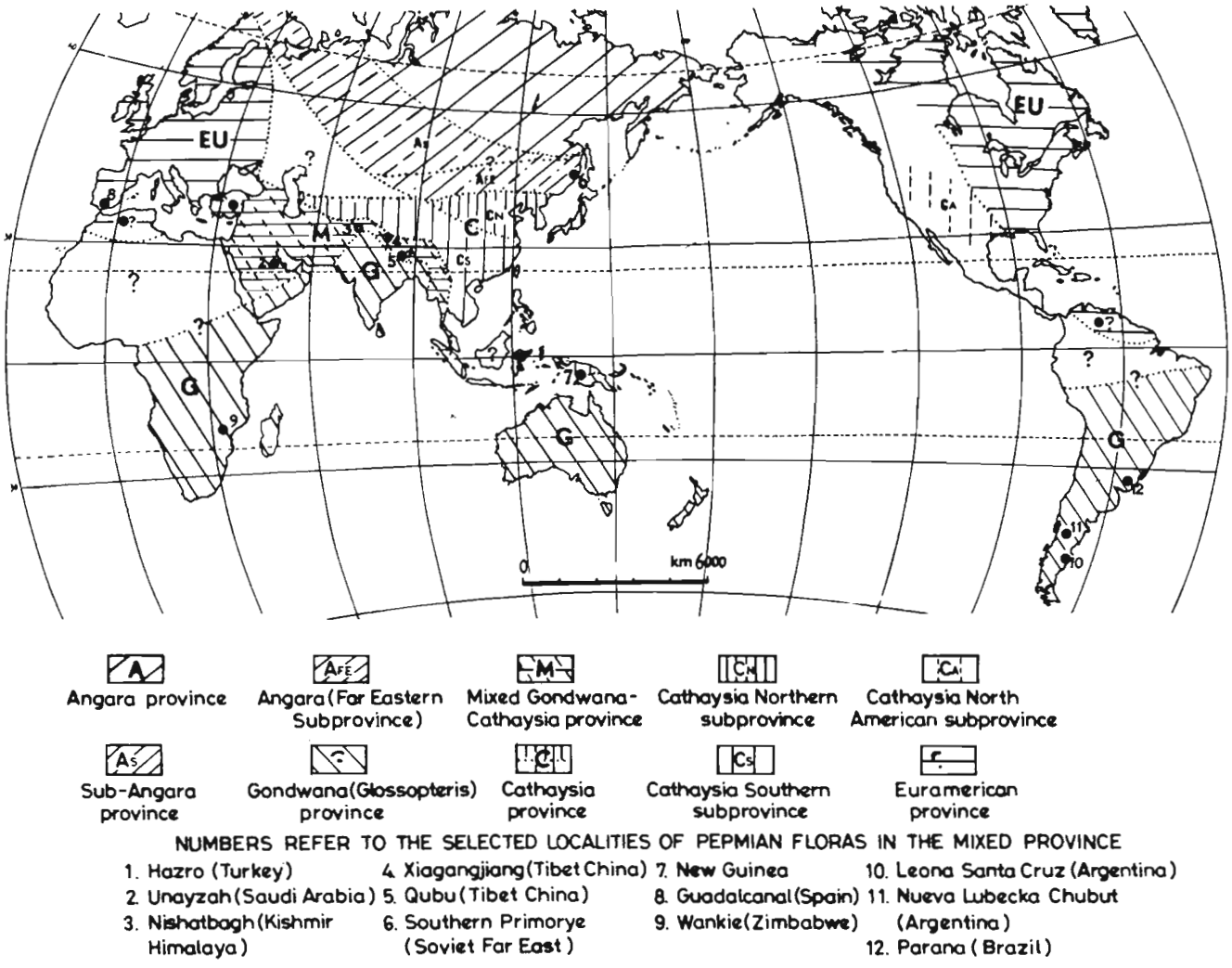
THE reasons for my talking about the mixed flora problem here are threefold; first, as you are well aware, early in the middle of thirties, late Professor Birbal Sahni (1935, 1936) had furnished elaborate explanations about the formation of the sub-continent of South Asia and the Qinghai-Xizang (Tsinghai-Tibet) Plateau as well as the subdivision of palaeophytogeographical provinces of East Asia. Second, it is a very interesting problem relating to many branches in geology, geography and biology and deserves special attention and further study. And third, some important new ideas were put forward during the last decade on the Qinghai-Xizang Plateau through investigations made by Chinese and foreign scientists. Therefore, I consider it appropriate to summarize the relevant data available with the hope that it might throw some light on this obscure problem and stimulate new researches. However, because the mixed flora problem concerns with many complicated subjects and has long been in dispute, some scholars even deny the occurrence of any mixed flora during geological times. Thus, what I am submitting here is preliminary and far from complete.

BRIEF REVIEW OF RELATED MIXED FLORAS OUTSIDE CHINA

Hazro flora (Turkey)—The Hazro flora of Anatolia in Turkey (Map 1) has been one of the most attractive known mixed floras (Wagner, 1959, 1962). There is little dispute to the remarkable Cathaysia nature of this flora; some authors, however, doubt identification of some specimens as *glossopteris*, a representative of the Gondwana flora. Archangelsky and Wagner (1983) re-investigated the original collection and complementary specimens obtained from the same locality. The plant remains originally assigned to *Glossopteris* cf. *stricta* has been identified as *Glossopteris anatolica* sp. nov.; and another genus *Botrychiopsis*, also a common member of the Gondwana flora, was recognized with certainty. Now it seems acceptable that the Hazro flora is a mixed flora with double aspects of both Cathaysian flora and Gondwana flora.

Unayzah flora (Saudi Arabia)—The Unayzah flora was found in the central part of Saudi Arabia and also attracted much attention among those who are interested in the research of mixed flora. The earliest account (El-Khayal *et al.*, 1980) suggested that it was a typical Euramerican flora without any reliable elements of Cathaysian flora or Gondwana flora. But subsequent study (Lemoigne, 1981) demonstrated that it is really a mixed flora, containing such important Cathaysian representatives as *Annularis mucronata* Schenk, *Lobatannularia* cf. *heianensis* (Kod.), *Fascipteris hallei* (Kaw.), etc. associated with "Northern" elements. The memoir of a comparatively systematical study for this flora by Wagner and others (pers. comm., 1984) has been sent to press. Although the detailed content we do not know, yet my colleague Dr. Zhou tells me that he had an opportunity to observe the Wagner collection from the same locality at Sheffield University. He recognized with confidence the presence of Cathaysian elements, e.g. *Gigantonoclea*, etc. in this flora. Of course, there are other northern elements in the flora. At present, it is difficult to judge whether this flora contains Gondwana elements? The specimen with loose reticulate venation identified by Lemoigne (1981) as *Zamiopteris* (?) sp. is a doubtful plant. Considering the presence of *Glossopteris* in the Hazro flora north to the Unayzah flora, I think it highly possible that Gondwana elements may be found in the Unayzah flora. Now it would seem that the traditional view to regard the Arabian Peninsula as a part of the Gondwanaland has lost its basis, as the occurrence of the mixed Permian flora in this area is beyond doubt. The presence of some Cathaysian elements in Central Saudi Arabia is not unexpected, because several Permian Cathaysian species, e.g.



Map 1—World map showing distribution of Permian floral provinces (dotted lines indicate only the approximate boundary of floral provinces).

Plagiozamites oblongifolius Halle have been also discovered in Iraq (Ctyroky, 1973), a neighbouring country to the Hazro flora of Turkey as mentioned above. Consequently, a question in front of us is that what kind of flora occupied the vast area of northern Africa to the west of the Red Sea?

Mamal flora (Kashmir)—According to Singh, Maithy and Bose (1982) in this flora some representatives of the Cathaysian flora, i.e. *Lobatannularia ensifolia* Halle, *Rajabia mamalensis* sp. nov. and *Sphenophyllum thonii* var. *minŏr* Sterzel, are found in association with typical elements of the Gondwana flora, i.e. *Trizygia speciosa* Royle, *Glossopteris intermittens* Feistmantel and *G. angustifolia* Brongn. Below the strata containing the Mamal mixed flora and separated by the Panjal Volcanic Series is the Nishatbagh Formation containing Glossopteris flora; beneath the Nishatbagh Formation is the Agglomerate Slate Formation which is widely spread in Kashmir Himalayas and possibly of late Carboniferous age.

The discovery of the Mamal mixed flora and the stratigraphical succession in the Nishatbagh area is very interesting and significant to the study of stratigraphy and palaeontology of the central and southern parts of Tibet and I will touch it again later.

Mixed flora of the Soviet Far East—The discovery of mixed Permian flora in a place near Vladivostok, southern Primorye of the Soviet Far East is a matter of great interest (Zimina, 1967, 1969, 1983). The most prominent feature is that this flora includes many typical Gondwana plants, such as *Glossopteris*, several new forms of *Gangamopteris* and *Palaeovittaria* and another known species, *Euryphyllum whittanium* Feistmantel. Secondly, it is interesting that this flora includes such Cathaysian species as *Labatannularia heianensis* (Kod.) and *Pecopteris* (*Asterotheca*) *orientalis* (Shenk) in association with some Angaran and Euramerican elements. This flora is divided into three—upper, middle and lower assemblages, occurring in about 3,000 m thick marine-continental intercalated deposits. The lower assemblage

is mainly composed of Angaran of Early Permian age. The middle assemblage is dominated by taxa of the Gondwana flora associated with a few Cathaysian elements and is dated as late Early Permian to early Late Permian. The upper assemblage is distinguished by a few Cathaysian elements but without any Gondwana taxon.

The age determination of these assemblages and the presence of Cathaysian elements seem reliable because Burago (1973) also reported the discovery of floras equivalent to those of the Upper and Lower Shihhotse formations of North China in the same district (not far from the north to Vladivostok). Why almost all the Gondwana elements in this flora are new species? Why this mixed flora occurs in the very north-eastern Asia, and why a vast area separates this place from the currently known distribution of Glossopteris flora? All these phenomena need reflection.

Flora of Western Guinea—Jongmans (1940) first reported the occurrence of a mixed flora in New Guinea. Subsequently, Visser and Hermes (1962) reported the presence of *Glossopteris* and *Vertebraria* associated with a few Cathaysian elements in the east of western New Guinea, while Asama and others (1975) doubt the presence of latter. Recently I received from Dr J. Rigby two photos of fossil plant fragments obtained from western New Guinea which he suspects are Cathaysian elements associated with Gondwana elements. I believe they can be identified as *Gigantonoclea* sp. and *Fascipteris* sp.; thus the presence of Cathaysia Gondwana mixed Permian flora in this area is proved, though I am not very clear about the geological relations of the fossil site.

Guadalcanal Flora of Southeastern Spain—This flora, through the palaeobotanical and palynological study made recently by Broutin (1981, 1982), is considered to be mixed flora containing Angara, Cathaysia, Gondwana and Euramerica elements. This area refers formerly to the Euramerican floristical province, so that the Euramerican elements need not to be listed. The remarkable feature of this flora is the presence of Cathaysian elements, i.e. *Protoblechnum wongii* Halle cf. *Fasicpteris* (*Validopteris*) *robusta* Gu et Zhi *Sphenopteris pseudogermanica* Halle and *Lobatannularia*—type, etc. The species that is more or less comparable with the Gondwana Permian element is *Ginkgophytopsis* sp. cf. *G. kidstonii*-type cf. *Entsovia* sp. shows some affinity with the Angara flora. In addition, there are *Rhipidopsis baetica, R. ginkgoides, Phyllotheca* sp. and *Psygmophyllum* spp. which are common components of the above mentioned three floras.

The palynological result coincides quite well with that of the macroflora study as to the nature of the flora. In this paper, Broutin simply mentioned a similar mixed flora found from Algeria in northern Africa. A formal article for the flora by Doubinger is in press.

There seems to be little doubt that Guadalcanal flora has some Cathaysian elements; however, the presence of Angara or Gondwana elements in the flora has not yet been proved. One can hardly judge such plants as *Rhipidopsis ginkgoides* and *Psygmophyllum* belonging to any phytogeographical province, and the determination of these plant taxa is often difficult.

Wankie flora in Zimbabwe—The Wankie flora has been well known as a mixed Permian flora consisting of elements of both southern and northern Hemisphere types (Walton, 1929). Teixeira (1949, 1952), Lacey and Huard-Moine (1966), Lacey and Smith (1972) and others successively went to the original locality in Zimbabawe, and also investigated the equivalent strata in Mozambique and Malawi in some detail. Although some additions or changes about the composition and identification of the Wankie flora were made by these authors, however, there is no dispute about the nature of flora which is dominated by Gondwana elements and mixed with quite a number of northern hemisphere elements, including Cathaysian ones. Some "northern" elements which Walton originally mentioned without confidence, are also confirmed by Lacey and others; for example, they recognized the presence of *Pecopteris arcuata* Halle in this flora. The Wankie material, both sterile and fertile, under this designation, in my opinion, differs in venation and fructification of the typical specimens of Halle's species described from China.

Mixed floras of South America—The mixed Permian floras have a wider distribution in South America (Archangelsky, 1958, 1970, 1971; Archangelsky & Sota, 1960; Archangelsky & Arrondo, 1975). Nueva Lubecka of Chubut, Leona of Santa Cruz, and Central Patagonia in Argentina, and the Parana Basin in southern Brazil are among the more famous localities. One of the most prominent features of the Glossopteris flora in these area is that in addition to many Euramerican elements, e.g. *Sphenophyllum thonii* Mahr, *S.* cf. *oblongifolium* (Germ. et Kaulf.) and *Pecopteris unita* Brongn., there are a few representatives of the Cathaysian flora, e.g. *Pecopteris* (*Asterotheca*) *anderssonii* Halle in the Lubecka Formation of Argentina and *Chiropteris reniformis* Kaw. in the Tubaro Formation (or Tatui Formation of Rigby, 1970), Parana Basin of Brazil. The composition of these floras in South America is largely the same as that of the Wankie flora in South Africa, and the present geographical position of both areas is widely separated by the Atlantic Ocean. Lacey and Huard-Moine (1966) suggested that both show a close affinity with the Cathaysian flora of East Asia. Archangelsky and others (1975), on the other hand, are inclined to combine floras in South America and South Africa with the coeval floras in Australia, and inlay the relevant ancient plates together as shown in their new Paleofloristic Province—Austroafroamerican—which has characters of its own. However, these assumptions seem to deserve further consideration.

RECENT STUDIES ON THE MIXED FLORAS OF XIZANG, CHINA

1. *The Xiagangjiang mixed flora in Central Xizang*—This interesting flora has been recently studied by Li *et al.* (in press). It is most probably latest Early Permian in age. It is situated approximately at 32°26′N —84°15′E, a locality about 120 km southeast to the Gerze city (Map 2). The plant-bearing horizons and generalized stratigraphic columnar section of Xiagangjiang area are shown in Text-fig. 1.

The plant remains are all preserved as impressions and seldom well preserved enough for a specific determination. Attempts at cuticular preparation and palynological analysis for the material have been made, but yield no results. The identification of 17 species or types of the flora listed in the following is based merely on their macroscopic features.

Phyllotheca sp. (cf. *P. australis* group)
?*Schizoneura* sp. (cf. *Schizoneura gondwanensis* Feistmantel)
Indeterminable arthrophytic leaves
Sphenopteris xiagangjiangensis sp. nov.
Sphenopteris sp.
Pecopteris aff. *arcuata* Halle
Pecopteris sp. 1 (? sp. nov.)
Pecopteris sp. 2
Pecopteris sp. 3
?*Alethopteris* sp.
Noeggerathiopsis hislopii (Bunbury)
Noeggerathiopsis sp.
?Squamous leaf
?*Plagiozamites oblongifolius* Halle
Cardiocarpus sp. 1
Cardiocarpus sp. 2
Carpolithus sp.

At the first glance, the Xiagangjiang flora does not show a close relationship with any known Permian flora. However, in the dominance of strongly ribbed arthrophytic stem-casts *Phyllotheca* sp. and ?*Schizoneura* sp., and cordaitalean leaves, i.e. *Noeggerathiopsis* spp., bears a striking resemblance to that of the Glossopteris flora; they are very rarely found in the Permian Cathaysian flora. Another distinctive feature of the flora is the relatively rich occurrence of Pecopterids and Sphenopterids, which remind us also of a floral aspect of the Permo-Carboniferous of northern hemisphere. Of particular interest among these forms is a specimen named *Pecopteris* aff. *arcuata* Halle which distinguishes itself by a venation of *P. unita*-type. Pecopterid plants with this type of venation have never been found in the typical Glossopteris flora. In this connection, it seems appropriate to point out that a specimen from southern Xizang (Tibet) described by Hsü (1976) as *Dichotomopteris qubuensis* bears also the venation of *P. unita*-type, which, in my opinion, probably is conspecific with *P.* aff. *arcuata* of the Xiagangjiang flora. Another specimen from Xiagangjiang, i.e. ?*Plagiozamites oblongifolius* Halle might show a certain relationship with the Cathaysian flora, too.

In the tectonic region in the nearby area, where the Xiagangjiang flora occurs, some Blaini type glacial deposits and cold water invertebrate assemblages such as *Eurydesma* fauna have been found (Liu *et al.*, 1983). Furthermore, the stratigraphic succession, mainly of the Permian, in the Xiagangjiang area corresponds rougly to that of the Mamal mixed flora in the Nishatbagh area of Kashmir. The Xiagangjiang flora is thus considered to be a mixed Permian flora, although the total absence of either typical Gondwana genera such as *Glossopteris* and *Gangamopteris* or the Cathaysian gigantopterids, *Lobatannularia* and *Tingia* in the Xiagangjiang area is a noteworthy feature.

2. *The Qubu flora of southern Xizang (Tibet)*—This flora has attracted much attention due to its importance in geo-tectonics and palaeobotany (Hsü, 1973, 1976, 1978, 1981). It was thought to be typical Glossopteris flora. However, Singh and others (1982) transferred the specimens originally identified as *Raniganjia qubuensis* Hsü to *Lobatannularia*, an important Cathaysian genus; they also pointed out that the Mamal mixed flora found in Kashmir "show close similarity with the assemblages described by Hsü (1973, 1976) from... southern Xizang". Obviously, they doubted somewhat the typical nature of Glossopteris flora of Qubu. In 1983, I published a paper "Notes on the three new species of the Glossopteris flora from Qubu Formation, S. Xizang", with the conclusion that this flora should be dated as late Early Permian instead of early Late Permian as originally advocated. Besides, as has been mentioned above, the so-called *Dichotomopteris qubuensis* in the Qubu flora is probably conspecific with *Pecopteris* aff. *arcuata* in the Xiagangjiang flora. In the following, a discussion will be made on the close similarity between several specimens originally identified as *Dizeugotheca qubuensis* Hsü of the Qubu flora and some specimens of the Wankie mixed flora from Zimbabwe in South Africa. Thus, whether the Qubu flora is a typical Glossopteris flora or a mixed flora must be reconsidered. I think the latter assumption is more probable. But due to the true nature of this flora having great influence upon the approaches of geo-tectonics and palaeobiogeography, for caution's sake, I think it wiser not jumping at conclusion about this problem at this moment.

SOME REMARKS ON THE MIXED FLORAS

The preceding review of the relevant mixed floras indicates that one of the most remarkable features is that Wankie flora of south Africa and its corresponding mixed floras of South America appear to show a closer affinity

with the Cathaysian than with Euramerican flora. However, this depends on the reliability in identification of some relevant plant taxa. Therefore, some remarks should be made here to certain significant or debatable species listed in Table 1 (Numbers in brackets refer to those shown in the Table):

1. Specimens described by Archangelsky (1960) as *Sphenophyllum thonii* from Chubut of Santa Cruz, Patagonia of Argentina, are found by Srivastava and Rigby (1983) to be distinct from the Euramerican plant. They are placed under a new species *S. archangelskii.*

2. Forms described under *Sphenophyllum thonii* var. *minor* Sterzel by Walton (1929) from the Wankie District of Zimbabwe, by Teixeira (1946) as *S. thonii* from Mozambique, and by Arrondo (1972) as *S. thonii* from Argentina are considered by Srivastava and Rigby (1983) to be a new species *S. waltonianum.*

3. It seems to be doubtful whether the form *Pecopteris* (*Asterotheca*) *anderssonii* found in Argentina has any real affinity to Cathaysian species. The type-specimens of the latter are distinguished by the slightly lobed based pinnules and more divided lateral veins.

4. The Xiagangjiang form, *Pecopteris* aff. *arcuata* with a venation of *Pecopteris unita*-type, in my opinion, is probably identical with the specimen described by Hsü (1976) as *Dichotomopteris qubuensis* and also more or less resembles the specimen named *P. unita* by Walton (1929) from the Wankie flora.

5. Both the sterile and fertile specimens of the Wankie flora regarded by Lacey and others (1966) as *Pecopteris arcuata* Halle and those originally assigned by Walton (1929) to *P. unita* from *emarginata* (Goepp.) resemble so strongly in shape, size and venation the material described by Hsü (1976) as *Dizeugotheca qubuensis* from the Qubu flora that they may be of specific identity with one another and represent a new form of *Pecopteris.* The Qubu specimens have been later named *Pecopteris qubuensis* (Hsü) Li (1983, p. 138).

6. Rigby (1970) has expressed the opinion about the Brazil form described as *Chiropteris reniformis* Kaw. that its specific identity is probably not entirely free from doubt.

Judging from the above remarks, one can see that the true relationship between the southern and northern floras as indicated by the presence of Cathaysian or "Northern" elements in South Africa and South America is somewhat doubtful. Then how about the view point for the mixed floras concerned that has held by some palaeobotanists should be? Is it groundless? I don't think we can arrive at this conclusion for the time being,

Table 1—Some significant Cathaysian and "Northern" elements of the mixed Permian floras.

REGION / FLORA or FORMATION / AGE / SPECIES	Turkey	Saudi Arabia	Kishmir Area	Xizang, China: South	Xizang, China: Central	Soviet Far East	W. New Guinea	S. Spain	Zimbabwe etc.	Chubut etc. Argentina	Parana, S. Brazil	Remarks
	Hazro	Unayzah	Mamal	Qubu	Jianzhanong Fm. Xiagangjiang	Barabash-kaya Fm. Pospelovka Fm.	Irian Jaya	Guadalcanal	Wankie (U. Ecca)	Lubeckense	Itararé & Guata	
	P_2^2	P_2 or P_1^2	P_1^2	P_1^2	$?P_1^2$	P_1 & P_2	P_2	P_1^2	P_1	P_1	P_1	
Annularia mucronata		x										(1)– (6) See explanations in the text
Lobatannularia ensifolia			x									
Lobatannularia heianensis	x	cf.				x						
Lobatannularia sp. (or type)				x				x				
Sphenophyllum thonii									x	x(1)		
Sphenophyllum thonii var. *minor*			x						x(2)			
Sphenophyllum cf. *koboense*	x											
Sphenophyllum cf. *oblongifolium*								x	x	x	cf.	
Sphenophyllum cf. *verticillatum*								x	x			
Pecopteris (*Asterotheca*) *anderssonii*										x(3)		
Pecopteris (*Asterotheca*) *orientalis*					?	x						
Pecopteris (*Asterotheca*) *hemitelioides*		cf.							x	x		
Pecopteris (*Ptychocarpus*) *arcuata*				?(4,5)	aff.(4)				x(5)			
Pecopteris unita								x	x(4)	x		
Rajahia (*Pecopteris*) *mamalensis*			x		?							
Fascipteris hallei	x	x										
Fascipteris sp.							x	x				
Chansitheca cf. *kidstonii*									x			
Chiropteris reniformis											x(6)	
Gigantonoclea hallei	x											
Gigantonoclea sp.		x					x					
Plagiozamites oblongifolius					?							
Psygmophyllm cf. *multipartitum*								x				
References	Wagner, 1962; Archangelsky & Wagner, 1983	El-Khayal et al., 1980; Lemoigne, 1981; Pers. comm., 1984	Singh et al., 1982	Hsü 1976; Singh et al. 1982; Li, 1983	Li et al., (in press)	Zimina, 1967, 1969, 1983	Pers. Comm. 1983	Broutin, 1981, 1982	Walton, 1929; Lacey et al., 1966	Archangelsky, 1957, 1960, 1971; Archangelsky & Arrondo, 1967, 1975, etc.	Dolianiti, 1952; Archangelsky, 1960; Rigby, 1970, etc.	

because the distribution pattern of these elements, the close resemblance in floral composition among different sites as well as the presence of some species closely similar to those of northern hemisphere all point to the fact that these characteristics cannot be considered to be from any accidental event. Even judging only from morphological features of the megafossil plants is not meaningless. For example, a commonly presented pecopterid plant with a venation of *Pecopteris unita*-type, the widely distributed *Sphenophyllum thonii* or *S. thonii* var. *minor* of northern hemisphere and the superficial likeness of some other arthrophytic plants—all of these have not been found in the typical Glossopteris flora indeed, and appear to indicate a special aspect of mixed flora. The importance of these elements thus should not be overlooked.

Besides, another pecopteroid form (not listed in Table 1), i.e. the socalled "*Pecoteris phegopteroides* (Feistmantel) has been found in the Hazro and Unayzah floras. The likeness between this plant and *Dizeugotheca phegopteroides* of Gondwanaland seems to be superficial. The specimens of the Hazro flora have recently been transferred to *Pecopteris nitida* Wagner (Archangelsky & Wagner, 1983, p. 89). The Unayzah specimens seem probably to have nothing to do with true *Asansolia* (*Pecopteris*) *phegopteroides* (Feistmantel) Pant & Lata, 1976, either.

It should be mentioned here that the occurrence of many species of *Sphenophyllum* in the mixed floras of South Africa and South America, represented by *S. thonii* and *S.* cf. *oblongifolium*, etc. was once considered to be a curious phenomenon by Lacey and others (1966, p. 24) and they wrote: "The curious assemblage of *Sphenophyllum* alone suggests that the affinity of the Wankie flora is closer to the Cathaysian than the Euramerican flora."

Of course, more emphasis should be laid on the presence of such plants as *Lobatannularia, Gigantonoclea* and *Fascipteris* which indicate a true affinity with the Cathaysian flora; especially the important genus *Lobatannularia* which is not only widely distributed in the Permian floras of Hazro, Unayzah, Mamal, Qubu, Guadalcanal and the Soviet Far East, but often occurs in the Nanshan (Qilianshan) mixed flora of Cathaysia-Angara type and in the southern belt of the Far East subprovince of the Angara flora (e.g. the Dzungaria Basin in Xinjiang and Ichun in Heilungjiang, China). It appears that this kind of arthrophyte has a high adaptability* to different ecological environments : it possibly often played a pioneer role as a representative of the Cathaysian flora when the floras migrated or mixed together with the change of ecological conditions. Thus, in some mixed floras they are found as individual "stray elements" of the Cathaysian flora.

One can see from the above discussion that although the identification of some taxa among the mixed floras is doubtful, the significance of their being taken as indicators of a given flora should not be strongly reduced. Some plants mentioned above, i.e. *Sphenophyllum waltonianum, S. archangelskii, Pecopteris* aff. *arcuata* (or *P. qubuensis*) and "*Pecopteris phegopteroides*", might be taken as indicators of the mixed Permian Cathaysia Gondwana floras.

DISTRIBUTION AND ORIGIN OF THE MIXED FLORAS

The Permian floras of the Wankie District of Zimbabwe, of Santa Catherina, Argentina and the Parana Basin, southern Brazil have long been accepted as mixed floras dominated by Gondwana elements in association with northern elements. However, little discussion has been given to their distribution area, mutual relation and origin.

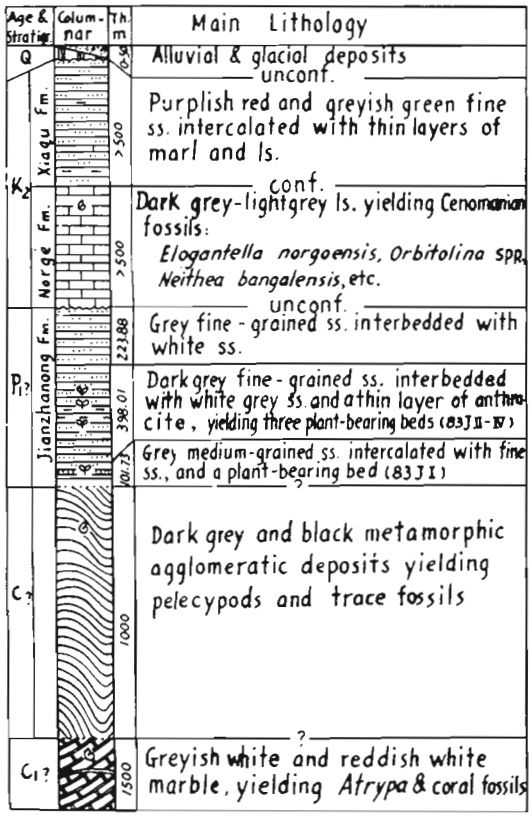
Since the sixties, different assumptions have been put forward by many scientists, e.g. Wagner (1962), Chaloner and Meyen (1973), Plumstead (1973), Lemoigne (1981), Archangelsky (1975) and Broutin (1981) on the palaeophytogeography of the southern and northern floras to the migration direction of the relevant floras and the formation of the mixed floras during Permian time. However, most of those assumptions are too simple to explain such complicated problem.

The Permian phytogeographical distribution is shown in Map 1 (including the mixed floras). This is based on the previous works combined with the data derived from Qinghai-Xizang Plateau of China during the last decade. It also attempts to discuss respectively the origin of the mixed floras according to different areas or different geographical position.

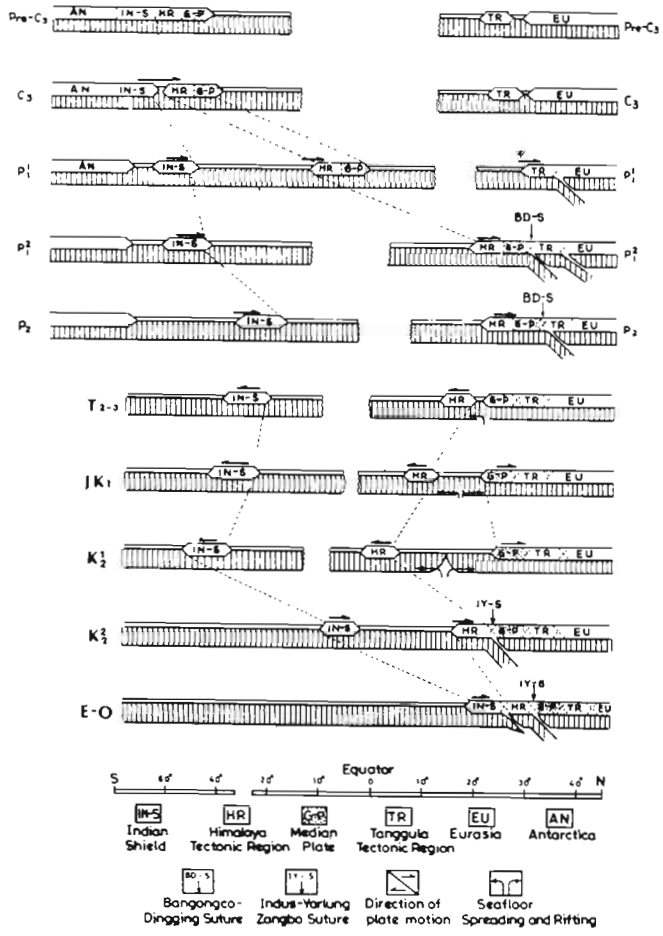
Asia and its neighbouring areas

As shown in Map 1, the distribution area of the mixed floras in Asia would be largely restricted to the presumed Median Plate supposed by Li Chun-yu and others* (1982, 1983). If we reconstruct the Qinghai-Xizang Plateau, the Himalayan ranges and the Indian Shield into their original manner during Permian, this belt or the Median Plate approximately would lie in an east-west direction between the Gondwanaland and the Eurasian Plate. And judging from the plentiful data about the sedimentary facies and invertebrate faunas in the Qinghai-Xizang Plateau and Himalayas, the severe cold climate in Gondwanaland had been persistently prevailing till the beginning of the Asselian-Sakmarian epochs. The climate became warmer towards the end of

*It does not resemble those continental plates which are usually composed of one or some nuclei, but consists of a cluster of microcontinents separated from Gondwanaland and then welded together through interactions of Eurasian and Arabian-Indian Plates (after Li Chun-yu *et al.*, 1982).



Text-fig. 1—Generalised columnar stratigraphic section on the Xiagangjiang area of Gerze and Cogen counties, Xizang (Tibet).



Text-fig. 2—Schematic cross section from North Antarctica to Xizang (Tibet) mainly illustrating activity of Plates in Tethys-Himalaya Tectonic Domin.

Sakmarian. Since then, warm water faunas abundantly flourished at the Artinskian epoch, while cold water faunas only occasionally developed—these indicate that a warm or subtropical climate prevailed in the Median Plate area. The background leading to this change is the global regression at the end of Early Permian on the one hand and, on the other, the start of the drift of Indian Subcontinent (once a part of the Gondwanaland) and the southern part of the Qinghai-Xizang Plateau since Late Carboniferous from the main body of Gondwanaland which drifted successively northwards to the warm-subtropical area.

Such ecological environment and time-space relations provide natural conditions for the formation of mixed floras through mutual connection and migration of some elements came from essentially different floras of the southern and northern continents during Permian Period.

Based on these considerations, here I first attempt to give an explanation for the formation process of the mixed floras of Tibet and its neighbouring areas (Map 2; Text-fig. 2).

1. The Bangongco-Dingqing Suture Zone is tentatively considered by the writer to represent the Palaeo-Tethys lying between Gondwanaland and ancient Eurasia. All tectonic regions south of this Zone formed, together with the Indian Shield, parts of Gondwanaland which was situated near the Antarctic Region in Late Palaeozoic.

2. They drifted northwards in Late Carboniferous, crossed the Equator in earliest Permian and finally, highly probably, collided with the Tanggula Tectonic Region in Late Early Permian.

3. After the collision, the Permian flora that originally flourished in the Cathaysian South Subprovince might have migrated southwards across the Bangongco-Dingquing Suture Zone first to meet the Glossopteris flora in some places, such as Xiagangjiang in central Xizang, where the latter flora had flourished.

4. Meanwhile or slightly later, the successive and continuous southward migration of the Cathaysian flora and its intermingling with the local flora of southern Xizang produced the Qubu Glossopteris flora; but only a few forms of the Cathaysian flora survived in the Qubu flora. This was either due to somewhat severe natural conditions, or because the Qubu area stands so far away south of the original sites of the Cathaysia flora that only those forms with highly adaptive ability were able to arrive here and survive.

5. As for the Indus-Yarlung Zangbo Suture Zone it has now become relatively clear that it started from the Middle-Late Triassic onward. A great fracture occurred with the expansion of the sea floor and a Mesozoic Ocean or Mesotethys was progressively formed; from the Late Cretaceous onward, this ocean began to reduce and the crust plate quickly drifted northward resulting in subduction. This suture zone did not come into being until both crustal plates, to the north and south of this line, collided in the latest Late Cretaceous or the earliest Tertiary. In short, this suture was formed only after the existence of the mixed Permian flora in the Himalayan-Southern Xizang Region.

As mentioned above, the Kashmir Mamal mixed flora lies in or very near to the Indus-Yarlung Zangbu Suture Zone; the formation of this flora could naturally be explained by the same plate tectonic history as that of Xizang (Tibet). Singh *et al.* (1982, p. 220) expressed a somewhat similar view to the Median Plate assumption in explaining the origin of the Mamal mixed flora. They wrote: "This naturally raises the question whether there was a separate landmass between the Cathaysia on the north and the Gondwanaland on the south".

Western Asia and South-western Europe

The mixed floras in this area include those found from Hazro in Turkey, Unayzah in Saudi Arabia and Guadalcanal in southwestern Spain. Either in geographical position or in the main floral composition, these floras stand very close. Wagner (1962, fig. 1) is inclined to call the area which covers Turkey, Spain and North Africa next to the Mediterranean Sea—the Permo-Carboniferous Equatorial Belt. Now the Unayzah mixed flora has been found in the Arabian Peninsula, the southern boundary of Wagner's belt naturally can be extended southward. Accordingly, the whole North Africa could be regarded as a part of the Mixed Floral Province. The background of the formation of the mixed floras in this area is possibly similar to that occurring in Tibet-Himalayas. Of course, the concrete process can not be inferred until the tectonic situation and the type of plate movement is understood.

The Soviet Far East

Zimina (1983) attempted to explain the migration route of *Glossopteris* and *Gangamopteris* etc. of the flora of Soviet Far East through the Cathaysian floral Province in the mainland China. This is obviously very difficult and unacceptable.

I consider we could explain this puzzle—why *Glossopteris*, etc. are present in the northeastern corner of Asia in another way according to Plate Tectonic Theory and some geological and palaeontological phenomena observed from Japan Isles.

Using the Plate Tectonic theory and palaeomagnetic data, McElhinny *et al.* (1981) inferred that the Asian Continent was quite different in Permian from what it appears today. It was composed of several isolated palaeo-blocks distributed in different positions in the Tethys or Proto-Pacific (cf. McElhinny's fig. 1). The "Sikhote Alin" block, where the mixed flora under discussion existed, lies in a place around 30°N, as shown in their Late Permian phytogeographical map. To the west of, and not far from, it was the "Tarim" (including the Dzungarian basin) palaeoblock in Xinjiang, China; while to the east was the "Southeast Asia" palaeoblock (south China included) separated by sea.

If my explanation about the formation of the mixed flora in Tibet and Himalayan Kashmir could be applied here, and the "Sikote Alin" palaeoblock be presumably extended back to Middle-Late Carboniferous, then this block together with northeastern Africa and Arabian Peninsula would be a part of the Gondwanaland in Late Permian resulting in a situation as shown in McElhinny's figure 3. In this case, the "Sikhote Alin" palaeoblock possibly the Late Permian Angara Far East subprovince belonging to the "Tarim" Dzungaria block on the one hand and stood close to came into contact with some Cathaysian elements migrated from the "Southeast Asia" palaeoblock on the other; consequently, a peculiar mixed flora with three aspects of Gondwana-Cathaysia-Angara floras took shape. The "Sikhote Alin" block continuously drifted northward in Mesozoic and finally to the present position in Cenozoic and conjugated with the Asia mainland into a huge mass along the folded belts formed in Late Mesozoic. In this regard, the paper given by McElhinny and others also mentioned that Japan and Southeast Asia were also connected together in Permian and positioned near the Equator; subsequently it moved northward progressively until arriving at the present position.

It should be pointed out that the concept "Japan" as used by McElhinny and others is much encompassing for explaining its geological history. As currently recognized, the Permo-Carboniferous strata of Japan are mainly marine and hence unfavourable for preservation of fossil plants; only a few Cathaysian elements of late Early Permian to Late Permian age were occasionally found. However, the Mesozoic floras and related strata of Japan are well documented through detailed investigation; based on which the Japan Isles can be divided palaeobiogeographically and tectonically into two distinct zones: the Inner Zone (near the Asia mainland) and the Outer Zone (toward the Pacific Ocean). Taking the Late Jurassic Early Cretaceous floras as an example, here we have an Inner Zone Tectori-type flora and an Outer "Ryoseki"-type flora, and they are entirely different either in floral composition or in the source material of the plant bearing strata. It was thought that this difference was due to age discrepancy, now it has become clear that it is not the case. Other assumptions do not lead to a reliable result either. Recently some

Japanese scientists (e.g. T. Kimura, pers. comm., 1982) are also inclined to rely the data given by McElhinny and others, and suggest that the Outer Zone was originally a fragment of the Gondwanaland at the beginning of Permian and then it drifted northward and conjugated with the Inner Zone which once existed as the marginal part of the main continent. This background thus leads to the great difference geologically and palaeontologically between the Inner and Outer Zones. This difference is clearly shown in the map "Floral Provinces of 'Tectori'-type flora and 'Ryoseki'-type flora during Late Jurassic-Early Cretaceous prepared by Kimura (1979, 1980). More interesting is that a locality with 'Ryoseki'-type flora inserted strangely into a place near Vladivostok where it seemed to belong to the Inner Zone. This is quite similar to the mixed flora of the Soviet Far East under discussion. It is very likely that both of them belong to the 'Sikote Alin' palaeoblock. Of course, the presumption here I present needs to be verified in the future.

Western New Guinea

This is a very complex place where several big plates and some tectonic fracture zones were passing through or conjugated together. The regional geology related to the mixed flora is not yet clear and so any inference must be premature. However, this site is not very far from Djambi in Sumatra which has yielded a Cathaysian flora and stands as its southern most reach adjacent to the northern part of the Australian Plate. Furthermore, if the Qinghai-Xizang Plateau and the Indian shield be reconstructed to the earlier situation, i.e. prior to their northern subduction, compression and folding, then New Guinea would possibly belong to the eastern extension of the Li's Median Plate. In this kind of transitional belt the Gondwana-Cathaysia mixed flora is not unexpectable. Rigby (pers. comm., 1983) is inclined to explain the occurrences of this mixed flora that the only way this could have happened is based on the reconstructions (Plate 6) given by Carey (1982) for the expanding earth theory.

South-eastern Africa

Lacey *et al.* (1966, p. 23) wrote "The nearest comparison of the Wankie flora is certainly with the Cathaysia flora of Shansi in China, described by Halle (1927)". Discussing the close similarity between the Wankie flora and the contemporaneous mixed floras of Santa Cruz, Argentina they pointed out again, "The curious assemblage of *Sphenophyllum* species alone suggests that the affinities of the Wankie flora are closer to the Cathaysia than the Euramerica flora". On the other hand, another fact should not be overlooked that is in the South Asia Subcontinent proper which is near to the northern Cathaysian flora province; no Cathaysian elements have been reported here in the *Glossopteris* flora. Such curious relations like a Chinese saying, "far and wide for what lies close at hand" how did it happen? In discussing the development history of the Wankie flora in South Africa, naturally one can not avoid answering this question.

I don't know the detail of the geological history of south-eastern Africa but from Map 1 we can see that the Arabian Peninsula, which has the Unayzah flora with many Cathaysian elements, is separated from the northeastern Africa only by the recently formed rift of the Red Sea. Many Cathaysian and/or other "Northern" elements in the Unayzah flora, under favourable conditions, naturally could move southward to Zimbabwe and its neighbouring areas to intermingle with the local Glossopteris flora. This might be how the Wankie type mixed flora happened.

Besides, one can see from the "Late Permian Continental Reconstruction" by Scotese and others (1979; see Condie, 1982, p. 192, figs 9, 7) that the Arabian Peninsula is close next to the northwestern corner of Africa, while India and Madagascar insert obliquely between the main Gondwanaland (through conjugation of South Africa and South America) and Antarctica. There is a quite wide ocean between India and Tibet plus Turkey-Iran palaeoblock. If these tectonic units or blocks which are the components of Li's Median Plate began to be separated from Indian Plate in Late Carboniferous, as some new data indicated and drift quickly to the Equator and then to the northern subtropical temperate zone, the distance between these units and India would be progressively bigger with the change in time and place. Consequently, the chance for elements of the Cathaysian flora intermingling with those of the Gondwana flora in the Subcontinent of south Asia became little and little. That is why the Wankie flora shows a much more close affinity with the Cathaysia flora than other floras.

South America

The mixed floras of Argentina and southern Brazil in South America and the Wankie mixed flora in South Africa have long been considered to resemble each other in a certain floristic composition. As already mentioned above, based on the Plate Tectonic Theory Archangelsky and Arrondo (1975) conjugated these floras on both sides of the Atlantic Ocean into a specially named "Austroafroamerican Floristical Province".

However, though some *Sphenophyllum* species in the mixed flora of South America are largely the same as those in the Wankie flora, the associated so-called Cathaysian elements in the former are different from and rarer than those in the Wankie flora. Therefore, I think both floras possibly have different origin. As for South America, it concerns with the true relationship of its flora with *Gigantopteris* flora *sensu lato* found in Kansas and Oklahoma of the southwestern United States. Especially after the preliminary report of the discovery of Cathaysian

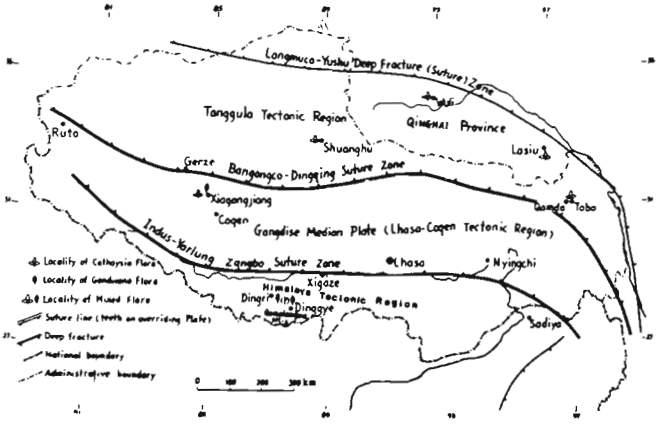
flora in Venezuela (Wagner, 1978*), this possible relation becomes more reasonable. However, the question is that the known presumed Cathaysian elements in the mixed flora of South America have not yet been found in the "Gigantopteris" flora of North America. So it seems attractive that the mixed flora or some of its components in South America migrated through the route passing the Guadalcanal flora in Spain and the Hazro flora in Turkey if there was a real relationship between the mixed flora of South America and that of East Asia. The occurrence of the Atlantic Ocean is a later event in geological time; during Permian this distributional belt of mixed floras along Turkey, southeastern Spain and possibly northern Africa extended westward just pointing to Venezuela where the presence of Cathaysian flora is thus not unexpectable. However, this will meet with a difficult problem again because the mixed floras around the present day Mediterranean Sea, being nearly all of Late Permian are younger than that of mixed floras of South America. I am still puzzled over these mixed floras having Cathaysian elements associated with the Glossopteris flora.

CONCLUSION

Agreeing with the view that mixed floras were really present in the geological past, the present paper deals with the origin and distribution of the mixed Permian Cathaysia-Gondwana floras and other problems.

In Asia, except for the Soviet Far East, almost all the known mixed floras are distributed in the same geographical belt which roughly corresponds to the Turkey-Iran-Gandize Median Plate named by Chinese scientists. This correspondence is not a mere accident but is difficult to explain by some theories such as Parallelism in evolution, etc. Using some relevant achievements resulting from the recent researches based mainly on the Plate Tectonic Theory, especially that concerned with Tibet I attempt to apply the Median Plate supposition to explain the distribution and formation of mixed floras. And for this purpose, a comprehensive map showing the distribution of Permian floristical provinces in the world and model of schematic cross-sections mainly illustrating the activity of Plates in Himalayas-Tibet Tectonic Domain have been tentatively made which, I hope, might somewhat be useful to further researches on this subject.

The composition of a given mixed flora, except those species descending from its parent floras (s), most probably includes some newly evolved endemics. It could not be produced in isolation, nor is one of the parent floras simply intermingled with another. A certain number of new plants might have evolved characteristics of their own, either from the native parent flora or any



Map 2—Showing fossiliferous localities of Permian plants and main structure pattern in Xizang (structure pattern after Li Chun-yü & others, 1982).

flora(s) originating in some other places, which is intimately related with time and space in migration process of its parent floras as well as the ecological conditions. Such new forms as *Pecopteris* cf. *P. unita*—type and *Sphenophyllum waltonianum*, both known from southeastern Africa and Kashmir Himalayas and Tibet, may be regarded as diagnostic plants of the related mixed flora. The same perhaps holds good for explaining the presence of some new glossopteroid plants found in the mixed floras in Hazro, Turkey and the Soviet Far East area near Vladivostok.

Of course, the reliability of the assumption explaining the mixed flora problem needs the big premise, i.e. some tectonic maps and palaeo-phytogeographical reconstructions for a particular geological period, are trustworthy. This question still exists in the present paper. Furthermore, objections would be lodged against my interpretation for it just based on the morphologic features of plant megafossils and a few taxa in particular, without any evidence of fructification and cuticular structures. But, I just confined my discussion on objective material that I could gather, though my interpretation naturally includes some assumptions: I hope this would be missible and excused.

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*See IOP Newsletter 8 (Jan., 1979), p. 16.

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