Micro- and megafloral remains of Namurian H-G1 zones from Zhongwei of Ningxia, China

Wang Yongdong, Shen Guanglong & Wu Xiuyuan

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Abundant micro- and megafloral remains of Namurian H-G1 zones have been studied from the Hongtuwa Formation in Zhongwei, Ningxia, China. The former consists of 80 species of 45 genera, which can be subdivided into two miospore assemblages, i.e., *Lycospora subtriquetra-Gansusispora mammilla* (SM) Zone and *Gardenasporites pinnatus-Microreticulatisporites concavus* (PC) Zone. They are roughly correlative to the H Zone of Namurian A stage and R-G1 zones of Namurian B-C stages, respectively. The megafloral remains include 23 species of 18 genera and is known as *Mesocalamites cistiformis-Paripterisgigantea* assemblage. It is comparable with the Middle to Late Namurian flora of the North Qilian Mountains, China. Both micro- and megaplant fossils indicate that the Middle to Late Namurian flora in Zhongwei is dominated mainly by Filices and Pteridospermopsida. Lycopsida and Sphenopsida occupy a subdominant position, while Cordaitopsida and Coniferopsida are not significant. The present flora reflects the coastal plain and delta environments as well as a tropical-subtropical warm and humid palaeoclimate.

Key-words—Palynology, Plant megafossil, Namurian, Ningxia (China).

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सारांश

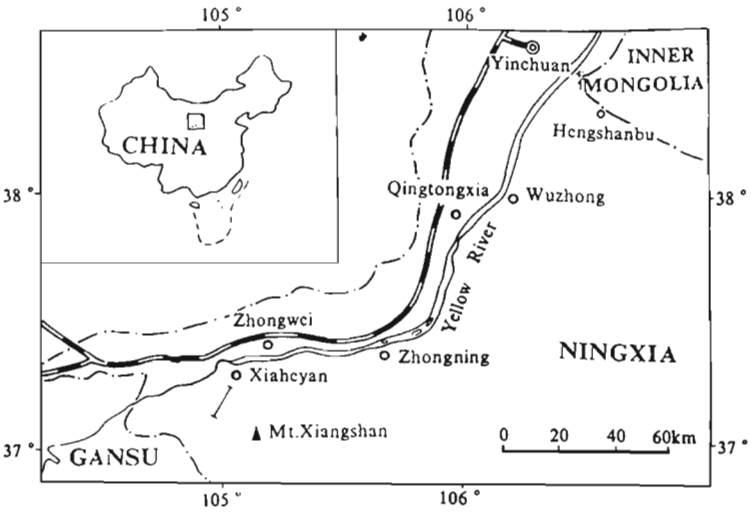
चीन में निंगसआ में झोंगवी से नामुरियन युगीन एच-जी 1 मंडलों से सूक्ष्म-एवं गुरु वनस्पतिजातीय अवशेष

वाँग योंगडोंग, शेन गवाँगलाँग एवं वु जिउयुआन

चीन में निंगसआ में झोंगवी के हाँगतुवा शैल-समूह से नामुरियन युगीन एच-जी 1 मंडलों से प्राप्त प्रचुर सूक्ष्म- एवं गुरु वनस्पतिजातीय अवशेषों का अध्ययन किया गया है। सूक्ष्म वनस्पतिजात में 45 प्रजातियों की 80 जातियाँ हैं जो कि *लाइकोस्पोरा सबट्राइक्वेट्रा–गेन्सुसिस्पोरा* (एस एम) मंडल एवं *गार्डीनास्पोराइटिस पिन्नेटस–माइक्रोरेटिकुलेटिस्पोराइटिस कोनकेवस* (पी सी) मंडल में विभक्त की जा सकती हैं। ये क्रमशः नामुरियन ए चरण के एच मंडल तथा नामुरियन बीसी चरणों के आर-जी 1 मंडलों से तुलनीय हैं। गुरु वनस्पतिजात में 18 प्रजातियाँ एवं 23 जातियाँ हैं जो कि *मीसोकैलेमाइटिस सिस्टिफॉर्मिस–पेअरिप्टेरिस जाइगेन्टिआ* समुच्चय के नाम से विदित हैं। ये समुच्चय चीन के उत्तरी किलियन पर्वतों के मध्य से अनंतिम नामुरियन वनस्पतिजात से तुलनीय हैं। गुरु- एवं सूक्ष्म वनस्पतिजातों से प्रदर्शित होता है कि झोंगवी में मध्य से अनंतिम नामुरिअन वनस्पतिजात मुख्यतया फिलिसेज एवं टेरिडोस्पर्मोप्सिड पौधों से प्रभावी है। लाइकॉप्सिड एवं स्फीनॉप्सिड पौधों की अपेक्षाकृत कम बाहुल्यता है तथा कोर्डेटॉप्सिड एवं कोनिफरॉप्सिड पौधों के अवशेष उतने महत्वपूर्ण नहीं हैं। वर्तमान वनस्पतिजात से तटीय मैदान, डेल्टीय पर्यावरण तथा उष्णकटिबन्धीय-उपोष्णकटिबन्धीय गर्म एवं आद्र पुराजलवायु की विद्यमानता इंगित होती है।

THE Carboniferous System is widespread in the Ningxia Hui Autonomous Region, northwestern China, which is one of the important coal-bearing strata. In recent years, biostratigraphic research has progressed greatly in this area (Liu *et al.*, 1988; Huo *et al.*, 1989; Liu, 1990; Yang *et al.*, 1983; Yang, 1987; Wang *et al.*, 1992, 1995). However, there are few reports on Namurian palynology and palaeobotany from the same section in Ningxia region.

Zhongwei county is located in central Ningxia. The Xiaheyan section is approximately 15 km southwest of the county, at 105° 5 E and 37° 25 N (Text-figure 1). The section is bounded by Yellow River and Tengerli Desert in the north and by Mt. Xiangshan in the south. The Carboniferous strata (Namurian-Stephanian) in this section are well developed and exposed, yielding abundant animal and plant fossils. Several species of fossil plants have been recorded recently by Li *et al.* (1993). The purpose of present paper is to report both micro-and megafloral remains recovered in the lower part of Upper Carboniferous Namurian stage, i.e., the Hongtuwa Formation in Zhongwei, and to discuss the assemblage zones, geological age and the floral characteristics.



Text-figure 1—A sketch map showing the geographical location of the Xiaheyan section in Zhongwei of Ningxia.

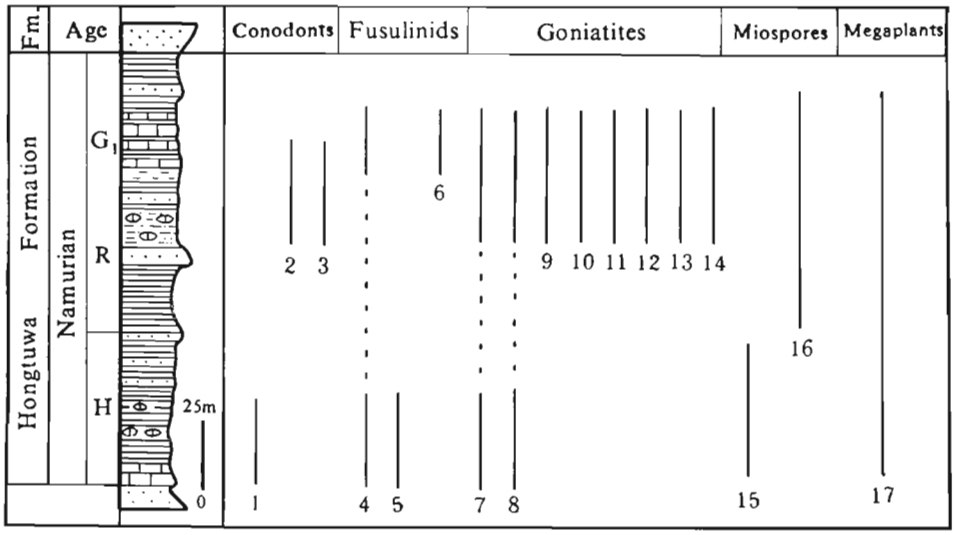
GEOLOGICAL SETTING AND STRATIGRAPHY

Tectonically, Xiaheyan in Zhongwei lies at the eastern margin of the Caledonian Fold Belt in the North Qilian Moutains. It borders on the North China Plate in the east and North Qilian Fold Series in the west, and os of the distinctive significance in tectonic evolution.

The Carboniferous strata in Xiaheyan section consist of clastic rocks with intercalations of limestone and thin coal-beds, indicating an alternating marine and non-marine succession. Four lithological units, namely, the Jingyuan, Hongtuwa, Yanghugou and Taiyuan formations are recognized in ascending order with the geological age as Namurian E, Namurian H-G1, Westphalian and Stephanian, respectively (Wang *et al.*, 1992).

The Hongtuwa Formation consists mainly of greyish black shales with thin-bedded limestones and lenticules, with a maximum thickness of 170 m, yielding conodonts, goniatites, fusulinids, spores and pollen, as well as plant megafossils (Text-figure 2).

Conodonts are : *Declinognathodus noduliferus*, *Idiognathoides sulcatus*, *Neognthodus symmetricus*; Fusulinids : *Eostaffella postmosquensis*, *Millerella marblensis*, *Schubertella sphaerica* var. *staffelloides*;



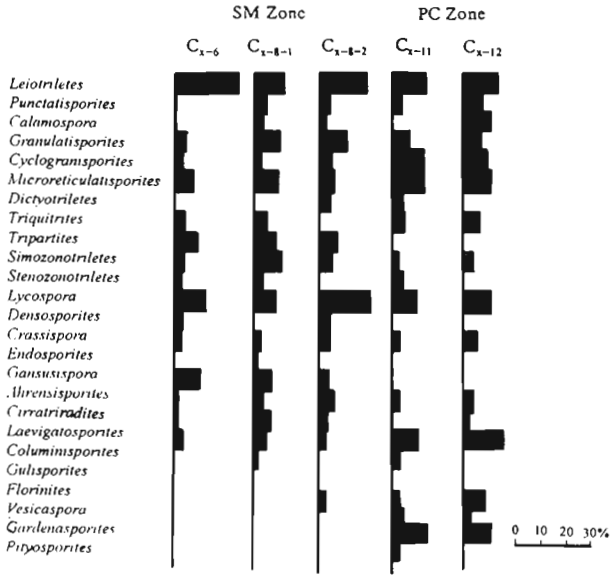
Text-figure 2—Stratigraphic column and vertical range of animal and plant fossils in the Hongtuwa Formation, Zhongwei.

Goniatites : *Anthracoceras paucilobum, A. glabrum, Cancelloceras bisati, Gastrioceras montgomeryense, Wiedeyoceras xiaheyianense, Physematites globosus, Pseudoschartymites xiaheyianensis, P. ningxiaensis*; Miospores : *Lycospora subtriquetra-Gansusispora mammilla* (SM) Zone, *Gardenasporites pinnatus-Microreticulatisporites concavus* (PC) Zone; Megaplants : *Mesocalamites cistiformis-Paripteris gigantea* assemblage.

The conodonts in the lower part of the Hongtuwa Formation are dominated by the index fossil *Declinognathodus noduliferus* (Ellison et Graves) for the Namurian H Zone. Its first appearance in the strata has been regarded as the basal boundary of the Upper Carboniferous. The upper part of the formation yields *Idiognathoides sulcatus* Higgins et Bouckaert and *Neognathodus symmetricus* (Lane), which are often found in the R-G1 zones of Namurian.

The fusulinids are characterized by *Eostaffella postmosquensis* Kireava, *Millerella marblensis* Thompson, and *Schubertella sphaerica* var. *staffelloides*. The first occurrence of *M. marblensis* in the strata has been taken as an auxiliary fossil indicator for the recognition of the boundary line between the Lower and Upper Carboniferous, while the other two species are also the common elements of Namurian.

About 8 species of fossil goniatite are identified in the Hongtuwa Formation in Xiaheyan (Yang *et al.*, 1983; Yang, 1987). Amongst them, *Anthracoceras paucilobum* (Phillips) and *A. globum* Bisat occur in both lower and upper parts of the formation. Others, such as *Cancelloceras bisati* Ruzhencev et Bogoslovskaya, *Gastrioceras montgomeryense* (Miller et Gurley), *Wiedeyoceras xiaheyianense* Yang, *Physematites globosus* Yang, *Pseudoschartymites*



Text-figure 3—Showing the percentage diagram of principal miospore genera from the Hongtuwa Formation in Zhongwei, Ningxia SM Zone: *Lycospora subtriquetra-Gansusispora mammilla*; PC Zone: *Gardenasporites pinnatus-Microreticulatisporites concavus*.

xiaheyianensis Yang and *P. ningxiaensis* Yang are found in the upper part of the Hongtuwa Formation. This part of the formation corresponds to the horizon of the conodonts *Idiognathoides sulcastus* and *Neognathodus symmetricus*, indicating Late Namurian (R-G1 Zones) age.

MICROFLORA

Abundant fossil spores and pollen grains have been studied from the Hongtuwa Formation, which comprise 80 miospore species belonging to 45 genera. According to the quantitative analysis (Text-

PLATE 1

Figures in Plate 1 are X 600. indicated.

1. *Granulatisporites piroformis* Loose Cx-8-2-(6).
2. *Microreticulatisporites concavus* Butterworth et Williams Cx-11-(1).
3. *Acanthotriletes echinatus* (Knox) Potonié et Kremp Cx-4- (3).
4. *Lophotriletes microsaetosus* (Loose) Potonié et Kremp Cx-6-(4).
5. *Dictyotriletes bireticulatus* (Ibrahim) Smith et Butterworth Cx-8-2-(3).
6. *Calamospora microrugosa* (Ibrahim) Schopf, Wilson et Bentall Cx-8-2-(10).

7-8. *Lycospora subtriquetra* (Luber) Potonié et Kremp Cx-8-2- (4).

9. *Stenozonotriletes triangulus* Neves Cx-11-(6).
10. *Simozonotriletes sinensis* Zhu Cx-3-(4).
11. *Densosporites sphaerotriangularis* Kosanké Cx-8-2(8).

12-13. *Gansusispora mammilla* Gao Cx-23-1(4).

14. *Cirratriradites saturnii* (Ibrahim) Schopf, Wilson et Bentall Cx-11-(8).

15-16. *Tripartites trilinguis* (Horst) Smith et Butterworth 15.Cx-8-2-(6) 16. Cx-6-(3).

17. *Tripartites vetustus* Schemel Cx-6-(2).
18. *Laevigatosporites medius* Kosanke Cx-8-2-(5).
19. *Crassispora kosankei* (Potonié et Kremp) Bharadwaj Cx-3- (9).
20. *Florinites* sp. Cx-11-(8).
21. *Gardenasporites pinnatus* Krusina Cx-11-(4).

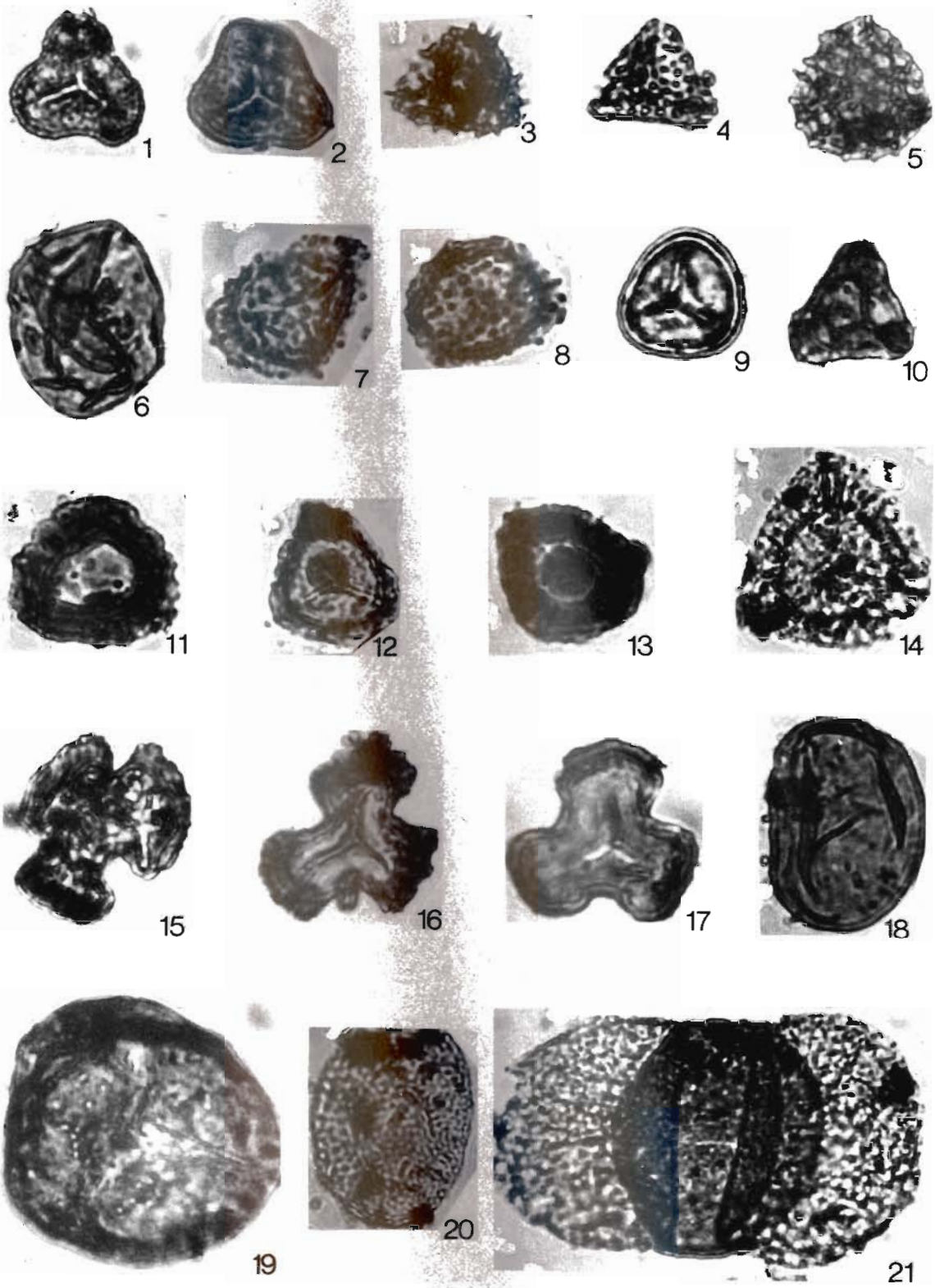


PLATE 1

figure 3), two assemblage zones have been established as follows :

1. *Lycospora subtriquetra-Gansusispora mammilla* (SM) Zone

This assemblage zone occurs in the lower part of the Hongtuwa Formation. It is marked by the dominance of pteridophytic spores (97.7-100%), among which the most common species of azonolete spores (53.8-55.9%) are *Leiotriletes* spp., *Granulatisporites granulatus* Ibrahim, *G. piroformis* Loose, *Cyclogranisporites pressoides* Potonié et Kremp, *Microreticulatisporites punctatus* Knox, *Acanthotriletes echinatus* (Knox) Potonié et Kremp, *Dictyotriletes bireticulatus* (Ibrahim) Smith et Butterworth and *Punctatisporites aerarius* Butterworth et Williams.

The zonolete spores (38.5-43.3%) include *Lycospora subtriquetra* (Luber) Potonié et Kremp, *Gansusispora mammilla* Gao, *Simozonotriletes sinensis* Zhu, *S. labellatus* Wang, *Densosporites sphaerotriangularis* Kosanke, *Triquitrites* spp. and occasional *Stenozonotriletes rotundus* (Wang) Zhu, *Tripartites trilinguis* (Horst) Smith et Butterworth, *T. vetustus* Schemel and *Crassispora kosankei* (Potonié et Kremp) Bharadwaj. *Cirratriradites saturni* (Ibrahim) Schopf, Wilson et Bentall and *Savitrisporites nux* (Butterworth et Williams) Smith et Butterworth make their first appearance in this formation. The frequency of occurrence of other genera, such as *Endosporites, Radizonates, Rotaspora* and *Reinschospora* is less than 1 per cent.

Monolete spores (1.7-4.9%) and monosaccate pollen grains (0-1.8%) are represented by *Laevigatosporites* and *Florinites*. In addition, some acritarchs assigned to *Tetraporina* have been discovered in the SM assemblage. The dominant species of SM Zone, *Lycospora subtriquetra*, is an index miospore for the Namurian H Zone in Western Europe (Clayton *et al.*, 1977; Owens *et al.*, 1977). Its miospore assemblage belongs to the SO Zone (*Lycospora subtriquetra-Krauselisporites ornatus*) (Clayton *et al.*, 1977). Other species, such as *Densosporites sphaerotriangularis, Crassispora kosankei* and *Savitrisporites nux* are also common in the Namurian H Zone. *Tripartites trilinguis* and *T. venustus*, which are the marker species for the Namurian E Zone in Western Europe, are also distributed in the Namurian H Zone in China (Gao, 1987). *Simozonotriletes sinensis* and *Stenozonotriletes rotundus* are often found in greater number in the Namurian E Zone of Jingyuan, Gansu (Zhu, 1989, 1993). However, their percentages are distinctly lower in the present SM Zone. *Gansusisporites mammilla* was first discovered in the Namurian H Zone of Jingyuan, Gansu together with the acritarch *Tetraporina* (Gao, 1987).

In general, the SM Zone of Xiaheyan, Zhongwei correlates with not only the SO Zone of Western Europe, but also with the SB Zone (*Densosporites sphaerotriangularis-Dictyotriletes bireticulatus*) in the Hongtuwa Formation of Jingyuan, Gansu as proposed by Zhu (1989, 1993). Therefore, the SM Zone belongs to the Namurian A (goniatite H zone) age. This conclusion is in agreement with the age of the conodont *Declinognathodus noduliferus*.

2. *Gardenasporites pinnatus-Microreticulatisporites concavus* (PC) Zone

The PC Zone stratigraphically is equivalent to the upper part of the Hongtuwa Formation. It is also characterized by the dominance of pteridophytic spores (77.8-84.4%), and by the gradual increase of gymnospermous pollen grains (15.6-22.2%).

The most common azonolete spores include *Microreticulatisporites concavus* Butterworth et Williams, *Dictyotriletes bireticulatus* (Ibrahim) Smith et Butterworth, *Cyclogranisporites aureus* Potonié et Kremp, *Granulatisporites piroformis* Loose, *G. granulatus* Ibrahim, *Punctatisporites minutus* Kosanke, and *Leiotriletes* sp. *Calamospora* sp., *Convolutispora* sp. and *Gulisporites cochlearius* Imgrund make their first appearance.

PLATE 2

Figures are in natural size unless otherwise mentioned.

1, 2. *Reticalethopteris yuanii* (Sze) Li, Shen et Wu. 2, X3.
3. *Linopteris maxima* Shen, Gou et Liu.
4,4a. *Potoniea adiantiformis* Zeiller 4a, X5.
5. *Paripteris otozamioides* (Sze et Lee) Gothan
6, 7, 7a. *Linopteris germanii* Giebel 7a, X5.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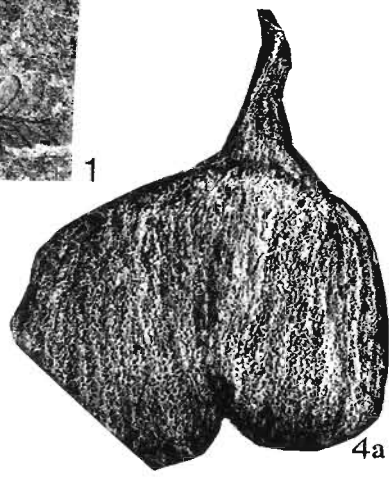
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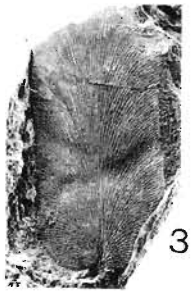
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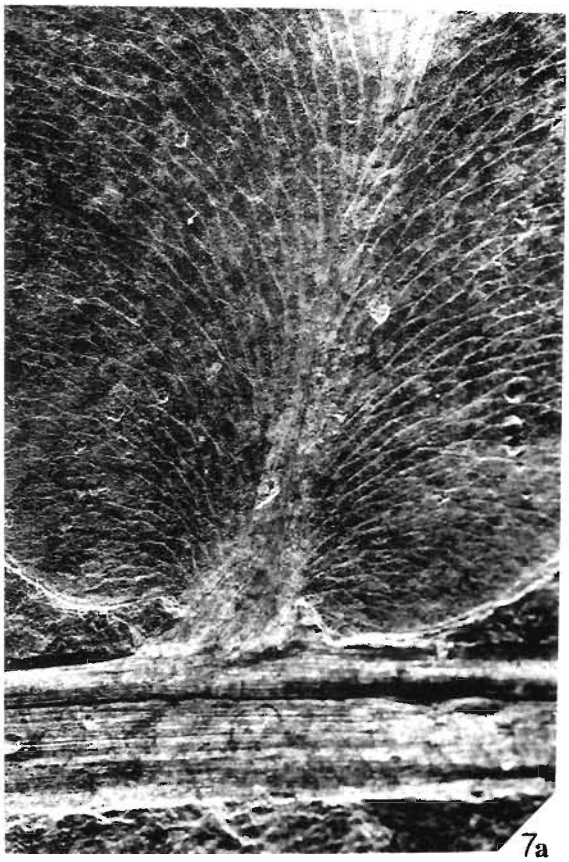
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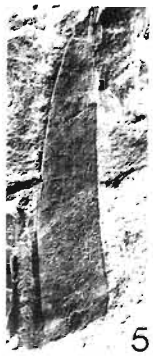
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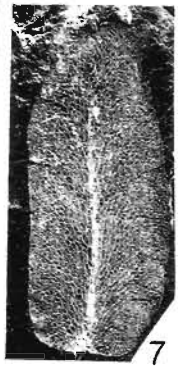
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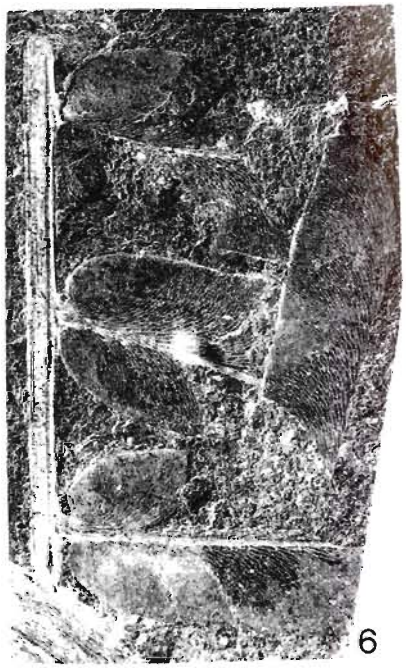
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PLATE 2

The zonolete spores begin decreasing in the PC Zone (11.1-17.8%). The important taxa are *Lycospora, Triquitrites, Densosporites, Crassispora kosankei, Simozonotriletes labellatus* Wang, *Ahrensisporites guerickei* (Horst) Potonié et Kremp, *Cirratriradites, Stenozonotriletes* and *Reinschospora*. Several species such as *Tripartites trilinguis, T. vetustus, Simozonotriletes sinensis* and *Gansusispora mammilla* become rarer in this zone and some of them disappear at the top of the formation.

Monolete spores begin increasing slightly (9.8-13.3%) and are marked by *Laevigatosporites* and *Columnisporites*. Another characteristic of the PC Zone is the increase of disaccate pollen grains assigned to *Gardenasporites pinnatus* Krusina. It is more than 8 per cent in most slides. Some other pollen, such as *Florinites* spp., *Vesicaspora* spp. and *Pityosporites* spp. also occur in this zone.

The PC Zone is comparable to zones KV (*Crassispora kosankei- Grumosisporites varioreticulatus*) and FR (*Raistrickia fulva-Reticulatisporites reticulatus*) of Western Europe (Clayton *et al.*, 1977) based on the following common species: *Microreticulatisporites concavus, Crassispora kosankei, Ahrensisporites guerickei, Cirratriradites saturni* and *Lycospora* spp. The disaccate pollen *Gardenasporites pinnatus* is also a common species of zones KM (*Crassispora kosankei-Rugaspora minuta*) and BP (*Triquitrites bransonii-Lycospora pellucida*) in the Hongtuwa Formation in Jingyuan, Gansu (Zhu, 1993). Other comparable species in both PC Zone and KM, BP zones include *Crassispora kosankei, Punctatisporites minimus, Cyclogranisporites aureus, Ahrensisporites guerickei, Dictyotriletes bireticulatus, Lycospora* spp. and *Triquitrites* spp. as well as the increase of *Laevigatosporites* spp. and the decrease of *Tripartites* spp, *Simozonotriletes* and *Stenozonotriletes* spp. Therefore, the geological age of the present PC Zone should be regarded as equal to the R-G_1 zones of Namurian B-C. Furthermore, the conodonts-*Idiognathoides sulcatus, Neognathodus symmetricus*, and the goniatites *Cancelloceras bisati, Gasterioceras montgomeryense, Wiedeyoceras xiaheyianense, Physematites globosus, Pseudoschartymites ningxiaensis* and *P. xiaheyianensis*, also support the palynological dating.

MEGAFLORAL REMAINS

The megaplant fossils in the Hongtuwa Formation comprise 23 species belonging to 17 genera and named it as *Mesocalamites cistiformis-Paripteris gigantea* assemblage. The most common species include *Lepidodendron tripunctatum* Stockman et Mathieu, *Lepidostrobophyllum* sp., *Stigmaria rugulosa* Gothan of Lycopsida; *Sphenophyllum tenerrimum* Ett., *Mesocalamites cistiformis* Stur, *Asterophyllites longifolius* (Sternb.) Brongniart, *Asterophyllites* sp., and *Calamostachys* sp. of Sphenopsida; *Eusphenopteris scribanii* Ammerom, *Rhodeopteridium* sp., *Pecopteris plumosa* (Artis) Brongniart, *Neuropteris* sp., *Linopteris maxima* Shen, Gou et Liu, *L. germarii* Giebel, *Paripteris gigantea* (Sternb.) Gothan, *P. kaipingiana* (Sze), *P. otozamioides* (Sze et Lee) Gothan, *Potoniea adiantiformis* Zeiller, *Reticalethopteris yuanii* (Sze) Li, Shen et Wu and *Trigonocarpus* sp. of Filices or Pteridospermopsida as well as *Cordaites principalis* (Germar) Geinitz of Cordaitopsida.

Most of these fossil plants are the important elements of Namurian in Western Europe. *Sphenophyllum tenerrimum* mainly occurs in Visean to Namuian A, and even reaches to Namuian C. It is also discovered in Jingyuan and Jingtai areas of Gansu, China (Li, Wu *et al.*, 1993). However, other index fossil plants of Namurian A, e.g., *Eleutherophyllum waldenburgense* (Stur) and *E. drepanophyciformae* Remy et Remy do not appear in Xiaheyan, Zhongwei. *Mesocalamites cistiformis*, which occurs mainly in the middle-Late Namurian (H Zone) both in China and other countries, has been regarded as an important indicator for testing the boundary line between Lower and Upper Carboniferous. *Eusphenopteris* did not begin its development until the Namurian. *Rhodeopteridium* is also a common genus of Namurian in Western Europe. *Pecopteris plumosa* was reported in the lower part of the Oulong Bruke Group in Qinghai and the Hongtuwa Formation in Gansu. The extremely rich *Paripteris gigantea* in this assemblage is a frequent element of the Westphalian in the Euramerican Province, its lowest horizon so far known outside China being the middle Namurian *Reticuloceras* (R) Zone in France. In the present assemblage, the neuropterid plants are dominated by the Parispermae. In addition to *Paripteris*, its sister

genera *Linopteris, Neuropteris* and the fossil male reproductive organ *Potoniea* are also discovered alongwith the seed fossil *Trigonocarpus*. It has been established that the first appeared horizon of parispermous plants is lower in China than that in Euramerican Province. They are mostly distributed in the Namurian, some even in middle-Late Visean in China. Therefore, Li Xingxue *et al.* (1992) proposed that the parispermous plants first appeared in China, and then migrated and spread towards the Euramerican Province. Furthermore, *Linopteris* with reticulate veins is quite abundant in Namurian E Zone in Jingyuan, Gansu, and greatly decreases in the Namurian H Zone. In Xiaheyan of Zhongwei, only two species, *L. maxima* and *L. germarii* have been collected in the Hongtuwa Formation. On the other hand, specimens of *Paripteris* are dominant in this formation, including *P. gigantea, P. kaipingiana* and *P. otozamioides*. This is identical with that of the Hongtuwa floral assemblage in Jingyuan, Gansu (Li, Wu *et al.*, 1993).

Moreover, the endemic element represented by *Reticalethopteris yuanii* (Sze) Li, Shen et Wu is discovered in Xiaheyan, Zhongwei. This type of plant has long been regarded as *Palaeoweichselia*, a Westphalian C-D element. According to a recent study by Li, Shen *et al.* (1993), the specimens assigned to *Palaeoweichselia* in China are, in fact, different from that of Europe. Therefore, a new genus, *Reticalethopteris* was proposed for the Chinese material. The geological duration of *Reticalethopteris yuanii* known so far is restricted to middle-Late Namurian in China. This conclusion is also supported by Luo's recent report from Tianzhu, Gansu (Luo, 1993).

It is clear that the megaplant fossils in Xiaheyan, although not abundant, still represent middle-Late Namurian (H-G_1 zones) age. It is comparable with the floras of Jingyuan and Jingtai, Gansu of the same geological age (Li, Wu *et al.*, 1993) based on the following species, *Sphenophyllum tenerrimum, Paripteris gigantea, P. kaipingiana, P. otozamioides, Linopteris maxima, Neuropteris* sp., *Mesocalamites cistiformis, Eusphenopteris scribanii, Rhodeopteridium* sp., *Pecopteris plumosa, Potoniea adiantiformis, Reticalethopteris yuanii, Trigonocarpus* sp., *Stigmaria rugolusa* and *Cordaites principalis*.

DISCUSSION

Among the microflora in Xiaheyan, most spores belong to the Filices and pteridosperms, such as *Leiotriletes, Cyclogranisporites, Granulatisporites, Microreticulatisporites, Triquitrites, Tripartites* and *Dictyotriletes*, etc. They represent the highest percentage (56%) in the assemblage. Lycopsid spores including *Lycospora, Crassispora, Densosporites* and *Cirratriradites* occupy the subdominant position. Spores of sphenopsids are represented by *Calamospora* and *Laevigatosporites* (part), while cordaitopsids and coniferopsids are mainly represented by *Florinites* and *Gardenasporites*. As it is shown by both micro- and megaplant fossils, the present flora in Xiaheyan is mostly dominated by Filices and Pteridospermopsida; Lycopsida and Sphenopsida occupy the subdominant position, while gymnosperms (Cordaitopsida and Coniferopsida) are not very common.

According to the analysis of both marine and non-marine fossils and lithological characteristics, the middle to Late Namurian palaeoecology in Zhongwei may be coastal plain or delta environments (Tong *et al.*, 1994). The swamp vegetation represented by arborescent lycopsids, sphenopsids and herbaceous pteridophytes was distributed in the coast swamp area. The pteridosperms possibly grew at the lower hydro- and wet land of the swamp. Only a few gymnosperms (cordaitopsids and coniferopsids) lived on the onshore plain or lower upland. The present flora indicates a tropical-subtropical warm and humid palaeoclimate, which is favourable for the formation of coal resources. The palaeomagnetic data (Wu *et al.*, 1993) also support the palaeoclimatic conclusion.

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