Palynological zonations and paleoecology of Carboniferous sequence from Zhongwei of Ningxia, Northwest China

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Six miospoe assemblage zones are established for Carboniferous strata (Namurian-Stephanian) in the Xiaheyan Section of Zhongwei, Ningxia, Northwest China. They correspond to the Early Namurian (goniatite E Zone and H Zone), Late namurian (goniatite R- G_1Zone), Westphalian A-B, Westphalian C-D and Stephanian of West Europe, respectively. The general aspect of Carboniferous palynoflora in Zhongwei is dominated by spore types with affinities of Filicopsida and Pteridospermospsida; Sphenopsid and Lycopsid spores occupy the subdominant position, while the gymnospermous pollen grains of Cordaitopsida and Confiferopsida make lesser contribution to the flora. Three miospore phases are recognized in ascending order as *Lycospora-Crassispore* phase, *Laevigatosporites-Torispora* Phase and *Florinites-Pityosporites* phase. The paleoecological considerations of each phase are also discussed.

Key-words — Palynology, Biostratigraphy, Miospore phase, Carboniferous, Zhongwei, Northwest China.

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साराँश

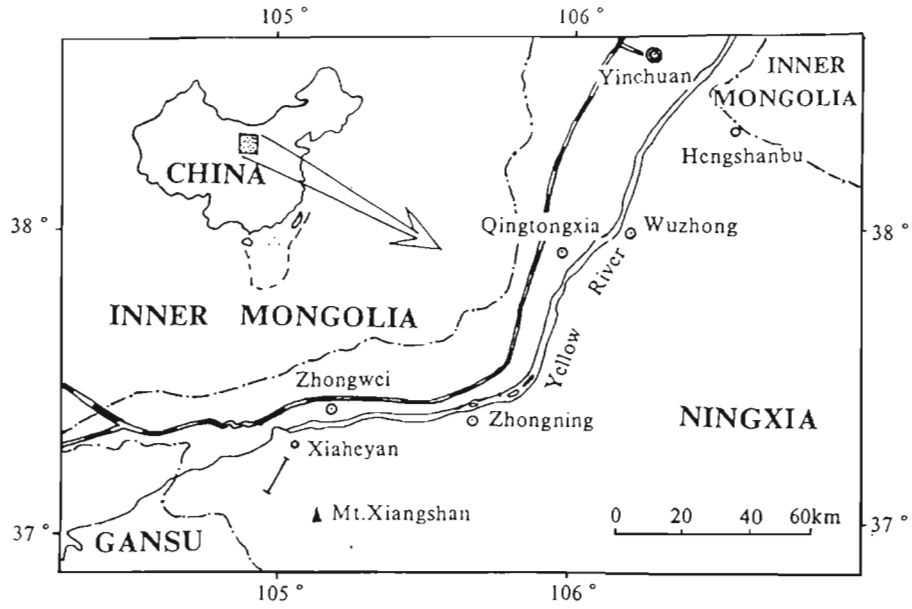
उत्तरपूर्व चीन में निंग्सिआ के झौंग्वी अनुक्रम की पुरापारिस्थितिकी एवं कार्बनीफेरस परागाणविक मंडलन

वाँग यॉंग-डाँग

उत्तर पूर्व चीन में निंग्सिआ के झौंग्वी अनुक्रम में कार्बनीफेरस स्तरों (नामूरिअन–स्टिफानियन) के लिए छः सूक्ष्मबीजाणु समुच्चय मंडल स्थापित किये गये हैं। ये पश्चिम यूरोप के क्रमशः प्रारम्भिक नामूरिअन (गोनिआटाइट ई. एवं एच. मंडल), अनंतिम नामूरिअन (गोनिआटाइट आर–जी–1 मंडल), वेस्टफालिअन ए–बी., वेस्टफालिअन सी.डी. तथा स्टीफानिअन से तुलनीय हैं। इस अनुक्रम से उपलब्ध वनस्पतिजात में फिलीकोप्साइडा एवं टेरीडोस्पर्मोप्साइडा के बीजाणुओं की बाहुल्यता है, स्फीनॉप्सिड एवं लाइकॉप्सिड के बीजाणुओं की उपबाहुल्यता है जबकि अनावृतबीजी एवं आवृतबीजी परागकण बहुत कम हैं। इस शोध-पत्र में प्रत्येक चरण की पुरापारिस्थितिकीय स्थिति की भी विवेचना की गई है।

CARBONIFEROUS system is one of the principal strata having coal, oil and gas resources in Northwest China, which shows the important geological and economical significance. In recent years, paleontologists and geologists have taken a comprehensive research on biostratigraphy in this region. However, only a few studies were undertaken on Carboniferous palynology except those published from Jingyuan, Gansu (Gao, 1980, 1987; Zhu, 1989, 1993).

Zhongwei lies in the middle part of Ningxia Autonomous region in Northwest China. Xiaheyan Section is situated at the southeast part of Zhongwei, at latitude 105° 05'E and longitude 37°25'N (Text-figure 1). The Carboniferous strata (Namurian-Stephanian) in this section is well developed and exposed clearly, yielding abundant animal and plant fossils. This section has been considered as an ideal sequence for biostratigraphical and palynological studies. The present paper mainly discusses the palynological zonations, correlation and paleoecological interpretations of mioflora based upon systematic study on spore-pollen assemblages.



Text-figure 1 — A sketch map showing the geographical location of the Xiaheyan Section in Zhongwei of Ningxia, Northwest China.

STRATIGRAPHY

Tectonically, Xiaheyan in Zhongwei lies at the east margin of the Caledonian Fold Belt in the North Qilian Mountains. The Carboniferous strata in this area are mainly composed of clastic rocks and intercalations of limestones and this coal bed, indicating marine and nonmarine alternating deposits. Four lithological units, namely — the Jingyuan, the Hongtuwa, the Yanghugou and the Taiyuan formations are recognized in ascending order. The primary results of biostratigraphy in Siaheyan had been published at the 29th International Geological Congress in Kyoto, Japan (Wang *et al.*, 1992). The litho-and biostratigraphic characters are briefly introduced as follows:

The Jingyuan Formation — This formation consists of black silty shales and greyish black sandstones intercalated with lenticular limestones. The Xiaheyan Section outcrops only the upper part of the formation with the thickness of 46 m because the lower part is overlapped by a Neogene fault. A large number of plant megafossils including *Eusphenopteris scribanii* Ammerom, *Paripteris gigantea* (Sternberg), *Linopteris* sp., *Cordaites principalis* (Germ.) Geinitz, *Stigmaria rugosa* Gothan, *Rhodeopteridium* sp., *Mesocalamites* sp. and *Lepidodendron* sp. have been recovered from the formation.

The Hongtuwa Formation — This formation consists principally of greyish black shales with thin-bedded limestone intercalations, with a thickness of 170 m. In the lower part of the formation the conodonts are dominated by *Declinognathodus noduliferus* (Ellison & Graves), and in the upper part by *Idiognathoides sulcatus* Higgins & Bouckaert and *Neognathodus symmetricus*

PLATE 1

1 *Leiotriletes parvus* Günnel Cx-8-2-(2)
2. *Leiotriletes gracilis* (Imgrund) Imgrund Cx-6-(4)
3 *Shanxispora cephala* Gao Cx-24-(1)
4, 5 *Punctatisporites hians* Wang 4.Cx-24-(3) 5.Cx-24-(4)
6. *Granulatisporites granulatus* Ibrahim Cx-6-(1)
7.8 *Lophotriletes microsaetosus* (Loose) Potonié & Kremp 7.Cx- 6-(4) 8.Cx-3-(2)
9,10. *Acanthotriletes echinatus* (Knox) Potonié *et* Kremp 9. Cx-3-(3) 10.Cx-4-(3)

11 *Microreticulatisporites concavus* Butterworth & Williams Cx-11-(1)
12. *Microreticulatisporites punctatus* Knox Cx-11-(4)
13. *Convolutispora minuta* Zhu Cx-3-(5)
14, 17. *Dictyotriletes bireticulatus* (Ibrahim) Smith & Butterworth 14.Cx-23-1-(1) 17. Cx-8-2-(3)
15. *Gulisporites cochlearius* Imgrund Cx-30-2-(7)
16. *Convolutispora cerebra* Butterworth & Williams Cx-11-(1)
18. *Convolutispora venusta* Hoffmeister, Staplin & Milloy Cx- 11-(1)
19-20. *Cyclogranisporites aureus* (Loose) Potonié & Kremp 19. Cx- 8-2-(6) 20. Cx-11-(3)
21 *Verrucosisporites verus* (Potonié & Kremp) Smith & Butterworth Cx-30-2-(3)
22. *Verrucosisporites kaipingiensis* Imgrund Cx-30-2-(1)
23. *Convolutispora arcuata* Gao Cx-30-2-(10)
24. *Verrucosisporites donarii* Potonié & Kremp Cx-11-(7)

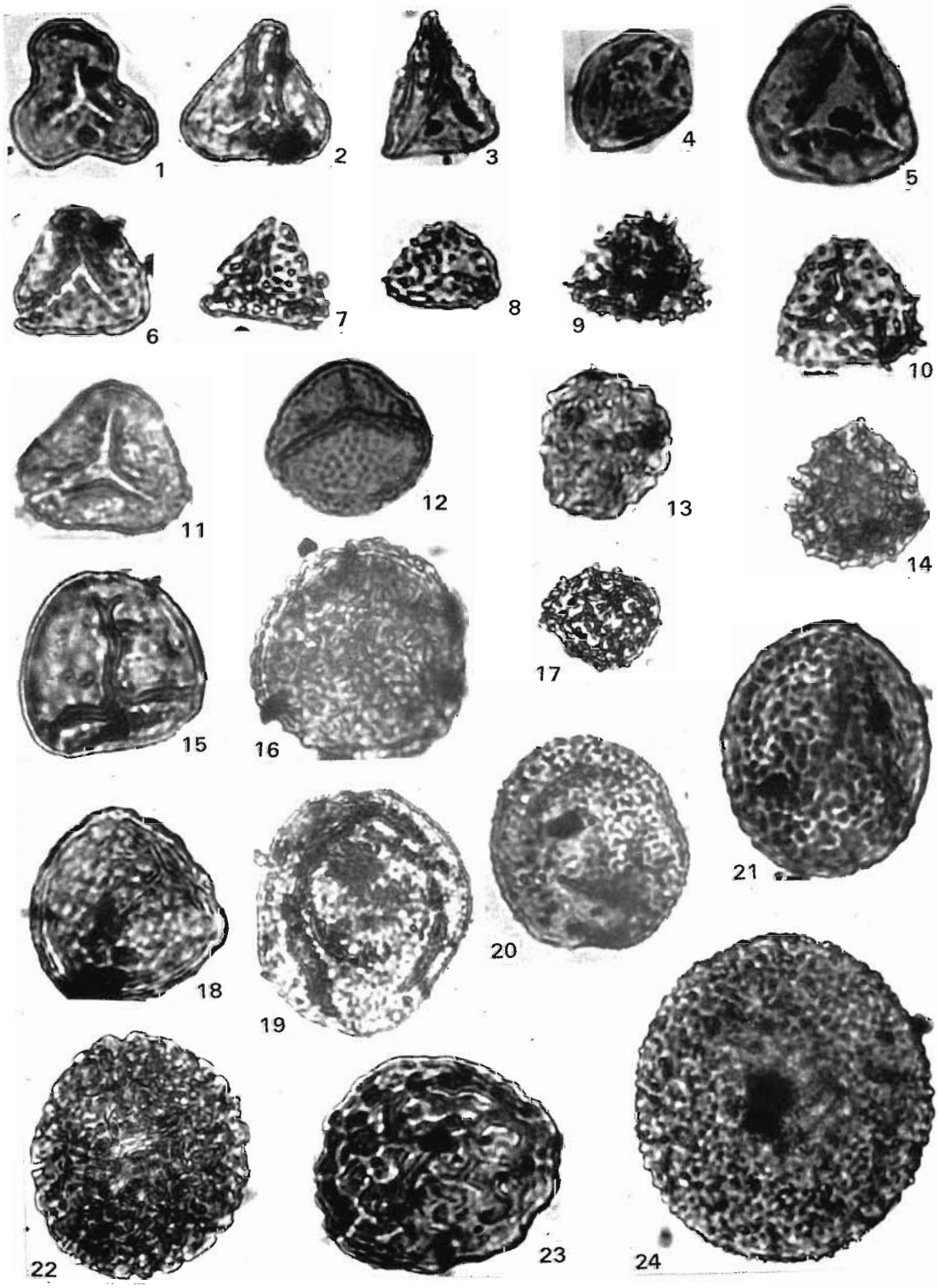


PLATE 1

(Lane). The fusulinids assemblage is characterized by *Eostaffella postmosqensis* Kireeva and *Millerella marblensis* Thompson. The fossil plants are mainly represented by *Asterophyllites longifolius* (Sternberg) and *Pecopteris plumosa* (Artis).

The Yanghugou Formation — This formation is primarily made up of sandy shales intercalated with thin-bedded coal seams and limestones, with a thickness of 192 m. The dominant conodonts are *Idiognathodus delicatus* Gunnell, *I. claviformis* Gunnell; *I. magnificuus* Stauffer & Plummer, and fusulinid is represented by *Pseudostafella*. Some bivalvias are also recovered from this formation, such as *Dunbarella subpapyraceous* (Verneuil), Dumbarella sp., *Posidoniella* cf. *vetusta* (Sowerby). Fossil plants in the formation are not well preserved; only *Lepidodendron oculusfelis* (Abb. Zeill. *Pecopteris* sp. and *Sphenophyllum oblongifolum* (Gern. et Kaulf.) Unger are identified.

The Taiyuan Formation — This formation is composed of greyish black shales and sandstones with thin-bedded limestones and coal seams. It can be divided into two parts: the Lower Member (113 m) and the Upper Member (159 m). The Lower Member is considered as of Late Carboniferous age on the basis of recovered fossil conodonts — *Idiognathodus delicatus* Gunnell, *I. claviformis* Gunnell fusulinids — *Ozawainalla, Mediocris* and *Pseudostafella* as well as plants— *Neuropteris pseudovata* Gothan & Szé and *Sphenophyllum oblongifolium* (Germ. et Kaulf.) Unger. The Upper Member is regarded as Early Permian due to the presence of following fossil evidences: fusulinids *Sphaeroshwagerina, Rugosofusulina, Rubostoschwagerina* and *Schwagerina;* conodonts *Streptognathodus elongatus* Gunnell, *S. gracilis* Stauffer & Plummer, *S. simplex* Gunnell and *S. wabausensis* Gunnell as well as the oriental-type lepidophytic plants, i.e., *Lepidodendron posthumii, Cathaysiodendron nanpiaoense* Lee and *Bothrodendron kuianum* Lee (Wang *et al.*, 1995). Presently, the Permo-Carboniferous boundary could be placed between the Lower and Upper members. This also corresponds to the lower part of Asseliah and correlates with the horizon of the first appearance of conodont *Streptognathodus barskovi.* This boundary position is somewhat lower than the traditional subdivision on Permo-Carboniferous boundary in China, but is considered as equivalent to the division scheme widely adapted internationally (Wang *et al.*, 1995).

PALYNOLOGICAL ZONATIONS

The fossil miospore assemblages, recovered from the productive samples from Xiaheyan Section, comprise a total of 110 miospore species belonging to 65 genera, some of which have been selected as the zonal index. Based on combination of criteria, including both major quantitative changes in assemblage composition and the appearance or disappearance of characteristic species, six miospore assemblage zones extending from the Early Namurian to Stephanian are proposed in descending order alongwith the suggestion of their geological age:

6. *Laevigatosporites florinites* (LF) Zone = Stephanian
5. *Torispora securis - Punctatisporites hians* (SH) Zone = Westphalian C-D
4. *Laevigatosporites medius - Cyclogranisporites aureus* (MA) Zone = Westphalian A-B
3. *Gardenasporites pinnatus - Microreticulatisporites concavus* (PC) Zone = Namurian B-C (goniatite R-G_1Zone)
2. *Lycospora subtrequetra-Gansusispora mammilla* (SM) Zone = Namurian A (goniatite H Zone)
1. *Tripartites trilinguis-Simozonotriletes* sinensis (TS) Zone = Namurian A (goniatite E Zone)

PLATE 2

1. *Lycospora pusilla* (Ibrahim) Schopf, Wilson & Bentall Cx-3- (8)
2. *Lycospora subtrequetra* (Luber) Potonié & Kremp Cx-8-2-(4)
3-5. *Simozonotriletes sinensis* Zhu 3. Cx-3-(6) 4. Cx-3-(4) 5. Cx-3-(1)
6. *Simozonotriletes labellatus* Wang Cx-24-(4)
7. *Stenozonotriletes triangulus* Neves Cx-11-(6)
8-10. *Stenozonotriletes rotundus* Wang 8.Cx-3-(15) 9. Cx-6-(2) 10. Cx-3-(3)
11. *Densosporites sphaerotriangularis* Kosanke (Cx-8-2-(8)
12-14. *Gansusispora mammilla* Gao 12. Cx-23-1-(3) 13. Cx-23-1-(4) x 500 14.Cx-3-(2)
15, 16. *Cirratriradites saturni* (Ibrahim) Schopf, Wilson & Bentall 15.Cx-8-2-(5) x 500 16.Cx-11-(8) x 500
17. *Reinschospora* cf. *triangularis* Kosanke Cx-15-(3) x500
18. *Densosporites reticuloides* Ouyang & Li Cx-15-(2) x 500
19. *Crassispora kosankei* (Potonié & Kremp) Bharadwaj Cx-3-(9)
20. *Crassispora maculosa* (Knox) Sullivan Cx-6-(4)

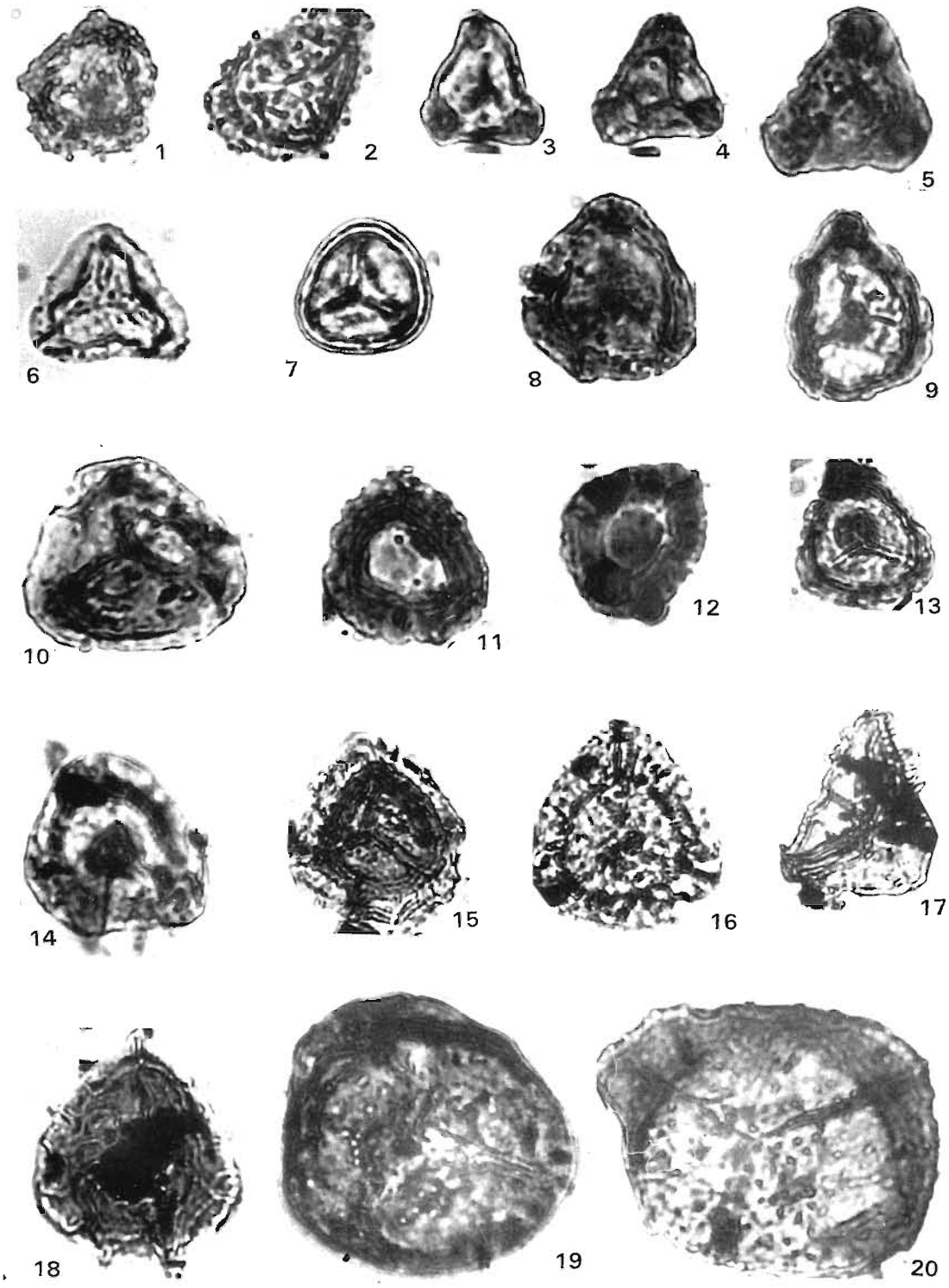


PLATE 2

Series	Zhongwei, Ningxia			West Europe		
	Formation	Palynological Zonations			Goniatite Zone	Stage
Upper Carboniferous	Taiyuan Fm. (Lower M.)	*Laevigatosporites*– *Florinites*	LF	NBM ST		Stephanian
	Yanghugou Fm.	*Torispora securis*– *Punctatisporites hians*	SH	OT SL		D C Westphalian
		Laevigatosporites medius– *Cyclogranisporites aureus*	MA	NJ SS		B A
	Hongtuwa Fm.	*Gardenasporites pinnatus*– *Microreticulatisporites concavus*	PC	FR KV	G_1 R	C B
		Lycospora subtrequetra– *Gansusispora mammilla*	SM	SO	H	Namurian
Lower Carb.	Jingyuan Fm.	*Tripartites trilinguis*– *Simozonotriletes sinensis*	TS	TK	E	A

Text-figure 2 — Correlation of stratigraphy and palynological zonations between Zhongwei and West Europe.

In the description of zonal assemblages the relationship of rock units and palynological zonations between Zhongwei and West Europe has been shown in Text-figure 2.

1. *Tripartites trilinguis—Simozonotriletes sinensis* (TS) Zone—This is the oldest zone proposed for the miospore zones of Carboniferous in Xiaheyan of Zhongwei. All miospore types recorded are represented by pteridophytic spores. Zone TS is characterised by the presence of *Tripartites trilinguis* (Horst) Smith *& Butterworth, T. vetustus* Schemel, *Simozonotriletes sinensis* Zhu, *Stenozonotriletes rotundus* (Wang) Zhu, *Crassispora kosankei* (Potonié & Kremp) Bharadwaj, *Gansusispora mammilla* Goa, *Lycospora pusilla* (Ibrahim) Schopf, Wilson & Bentall, *Densoisporites sphaerotriangularis* Kosanke and *Ahrensisporites querickei* (Horst) Potonié & Kremp. It is noteworthy that both the species, *Tripartites trilinguis* and *Simozonotriletes sinensis*, are more common in this zone, usually making up more than 10 per cent of the total and reaching up to 20 per cent in some slides.

A comparison between the TS Miospore Zone in Zhongwei and Zones NC, TK, SO, KV and FR of Namurian in West Europe (Clayton *et al.*, 1977; Owns *et al.*, 1977) suggests that TS is equivalent to Zone NC (*Bellispores nitidus - Reticulatisporites carnosus*) and TK (*Stenozonotriletes triangulus-Rotaspora knoxi*) based on several common species, namely *Tripartites trilinguis, T. vetustus, Crassispora kosankei, Ahrensispora guerickei, Lycospora pusilla* and comparable species of genera *Simozonotriletes* and *Stenozonotriletes*. It is also comparable to TA (*Tripartites trilinguis-Simozonotriletes arcuatus*) Zone in Jingyuan, China (Zhu, 1993) in having *Tripartites trilinguis, T. vetustus, Simozonotriletes siensis* and *Stenozonotriletes rotundus*. Therefore, TS Zone should be regarded as goniatite E Zone of the Early Namurian.

PLATE 3

1-3. *Tripartites trilinguis* (Horst) Smith et Butterworth 1.Cx- 8-2-(3) 2. Cx-3-(1) 3.Cx-6-(3)
4,5. *Tripartites vetustus* Schemel 4. Cx-6-(2) 5. Cx-3-(2)
6,8. *Ahrensisporites guerickei* (Horst) Potonié et Kremp 6.Cx-8- 2-(8) 8.Cx-11-(1)
7. *Triquitrites petaloides* Wang Cx-8-2-(5)
9. *Knoxisporites triradiatus* Hoffman, Staplin & Malloy Cx-24- (8) x 500
10-12. *Torispora securis* Balme 10.Cx-23-3-(1) 11.Cx-23-3-(4) 12. Cx-23-3-(4)
13. *Thymospora thiessenii* (Kosanke) Wilson & Venkatachala Cx- 23-2-(1)
14. *Laevigatosporites ovalis* Kosanke. Cx-23-(2)
15. *Laevigatosporites medius* Kosanke Cx-30-2-(30)
16. *Laevigatosporites globosus* Schemel Cx-8-(8)
17. *Laevigatosporites desmoinensis* (Wilson) Schopf, Wilson & Bentall Cx-3-(15)
18. *Columinisporites ovalis* Peppers Cx-16-(3)
19. *Laevigatosporites vulgalis* (Ibrahim) Ibrahim Cx-11-(2)

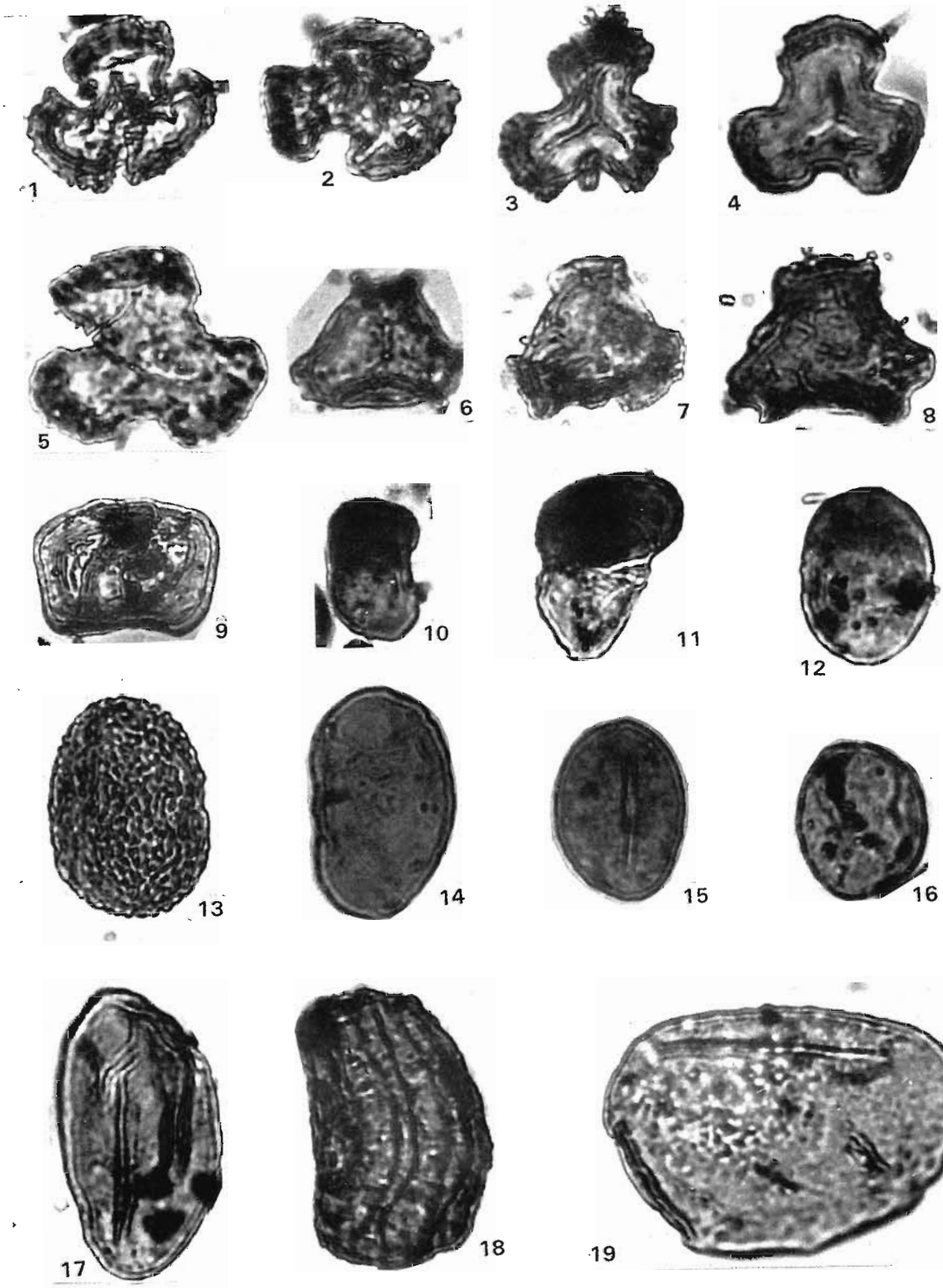
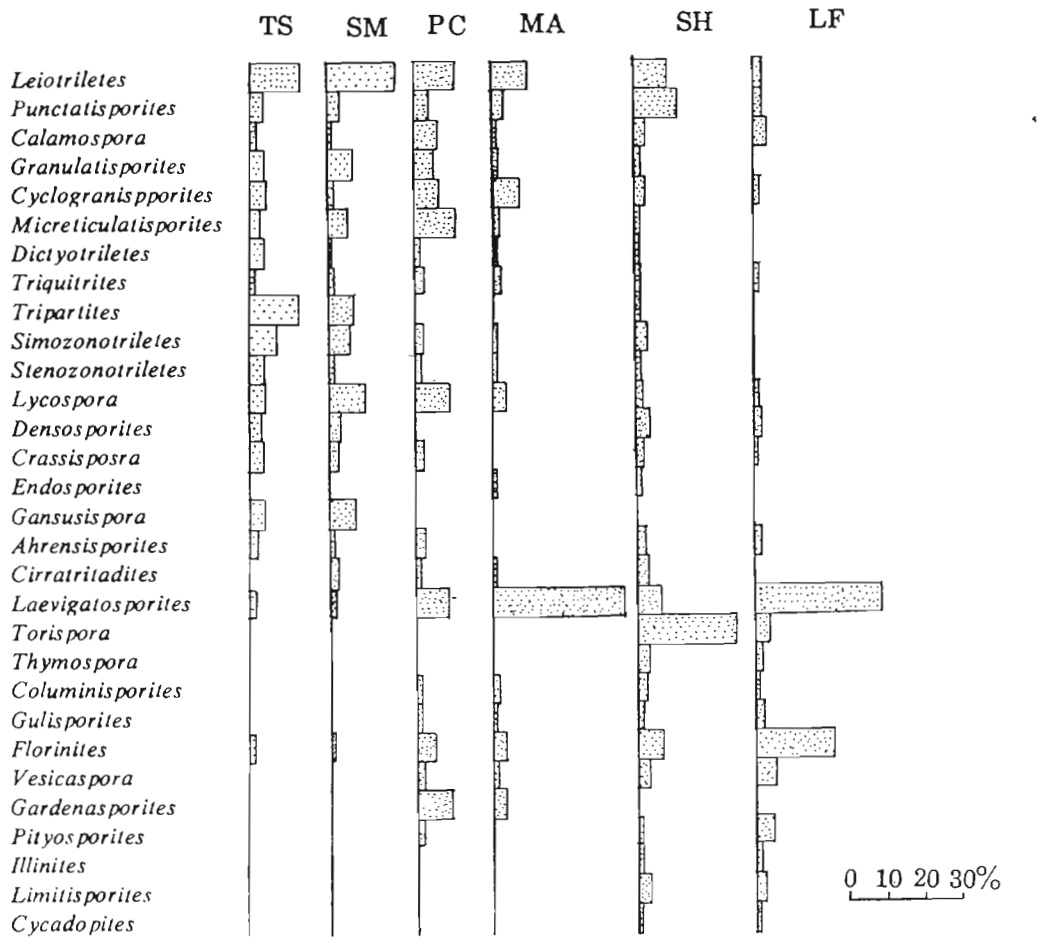


PLATE 3



Text-figure 3 —Showing the percentage diagram of main meiospore genera from Carboniferous in Zhongwei, Ningxia

2. *Lycospora subtrequetra-Gansusispora mammilla* (SM) Zone — Assemblage Zone SM occurs in the lower part of the Hongtuwa Formation. It is marked by the abundant appearance of *Lycospora subtrequetra* (Luber) Potonié & Kremp, *Gansusispora mammilla* Gao, *Dictyotriletes bireticulatus* (Ibrahim) Smith & Butterworth, *Densosporites sphaerotriangularis* Kosankei, *Triquitrites* spp., *Granulatisporites piroformis* Loose, *Cyclogranisporites pressoides* Potonié & Kremp, *Punctatisporites aureus* Butterworth & Williams and the first appearance of *Cirratriradites saturni* (Ibrahim) Schopf, Wilson & Bentall and *Savitrisporites nux* (Butterworth & Williams) Smith & Butterworth. Some species which are abundant in TS Zone, such as *Simozonotriletes sinensis, Tripartites trilinguis, T. vetustus* decline in this zone. Monosaccate pollen referred to *Florinites* are often found but never reach more than 1 per cent.

SM Zone is comparable with SO *(Lycospora subtrequetra - Krauselisporites ornatus)* Zone of West Europe because of the common species of *Lycospora subtrequetra, Densosporites sphaerotriangularis,*

PLATE 4

1 *Florinites junior* Potonié *et* Kremp Cx-30-(2)
2, 3. *Florinites* spp. 2.Cx-11-(8) x500 3.Cx-30-2(4) x500
4. *Vesicaspora wilsonii* (Schemel) Wilson *et* Venkatachala Cx-23-2-(8)
5. *Wilsonites delicatus* (Kosanke) Kosanke Cx-30-(18)
6. *Florinites ovalis* Bhardwaj Cx-30-2-(4)
7. *Illinites* sp. Cx-30-2-(9)
8,11. *Pityosporites westphalensis* Williams 8. Cx-30-2-(8) 11. Cx-30-2-(4)
9. *Illinites unicus* Kosanke Cx-30-2-(4)
10. *Pinuspollenites* sp. Cx-32-(1)
12. *Cycadopites* sp. Cx-23-3-(17)
13,14. *Gardenasporites pinnatus* Krusina 13. Cx-11-(4) x500 14. Cx-15-(2) x500

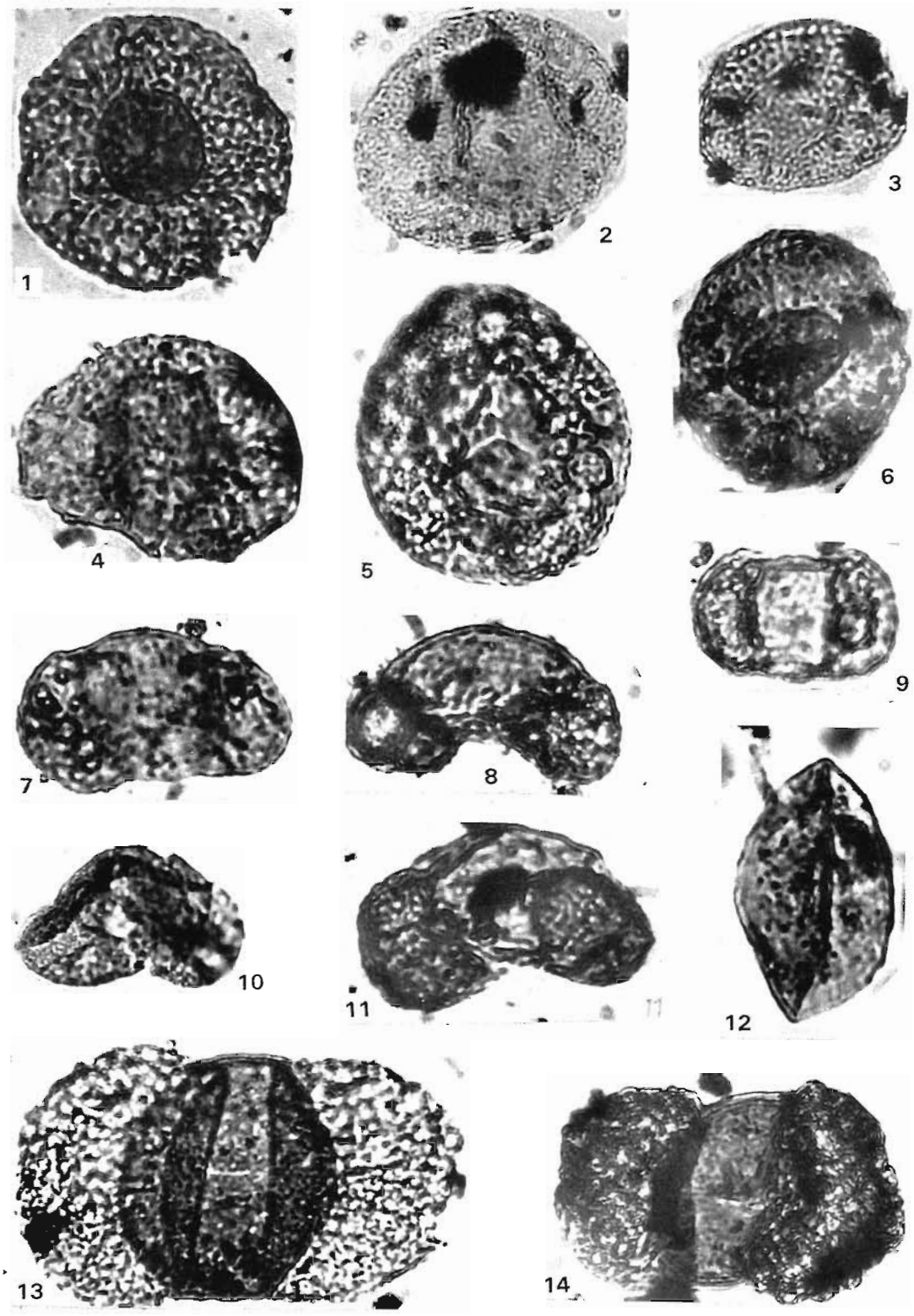


PLATE 4

Savitrisporites nux, and is also equivalent to SB *(Densosporites sphaerotriangularis-Dictyotriletes bireticulatus)* Zone in Jingyuan, China (Zhu, 1993).

The intercalations of thin-bedded limestones which share the same horizons with SM Zone contain conodont *Declinognathodus noduliferus* (Ellison & Graves) and *Neognathodus symmetricus* (Lane). They are taken as marker of the base of the Upper Carboniferous, equivalent to goniatite Zone H of Namurian in West Europe.

3. *Gardenasporites pinnatus-microreticulatis porites concavus* (PC) Zone — This assemblage zone occurs in the upper part of the Hongtuwa Formation. The marked species in PC Zone include *Microreticulatisporites concavus* Butterworth & Williams, *Cyclogranisporites aureus* Potonié & Kremp, *Crassispora kosankei* (Potonié & Kremp) Bharadwàj, *Gulisporites cochlearus* Imgrund, *Lycospora* spp., *Ahrensisporites* spp., *Cirratriradites saturni, Triquitrites, Convolutispora* and *Densosporites,* etc. Several species, such as *Tripartites trilinguis, T. vetustus and Simozonotriletes sinensis, Stenozonotriletes rotundus, Gansusispora mammilla,* become more rare in this zone and even disappear at the top. The monolete spores begin to increase slightly and are marked by the presence of *Laevigatosporites.*

Disaccate pollen assigned to *Gardenasporites pinnatus* Krusina reach up to 8 per cent in most of the samples. The PC Zone is regarded as comparable to Zones KV *(Crassispora kosankei-Grumosisporites varioreticulatus)* and FR *(Raistrickia fulva-Reticulatisporites reticulatus)* of West Europe (Clayton *et al.*, 1977) based on the basis of common species, such as *Microreticulatisporites concavus, Crassispora kosankei, Ahrensisporites guerickei, Lycospora* spp., etc. The conodonts—*Idiognathoides sulcatus* Higgins & Bouckaert, bivalvia— *Leptodesma* sp. and plants—*Eusphenopteris* sp., *Palaeoweichselia yuanii* Szé, *Paripteris gigantea* Sternberg, *P. kaipingiana* (Szé), *Asterophyllites longifolius* (Sternberg), *Pecopteris plumosa* (Artis), which occur in association with Zone PC, also indicate the age of goniatite R-G_1 Zone of Namurian.

4. *Laevigatosporites medius-Cyclogranisporites aureus* (MA) Zone — MA Zone is established from the deposit of lower part of the Yanghugou Formation. Zone MA is characterised by the first recorded high proportion of monolete spores, which make up to 44.2-44.6 per cent (Text-figure 3), and include *Laevigatosporites medius* Kosanke, *L. ovalis* Kosanke, *L. desmoinensis* (Wilson & Coe) Schopf, Wilson & Bentall, *L. vulgalis* (Ibrahim) Ibrahim, *L. globosus* Schemel and *Columinisporites ovalis* Peppers. Other spores, such as *Cyclogranisporites aureus* (Loose) Potonié & Kremp, *Granulatisporites granulatus* Ibrahim, *Microreticulatisporites concavus* Butterworth & Smith, *M. nobilis* (Welcher) Knox, *Endosporites globiformis* (Ibrahim) Schopf, Wilson & Bentall, *Cirratriradites saturni* (Ibrahim) Schopf, Wilson & Bentall, *Triquitrites bransanii* Wilson *et* Hoffman, *Dictyotriletes bireticulatus* (Ibrahim) Smith *et* Butterworth and *Florinites junior* Potonié & Kremp are common.

The present zone is equated to palyno-assemblages of the Yanghugou Formation in Inner Mongolia (Yu, 1983), the eighth zone of North China by Goa (1979) and Zones SS *(Triquitrites sinani - Cirratriradites saturni)* and NJ *(Microreticulatisporites nobilis-Florinites junior)* of Westphalian A-B stage in West Europe (Clayton *et al.*, 1977) considering the appearance of *Laevigatosporites* spp., *Columinisporites ovalis, Cirratriradites saturni, Endosporites globiformis, Microreticulatisporites nobilis, Triquitrites bransonii* and *Florinites junior.* In addition, the geological age of fossil bivalvias *Dunbarella* sp., *D. subpapyraceous* (Verneuil), *Posidoniella* cf. *vetusta* (Sowerby) also coincide with the MA Zone as Westphalian A-B stages.

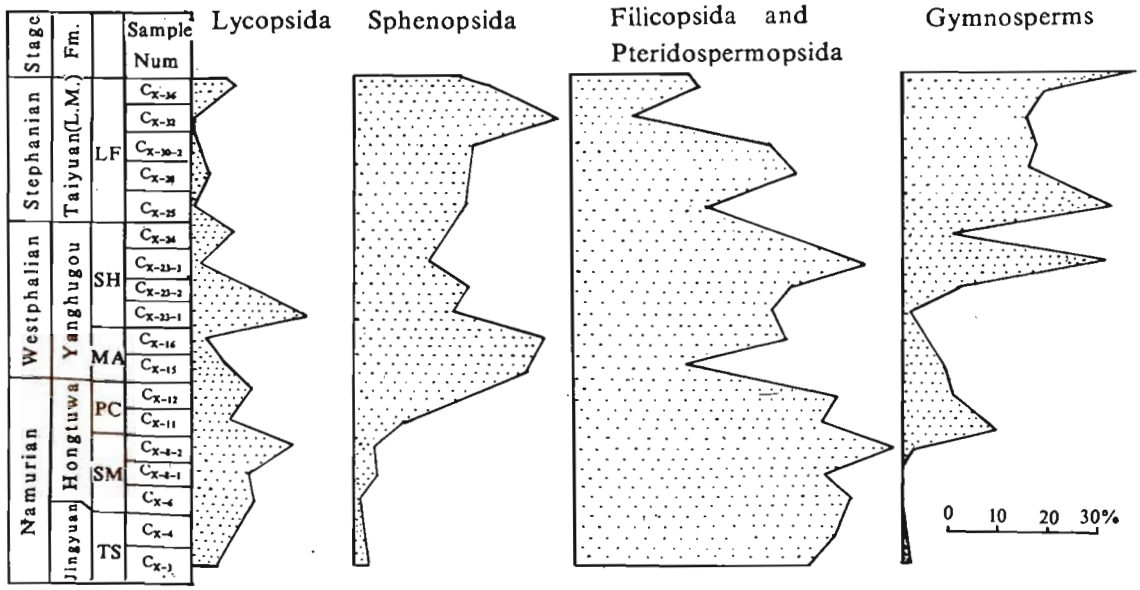
Torispora securis-Punctatisporites hians (SH) Zone—The SH Zone is stratigraphically equivalent to the upper part of the Yanghugou Formation. The base of the zone is marked by the significant increase of *Torispora securis* Balme (10.0-44.4%) and the first appearance of *Thymospora thiessenii* (Kosanke) Wilson & Venkatachala and *Punctatisporites hians* Wang (Text-figure 3). The other monolete spores (mainly *Laevigatosporites, Latosporites* and *Columinisporites)* are also higher in this zone. In addition, the species *Gulisporites cochlearius* Imgrund, *Verrucosisporites kaipingiensis* Imgrund, *Shanxispora cephala* Gao, *Knoxisporites triradiatus* Hoffmeister, Staplin & Malloy, *Triquitrites petaloides* Wang, *Densosporites annulatus* (Loose) Smith & Butterworth, *D. reticuloides* Ouyang & Li and *Simozonotriletes labellatus* Wang are common. The pollen which can be referred to *Florinites, Vesicaspora, Pityosporites, Illinites* and *Platysaccus* increase gradually in abundance with frequency of 7.8-20.5 per cent.

This zone compares closely with the assemblages of the upper part of the Yanghugou Formation in Hengshanbu (Wang Hui, 1984) and the Ordos Basin (Geng, 1985), the Benxi Formation in Sanxi (Liao, 1987; Ouyang *et al.*, 1980; Gao, 1979) as well as SL *(Torispora securis - T. laevigata)* Zone and OT *(Thymospora obscura - T. thiessenii)* Zone of West Europe based on the species *Torispora securis, Thymospora thiessenii, Laevigatosporites* spp., *Punctatisporites* spp., *Triquitrites* spp., etc. Therefore, the present SH Zone should be referred to Westphalian C-D stages in age. Furthermore, the conodonts *Idiognathodus delicatus* Gunnell, *I. claviformis* Gunnel and *I. magnificus* Stauffer & Plummer, which are the index fossils of Westphalian C-D, also support the present palynological age determination.

6. *Laevigatosporites - Florinites* (LF) Zone — The Zone LF occurs in the Lower Member of the Taiyuan Formation and is characterised by the predominance of both monolete spores and monosacate pollen. The former are represented mainly by *Laevigatosporites* with frequencies 44-45.6 per cent as well as *Torispora, Thymospora, Striatosporites* and *Columinisporites.* Clayton *et al.* (1977), and Owens *et al.* (1989) suggested that the well developed mololete spore-group marks the base of Stephanian in Europe. Monolete pollen in LF Zone are represented mainly by *Florinites,* with frequencies as 20 per cent; some slides even contain 40 per cent. Some other species, such species of *Triquitrites, Crassispora, Cirratriradites* and *Densosporites* sharply decrease and even disappear in LF Zone. Other fossils from the Lower Member of the Taiyuan Formation which are equivalent to LF Miospore Zone appear, e.g., fusulinids *Ozawinella, Mediocris* and *Pseudostaffella;* conodonts *Idiognathodus delicatus* Gunnell; plants *Sphenophyllum oblongifolium* (Germ. *et* Kaulf.) Unger and *Neuropteris pseudovata* Gothan & Sze. They are also common elements encountered from Stephanian deposit in China and abroad. These characters in association with the present miospore evidence, demonstrate that the LF assemblage zone should be considered as of Stephanian and might be comparable with zones of ST *(Angulisporites splendidus-Latensina triletes)* and NBM *(Potonieisporites novicus-Bharadwaji-Cheileidonites major)* of West Europe, although these zonal species do not occur in Zhongwei, mainly because more clear phytogeographical provinces existed at the end of Late Carboniferous.

PALAEOECOLOGY OF MIOFLORA

Variation within the mioflora reflects, in part, changes in the spore producing plant community. The floral composition of swamp community is typically changed by ecomorphic replacement (Dimichele *et al.*, 1985, 1987). The replacement of species is reflected in the extinction and appearance of spores and pollen (Turner *et al.*, 1993). A further complication in interpretation of



Text-figure 4 — Palynofloristic composition and percentage of major miospore groups from Carboniferous in Zhongwei, Ningxia.

palaeoecology is faced by the extend of bias and incompleteness of the fossil record within Namurian-Stephanian. Despite these problems, the interpretations offered herein are based on detailed studies of plant-spore association (Chaloner, 1953, 1958; Potonié, 1962; Piérart, 1968; Dimichele, 1985) and are considered as accurate reflection of palaeoecological reconstructions as possible, given the limitations of the available data (Turner *et al.*, 1993). The quantitative results of mioflora are shown graphically in Text-figure 4.

Fossil Lycopsida in Zhongwei are mainly represented by miospores *Lycospora, Crassispora, Densosporites* and *Cirratriradites*. The former two are regarded as arborescent lycopods and the others are referred to herbaceous lycopods (Eble *et al.*, 1990). These lycopod spores are largely distributed at the Jingyuan, the Hongtuwa and Yanghugou formations. Traverse (1988) suggested that the densospore production by lycopods require much moisture and humidity. The parent plants of these spores are represented by *Lepidodendron, Lepidophloios* and *Sigillaria,* which must have occupied the dominant population in the Carboniferous coal-swamp phytocommunity, indicating a coastal lowland swamp environment as well as warm and humid climate.

Spores of Sphenopsida affinities are characterised by *Calamospora* type and *Laevigatosporites* type. Other Sphenopsida spores include *Latosporites, Columinisporites* and *Reticulatisporites*. Their contribution does not exceed 28 per cent and is more prominent at the Yanghugou Formation and Lower Member of the Taiyuan Formation. The plants which produce *Calamospora* and *Laevigatosporites* are represented by *Calamites, Mesocalamites, Asterophyllites* and *Annularia*; they are always minor constiuents of swamp community, interpreted by various authors that the parent plant of *Calamospora* lived outside the swamp on levees or point bars (Traverse, 1988), and those of *Laevigatosporites* lived at the lowland of the swamp flora. They preferred dark, wet condition and humid climate.

The spores referred to Filicopsida and Pteridospermopsida are composed of *Leiotriletes, Punctatisporites, Cyclogranisporites, Triquitrites, Dictyotriletes, Granulatisporites, Microreticulatisporites, Torispora* and *Thymospora,* etc. They are the dominant elements of the Carboniferous palynoflora in Zhongwei, which show a tendency of gradually decrease from Namurian to Stephanian. These pteridophytic spore types were most probably produced by lowland mesophytic to hydrophilous plant communities. Except some high arborescent trees, most of them are herbaceous plants, with giant pinnate leaves, which lived in the bottom tier of the forest as well as wet and humid lowland environment.

Gymnospermous pollen are represented by *Florinites, Pityosporites, Vesicaspora, Illinites* and *Limitisporites*. In Zhongwei, they began to develop from Namurian stage, and gradually increased in Westphalian. As a consequence, they became the subdominant group of palynoflora at Stephanian (about 305) — Text-figure 4. These saccate pollen are known to have derived from high or upland environments, migrating to the lowland, flourished by xerophytic vegetation (Habib, 1968). *Florinites*, which is derived from cordaites and conifers, has also been considered an indicator of upland vegetation (Chaloner, 1968). At Stephanian, the Zhongwei area became a coastal flat environment due to the widespread marine transgression (Tong *et al.*, 1994). The regional flooding reduced the areas available to the wetland (swamp) plant communities, meanwhile the cordaites and conifers represented by *Florinites* covered a land surface external to the coal swamp area. They survived continuously and gradually colonized in the coal swamp vegetation and became the subdominant population. In addition, the increase of saccate pollen reveals that the climate of the studied area began to change to slightly warm and dry.

Smith (1962) initiated the study of Carboniferous miospores and their associated sediments. He introduced the concept of Miospore Phase, which had been proved to be an effective means for palaeoecological study. Following the scheme of Smith (1962), three following miospore phases have been recognized with their palaecoecological considerations.

1. *Lycospora - Crassispora* phase — The selected miospores are represented by *Lycospora, Crassispora, Densoisporites, Simozonotriletes* and *Stenozonotriletes.* They occur in the Jingyuan and Hongtuwa formations. This miospore phase is regarded as of Namurian (Goniatite E-G_1 Zone) in age, which stands for the coastal swamp environment as well as warm and humid climate.

2. *Laevigatos porties - Torispora* phase — The major miospores in this phase are *Laevigatosporites, Punctatisporites, Cyclograni-sporites, Triquitrites, Torispora* and *Thymospora.* They are mainly distributed in the mioflora of Yanghugou Formation. This phase is considered as of Westphalian age, which indicates a marine and nonmarine alternating coal-bearing environment and warm-humid climate.

3. *Florinites-Pityosporites* phase — The marked miospore genera are *Florinites, Pityosporites, Vesicaspora, Illinites* and *Limitis-porites.* They are distributed in the lower member of the Taiyuan Formation, which is recognized as of Stephanian age. This phase demonstrates the tidal flat environment and upland vegetation. The palaeoclimate was warm and humid earlier, but gradually became drier at the end of Stephanian.

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