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FEATURES OF NAMURIAN FLORA IN CHINA

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Abstract: The Namurian flora has been studied in great detail, with abundant fossils well preserved in such places as Belgium, Upper and Lower Silesia Basin, etc. In China, this flora was well developed in Gansu and Qinghai, with a few plants also discovered from Zhejiang and Jiangxi. The present paper gives a brief account of the principal materials of the Namurian flora studied in China over the past 30 years, with a summary of the main characteristics of the early and late Namurian floras. These characteristics have provided important evidence for delimitation of the paralic mid-Carboniferous boundary in China and also for broad correlations with the coeval floras of the Euramerica Province, and thus offers significant information for the early evolution of the Cathaysian flora.

Keywords: China, Namurian flora, features.

INTRODUCTION

The Namurian Stage is an intermediate stage of the Carboniferous, with its type locality at Namur, Belgium. In Belgium, this stage is placed in the lower part of Upper Carboniferous, and has been divided into two parts. The lower part, called Assisee de Chokler, yields the ammonoids Eumorphoceras (Zone E) and Homoceras (Zone H), together with brachiopods, representing Namurian A, while the upper part, called Assisee d’Andenne, yields the ammonoids Reticuloceras (Zone R) and Gastroceras (Zone G), together with fossil plants, representing Namurian B-C (Stockmans and Williere, 1952-53, 1955). In the past, there was no unanimous opinion on the chronology of the Namurian among scholars in different parts of the world; some attributed it to the uppermost part of the Lower Carboniferous, while others placed Namurian A and Namurian B-C in Lower and Upper Carboniferous respectively.

In 1983, a concrete proposal was made at the 10th International Congress of Carboniferous Stratigraphy and Geology. Since then, there has been an international tendency towards gradual unity in the opinion among different scholars. This means the twofold division of the Carboniferous, with the lower-upper series boundary selected between the Namurian strata; the early Namurian takes the ammonoid Eumorphoceras (Zone E) as its index fossil, while the late Namurian is represented by Homoceras (Zone H), Reticuloceras (Zone R) and part of Gastroceras (Zone G). Providing that no fossils of the Homoceras Zone have been found in the strata, then some other fossils may be taken as evidence marking the beginning of Upper Carboniferous deposits, such as the first appearance of the conodont Declinognathodus noduliferus noduliferus (Ellison and Graves), or the first appearance of the foraminifers Globivalvulina moderata, Millerella pressa and M. marblensis.
Since the 11th International Congress of Carboniferous Stratigraphy and Geology held in Beijing in 1987, the mid-Carboniferous boundary of the marine or paralic strata in China has been delimited basically following the international proposal.

In China, the representative strata bearing the Namurian fossil plants may be divided into the early Namurian Tsingsuyuan Formation attributed to the upper part of the Lower Carboniferous, and the late Namurian Hongtuwa Formation attributed to the Lower part of the Upper Carboniferous, both also being different from each other in floral features (see Fig. I).

CHARACTERISTICS AND ASSEMBLAGE FEATURES OF EARLY NAMURIAN FLORA

In Southern China, the early Namurian strata bearing fossil plants may be found in several places, including the upper member of the Yehechiacean Group in western Zhejiang, the upper member of the Tzushan Group in Jiangxi, and the upper part of the Yangshan Formation in Gushi of Henan of North China together with the basal part of the Penchi Formation close to Benxi of eastern Liaoning; possible early Namurian flora also has been found from the Carboniferous Aqike section in Lop County, Xinjiang (Yao Zhaoqi, 1991). However, the Tsingyuan Formation flora of the section at the eastern trench of Yushulian, Ciyao in Jingyuan, Gansu (Li Xingxue et al., 1993), has been studied in detail and supported by evidence of numerous fossil invertebrates with a reliable geological age.

At the Aqike section in Lop County, Xinjiang, although there exist only rare taxa such as Mesocalamites cistiformis, Calamostachys cf. haosensis Leggewic et Schonefeld, Cardiopteridium spetsbergense, Allotopterus cf. angustissima Sternberg, Neuropteris (=Paripteris) cardiophoides and N. gigantea, they not only provide us with the approximate geological age of the strata, but also enable us to have a better knowledge of the late Early Carboniferous, on the Tarim Landmass there spread plants similar to those in the North Qilian Mt., known particularly as Neuropteris (Paripteris) cardiophoides.

The flora of Namurian Zone E at Ciyao in Jingyuan, Gansu is so numerous in taxa and abundant in specimens that it is the most flourishing and developed flora in this Zone so far known throughout the world. The Tsingyuan Formation yields a total of 40 genera and 90 species (Li Xingxue et al., 1993, pp. 31-33), including 6 genera and 11 species of lycopsids, 5 genera and 11 species of sphenophytes, and 25 genera and 64 species of ferns and pteridosperms, all accounting for 71.2% of the taxa of the entire flora, together with a small amount of Noeggerathiales (2 genera and 2 species) and cordaitans (2 genera and 2 species). In lycophytes are included Eleutherophyllum waldenburgense and E. drapanophyliciforme Remy and Remy. In addition to Eleutherophyllum mirabile (Li Xingxue et al., 1989) derived from the Sancha Formation of the Longshou Mt. in Shandan of Gansu. As an important key fossil in the goniatitid Eumorphoceras Zone of Namurian A in West Europe, Eleutherophyllum waldenburgense has so far been found in China only at Dashiugou, Ciyao in Jingyuan; its discovery is undoubtedly of great importance to the age-dating of the flora. The occurrence of Lepidodendron aolingpuhkense generally existing in the Namurian strata of Northwest China is of equal importance, while the appearance of Bothrodendron ruchengense in Northwest China, which was prosperous in the Visean of South China, has provided practical data for discussion of synchronous floral relationship between South and Northwest China. In the current material of lycophytes, none of Sigillaria has ever been found, which was flourishing in the Namurian Stage of Euramerica. In sphenophytes, Mesocalamites and Sphenophyllum characterized by fine and forked leaflets are more in number while Sphenophyllum jingyuanense Li et al. with 6 leaves almost equal in size strongly resembles Sphenophyllum lungtaense (Gothan and H.C. Sze, 1933) of the Wutung Formation, providing valuable material for the study on both ecology.
Fig. 1 Important localities of the Namurian flora in China

- 1. Lop, Xinjiang  15. Wuwei, Gansu  17. Zhangye, Gansu
- 2. Shanghai, Fujian  16. Helanshan
- 5. Kaihua, Zhejiang
- 6. Tiandou, Zhejiang
- 7. Gusxi, Henan
- 8. Benxi, Liaoning
- 9. Fuzhou, Liaoning
- 10. Pengxi, Shaanxi
- 11. Dashetai, Nei Mongol
- 12. Zhongwei, Ningxia
and evolution of sphenophytes. There are more genera and species in ferns and pteridosperms, including not only Cardiopteridium and Triphyllopteris bearing primitive radiating veins, but also Neopteris, Paripetis, Linopteris, Neuraleiopteris and Cyclopteris with simple pinnate venation and simple reticulate veins. It is worth while to mention that the genus Linopteris with reticulate venation had already been well developed in Zone E1 and differentiated rapidly into as many as 9 species in Zone E2. Linopteris with numerous specimens which increased so fast in number and differentiated so markedly in species population that it may be regarded as representing a major distinguishing feature of the early Namurian flora in the Northwest China. This is unprecedented in other parts of the world, whereas the paripetid male reproductive organ Potoniea often occurs at the same horizon with Linopteris, implying its possible connection with the latter, a genus which did not make its appearance until Westphalian in Euramerica. Between the strata in which the above-mentioned flora is located, the associated fossil invertebrates include the goniatitids Eumorphoceras bisulcatum Girty, Cravenoceras arcticum Librovitch of Subzone E2, and the conodonts represented by Gnathodus bilineatus hollandensis (Higgins et Bouckaert). The Tsingyuan Formation conformably overlies the Visean Choumiukou Formation and is overlain by the Hongtuwa Formation which is marked by the appearance of the conodont Declinognathodus noduliferus noduliferus (Ellison et Graves) in place of the Homoceras Zone. Among the plants in the Tsingyuan Formation, Eleutherophyllum waldenburgense and Sphenophyllum tenerrimum are stratigraphically significant, also known as index elements for the Namurian Stage. Moreover, the repeated appearance of Linopteris in this formation is another distinguishing feature of the flora in this stage.

In South China, the upper part of the Tzushan Group, and the Yehchiangtang Group are known to yield Paripetis gigantea, Karinopteris acuta cf. obtusa, Sigillaria brardii, Linopteris sp., etc. These plants were mostly flourishing in the Westphalian in West Europe but with a much lower content as compared with those derived from the Tsingyuan Formation. In consideration of the regional geological structure and the age characterized by those associated fossil invertebrates, the upper part of the Tzushan Group and the Yehchiangtang Group may not be later than the early Namurian in age. Since the Datang Stage is typically of marine origin and covers the deposits of Visean to early Namurian, while the Tzushan and Yehchiangtang Groups have traditionally been considered to be its equivalent, thus the presence of Paripetis gigantea in both groups implies that it had come into existence in the middle-late Visean in South China.

With representative elements derived from the upper part of the Tzushan Group in Jiangxi, the late Early Carboniferous plants in South China are called the Paripetis gigantea-Karinopteris acuta cf. obtusa Assemblage.

CHARACTERISTICS AND ASSEMBLAGE FEATURES OF LATE NAMURIAN FLORA

The early Late Carboniferous flora in China is equivalent to the flora of Namurian B-C or the flora in the goniatitid Zone H-G1 of West Europe, with a majority of taxa in content being descendants from the early Namurian plants. The principal localities and horizons of this flora are recognized as follows.

1. Keluke Group in Aolungpuluke on Northern Margin of Qaidam Basin in Qinghai

The lower horizon of the Keluke Group yields fossil plants (H.C. Sze, 1960; He Yuan-liang et al., 1979) which have been identified as Rhodeopteridium chinghaiense, R. parasparsa (=R. sparsa), Pecopteris aspera, P. plumosa, Bothrodendron circulare, B. reticulatum, Lepidodendron

4. Lower Shetai Formation in Dashetai Region of Nei Mongol on Northern Margin of North China Platform

A total of 9 genera and 17 species of fossil plants have been discovered (Huang Benhong, 1987), mostly bearing a strong resemblance to those of the Hongtuwa Formation. These taxa, though less in number, are characterized by the presence, for the first time, of Alethopteris bearing subsidiary veins and Reticalethopteris with both subsidiary and reticulate veins.

According to Mi Jiarong et al. (1990), the flora from the basal part of the Penchi Formation on the eastern border of North China belongs to the late Namurian in part.

In the early Late Carboniferous flora in the different localities mentioned above, ferns and pteridosperms occupy a predominant position; especially, in the Caoliangyi Formation the flora is composed almost entirely of pteridophytes and pteridosperms, with a total of about 11 genera and 23 species, including 3 genera and 9 species of lepidophytes and 3 genera and 4 species of sphenophytes. Among them, quite a number are the successors of the early Namurian plants; especially, Paripteris and Rhodeopteridium kept on flourishing, both accounting for about 40% of the total flora. However, in the early Namurian, some relic elements were left over from the Viséan, such as Cardipteridium speickbergense, C. podozioides, Triphylopteris collombiana as well as the early Namurian index element Eleutherophyllum waldenburgense. By the late Namurian, these plants basically disappeared and were replaced by some of the Westphalian floral elements or those flourishing only
in the later stages, such as *Lepidodendron ninghsiaense*, *Lep. aolungpylukense*, *Eusphenopteris parabaemleri*, *Alethopteris* sp., *Tingia trilobata* and *Tingiostrachya* sp., among which *Eusphenopteris parabaemleri* and *Lepidodendron aolungpylukense*, although with a doubtful record in the Westphalian Penchi Formation, were best developed in the late Namurian. Therefore, these two species may by taken as the representative elements of this assemblage, with the Hongtuwa Formation in Gansu and Ningxia as their representative rock series.

**MAIN FEATURES OF NAMURIAN FLORA IN CHINA**

The Namurian strata in the Euramerica Province are widely distributed, with relevant fossil plants having been studied in an earlier time, ranging from those in Wales and England (Kidston, 1923-1925; Crookall, 1955-1976, etc.), the basins in North France (Hirmer, 1940; Gothan, 1952a, 1954, etc.), north Spain (Wangner, 1962); the Südburg Basin in Holland (Jongmans, 1928, 1955-1956); the Rhein-Westphalia and Aachen areas in Germany (Hirmer, 1940; Joston, 1983), the Upper and Lower Silesia Basin bordering on Poland, Czech and Slovakia (Stopia, 1957; Havlena, 1961; Purkynova, 1970), the location of stratotype in Belgium (Stockmans and Williere, 1952-1953), eastward to Bulgaria (Hartung and Patteisky, 1960; Nemejc, 1942), Turkey (Jongmans, 1955-1956) and the Dnieper River-Donets Basin and the Donbass area in Ukraine (Novik, 1952, 1954). In North America and Canada, despite of a break existing between the Lower and Upper Carboniferous Series, the Hale Member of the Merrow Formation and the Chester Formation still yield some fossil plants which are roughly equivalent to the 3rd *Fryopsis* (similar to *Cardiopteridium* in morphotype) flora zone proposed by Reed and Marnay (1964) to the 4th floral zone, i.e., the *Neuropteris* pocahontes-Mariopteris (=Kariopteris) eremopteroides Zone, with their main localities situated along the mountains. Appalachian and in the central part of the U.S.A. The Namurian plants, rather rare in taxa in Canada, have been studied by Bell (1938, 1944), Zodrow, E.L. and McCanolish, K., (1980) and others, with their main locality in the northern part of Nova Scotia along the east coast.

In Euramerica, the early Namurian (Stage A, corresponding to Zones E and H) flora was in the same situation as in China, carrying a certain amount of ancient Early Carboniferous Visean plants, such as *Archaeocalamites*, *Lepidodendron volkmanianum*, *Rhodeopteridium*, *Anisopteris*, *Fryopsis*, *Sphenophyllum tenerrimum* and *Cardiopetidium*, with the disappearances of *Sublepidodendron*, *Lepidodendropsis* and *Aneimites*. During early Namurian, there occurred *Diplomema adiantoides*, *Eleutherophyllum waldenburgense*, *E. mirabile*, etc.; by the late Namurian, there appeared large amounts of *Sigillaria*, *Calamites*, *Alethopteris* and *Lyginopteris* together with more *Neuropteris* and *Mariopteris*, *Sphenopteris*. The diagnostic elements of the Namurian are *Mesocalamites* and *Diplomema*.

As compared with that in Euramerica, the Namurian flora in China shows the following features:

(1) In Early Namurian, the fossil plants in the upper and lower strata of the goniatitid *Eumorphoceras* Zone (i.e. Zones E₁ and E₂) were in full bloom, and the flora at the boundary between Visean and Namurian seemed to have been in a state of "Florensprung". In Europe, the plants in Zone E₂ went on developing in Upper Silesia, while the flora of the entire Zone E was underdeveloped with less genera and species in other localities. According to Gothan (1952b), the "Florensprung" in Europe happened at the boundary between Namurian A and B.

(2) Judging from the statistics of total taxa in the entire flora, except those at generic level (about 80%) sharing the similarites, those endemics at the specific level are rather numerous and common
in both regions, accounting for about 20% of the total plants, reflecting a inconsistent climate in both regions during that time.

(3) Among the ferns and pteridosperms, paripterids made their appearance in great abundance, but they had occurred earlier in China. *Paripetris gigantea* did not emerge until Namurian B in Euramerica, whereas it had really come into existence in the middle and late Visian and was in full bloom in Namurian. The genus *Linopteris* did not appear in Euramerica until the Westphalian with the only exception *Neuropterus reticulopteroides* Purkynova (Hartung and Patcisky, 1960) (=*Linopteris reticulopteroides* comb. Li et al., 1993) with characteristic reticulate veins which was found in the middle part of Zone E₁ in Upper Silesia; and so was the paripterids male reproductive organ *Potoniea* in the middle Visan in southern and northwestern China.

(4) In the imparipinnate neuropterids, *Neuropterus* and *Alethopteris* are a very few. In the Euramerican Namurian flora, neuropterid imparipinnatae and *Alethopteris* as well as other genera are numerous in quantity and play a vital role, especially *Alethopteris* which is flourishing, whereas in China, only individual elements are known to occur in the late Namurian, Lower Shetai Formation, in Dashetai region in Nei Mongol; it is difficult to ascertain whether they belong to the late Namurian or, instead, they are likely of early Westphalian in age. The genus *Alethopteris* has not been found in the Namurian strata in other regions of China, whereas its sister genus *Neuralthopteris* came into existence in abundance in the Namurian strata of West Europe, ranging from Namurian to Westphalian A, but rarely extending to Westphalian B, known as an index element. However, in China, none of the specimens with a real *Neuralthopteris* origin has ever been found, except the tentatively identified early Namurian *Neuralthopteris aff. schlehanii* occurring in Ciya of Jingyuan.

(5) During Namurian, not only ferns and pteridosperms but also lycophytes were abundant, particularly *Lepidodendron* and *Bothrodendron*, whereas in Europe besides *Lepidodendron*, the genus *Sigilaria* was also well developed, attaining as many as five species, together with *Lepidophloios*, etc.; thus in vegetation of Europe and China, the lycophytes are different in content.

(6) In sphenophytes, besides the common element *Sphenophyllum tenerrimum*, the species *Sphenophyllum jingyuanense* Li et al. is typified by six leaves equal in form and size, *Annularia* is absence and *Mesocalamites* is poorly known.

(7) A number of Cathaysian elements are represented by *Tingia, Cathaysiodendron*, etc., indicating the existence of certain elements of the early Cathaysian flora.

After studying for more than 20 years the Namurian floras of southern and northwestern China and their correlations with the synchronous floras of Europe, the authors have found that the floras of both areas share both identical and different aspects. Li Xingxue et al. (1993) suggested that these Chinese floras from this period be called the Procathaysian flora.

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EXPLANATION OF PLATES
All figures are unretouched and in natural size unless otherwise stated.

Plate 1
1. Lepidodendron quadratum Zhao et Wu

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Horizon: Upper part of Tzushan Group; Locality: Yudu, Jiangxi Province (after Zhao Xiuhu and Wu Xiuyuan, 1982).

2; 3. Lepidodendron cf. gushiense Wu


4. Lopinopteris intercalata Sze

Fragment of a penultimate pinna (or frond?), arrow showing the very regularly presented intercalated pinnules filling the basal gaps between two adjacent pinnules. Horizon: Upper part of Tzushan Group. Locality: Leping, Jiangxi Province. (after Sze, H.C., 1958).

5,6. Karinopteris acuta Bronn. forma obtusa Gothan

Upper part of Penultimate Pinna; Pinnules of lower ultimate Pinnae slightly lobed, upper almost entire, decurrent. fig. 6, part of the same pinna in fig. 5 x3 showing very fine striations almost parallel to the veins. Horizon: Upper part of Tzushan Group. Locality: Funchen, Jiangxi Province. (after Li Xingxue (Lee Hsing-Hsiueh), 1964).

7. Paripeteris gigantea (Stemberg) Gothan


8. Linopteris densissima Gu et Zhi

Horizon: Tsingyuan Formation; Locality: Jingyuan, Gansu Province. (after Li Xingxue et al., 1993).

9. Sphenophyllum jiangyuanense Li et al.

Horizon: Tsingyuan Formation, Locality: Jingyuan, Gansu Province. (after Li Xingxue et al., 1993).

Plate 2

(All specimens collected from Tsingyuan Formation and the localities are in Jingyuan, Gansu Province, after Li Xingxue et al., 1993)

1. Lepidodendron cf. wortheni Lesquereux

2. Eleutherophyllum waldenburgense (Stur) Zim.

3. Eleutherophyllum drepanophyciforme Remy et Remy

4. Asterophyllites tenuifolius (Stemb.) Stockm. et Will.

5. Sphenophyllum tenerrimum Ett.

6. Pecopteris aspera Brongniart

7. Alloopteris femineaformis Li et al.

8. Linopteris neuropteroides (Gutb.) Potonie, × 3.


10. Linopteris intricata Gu et Zhi

11. Linopteris lepida Gu et Zhi, × 3.

12. Linopteris sp., × 3.
Plate 3

1.2. *Lepidodendron ninghsiaense* Sze et Lee

2. × 3. Horizon: Hongtuwa Formation; Locality: Helanshan, Nei Mongol. (after Wu Xiuyuan and Zhao Xiuhu, 1987).

3.4. *Lepidodendron aolangyulukense* Sze


5.6. *Boothrodendron circulare* Sze

6. × 5. Horizon: Lower part of Keluke Group, Locality: Delingha, Qinghai Province. (after Sze, H.C., 1960).

7. *Boothrodendron reticulatum* Sze


Horizon: Lower part of Keluke Group, Locality: Delingha, Qinghai Province. (after Sze, H.C., 1960).

Plate 4

1,2,3.4. *Cathaysiodendron* sp.

Fig.2. Portion of the fig.1, enlarged three times to show the leaf scars relatively large, of almost the same shape and size as the cushions with three cicatricules situated in the upper of the scar. Horizon: Upper part of the Yangshan Formation, Locality: Gushi, Henan Province. (after Wu Xiuyuan, 1992).

Fig.4. portion of the fig.3, enlarged three times to show the leaf scars of almost the same shape and size as the cushions, more or less a zigzag appearance. Horizon: Hongtuwa Formation; Locality: Helanshan, Nei Mongol. (after Wu Xiuyuan and Zhao Xiuhu, 1987).


Fig.6. part of the fig.5. × 3. Showing the deeply lobed apex of the leaves and whether they are attached to a rachis by a semi-amplexicaul base. Horizon: Hongtuwa Formation; Locality: Jingtai, Gansu Province.

7. *Sphenopteris parabaeumleri* Sze


8.9. *Linopteris neuropteroides* (Gutb.) Potonie

Fig.8, × 3. Horizon: Hongtuwa Formation; Locality: Zhongwei, Ningxia.

Fig.9, Horizon: Hongtuwa Formation Locality: Helanshan, Ningxia. (after Wu Xiuyuan and Zhao Xiuhu, 1987).

10. *Paripteris* sp.

× 3, Horizon: Hongtuwa Formation; Locality: Zhongwei, Ningxia. (after Wu Xiuyuan and Zhao Xiuhu, 1987).

11. *Paripteris gigantea* (Stemberg) Gothan


12, 13. *Paripteris pseudogigantea* (Potonie) Gothan

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Horizon: Caoliangyi Formation; Locality: Fengxian, Shaanxi Province. (after Wu Xiuyuan and Deng Bao, 1983).

14. *Paripiteris otozamioides* (Sze et Lee)

Showing the Finnule is lanceolate-falcate, the base of the pinnule is strongly auriculate and asymmetrical; the veins are very fine and dense. Horizon: Hongtuwa Formation; Locality: Helanshan, Nei Mongol. (after Wu Xiuyuan and Zhao Xiuhu, 1987).

15. *Linopteris* cf. *neuropteroides* (Guth.) Potonie

The lateral veins are very fine and dense, they are fully anastomosed forming a network of elongate vein meshes. Horizon: Hongtuwa Formation; Locality: Helanshan, Ningxia. (after Wu Xiuyuan and Zhao Xiuhu, 1987).