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# The Early Jurassic flora and palaeoclimate in northeastern Sichuan, China

Huang Qisheng, Lu Zongsheng & Lu Shengmei

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The present paper deals with the composition, features and the geological age of the flora from the Zhenzhuchong Formation, northeast of Sichuan Province. The plant fossils recovered include 95 species of 57 genera. This flora may be classified as *Ptilophyllum-Contopteris* assemblage of the *Dictyophyllum-Clathropteris* Series equivalent to the Pliensbachian-Aselian Stage. In this sense, the flora may be compared with that of the *Thaumatopteris* zone in Greenland and Sweden. The Jurassic palaeoclimate in the Sichuan Basin is studied on the evidence of sedimentary environment and coal-formation. It is concluded that an increase in humidity and decrease in temperature were favourable to the formation of coal.

**Key-words**—Plant megafossils, Pteridophytes, Palaeoclimate, Sichuan Basin, Early Jurassic (China).

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## सारांश

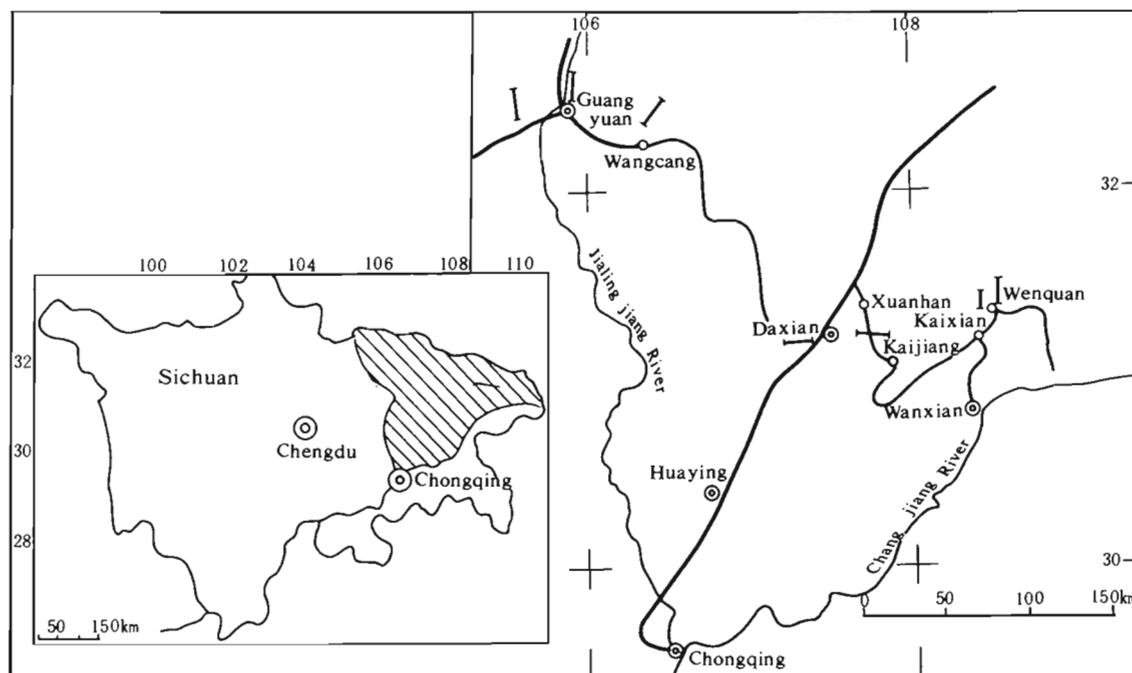
प्रारम्भिक जुरेसिक वनस्पतिजात एवं चीन में उत्तरपूर्वी सिचुआन में पुराजलवायु

हवांग क्विशेंग, लु जोंगशेंग एवं लु शेंगमी

प्रस्तुत शोध-पत्र में उत्तरपूर्व सिचुआन प्रान्त में झेनझुचांग शैल-समूह से प्राप्त वनस्पतिजात की संरचना, लक्षण एवं भूवैज्ञानिक आयु पर विवेचना की गई है। प्राप्त पादपाश्र्मों में 57 प्रजातियाँ एवं 95 जातियाँ विद्यमान हैं। यह वनस्पतिजात प्लायनसबेकियन एसेलियन चरण के समतुल्य *डिक्टियोफिल्लम-क्लेथ्रोप्टेरिस* श्रेणी के *टाइलोफिल्लम कोनियोप्टेरिस* समुच्चय के अन्तर्गत रखा जा सकता है। इसी कारण इस वनस्पतिजात की ग्रीनलैंड और स्वीडन के *थोमेटॉप्टेरिस* समुच्चय से तुलना की जा सकती है। अवसादीय पर्यावरण एवं कोयला-निर्माण के आधार पर सिचुआन द्रोणी में जुरेसिक पुराजलवायु का अध्ययन किया गया है। इस अध्ययन से यह निष्कर्ष निकाला गया है कि कोयले के निर्माण में आर्द्रता में वृद्धि और तापक्रम में कमी ने महत्वपूर्ण भूमिका निभायी है।

THE material which forms the basis of the paper was collected in 1985 to 1990 from Guanyuan, Wangcang, Daxian, Xuanhan, and Kaixian regions (Text-figure 1). The Mesozoic strata in the north of the Sichuan Province were classified in ascending order as: the Early Triassic Feixianguan Formation (or Daye Formation) and Jialingjiang Formation, Middle Triassic Leikoupo Formation (or Badong Formation), Late Triassic Xujiahe Formation (which could be divided into seven members with Members 1, 3, 5, and 7 containing coals), the Early Jurassic Zhenzhuchong

Formation (or Baitianba Formation), Middle Jurassic Ziliujing Formation (including Dongyuemiao limestones, Maanshan shales, Daanzhai limestones), Xintiangou Formation, Shaximiao Formation, Late Jurassic Suining Formation, Penglaizhen Formation and the Early Cretaceous Jianmenguan Formation. The coal-bearing strata in Xujiahe and the Zhenzhuchong formations contain abundant plant fossils. The detailed study on the Xujiahe flora were published in 1992 by the same authors (Huang & Lu,



**Text-figure 1**— Geographic location of Early Jurassic sections in NE Sichuan, China. Shadow—Research Area, I - Cross sections measured.

1992). In this paper, the Early Jurassic Zhenzhuchong flora has been dealt with.

### SUCCESSION OF ZHENZHUCHONG FORMATION, WENQUAN, KAIXIAN COUNTY AND THEIR SEDIMENTARY CHARACTERS

#### Succession of strata

The Zhenzhuchong Formation can be classified into 24 beds of 4 members, totalling 336.10 m in thickness (Text-figure 2). A parallel unconformity occurred between the Zhenzhuchong Formation and its underlying Xujiahe Formation, while a conformity contact was present between the Zhenzhuchong Formation and its overlying Dongyuemiao Member, Ziliujing Formation. In descending order following four members are shown below.

**Member 4 (beds 24-16) 136.98 m**—The top part of the member consists of brown yellow thin layered sandstones, siltstones, and occasional conglomerates containing small sized current ripple laminations. In the middle and upper parts of the member the cyclothem consisting largely of grey yellow medium bedded fine sandstones, siltstones, mudstones and occasionally coals are present. In the sandstones

wedge-like and lenticular beddings are present; in the siltstones often horizontal laminations and abundant fossils occur. The lower part of the member consists largely of grey green medium bedded fine sandstones and siltstones. In the fine sandstones the large-sized cross beddings and stem fossils are present. While plant megafossils such as *Equisetites* sp., *Neocalamites* sp., *N. nathorstii*, *Todites williamsonii*, *T. princeps*, *Cladophlebis asiatica*, *Marattiopsis* sp., *Plebopteris polypodioides*, *Coniopteris* sp., *C. tiehshanensis*, *Dictyophyllum* sp., *D. nathorstii*, *Clathropteris meniscioides*, *C. platyphylla*, *Pterophyllum* sp., *Ptilophyllum hsingshanense*, *Nilssonia pterophylloides*, *N. parabrevis*, *N. cf. orientalis*, *Baiera guilhaumatii*, *Sphenobaiera huangii*, *Vitifoliolum segregatum*, *Pityophyllum* sp., *Podozamites lanceolatus*, *Stenorachis* sp., *Stachyotaxus* sp., *Swedenborgia* sp., *Storgardia cf. spectabilis*, *Carpolithus* sp., and small-sized bivalves *Pseudocardinia* sp. are found in siltstones.

**Member 3 (beds 15-12) 55.78 m**—The upper part of the member consists of grey green thin layered siltstones, and mudstones with coal streaks. The middle part of the member consists of grey green thin layered siltstones and mudstones. In the siltstones

with wavy horizontal lamination and abundant fossils are found. These are *Equisetites* sp., *Neocalamites* sp., *Todites princeps*, *Coniopteris tiehshanensis*, *Dicthyophyllum* sp., *Ptilophyllum contiguum*, *P. pecten*, *Otozamites mixomorphus*, *Baiera gracilis*, *Podozamites lanceolatus* and bivalves *Pseudocardinia* sp. The lower part of the member consists of grey green medium bedded fine sandstones containing stem fossils, large-sized cross beddings, and parallel beddings.

**Member 2 (beds 11-4) 85.80 m**—The upper part of the member consists of grey yellow mega-thick arkose quartz fine sandstones with mudstones and coal seams, which were distributed in a distinctively rhythmic pattern. In the fine sandstones the plant fossils are found. In the middle part of the member alternate layers of grey yellow, grey green medium bedded fine sandstones and siltstones, mudstones, and thin-layered coal seams are present. Beneath the coal seams multi-layered coal seat with a large number of ginkgopsids and a few bivalves are present. The lower part of the member consists of grey yellow thick layered sandstones containing gravels, argillaceous gravels, and stems. In the sandstones the large sized wedge cross beddings, trough cross beddings, and parallel beddings are found. Beneath the sandstones the fluvial filling structures are present. In the fine sandstones *Equisetites* sp., *Neocalamites* sp., *Todites denticulata*, *T. williamsonii*, *Cladophlebis raciborskii*, *C. asiatica*, *C. cf. integra*, *Coniopteris tiehshanensis*, *Nilssonia* sp., *N. cf. compta*, *Pseudocatenis* sp., *Weltrichia* sp., *Ginkgoites cf. marginatus*, *G. sp.*, *Baiera multipartita*, *B. gracilis*, *Sphenobaiera spectabilis*, *S. huangii*, *Ginkgodium* sp., *Vittifolium segregatum*, *Czekanowskia hartzii*, *Podozamites* sp., and bivalves *Pseudocardinia* sp. are found.

**Member 1 (beds 3-1) 57.5 m**—This member consists of grey yellow, grey green medium and thick bedded arkose quartzose sandstones with multi-layered gravels. Beneath the sandstones the fluvial filling structures are present. The siltstones in the upper part of the member contain a layer of such plant fossils as *Equisetites koreanicus*, *Todites williamsonii* and *Podozamites* sp. The mudstones in the top part of the member contained *Pseudocardinia* sp.

### Sedimentary characters

Various types of depositional facies are present in the Zhenzhuchong Formation. The fluvial depositional system occurs in the upper and lower parts of the formation, while the lake and deltaic depositional system occurs in the middle part of the formation. Member I largely consists of a suite of conglomerates. The mudstones and siltstones occur within the sandstones in the form of unstable lenticules. The deposits become generally thinner upward, reflecting the braided stream depositional features in the upstream of the river. Member II can be classified as two depositional sequences which become generally thinner and thinner upward. Each sequence is divided into two parts: the lower part of the sequence contains large-sized trough cross bedded grit stones beneath which the wash plane occurs, while the upper part of the sequence consists of alternate thin layers of sandstones and mudstones within which thin coal seams on the seat clay occurs. The plant fossils include largely ginkgopsids. These kinds of depositional structure reflect the meandering current deposition. Member III consists of lacustrine and deltaic depositional systems. The middle part is rela-

### PLATE 1

All the photographs are taken by Mr Deng Dongxing, and are in natural size except those otherwise stated. All the original specimens are preserved in the Palaeontology Research and Teaching Section, China University of Geosciences (Wuhan).

The *Sphenobaiera spectabilis* - *Baiera multipartita* Assemblage in the lower part of Zhenzhuchong Formation.

- Pseudocatenis* sp. Horizon: Bed 6 in the lower part of the Zhenzhuchong Formation. Locality: Wenquan, Kaixian County Specimen no. CH9501.
- Podozamites schenkii* Heer, Horizon: Lower part of the Zhenzhuchong Formation, Locality: Qilixia, Xuanhan County, Specimen no. CH9502.
- Sirobilites* sp., Horizon: Lower part of the Zhenzhuchong Formation, Locality: Qilixia, Xuanhan County, Specimen no. CH9503.
- Scoresbya szeiana* Li, Horizon: Lower part of the Zhenzhuchong Formation, Locality: Tieshan, Daxian County, Specimen nos
- CH9504, CH9505.
- Czekanowskia hartzii* Harris, Horizon: Lower part of the Zhenzhuchong Formation, Specimen no. CH9506.
- Baiera multipartita* Sze et Lee, Horizon: Bed 6 in the lower part of the Zhenzhuchong Formation, Locality: Wenquan, Kaixian county, Specimen no. CH9507.
- Sphenobaiera spectabilis* (Nath.) Florin, Horizon: Bed 10 in the lower part of the Zhenzhuchong Formation, Locality: Wenquan, Kaixian County, Specimen no. CH9508.

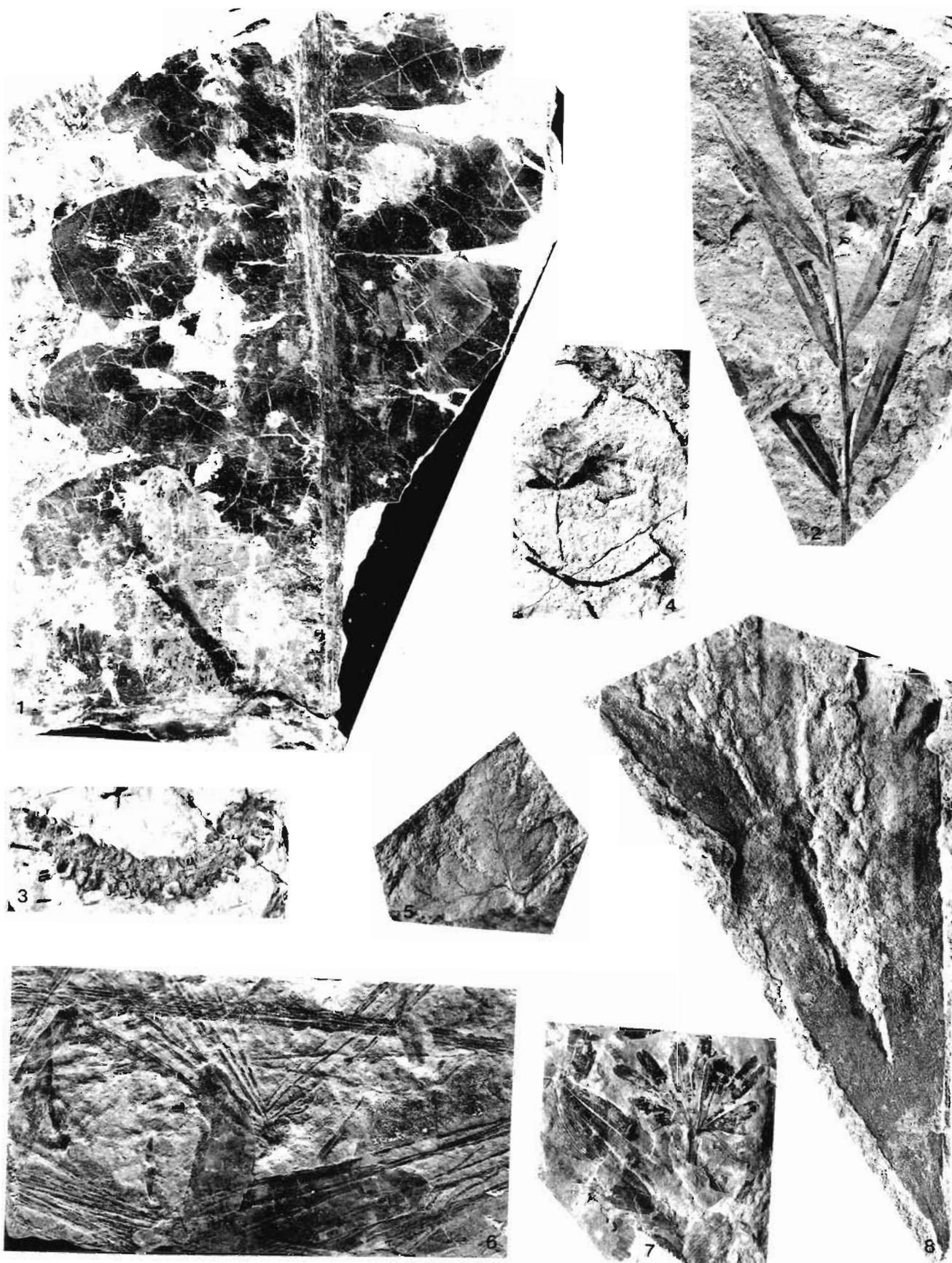


PLATE 1

tively thick while the horizontal distribution remains stable. This middle part also contains fine-grained black mudstones with bivalve fossils. All these evidences signify the presence of a wide spread lake basin. The lower part of Member IV is characterized by the depositional sequence which turns thinner upward, reflecting a deltaic deposition. The upper part of the member consists of a suite of gravel sandstones and the wash plane, indicating the rejuvenescence of stream in the Late Zhenzhuchong depositional period.

## THE FLORA OF ZHENZHUCHONG FORMATION

### Composition

Lycopsida : *Grammaephloios ichtya* Harris

Equisetales : *Equisetites koreanicus* Kon'na, *E. beanii* (Bunbury) Seward, *E. sp.*, *Neocalamites cf. nathorstii* Erdtman, *N. carrerei* (Zeiller) Halle, *N. carcinoides* Harris, *N. sp.*, *Radicitis sp.*

Filices

Marattiales:

Marattiaceae: *Marattiopsis asiatica* Kawasaki, *Marattiopsis sp.*

Filicales :

Osmundaceae : *Todites princeps* (Presl) Gothan, *T. denticulata* (Brongniart) Krasser, *T. williamsonii* (Brongniart) Seward, *T. cf. bartzii* Harris.

Matoniaceae : *Phlebopteris polypodioides* Brongniart.

Dicksoniaceae : *Coniopteris sp.*, *C. tiehsanensis* Ye et Lih, *C. hymenophylloides* Brongniart, *C. bella* Harris, *C. cf. nerifolia* Genkina, *Eboracia lobifolia* (Phillips) Thomas.

Dipteridaceae : *Thaumatopteris sp.*, *Dictyophyllum sp.*, *D. nathorstii* Zeiller, *D. nilssonii* (Brongniart) Nathorst, *Clathropteris sp.*, *C. meniscioides* Brongniart, *C. platyphylla* (Goeppert) Brongniart, *C. obovata* Oishi, *Hausmannia crenata* (Nathorst) Moeller, *H. ussuriensis* Kryshtofovich, *Scoresbya sziana* Li.

Filices incertae sedis : *Cladophlebis sp.*, *C. raciborskii* Zeiller, *C. asiatica* Chow et Yeh, *C. cf. integra* (Oishi et Takahashi) Frenguelli, *Spiropteris sp.*, *Rhizomopteris sp.*

Pteridospermopsida : *Ctenozamites stomatigerus* Huang et Lu.

Cycadopsida :

Bennettitales : *Pterophyllum sp.*, *P. angustum* (Braun) Gothan, *Anomozamites inconstans* (Braun), *Otozamites hsiangchiensis* Sze, *O. mixomorphus* Ye, *Ptilophyllum contiguum* Sze, *P. hsingshanense* Wu, *P. pecten* (Phillips) Morris, *P. cf. sokalense* Doludenko, *Tyrmia nathorstii* (Schenk) Ye, *T. latior* Ye, *Waltrichia sp.*, *Cycadolepis corrugata* Zeiller, *C. rugosa* Johansson.

Nilssoniales : *Nilssonia sp.*, *N. pterophylloides* Nathorst, *N. complicatis* Li, *N. cf. compta* (Phillips), *N. cf. orientalis* Heer, *N. polymorpha* Schenk, *N. parabrevis* Huang.

Cycadales : *Ctenis sp.*, *Pseudoctenis sp.*

Ginkgopsida :

Ginkgoales : *Ginkgoites sp.*, *G. cf. marginatus* (Nathorst) Florin, *Baiera sp.*, *B. multipartita* Sze et Lee, *B. guilhaumatii* Zeiller, *B. gracilis* Bunbury, *B. furcata* (L. et H.) Braun, *Sphenobaiera sp.*, *S. spectabilis* (Nathorst) Florin, *S. huangii* (Sze) Hsü, *Ginkgodium sp.*, *Vittifolium segregatum* Zhou.

## PLATE 2

The *Ptilophyllum contiguum* - *Coniopteris* Assemblage in the upper part of the Zhenzhuchong Formation.

- 1, 2. *Cladophlebis asiatica* Chow et Ye, 1 from 2 x 3, showing the venation, Horizon: Bed 20 in the upper part of the Zhenzhuchong Formation, Locality: Tieshan, Daxian County, Specimen no. CH9509.
3. *Tyrmia nathorstii* (Schenk) Ye, Horizon: Upper part of the Zhenzhuchong Formation, Locality: Qilixia, Xuanhan County, Specimen no. CH9510.
4. *Coniopteris tienshanensis* Ye et Lih, Horizon: Bed 13 in the upper part of the Zhenzhuchong Formation, Locality: Wenquan, Kaixian County, Specimen no. CH9511.
5. *Todites princeps* (Presl.) Gothan, Horizon: Bed 16 in the upper part of the Zhenzhuchong Formation, Locality: Wenquan, Kaixian County, Specimen no. CH9512.
6. *Equisetites koreanicus* Kon'no, Horizon: Upper part of the Zhenzhuchong Formation, Locality: Tieshan, Daxian County, Specimen no. CH9513.
7. *Nilssonia pterophylloides* Nathorst, Horizon: Upper part of the Zhenzhuchong Formation, Locality: Tieshan, Daxian, Specimen no. CH9514.
8. *Nilssonia parabrevis* Huang, Horizon: Bed 16 in the upper part of the Zhenzhuchong Formation, Locality: Wenquan, Kaixian County, Specimen no. CH9515.
9. *Ptilophyllum pecten* Sze x 2, Horizon: Bed 16 in the upper part of the Zhenzhuchong Formation, Locality: Wenquan, Kaixian County, Specimen no. CH9516.
10. *Clathropteris platyphylla* (Goeppert) Brongniart, Horizon: Bed 19 in the upper part of the Zhenzhuchong Formation, Locality: Wenquan, Kaixian County, Specimen no. CH9617.

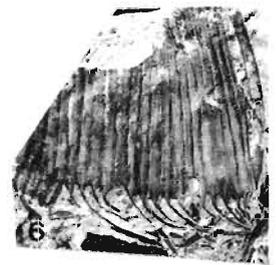
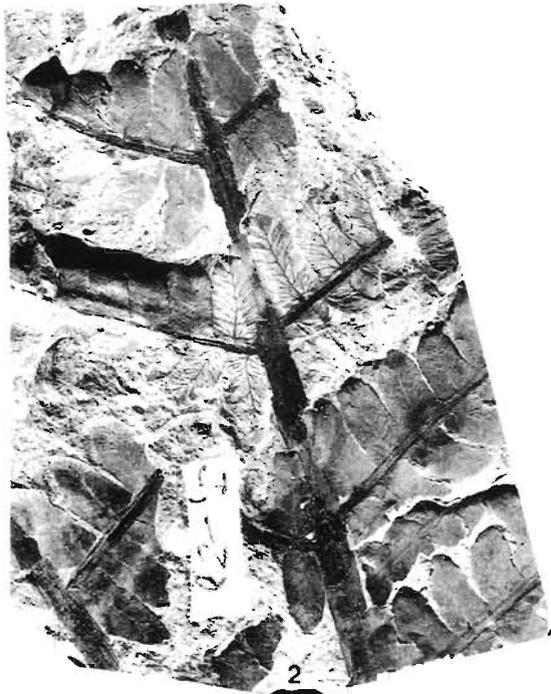
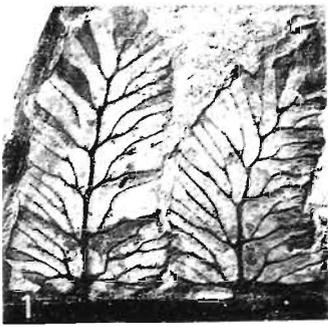


PLATE 2

**Table 1—The species numbers and percentage of the hygrophilous and xerophilous plants and the thermophilous and eurythermic plants in the lower and upper parts of the Zhenzhuchong Formation in the Northeast Sichuan**

Location		Kaixian		Xuanhan		Daxian	
Horizon		Lower	Upper	Lower	Upper	Lower	Upper
Plant Feature							
Humidity	Hygrophilous Plant						
	Species Number	9	15	5	4	3	11
	Percentage Content	40	42.9	71.4	28.6	50	37.9
	Arid-resistant Plant						
Species Number	13	20	2	10	3	18	
Percentage Content	60	57.1	28.6	71.4	50	62.1	
Temperature	Termophilous Plant						
	Species Number	4	14	4	6	4	15
	Percentage Content	18.2	40	57.1	42.9	66.7	51.7
	Eurythermic Plant						
Species Number	8	21	3	8	2	14	
Percentage Content	81.8	60	42.9	57.1	33.3	48.3	

Czekanowskiales : *Czekanowskia* sp., *C. setacea* Heer, *C. hartzii* Harris.

Coniferopsida : *Pityophyllum* sp., *P. nordenskioides* Heer, *P. longifolium* (Nathorst) Moeller, *Podozamites* sp., *P. lanceolatus* (Lindley et Hutton) Braun, *P. schenkii* Heer, *Swedenborgia* sp., *Pagiophyllum* sp., *Brachyphyllum* sp., *Ixostrobuss* sp., *Storgaardia* cf. *spectabilis* Harris, *Stenorachis* sp., *Stachyotaxis* sp., *Carpolithus* sp., *Araucarites* sp., *Schizolepis* sp.

Form genus incertae sedis : *Taeniopteris* sp.

### Characters

The Zhenzhuchong flora comprises 57 genera and 95 species, of which, 51 species may be referred to the known species. The flora evolved from the underlying Xujiahe flora and both belong to the *Dic-*

*tyophyllum-Clathropteris* series (Sze, 1956) equivalent to Rhaetic-Liassic. However, both the floras have their own specific features. The flora in the Zhenzhuchong Formation is characterized by the following 8 features :

1. The pteridophytes include 17 genera and 39 species occupying 41.1 per cent of the total flora. Gymnospermopsida group comprises 56 species belonging to 30 genera which is 58.9 per cent of the total flora, in which 23 species are of cycadopsids (24.2%), 15 species of ginkgopsids (15.8%), 16 species coniferopsids and dispersed organs (16.8%) and 2 species of Pteridospermopsida with other form genera whose classification was not known (2.1%).
2. Only 1 species *Grammaephloios-ichthyta* of lycopsids (occupying 1.1%) has been found,

**Table 2—The humidity and temperature and their changes from the east to the west in the early and late periods of the Early Jurassic Zhenzhuchong Formation in the Northeast of Sichuan.**

Temperature and humidity period	Location		
	Kaixian	Kuanhan	Daxian
Late	humid hot ↑	semi-humid hot ↓	semi-humid hot ↓
Early	humid cool ↑	humid hot ↓	humid hot ↓

- which was first discovered in the *Thaumatopteris* zone, Scoresby Sound, eastern Greenland (Harris, 1935). The occurrence of this species in the Zhenzhuchong Formation indicates a close relationship between this flora and the Early Jurassic flora in North Europe. The Equisetales are represented by commonly seen Early Mesozoic species, totalling 8 species belonging to 3 genera and occupy 8.4 per cent of the flora.
3. Filices comprise 30 species belonging to 13 genera including Marattiaceae, Osmundaceae, Matoniaceae, Dicksoniaceae, Dipteridaceae and form-genus *Cladophlebis*. As compared with those in the Xujiahe flora, Filices are greater in proportion (31.6%) in the Zhenzhuchong flora. Osmundaceae and Dipteridaceae are in abundance, but the total number of the species decreases markedly. It is important that *Goeppertella*, *Todites kwangyuanensis*, *T. shensiensis* are absent in the Zhenzhuchong flora. However, the occurrence of the Dicksoniaceae is characteristic of the Early Jurassic Epoch.
  4. The decline of the Pteridospermopsida is also characteristic of the Zhenzhuchong flora. *Lepidopteris* and *Ptilozamites*, widely distributed in the Xujiahe flora, were completely extinct in the Zhenzhuchong Formation.
  5. In the Xujiahe flora, Cycadopsida occupy 33 per cent, but in Zhenzhuchong flora, they are only 24 per cent. Although the proportion of Cycadopsida in the Zhenzhuchong Formation decreases drastically, some new species occur. *Anthrophyopsis*, *Doratophyllum* and *Sinoctenis*, characteristic of the Xujiahe flora, were extinct in the Zhenzhuchong flora. The diversity of *Pterophyllum*, *Zamites* and *Ctenis* decreases to a great extent, but the *Ptilophyllum* and *Tyrmia* occur in abundance with diversity and wider distribution. *Nilssonia parabravis*, an Early Jurassic species widely distributed only in the middle and lower reaches of the Changjiang River, was first reported in Xiangshan flora, Anhui Province (Huang, 1983) and later discovered in Daye County (Huang, Lu, 1988b), Puqi City, Zigui County (Zhang, Meng, 1987), Hubei Province and Shangrao County, Jiangxi Province. The occurrence of the species in Wenquan, Kaixian County, indicates close relationship between the Zhenzhuchong flora of the Sichuan Basin and the Early Jurassic floras of the middle and lower reaches of Changjiang River.
  6. Simple leaved gymnosperms increase significantly, while compound leaved ones decrease. Ginkgopsida and Coniferopsida occur in the Zhenzhuchong Formation in abundance with high diversity and wider distribution. They occupy 32.6 per cent in the Zhenzhuchong flora, a higher percentage than that in the Xujiahe flora (22.9%).
  7. Ginkgopsida and Coniferopsida were abundant in the lower part of the Zhenzhuchong Formation (Members I and II), while Filices and Cycadopsida were abundant in the upper part of the same formation (Members III and IV). The vertical distribution of plant fossils, characteristic of the Zhenzhuchong Formation, is closely comparable with that of the Early Jurassic deposits in the middle and lower reaches of Changjiang River, where two plant assemblages have been established: (i) *Sphenobaiera spectabilis*-*Baiera multipartita* assemblage (Pl. 1, figs 1-8) in the lower part of the Wuchang Formation, and (ii) *Ptilophyllum-Coniopteris* assemblage (Pl. 2, figs 1-10) in the upper part of the Wuchang Formation (Huang, 1983, 1988a).
  8. Dicksoniaceae and Gymnospermopsida of the Zhenzhuchong flora contain a number of aboriginal species such as *Coniopteris teishanensis*, *Ptilophyllum contiguum*, *Otozamites mixomorphus* and *Nilssonia parabravis*. On the whole, the Zhenzhuchong flora could be correlated with the Early Jurassic Xiangxi flora (Wu, Ye & Li, 1980), Wuchang flora (Huang & Lu, 1988b), Xiangshan flora (Huang, 1983) and Linshan flora in the middle and lower reaches of Changjiang River. All these floras belong to the middle and late Early Jurassic. The Zhenzhuchong flora was also related to the *Thaumatopteris* zone in the eastern Greenland (Harris, 1937), and equivalent to the upper *Dictyophyllum-Clathropteris* Series (Liassic) of southern China (Sze, 1956) and to the *Ptilophyllum-Coniopteris* flora (Wu, Ye & Li, 1980).

**JURASSIC PALAEOCLIMATE AND COAL-FORMATION IN SICHUAN BASIN**

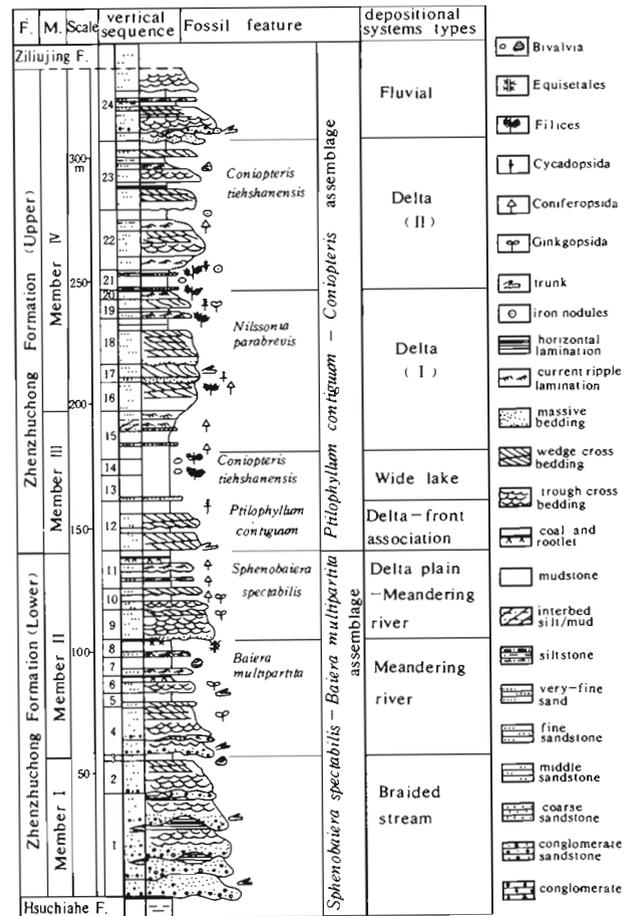
The hot arid climate dominating the Early and Middle Triassic in the Sichuan Basin is indicated by marine carbonates such as limestone and dolomite, and gypsum and salt. The organisms are scarce in the basin. The semi-arid and semi-humid climate characteristic of the early Late Triassic in the Sichuan Basin, representing alternate facies of marine and continental sediments is marked by brackish water bivalves, quasi-autochthonously buried plant fossils and lip-tobiolites. Tropical and subtropical humid climate was prevalent in the middle and late Late Triassic in Sichuan Basin where plants were abundant and the lakes were widely distributed, resulting in the formation of thick coal seams. A semi-humid cool climate prevailed in the early Early Jurassic, while in the late Early Jurassic the Sichuan Basin enjoyed humid and hot climate. During the period when the Zhenzhuchong flora flourished, the number of species decreased, and the coal-forming conditions became adverse. The sediments are interbedded with the variegated sandstones and mudstones. In the Middle Jurassic in Sichuan Basin semi-arid and hot climate was present where the typical fresh-water lacustrine Ziliujing Formation consists of Dongyuemiao limestones, Maanshan shales and Daanzhai bivalve limestones. The Dongyuemiao limestones contain rich bivalves, while the Maanshan shales comprise ostracods and conchostracans. Allochthonous plant stems are also occasionally found. Typical arid and hot climate was prevailing in the Late Jurassic in the Sichuan Basin, where red sandstone and mudstone were deposited in the Xintiangou Formation. In these sandstones and mudstones, very few trace fossils and coniferopsids are found.

**Early Jurassic palaeoclimate**

The coal-bearing strata are the characteristics of the Zhenzhuchong Formation. The clay mineral mainly consists of kaoline. The flora chiefly consists of Dipteridaceae, Matoniaceae and Cycadopsida. All these indicate that a tropical and subtropical humid climate was prevalent in this region during Early Jurassic.

The plant fossils are abundant in the Zhenzhuchong Formation. The assemblage comprises 33 species: 2 Equisetales, 6 Osmundaceae and *Cladophlebis*, 5 Dipteridaceae, 2 Dicksoniaceae, 8 Cycadopsida, 8 Ginkgopsida, and 2 Coniferopsida. The late assemblage contained 56 species: 6 Equisetales, 2 Marattiaceae, 5 Osmundaceae and *Cladophlebis*, 6 Dipteridaceae, 1 Matoniaceae, 3 Dicksoniaceae, 1 Pteridospermopsida, 14 Cycadopsida, 8 Ginkgopsida, and 10 Coniferopsida. The abundance of ginkgopsids in the early assemblage and of Cycadopsida, Dipteridaceae, Marattiaceae and Matoniaceae in the late assemblage respectively indicates that the early period enjoyed cool climate, while a humid and hot climate prevailed in the late period.

On the basis of temperature difference the plants may be classified into two major types—the thermophilous and eurythermic plants. When the ther-



**Text-figure 2**—Column section of the Early Jurassic Zhenzhuchong Formation, Wenquan, Kaixian County, Sichuan, China.

mophilous plants were more than 30 per cent in the flora, the climate of the region was hot and when the climate of this region was cool these thermophilous plants were below 30 per cent. The plants can also be classified into two major types in terms of the humidity difference: hygrophilous and arid resistant plants. There are four major types of floras in terms of the percentage content of the hygrophilous plants in the flora—the humid type containing over 40 per cent hygrophilous plants, semi-humid type with 20–40 per cent, semi-arid type below 20 per cent, and the arid type with few plant fossils. As shown in Text-figure 2 in Kaixian the Early Jurassic deposits change from those of intramontane streams to lakes and marshes. In the early period, the ginkgopsid and coniferopsid fossils were abundant, while in the late period, the cycadopsida and the Filices were abundant. The column (Text-figure 2) shows a marked vertical diversity of plant fossils: the cool climate is characteristic of the early period, while the warm climate represents the late period. The lacustrine and deltaic sediments are widely distributed in the Early Jurassic Xuanhan and Daxian regions. Because these regions were relatively flat, there was no distinction in vertical diversity of plant fossils. In this case, the majority of the plants were thermophilous. A humid climate in the Kaixian mountainous region lasted from the Late Triassic to the Early Jurassic. A humid climate in the lacustrine deltaic region along Xuanhan and Daxian counties lasted from the Late Triassic to the Early Jurassic. The decrease in the humidity in the late period of the Early Jurassic resulted in the semi-humid climate in this region. Generally speaking, the temperature and the humidity in the Early Jurassic Zhenzhuchong period did not change much. Compared with those in the Late Triassic Xujiahe period, the humidity in Zhenzhuchong period decreased while the temperature increased.

#### PALAEOCLIMATIC CHANGES AND COAL-FORMATION

The study on the palaeoclimate and coal-formation in the Late Triassic in Sichuan Basin shows the increase in the humidity and decrease in temperature which were favourable for coal formation (Huang, 1995). The coal-forming conditions in the Zhenzhuchong Formation were not as good as those

in the Xujiahe Formation. The following phenomena can be derived from the correlation between palaeoclimatic variation and coal-formation in the depositional period of the Early Mesozoic coal-bearing strata in the Sichuan Basin.

1. The increase in humidity and decrease in temperature were favourable for the formation of coals in the lakes and marshes where plants were abundant. For example, in the early and middle periods of the Late Triassic Xujiahe Formation the increase in humidity and decrease in temperature resulted in the formation of thick coal seams in a large area of the Guangyuan, Wangcang and Huayingshan coalfields.
2. The simultaneous increase in humidity and temperature were not favourable for the formation of coal. For example, in the Kaixian Zhenzhuchong Formation where the humidity and temperature increased simultaneously resulting the formation of few thin coal seams.
3. The simultaneous decrease in humidity and temperature was also not favourable for the formation of coal. The best example is Zhenzhuchong Formation in Xuanhan and Daxian.
4. The decrease in humidity and increase in temperature also not resulted the formation of coal. For example, in Member 7, Kaixian County where the humidity decreased and the temperature increased in the Late Xujiahe period (Huang, 1995).

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