MICROSCOPIC STRUCTURE OF TZUHSIEN COALS AND ITS BEARING ON COKING PROPERTY[1]

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(*The Geological Survey of China*)

Introduction.

The samples for microscopic study are all collected from the Hsitso coal field situated about 50 li northwest of the Tzuhsien city and 40 li east of the Matouchen station of Pinghan Railway. In order to understand the geological occurrence of the different coal seams from which the samples were taken, the general topographic features and an outline of the geology in the region should be briefly stated first.

Between Matouchen and Hsitsotsun there appears a gentle rolling land in which the highest ridge, for example on the south of Lintan, is not over 40 meters. Near Hsitsotsun the land is much flatter though active vertical cutting due to recent upwarp of the land surface still exists so as to form a number of east-westward narrow steep valleys, the depth of which is generally from a few to twenty or thirty meters. West of Hsitsotsun the topography becomes rougher into a hilly land.

The writer is much indebted to Mr. C. Y. Hsieh who gave many criticisms during the microscopic work. He also expresses his thanks to Mr. C. H. P'an for his field help.

Stratigraphy.

1. *Ordovician limestone.* The oldest formation in the region under study is the Ordovician limestone exposed along the Kushan range. It often constitutes hills of about 200 or 300 meters in height and thus forms the western boundary of the Hsitso coal field.

2. *Carboniferous and Permo-Carboniferous coal series.* On the Ordovician limestone rests the Carboniferous and Permo-Carboniferous coal series with numerous workable coal seams. Its lower portion being in proximity with the Ordovician limestone, is generally well exposed along the eastern foot of

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Kushan, while its middle and upper ones are nearly all covered by loess and alluvium. It is thus impossible to find a section of complete succession of the rock series though considerable effort has been made in the field. On the northwest of Fengfengtsun (丰丰村), however, an incomplete section (Fig. 1.) along a stream valley has been surveyed as described below:—

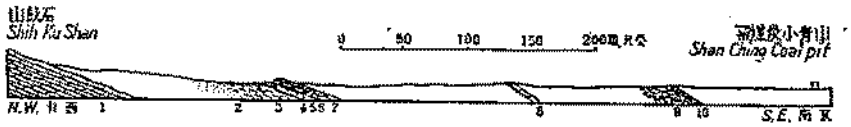


Fig. 1. Section of the Carboniferous strata, N. W. of Fengfengtsun. 1, Ordovician limestone; 2, Grayish white sandstone; 3, Bluish clay shale; 4, Hsiachia coal seam; 5, Bluish clay; 6, Taching coal seam; 7, Deep gray limestone with flint nodules (Taching limestone); 8, Grayish limestone (Hsiaoching limestone); 9, Grayish sandy shale; 10, Yellowish gray limestone with flint nodules (Fuching limestone).

In the above mentioned section the contact between the coal series and the Ordovician limestone is not exhibited. The lowest bed observed in the coal series is a white gray sandstone partly tinted reddish yellow with iron and it is believed to be a member near the bottom of the coal series. Above the sandstone is a blue clayey shale about 10 m. thick, and extensively used for porcelain industry by the natives. This is succeeded by a coal seam about one foot thick as estimated from its exposure and probably equivalent to the so-called Hsiachiamei by the natives. From this upwards appear a blue clay at a thickness of about 1.5 ft., a coal seam about 2 ft. thick and called Tachingmei by the natives, and a deep gray limestone called Tachingshih by the natives with numerous flint-nodules at a thickness of about 5 ft. Above Tachingshih the strata are all buried by sands and gravels, but from here down the valley to a distance of about 170 meters crops out a gray limestone about 3 m. thick and probably equivalent to the so-called Hsiaochingshih of the natives. Then the strata are buried again to a distance of about 120 m. until another gray limestone containing a few flint nodules comes out at a thickness of about 2. m. This limestone is probably equivalent to the Fuchingshih of the natives. From here up to Fengfengtsun no rock exposures are observed. But on the west of the village

Fengfengtsun there is a native coal pit and the coal seam being worked is said to be Shanchinghsiaotan about 1.5 ft. thick. According to the native report, there should be a horizon of limestone called Shanchingshih between Shanchinghsiaotan and Fuchingshih. Moreover, on the east of Shanchinghsiaotan there should be some other limestone horizon named Yehchingshih and the important coal seams such as Itsomei, Tachingmei, etc. are all above the last limestone.

In consequence of the scarcity of the exposures of the coal series its distribution is hardly to be surveyed in detail. Fortunately, there are numerous native coal pits which may be utilized for indicating the existence of the coal series. The strata in the coal series generally dip toward the east. The uppermost workable coal seam is Tamei and thus east of the coal pits mining Tamei there should be near the top of the coal series unless special faults or folds occur. From Hsitsotsun and Fengfengtsun up to Chienerhchuang, a great number of native coal pits are scattered here and there. Between Chienerhchuang and Tungtzufang there exists a modern coal shaft by Chungho coal mine with a few native coal pits. Hence, from the distribution of the coal pits it seems that the coal series forms a narrow north-south belt from Hsitsotsun through Fengfengtsun and Chienerhchuang up to Tungtzufang.

3. *Permian and Permo-Triassic yellow shales.* Overlying Carboniferous and Permo-Carboniferous coal series is the alternative beds of yellow shale and yellow greenish sandstone here included under the name of Permian and Permo-Triassic yellow shales, for from the similar formation in Shansi[1] numerous Permian and Permo-Triassic plant fossils were collected. Though the contact between the yellow shale formation and the Permo-Carboniferous coal series is all covered by loess and alluvium, the detailed succession of the former is well exposed along the valley of Tungkou, S. E. of Hsitsotsun. Further, a great number of plant fossils has been collected there and determined by Mr. C. H. Pan as follows:—

Pecopteris acuata Halle

Protoblechnum cf. *wongi* Halle

1. C. C. Wang: Stratigraphy of Pao Teh Chou, N. W. Shansi. Bull. Geol. Surv. China. No. 4. 1922.

Neuropteris flexuosa Brongniart
Cardiopteris sp.

The total thickness of the yellow shale formation is estimated to about 220 m. or more.

4. *Triassic red sandstone.* The exposure of this formation is very poor in the region visited, but it is evident that the change of the lithological characters and colors of the transitional beds from the Permian yellow shale to the Triassic red sandstone is very gradual without any sharp boundary.

5. *Cenozoic conglomerate, reddish clay and loess.* Between Matouchen station and Lintan there is a group of low gentle ridges composed mainly of coarse conglomerate with rounded quartzite and limestone pebbles. Sometimes a layer of sandstone intercalated in the conglomerate exhibits more or less inclination. Its geological age may belong to the Pliocene in equivalence to the Sanmen Series. Above the conglomerate reddish clay and loess often accumulate in great thickness, and probably belong to Pleistocene.

Geological Structures.

The geological structure of the Hsitso coal field is simple and all the strata generally dip toward the east. As the coal field is mainly buried under the Cenozoic deposits of the Hopei great plain, detailed structure is hardly detected, though local fault and fold are certainly present.

Coal Seams.

To correlate the different coal seams in the Hsitso coal field is difficult, for the exposures of the coal series are rare. Valuable informations have been, however, often obtained from native coal pits. According to the records given by the Ili Coal Mine, a columnar section for the different coal seams should be as in Plate II.

From the columnar section, there should be seven workable coal seams, but during the author's visit only three seams, namely, Yehchingmei, Itsomei, and Tamei, are in operation. The latter two seams are more important, as they are good in quality. Tamei is the thickest seam in the coal field, though it is often divided into two sub-seams called Toumei and Erhmei by a layer of black shale.

Quality of the Coals.

About 10 li north of Hsitsotsun, the coal all becomes anthracite or semi-bituminous coal. The true bituminous coal occurs only from Hsitsotsun southward to Liuhokou at a distance of about 60 li. Farther south anthracite appears again. The so-called Hsitso coal field occupies the north portion of the above bituminous coal area. According to the native mining experience, Tamei and Itsomei are both coking and the latter is much better, while all the other coal seams are never used for burning coke. Coal samples from five coal seams have been analysed in the Survey Laboratory, showing the following results:

Localities	Coal seams	Class[1]	Moist.	Volat. Matter	Fixed Carbon	Ash	Sulphur	Coke	Heat value
Ili Coal Mine	Toumei	Bh $\frac{1}{2}$	0.62	20.32	72.78	6.28	0.65	Caking & swelling	8141 cal.
,,	Erhmei	Bh $\frac{1}{2}$	0.44	17.94	72.26	9.56	0.68	,,	7876 ,,
,,	Toumei	Bh $\frac{1}{2}$	0.24	21.20	72.10	6.46	0.65	,,	8159 ,,
,,	Erhmei	Bh $\frac{1}{2}$	0.28	21.04	73.08	5.60	0.57	,,	8222 ,,
,,	Itsomei	Bh $\frac{1}{2}$	0.32	21.10	73.62	4.96	0.74	Caking & non-swelling	8272 ,,
,,	Yehching-mei	Bh $\frac{1}{2}$	0.52	19.97	70.81	8.70	1.50	,,	7702 ,,
,,	Shanching-hsiaotan	Bh $\frac{1}{2}$	0.32	21.00	58.80	19.52	3.50	Caking & swelling	6795 ,,
Chungho Coal Mine	Toumei-hsiaotan	Bm $\frac{1}{2}$	0.55	24.60	53.86	20.99	1.20	,,	6801 ,,
,,	Tamei	Bh $\frac{1}{2}$	0.58	21.62	64.32	13.48	0.94	,,	7500 ,,
,,	Itsomei	Bm $\frac{1}{2}$	1.26	22.01	63.43	13.30	3.80	,,	7467 ,,
	Yehching-mei	Bm $\frac{1}{2}$	1.88	22.86	64.56	10.70	2.00	,,	7624 ,,

1. For the meaning of the symbols, see W. H. Wong, Classification of Chinese coals. Bull. Geol. Surv. China, No. 8, 1926.

From the above analyses it is evident that the ash and sulphur contents are generally low in Toumei, Erhmei, and Itsomei whose coke characters are all caking and swelling. The agreement of the analyses with the native mining experience is exceedingly interesting. On the other hand the ash and sulphur contents in Yehchingmei, Shanchinghsiaotan, and Toumeihsiaotan, are mostly too high for making good coke.

Coal Reserves.

The estimation of the coal reserves in the Hsitso field is restricted to the coal-producing area between Hsitsotsun and Tungtzufang. In this area the coal series extends at a distance of 8,000 m. and generally dips toward the east at angles varying from 10° to 30° or averaging at 20°. If the workable depth of the coal seams is considered to be 600 m. and the average specific gravity of the coals to be 1.3, the coal reserves should be calculated as shown in the following table:

Coal seams	Average thickness	Coal reserves
Tamei	5 m.	91,208,000 tons
Itsomei	0.7 m.	12,769,120 ,,
Yehchingmei	1.5 m.	27,362,400 ,,
Shanchingmei	1.5 m.	27,362,400 ,,
Hsiaochingmei	1.7 m.	31,010,720 ,,
Tachingmei	1 m.	18,241,600 ,,
Hsiachiamei	2 m.	36,483,200 ,,
Total		244,437,440 ,,

The coal seams of which the thickness is below 2 ft., are not included in the above table. If 4,400,000 tons of coal are assumed to have been extracted by the native coal pits, the real total reserve should be 240,000,000 tons. In regard to the coking coals of good quality such as Tamei and Itsomei, a real reserve of 100,000,000 tons seems at least to be present.

Microscopic study of the Coals.

Toumei seam.

Under the microscope the polished sections show that the coal is composed mainly of durain in which fragments of fusain are usually abundant. Regular lenses of fusain are also present and generally exhibit distinct cellular structure. (Pl. III, Fig. 2). Seriated cells probably derived from secondary xylem are not infrequently met with, while cortex is also commonly found in well preserved cells (Pl. III, Fig. 1). A few narrow bands of vitrain generally occur in structureless mass. Argillaceous material is occasionally in great amount. Pretty woody tissue (Pl. III, Fig. 4) is sometimes well preserved by such material. In the durain cuticles are only rarely found though not entirely absent.

Erhmei seam.

Durain is the essential constituent of the coal though in certain sections fusain bands seem also abundant. Generally speaking, lenticles of vitrain are rare and scarcely over 3 mm. in width. Fig. 1 (Plate IV) represents a section of seriated cells of secondary xylem with their lumens mostly filled by ash material. Very fine fibers of primary wood of some lepidodendrids are often well preserved especially when the tissue is partly filled and replaced by inorganic matter as shown in fig. 2 (Plate IV). Even in the durain some fragments of wood can occasionally be recognised by numerous dots in definite disposition, indicating the lumens of the cells. A few grains of pyrite are found in some sections. So far as the writer's observation goes, no cutinized materials such as spore exines, cuticles, etc. appear. This phenomenon may be interpreted as (1) they have been destroyed during the process of coalification or as (2) they were originally rare in the formation of the coal. In view of the abundance of well preserved wood cells the latter explanation seems more probable.

Itsomei seam.

There are a great many lenticles of xylain exhibiting distinct cellular structure. (Pl. IV, Fig. 3). The lumens of such cells when filled by mineral matter, have apparently suffered little compression, but those in the ends of

some lenticles are often reduced to dots or short lines which in some cases, have lost their definite outline and become granular. Ash bands are abundant and generally irregularly distributed here and there in some sections. Vitrain is scarcely visible though xylo-vitrain with a few granules indicating the position of the lumens, is not infrequently met with.

Fusain occurs both in lenses and fragments, in which the cells are often intensely compressed and thus usually partially obliterated though their general outline is still well traceable. Pyrite is abundant in some samples especially in those taken from the Chungho coal mine. It generally occurs in fine grains either uniformly disseminated through the section or aggregated in thick masses.

Yehchingmei seam.

The samples of the Yehching coal seam were collected both from the Ili and Chungho coal mines.

The polished sections made from those of the former are specially interesting for microscopic structures. Fusain bands mostly occur in lenticular form. Their cell structures are generally in ill-preservation and usually only represented by tiny dots for the lumens. Exceptional cases are, however, present. For example, in figure 5 (Pl. IV) not only the lumens of the cells are well preserved but the intercellular spaces are also distinct. Durain constitutes the main part of most sections, in which cuticles are often observed. Fig. 4 (Pl. IV) shows a transverse section of a leaf in durain with its both upper and lower cuticles, when the parenchyma between is chiefly obliterated due to advanced coalification. Vitrain is generally rare and when present it occurs only in thin layers. In fig. 2 (Pl. V), there are three bands of xylain in parallel disposition and alternative with structureless zones. This phenomenon may be interpreted by two possible explanations. In one possibility, the xylain bands represent the thick-walled cells of autumn wood while the structureless zones indicate the spring wood. In another one, each band of xylain shows a separate lenticle of xylem while the structureless portions are durain. Which of these two possibilities is more reasonable is hard to say. But it is understood that annual rings of growth in Paleozoic coals are very rare.

The polished sections from the samples of the Chungho coal mine often exhibit a few pyrite grains and sometimes a great amount of ash in bands. In a lenticle of fusain as shown in Fig. 3 (Pl. V) the lumens of the cells are particularly conspicuous in oval forms and partly filled by inorganic matter giving dark areas under microscope and partly filled by humic material showing more or less bright nature. Further, the infiltration of the lumens by ash is also frequently observed here and there in the xylain. All the features described seem to show that the quality of the coal in the Chungho Coal Mine is much inferior to that in the Ili mine. This is also confirmed by the chemical analyses as shown in the coal analytical table.

The following two coal seams are not important in economic significance, but they are very interesting from scientific point of view.

Shanchingtsiaotan seam.

The special feature of this coal is rich of argillaceous matter. Sometimes shale bands alternative with thin layers of coal may be visible even with naked eyes. Pyrite is aboundant in some sections and in one case a band of pyrite is as wide as from about 2 to 4 mm. It is, therefore, obvious that the coal is much inferior in quality. If a comparison between the microscopic examination and the chemical analyses is made, there is a notable agreement.

Another special feature of this coal is of the common presence of fragmented cells. This phenomenon indicates that the nature of the chemical changes which occurred in the cell walls of this coal is somewhat different from those for other coals and so the walls were brittle and easily fractured under pressure. Fig. 4 (Pl. V) shows a longitudinal section of fragmented elongated cells in a band of fusain, while fig. 5 (Pl. V) represents the bogen structure of the broken cells in a transverse section. Xylain is in great amount and its cell lumens are generally filled with argillaceous material. By enlargement of the infiltration of the lumens in seriated disposition, argillaceous bands may thus be established.

Tousungtsiaotan seam.

The coal is composed essentially of durain intercalated with a few bands of fusain, vitrain and inorganic matter. In certain layers of durain the abundance of spore-exines attracts special attention. Both megaspores and microspores are present. The exines of the former are usually thin-walled while those of the latter generally appear as minute bright objects. Fig. 1 (Pl. VI) is of an excellent illustration for spores. Fragments of megaspore exines are sometimes abundant. Besides, there often occur some bright oval bodies (Pl. VI, fig. 2) in the durain under microscope, which are probably resinised substances though their exact nature is hardly to be detected in polished sections due to their advanced coalification.

In some cases ash layers are numerous and even visible with naked eyes. Broken cells are often found in fusain, giving rise more or less bogen structure which probably represents fractured secondary tissue either of xylem or of cortex. Fig. 3 (Pl. VI) represents the fibers of primary wood of a lepidodendrid while fig. 4 (Pl. VI) shows a tangential section of primary wood of the same plant, giving delicate scalariform structure.

Conclusion.

To compare the results of chemical analyses of the samples with their corresponding microscopic study, it is obvious that the ash content above 10% or the pyrite percentage above 1 is usually fairly recognised under microscope in polished sections, while either the former or the latter below the given amounts is often insignificant in sections though exceptional cases are not entirely absent. The quality of the coals may, thus, be studied with microscope instead of chemical analyses. The analyses and microscopic studies of Shanchingtsiaotan and Tousungtsiaotan offer good illustrations.

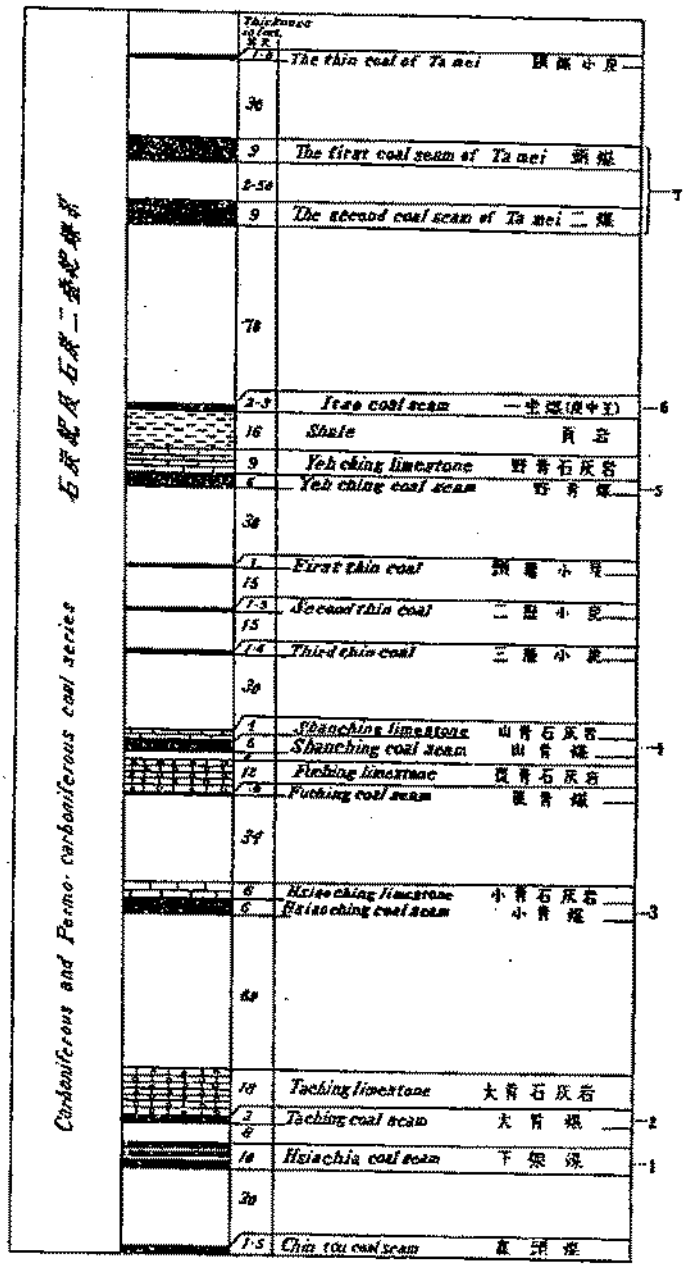
Nearly in all coal seams except Tousungtsiaotan in which spore-exines are numerous, there are abundant bands or lenticles of fusain, xylain, xylovitrain and vitrain, in which fragmented or unfragmented cellular tissues are generally more or less visible. It follows with the exception of Tousungtsiaotan, that nearly all the Tzuhsien coals which are generally coking, are composed

essentially of wood, or materials of woody origin. Particularly in Toumei, Erhmei, and Itsomei which offer better coking property as proved both by the native experience and chemical analyses, the above named bands are specially common under miscroscope. Such conclusion well agrees with Jeferey's hypothesis[1]. In 1925 he published a paper of "coal in relation to coke" and has pointed out that wood should be the predominant constituent of the original raw materials of coking coals and the worth of coal, from the standpoint of the coking industry, was in direct proportion, other things being equal, to its contents of modified wood. The writer's microcopic study of Tzuhsien coals thus gives a good support to Jeferey's statement.

1 E. C. Jefery: Coal in relation to coke, Trans. Am. Inst. Min. Met. Eng. Vol. LXXI, pp. 149-164, 1925.

西佐煤田煤層柱形圖 Pl. II.

Columnar section of the Hsitso coal field showing The different coal seams.



Explanation of Plate III.

Plate III

Fig. 1. A nest of sclerotic cells in the cortex. The lumens of the cells are still well preserved with distinct intercellular spaces. Toumei (The uppermost coal seam). × 100.

Fig. 2. A transverse section of a stem with its pith in the centre, surrounded by xylem cells more or less compressed. Toumei. × 80.

Fig. 3. A band of cortex showing its elongated cells. Toumei. × 90.

Fig. 4. Some wood tissue preserved by ash bands. Toumei. × 80.

Fig. 1.

Fig. 2

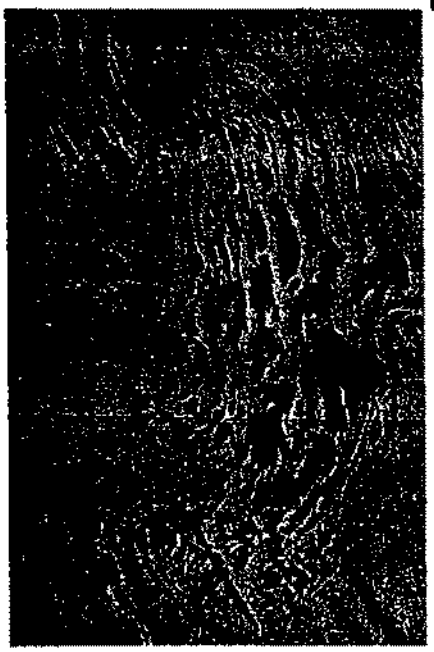


Fig. 3

Fig. 4

Explanation of Plate IV.

Plate IV

Fig. 1. Seriated cells of secondary xylem. Erhmei. × 90.

Fig. 2. Microphotograph of the fibers of primary wood of a lepidodendrid. Erhmei. × 90.

Fig. 3. A lenticle of xylain showing beautiful cell structure. The lumens are generally filled by ash. Itsomei. × 90.

Fig. 4. A transverse section of a leaf showing both upper and lower cuticles though the parenchyma between is not well preserved. Yehchingmei. × 90.

Fig. 5. A band of fusain representing a piece of wood with distinct intercellular spaces. The filling of the lumens is mostly ash, and the structureless portion near the centre of the wood may represent the pith. Yehchingmei. × 90.

Fig. 1.

Fig. 2

Fig. 3

Fig. 4

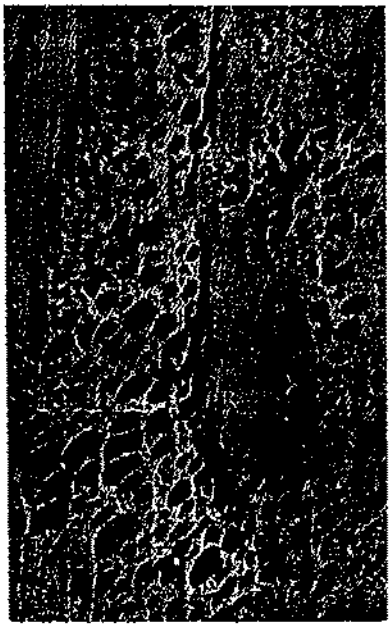


Fig. 5

Explanation of Plate V.

PLATE V

Fig. 1. Fragments of fusain showing decayed parenchyma cells. Yenchingmei. × 90.

Fig. 2. Bands of xylain with well preserved cells are alternative with zones of advanced decay. This may be interpreted as the spring and autumn woods, though further confirmation seems necessary. Yenchingmei. × 90.

Fig. 3. A fusain lenticle of sclarenchyma partly filled with ash and partly with coaly material. Yehchingmei. × 90.

Fig. 4. A fusain band showing the fragmental elongated cells. Shanchingtsiaotan. × 90.

Fig. 5. Fragmented cells showing bogen structure. Shanchingtsiaotan. × 90.

Fig. 1.

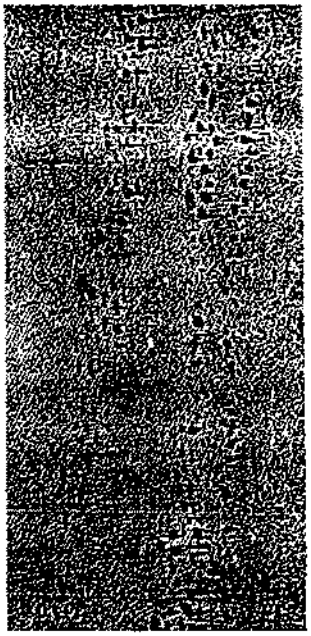


Fig. 2.

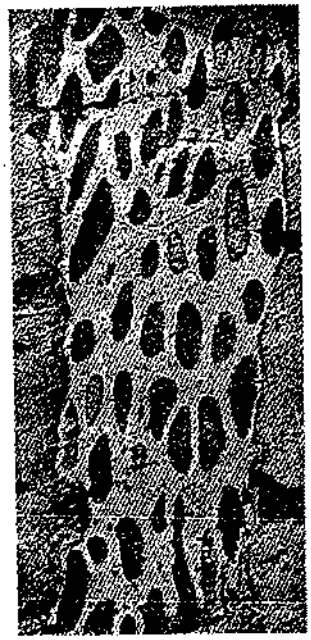


Fig. 3.

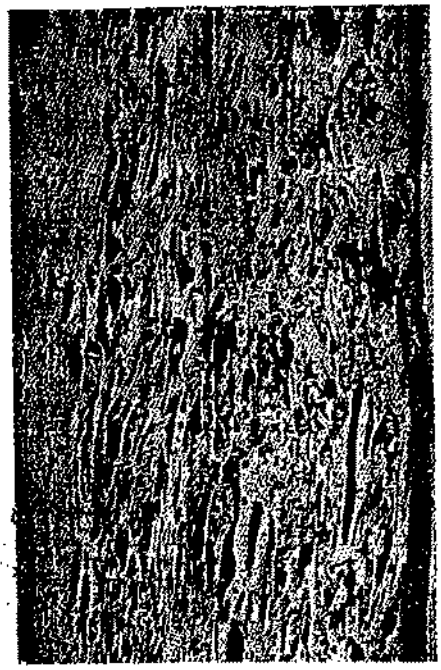


Fig. 4.

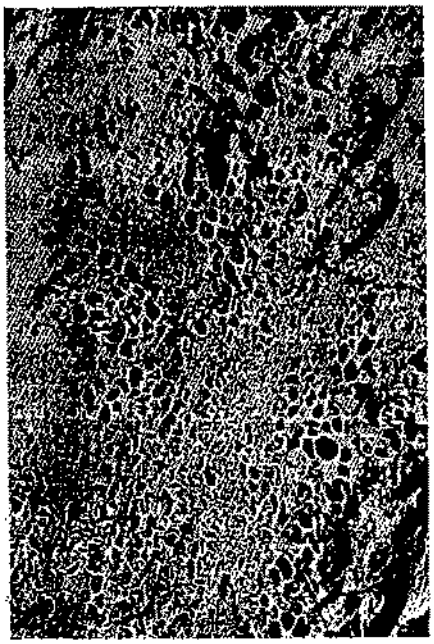


Fig. 5.

Explanation of Plate VI.

PLATE VI

Fig. 1. Microphotograph of the exines of megaspores and microspores. Tousungtsiaotan. ×× 90.

Fig. 2. Some oval resin bodies in durain. Tousungtsiaotan. × 90.

Fig. 3. Microphotograph of the fibers of primary wood of a lepidodendrid. Tousungtsiaotan. × 90.

Fig. 4. A section of primary wood of a lepidodendrid showing delicate scalariform structure. Tousungtsiaotan. × 90.

Fig. 1.

Fig. 2.

Fig. 3.

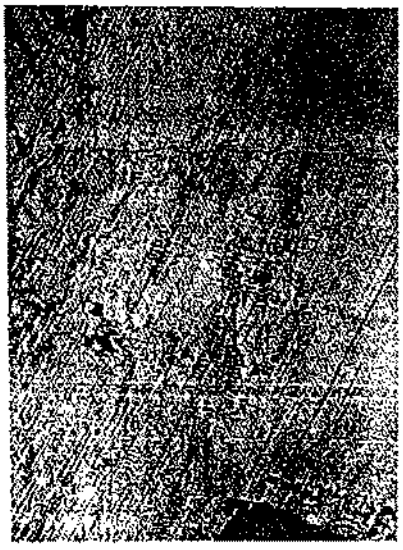


Fig. 4.