A MICROSCOPICAL STUDY OF SOME COALS FROM SZECHUAN, S. W. CHINA*

(BY C. Y. HSIEH M. A.)

(With 7 Plates)

I. INTRODUCTION

That the geology of the Chinese coal fields is becoming better and better known is evidenced by the numerous publications put out from time to time by the different investigators, especially by the members of the National Geological Survey in Peking. But little attention seems to have been paid to the microscopical study of the coal itself, which is of fundamental importance for a better understanding of the origin composition etc. of the coal as well as rendering a great help to the correlation and comparison of different coal seams in one or different coal fields.

In 1913 H. Winter[1] in his article on the investigation of coal by the reflected light mentioned some observations on the polished section of a Chinese coal from Manchuria. This is perhaps, I believe, the first Chinese coal specimen that has been ever studied microscopically. In the important monograph of Kono Yasui[2] on the study of Japanese coal she has carelessly included some Chinese coal from Fushun and Sha Ho Tze Colliery of S. Manchuria. A more extensive study on the Chinese coal was made in 1926 by Y. Akasegawa[3] in the Geological Institute of the National University of Peking. Unfortunately Akasegawa was not able to obtain coal sections thin enough to show all the important structures. More recently C. Iwasaki[4] has published a very important paper on the microscopical study of Fushun coal of S. Manchuria.

During my sojourn in Germany in 1928, I had the opportunity to work in the Laboratory of the Palæobotany and the Petrography of Combustable Rocks in the Prussian Geological Survey at Berlin. Under the close guidence of the

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* A research conducted in the "Institut für Palaobotanik und Petrographie d. brennbare Gesteine" in the Prues. Geological Survey at Berlin.

1. H. Winter: Die mikroskopische Untersuchung der Kohle im Auffallenden Licht. Glückauf, 1913.

2. Kono Yasui: Studies on the structure of Lignite, Brown coal and Bituminous coal in Japan. Journ. Faculity Science, Imp. Univ. Tokyo, Section 3, Vol. 1, pt. 4, 1928.

3. Y. Akasegawa: Notes on the Micro-structure of some coals from N. China. Bull. Geol. Soc. China, Vol. V, No. 2, 1926.

4. Chozi Iwasaki: Fushun coal and its geological significance, Tech. Rept., Tohoku Imp. Univ. Vol. 8, No. 1, 1928.

staff of the Laboratory, the writer was able to learn and to familarize with all the methods that are necessary to the petrographical study of coal. A collection of about 90 specimen consisting of coals of various types and different geological ages was sent from the Geological Survey at Peking. Unfortunately the shipping of the specimen was much delayed and the collection did not come until the January of 1929. In order that no time was to be lost, the writer, by the permision of Prof. Gothan, has selected a collection of Chinese coal from the Province of Szechuan then kept in the Prussian Geological Survey, as my material of preliminary investigation. This collection consisting altogether of 30 pieces of coals was collected by G. Cremer, who during the year of 1905-1906 took an extensive trip in examining geology and mineral resources in various parts of Szechuan.

My investigation on the coals of Szechuan, though being preliminary in nature and limited to only small number of specimen, has yielded, nevertheless very interesting results. Before the finishing of my study on the bigger collection which is still going on in the present time, it seems worth-while for me to write beforehand a short note on that results that have been already obtained. Because of the limited scope of this paper, only microscopic characters will be treated. More important questions such as origin and classification of coal, correlation and comparison with coals of other districts etc. are entirely untouched; they will be discussed in my next paper.

I take this occassion to acknowledge my indebtedness to Prof. W. Gothan of the Prussian Geological Survey, under whose supervision the present investigation was conducted. To Dr. R. Potonie and especially to Dr. H. Bode, I am indebted for their practical directions and criticism. Acknowledgements are also due to President P. Krush and Director W. Weissermel of the Prussian Geological Survey for their kindness in permitting me to work in this well equipped laboratory of the Survey.

II. GEOLOGICAL OCCURRENCE

The different coal fields or mines which have been visited by G. Cremer are plotted in Pl. VII. In this map the Palæozoic coal is represented by a dot while the Jurassic coal by a cross. The number refers to the locality which is listed in the accompanied analytical table.

Only about half of the total fields have their specimen represented in the collection of the Prussian Geological Survey. Those fields the specimen of which have been studied microscopically in the present investigation are marked by an asterisk in the table.

According to Cremer[5] the coal formation of Szechuan belongs to three distinct geological periods, namely, the Carboniferous, the Permian, and the Jurassic, the last one is however by far the most importar t.

The Carboniferous coal series is distributed, according to Cremer's map, in three principal districts, namely (1) At west of Ling Chui Hsien (鄰水縣) near the river Chu Kiang (渠江); 2) South of Nan.Chuan (南川縣) in S. E. Szechuan; (3) In the neighbourhood of Tien Chuan Hsien (天全縣) of western Szechuan. Most of these occurrences contain coal seams too thin or too poor in quality to be workable with modern method. Only the fields at south of Nan Chuan which have been mined since long time by the local people seems to deserve some attention. A section of the coal series as measured by Cremer near the mine Ban Chia Kou is reproduced here. (In descending order):

1. Dark gray, thick bedded compact limestone.
2. Yellowish soft strata.
3. Hard and gray colored crystalline limestone.
4. Reddish brown shale.
5. Reddish brown shaly clay with abundant fossils.
6. 20-30 m. covered.
7. Tough shale with pyrite concretions.
8. Coal seam 1.36 m thick.
9. Clay shale.
10. Hard gray limestone.

The Permian coal series is found at north of Kwang Yuan Hsien (廣元縣) and An Hsien (安縣), in north Szechuan. They are equally of no economic importance.

The Jurrssic coal series is widely distributed in Szechuan; only a small part of the whole being visited by Cremer. The formation is characterized by an alternation of yellowish to brownish sandstone and shale in which thin layers of limestone are frequently intercalated. One to three seams of coal have been encountered ranging in thickness from 0.15 to 0.5 meter. The most important coal fields of this group are found in the valley of Ki Ling Kiang between Chung King and Ho Chow (合州) among which the coal of Lung Wang Tung receives special reputation on account of its lower percentage of ash. (5.3% see No. 13 of the table).

5. G. Cremer: Bericht über eine Reise in der chinessischen Provinz Szetschuan, Zeit. für das Berg.-Hütten u. Salinen Wesen, Bd. 61, Berlin, 1913, p. 1-149.

III. METHODS OF STUDY.

During recent years many different methods for the microscopic study of coal have been proposed among which only three are used in the present investigation. They are: (1) Examination of the thin section by the transmitted light (2) examination of the polished section by the reflected light (3) Maceration of the coal by the so called Schulze's reagent, i.e. to treat the coal first with a mixture of Potassium Chlorate and strong Nitric acid (sp. gr. 1.40) and then with Ammonia. The residue left over from this treatment consists of the most resistent parts of the coal such as spore exines, cuticles, etc. and they can be examined under the microscope in a very detailed way.

For every specimen of the coal studied, a polished section and a maceration by the Schulze's reagent were made. This last method has yielded many interesting results especially from the palæobotanical point of view. Thin sections of coal were made only when it needed to show some special structures which are not distinguable in the polished section.

IV. DESCRIPTION OF DIFFERENT COALS

The following is a microscopical description of different coals studied. The coals are divided into two groups, i.e. (1) coals of Carboniferous or Permian age (2) coals of Jurassic age.

In describing the constituents of coal I have adopted entirely the nomenclature of the Pruess. Geological Survey,[6] i e. to omit the term clarain as was originally proposed by Stopes[7] and to include the inhomogenous part of the clarain under durain while the homogenous layers to vitrain.

1. Coals of Carboniferous and Permian age.

Sample 1 (No. 20 in Table 1). Coal from the mine Hsian Chia Kou on the pass of a high mountain range between Li Tze Wei and the coal mine Lan Lu Tung 30 li S.E. of Kuan Ku Tschau, Kuang An Hsien (廣安縣).

Megascopically this coal is composed of alternating bands of bright and dull coal. Under the microscope the polished section shows that the bright band is not homogeneous as the ordinary vitrain, but is mixed with many small grains of ashy matter and pyrite, the latter is more large and irregular in form. In the dull

6. Haus Bode: Zur Nomenclatur in der Kohlenpetrographie, Kohle u. Erz. 1928, p. 699-708.

7. M. C. Stopes: On the four visible ingredients in banded bituminous coal. Proc. Roy. Soc. B. Vol. 90, 1919, p. 470-487.

band or durain ash forms the most conspicuous contituents; it occurs never as continuous band or layer, but simply as an aggregate of many small grains which on account of their high resistence to polishing stand very prominent in the section.

Sample 2 (No. 21). Coal from the mine Lan Lung Tang, 45 li S. S. W. from Tien she, 60 li S. E. from Kuang An Hsien.

The coal is badly crushed showing a glancing luster and several systems of cleavages. It is very soft and friable breaking usually into thin flakes or irregular fragments.

A study of the polished section reveals the fact that this coal is composed principally of vitrain with here and there the intercalated lenses or fragements of fusain which can be easily recognized from its cellular structure. Ashy matter is present, but not abundant. Fine grains of pyrite are found to dessiminate throughout the mass. Rests of cutinized matter such as cuticles, spores, etc. have so far not been observed; evidently they have been destroyed during the process of coalification.

The maceration product gives nothing else than fragments of fusain and undecomposed bituminous matter.

Sample 3 (No. 22). Coal from Liang Sü Chin, 10 li N. E. of Tien She and 40 li S.W. of Kuang An Hsien (廣安縣).

This is a typical banded coal of alternating vitrain and durain, in the latter many ashes are present. Fusain is very abundant forming sometimes long slender lenticles. In the durain, besides the bituminous ground mass and the ashy matter, is in certain layers abundant cuticles and spore-exines. Both microspore and megaspore are observed, the former appears under the microscope as tiny flakes of yellow color and is present in only a moderate amount. Megaspore exine is rather rare. Pl. I, Fig. 1—shows the general appearance of the coal under the microscope.

The maceration products of this coal contain the following:

(1) Abundant anguler fragments of quartz, feldspar and other mineral matter.

(2) Many cuticles of different kinds, most of them showing an undulating cell walls and a roughly four or five sided polygonal to rounded or irregular cells. A few of the cuticles show also a rectangular cells with straight cell walls.

(3) Some fusain generally occurs in prismatic form and with a thin translucent border.

(4) A brownish colored sclerotio tissue with very thick and strong cell walls, a picture of which is shown in Pl. I, Fig. 2. The exact nature of this tissue is at present unable to determine.

(5) Many irregular fragments of deep brown color probably represent the remains of megaspore exines.

(6) Microspore exines of many different kinds. The most abundant microspore in this coal is a brownish colored, nearly rounded one showing frequently clear tetrasporic markings. Its surface is skulptured by a dense system of serpentine ridges and its edge is a little zigzag, but in no case to show any trace of spines or appendages. The observed diameter varies from 70-90 u.

Another kind of spore exine is of light yellow color, having a triangular form and very smooth surface. Tetrasporic marking is generally distinctly shown. In size this is smaller than the one just mentioned being only 30-40 u in diameter.

Still another kind of microspore exine shows what similar to above one a sculptured surface and a brownish color but differ from it by the presence of a ring. This kind of spore exine is however very rare.

Sample 4 (No. 4). Coal from the mine Ban Ge Kou, 15 li S. S. E. from Nan Chuan. Sample was taken from the upper portion of the seam.

The coal in question is a highly glanced and badly crushed one with the development of an extensive system of cleavage. Banding is only faintly seen. Under the microscope the banding character is revealed by the existence of layers of durain and vitrain, but their contact are more transitional rather than sharp. In the durain are found many ashy matter, fusain fragments and some other bituminous substances. Spore exines and cuticles are very rarely preserved, if not entirely absent.

Sample 5 (No. 38). Coal from the "Kohlen kalk" 7 li E. of Ma-ling Wan, 35 li N. of An Yuan (安縣).

This is a half brilliant bituminous coal. Under the microscope it is seen to be composed principally of vitrain with intervening lenses or fragments of fusain in which cellular structure is clearly preserved. It contains practically no spores or cuticles. Ashy matter is rarely to be found, therefore it is a coal of high grade. Very fine grains of pyrite occurs as dessiminations in the whole mass. The study of thin section gives exactly the same result as obtained from the polished section.

The maceration leaves very few things behind. This is quite to be expected from what has been studied microscopically. Fusain is perhaps the only prominent

constituent among the residue; besides there is also some rounded, dark bituminous matter. A broken megaspore is isolated; by approximate estimate it is found to have a diameter about 560 U: It is a spore of the ringed type and shows besides also a rough surface.

Sample 6 and 7: In Cremer's collection there are two samples from the westernmost Szechuan, i. e. near the boundary between Szechuan Proper and the Chuan-pien province. The coal sample consists of very small pieces and moreover is too much crushed, so that it is not suitable for making either polished or thin sections. So far only one polished section has been made. Under the microscope this section shows in the main a vitrain with here and there thin lenses or streaks of ashy matter fusain in forms of twigs and isolated fragments are rather abundant. Cutinized materials such as spore exines and cuticles are not observed. Therefore it indicates a product of advanced coalification.

By maceration this coal leaves behind very few things; a great part is dissolved by Ammonia. Fusain and mineral matter form the principal constituents. Some small pieces of wood, cuticles, and some tissue showing the characteristic "Sclarariform" cells are occasionally observed. Spore exines are surely not observed.

2. Coals of Jurassic age.

Sample 8 (No. 1). Coal from the mine Tai Shan Miau near Lung Wang, 20 li N.W. from Kueichow (i e. Feng Chieh Hsien).

To the naked eye the coal is distinctly banded and shows a high glance. Under the microscope it is seen to be composed of great amount of ash which occurs as lenses, layers and small grains uniformly distributed in a bright ground mass of vitrainic nature. The lenticular form of the ash is especially characteristic such as shown in Pl. I fig. 3. All lenses are regularly arranged with their longer axes parallel to the bedding planes. They are of different sizes, some of the larger ones reaching a length of 0.7 mm and a width of 0.2 mm. Fusain is very rare. Spore exines and cuticles have not been observed. It seems that here the coalification process has been so advanced that any trace of vegetable constituents that may exist have been almost entirely destroyed.

The maceration product leaves nothing important except some fusain and an abundant amount of mineral matter. One interesting thing is the occurrence here of an amorphous clayey substance exhibiting a pseudocellular structure. Such structure is also observed in the clayey substances from a coal near Chungking to be described later. As the cellular structure here is less marked than the Chungking coal, therefore its inorganic nature is established without any doubt.

Sample 9 (No. 23). Coal from the mine Chên Chia Shan, 15 li S. E. from Kuan Yin Kou, 90 li S. W. from Kühsien.

This is principally a matt coal with frequent bands of glance coal. It is much crushed showing here and there slicken-sides. Under the microscope the coal is seen to be composed of broad bands of durain intercalated with lenses of vitrain, the size of which varies from mere a thread (15-20 uu thick) to bands of several mm. in width. They are mostly discontinuous and are of short length.

In the durain is seen besides the mineral matter a great amount of microspore exines; they appear as thin and tiny flecks showing a grayish yellow color and have a length of 20-40 u. A very characteristic structure here is the occurrence of vitrain lenses which form very often cross bands or threads of most confusing manner traversing from one durite to another. In fact these two constituents here are so closely associated and to form such an intricate and delicate structure that a well separation between the two is almost impossible. This intimate intergrowth of vitrain in durain may be taken as to indicate, during the time of coal formation, a colloidal and fluidal state of the humic matter from which vitrain was formed. Because of its soft and fluidal nature, it was then possible for the humic matter to penetrate or to fill in whatever open spaces then may exist in that half consolidated slimy mass which afterwards to become the durain layers.

Cuticles are very abundant most of them are exceptionally long and thick reaching sometimes over 6 or more mm. in length. (Pl. I Fig. 4 & Pl. II Fig. 5).

Fusain is present but in an insignificant amount. It forms lenticular bands, needles, or isolated fragment.

Macerated products contain fusain, slices of woods, cuticles, fragments of megaspore and aggregates of microspore exines. Wood slices are very abundant, but none of them show the bordered pits or other diagnostic characters, so that their nature can not be determined. Woody tissue with the characteristic sclarariform thickening cells are in this coal especially common and well preserved. Cuticles are badly preserved, only small fragmentary pieces were found. It seems that most of the cuticles show a straight cell walls. The microspore exines show almost the same character as those found in coal from Jung Hsien (which is to be described later) i.e. a triangular shaped yellowish colored spore with distinct tetrasporic markings. It is a curious fact that nearly all the spores occur in aggregated form, therefore single, isolated ones are very rare to find. The aggregate assumes an oval to rounded form with a diameter about 370 u. The size of a single exine measures only 36 u.

Sample 10 (No. 24). Coal from a high mountain near Yen Tang Wan, on the right bank of Kü-ho, 80 li above San Hui, Kü Hsien, Sui Ting Fu.

To the naked eye this coal is in the main a glance coal in which durain and fusain are inter-banded. It is a coal of high quality.

When seen under the microscope it is found that the bands of vitrain and durain are almost equally distributed and are of almost equal size. They show about the same luster and color and will not be differentiated without a careful study. The vitrain bands which reach here a thickness from 2 mm. or more are rather continuous. Some vitrain showing woody structure is also found.

The chief character by which durain can be distinguished from the vitrain is through the inhomogenity of the former. Among the different ingredients found in the durain, cuticles are especially abundant, then comes exines of microspore and ashy matter.

Fusain is rather abundant occurring in long band or irregular fragments. Cellular structure is always clearly shown. In some fusain it can be seen that the cellular structure gradually disappears when trace from one end to another and finally to wholly structureless vitrain.

A very interesting feature of this coal is the presence of numerous veinlets of calcite which crossing both durain and vitrain in a most confused way. That the calcite is of secondary origin and has no relation with the coal deposition is shown clearly by its structure (See Pl. II, fig. 6).

The study of thin sections gives exactly the same results. It is in the main a vitrain in which is intercalated by fine streaks or lenses of fusain, cuticles, and microspore exines. The presence of calcite veinlets is especially convincing as the mineral can be easily identified by its optical characters such as cleavages and birefringence.

The macerated products contain, among other things, many fusain in form of fragments or needles, the latter form is especially characteristic for that substance, being derived from its cellular structure.

Cuticles are rather abundant; their cells are comparatively small, rather long streatched with gently undulating cell walls. Both megaspore and microspore exines are present, the former is deep brown in color showing a circular outline, and a smooth surface. Only few of them have the tetrasporic marking clearly shown. They have a diameter about 300 u.

Microspore exine is rather rare. Probably it consists of only two kinds: (1) the egg-shaped, smooth surfaced spore with a size 56 u X 48 u. (2) the triangular,

light yellowish colored spore with tetrasporic markings nearly always clearly shown. Its diameter measures about 48 u. Woody tissue showing spiral-form cells is also found in this coal.

Sample 11 (No. 8). Coal from Hsiang Ku, 15 li S. W. from Li Yuan Pa, Chung King Fu.

As seen by the naked eye, this coal is composed of broad bands of glance coal with only a small portion of dull coal. The coal has evidently suffered a great amount of compression, by which all bands are smashed together in a most complicate and confused manner. Another sign of the tectonic movement is evidenced by the cleavage which is here also strongly developed.

Under the microscope the dull coal is seen to be composed almost entirely of fusain which occurs in various forms such as lenticular bands, twigs, fragments, grains or even fine powders. In the fragmentary state, although being broken and devoid of any structure, the fusain can still be recognized as such by its peculiar forms (as needle shapes etc) and especially by its high relief as compared with the rest of the mass. Ashy matter is also present. As to spore exines or cuticles are here exceptionally rare, if they are not entirely absent.

The bright band of the coal is vitrain, but it is not entirely homogeneous, because in it is also found some fusain and occasionally ashy matter.

A study of the thin section confirms the existence of many fusain which is irregularly arranged in a humic ground mass. At one spot is seen a horizontal section of fusain, the cells of which are filled by quartz.

The macerated products contain chiefly fusain and undecomposed bituminous matter. It leaves almost nothing of the cutized matter such as spore exines and cuticles. What is of extreme interest is the reappearance in the maceration residue of an amorphous clayey substance with pseudocellular structure which bears close resemblance with the one described in foregoing pages. This clayey mass is yellowish white in color, very thinly sliced, therefore it resemblances closely with the cuticles. Under the microscope it shows somewhat a cellular structure (see Pl. II, fig. 8) but this structure is too irregular to be of organic origin. It shows no birefringence, therefore it is probably an amorphous substance of clayey nature.

Sample 12. Coal from the right bank of Kiu Ling Kiang, at the S. E. end of Kuan Hsia gorge, above Tu Tai between Chung King and Ho Chow. The sample was taken from the lowest part of a seam lying directly above the limestone.

In hand specimen this coal is mainly a bright coal, but when seen under the microscope, the bright band is again resolved into a number of constituents which

consist chiefly of microspore exines and cuticles, therefore it is in the main a glancing durain. Fusain in forms of fragments, twigs or lenses is present. Some rounded grains are probably resinous matter. Small grains of pyrite are seen to be scattered here and there in the mass.

In another specimen from the same locality, the coal shows a clear banding, which is more distinct when seen under the microscope. Bands of vitrain are alternately interlayered with durain, in latter, besides cuticles and microspore exines there is also a great amount of ash occurring either as lenticular layers or as fine streaks. Cuticles are especially characteristic and abundant. Pl. III, Fig. 9 is a microphoto of the coal showing its general structure and different constituents.

A study of the thin section gives nothing new than what is observed from the polished section. The ashy matter is identified to be mostly quartz which occurs either as small angular fragments distributed through the durain or to form a lenticular band of its own; in this case it is in reality a "microscopic parting".

The maceration products leave behind cuticles, fusain, undecomposed bituminous matter and what is of most interesting is the presence of many varied forms of spore exines.

Both microspore and megaspore exines are found, but the former is by far the more abundant. According to its forms, the microspore exines may be divided into three different types.

(1) Microspore exine of rounded triangular shape. The spore is bordered by a ring and shows nearly always a distinct tetrasporic marking. Its surface is rather rough and its edge is appended with many short delicate spines. The size of the exine amounts to 45 u, while the thickness of the ring is only 9 u.

(2) Microspore exine of the the same shape as (1) but without a ring. It differs further from the above by the absence of spines and ornamentation, therefore a quite smooth surfaced and neatly outlined microspores. In size it is a little smaller than the previous one measuring only 36 u in diameter.

(3) An egg-shaped microspore shows also a distinct ring. In size it is 45 u X 58 u while the thickness of the ring is about 9 u. It has also a smooth surface and is free from any ornamentation or spines.

The cuticles show generally a long streatched cells with straight cell walls which are very thin, a microphoto of such cuticles is shown in Pl. III, fig. 10.

Sample 13 (No. 18). Coal from Mutzetou on the right bank of Kia Ling Kiang at the beginning of the Niu Pi or Niu Kung gorge which is the third gorge above Tu Tou between Chung King and Ho Chow.

This is a distinctly banded coal of bright and dull layers, the former is generally more narrow and lenticular than the latter. Under the microscope the bright band is composed entirely of vitrain which is here very homogeneous and showing no structure at all. The durain is characterized by an abundance of cuticle and pyrite, the latter in forms of tiny particles is found to be densely distributed in the mass. Some microspore exines are surely present. Twigs of fusain and also isolated fragments or grains of the same substance are commonly observed in the durain layer.

Pyrite is not only abundant in the durain, but is also common as a filling in the cells of fusain. The open cellular structure of the fusain has become most suitable for the deposition of pyrite which is evidently of secondary origin. The reducing action of the charcoal which the fusain is mainly composed of, seems to have also some influence upon the deposition of pyrite.

Examination of the thin section confirms the existence of many fusain and cuticles, the latter ore especially abundant and characteristic.

A study of the maceration products from this coal shows that fusain and cuticles are among the most abundant constituents. Some microspore exines of reddish brown color with an apparent tetrasporic marking are found; they are triangular in shape, exhibiting a rough surface and with tiny spine-like ornamentations. An aggregate of such spore exine is also observed. On the whole spore exines are not very abundant in this coal.

Cuticles are very abundant and moveover are the most beautifully preserved ones that one can ever see. I have succeded to isolate and to prepare two big cuticles measuring about 4 mm in length. They show under the microscope every details of what a cuticle from the living plant should give. In the lower side of the cuticle it shows a dense distribution of stomatic openings (amounts to about 150 per sq. mm.) and some drusses while in the upper side, no stomatic openings can be seen, but a large number of rounded granules which are supposed to be the coalified cell contents. These granules are especially abundant near the veins. In Pl. IV, fig. 14, the highly magnified veiw of the upper cuticles, one can see very clearly the cells and their cell contents, the latter are more or less angular being located not in the center but rather attached to some sides of the cells. In regard to the nature of these cell contents, their composition and their physiographic function, I can say at present nothing definite. They are probably not the chlorophyll, because the latter is much smaller and is so soft and delicate that it could perhaps never be preserved. In this connection, I should mention that

Bertrand[8] and Zimmermann[9] have described and figured somewhat similar structures which they supposed to be the nucleus of the epidermal cells. Along the vein courses of the cuticles vascular bundles with its characteristic spiral forms of cell thickening can be distinctly observed. A highly magnified view of the stomatic opening is shown in Pl. IV, fig. 15.

Thomas and Bancroft[10] in their study on the cuticles of recent and fossil cycadean fronds have distinguished among the fossil cuticles, two main groups as follows:

(1) Group of Bennettitales including Ptilophyllum, Otozamites, Dictyozamites and Zamites. This group is characterized by undulating epidermal cell walls and comparatively thin cuticles. The cells are in general rectangular in shape. The stomata occur only on the lower side of the leaf and are usually absent below the vein courses. The guard cells of the stomata were level with the surface or only slightly sunk. They are characterized by a thickening which appears as lamellæ of definite shape.

(2) Cuticles of this group including Nilssonia, Ctenis, and Ptilozamites are characterized by cells of elongated, rectangular, rounded or fusiform shapes with straight walls. The stomata exhibit no regular arrangement. The guard cells are deeply sunken with no definite lamellar thickenings and the six or eight thickened subsidiary cells which surround them often form a somewhat overarching canopy.

The stomatal structure of the cuticles isolated from the coal of Mu Tze Tou presents some similarity to the cuticles of the first group of Thomas and Bancroft. The only difference is the form of epidermal cells which in this case is smaller and hexagonal in shape and with straight cell walls.

Besides these exceptionally well preserved cuticles described above, there are many other cuticles generally with a rectangular epidermal cells and half undulating to only slighly undulating cell walls, the latter are rather thick. (Pl IV, fig. 16).

Sample 14 (No. 9). Coal from Tu Tai, 30 li S.S.W. from Kan Shui on Kikiang. The sample was taken from the mine She Ban Teng 2 li S. from Tu Tai.

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8. M. C. Eg. Bertrand: Ce que les coupes minces des Charbons de terre nous ont affris sur leurs modes de formation. Congrss intern. mines Métall, Mécan., Géol, Liège, 1905.

9. W. Zimmermann: Die spaltöffnungen der Psilophyta und Psilotales. Zeits fûr Botanik, 19 Band, 1926, p. 153.

10 H. H. Thomas & N. Bancroft: On the cuticles of some recent and fossil cycadean fronds. Trans. Linnean Soc. London, Vol. 8, pt. 5, 1913.

This coal is exceptionally rich in fusain which is black and dull and is so friable that during grinding and polishing it always broke into pieces and yield therefore no good polishing surface.

In one of the polished sections prepared there shows under the microscope a broad band of vitrain into which is invaded by an aggregate of fusain. The latter is composed in the main of broken fragments of fusain which are irregularly arranged and are being cemented by ashy matter.

In one polished section one can see clearly the preservation of bast fibers as is shown in Pl. V, fig. 17.

Sample 15 (No. 29). Coal from the mine Kwei Yang Chen, 8 li N. of Jung Hsien, Kia Ting Fu.

This is a beautifully banded coal of bright and dull layer, the former maintains sometimes a thickness of half an inch or more.

Under the microscope the dull layer is seen to be composed of ashy matter, microspore exines, cuticles, fusain and probably also resinous matter. In certain layer of durain only ashy matter in form of lenticular masses is found. Fusain is very abundant, some of them is of immense size. Megaspore exine is not observed. Pl. V, fig. 18 & 19 show general microscopical appearance of the coal.

After maceration the coal leaves behind many cuticles, fusain and a few microspore exines. The cuticles are extremely abundant showing a great many forms, the most abundant of which is, however, a rectangular cells with thick and half undulating cell walls. The form of cells of the lower cuticle is distinctly different from the upper one, especially when one compares the cells around the stromatic openings (see Pl. V, fig. 20). Cuticles with more polygonal-shaped cells and extremely undulating cell walls have also been observed, but they are not so abundant as the other kind. Another kind of cuticle seems to have a rectangular to cubic shaped cell and possess a straight cell wall.

Microspore exines are distinctly of two kinds:

(1) The light colored, triangular shaped spore with always distinct tetrasporic markings. They are common not only in this coal but also in many of the other coal herewith studied

(2) A rounded brownish colored spore showing a smooth surface, and a diameter of about 12 u. Spore aggregate such as found in Sample 17 of this group (to be described later) is also observed here.

Sample 16 (No. 31). Coal from the mine Chin Ling Fan, 24 li N. N. W. from Jung Hsien, Kia Ting Fu.

Both in hand specimen and under the microscope, this coal is a distinctly banded one, but the bands of bright and dull coal are often arranged in a confusing manner. The vitrain band is narrow and lenticular showing sometimes a not undistinct woody structure. The durain on the other hand, is rather broad and persistent, and is extremely rich in ashy matter, besides which one can also see in the same band abundant fragments of fusain, some cuticles and also exines of both micro-and megaspores. The microscopic structure as a whole resembles quite closely the coal just described, but here it is more durainic and contains more ash.

Fusain is present, very often occurring in long and broad band representing evidently a single twig. In one of these twigs it shows in the center a band of undisturbed and well preserved cells while both above and below it, the cells have been pressed and smashed to form the characteristic "bogen structure" (Pl. VI, fig. 21). Such a difference in preservation can only be due to the different nature of the wood cells, since the amount of pressure acted on the wood must have been the same in all parts. It is a well known fact that the cells of the autumn wood is generally more strong and thick walled than that of the spring wood. Consequently when a piece of wood is subjected to pressure or more generally speaking to the process of geological decomposition, the summer wood would nearly always be more smashed and destroyed than that of the autumn wood which in many cases is well preserved. Such phenomena have been frequently observed in the study of fossil woods. By applying this principle to the present case then it is easy to see that the central band of well preserved wood should correspond to the autumn wood, while the cells both above and beneath it belong evidently to the spring wood. In other words we have here a fusain which shows clearly the existence of annual ring. Since Palæobotanical study has informed us that the growth of annual ring was not existed in geological period until Jurassic, therefore, from this single microscopical investigation we can fairly well conclude that the age of this coal must also not be older than Jurassic. As a matter of fact this coal is really of Jurassic age, so it agress quite well with what the above conclusion has reached.

The result obtained by the study of thin section agrees precisely with that from the polished section. The coal represents as a whole an ash-rich durain with many lenses of vitrain. The ashy matter consists mostly of quartz which is here very fine grained and is uniformly distributed through the mass. Cuticles are very abundant. What is of most interesting is the presence of many megaspore exines which in thin section are much more striking and better shown than in the polished section. Some megaspore shows the so-called "zangen" structure of

Lange.[11] The following is a list of some measurement on the sizes of the megaspore in this coal:

	Length	Thickness of wall	Remarks
1	448 uu	14 uu	Edge with indentation
2	336 „	4-6 „	Edge a little indentated
3	528 „	6-8 „	Straight edge, shows "zangen" structure.
4	336 u	8 u	Edge indentated with some small appendages at one end.
5	224 u	8 u	Straight edge.

Besides the megaspore exines just mentioned, there is present in this coal a peculiar shaped brown bituminous body, the nature of which is at present not able to determine. It is 256 u. long and 48 u broad showing an undistinct sculpture on its surface.

The maceration study of this coal proves the existence of many cuticles and several megaspore exines, the latter are isolated and studied. These bodies have a diameter varying between 279-405 u, which is fairly in agree with the measurements in the thin section. They are perfectly rounded, rather smooth and of often show distinct tetrasporic marking. In one of the megaspore exine one can still see traces of spines attached to the spore wall. This character is also observed in the thin section as has just been described.

Cuticles are mostly so badly preserved that distinct structure can not be made out. A few cuticles with undulating cell walls have been observed (Pl. VI, Fig. 22). The macerated product contains also a great amount of mineral fragments among which quartz is the most important constituents.

Sample 17 (No. 32). Coal from the mine Ken Ko, 53 li N. W. from Jung Hsien, Kia Ting Fu.

This also a banded coal in which bands of bright coal are more frequent and more wide than the dull coal; therefore it is a coal of more vitrain than durain.

Microscopical study of the polished section shows the durain to be composed of a bright ground mass in which is inserted cuticles, microspore exines, fragments of fusain and probably also resinous matter. Grains and fragments of ashy matter are also present.

Fusain is extremely abundant in this coal forming fragments, lenses or layers of some persistence. (Pl. VI, fig. 23). It shows all kinds of cellular structures

11. Th. Lange: Zur Kohlenpetrographie Oberschlesiens. Z. d. Oberschl. Berg. M. Hutten m. Ver., 1920.

varying from coarse granular cells to fine and lamella ones. The isolated fragments of fusain which occur so abundantly in this coal can easily be recognized by their high relief in the section.

The study of thin section gives exactly the same result. It shows the exist of many fusain, cuticles etc. in a vitrainic groundmass.

The maceration product contains many fusain, spore exines of both micro and mega-type, tissues of sporangean wall and finally cuticles of many different kinds.

It seems that here in this coal we have three different kinds of microspore exines:

(1) Microspore exine of rounded triangular shape shows a smooth surface and nearly always a distinct tetrasporic marking. In size it varies from 54 u-72 u in diameter. Very frequently an aggregate of such microspore—evidently representing the original aggregating mass in a sporangian—is found (see Pl. VI, Fig. 24). Such aggregates are so compactly packed together that it is not easy to separate apart each of the single spore even with a hard force. Same phenomena was observed by A. G. Nathorst[12] who explained that such aggregates represent unriped spores in a not yet opened sporangean. Nathorst further remarked that it is remarkable such unriped spores had possessed a very resistent cutinized wall. The size of these spore aggregates has been measured to vary from 300-400 u or more.

(2) Round microspore exine a smooth surface. In size this is a little smaller than (1). This type is however exceedingly rare.

(3) Rounded spore exine with a rough surface. This is also very rare and has a size a little larger than (1).

Several megaspore exines were isolated among which at least two types may be distinguished:

(1) A deep brown megaspore exine shows smooth surface and thick cell wall. This particular type is unfortunatly broken and fragmentary; by approximate estimate its diameter may be given as 1.04 mm. (2) A better preserved megaspore of about 0.3 mm. in diameter. It is rounded in form and shows many spines.

Cuticles are very abundant and are of different kinds. Most of the cuticles have their cell walls distinctly undulating. The form of cell vary from rounded to polygonal. Long streached cells with straight cell walls are also common in this coal.

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12. A. G. Nathorst: Über die Untersuchung kutinisierter fossiler Pflangenteile, pp. 9, Palaobotanische mitteilungen 4-0, 1908.

Sample 18 (No. 36). Coal from a mine 5 li S. E. from Schuang Ho Tschang, 60 li S. from Hsu Chou Fu (now I Ping Hsien).

This is a distinctly banded coal with more bands of dull coal than bright coal.

Under the microscope it is seen that the bright band is composed entirely of vitrain. The durain contains chiefly fragments of fusain and also some ashy matter. In one of the fusain twigs the cellular stucture is beautifully preserved with the indication of annual ring.

Sample 19 (No. 37). Coal from a mine at 2 li S. from Ma Tou Shan, 90 li W. from Tsching Fu Hsien, Hsu Fu.

This is a dull looking coal containing an exceptionally rich content of fusain which are scattering in the coal in a most irregular way. Cellular structure in the fusain is always well preserved. Some of the fusain twigs are of immense size measuring several centimeter in length and breadth. Pyrite grains are sometimes found to fill up the cell spaces of the fusain.

V. CONCLUSION.

The present investigation intends only to describe the microscopical structure as well as constituents of the coals studied. Altogether 19 samples of coal were investigated, among which 6 are of Carboniferous age and the rest belongs to Jurassic.

The microscopic appearance of these coals presents a great many of different forms. The three principal constituents of the coal, namely durain, vitrain and fusain are found to distribute in different ways and in different proportions. No definite relation seems to exist between the geological age of the coal and the presence or proportion of any of these constituents. In some of the Carboniferous and also of Jurassic coals, an account of the advanced coalification, vitrain or glancing durain forms the principal constituents. Fusain is nearly always present occurring in various forms of twigs, bands, lenses, fragments or fine powders.

Ashes are very abundant in most of the coals studied; they affect in a great deal the quality of the coals. Three different forms of occurrence of the ashes are found, namely: (1) In narrow bands or streaks (2) In lenticular fragments regularly distributed with their longer axis parallel to the bedding planes. (3) In spine powders or fragments densely distributed through the durain.

As to the mineralogical composition of the ashes, it is found to be mostly quartz and clayey substance, in rare instances are also feldspar, mica etc.

Exines of microspores are found in many of the coals studied, only in few cases are they rarely preserved. On the other hand, the exines of megaspore are generally very rare. They are found in moderate amount only in Jurassic coal from Chin Lin Fan, N. of Jung Hsien. The rareness of megaspore is quite to be expected, because the Pteridophyta of the Mesozoic time were characterized generally by plants of isosporic kinds.

Cuticles are generally better preserved in the case of Jurassic coal than that of the Carboniferous age. According to the forms of cells and the nature of the cell walls, the cuticles can be divided into three groups as follows:

(1) Rectangular cells with straight cell walls.

(2) Rectangular cells with half undulating cell walls.

(3) Polygonal cells with undulating cell walls.

According to Nathorst[13], Thomas and Bancroft[14] and Gothan[15], the cuticles of undulating cell walls belong in most cases to Bennettitales, whils those with straight cell walls probably belong to Nilssonia & certain Pterophyllum.

An exceptionally well-preserved cuticle was isolated from the coal of Mu Tze Tou between Chung King and Ho Chow. This cuticle shows a very small polygonal or hexagonal cell with straight cell wall; in the cells coalified cell contents of unknown nature are found. It is further characterized by the presence of densely distributed stomatic opening, the structure of which points some similarity to forms described by Thomas and Bancroft as characteristic for Bennettitales.

Most of the cuticles showing the typical undulating cell walls are found in the Jurassic coal, but some of them have also been observed in the Carboniferous coal, such as the coal of Kuang An Hsien.

In a general way the microscopic criteria of Bode[16] for distinguishing Mesozoic coal and Paleozoic coal can very well be applied here, although certain deviations from the general rule seems to exist, such as the existence of many megaspore in a Jurassic coal of Chin Lin Fan, N. Jung Hsien and the finding of undulating epidermal cell walls in a carboniferous coals of Kwang An Hsien.

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13. A. G. Nathorst: Einige palaeobotanische Untersuchungs methoden.- Palaeobot. Zeitschr. 1, 1, 1912.

14. Op. cit.

15. W. Gothan: Unterliassische Flora von Nüruberg. Abh. Naturh. Ges. Nüruberg, Bd. 19. 1914.

16. H. Bode: Stratigraph. Wert der Kohlenpetrographie, Glückauf, 1929.

TABLE I.

Analysis of some coals from Szechuan. (after Cremer).

	Locality	Water %	Volatile matter %	Ash %	Property of co.	Geological age.
1.*	Lung Wang, 20 li N. W. Kweilin	1.28	6.42	32.91	pulverig	Jura.
2.	Pu Chen, 50 li N. Wang Hsien.	1.00	17.57	36.09	gebacken	
3.*	Ban Ge Kou, 15 li S. S. E. Nan Chuan.	0.75	11.35	8.98	gesintert	Carbon.
4.	Same as 3, upper part of the seam.	0.68	9.77	15.35	schwach gesintert	"
5.	Ho Shai Bien, 25 li S. E. Nan Chuan.	6.75	17.50	16.10	pulverig	Carbon.
6.	Ho Shai Bien, 25 li S. E. Nan Chuan.	0.00	8.03	4.63	schwach gesintert	"
7.	Mei Tan Kou on the Tjien Fu Shan.	1.68	9.30	11.04	pulverig	"
8.*	Hsiang Ku, 15 li N. W. Li Yün Pa.	0.33	17.47	5.53	Schaumig	Jura.
9.*	Tu Tai, 30 li S. S. W. Kan Shui.	1.10	19.39	24.30	gebacken	"
10.	Pei Ta in Miao Erh Hsia.	1.70	27.43	34.43	"	"
11.	She Yen Kou, 6 li E. Wön Tang.	1.87	22.25	27.70	"	"
12.	Wa Kuan Tiao in Huang Tsan Hsia.	0.98	19.09	10.84	"	"
13.	Lung Wang Tung, 40 li N. E. She Tze Kou.	1.07	32.67	5.30	"	"
14.	Chang Chi Kan, 110 li N. E. Tu Tou.	1.16	27.34	18.90	Schaumig	"
15.	Orh Ma Tou in Kuan Hsia upper seam.	1.78	24.50	16.56	gebacken	"
16	Orh Ma Tou in Kuan Hsia lower seam.	1.23	24.84	26.33	Schaumig	"
17.	Orh Ko in Won Tang Hsia.	1.67	23.05	34.11	gebacken	"
18.*	Mu Tze Tou in Niu Kung Hsia.	1.47	22.31	17.13	"	"
19.	Pei Liang Wan, W. Wön Tang Hsia.	1.91	17.17	27.92	"	"
20.*	Hsian Chia Kou, E. of Li Tze Wei.	0.76	14.73	14.01	Schaumig	Carbon.
21.*	Lau Lung Tung, E. Hsian Chia Kou.	0.63	19.42	9.08	"	"
22.*	Liang Su Chin, 10 li W. Tien She.	1.20	23.89	28.	gebacken	"
23.*	Che Chia Shan, 15 li S. E. Kuan Yin Kou.	1.38	20.20	5.57	"	Jura.
24.*	Yeh Tang Wan, 80 li above Sanhui.	1.25	30.80	4.34	Schaumig	"
25.	Ta Ku Men, 35 li W. N. W. Sui Ting Fu.	1.03	19.40	6.23	gebacken	"
26.	Huang Chia Kou, 15 li N. W. Pu Tung Tze.	0.52	18.27	23.30	Schaumig	"
27.	Hsu Chia Ho, 20 li N. Kuang Yuen Hsien.	1.91	36.32	8.85	"	"
28.	Chao Tien Chen	1.19	15.24	39.97	pulverig	Carbon.
29.*	Kuei Yin Chow 8 li N. Yung Hsien.	1.60	27.60	27.25	Schaumig	Jura.
30.	Tung Chia Men, 20 li N. N. W. Yung Hsien.	1.43	20.28	25.59	schwach gesintert	"
31.*	Ting Ling Fan, 16 li N. N. W. Yung Hsien.	1.38	22.48	32.04	gebacken	"
32.*	Kau Ko 53 li N. W. Yung Hsien.	1.75	29.03	6.25	Schaumig	"
33.*	Lung Pa Pu.	3.31	12.19	12.40	pulverig	Carbon.
34.*	Hsiang Lo Ying 150 li W. Tien Chuan Chow.	1.37	7.84	42.96	"	"
35.	Suang Ho Chuang, 40 li N. W. Lu Shan Hsien	1.96	14.70	47.52	"	"
36.*	Shuang Ho Chuang, 60 li S. Siu Fu.	0.80	23.66	15.38	"	Jura.
37.*	Ma Tou Shan, 90 li W. King Fu Hsien.	1.94	4.68	27.18	"	"
38.*	Ma Ling Wan, 35 li N. An Hsien.					

* Specimens have been studied microscopically.

EXPLANATION OF PLATE I

PLATE I.

Fig. 1. Polished section of a coal from Liang Sü Chin, Kuang An Hsien. The picture shows a durain with narrow lenses of vitrain. In the durain is found numerous exines of microspore, cuticles (upper portion), resin bodies (gray and rounded body) and ash particles (black fragments (a)). Age: Carboniferous. Magnification ×95.

Fig. 2. A reddish brown colored sclerotio tissue isolated from the coal by maceration, locality same as fig. 1. ×87.

Fig. 3. Polished section shows a durain with thin layers of vitrain. The black lenticular fragments are ashy matter which is mostly quartz. Lung Wang, Feng Chieh Hsien. E. Szechuan. Jurassic. ×55.

Fig. 4. Polished section of a coal from Kuan Yin Kou, Kühsien. It shows an ash-rich durain with cuticles (lower middle part) and fragments of megaspore. Exines of microspore are abundant in the durain but they are not distinctly shown in the picture. Jurassic. ×60.

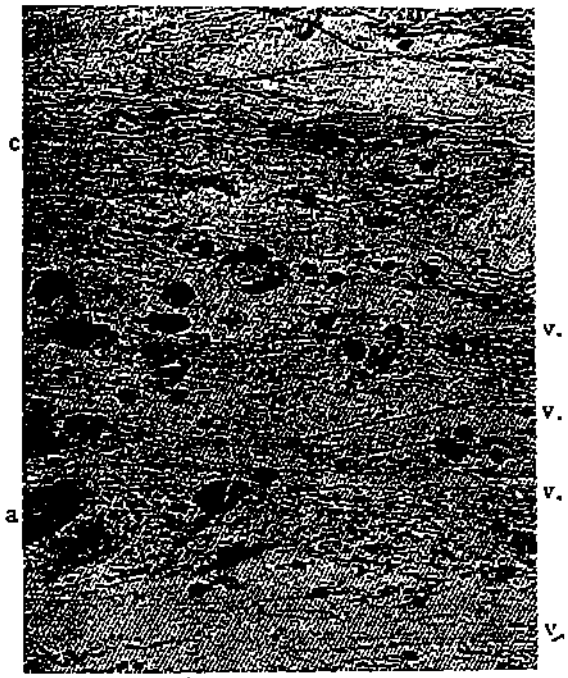

Fig. 1.

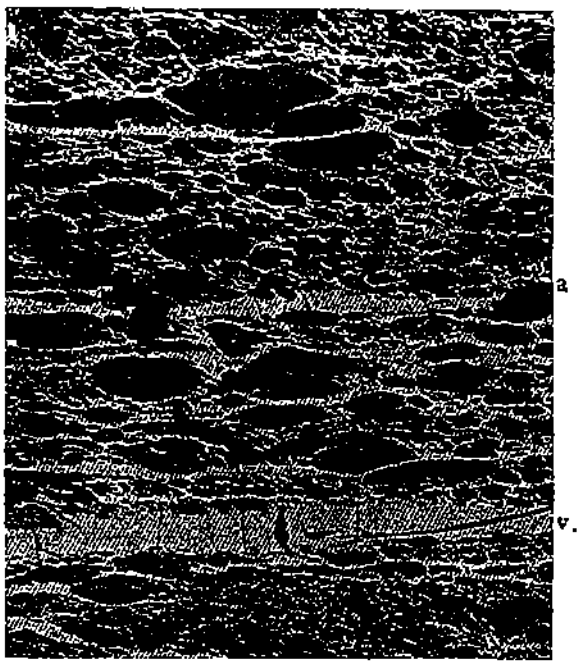

Fig. 3

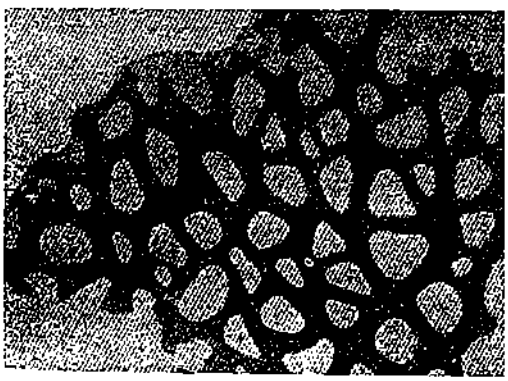

Fig. 2

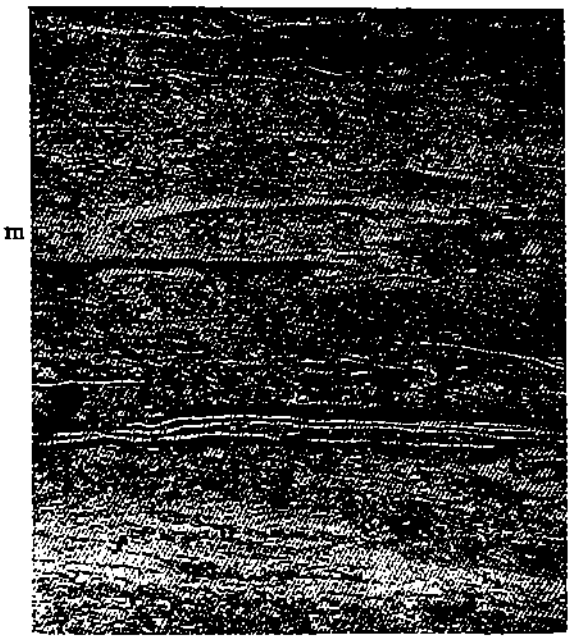

Fig. 4

EXPLANATION OF PLATE II

PLATE II.

Fig. 5. Another picture of polished section of coal from Kuan Yin Kou, shows a durain with broad band of vitrain (v) and several cuticles (c). The end of the vitrain band is marked here by its sharp, dentated form evidently representing a broken piece of wood. ×33.

Fig. 6. Polished section of a coal from Yen Tan Wan, Kü hsien. It shows a glancing durain intercalated with bands of vitrain (two bands in the lower and one band in the upper portion v.) A great number of microspore exines and some cuticles are found in the durain. The light-gray veinlets are calcite (ca) which is abundantly distributed both in durain and vitrain. ×50.

Fig. 7. A horizontal polished section of a coal from Hsiang Ku, S. W. from Li Yun Pa, showing fusain in forms of twigs, fragment and powders irregularly distributed in the durain. Jurassic. ×60.

Fig. 8. Amorphous clayey substance exhibiting a pseudocellular structure isolated by maceration from coal of Hsiang ku. ×100.

Fig. 7

Fig. 5

Fig. 6

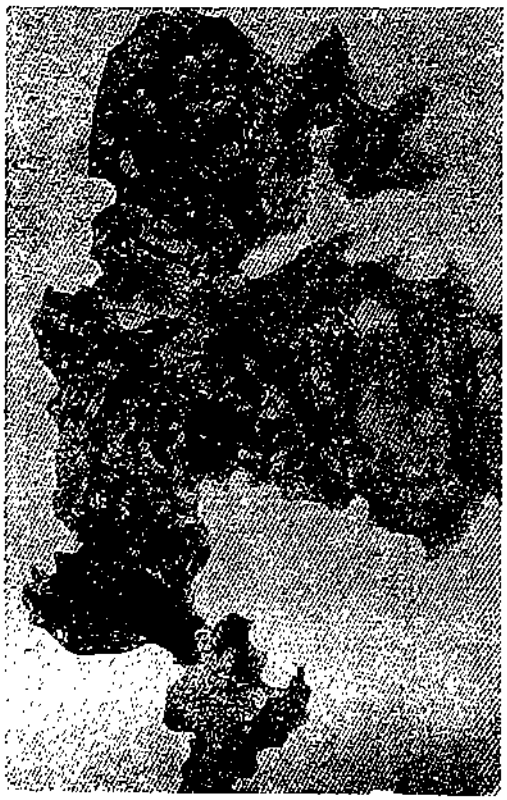

Fig. 8

EXPLANATION OF PLATE III

PLATE III.

Fig. 9. A glancing durain composed of numerone microspore exines and cuticles (only faintly shown in the picture) and long lenses of ashes (a). The black grains are the fragments of fusain. In the lower side is a vitrain band. Locality: above Tu Tai between Chungking & Hochow, Jurassic. ×42.

Fig. 10. A cuticle isolated by maceration from the coal of Tu Tai. The rectangular forms of the cell and its straight cell walls are distinctly shown. ×170.

Fig. 11. An exceptionally well preserved cuticle from the coal of Mu Tze Tou, between Chung King and Ho Chow. The spiral formed vascular bundles along the vein and the coalified cell contents are especially characteristic. Jurassic. ×94.

Fig. 12. Lower side of a big cuticle isolated from the coal of Mu Tze Tou shows the densely distributed stomatic opening. ×75.

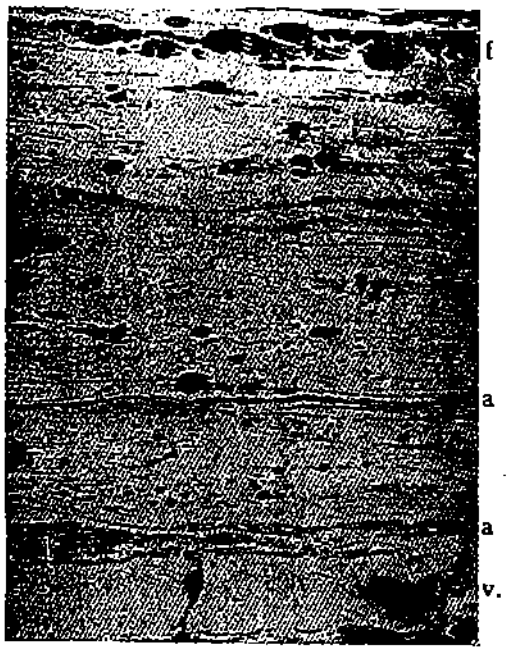

Fig. 9

Fig. 12

Fig. 10

Fig. 11

EXPLANATION OF PLATE IV

PLATE IV.

Fig. 13. Upper side of the same cuticle showing veins and coalified cell contents. ×95.

Fig. 14. Enlarged view of Fig. 13 showing form of cells and their coalified cell contents. ×210.

Fig. 15. Enlarged view of fig. 12 showing stomatic openings and drusses. ×450.

Fig. 16. A cuticle with half undulating cell walls and long stretched cell forms. Isolated by maceration from the coal of Mu Tze Tou. ×190.

Fig. 13

Fig. 15

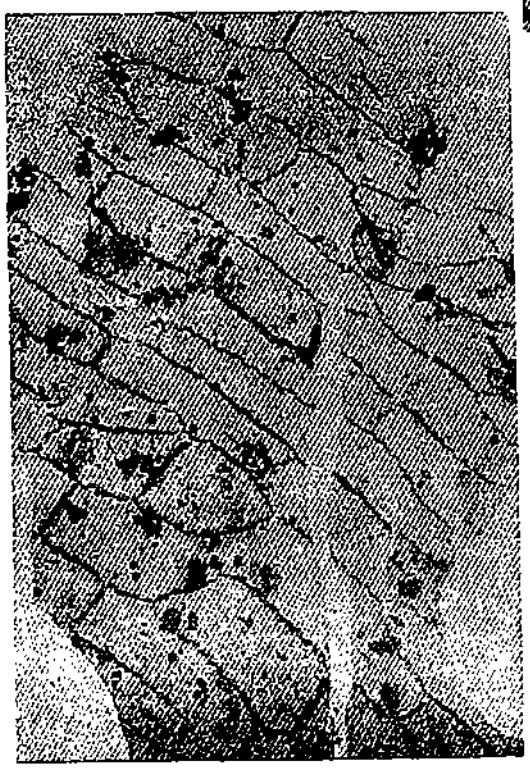

Fig. 16

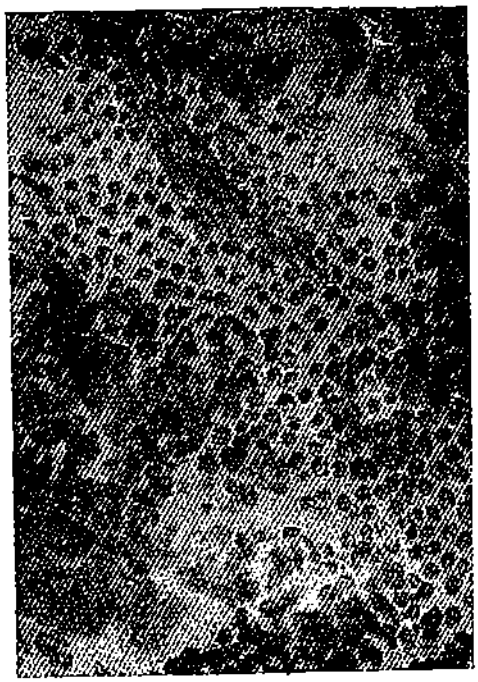

Fig. 14

EXPLANATION OF PLATE V

PLATE V.

Fig. 17. Bastfiber in coal of Tu Tai, polished Section. ×87.

Fig. 18. General microscopic appearance of the coal from Kwei Yang Chen, N. of Jung Hsien. It shows alternating bands of durain (d) and vitrain, (v), in former numerous spore exines and cuticles are found. The dark gray colored grains with a black border are fusain fragments. ×104.

Fig. 19. Another portion of the same coal as fig. 18, shows the extremely abundant amounts of fusain fragments. ×42.

Fig. 20. Cuticle isolated by maceration from the coal of Kwei Yang Chen, N. of Jung Hsien. It shows rather long stretched cells and half undulating cell walls, and with stomatic openings (s) on the lower side of the leave (L). ×94.

Fig. 17

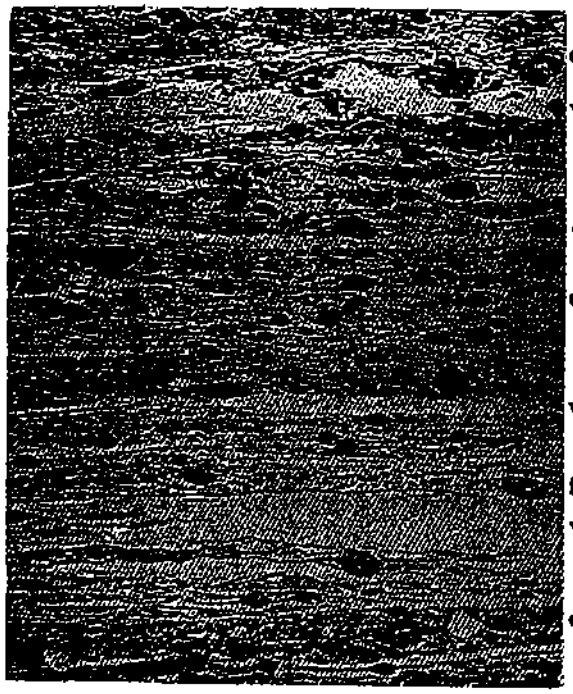

Fig. 18

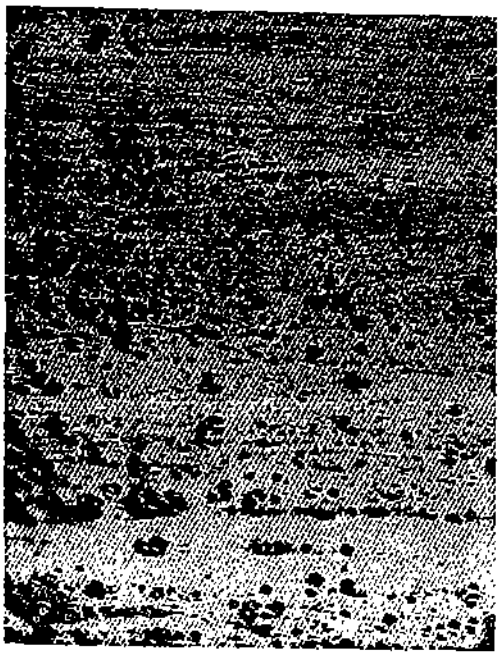

Fig. 19

s L.

Fig. 20 u

EXPLANATION OF PLATE VI

PLATE VI.

Fig. 21. Fusain in coal from Chin Ling Fan, N. of Jung Hsien with the indication of annual ring structure. The autumn wood in the center of the picture, because of its thicker and resistent cell walls remained unchanged while the summer woods on its both sides have been badly smashed, polished section. ×60.

Fig. 22. Cuticle with polygonal cells and undulating cell walls, isolated by maceration from the coal of Chin Ling Fan, N. Jung Hsien.

Fig. 23. General microscopic appearance of the coal from the mine Kau Ko in N. Jung Hsien. The section shows here an extreme abundance of fusain (f) occurring both in twige and fragments and numerous microspore exines (s) and cuticle. Vitrain bands are frequently intercalated. Polished section. ×40.

Fig. 24. A heap of microspore exine isolated by maceration from the coal of Kau Ko. ×120.

Fig. 25. A cuticle and a megaspore exine, both being found in maceration product of the coal of Kau Ko. The cuticle shows the same type as found in coal of Chin Ling Fan. Spine-like appendages are found to be still attached to the megaspore. ×120

Fig. 22

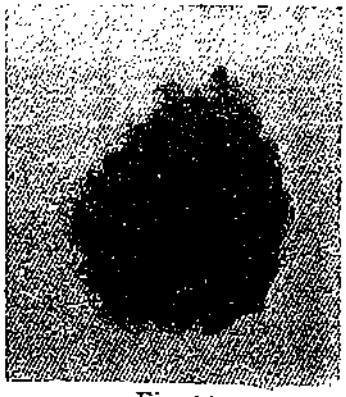

Fig. 24

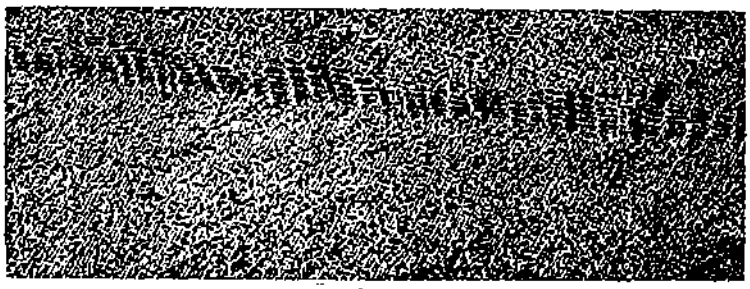

Fig. 21

Fig. 23

Fig. 25

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