SOME NEW METHODS IN COAL PETROGRAPHY

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(Contribution from the Sin Yuan Fuel Laboratory, Geological Survey of China No. 2)

1. INTRODUCTION.

The microscopical study of coal either by thin section or by polished section has formed now a special branch of geological science which is called in Germany "Kohlenpetrographie." This name is not at all a satisfactory one as, so far as I know, it has been followed neither in America nor in European countries outside Germany. However as there exists now no better term than this, I can only use it until some better one be created.

The coal petrography is a science which has been developed only within recent ten years. Thanks to the pioneer works of Jeffrey, Thiessen and Winter and followed afterwards by Duparque, Seyler, Gothan, Stach, Potonie, Bode etc., this science has made such remarkable progress that its practical value as well as theoretical significance have now been fully recognized.

For the technique part of the petrographical study of coal we should mention first of all the name of Jeffrey (1), whose ingenious method in cutting coal thin slice by a microtome was indeed a marvelous invention. The improvement of grinding method (the same as in making a thin section of rock) by Lomax (2) and Thiessen (3) has made possible the making of coal thin section in a simpler and quicker way than required in the method of Jeffrey. In spite of all these invention and improvement, the preparation of coal thin section transparent enough to show every detail and permitting microphotography under higher magnification still remains a difficult task for most of the coal investigators. In the case of anthracite, however, no method is yet known as to its preparation of thin and even translucent section.

On account of the difficulties involved in the preparation of transparent thin section of coal, most investigators have now turned their attention to polished section, a method well known in metallography and mineragraphy but was first adopted to coal investigation by Winter as late as in 1913. This was

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followed by Gothan & Stach in Germany, Duparque in France, Seyler in England, and Turner & Randall in America. Seyler's method of etching the polished surface of coal by chromic acid (4) and Turner and Randall's flame etching method (5) have both made a great progress in the technique part of the science, as otherwise some of the delicate and internal structure of the vitrain would not be visible. The usefulness of the etching method especially by the Seyler's reagent has been well shown by the author in his study of the etching structure of some of the Chinese coals (6).

From what has been said above it is evident that the present state of the microscopical study of coal has utilized all possible facilities such as thin section, polished section and etching methods (To this should be added also the maceration method) the last two methods were largely shared from the metallographic and mineragraphic sciences. However those who are familiar with the newly developed mineragraphic methods (7) in connection with ore investigation will at once be struck by the fact that coal petrographer has utilized only a part and not yet the whole of the principle and method as now known to the mineragrapher. The reason is that coal research falls now largely in the hands of palaeobotanist or chemist who care but little with either the newly developed petrographic or mineragraphic methods.

In the new model of the Leitz ore microscope, a polariser has been set in front of the vertical illuminator and an analyser in the microscopic tube above the specimen, so that ore surface can be studied in polarized light and in crossed nicols. By this arrangement, anisotropism, internal structure and other phenomenon could be accurately determined. The internal reflection color of the ore and gangue can be best seen by oil immersion, by which the image acquires at the same time a better contrast and more distinct aspect. All these methods seem to be adaptable to coal petrographical research; yet to our great surprise, no such attempt has ever been made by coal investigator. The present paper is intended to describe some of the experience and result obtained in our attempt to apply mineragraphic methods to coal research.

2. Anisotropism in Coal

Coal is an amorphous rock consisting of material of colloidal nature; consequently it must be isotropic i. e. dark between crossed nicols and showing no change of color intensity when the stage is rotated. In reality this is not the case. In most of the coals examined there shows always some anisotropism,* which becomes most distinct and marked in the case of anthracite, whereas in bituminous coal the anisotropism seems to vary from faint and unnoticeable to strong and well marked just as anthracite. In the case of lignite (Lignite from Kirin, China, Glanzbraunkohle from Peissenberg, Bavara etc) and some of the sub-bituminous coal (For example the Fushun coal, the coal of Pa Tao Ho, S. Fengtien) there shows a distinct isotropic character; the coal however never becomes perfectly dark when the nicols are crossed as does isotropic mineral, but its dark gray color remains unchanged when the stage is being rotated.

In studying anisotropism and other characters of the polished coal surface, a strong source of light must be used, as otherwise the weak reflecting power of the coaly substances will transmit very little light to enable accurate investigation. A Leitz Liliput arc lamp of 4-5 amp. is used throughout the present work, and the matt glass must also be removed in order to increase the light intensity.

It is well known in Mineralogy that isotropic minerals such as garnet often show optical anomalies when it has suffered intense dynamic metamorphism. The stress thus created has forced the mineral to rearrange internally and thus appears as anisotropic in crossed nicols. The same explanation could perhaps be applied to the optical anomalies of coal, though in detailed process it may not be exactly the same. As the degree of metamorphism is expressed in the different ranks of coal, that is to say anthracite has suffered the greatest stress while the lignite the least. Theoretically then anthracite must show greatest anomalies i. e. anisotropism whereas lignite the least or none i. e. isotropic. And this is just what I have found in the Chinese coals.

3. THE ORIGINAL STRUCTURE OF ANTHRACITE.

As a result of the strong anisotropic character of anthracite, its original banded structure and structures showing original cellular forms or grain bounderies can be marvelously shown when the analyser is crossed. Two of the examples are given in the illustration Pl.I, Fig. 1 & 2. When examining in parallel nicols, the polished surface of the coal aside from a few lenses or fragments of fusain shows almost a perfect, homogenous and structureless vitrain. In fact most of the work dealing with microscopic structure of anthracite has described it as consist in essentially of an structureless mass of vitrain intercalating only here and there with some lenses of fusain. Now

* Study of anisotropism in coal by thin section method has already been made by C S. Fox. See Nature, Dec. 25, 1926, p. 913 and Oct. 15, 1927. p. 547.

when the upper nicol is crossed, an entirely different aspect is obtained; it shows a distinct banded structure of vitrain, durain and fusain just as bituminous coal (Plate I & Plate II). The durain is composed of an aggregate of cellular material together with perhaps some microspore exines and other substance, their recognition is however not possible even under very strong magnification, Most of the cellular material seems to show some degree of granulation and crushing; in other words a *cataclastic* structure (see Plate I, a). This structure is very important as by its existence we are led to realize what an enormous degree of stress the coal has suffered in its changing from bituminous coal to anthracite. This seems to give another evidence to support the dynamic stress as one of the important factor in anthracite formation.

The original banded structure as well as vegetable tissue in anthracite were not visible until when the ingenious method of flame etching by Turner and Randall was discovered. Now since the same structure can be observed more easily and distincty with polarized light and crossed nicols, it is needless to say that the flame etching becomes not necessary. The flame etching method, simple as it is, takes always some time and in some cases it is rather difficult to conduct. Moreover it is difficult to compare the unetched structure with that of the etched one, nereas in using polarized light and crossed nicols, the comparison is a very simple matter.

The original banding and other structure in anthracite becomes more distinct and marked when a drop of oil (Cedarwood oil or Glycerine) is introduced between the objective (oil immersion objective) and the coal surface.

4. Oil Immersion Method.

Oil immersion in mineragraphy is used for several purposes: (1) to increase detail and fineness of the image when examining under strong magnification, (2) to detect in an approximate way the rate of decreasing of reflecting power which in the case of opaque mineral varies largely with the index of absorption; (3) to detect internal reflection color, i. e. the true color of the substance.

In applying oil immersion method to coal petrographical research, very excellent results some of them are of diagnostic value, have been obtained. First of all when a drop of glycerine or cedarwood oil is introduced between the objective and the coal surface, the image becomes more sharp and distinct;

unevenness of the image due to relief or scratch of the polished surface can to some extent be improved by oil immersion, thus it permits the taking of better microphotographs, (Plate III & Plate IV) though the exposure time must be considerablly increased.

The reflecting power of different constituents in the coal will be reduced when a drop of oil is introduced. The rate of reduction varies inversely with the index of absorption and diminishes directly with the index of refraction. Those substances which absorb most will reduce least their reflecting power, therefore exhibit still a bright luster after oil immersion. On the other hand when a highly refracting substance is examined by oil immersion, its reduction in luster will only be very slight and in contrast with the strongly reduced mass of coaly matter, the substance appears as if its reflecting power were increased. In this way we are enabled to distinguish mineral matter from the coal mass as will be described below.

When examining a coal surface under oil immersion, fusain seems to reduce little or none of its reflecting power so that it remains always in a bright state of yellow color. Vitrain has suffered great reduction and showing therefore a darker color, while exines of both microspores and macrospores, cuticles, resinous bodies etc have greatest reduction so that they become dark gray or nearly black when oil immersion is applied. Xylainic debris or tissues exhibit a luster intermediate between fusain and vitrain. In this way we are enabled to obtain a better contrast view on the different constituents in the coal and what is more important is the surer distinction between true fusain (charred wood) and xylain (uncharred wood) since both are cellular in structure and are in some cases almost indistinguishable when examined by dry system objective alone.

The microphotographs thus obtained are distinct enough as to be comparable with those taken by Jeffrey and Thiessen with their thin section method, while the photographing of polished section by the ordinary method, such a contrast view has hitherto not yet been reached. If a positive be made from the negative from which a print is again made, the exines of both microspores and macrospores will appear white just same as in the microphotographs of thin section.

The internal reflection color is beautifully shown in the case of resin which appears brown, reddish brown or yellow when oil immersion and especially crossed nicols are applied. The color becomes more distinct when scratches or pores occur in the resin body and thereby light is enabled to penetrate and then to reflect again. A lignite from Holunghsien (和龍縣) in Kirin province was found to contain abundant nicely preserved wood in which crushed tracheids and rectangular, uncrushed cells are beautifully shown. This latter cell was supposed to be resinous filling in the wood parenchyma, but such identification was only morphological and not conclusive. Now by the use of oil immersion method, very distinct reddish brown color is shown in practically all of the rectangular cells, therefore their resinous nature is proved.

Another application of the oil immerston method is in the identificaton of mineral matter in the coal. As has been stated above reduction of reflecting power varies inversely with index of absorption and directly with index of refraction. Mineral matter such as calcite, quartz are all transparent, but having higher indices of refraction as compared with sporic constituent or resinous bodies which are also transparent, so that after oil immersion they are found to show a more bright luster and translucent color. Sometimes the rhombohedral cleavage of calcite is equally well shown. The earthy ferruginous matter is characterized by a yellow color while quartz is white and translucent, devoid of any cleavage. From these charcaters we can see that by oil immersion method it is not only possible to distinguish between coaly and mineral matter but a discrimination among the common species of minerals in a polished section of coal is equally feasible.

5. Study of Jet.

Jet is a variety of brown coal; it is compact and tough resembling cannel coal, but its luster is more bright and when polishing yields a splendid polished surface. When seen under the microscope by ordinary method, (vertical illumination) the polished surface (specimen from Fittlingen, Schweben, S. Germany) shows to be an homogenous vitrain exhibiting no structure whatsoever. Now when the upper nicol is crossed and what is better when oil immersion is also applied, a somewhat distinct woody structure of tracheids of brown color appears. Owing to the weak anisotrotic character of the substance the structure is only faintly shown, though its woody nature is proved beyond any doubt. A thin section of the Jet shows exactly the same structure. Study of polished Jet by oblique illumination gives the same or even better woody structure as will be described below. Thus the study of polished section of coal by polarized light can be claimed as well to replace the thin section method, which is more difficult to conduct.

6. Oblique Illumination.

The methods thus far described are all made under vertical illumination. The study of polished section by oblique illumination has yielded also good and diagnostic result in mineragraphy and the same method could well be applied to coal research. Uniform oblique illumination can best be produced when two arc lights are directed to the polished surface from opposite sides, or what is the same or even better when an instrument known as Silvermann oblique illuminator is available. (8) The high relief of the fusain with its cellular structure and black charcoal like internal reflection color from the cellular open spaces are then remarkably well shown. It is believed that a surer distinction between true fusain and xylain can thus be easily made in polished section. (In thin section fusain is black and opaque so it can easily be distinguished from xylainic substances.) The oblique illumination method is especially good for the study of woody structure in lignite or brown coal. The resinous filling in wood from a lignite of Holunghsien, Kirin Province and the woody structure of a Jet from S. Germany could be equally well or even better detected by oblique illumination. The image so obtained shows such a weak intensity of light that considerable long exposure must be used before a good microphatograph can be taken.

7. The Cellulose Printing Method for the Preservation of Etching Structure of Coal.

In spite of the fact that the study of polished coal section by polarized light and oil immersion method could to a large extent replace the etching method, but in some cases especially in coal of younger age, etching test seems to be indispensable. The structure produced by etching is usually extremely distinct, yet it does not last very long. The entire structure is often destroyed when the section has been exposed to the air for some time. Therefore it is necessary to devise some means to preserve the structure, so that it could be kept for ever.

In the spring of 1930 the writer, while making some coal research work in the Laboratory of the Preussisch Geologische Landesanstalt in Berlin has found a cellulose printing method for the preservation of coal structure. Detailed description of the method is given in his article on the "Ätzstrukturen der Kohle". A short summary of the method is given below:

In making such a print, the etched surface of the coal must be thoroughly dried, or better to wait a few days after the etching has been made. The surface must then be moistened with aceton and on it poured the cellulose liquid until a layer of about 2 or 3 millimeters is formed. The layer must be kept perfectly level and the whole thing is left in a quiet place without disturbance for about 24 hours. The cellulose will then be evaporated and dried to form a very thin film which can be easily taken away by a knife. On the lower side of the cellulose film, a print of the structure is obtained which can be studied under the microscope either by transmitted light or by reflected light.

It goes without saying that the same method can be applied to the printing of coal structure before the etching. In that case the coal surface must be polished a little longer than usual in order to obtain a higher relief. Distinct prints of fusain, macrospore, as well as other structure have been obtained by the writer.

The usefulness of the printing method lies not only in the fact that the structure can be preserved for permanent study, but also that it is possible to secure an accurate comparison of the structures produced before and after the etching. As it is sometimes not easy to say from which component of the coal does the etching structure originate, so the providing of certain means for accurate comparison is not at all superfluous. Another application of the method is to make a series of prints from successively polished surface of the same section, so as to facilitate the study of vertical variation of the component found in the coal.

8. Conclusion.

The present work is an attempt to apply some of the mineragraphic methods to coal petrography. From what has been discussed it seems that the new methods permit an accurate identification of some of the coal constituents such as true fusain. resin and mineral matter contained in the section, a better presentation of original banded and cellular structure in anthracite, and lastly a means to reveal the woody structure in jet or similar seemingly structureless vitrain. When properly applied these new methods could replace almost entirely the thin section and to a large extent also the etching method. A method for the preservation of etching or relief structure of coal by cellulose printing is also described.

Being a newlv developed science the coal petrography especially the technique part of it has a splendid field for future research. We must not only confine ourselves to morphological study of the vegetable constituents alone, but a full utilization of their physical and chemical properties as well. The application of polarized light, oil immersion and oblique illumination as described above is merely one phase of such an attempt. The quantitative determination of reflecting power of the ore mineral has been recently made possible by the invention of Schneiderhöhn-Bereck's photometer ocular (8) and the Photoelectric method of Orcel (9). The writer wonders if such determination could also be conducted with profit in the study of polished section of coal. The refractive indices of the spore exines, cuticles or other vegetable tissues could perhaps also be determined and utilized for correlation purposes. These are some of the more important phases of research which the coal petrographer of to-day should follow.

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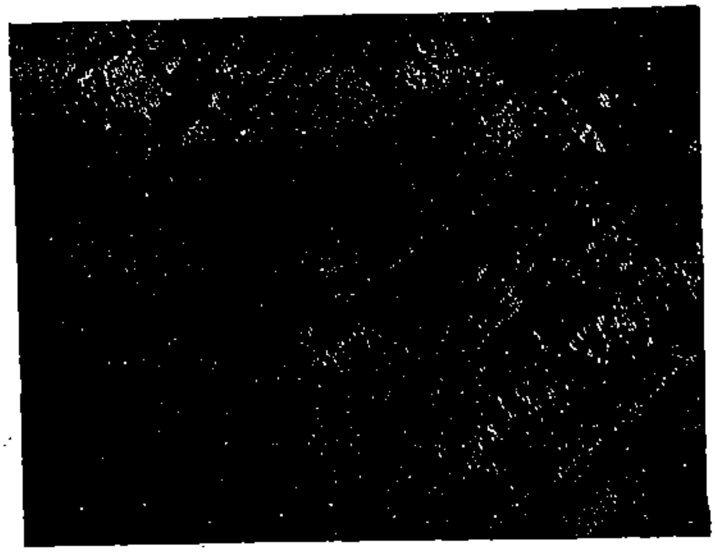
Explanation of

Plate I

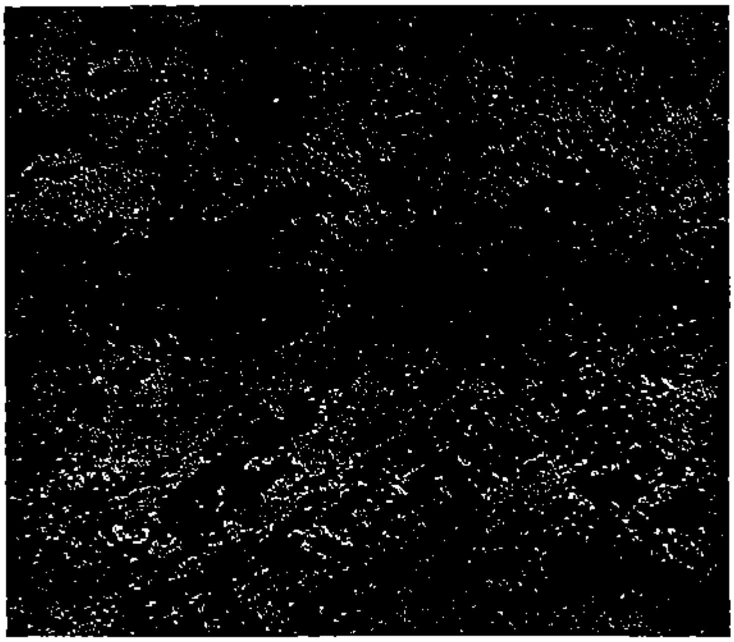
PLATE I.

a) Banded structure in anthracite consisting of alternating vitrain and crushed fusain becomes visible when observed in crossed nicols. Polished vertical section of anthracite from Lou Fu Yen, Lien-Chen Hsien, Fukien Province (福建連城縣老虎岩) X 105.

b) A band of crushed cell or cataclastic structure in anthracite indicating clearly what an enormous amount of pressure the coal has suffered during its stage of development Polished vertical section seen in crossed nicols. Jen Tsun, Lu Chen Hsien, Kwangsi Province (廣西羅城縣銀村). X 300.



a.



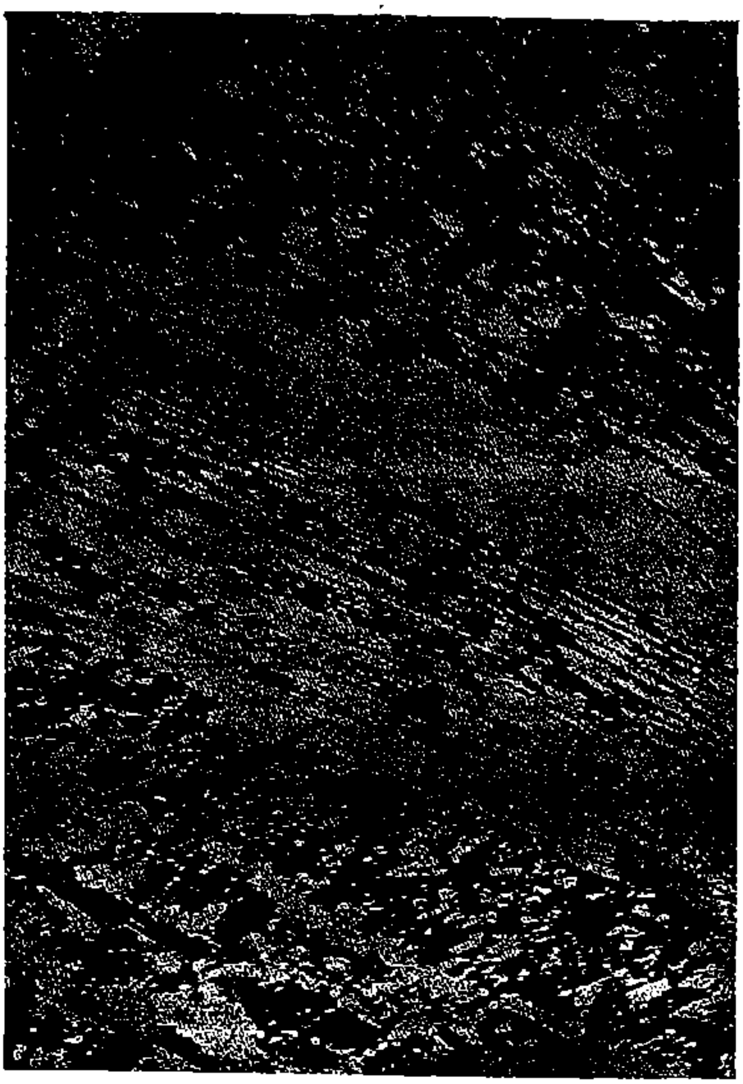
b.

Explanation of

Plate II

PLATE II

Banded structure in anthracite showing crushed fusain and a vitrain with distinct preservation of lenticular, compressed cells. Locality same as Pl. I a. Polished vertical section seen in crossed nicols. X 300.

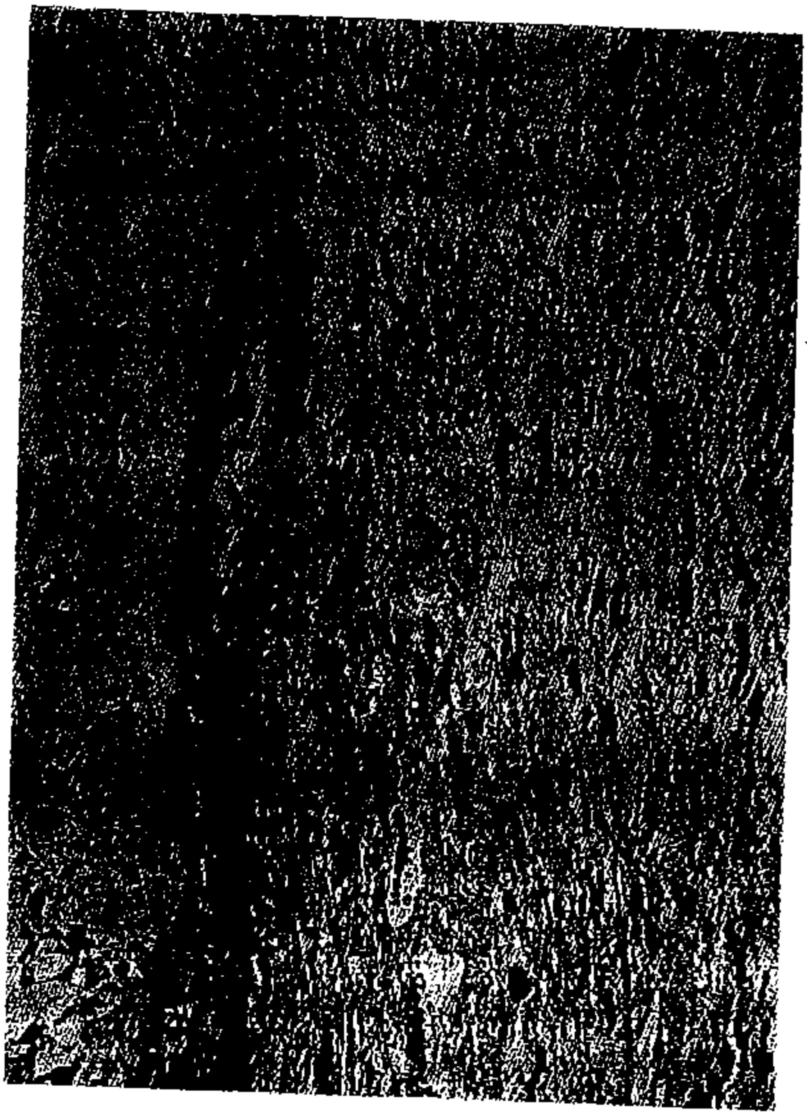


Explanation of

Plate III

PLATE III

Vertical crossed section of a bituminous coal as seen under oil immersion. The microspore exines (small lenticular bodies of black color) and the ground-mass (gray) have greatly reduced their luster when oil is introduced, whereas fusain (light gray with cellular structure) and xylainic debris (white) have reduced but slightly; thus a more contrast view is obtained. If a print of the positive of the plate be made, the microspore exines will appear white just same as in a microphotograph of thin section. Seam No: 12 of the Chao Ko Chuang Colliery, Kaiping basin, Hopei Province. (河北省開平趙各庄). X 280.



Explanation of Plate IV

PLATE IV.

Microphotograph of vertical cross section of a bituminous coal when observed under oil immersion. Both the exines of microspores and macrospores appear black, the xylainic and fusainic (with cellular structure) materials white, the groundmass, dark gray. Tien Wu Tsun, Wu Tai Hsien, Shansi Province (山西五台縣天和村). X 280.