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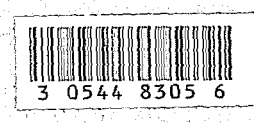
No. 16 December 1933

THE SOLVENT EXTRACTION OF CHINESE BITUMINOUS COALS

BY

K. PING



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SOLVENT EXTRACTION OF CHINESE BITUMINOUS COALS

By K. Ping

1. INTRODUCTION.

Since De Marsilly systematically studied the extraction of some of the organic compounds in coal by means of benzene, alcohol, ether, carbon disulphide and chloroform, the solvent extraction has attracted sufficient attention of many coal investigators, who endeavored to find the chemical composition of coal. However, in spite of many theories that were deduced from the results of their research, the chemical constitution of coal still remains obscure and speculative.

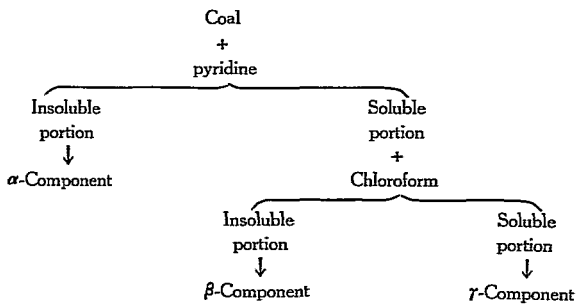
Among the organic solvents used for the extraction pyridine, which was first used by Bedson,[1] proved to be the best. The strong solvent properties of pyridine on coal, as stated by Hargar[2] is however not merely a physical action but a chemical process which depolymerizes the polymeric compounds of coal into simpler ones easily soluble. Wheeler[3] and Clark showed moreover, that the pyridine extract can be further divided by the treatment of chloroform, and termed the components thus separated by the two solvents as follows:—

α-Component—The portion of coal which does not dissolve in pyridine.

β-Component—The portion which is soluble in pyridine but not in chloroform.

γ-Component—The portion which is soluble in both solvents.

The separation is shown more clearly in the following diagram.



The alpha and beta compounds are supposed to be of the same type of substance which was derived from the plant remains, while the gamma compounds are considered to be of resinic nature. It is generally believed that, in the carbonisation of of coal, the gamma compounds impart the agglutinating action and play the most important part in the coke formation.

In view of the great range of variation in the Chinese bituminous coals as to their coking proprieties, different methods have to be used in order to determine these coking proprietes in the laboratory with small samples of coal porior to the utilization on an industrial scale. It is the purpose of this study to test coals by means of solvents with the aim to see how they influence on their caking properties.

2. COAL SAMPLES.

Sixteen coal samples from important mines were chosen for the test. Their sources, geological age and proximate analysis on dry and ash free basis are herein tabulated below:

Lab. No.	Locality	Company	Geological Age	Vol. Mat.	Fixed Carbon
321	Tsuhsien, Hopei	Yili	P-C	22.28	77.72
319	,, ,,	Yili	,,	22.72	77.28
310	Poshan, Shantung	Potung	,,	25.67	74.63
309	,, ,,	,,	,,	24.00	76.00
365	Liuhokou, Honan	———	,,	28.15	71.85
362	Chinghsing, Hopei	Chinghsing	,,	26.72	73.28
374	Lanhsien, Hopei,	K. M. A.	,,	35.96	64.04
373	,, ,,	,,	,,	35.76	64.24
369	Ihsien, Shantung,	Chunghsing	,,	34.21	65.79
587	Shunkengshan, Anhui	Tatung	,,	38.75	61.25
591	Hsiangt'an, Hunan	Yiuli	P	23.69	76.31
597	Changhsing, Chekiang,	Changhsieng	,,	42.39	57.61
448	Hsuancheng, Anhui	———	,,	41.66	58.34
655	Pinghsiang, Kiangsi	Pinghsiang	J	36.42	63.58
349	Hsuanhua, Chahar,	Houfeng	,,	42.68	57.32
523	Tatung, Shansi	———	,,	38.01	61.99

P-C=Permo-Carboniferous
P =Permian
J =Jurassic

3. DESCRIPTION OF THE COKING PROPERTIES

Nos. 321 and 319 (Tsuhsien) are obtained from different seams of a same mine. They all form coherent semi-cokes, but 319 is slightly shrinking and 321 more or less swelling.

Nos. 309 and 310 (Poshan) are used for coke production by native method as well as by modern coke oven process. No. 309 produces a highly swelling semi-coke, lustrous, hard and porous. No. 310 produces a slightly swelling hard semi-coke.

No. 365 (Liuhokou) is used to produce coke with a production of more than 10,000 tons annually. The semi-coke is swollen, hard and lustrous.

No. 362 (Chinghsing) on heating shrinks to a very hard and compact semi-coke. It is used in by-product coke ovens of Chinghsing Mining Administration with a maximum daily capacity of about 110 tons.

No. 373 and 374 (Kailan) yield slightly swollen semi-coke, hard and lustrous, and have been used to produce coke in bee-hive ovens.

No. 369 (Chunghsing of Ihsien) gives a highly swelling coke, porous but friable. This coal is carbonized in native coke ovens with a monthly production of about 3200 tons.

No 587 (Shunkengshan) The semi-coke from it is hard, compact and slightly shrinking, considered as not good coking.

No. 591 (Hsiangtan) gives a non-swelling coherent semi-coke, and cokes produced in native ovens are said to be of good quality.

No. 597 (Changhsing) produces a very highly swelling coke, lustrous and porous.

No. 448 (Hsuancheng) gives a highly swelling semi-coke, porous and friable, but it suffers the disadvantage of very high sulphur content.

No. 655 (Pinghsiang) gives a coherent and moderately hard semi-coke, with a slight shrinkage. It had been used on a large scale for the manufacture of metallurgical coke.

No. 523 (Tatung) is rich in fusain content which probably renders the coal unsuitable for the production of coke. However, it cakes slightly, and yield a loosely bound semi-coke which crumbles easily into powder.

No. 349 (Hsuanhua) is entirely non-coking but rich in volatile matter.

4. EXPERIMENTAL

A procedure for carrying out the extraction of coal by pyridine was described by Illingworth[2]. He used a five-gram sample in an all-glass joint Soxhlet apparatus. The extraction however requires a long time of about one week or two. Moreover, owing to the prolonged heating the compounds in the extract tend to polymerize again to form a film of gummy substance which adheres firmly on the inner surface of the flask and is hard to remove even with fresh pyridine. A modified method employed by U. S. Bureau of Mines is consequently adopted.

The samples were made to pass through a 60-mesh sieve and dried at 105°C for two hours. A one-gram portion of each was mixed with four to five volumes of clean sand in an alundum thimble, and was extracted with 125 cc. of pyridine in an all-glass joint Soxhlet extracter in an atmosphere of nitrogen. The extraction was

so regulated that the syphon of extract occurred once in about ten minutes, and was continued for 48 hours. In order to remove the coal particles which might be carried over by pyridine, the extract was filtered into a tared 150 cc. pyrex florence flask. The filtered extract was then concentrated by distilling off the pyridine until the content tends to splash up. The pyridine remaining in the flask was removed by repeated evaporation with portions of 15 cc. of xylene. After the removal of pyridine, the flask was heated in a vacuum oven at 105°-110°C to drive out xylene. Then the flask was cooled in a desicator, and weighed. The increase in weight represents the amount of beta and gamma compounds in the coal.

The dried pyridine extract which contained the beta and gamma compounds was broken up with a glass rod, washed with chloroform and poured into the thimble already in the Soxhlet extractor. The adhering particles on the flask were removed with a policeman and rinsed out again with chloroform into the thimble. Fresh chloroform was added to the extractor to a volume of about 125 cc. The extraction was proceeded in the same way as that with pyridine, until the descending solvent was colorless. The extract was filtered into a flask previously weighed and distilled off the major portion of chloroform. Then it was dried in vacuo at 105°C to constant weight. The amount of gamma compounds is obtained by difference again.

5. RESULTS.

The following results were recorded on ash-free basis:

Coal	Pyridine Extract	Alpha Compd.	Beta Compd.	Gamma Compd.
321	2.74	97.26	0.46	2.28
319	3.95	96.05	1.29	2.66
310	6.82	93.18	2.03	4.79
309	7.24	92.76	0.66	6.58
365	6.07	93.93	2.39	3.68
362	6.37	93.63	1.74	4.63
374	29.41	70.59	18.09	11.32
373	32.72	67.28	16.95	15.77
369	32.75	67.25	16.33	16.42
587	11.12	88.88	4.85	6.27
591	7.73	92.27	2.97	4.76
597	18.75	81.25	8.63	10.12
448	19.21	80.79	7.93	11.28
655	23.44	76.56	13.52	9.92
349	14.51	88.49	6.07	8.44
523	19.52	80.48	10.36	9.16

6. DISCUSSION OF RESULTS.

In order to facilitate the discussion of the results certain factors listed below must be taken into consideration.

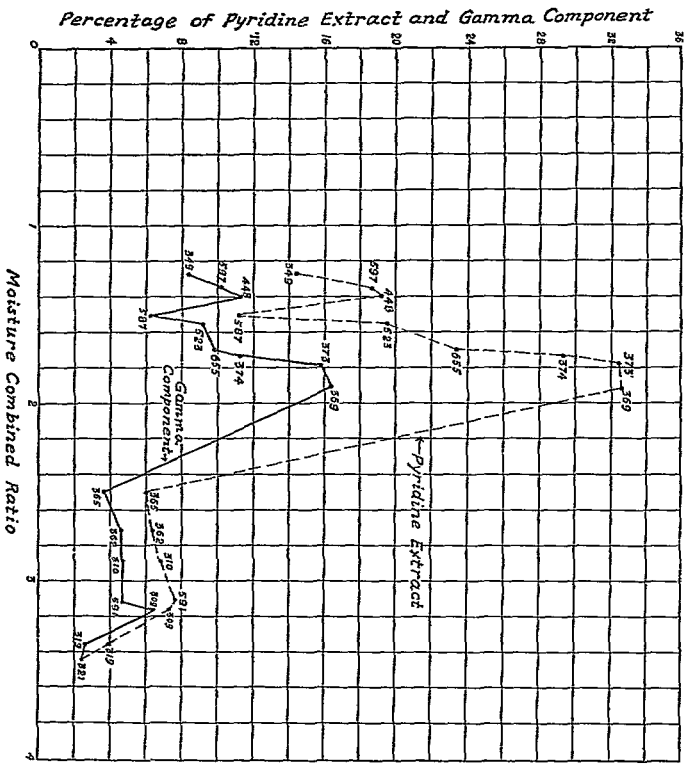
Coal	Age	Notation	Moisture[5] combining ratio	Gamma Compd.	Oil yield[6]	Swelling coefficient.
321	P-C	Bh	3.44	2.28	5.73	1.06
319	,,	Bh	3.37	2.66	4.97	—
310	,,	Bm	2.88	4.79	5.70	1.04
309	,,	Bh	3.16	6.58	5.05	1.40
365	,,	Bm	2.50	3.68	5.92	1.04
362	,,	Bm	2.72	4.63	6.65	0.90
374	,,	Bm	1.73	11.32	10.50	1.14
373	,,	Bm	1.78	15.77	9.76	1.96
369	,,	Bm	1.90	16.42	8.05	2.56
587	,,	Bl	1.51	6.27	12.10	0.94
591	P	Bh	3.12	4.76	4.65	1.00
597	,,	Bl	1.34	10.12	7.59	2.72
448	,,	Bl	1.39	11.28	8.37	2.64
655	J	Bl	1.69	9.92	9.15	1.00
349	,,	Bl	1.27	8.44	10.50	1.00
523	,,	Bl	1.55	9.16	11.05	1.00

7. THE RELATION BETWEEN MOISTURE COMBINED RATIO AND THE GAMMA CONTENT.

By moisture combined ratio is meant the ratio of fixed carbon to the sum of moisture and volatile matter. It is the common opinion that this ratio shows the degree of coalification of coals in that it increases with the increase of the latter. Two curves obtained by plotting the gamma content and pyridine extract against the moisture combined ratio are shown herewith.

The curves though appearing in a zigzag manner seem to show that the degree of coalification has a striking influence on the pyridine and chloroform extract. Of course, there seems to be no definite relationship existing between each other but it is evident that as the moisture combined ratio is higher, that is the coalification is increased, the difference among the gamma contents is very

much smaller. Among the coals studied, Nos. 523, 587 and 349 have been known to be of very poor caking quality, Nos. 448, 597 and 591 are of doubtful caking quality, while the rest of them are all good coking coals and have actually producing cokes in the market. It is therefore quite probable that among the bituminous coals of lower coalification, the gamma content is very important to the caking quality.



Moreover, it is interesting to note that those coals which locate on the paramount points of the gamma curve, swells greatly on heating. The coals of that category are:—Nos. 597, 448, 373, 369 and 309. On the contrary, the coals that lie on the lower part of the curve are not greatly swelling, or non-swelling or even shrinking on heat treatment. Thus, it seems that there is a natural grouping of the coals. In each group the coal which gives a higher gamma content is comparatively more swelling on heating.

8. THE RELATION BETWEEN THE GEOLOGICAL AGE AND THE GAMMA CONTENT.

Without considering the coalification as measured by the moisture combined ratio, the gamma contents of the coal seem to bear no relation to the caking property at all. A non-coking coal like No. 349 gives 8.44% of gamma but a good coking coal like No. 321 gives only 2.28% of the chloroform extract. However, the result is also of interest if the coals are assorted into groups according to their geological age, and gives evidence that the gamma compounds really impart their cementing influence in the formation of coke.

Thus, among the Jurassic coals, No. 655 which is good coking and has been used for coke producing, contains 9.92% of gamma. No. 523 which is poor coking contains 9.16% and No. 349 which is non-coking contains still less, only 8.44%. In the Permian coals, the relation holds true too. No. 597 and 448 which yield very highly swelling semi-cokes have gamma contents of 10.12% and 11.28% respectively. And, No. 591 contains 4.76% of gamma yield a non-swelling semi-coke. Among the coals of Permo-Carboniferous age, No. 369 which forms a highly swelling coke, contains 16.42% of gamma compound. Next to it are No. 373 and 374 which contain 15.77% and 11.32% of gamma respectively. The rest of the coals except No. 587 6.27%. all form coke on heating with little swelling, and contain much less gamma compounds than Nos. 374 & 369.

9. THE GEOLOGICAL AGE AND THE COALIFICATION OF COALS AS INFLUENCES ON THEIR COMPOUNDS.

Now the problem arises: why Jurassic coals like No. 349 and 523 which are rich in gamma component have poorly coking properties, but Permo-carboniferous coals such as Nos. 320 and 321 contain much less gamma compounds and are good coking? It seems that the gamma contents of various coals are different in composi-

tion. The gamma compounds are proved to be of resinic nature and are supposed to be derived from the resin in wood or plant remains, as a result of polymerisation. As a rule, the polymerisation of a compound, depends on aging, temperature, pressure or catalytic action of foreign materials. It is self-explanatory, that the polymers are greater in molecular weight than the original compounds, and consequently their melting point and boiling point are higher. It is the same case with the gamma compounds. The more they were aged and the higher the degree of coalification; the more they polymerize and hence the higher their boiling point.

In the process of carbonisation the gamma compounds are decomposed into simpler compounds as gases, oils, tars and also compounds of still higher carbon content which cement the coal particles to form coke. It is obvious that the gamma compounds of lower molecular weight volatiles more easily and escape from serious decomposition before a high temperature is reached. On the contrary, those of higher molecular weight are hard to volatile until at high temperature, at which decomposition and cracking set in. From the present experiment it is clear that the Jurassic coals are rich in gamma compounds which do not help coking but give a higher yield of oil. The coals of Permo-Carboniferous ags, like Nos. 369 and 373 etc., though containing much gamma compound yield less tar which show that the major portion of gamma compounds is left as cementing material.

In conclusion, the coking property of coal depends not only on the amount of gamma compounds but also on the nature and the decomposition products of these compounds. As this experiment shows, the coals of younger age though rich in gamma compounds are poorly coking, but that of older age, though less rich in gamma component, are good coking. So in the examination of coal the geological age, and the degree of coalification must be considered. As a matter of fact, they influence greatly the nature of gamma compounds.

10. SUMMARY.

Sixteen bituminous coals collected from different districts in this country, were examined by means of solvent extraction. The results are, however, not very promising, if the amount of gamma component were taken alone as a criterion of coking properties. Since the coals are of different origin, age and degree of coalification, due consideration should be paid to these factors in the examination of coal by solvent extraction.

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丙化合物之變遷亦復如是。年代愈長，炭化愈久，温度愈高，其複化程度亦愈深，是以其熔點沸點亦因之愈高也。

煉焦之時煤中之丙化合物分解爲簡單之化合物，如煤氣，油類，瀝青之屬，而碳分較高之化合物，則膠結煤末而成焦。温度愈高則後者之產生亦多，分子量較小之丙化合物易蒸發，且未至高温即行逸出，故不易分解。反之，分子量較大者，蒸發較難，在低温不易出，直至高温遂分解。此次試驗結果，頗爲明晰，侏羅紀煤含丙化合物多，並無補於焦性，僅增油之產量。二疊石炭紀之煤如三六九，三七三等各號所含丙化合物亦多，而油量頗少，是知其丙化合物大部用於膠結也。

總之，煤之焦性不能僅恃其丙化合物之多寡，而須視此化合物之本性，及其分解後之物質爲定。如本試驗所示年代較近之煤，雖富有丙化合物而其焦性殊劣。時代較遠之煤，其丙化合物較少而焦性甚佳。故別擇烟煤以煉焦者，不可僅測其丙化合物之多寡，同時於地質年代亦宜兼注意及之。

（十）綱要

本試驗以溶劑方法測定各地烟煤十六種之焦性，其結果如下（一）僅以丙化合物之含量而預定，煤之焦性絕少把握。（二）選擇煉焦烟煤時，除丙化合物外，其來源，時代以及炭化程度等均應注意，始可得相當之標準。

參攷書見英文篇中。

不齊。粘結而膨脹者其丙成分多不粘結，及稍粘結者其丙成份稀少。據實驗所得五二三，五八七，及三四九各號煤其焦性甚小，四四八，五九七及五九一各號煤性不明，其餘皆爲優良之煉焦煤，其出產之焦皆已銷用於市場。由此言之，丙化合物對於烟煤之粘性甚爲重要，再於丙化合物曲綫上最可注意之點，卽位於曲綫上最高點之煤，當加熱時其膨脹甚大。例如五九七，四四八，三七三，三六九及三〇九，各號。反之，煤之位於曲綫較低位置者，則不甚脹，或不脹，或竟於加熱時而起收縮。此或爲諸煤之本性，亦未可知。

（八）地質年代與丙化合物之關係

如不計煤之碳化程度或加水燃率，煤之丙化合物似與其粘性無關，蓋不能煉焦者如三四九號含丙化合物百分之八・四四，而焦性甚佳者如三二一號僅含百分之二・二八。然將各煤按地質時代分列，而再視其粘結力與丙化合物之關係，則似頗有相當之規則。

侏羅紀煤中有良焦性，並已用於煉焦之六五五號，含有百分之九・九二之丙化合物，焦性甚劣之五二三號則含百分之九・一六，而不能煉焦之三四九號僅含百分之八・四四。二疊紀之煤關係亦然：五九七號及四四八號其半焦膨脹甚大，含丙化合物百分之一〇・一二及一・二八，半焦不脹之五九一號含百分之四・七六，二疊石炭紀中三六九號含百分之一六・四二，其半焦膨脹亦甚，其次三七三號三七四號含百分之一五・七七及一一・三二，其餘除五八七號含百分之六・二七外，當加熱煉焦時皆微脹且其丙化合物之百分數皆較三七四及三六九爲小。

（九）煤之炭化程度對于丙化合物之影響

何以侏羅紀之煤如三四九號及五二三號含丙化合物多而焦性劣，而二疊石炭紀者如三一〇號及三二一號含丙化合物少而焦性良。不同之煤其所含之丙化合物似亦不同，丙化合物既已證明類似樹脂並斷爲古代植物所遺留之樹脂複化而成者，按諸定則，複化作用與時間之久暫溫度之高低以及壓力之大小有密切之關係，而複化物之分子量較原化合物者爲大，因是其熔點沸點均較高。

三〇九	二疊石炭紀	Bh	三·一六	六·五八	五·〇五	一·四〇	
三六五	二疊石炭紀	Bm	二·五〇	三·六八	五·九二	一·〇四	
三六二	二疊石炭紀	Bm	二·七二	四·六三	六·六五	〇·九〇	
三七四	二疊石炭紀	Bm	一·七三	一一·三二	一〇·五〇	一·一四	
三七三	二疊石炭紀	Bm	一·七八	一五·七七	九·七六	一·九六	
三六九	二疊石炭紀	Bm	一·九〇	一六·四二	八·〇五	二·五六	
五八七	二疊石炭紀	Bl	一·五一	六·二七	一二·一〇	〇·九四	
五九一	二疊紀	Bh	三·一二	四·七六	四·六五	一·〇〇	
五九七	二疊紀	Bl	一·三四	一〇·一二	七·五九	二·七二	
四四八	二疊紀	Bl	一·三九	一一·二八	八·三七	二·六四	
六五五	侏羅紀	Bl	一·六九	九·九二	九·一五	一·〇〇	
三四九	侏羅紀	Bl	一·二七	八·四四	一〇·五〇	一·〇〇	
五二三	侏羅紀	Bl	一·五五	九·一六	一一·〇五	一·〇〇	

上表中加水燃率係據金開英洪曾荃著各省煤質分析。產油量係據遊之讓低溫蒸餾試驗。

(七)加水燃率與丙化合物 γ 之關係

固定炭與水份及揮發物之和之比名曰加水燃率，蓋此可以表示煤之碳化程度，卽碳化高者其燃率亦增高，今將丙化合物及此所溶者，與加水燃率所作之兩曲綫列後。(見英文篇中)

曲綫雖如犬齒交錯，毫無一定規則，但細考之則凡在加水燃率二·五以上者，丙部份之差別甚小。在二·五以下者，則參差

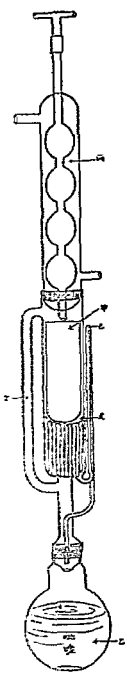
三六五	六〇七	九三・九三	二・三九	三・六八	
三六二	六・三七	九三・六三	一・七四	四・六三	
三七四	二九・四一	七〇・五九	一八・〇九	一一・三二	
三七三	三二・七二	六七・二八	一六・九五	一五・七七	
三六九	三二・七五	六七・二五	一六・三三	一六・四二	
五八七	一一・一二	八八・八八	四・八五	六・二七	
五九一	七・七三	九二・二七	二・九七	四・七六	
五九七	一八・七五	八一・二五	八・六三	一〇・一二	
四四八	一九・二一	八〇・七九	七・九三	一一・二八	
六五五	二三・四四	七六・五六	一三・五二	九・九二	
三四九	一四・五一	八八・四九	六・〇七	八・四四	
五二三	一九・五二	八〇・四八	一〇・三六	九・一六	

(六)討論

爲討論時簡易起見，茲將下表列入。

煤	時代	記號	加水燃率	γ	產油量	膨脹係數
三二一	二疊石炭紀	Bh	三・四四	二・二八	五・七三	一・〇六
三一九	二疊石炭紀	Bh	三・三七	二・六六	四・九七	一
三一〇	二疊石炭紀	Bm	二・八八	四・七九	五・七〇	一・〇四

甲，卽鋁土瓷管，有微孔，溶劑可滲透。乙爲燒瓶中置吡啶。丙爲冷凝器，上接丁字形管。管之兩端一接抽氣機，一接蓄氮器，將蘇氏器抽空，貯以氮氣，於瓶底加熱，吡啶蒸氣沿丁管上升至冷凝管結而下落於瓷管中。煤中有機質之一部，漸溶解，自管中滲出。迨戊筒中溶液表面過「己」管時，卽因虹吸作用溶液盡流下瓶中。溶劑再蒸發至瓷管，再落下，如是循環，直至下降溶液無色時爲止，調節熱度，使每十分鐘循環一次。試驗終始約需四十八小時。將溶液濾入一已知重量一百五十公分之燒瓶中，蒸餾吡啶，使濃至溶液將乾涸時，逐次加十五公分之二甲烷苯（Xylene），蒸發直至吡啶惡臭嘔盡爲止。將燒瓶置一〇五至一一〇度之眞空乾燥器中使乾。冷却後衡其重。乙丙兩種化合物之總量卽燒瓶前後之差。以三氯甲烷代吡啶，依同一方法可使乙丙兩種化合物分開，而得其重。惟蒸發溶液時可不用二甲烷苯而已。



（五）結果

依滅灰煤計算，所得結果如下。

煤	吡啶吸收者	甲 α	乙 β	丙 γ
三二一	二·七四	九七·二六	〇·四六	二·二八
三一九	三·九五	九六·〇五	一·二九	二·六六
三一〇	六·八二	九三·一八	二·〇三	四·七九
三〇九	七·二四	九二·七六	〇·六六	六·五八

三四九　　察哈爾宣化　　厚壘　　全　上　四二·六八　五七·三二

五二二　　山西大同　　—　　全　上　三八·〇一　六一·九九

(三)各煤之焦性

三二一及三一九—係同自一礦而不同煤層，二者皆可成粘結之半焦，但三一九微縮而三二一稍脹。

三〇九及三一〇—此煤已用於土法及新式煉焦，三〇九之半焦甚脹，有光澤，堅硬並多氣孔，三一〇之半焦稍脹亦堅硬。

三六五—近數年來已用之於煉焦，可爲鍊鐵用，其半焦堅硬，有光澤，且膨脹。

三六二—加熱時收縮成堅實之半焦，此煤用之於井陘礦局之副產煉焦爐，其最大之產額，每日可至百一十噸。

三七三及三七四—其半焦稍脹，堅硬而有光澤，此煤已用於新式之蜂巢式煉焦爐。

三六九—焦甚脹，多孔而易碎，當地用此煤煉焦，月產約三千二百噸。

五八七—其半焦堅實而微縮，通常以爲不宜煉焦。

四四八—半焦甚脹，多孔易碎，惟含硫甚多，是其缺點。

六五五—半焦有粘性稍硬，其焦炭已大量用於冶金。

五二三—因其富於絲炭故不宜煉焦，其半焦稍俱粘性而粗鬆，極易碎爲粉末。

三四九—不能煉焦，毫無粘性，但富於揮發物。

(四)實驗方法

本試驗採用美國礦務局所用方法，茲略述如下。以一公分過六十孔篩已乾煤末與四至五倍體積之淨砂混合，置於鋁土瓷管(Alundum Thimble)中，於蘇克施器(Soxhlet Extractor)中，以百二十五公分之吡啶提出之。蘇氏器之構造如圖所示。

究是否以溶劑方法可預斷烟煤之焦性，乃本試驗之目的。

(二)煤樣

所擇煤樣均採自重要礦場，其質皆爲烟煤凡十六種。其地質年代，減潮減灰之實用分析，列表如下。

試驗室號數	產地	公司	地質時代	揮發物	固定炭
三二一	河北磁縣	怡立	二疊石炭紀	二二·二八	七七·七二
三一九	河北磁縣	怡立	仝上	二二·七二	七七·二八
三一〇	山東博山	博東	仝上	二五·六七	七四·六三
三〇九	山東博山	博東	仝上	二四·〇〇	七六·〇〇
三六五	河南六河溝	一	仝上	二八·一五	七一·八五
三六二	河北井陘	井陘	仝上	二六·七二	七三·二八
三七四	河北灤縣	開灤	仝上	三五·九六	六四·〇四
三七三	河北灤縣	開灤	仝上	三五·七六	六四·二四
三六九	山東嶧縣	中興	仝上	三四·二一	六五·七九
五八七	安徽舜耕山	大通	仝上	三八·七五	六一·二五
五九一	湖南湘潭	有利	二疊紀	二三·六九	七六·三一
五九七	浙江長興	長興	仝上	四二·三九	五七·六一
四四八	安徽宣城	一	仝上	四一·六六	五八·三四
六五五	江西萍鄉	萍鄉	侏羅紀	三六·四二	六三·五八

中國烟煤之溶劑試驗

賓果

(一)緒言

烟煤之化學成分甚不易知，蓋實用分析僅知揮發物固定炭若干，而揮發份實僅一籠統名詞，其中所包何種成分仍未知也。如作元素分析，則又將煤質破壞過甚，只知其元素成分，而不能得原含之化學組合。自馬錫爾氏發現煤中之有機質能以溶劑取出後，學者迭加試驗，皆企以此法得知煤之化學成分。然研究之結果甚多，演繹之理論亦衆，而煤之化學組成固仍曖昧不明也。

溶劑之可用於此試驗者甚多，其較優者首推吡啶(Pyridine)(化學專名皆遵用教育部公布化學命名原則)最初爲彭特生氏所採用，據哈格氏稱吡啶溶煤力之所以強者，以其對煤中之複化合物有相當化學分解作用，非僅單純之物理作用已也。衛力及柯賴氏更將吡啶所溶者以三氯甲烷(Chloroform)再分別之，並將此二溶劑所分開之部分各列如左：

甲化合物—煤中部分之不能溶於吡啶者

乙化合物—煤中部分之溶於吡啶而不溶於三氯甲烷者

丙化合物—煤中部分之溶於二種溶劑者，爲明瞭此分開手續起見列表如下：

煤＋吡啶 ⟨溶解者＋三氯甲烷 ⟨溶解者—丙化合物 / 不溶者—乙化合物⟩ / 不溶者—甲化合物⟩

甲乙兩種化合物爲同一之物質，其由來多自植物；丙化合物則類樹脂。論者皆謂煤之能適於煉焦與否，均視丙化合物之多少爲斷，以其富有膠結能力故也。

吾國烟煤儲藏甚豐，以產地之不同，成分迥異，其煉焦之可能性亦復懸殊，故在大規模應用之先，煤樣之測驗至爲重要。研

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中國烟煤之溶劑試驗

賓果著

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CONTRIBUTION FROM THE SIN YUAN FUEL LABORATORY GEOLOGICAL SURVEY OF CHINA

No. 15 December 1933

(A) THE SULPHUR FORMS IN CHINESE COALS

(B) THE USE OF CALCIUM HYDROXIDE AND SODIUM NITRATE IN THE DETERMINATION OF TOTAL SULPHUR IN COAL

By

C. H. YOUNG

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THE SULPHUR FORMS IN CHINESE COALS

By C. H. Young

1. INTRODUCTION.

Methods for the analysis of total sulphur in coal have been in use for many years. It depends on the general principle of complete oxidation of the sulphur present in coal, followed by the gravimetrical estimation of the sulphate as barium sulphate. From technical stand-point a total sulphur determination is useful as it fixes the value of a particular coal for particular use. However in determining the value of coking coals it is usually desirable to know not only the total sulphur content, but also how the sulphur is distributed in the coal and the exact amount of each form present. Work of this kind would be useful in indicating how much of the sulphur-containing material can be removed from the coal by washing, what effect the sulphur has on the coking value of the coal, how the various sulphur forms behave during the coking processes.

Though China is well known for her enormous resources of coal, yet no work along this line has been done, consequently no data are available so far on the exact forms of the sulphur present in the Chinese coals. It is the intention of this paper to study these forms which would be useful to those who are interested in the coking coals in the country.

2. DESCRIPTION OF COALS USED

The coals analyzed were all gathered from important and working mines located at different parts of the country. With a few exceptions, they are limited to good and well-known coking coals. Their total sulphur contents vary from 0.5 to over 5 per cent. The following tables (Table 1 and Table 2) give a general description of each coal used in these experiments.

TABLE 1. SOURCE OF COALS USED IN EXPERIMENTS.

Lab. No.	Province	District	County	Co. operating mine	Symbol
306	Shantung	Poshan	Hsiho	Tunghsing Co.	AB
319	Hopei	Tzuhsian	Hsitsochun	Yili Co.	Bm
321	Hopei	Tzuhsian	Hsitsochun	Yili Co.	Bh
349	Chahar	Hsuanhwa	Yutaishan	Houfeng Co.	Bl
362	Hopei	Chinghsing	Kangtouchun	Chinghsing Mining Adm.	Bm
365	Honan	An-yang	Liuhokou	Liuhokou Co.	Bm
369	Shantung	I-hsian	Tsaochuang	Chunghsing Co.	Bm
373	Hopei	Lanhsian	Chaokouchuang	Kailan Mining Adm.	Bm
374	Hopei	Lanhsian	Chaokouchuang	Kailan Mining Adm.	Bm
448	Anhwei	Hsuancheng	Tawangchun	Suitung Mine	Bl
485	Anhwei	Hwaiyuan	Shunkengshan	Hwainan Co.	BC
523	Shansi	Tatung	Kakata	———	Bl
591	Hunan	Hsiangtan	Tanchiashan	Youli Co.	Bh
597	Chekiang	Changhsing	Tameishan	Changhsing Co.	BC
655	Kiangsi	Pinghsiang	An-yuan	Pinghsiang Co.	Bl

TABLE 2. PROXIMATE ANALYSIS AND CALORIFIC VALUES OF COALS USED IN EXPERIMENTS.

Lab. No.	Moisture	Vol.Mat.	F. Carbon	Ash	Sulphur	Calories	B.T.U.
306	0.50%	16.81%	73.97%	8.72%	2.86%	7923	14288
319	0.24%	21.20%	72.10%	6.46%	0.65%	8153	14675
321	0.32%	21.10%	73.62%	4.96%	1.43%	8279	14902
349	1.96%	36.02%	48.38%	13.64%	0.75%	6612	11902
362	0.14%	23.70%	65.01%	11.15%	0.78%	7733	13919
365	0.46%	23.79%	60.73%	15.07%	0.84%	7355	13239
369	0.40%	31.75%	61.05%	6.80%	0.79%	8009	14416
373	0.31%	31.94%	57.39%	10.36%	0.97%	7636	13745
374	0.78%	31.27%	55.69%	12.26%	1.39%	7503	13505
448	0.10%	33.34%	46.68%	19.88%	5.47%	6348	11426
485	2.11%	36.32%	48.67%	12.90%	1.66%	6646	11963
523	2.00%	35.63%	58.11%	4.26%	0.57%	7791	14029
591	0.62%	22.03%	70.98%	6.37%	0.65%	8125	14625
597	0.48%	33.49%	45.51%	20.52%	3.35%	6180	11124
655	0.92%	30.38%	53.03%	15.67%	0.54%	7219	12994

3. METHODS USED.

The method developed by Powell and Parr* has been well known and considered as a reliable and practical procedure. For that reason, their method was entirely adopted for this study. The procedure is abstracted below.

1. Total Sulphur Content.

One gram, or, preferably, the factor weight, 1.3736 grams, of the coal sample is heated with about three grams of Eschka mixture (one part of anhydrous sodium carbonate, two parts of calcined magnesium oxide and one-fifth part of ammonium nitrate) in a muffle furnace and the sulphur is determined in the water extracts as sulphates by barium chloride method. In case the sulphur content is exceedingly high, say over two per cent., one half the factor weight, 0.6868 gram, is used.

2. Total Inorganic Sulphur Content.

One gram of the sample is digested with 80 cc. of dilute nitric acid (1:3) with occasional addition of bromine water for a period of 24 hours at room temperature. The filtrate, after getting rid of the nitric acid by evaporating with hydrochloric acid, is taken up in dilute hydrochloric acid and treated with ammonium hydroxide to precipitate iron and the latter is determined by potassium permanganate titration. The sulphur is determined by usual method from the filtrate from which the iron is just removed. This amount of iron, in per cent., is termed as the nitric acid soluble ron content of the coal while that of sulphur, also in per cent., is known as the total inorganic sulphur content, that is, the pyritic sulphur plus sulphate sulphur.

3. Sulphate Sulphur Content.

A five-gram portion of the sample is extracted with 300 cc. of dilute hydrochloric acid (3%) for a period of 40 hours at a temperature of about 60°C. The extract is analyzed for iron and sulphur, the sulphur representing the sulphate sulphur present in the coal.

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* Forms in which Sulphur Occurs in Coal. By A. R. Powell and S. W. Parr. Bull. Am. Inst. Mining Met. Eng. 1919. 2041-9; C. A. XIV, 112.
The Analysis of Sulphur Forms in Coal. By A. W. Powell. U. S. Bureau of Mines, Technical Paper 254.

4. Pyritic Sulphur Content.

The per cent. of the pyritic sulphur in coal may be found in two ways, namely:

a. By subtracting the per cent of sulphate sulphur from the per cent of total inorganic sulphur.

b. By calculating from pyritic iron content of the coal. The difference between nitric acid soluble iron and hydrochloric acid soluble iron is the pyritic iron content and by means of the latter the pyritic sulphur is readily computed.

5. Total Organic Sulphur Content.

The total organic sulphur content of the coal may be estimated as follows:

a. By difference. The per cent. representing the sulphate sulphur in the coal is added to the correct per cent. representing the pyritic sulphur, and the sum is subtracted from the per cent., representing the total sulphur in the coal.

b. By direct determination. The sulphur is determined by Eschka method from the residue of the dilute nitric acid extraction.

6. Two forms of Organic Sulphur.

One gram, or the factor weight, 1.3736 grams, of the coal sample is extracted with 25 cc. of phenol at a temperature of about 150°C. for twenty hours. The mass is filtered hot and washed with alcohol and sulphur is determined from the residue by Eschka method. This amount of sulphur, in per cent, represents the phenol insoluble, non-phenolic, sulphur of the coal, while the per cent of the phenol soluble, phenolic, sulphur is obtained by subtracting the per cent of non-phenolic sulphur from the total sulphur content of the coal. The total organic sulphur minus the phenolic, resinous organic, sulphur both represent in per cent, gives the per cent of humus organic sulphur.

4. ANALYTICAL RESULTS OF EXPERIMENTS.

1. The first set of experiments was, of course, the determination of the total sulphur in coal, the data of which were already given in Table 2. Now comes the second which was performed with regard to the analysis of the sulphate and pyritic

forms of the sulphur alone. The data from these experiments are given in the following table (Table 3).

TABLE 3. SULPHUR AND IRON IN COAL AND ALSO WITH A COMPARISON OF THE PYRITIC SULPHUR AS OBTAINED WITH THE PYRITIC SULPHUR AS CALCULATED FROM THE PYRITIC IRON CONTENT:—

Lab. No.	Inorg. Sulphur	SO_4 Sulphur	Pyritic Sulphur	HNO_3 Sol. Fe	HCl Sol. Fe	Pyritic Iron	Pyritic Sulphur	Differ.
306	1.40%	0.25%	1.15%	1.83%	0.86%	0.97%	1.11%	+0.04%
319	0.11%	0.02%	0.09%	0.23%	0.14%	0.09%	0.10%	−0.01%
321	0.92%	0.08%	0.84%	0.88%	0.18%	0.70%	0.80%	+0.04%
349	0.49%	0.06%	0.43%	0.59%	0.22%	0.37%	0.42%	+0.01%
362	0.25%	0.02%	0.23%	0.40%	0.20%	0.20%	0.23%	0.00%
365	0.32%	0.08%	0.24%	0.46%	0.27%	0.19%	0.22%	+0.02%
369	0.25%	0.23%	0.02%	0.55%	0.53%	0.02%	0.02%	0.00%
373	0.30%	0.12%	0.18%	0.42%	0.30%	0.12%	0.14%	+0.04%
374	0.60%	0.17%	0.43%	0.68%	0.32%	0.36%	0.41%	+0.02%
448	3.88%	0.05%	3.83%	3.64%	0.27%	3.37%	3.86%	−0.03%
485	1.04%	0.07%	0.97%	1.00%	0.16%	0.84%	0.96%	+0.01%
523	0.12%	0.00%	0.12%	1.57%	1.50%	0.07%	0.08%	+0.04%
591	0.00%	0.00%	0.00%	0.19%	0.18%	0.01%	0.01%	−0.01%
597	1.77%	0.22%	1.55%	1.75%	0.42%	1.33%	1.52%	+0.03%
655	0.10%	0.00%	0.10%	0.35%	0.28%	0.07%	0.08%	+0.02%

It is claimed that a small quantity of organic sulphur may have been taken into solution by dilute nitric acid. According to the present data it seems correct since the pér cent of pyritic sulphur obtained by direct extraction method are generally higher than those calculated from the pyritic iron content. For this reason the latter figures are considered as the correct per cent of the pyritic sulphur in coal.

2. Total Organic Sulphur. The following table (Table 4) gives the per cent of total organic sulphur obtained in two ways. A comparison of the totals and their average values are also given.

TABLE 4. PER CENT REPRESENTING TOTAL ORGANIC SULPHUR:—

Lab. No.	Total Sulphur	Pyritic Sulphur	SO_4 Sulphur	Total By diff.	Organic S. Dir. Det.	Difference	Average
306	2.86%	1.11%	0.25%	1.50%	1.48%	+0.02%	1.49%
319	0.65%	0.10%	0.02%	0.53%	0.56%	−0.03%	0.55%
321	1.43%	0.80%	0.08%	0.55%	0.52%	+0.03%	0.54%
349	0.75%	0.42%	0.06%	0.27%	0.28%	−0.01%	0.28%
362	0.78%	0.23%	0.02%	0.53%	0.57%	−0.04%	0.55%
365	0.84%	0.22%	0.08%	0.54%	0.52%	+0.02%	0.53%
369	0.79%	0.02%	0.23%	0.54%	0.56%	−0.02%	0.55%
373	0.97%	0.14%	0.12%	0.71%	0.69%	+0.02%	0.70%
374	1.39%	0.41%	0.17%	0.81%	0.82%	−0.01%	0.82%
448	5.47%	3.86%	0.05%	1.56%	1.60%	−0.04%	1.58%
485	1.66%	0.96%	0.07%	0.63%	0.60%	+0.03%	0.62%
523	0.57%	0.08%	0.00%	0.49%	0.46%	+0.03%	0.48%
591	0.65%	0.01%	0.00%	0.64%	0.63%	+0.01%	0.64%
597	3.35%	1.52%	0.22%	1.61%	1.58%	+0.03%	1.60%
655	0.54%	0.08%	0.00%	0.46%	0.46%	0	0.46%

3. Two Forms of Organic Sulphur.

TABLE 5. PHENOLIC AND HUMUS ORGANIC SULPHUR IN COAL:—

Lab. No.	Total Sulphur	Nonphenolic Sulphur	Phenolic Sulphur	Aver. Total Org. sulphur	Humus Org. Sulphur
306	2.86%	2.72%	0.14%	1.49%	1.35%
319	0.65%	0.64%	0.01%	0.55%	0.54%
321	1.43%	1.42%	0.01%	0.54%	0.53%
349	0.75%	0.70%	0.05%	0.28%	0.23%
362	0.78%	0.72%	0.06%	0.55%	0.49%
365	0.84%	0.76%	0.08%	0.53%	0.45%
369	0.79%	0.59%	0.20%	0.55%	0.35%
373	0.97%	0.77%	0.20%	0.70%	0.50%
374	1.39%	1.15%	0.24%	0.82%	0.58%
448	5.47%	5.03%	0.44%	1.58%	1.14%
485	1.66%	1.52%	0.14%	0.62%	0.48%
523	0.57%	0.56%	0.01%	0.48%	0.47%
591	0.65%	0.57%	0.08%	0.64%	0.56%
597	3.35%	2.86%	0.49%	1.60%	1.11%
655	0.54%	0.48%	0.06%	0.46%	0.40%

According to the above table the majority of organic sulphur would be of humus type.

4. Summary of Analytical Results.

The following table gives in condensed form the results of the analyses for the various forms of sulphur and a comparison of the total of these with the total sulphur in the coal.

TABLE 6. SUMMARY OF ALL ANALYSES FOR SULPHUR FORMS IN COAL:—

Lab. No.	Pyritic Sulphur	SO_4 Sulphur	Humus Org. Sulphur	Phenolic Sulphur	sum	Total Sulphur	Total Difference
306	1.11%	0.25%	1.35%	0.14%	2.85%	2.86%	−0.01%
319	0.10%	0.02%	0.54%	0.01%	0.67%	0.65%	+0.02%
321	0.80%	0.08%	0.53%	0.01%	1.42%	1.43%	−0.01%
349	0.42%	0.06%	0.23%	0.05%	0.76%	0.75%	+0.01%
362	0.23%	0.02%	0.49%	0.06%	0.80%	0.78%	+0.02%
365	0.22%	0.08%	0.45%	0.08%	0.83%	0.84%	−0.01%
369	0.02%	0.23%	0.35%	0.20%	0.80%	0.79%	+0.01%
373	0.14%	0.12%	0.50%	0.20%	0.96%	0.97%	−0.01%
374	0.41%	0.17%	0.58%	0.24%	1.40%	1.39%	+0.01%
448	3.86%	0.05%	1.14%	0.44%	5.49%	5.47%	+0.02%
485	0.96%	0.07%	0.48%	0.14%	1.65%	1.66%	−0.01%
523	0.08%	0.00%	0.47%	0.01%	0.56%	0.57%	−0.01%
591	0.01%	0.00%	0.56%	0.08%	0.65%	0.65%	0.00%
597	1.52%	0.22%	1.11%	0.49%	3.34%	3.35%	−0.01%
655	0.08%	0.00%	0.40%	0.06%	0.54%	0.54%	0.00%

It is evident from this table that the sum of the several analyses checks very closely with the total sulphur content of each coal.

5. CONCLUSION.

1. The organic sulphur content of coal is generally known to be greater than pyritic sulphur content. This statement is proved to be correct with Chinese coals.

2. The method of Powell and Parr is well applicable to Chinese coals and values on duplicate determinations mutually agree.

3. Dilute nitric acid will extract small amounts of organic sulphur from certain coals. In order to avoid this error in laboratory determinations, it is recommended that the pyritic sulphur be calculated from the pyritic iron content.

4. Pyrite in coal can be quantitatively extracted by the same acid.

5. Semibituminous coals and the low volatile bituminous coals must be digested for a longer time with concentrated nitric acid in order to render the organic matter completely soluble in ammonia.

6. The percentages of phenolic sulphur are always lower than those of humus organic sulphur.

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THE USE OF CALCIUM HYDROXIDE AND SODIUM NITRATE IN THE DETERMINATION OF TOTAL SULPHUR IN COAL

By C. H. Young

1. INTRODUCTION.

The Eschka method for the determination of total sulphur in coal was first introduced as early as 1870 (1). More than three scores of years have elapsed, yet no better method has been proposed. Though both of the bomb washing and sodium peroxide methods (2) were mentioned by some fuel chemists as to give results in close agreement with the Eschka method, they are by no means better than the Eschka's. Consequently the latter has long been universally recognized as the best method and is adopted by many scientific institutions in the world as the standard method for total sulphur estimation in coals. If not for its expense, Eschka method should be accepted as the best one among all that have been proposed so far. It is expensive not only because of the high market price of the light magnesium oxide but also of the heat energy consumed during the fusion. The latter factor was always required practically for all the methods mentioned in the literature and it seems that no better method other than fusion is available in attacking the coal substance. The other factor, that is, the high cost of the light magnesium oxide, can however be replaced by using some cheaper reagent. Among the other methods, the one proposed by Ivison (3) seems to be most reliable. The author has tried the Ivison method for the determination of total sulphur in some Chinese coals and found that the sintered coal and the chemical mixture are liable to form a hard cake which is difficult to break up. A mixture consisting of calcium hydroxide and sodium nitrate

is recommended with the prime aim of lowering the cost for sulphur determination in coals. The results obtained from such a flux as mentioned are pretty close to those by the Eschka method.

2. THEORETICAL BASIS.

The methods for determination of total sulphur in coal are based upon the principle of complete oxidation of the sulphur-bearing materials to sulphates and the latter are estimated as barium sulphate. The process of oxidation is usually carried out in two stages, The first stage is that the sulphur is oxidized by a suitable oxidizing agent and then the second stage, the resultant sulphur oxides are absorbed by an efficient absorbent, which is generally performed by a basic substance against the acidic property of the sulphur oxides. The methods given in the literature may be classified as follows:

1. Air plays as an oxidizing agent and a basic substance is employed as an absorbent of the sulphur oxides formed. This is examplified by the Eschka method and Ivison method.

2. Oxygen gas performs the oxidation while water or caustic alkali, the absorption. Example, bomb washing method.

3. A single suitable flux is employed both as an oxidizing agent and absorbent. Sodium peroxide method (2) is of this type.

4. Different chemicals are employed as oxidizing agent and absorbent respectively. Potassium permanganate method (4, 5, 6) belongs to this class.

The use of the mixture of calcium hydroxide and sodium nitrate as a flux is of the last class, that is, sodium nitrate plays in part as an oxidizing agent while the calcium hydroxide serves as an absorbent.

The use of sodium nitrate in the mixture seems, for the first glance, quite objectionable to the subsequent precipitation of the sulphates as barium sulphate; as the latter is partially soluble in dilute nitric acid (7). But the fact is that the sodium nitrate is unstable at high temperature and is decomposed during the fusion into sodium nitrite with evolution of free oxygen and the sodium nitrite thus formed is also unstable at high temperature and splits into oxides of sodium and nitrogen (8). Since the temperature of the furnace is so high, always exceeding 900° C., that the

evolved nitrogen oxides are unable to combine with the lime of the flux and set free as they are, so the resultant fused mass is not expected to contain any nitrate or nitrite ions.

The author made tests on the fused mass for nitrate and nitrite with saturated ferrous sulphate solution and concentrated sulphuric acid and found that there is no detectable nitrate or nitrite ions. But he suspected that the tests were not conclusive and made several careful determinations assuming that the nitrate or nitrite is present as follows:—

The water extracts of the fusion was treated with bromine water and considerable excess of hydrochloric acid and evaporated to dryness on water bath in order to get rid of the nitric acid. The residue is taken up with dilute hydrochloric acid and sulphur is determined by usual method. The results thus obtained were just the same as those obtained from the mass without treatment of excess hydrochloric acid and evaporation. The absence of the nitrate or nitrite ions in the used mass is thus confirmed.

3. PREPARATION OF THE FLUX.

The author made a number of trials in estimating the correct proportion of the ingredients of the flux, that is, calcium hydroxide and sodium nitrate and found that the flux is best prepared by mixing three parts of finely pulverized slaked lime of superior quality with one part of pure sodium nitrate, also finely pulverized. When less amount of sodium nitrate is used it is found that incomplete oxidation of the sulphur resulted. And conversely, less slaked lime (or more sodium nitrate) is employed thef usion will cake as in the Ivison method and the results obtained are by no means better than the proportion quoted above.

Quick lime can, of course, be used as well as the slaked lime but when pulverized the quick lime is of a dense powdery mass which is not suitable, in the author's opinion, for the absorption of gases.

4. DESCRIPTION OF COALS USED IN EXPERIMENTS.

The samples are collected so as to cover all classes of coals, that is, from high rank anthracite, Ah, to lignite, C. In addition the coals are almost of all geological ages. The contents of sulphur range from 0.15 to 7.41 per cent. The descriptions of the samples are tabulated as in Table 1:—

TABLE 1.—THE SOURCES OF COALS USED.

Sample No.	Province	District	County	Mine, Co. etc.	Geol. ages	Symbol
335	Liaoning	Hsian	———	Tai Lai Mine	Cretaceous	Bm
450	Anhwei	Tsinghsien	Yenkungtang	———	Permian	Bm
479	Hopei	Wanping	Mentoukou	Chung Ying Co.	Jurassic	Ah
514	Yunnan	Chengkiang	Haipakeng	———	Permo-Carboniferous	Bm
517	,,	A-Mi	Wukeh	———	,,	BC
531	Suiyuan	Kooyang	Wehhsinhao	———	Jurassic	BC
563	Szuchuan	Ya-an	Kuanyinpu, Taotzeping	———	,,	Am
574	,,	Hanyuan	Niushihpo, Yangtzechiao	———	,,	AB
607	Anhwei	Hsuancheng	Tawangchun	Sui Tung Mine	Permo-Carboniferous	Bl
641	Hopei	Lincheng	———	Lin Cheng Mine	,,	BC
668	Hunan	Hsianghsiang	Hungshantien	Kuang Yu Co.	Permian	AB
694	Shansi	Huenyuan	Taoshahchun	———	Jurassic	BC
732	Kuangtung	Lochang	Lochiatu	———		Bm
740	,,	Chinhsien	Kuchahling	———	Tertiary	C
743	,,	Chiungshan	Chiatzeshih, Niushihshan	———	Permian	C
763	Hunan	Hsianghsiang	Ngenkou, Hweilungshan	Tien Pao Yu Co.	,,	Bm
813	Shantung	Ningyang	———	Hwa Feng Co.		BC
815	Kiangsu	Tungshan	Chiawang	Hwa Tung Co.	Permo-Carboniferous	Bl
820	Anhwei	Suhsien	———	———	,,	Bh
841	Kiangsi	Loping	Mingshan	Lo Ping Mine	Permian	C
845	Honan	Yuhsien	Sanshanfeng	———	Permo-Carboniferous	Bh
853	Shensi	Hancheng	Chiaoerkou	———		Bh
863	Chekiang	Kiangshan	Lihsien	Cheng Tang	Permian	Bh
886	Hupei	Tsingmen	Kuanmiaoping	———	Jurassic	Al

5. NOTES ON THE PROCEDURES.

1. The author in performing these analyses followed, with modifications, the procedure published by the American Society of Testing Materials (A.S.T.M.) for total sulphur determination in coal by Eschka method.

2. During the fusion a high-form porcelain crucible of 30 cc. in capacity is employed.

3. In extraction the fusion is not necessarily brought in to the beaker and digested with boiling water. The author proceeds as follows: The fused mass is crushed, if necessary, and transferred directly to a filter paper. The small particles adhering to the sides of the crucible are moistened with hot water. When they are readily detached with a glass rod and are transferred to the filter. The crucible is washed 4 or 5 times with hot water, scrubbed with a policeman, and the washings are poured on the filter. The paper and the contents are washed to the complete removal of sulphates.

4. During the digestion and washing of the fusion on the filter the present method takes slightly longer time than the Eschka method.

5. Examine the residue for sulphur after digestion, by dissolving it in hydrochloric acid and treating with bromine water and barium chloride solution. When an appreciable amount of sulphur is found, add it to the main precipitate. If the procedure is followed promptly there should be no detectable sulphur in the residue, and this recovery is unnecessary.

6. The filtered extracts from the present method are always rendered extremely turbid by calcium salts, which is soluble in acid in subsequent treatment and it does not interfere with the precipitation of sulphur as barium sulphate.

7. The addition of bromine water may be omitted when the present method is employed, but a little is always added as a precaution.

8. Always run a blank determination with each analysis, using the same amount of all reagents that were employed in the regular determination. Deduct the sulphur found in the blank from the amount found in the sample.

9. Determinations of ash in coal or coke must not be made in the same muffle at the same time with sulphur determination, since during the ashing process sulphur compounds are more or less evolved as gases that may be in turn absorbed by the flux for sulphur determination.

6. RESULTS OF EXPERIMENTS.

Lab. No.	Sample Number	Eschka Method	*Present Method*	Difference
1	335	0.72%	0.77%	+0.05%
2	450	0.41%	0.41%	0
3	479	0.15%	0.17%	+0.02%
4	514	6.05%	5.87%	−0.18%
5	517	7.41%	7.30%	−0.11%
6	531	3.39%	3.30%	−0.09%
7	563	0.63%	0.62%	−0.01%
8	574	0.60%	0.60%	0
9	607	3.94%	3.86%	−0.08%
10	641	2.66%	2.62%	−0.04%
11	668	0.62%	0.64%	+0.02%
12	694	0.72%	0.72%	0
13	730	3.31%	3.22%	−0.09%
14	740	3.73%	3.73%	0
15	743	1.33%	1.26%	−0.07%
16	763	3.29%	3.23%	−0.06%
17	813	5.28%	5.26%	−0.02%
18	815	0.59%	0.59%	0
19	820	0.86%	0.85%	−0.01%
20	841	2.18%	2.08%	−0.10%
21	845	0.46%	0.48%	+0.02%
22	853	0.47%	0.48%	+0.01%
23	863	1.12%	1.14%	+0.02%
24	886	0.53%	0.56%	+0.03%

7. CONCLUSION.

1. The method proposed by the author is almost as good as the Eschka's when the sulphur content of the coal is below 3 per cent.; while for coals of higher sulphur content the method gives generally a slightly lower result in comparison with the Eschka method. As the maximum difference in per cent. is only 0.18 in 6.0 per cent. (about 3 per cent. error) which seems allowable in the usual course of analysis.

2. This method is also preferable to the Eschka's for the reason that the market price of slaked lime is much cheaper than that of light magnesium oxide.

(MgO, G.$3.50 per pound; Ca $(OH)_2$, G.$1.30 per pound.) Sodium carbonate and sodium nitrate are of the same price, approximately.

3. During the digestion and washing of the fusion on the filter this method takes slightly longer time than the Eschka method.

4. The volume of light magnesium oxide is much looser than that of slaked lime and this property is favorable to the absorption of evolving gases as it gives more surfaces and takes better care of them. It is of this reason for the author to use slaked lime instead of quick lime.

5. Since sodium nitrate in the mixture and the resulted nitrite will completely decompose during the fusion, no nitrate ions are found in the solution from which the barium sulphate is to be precipitated.

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16	三·二九	三·二三	減〇·〇六
17	五·二八	五·二六	減〇·〇二
18	〇·五九	〇·五九	〇
19	〇·八六	〇·八五	減〇·〇一
20	二·一八	二·〇八	減〇·一〇
21	〇·四六	〇·四八	增〇·〇二
22	〇·四七	〇·四八	增〇·〇一
23	一·一二	一·一四	增〇·〇二
24	〇·五三	〇·五六	增〇·〇三

（四）結論

（1）本方法以分析之結果言之與愛氏法不相伯仲，惟於硫質稍高之煤樣結果視愛氏法爲低，最大差數爲百分之六之硫份中差百分之〇·一八（錯差約百分之三），謂爲試驗之錯誤當亦無不可。

（2）本方法之主要優點乃爲需價低廉，氧化鎂每磅售金元三元五角，氫氧化鈣則需一元三角（炭酸鈉與硝酸鈉幾屬於相同之價格），相差不爲不鉅矣。

（3）本方法在某種臆測之下，視愛氏法爲劣。

（a）本混合物之體積經熔融後不似愛氏混合劑之高度的收縮，而使洗滌費時。

（b）未經熾熱之愛氏混合劑體質鬆散，其體積殆視本混合物而倍之。其於氣體之吸收也當有加倍効率。著者因是之故，舍較廉之生石灰，而樂於用熟石灰也。

之虞。

(三)分析之結果

試驗室號數	愛氏法之結果(百分率)	本方法之結果(百分率)	相差(百分率)
1	○·七二	○·七七	增○·○五
2	○·四一	○·四一	○
3	○·一五	○·一七	增○·○二
4	六·○五	五·八七	減○·一八
5	七·四一	七·三○	減○·一一
6	三·三九	三·三○	減○·○九
7	○·六三	○·六二	減○·○一
8	○·六○	○·六○	○
9	三·九四	三·八六	減○·○八
10	二·六六	二·六二	減○·○四
11	○·六二	○·六四	增○·○二
12	○·七二	○·七二	○
13	三·三一	三·二二	減○·○九
14	三·七三	三·七三	○
15	一·三三	一·二六	減○·○七

測定煤內硫質之新法

楊珠瀚

（一）緒言

愛氏法（Eschka Method）自一八七〇年以來，迄數十年尙無較完善方法，其間雖有彈抵洗滌法（Bomb Washing Method）及過氧化鈉法（Sodium Peroxide Method），各有優點，然究屬不無遺憾。是以前者迄保持其優越之地位，進而爲公認之標準方法焉。惟該法需費較鉅。晚近學者致力於此研究者頗不乏人，就中以伊氏（Ivison）之方法似較便利而可靠。其法卽以石灰與炭酸鈉之混合物，代替愛氏混合劑。著者以此施諸華煤之分析，頗覺有一困難，卽用伊氏混合物所得煤之熔融物（Fused mass）頗難粉碎。著者因思及該熔融物之所以不易粉碎者，純係炭酸鈉之故，幷思有以代之。

硝酸鈉之爲物熔點甚低，且易熱解而發出氧素。如以此種物質代替炭酸鈉，其結果將大見進益，蓋此氧素適可應用於煤內硫質之氧化，於理既然，應用結果亦稱足符此旨。

本混合物之配合，以三份之氫氧化鈣（熟石灰）與一份之硝酸鈉，研碎攪勻備用。

（二）分析之手續

（1）本鑑定之手續大約與拙著華煤中硫質種類之分析文內全硫份之鑑定相同。

（2）著者於溶融煤質時係用細高式磁杯（High-form Porcelain Crucible），其體積約三十立公分（Cubic Centimeter, CC.）。

（3）溴水之加入在本方法爲可免之步驟，蓋硝酸鈉之存在於先，已足使全部硫質變爲硫酸基（Sulphate Radicle）而有餘，雖然，爲萬全計，究以加入少許爲是。

（4）普通葯品中往往含有少許某種硫質，鑑定此項硫份之於分析工作乃爲必要之手續，茲篇當亦不能例外。

（5）煤內之灰份不得與硫份同時在同一電爐內鑑定之，蓋煤在燃燒時往往有氧化硫氣體發出。後者將有被所用之混合物吸收

有三一九，四四八，及五九一，等三煤樣。因該三煤之由硝酸侵液所得之硫礦硫份，小於由該煤鐵量所計算之該項硫份。惟以各該煤之硫礦硫份，相差無幾（百分之〇·〇一—〇·〇三）。或屬可能之試驗錯誤，抑確有與二硫化鐵同性質之鐵質存在，未審孰是，茲誌以存疑。

（八）鳴謝

著者甚荷本所技師金開英先生之熱心指導與匡正，特此鳴感。又洪曾荃女士供給本篇以煤之實用分析表，亦一併申謝。參攷書目已列入英文篇，不另述。

五三	〇·〇六	〇	〇·四四	〇·〇二	〇·五六	〇·七	減〇·〇二
五九	〇·〇二	〇	〇·五六	〇·〇六	〇·六五	〇·六五	無增減
五七	一·五三	〇·三三	一·二二	〇·四四	三·三四	三·三五	減〇·〇二
六五	〇·〇六	〇	〇·四四	〇·〇六	〇·五四	〇·五四	無增減

總上分析結果，頗稱近似。此殆充分表現鮑氏及巴氏法之應用矣。

（六）結論

I 沿用鮑氏及巴氏法所得之結果，頗稱精確。該法之詳細步驟，已一并列入本文。

II 淡硝酸能溶解一部分有機硫質。故鐵量之鑑定極爲重要。

III 淡硝酸能溶解全部二硫化鐵，及其他溶解於淡鹽酸之鐵質。故由鐵量計算所得之硫礦硫份，較爲準確。

IV 全硫份中大抵以有機硫質之成分爲最高。

V 有機硫質內之膠性硫質，含量頗少。且少於腐植硫質。

VI 硫酸硫質之含量應極低，惟以某數煤暴露於空氣中時間較久之故，以致其成分稍高。

VII 半烟煤及低級烟煤浸蝕於濃硝酸之時間應久，次數應多。俾使全部有機物質得溶解於濃氫氧化鉀水，以便鑑定。

（七）志疑

淡硝酸能溶解全部二硫化鐵，及一應鹽酸所能溶解之鐵質，而不能溶解矽酸鐵，此爲事實。著者並假設華煤中之鐵質惟有二硫化鐵能溶解於硝酸，而不溶解於鹽酸，而有前項之結論焉。究於實際，是否如此，猶是疑問。蓋煤內或有與二硫化鐵同性質之鐵質：即溶解於硝酸而不溶解於鹽酸之時，則其由鐵量所計算之硫礦硫份，應高於實際之硫礦硫份矣。若然則前項結論，將無以自立矣。惟著者僅就試驗之結果，下該斷語，初未顧及是項可能之事實。且試驗所及，亦未發現類似該項之事實。其所可疑者則

五九一	〇·六五	〇·三七	〇·〇八	〇·六四	〇·五六
五九七	三·三五	二·八六	〇·四九	一·六〇	一·一一
六六五	〇·五四	〇·四八	〇·〇六	〇·四八	〇·四〇

由上表可知有機硫質中之腐植硫質占絕對多量。

分析之總結：

表六—總結各項分析之結果。並比較各煤內諸硫份之和與各該煤之全硫份。

試驗室號數	硫礦硫份	硫酸硫份	腐植硫份	膠性硫份	諸硫份和	全硫份	相差
三〇八	一·一一	〇·三五	一·三五	〇·一四	二·九五	二·九六	減〇·〇一
三一九	〇·一〇	〇·〇二	〇·五四	〇·〇一	〇·六七	〇·六五	增〇·〇二
三二一	〇·八〇	〇·〇八	〇·五三	〇·〇一	一·四二	一·四三	減〇·〇一
三四九	〇·四二	〇·〇八	〇·二三	〇·〇三	〇·七六	〇·七五	增〇·〇一
三六二	〇·二三	〇·〇二	〇·四九	〇·〇六	〇·八〇	〇·七八	增〇·〇二
三六五	〇·三三	〇·〇八	〇·四三	〇·〇八	〇·九二	〇·九三	減〇·〇一
三六九	〇·〇二	〇·三三	〇·三五	〇·二〇	〇·九〇	〇·八九	增〇·〇一
三七三	〇·一四	〇·一三	〇·五〇	〇·二〇	〇·九七	〇·九八	減〇·〇一
三七四	〇·四一	〇·一七	〇·五六	〇·二四	一·四〇	一·三九	增〇·〇一
四八六	三·八六	〇·〇五	一·一四	〇·四四	五·四九	五·四七	增〇·〇二
四九五	〇·九六	〇·〇七	〇·四八	〇·一四	一·六五	一·六六	減〇·〇一

665	0.54	0.08	〇	0.46	0.46	無增減	0.46

兩種全有機硫份，雖少有出入。然究未出乎可能的試驗之錯誤。故以各平均值爲準確之數字。庶與理論之數字，更近似矣。

III 兩種有機硫質之分析：

表五—兩種有機硫質之成分。

試驗室號數	全硫份	石炭酸不溶硫質	膠性硫質	全有機硫份(平均)	腐植硫質
308	2.66	2.73	0.14	1.49	1.35
319	0.65	0.64	0.01	0.55	0.54
321	1.43	1.42	0.01	0.54	0.53
349	0.75	0.70	0.05	0.28	0.23
362	0.78	0.72	0.06	0.55	0.49
365	0.84	0.76	0.08	0.53	0.45
369	0.79	0.59	0.20	0.55	0.35
373	0.77	0.77	0.20	0.70	0.50
374	1.39	1.15	0.24	0.82	0.58
448	5.47	5.03	0.44	1.58	1.14
485	1.66	1.53	0.14	0.62	0.48
523	0.	0.56	0.01	0.48	0.47

II全有機硫份—由兩種不同之方法所得之全有機硫份，稍有出入。茲列表四以比較之。並以各平均值爲各該煤之全有機硫份之准確數字云。

表四—全有機硫份，包括比較及其平均值。

試驗室號數	全硫份	硫鐵硫份	硫酸硫份	全有機硫份(間接)	全有機硫份(直接)	相差	全有機硫份(平均)
三〇六	二·八六	一·二一	〇·二五	一·六〇	一·四六	增〇·一一	一·五三
三一九	〇·六五	〇·一〇	〇·〇三	〇·五二	〇·五六	減〇·〇三	〇·五五
三二一	一·四二	〇·八四	〇·〇六	〇·五五	〇·五二	增〇·〇三	〇·五四
三四九	〇·七五	〇·四二	〇·〇六	〇·七七	〇·八一	減〇·〇四	〇·七九
三六三	〇·六一	〇·三二	〇·〇三	〇·五二	〇·五六	減〇·〇四	〇·五四
三六五	〇·八四	〇·三三	〇·〇六	〇·五四	〇·五二	增〇·〇三	〇·五三
三六九	〇·六九	〇·三三	〇·〇三	〇·五四	〇·五六	減〇·〇三	〇·五五
三七三	〇·九七	〇·四四	〇·一三	〇·七一	〇·六六	增〇·〇三	〇·六九
三七四	一·三九	〇·四一	〇·一七	〇·八一	〇·八三	減〇·〇一	〇·八二
四〇八	五·四四	三·八六	〇·五〇	一·三六	一·六〇	減〇·四四	一·五六
四五五	一·六六	〇·九六	〇·二四	〇·六六	〇·六六	減〇·〇三	〇·六五
五三三	〇·七四	〇·〇六	〇	〇·四六	〇·四六	增〇·〇三	〇·四六
五九一	〇·六五	〇·〇一	〇·〇四	〇·六四	〇·六二	增〇·〇一	〇·六四
五九四	二·三五	一·三三	〇·一三	一·六一	一·六六	增〇·〇三	一·六〇

三〇八	1·四〇	0·二五	1·一五	1·八三	0·九六	0·九七	1·一一	增0·〇四
三一九	0·一一	0·〇二	0·〇九	0·一三	0·一四	0·〇九	0·一〇	減0·〇一
三二一	0·九二	0·〇八	0·八四	0·八六	0·一八	0·八〇	0·八〇	增0·〇四
三四九	0·四九	0·〇六	0·四三	0·五九	0·一三	0·二七	0·四三	增0·〇一
三六二	0·二五	0·〇二	0·一三	0·四〇	0·二〇	0·二〇	0·一三	無增減
三六五	0·一三	0·〇八	0·一四	0·四六	0·二七	0·一九	0·一三	增0·〇二
三六九	0·二五	0·一三	0·〇二	0·五五	0·五三	0·〇二	0·〇二	無增減
三七三	0·二〇	0·一一	0·一八	0·四三	0·二〇	0·一一	0·一四	增0·〇四
三七四	0·六〇	0·一七	0·四三	0·六八	0·三三	0·三六	0·四一	增0·〇三
四四八	三·八八	0·〇五	三·八三	三·六四	0·二七	三·二七	三·八六	減0·〇二
四六五	1·〇四	0·〇七	0·九七	1·〇〇	0·一六	0·八四	0·九六	增0·〇一
五三三	0·一二	〇	0·一二	1·五七	1·五〇	0·〇七	0·〇八	增0·〇四
五九一	〇	〇	〇	0·一九	0·一六	0·〇一	0·〇一	減0·〇一
五九七	1·二七	0·一二	1·五五	1·五五	0·四二	1·三三	1·五三	增0·〇二
六八五	0·一〇	〇	0·一〇	0·五五	0·二六	0·〇七	0·〇八	增0·〇二

或謂有機硫質之一部，亦往往溶解淡硝酸。以試驗度之，不爲無因。蓋上表所列之硫磺硫份由硝酸浸液所鑑定者，大抵高於該項硫份由各該煤之鐵量計算所得之數字。著者遂亦以後項數字爲準確之硫磺硫份焉。

煤中之硫酸硫份，大抵甚少，前已道及。但證諸上表，似不盡然。此殆係某數種煤樣之出井時間較久所致。

e. 全有機硫份之鑑定—全有機硫份之鑑定方法亦有二：

1. 由全硫份減去硫酸硫份及準確硫礦硫份之和，即爲全有機硫份。

2. 以直接方法鑑定之。法以前經硝酸侵蝕而未溶解之煤末及濾紙，一併置諸該原燒杯內，加以足量之濃硝酸，置諸蒸氣鍋上乾之，約三四次。再加以濃氫氧鉀水於該乾燥物上，攪勻而後濾之。該濾液經再度乾以蒸氣鍋，而以愛氏法鑑定該乾燥物內之硫份焉。所得之硫酸鋇乘以一三·七三六，即爲該煤之有機硫份。

f. 有機硫質之分類及其鑑定—有機硫質約分爲二種：一爲膠性硫質(Phenolic or resinous sulfur)，係溶解於石炭酸(Carbolic acid or phenol)之有機硫質。一爲不溶解於石炭酸之有機硫質，名曰腐植硫質。(Humus Organic Sulphur)。其鑑定之方法如次：

盛一·三七三六克之煤末於五十立公分之三角玻瓶(Erlenmeyer Flask)內，傾入以二十五立公分之熬石炭酸。瓶口塞以軟木(Cork)，並通以長二尺許之玻管(Glass Tubing)，以防石炭酸氣體之揮發。置此瓶於油鍋(Oil Bath)或電爐(Electric Oven)內，熱之至溫度約達百五十度，並在此溫度下經二十小時後用顧氏濾器(Gooch Crucible)乘熱濾之。洗以純酒，並使乾之。倒將此乾燥物及石棉一併磨以二或三倍之愛氏混合劑。依法鑑定其硫份焉。是項硫份係不溶解於石炭酸之混合硫質之成分。故由全硫份減去是項硫份，始得溶解於石炭酸之膠性硫份。次由全有機硫份減去該膠性硫份，則得腐植硫份焉。

(五)分析之結果

I 無機硫份—分析之結果，第一步當屬各煤之全硫份。著者爲避免重複起見，將此部並入表四。本節所列者，則爲無機硫份之部。有機硫份則不及焉。

表三—各種無機硫質之成分，與由兩種不同之方法，所得之硫礦硫份及其比較。各煤之鐵量，亦一并列入。

試驗室號數	全無機硫份	硫酸硫份	硫礦硫份	硝酸鐵量	鹽酸鐵量	硫礦鐵份	硫礦硫份	相差

b. 全無機硫份之鑑定—煤內之硫磺硫質與硫酸硫質合稱爲無機硫質。是項硫質能全部溶解於淡硝酸中，而有機物質則否。故依鮑氏及巴氏法，前者易於鑑定之如次：

一克之煤末置於百五十立公分之燒杯內，傾入以八十立公分之淡硝酸，（酸比水爲一比三）而攪勻之，隨時攪以少許之溴水，於二十四小時後濾之。而置該濾紙及未被硝酸溶解之煤末於該原燒杯內，以備後部全有機硫份之鑑定。而於此濾液內，加入少許之濃鹽酸，置諸蒸汽鍋（Water Bath）上蒸發之使乾。而將此乾燥物，溶解於二十五立公分之水，及五立公分之鹽酸中，繼以熱氫氧鎂水（Ammonium hydroxide）使該酸液內之鐵質沈澱而後濾之。由此沈澱，鑑定鐵份以高錳酸鉀法（Potassium Permanganate Titration）。此項鐵份即爲硝酸鐵量（Nitric Acid soluble Iron）。同時由該濾液中，鑑定硫份，一如前述。惟所得硫酸鋇之重量，須乘以一三·七三六，始得該煤之全無機硫份。

c. 硫酸硫質之鑑定—煤內之硫酸硫份大都甚低。新出井之煤樣，甚至缺乏是項硫質。其出井時間較久者，則受外界之養化作用，形成少量之硫酸硫質。茲將此項硫質之鑑定法，簡述之如後：

置五克之煤末於五百立公分之燒杯或同容量之大口三角玻瓶（Wide Mouthed Erlenmeyer Flask）內，傾入以三百立公分之淡鹽酸（百分之三）而攪勻之，置於溫度約達六十度之電熱鐵板上，使其浸蝕，四十小時後濾之。由此濾液內鑑定鐵量及硫份，一如前述。而以所得之硫酸鋇乘以一·七四七二，即爲該煤之硫酸硫份。該鐵份則爲該煤之鹽酸鐵量。

d. 硫礦硫份之鑑定—此項硫份之鑑定方法有二：

1. 由全無機硫份減去硫酸硫份即得。

2. 由硝酸及鹽酸溶液中之鐵量，計算得之—硝酸鐵份（Nitric acid Soluble Iron）減去鹽酸鐵份（Hydrochloric acid Soluble iron）乃爲鐵含於二硫化鐵內之鐵量。由此鐵量，與二硫化鐵之公式（FeS_2），即可得相當於該鐵量之硫份焉。是爲硫礦硫份。

a. 全硫份之鑑定，由來已久，方法亦夥。要皆不外以相當之氧化劑，使煤中之全部硫質成爲硫酸基（Sulphate Radical），而鑑定以氯化鋇焉。茲將其最重要之方法摘錄之如下：

1. 愛氏法（Eschka method）。—以愛氏混合劑（Eschka mixture）燒之。後者係由一份之無水炭酸鈉二份之養化鎂及五分一份之硝酸鉀三者混合而成。

2. 過養化鈉法（Sodium Peroxide method）。

3. 氧氣法（Oxygen Bomb washing method）—養氣法定量似不甚精確，過養化鈉法亦覺不甚適用，最近又有人以養化鈣代替愛氏混合劑中之養化鎂。就經濟觀點言，意至善矣。但以尚無充分之證實，著者遂不得不依舊沿用愛氏之法。

b. 硫質分類之鑑定，以鮑氏及巴氏法（Powell and Parr method）爲最重要，亦最準確。著者於後部之分析，亦一本此法。

II 試驗法

a. 全硫份之鑑定—先以三克之愛氏混合劑，盛於一適當之乾鍋或蒸發皿內；繼之以一·三七三六克之煤末而攪勻之；再以一或二克之愛氏混合劑覆於其上。如吾人確知某煤含硫過多時（超過百分之二），該煤末宜減半用之。即〇·六八六八克是也。而上層之愛氏混合劑，則應加倍覆之。蓋恐硫質之不及養化而揮發，致結果低於實際之硫份也。將此乾鍋置於電爐內，漸漸燒之。以鍋內黑色之炭質完全揮發爲度。如無電爐，燒以無硫焰之氣燈或酒燈，亦無不可。此殆視試驗室之設備而定耳。該鍋內之混合物，俟冷却後取出研碎之，傾於摺就之濾紙上，冲以熱水至濾液之體積約達二百立方公分（cc.）。傾入此濾液以二或三立公分之溴水（Bromine water），繼之以充分之鹽酸，使其酸化後，煮沸之。一俟溴氣全部揮發，卽以十立公分之氯化鋇（百分之十），漸漸滴入該沸騰之濾液內，頻攪以玻棍（Glass Rod）。使沸騰約五分鐘，將該杯置於暖處渡夜，而以定量濾紙濾之，先洗以淡鹽酸（百分之一），繼之以熱水者約六次，或以無氯基（Chloride Radical）爲度。此項濾過之洗澱，置於精確秤過之乾鍋內燒之。硫酸鋇之克數乘以十卽得該煤之全硫份（百分比）。其用〇·六八六八克者，須乘以二十方可。

試驗室號數	水份	揮發份	固定炭	灰份	公熱單位	英熱單位
三〇八	〇·五一	一六·八一	七三·九七	八·七一	七九三八	一四二八八
三一九	〇·二五	二一·二〇	七二·一〇	六·四五	八一三三	一四六三五
三二一	〇·三一	二一·一〇	七三·六三	四·九六	八一一二	一四六〇二
三四九	一·九六	三六·〇三	四八·二六	一三·七五	六六一三	一一九〇三
三六二	〇·一四	三二·七〇	六五·〇一	二·一五	七七三三	一三九一九
三六五	〇·四六	三二·七九	六〇·七三	五·〇七	七三五五	一三二三九
三六九	〇·四〇	三一·七五	六一·〇五	六·八〇	八〇〇九	一四四一六
三七三	〇·三一	三一·八四	五七·五九	一〇·二六	七六三六	一三七四五
三七四	〇·九八	三一·〇七	五五·六九	一二·二六	七五〇三	一三五〇五
四四八	〇·一〇	三三·二四	四六·九八	一九·六八	六三四八	一一四二六
四八五	二·一一	三六·三三	四八·六七	一二·九〇	六六四六	一一九六三
五二三	二·〇〇	三五·六三	五八·一一	四·二六	七七九四	一四〇二九
五九一	〇·六五	三一·〇二	六一·九六	六·三七	八一二五	一四六二五
五九七	〇·四六	三三·四九	四五·五一	二〇·五三	六一八〇	一一一二四
六三五	〇·九二	三〇·三六	五三·〇三	一五·六九	七三一九	一三一七四

(四)各種硫質之鑑定

I 理論

表一——煤樣之來源及其類別

試驗室號數	省份	縣名	產地	煤礦	俗名或煤層	種類符號	時代
三〇六	山東	博山	西河岳家莊	同興公司	小石炭	AB	二疊石炭紀
三一九	河北	磁縣	西佐村	怡立公司	頭煤	Bm	二疊石炭紀
三二一	河北	磁縣	西佐村	怡立公司	一坐煤	Bh	二疊石炭紀
三四九	察哈爾	宣化	玉帶山絲溝	厚豐公司	甲號(全下層)	Bl	侏羅紀
三六二	河北	井陘	崗頭村	井陘礦務局	南大井第五層	Bm	二疊石炭紀
三六五	河南	安陽	六河溝	六河溝煤礦		Bm	全上
三六九	山東	嶧縣	棗莊	中興煤礦	巳洗煤末	Bm	全上
三七三	河北	濮縣	趙各莊	開濮礦務局	洗煤	Bm	全上
三七四	河北	濮縣	趙各莊	開濮礦務局	特別洗煤	Bm	全上
四四八	安徽	宣城	大汪村	水東官礦	烟煤	Bl	全上
四八五	安徽	懷遠	舜耕山	淮南礦務局	三四號井南三槽	Bc	二疊紀
五二三	山西	大同	口泉格格塔			Bl	侏羅紀
五九一	湖南	湘潭	譚家山	有利公司		Bh	二疊紀
五九七	浙江	長興	大煤山	長興煤礦	大煤山樣	Bc	全上
六五五	江西	萍鄉	安源	萍鄉煤礦	洗焼煤	Bl	侏羅紀

表二——各煤之實用分析及發熱量

及原質硫（Elementary Sulphur）。後者經再度化學作用，成硫化氫（Hydrogen Sulphide）而揮發。其一硫化鐵則轉變爲易揮發之二硫化炭（Cerbon Disulphide），或少量不易揮發之含硫有機物。蓋後者可由焦中硫化硫份之減低，及有機硫份之增高，而得證實焉。總之是項硫鐵礦硫質，確能以相當方法，減低其含量，則毫無疑問矣。是以焦煤中之硫質，其於焦炭之硫份，所最舉足重輕者，厥惟有機硫質耳。且後者含量既高，化除亦難。或謂此項硫質，亦能於煉焦爐中，分解其一部而揮發。蓋全部有機物質，就廣義言之，皆屬於揮發物質故也。然證諸事實則有大謬不然者。前已言之：即硫鐵礦硫質，經炭化作用，而成有機硫質是也。著者以爲炭化作用，與其謂減低有機硫份，毋寧謂增加該項硫份之爲愈耳！究以衆說紛紜，莫衷一是。是故有澈底測驗之必要。茲有下列分類。

II本分類係小規模之煉硫試驗。其子目如下。

a. 揮發硫質（Volatile Sulphur）。—此項硫質，以其能揮發於煉焦爐中，故不甚爲害。就煉焦觀點言，此項硫質愈多則減低該焦炭之硫份愈易。

b. 固定硫質（Fixed Sulphur）—是項硫質與實用分析中之固定炭同一意義，即由全硫份減去揮發硫份及不燃燒硫份（灰內之硫份）之和。是類硫份之鑑定於含高量硫份之焦煤最關密切，亦絕對必要。設某煤含硫過多時，則藉以固定硫份之鑑定，以明其炭化後之是否減低其硫份，抑減低至何種程度，而決定各種硫質之鑑定，以及冲洗浮沈諸法之應用是否必要。匪特此也，由此鑑定亦可概見各焦之粘性硬度等，是故著者以爲是項工作對於煉焦堪稱首要。此次惜以時間關係未得向此方研求不無遺憾。

(三)本試驗所選之煤樣說明

本試驗所選之煤樣，係採自中國南北各重要之烟煤礦。大多數可以煉焦。所選計十有五種，要亦可進窺中國一般焦煤對此各種硫質之存在，及成分之梗概焉。茲將所選之煤樣，詳實表出之如後：

華煤中硫質種類之分析

楊珠瀚

（一）緒言

近世鋼鐵事業盛興，而焦煤（Coking Coal）遂見重于世。蓋焦煤云者，謂可供煉焦（Coke）之煤也。然完善之焦煤，頗不多覯。缺乏粘性者有之，灰份過高者有之。即或粘性強，灰份低，則又以硫份稍多之故，亦每爲煉焦者所屏棄。然硫之性質不同。有時有可以人力減低其含量者。則雖有較高之硫份，仍不失爲良好焦煤，故未可偏廢也。中國煤礦雖富而煉焦之煤則殊非甚多。其中所含硫份之性質尤向未有詳細研究。著者特就重要烟煤十五種詳加分析。費時半載，始告厥成。于中國焦煤問題或能有少補乎。

（二）煤中硫質之分類

焦炭內之硫質，係由原煤而來。是以原煤中之硫質及其成分，關係于焦炭者，至密且巨。因撰是節，茲將煤中硫質之分類以及炭化（Carbonization）作用影響於焦炭中之硫質及其成分者，簡述如次：

I 基於化學性質之分類，亦即本篇之藍本也。

a. 硫與碳，氫，氧，氮或磷諸原素，形成含硫之有機化合物，是爲有機硫質（Organic Sulphur）。

b. 硫與鐵經化合成爲二硫化鐵，是爲硫鐵礦硫質（Pyritic Sulphur）。

c. 硫礦硫質再經化學作用，轉變爲硫酸亞鐵（Ferrous Sulphate），是項硫酸亞鐵同極少量之硫酸鈣（Calcium Sulphate），合稱硫酸硫質（Sulphato Sulphur）。

煤中之硫酸硫質，大抵含量不高，似不致顯著的影響于煉焦，茲從略。二硫化鐵則又以其比重較大，大抵能以冲洗法（Washing Process）或浮游法（Flotation Method）削減或分除之。且是項硫質，於煉焦爐中，經分化作用變爲一硫化鐵（Ferrous Sulfide）

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燃料研究專報第十五號
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(乙)測定煤內硫質之新法

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No. 14 October 1933

ON LOPINITE, A NEW TYPE OF COAL IN CHINA

BY

C. Y. HSIEH

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ON LOPINITE, A NEW TYPE OF COAL IN CHINA

By C. Y. Hsieh§

With 2 plates & 2 text figures

CONTENT

1. Introduction

To the east of Nanchang, the capital of Kiangsi Province, there crops out a continuous belt of Permian coal series[1] trending approximately in the direction from N. E. to S. W. Broadly speaking, this coal belt forms a synclinal structure, though in detail it is much more complicated, as folding, faulting and perhaps overthrusting have all played important rôle in its construction. The syncline pitches towards S. W., so that the outcrops tend to close in a north-easterly direction as can be seen from the accompanied sketch (Fig. 1). The extent of the coal field is limited by different formations at different places; in Chinghsien, for instance, the coal series lies directly above a Permian limestone,

§ Prof. at the National University of Peking, and Geologist of the Geological Survey.

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while at Yükan and Loping, it is usually in fault contact with a phyllite formation of older Palæozoic age.

The thickness of the coal measure varies from 250-400 m, the maximum thickness being found chiefly in the Poyang-Loping districts. It is composed essentially of an alternation of sandstone and shale, together with, as at Mingshan in Loping, several layers of limestone. Only one principal coal seam varying

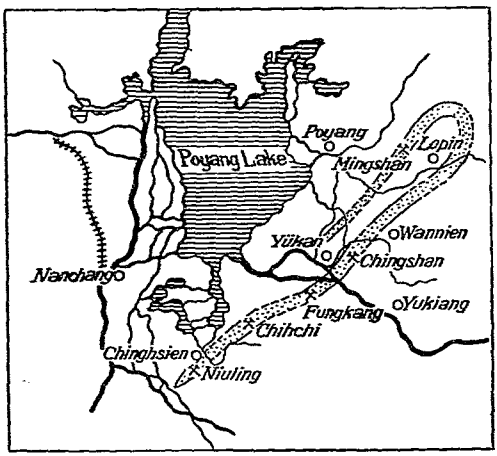

Fig. 1. Sketch showing the distribution of coal-bearing area in Loping, Poyang, Yükan and Chinhsien districts, N. E. Kiangsi. Scale 1:2,100,000,

from 3-10 feet or more in thickness is now worked, though several minor coal seams mostly unworkable occur also both above and below the principal one. At Mingshan the most famous coal mine in Loping district, coal seams were reported to be quite regular and persistent, whereas in other places there shows usually great variation in thickness. The topography of the region is characterized by rolling hills of low relief, a feature indicating late mature erosion.

Now the interesting thing which makes the topic of the present paper lies in the particular nature of the coal which is so remarkable that it should form a special type by itself. It is a kind of coal exceptionally rich in volatile matter which may amount to 60% or more and in some cases it may nearly double the amount of the fixed carbon. For this reason, in the classification of Dr. Wong[2] it has been taken to be a lignitic bitumite or lignite, similar to the coals of Fushun, Pataoho, Hsinchiu etc. Its remarkable nature, however, was also noted by Dr. Wong as can be seen from the following statement: "The Loping coal although very low in carbon like the younger coals is remarkable by its low moisture content, a feature which seems to be special to the Palæozoic coals." In another paper[3] Dr. Wong added: "The Permian coal of Loping constitutes a special type found in several other fields in Yangtze valley, for instance, in Yükan of the same Kiangsi Province". For reasons to be given below, this coal from Loping can never be called a lignite; neither could it be classified among the ordinary bituminous coals. As a matter of fact it constitutes a special type that has not yet been previously described, and accordingly a new name, the *Lopinite* is herewith proposed.

The following is a discussion of this new type of coal from chemical, microscopical and genetic points of view.

2. Proximate Analyses

The proximate composition of the Lopinite and its allied coals is listed in the following table (Table I):

There are altogether 14 analyses of the Loping coals made by different analysts based upon samples of widely different localities. Consequently harmonious results are not to be expected; yet on the whole the different analyses all show a constant and remarkable feature i.e. extremely high in volatile matter and low in moisture. There are 11 out of 14 analyses in which the

2 Wong, W. H. Classification of Chinese coals—Bull. Geol. Surv. China, No. 8, 1926, p. 52.

3 Wong. W. H. Coal Composition in triangular diagram—Bull, Geol. Soc. China Vol. 6, No. 1, 1927.

TABLE I. PROXIMATE ANALYSES OF LOPINITE & ITS ALLIED COALS.

No.	Locality	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Calorific power (Cal.)	Spec. gravity	Ash-Free-Basis Moisture	Volatile matter	Fixed carbon	Analyst
1.	Loping	0.47	62.73	33.08	3.72	2.06	8015	1.25	0.49	65.15	34.36	Miss Hung, Geol. Surv. China
2.	,, , S. district	0.47	47.15	42.05	10.35	3.333	7422	1.30	0.52	52.60	46.90	Yawata Iron Works, Japan
3.	,, ,,	0.93	35.11	37.75	26.21	5.801	5886	1.54	1.26	47.60	51.20	,,
4.	Tungchunchang, Loping.	0.31	45.94	40.15	13.60	2.585	7142	1.33	0.36	53.20	46.50	,,
5.	,, ,,	0.43	53.71	38.06	7.80	3.874	7748	1.25	0.47	58.20	41.40	,,
6.	,, ,,	0.41	48.53	40.34	10.72	2.679	7393	1.31	0.46	54.40	45.10	,,
7.	Yungwulhang, ,,	1.74	16.40	16.90	64.96	5.467		1.70	4.97	46.80	48.35	,,
8.	,, ,,	0.56	50.25	39.15	10.04	2.481	7321	1.26	0.62	55.90	43.40	,,
9.	,, ,,	0.65	51.21	42.89	5.25	3.207	8130	1.25	0.68	54.00	45.20	,,
10.	,, ,,	0.56	44.14	41.02	14.28	2.228	7014	1.33	0.65	51.50	47.90	,,
11.	,, ,,	0,20	50.17	36.87	12.76	4.49	7418	1.32	0.23	57.60	42.30	,,
12.	,, ,,	0.47	47.68	44.17	7.68	2.214	7631	1.27	0.51	51.70	47.90	,,
13.	,, ,,	0.72	36.65	43.10	19.54	2.784	6318	1.44	0.89	45.50	53.50	,,
14.	Pulo Co., Loping.	1.00	50.90	39.00	9.10	4.83			1.10	56.00	43.00	Hanyang Iron Works
15.	Niuling, Chinghsien.	0.24	38.16	48.63	13.36		6868	1.34	0.26	43.80	55.90	Chem. Lab. Ministry Agri. & Commerce
16.	Kwangta Co., Tayuanlin, Chinhsien.	0.70	28.02	49.87	21.41	9.19	6820		0.89	35.9	63.9	,,
17.	Taotzeling, Yükan.	0.33	40.11	59.56	14.27		8085		0.33	40.11	59.56	,,
18.	Chulowa, ,,	0.40	44.31	55.29	12.24		8140		0.40	44.31	55.29	,,
19.	Kwanshanling, ,,	0.44	31.04	60.48	8.04	1.88	7920		0.47	33.73	65.73	,,
20.	Tamiaoshan, Changhsing	0.65	34.77	38.98	25.60		5467		0.87	46.73	52.40	Miss Hung, Geol. Surv. China
21.	Szemotun, ,,	1.78	30.37	40.31	27.54		5516		2.46	41.91	55.63	,,
22.	,, ,,	0.82	30.93	39.83	28.42		5455		1.15	43.21	55.64	,,
23.	Kwanhsing Co., ,,	0.50	33.20	42.95	23.35		5876	1.29	0.65	43.31	56.04	,,

percentage of volatile matter much exceeds to that of the fixed carbon, while the extreme case is found in No. 1, the volatile matter content being nearly twice that of the fixed carbon. In the coals of Chinhsien and Yükan the volatile matter is also quite high (mostly over 40%) though it is all less than that of the fixed carbon. On the whole the coal is rather high in sulphur varying from 2-5.5% and owing to the fact that pyrite grains are rarely found it is inferred that most

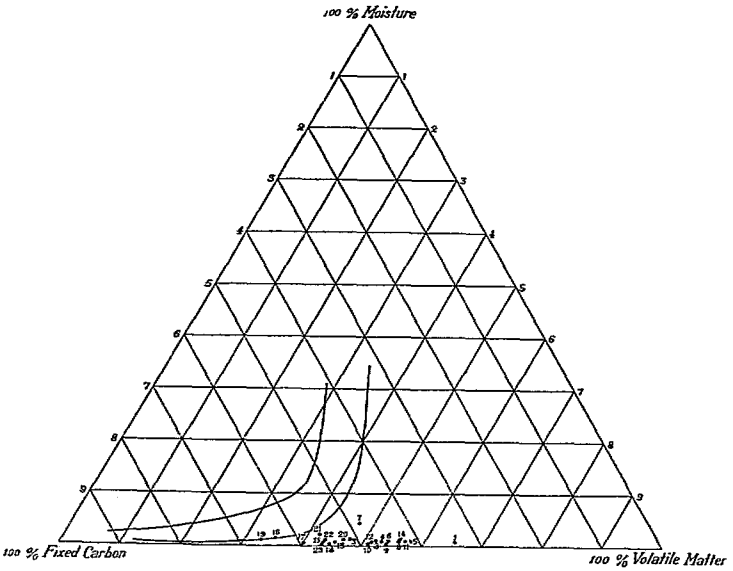

Fig. 2. Position of Lopinite (No. 1-19) in the triangular diagram of proximate chemical analyses. No. 20-23 are analyses of coals from Changhsing, Chekiang.

of the sulphur occurs in organic forms. Ash content is extremely variable and which can approximately be told from its specific gravities. The Calorific power is rather low varying from 6000-8000 B.T.U. or more. Under the

microscope, these coals show similar structures and are therefore to be classified under the same group.

In order to show more clearly the relationship between Lopinite and other coals in China, the chemical analyses of the above table are plotted in a triangular diagram (Fig. 2). In this same diagram is plotted together the variation curve of coals of normal sequence as has been done firstly by Dr. W. H. Wong[4] and afterward modified by H. S. Wang[5]. In the paper just cited Dr. Wong has already noticed the isolated position of the Loping coal (dot 17 in his diagram) and came correctly to the conclusion that the latter should constitute a special type. In a modified form of the triangular diagram Mr. H. S. Wang argued that by including the dot No. 17 (i.e. the Loping coal) there will form two parallel curves within which lies the continuous series of coal ranging from lignite up to anthracite. But the unnatural position of the dot No. 17 and the broken form of the lower curve is quite evident. The most simple explanation is that the coal of Loping is a distinct type and does not belong to the rest of the coals.

Now in our Fig. 2 in which a great number of analyses of Loping and allied coals are plotted, the relationship becomes more and more clear. The No. 1 analysis which represents perhaps an extreme case of the Loping type lies in the most distant part in the diagram while the rest of the dots are found mostly in the region of 50-60% of volatile matter. The coals of Yükan, Chinhsien though carrying smaller amount of volatile matter and lying consequently more close to the field of normal sequence, yet it is remarkable to see that most of the dots occupy a position still quite outside of the normal field. There is no doubt that these coals form the transitional cases between the Lopinite and the normal type.

In a similar triangular diagram for plotting proximate analyses of some American coals, Prof. Fisher[6] has noticed that cannel coal lies far outside of the

4 Wong, W. H. Coal composition in Triangular Diagram—Bull. Geol. Soc. China, Vol. 6, No. 1, 1927.

5 Wang, H. S. The rectangular graphs as applied to the proximate analyses of Chinese coals — Bull. Geol. Soc. China. Vol. 1, No. 2, 1928.

6 Fisher, D. J. Notes regarding the coalification process—Journal of Geology, Vol. 35, No. 7, p. 640.

field of the normal sequence, which fact points to a different origin and derivation of the latter coal. It is evident that so far as proximate analyses in triangular diagram is concerned, Lopinite may belong to the same field as the cannel coal, though the former contains an entirely different vegetal constituents.

3. Behavior of Low Temperature Distillation

Low temperature carbonization assay on Loping coal made recently by Mr. C. C. Hsiao[7] shows again that this coal is a most remarkable one. "Aside from its exceedingly high fusibility and swelling, the oil yield exceeds that of any other coal by more than two times". Recent investigation of our chemist K. Y. King demonstrates that the Lopinite has in addition a special property in increasing the agglutinating value when it is used as a blending constituent together with non-coking or moderate coking coals. The coal of Yükan and Chinhsien have not yet been tested, but on account of their similar chemical and microscopical characters as the Loping coal, similar result of low temperature carbonization may be predicated. The following is given the result of test for the coals of Loping.

Low temperature carbonization test on Loping coal.

(After C. C. Hsiao).

Semi-Coke	54.28
Oils	33.05
Liquor NH_3	3.12
Gas	8.11
Sp. gr. of oil	.893
Vol. of gas Sp. gr. of gas	.660

4. Other Chemical and Physical Characters.

From its high content in volatile matter the Loping coal might be suspected for lignite, although the low moisture content clearly distinguishes it from

7 Hsiao, C. C. Low temperature carbonization assay of some bituminous coals. Bull. Geol. Survey, China, No. 21, 1933.

the latter kind. Perhaps the surest way of differentiating lignite from the low type of bituminous coal is by following the German method of some simple chemical tests. This is done by boiling coal powder in either potassium hydroxide or dilute nitric acids; in the case of lignite the solution will be stained brown or reddish brown. In all the coals investigated there gives invariably negative results to these simple tests; therefore their non-lignitic nature is clearly proved.

To the naked eye the coals from Loping & Chinhsien are usually dull and compact, showing a well marked cleavable or sheeted structure, so that it can be easily splitted into thin slabs or sheets along the bedding planes. To this character is derived the local name at Loping "Pantzemei"[8] which means slabby coal. Along the bedding planes there appears frequently shining patches or layers, though on the whole the coal is characterized by a uniform dull luster. Banded or laminated structure of alternately dull and bright layers such as commonly seen in ordinary bituminous coal is absent, but on close examination there may reveal occasionally thin streaks of bright coal in alternating with the dull one thus giving an extremely fine laminated appearance. The specific gravity of the coal varies from 1.25-1.70 depending much upon its ash content, while its streak is black to dark brown.

The coal from Yükan shows a slightly different physical characters. It is more bright and massive with the sheeted structure not so marked. This is evidently due to crushing, polishing and granulation which the coal has suffered during tectonic movement and which has rendered the coal a more glossy appearance.

All these coals just described can be easily ignited by a match fire and gives in burning a long flame and asphaltic odour.

5. Microscopic Structures

Owing to the compact and tough nature of the coal and its rich content of transparent tissues, the making of thin section becomes comparatively an easy matter. This can usually be accomplished by the ordinary grinding method

8 Liu, C. C. Report on the Polo coal mines in Kiangsi Province (1925).

without resort to any special procedure of preparation and mounting such as has been marvellously worked out by Dr. Thissen & others. The final stage of grinding to the required transparency should, however, be made by rubbing on a Belgium hone which is the best and indispensable tool to every coal petrographer. Two kinds of sections i.e. vertical and horizontal were made and studied, and the results of investigation may be briefly described as follows:

(1) Coals from Loping, Kiangsi.

The vertical section of the Loping coal shows to be made up essentially of alternating layers of opaque to semi-opaque matter and transparent tissue, the latter on morphological ground has been identified to be mostly periderm which includes both the remains of phelloderm and cork tissue*. We know from Botany that true cork is rare or wanting in Cryptogams, even in the Pteridophytes, and since this coal under study is of Permian age, so the presence of any great quantity of real cork tissue in the coal seems to be rather questionable. On the other hand the rectangular brick-shaped cells suggesst strongly that some of them at least are real cork tissues.

The color of this tissue varies from yellow, brown or reddish brown all depends upon the thickness of the section. Under crossed nicols these tissues are distinctly anisotropic and showing a marked polarization color. The thickness of the layer may vary from extremely fine (5 μ) to 160 μ or more. Most of the layers are regularly and parallelly arranged; not infrequently they may also irregularly disposed with one layer interpenetrating or interlocking the others.

Although the preservation of the phelloderm and cork tissue is not very perfect yet there shows usually good structures as to make possible their exact identification. Practically all the tissues shown in the vertical sections represent cross view which is characterized by parallel and brick-shaped cells. In

* Thin sections and specimens of Loping Coal have been sent to Dr. Thissen. In replying, Dr. Thissen writes as follows: "Your interpretation of the coal from Loping, Kiangsi is quite correct. My opinion is that it consists largely of periderm, and includes remains of both phelloderm and phellem or cork, the former, the phelloderm, comprising probably the bulk of the coal." Microchemical test with Soudan III gives, however, negative result. This does not imply at all the impossibility of our interpretation, as vegetable tissues in coal may have been profoundly changed as to be insensitive to such test.

some layers these cellular structures are entirely wanting, and frequently the structure showing layers are alternately arranged with the homogeneous one the latter is believed to represent either phelloderm itself (which owing to its comparatively less resistant nature is liable to suffer destruction) or the altered woody material.

The longitudinal view of the periderm tissue can be seen in the horizontal section of the coal, i.e. the one cut parallel to the bedding planes of the coal seams. In these sections phelloderm and cork tissues are abundantly found and which occur mostly in forms of irregular pieces attaining sometimes considerable dimension (up to one cm or more in diameter). In some of these pieces cellular structure consisting of rectangular to polygonal shaped cells bounded by rather thin and straight cell walls are distinctly preserved. The sizes of each cell vary from 48 × 64 μ to 64 μ × 80 μ. Besides the larger pieces, there occur in the horizontal section also some thin streaks or lenticles representing evidently cross section of these irregularly or obliquely deposited cork tissues. In these streaks etc., the characteristic brick-shaped structures are again distinctly shown. All the tissues, like in vertical section, show a distinct polarization color under crossed nicols.

Occasionally, there is shown in the horizontal section some roughly cylindrical tissues showing rectangular cells (a cell form similar to cork tissue) arranged in a concentric way. This kind of tissue may represent transverse section of some young stem in which the peripheral portion is well preserved. The central portion is occupied by humified, probably woody material.

The opaque to semi-opaque matter in the coal represents evidently the more lignified or coalified substances which may be derived either from the periderm* itself or from the woody materials. The examination of thinned polished section[9] by both transmitted and reflected light shows however that these opaque matter exhibit in most cases some cellular structure. Besides its occurrence as separate layers or lenses alternated with the transparent tissues, the opaque and more frequently the less-opaque to translucent matter may occur also

* This may represent the remains of phelloderm cells.

9 Hsieh, C. Y. Thinned polished section of coal, a new technique in coal petrography—Bull. Geol. Soc. China. Vol. pp. 1932.

as streaks or patches inside the transparent tissue; this feature can best be seen in horizontal section in which certain cells may be translucent to opaque while the rest is distinctly transparent showing the usual brownish to reddish colors. This difference in color and transparency within same pieces of tissue can perhaps be explained by different degree of humification or decay due to bacterial action as will be explained latter.

The amount of the opaque to semi-opaque matter varies greatly in different parts of the section; in certain part it is greatly predominate, (Pl. I, Fig. 2) so that the transparent periderm tissue forms only subordinate constituent while in other part the reverse is the case. (Pl. I, Fig. 1).

The study of polished section under reflected light gives more information about the microstructure. To the naked eyes, the polished surface appears to be finely striated, the striation is due to the presence of a number of gray colored dull lines or laminæ which are higher in relief as compared with other constituents. Under the microscope, the dull lines or laminæ are proved to be periderm, as can be seen from the faintly but still distinctly marked cellular structures, while the rest is composed of thin lenticles of vitrain and some fusain. The transparent nature of the periderm can be well shown by examining under oil immersion; in this way the phelloderm as well as cork tissue changes to dark gray, whereas fusain and other opaque constituents becomes more bright in color. Under crossed nicols, the gray layers show frequently interior reflection color of red or brown, the true color of the periderm tissue. The same kind of color can also be observed under oblique illumination.

(2) Coals from Chinghsien, Kiangsi Province.

Several specimens of coal from two different localities in Chinhsien have been studied under the microscope. They show essentially the same kind of structure as the Loping coal except that the tissue seems to be somewhat crushed, and macerated and that the opaque or semi-opaque matter seems to be more abundant especially in that specimen from Kungta Company in N. E. part of Chinhsien. In the latter coal mineral fragments probably quartz are also frequently observed. The coal from Niuling is less abundant in opaque matter so it is of higher quality as compared with other one.

(3) Coals from Yükan, Kiangsi Province.

A polished section from Kwaninling, Yükan was studied. It is composed in the main of a number of dull lines, or layers usually folded and somewhat crushed, embedded in a vitrainic groundmass. Here and there are found fragments and lenticles of fusain and xylon, the former is, however, not so abundant as in the coal from Chinghsien. Under oil immersion these dull layers change also to a dark gray color, therefore they are undoubtedly periderm tissues.

The study of thin section of this coal confirms the presence of a great number of phelloderm and cork tissue which are usually bended, crushed and somewhat macerated. The cellular structure though faintly shown is in most cases clearly recognizable.

6. Maceration

In all the coals studied, perfectly preserved tissues of periderm were obtained by maceration in Schulze's Reagent (a mixture of concentric nitric acid and potassium chlorate). Good result can be obtained by allowing the coal powder in the solution for a week or ten days and then it is washed and treated again with ammonia. The residue is composed almost entirely of phelloderm or cork tissue which can be studied under the microscope.

Pl. II, Fig. 3 is a microphoto of the tissue separated from the Loping coal. It shows perfectly well preserved structures with rectangular formed cells of the following dimensions:

$$64 \times 96\mu \qquad 48 \times 112\mu \qquad 48 \times 80\mu$$

The tissue shows a deep brown to yellowish brown color and unlike in thin section it is isotropic under crossed nicols. The refractive index of the tissue as determined by immersion method lies approximately between 1.490-1.500.

The maceration product from the coal of Niuling, Chinhsien shows besides abundant periderm also some microspores, a few megaspores and several pieces of cuticle, Fig. 4, Pl. II, shows one of the cuticle separated with stomatic opening distinctly preserved.

7. Comparison with Other Coals

Besides the coals from Loping, Yükan and Chinhsien there is a group of coal also exceptionally high in volatile matter, and low in moisture. The coal from Changhsing in Chekiang Province, constituets perhaps one of the most interesting types. The coal is compact and tough showing neither laminated nor sheeted structure, it is composed entirely of dull coal and in this way it looks very like cannel coal or boghead coal in macroscopic appearance. The streak is black while its sp. gr. is nearly 1.30. Its position in the triangular diagram is shown in fig. 2. from which we can see that the Changhsing coal also lies outside of the normal sequence but very close to it.

The microstructure of the Changhsing coal is quite different than those previously described. The thin section is composed essentially of a reddish colored transparent and homogeneous layers intercalated with layers or lines of opaque material, the latter when examined under reflected light proves to resemble fusain. The entire mass of the transparent and opaque layers are often folded or curved exhibiting a form not unlike the woody structure. From the coal-petrographical sense these transparent layers may be called vitrain, though their botanical nature remains still a question. In some sections true fusain occurring in lenticles or fragments are also present. Such constituents like spores, cuticles, xylon etc. which are so common in ordinary types are conspicuously absent in the Changhsing coal.

Cork tissue is abundantly present in certain seams of the Shenkungshan coal field in Anhui Province, but here the tissues are usually associated with other constituents such as micro- and macrospores, resinous bodies etc., or when occurring alone, they form only certain fractional part of the seam. Nothing like that observed in the coals of Loping, Yükan and Chinhsien can be found. In the triangular diagram, the coal of Shenkungshan occupies a position well inside the normal field, so it has no relation with the Loping coal.

8. Conditions of Formation

Cork tissue as well as other vegetal elements in the periderm have been frequently found in coal anl more recently Wolfram Penseler[10] has found a great

10 Wolfram Penseler: The James Coal of New Zealand, Fuel, Vol. 12, No. 5, p. 166, 1933.

amount of cork tissue in the James coal of New Zealand. But the occurrence of this tissue in such a great amount as in Lopinite in Kiangsi Province is, so far as known to the writer, the first that has ever been described. The following is a short description of James coal quoted from Penseler.

The James coal occurs above a conglomerate bed with an intervening shaly band of about 6 in. thick and is below a sandstone formation; its age is Eocene. In thickness it may vary from 2-7 ft. but local thickening up to 20 feet is also found. The coal is dull, black and is peculiarly hard and tough, showing a conchoidal fracture. Chemically the coal is characterized by an unusually high content of volatile matter and hydrogen*, figures for which approach those for a cannel coal. It is rather high in sulphur. Under the microscope, the thin section shows a great amount of suberized tissue and cuticles together with fragments of xylon and disintegrated debris to form the ground mass. Sporic matter is conspicuously absent. In classification the James coal approaches that class of coal comprising cannels and bogheads. The extension of this special coal is however, rather limited, since mine working has shown its changing in character and becoming more like an ordinary bituminous coal within short distances.

From the above description, it is evident that Lopinite and James coal are closely related and may perhaps be classified under the same group. There are, however, several differences. The James coal is of Tertiary age and consequently it contains a great amount of perfectly preserved cork tissue while in the Lopinite, the periderm consists perhaps more of phelloderm than the true cork cells. With the exception of the coal from Chinhsien, the Lopinite contains usually no or very little cuticle. As can be seen from fig. 1 our coal has moreover a greater surface extension than the James coal.

Concerning the particular nature of the Loping coal, Dr. Thissen in his letter to the writer, writes as follows: "It is an interesting coal to study, and never have I seen even thin layers of coal of that purity of one tissue.

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* Recent work by K. Y. King shows Lopinite containing also a high content of hydrogen amounting to 7%.

Recently we have been studying a bituminous coal from the Upper Cretaceous of Utah. In this coal are found certain layers composed largely of remains of the outer envelope of the stem, namely, of phloem, cortex and periderm, but never of such purity of one or two tissues as in your coal."

As to conditions for the formation of the James coal, Penseler has written the following:

"The attrital nature of the James coal, and the large amount of cuticle and cork fragments, combined with the geological and chemical evidence, suggest that the coal has been formed from forest offal, which was drifted into brakish water in a sheltered region of an estuary. The offal was probably derived from a forest growth which bordered this area of accumulation and protected it from the washing in of inorganic sedimentary material, and a gradual transition would therefore be found from this small patch of special vegetal material into a more normal type of coal derived from the fringing forest growth."

It is well known in geology that coal represents product of decay of vegetal material and consequently the most resistant parts of the plant as spores, cuticles, barks, etc. are more frequently preserved. Because of their intimate association and lack of chance to be separated, these tissues are usually found together in a coal though in widely different proportions. Any coal that is composed essentially of one kind or one part of the tissue must require therefore special condition for its formation. The cannel coal, for instance, a coal composed essentially of spore has been considered by many geologists to be formed under a sapropelic condition i.e. an open water to which the wind-blown spores are most easily to be accumulated and deposited. In the case of cork tissue, and phelloderm because of their fixed and non-flying nature, they can not be accumulated in this way. On the other hand, owing to the extraordinary resistant nature of the cork tissue, the latter can usually be preserved under the most advanced stage of decaying when other things were destroyed and removed. It is therefore suggested that for the formation of Lopinite, the following two conditions are necessary:

(1) The vegetal material must have suffered previously an excessive degree of decay so that most of tissues were destroyed, coalified, or removed except the resistant outer part including cork tissue, phelloderm, cuticles, and

some others. Such advanced stage of decomposition can perhaps be brought about by prolonged action of bacteria or under special climatic condition. The presence of a great amount of opaque matter in the coal may be taken as to represent the much coalified and macerated debris left over from the work of the bacterial action.

(2) This mass of vegetal material already decayed and somewhat macerated must then be subjected to a process of transportation, thereby to enable the removal of other resistant tissues like spores etc. and the final concentration and deposition of the cork and its allied tissues. The often crushed and fragmentary forms of the tissues so frequently observed in the coals of Yükan and Chinhsien may perhaps be cited as evidence in favor of this drifting theory.

In order to fulfill the above stated conditions, we must assume that lopinite and its associated strata were formed in brackish water of estuarine condition. The high sulphur content of the coal may be cited as an evidence of the brackish water origin, as in the later water sulphur bacteria was usually more active. It still lacks, however detailed stratigraphical evidence, but the occurrence of several layers of limestone, the abundance of marine fossils and the irregular nature of the coal seams in Yükan and Chinhsien are perhaps strong arguments indicating esturiane condition. In his excellent memior on the Permian formations of Southern China[11], Mr. T. K. Huang has rightly concluded that coal in the Liupakou series (Permian) may be of two types; the *in situ* type and the drifted type, the latter "occurs in regions outside the three provinces, (the coastal provinces where land flora as *Gigantopteris* etc. have been found) especially in those places where the marine Choutang series is well developed". Although Huang has given no definite localities for the occurrence of the allochthonus coal, a glance at his Palæogeographic maps (Pl. VI) will show at once the Loping coal basin in N. E. Kiangsi as one of them. From the same map we can see again that N. E. Kiangsi formed that time in all probability an estuary which bordered the old coastal land of the lower Yangtze Province. So on the whole the condition of formation for Lopinite is essentially similar to that of James coal i.e. an esturiane deposit formed from drifted forest offal from a nearby forest growth.

11 Huang T. K. Memoir Geol Serv. China, Series 4, No. 10, p.66 1932.

Although allochthonus theory for the explanation of coal formation has been recently rejected by most of the geologists, yet in our special type of coal like Lopinite and James coal, this theory seems to be still plausible.

9. Acknowledgement

I wish in this occasion to acknowledge my indebtness to Dr. Thissen for his kindness in examining the thin sections of Lopinite in order to verify certain results of my microscopical investigation. To Dr. W. H. Wong and Mr. K. Y. King, the writer is indebted for their coöperative discussion on the chemical composition of this particular kind of coal. The writer is also indebted to Prof. C. Y. Chang of the Botanical Department, National University of Peking for help in carrying out some microchemical tests.

Explanation of Plate I.

EXPLANATION OF PLATE I

Fig. 1. Microphoto of a thin section of coal from Kwaninling, Yükan, Kiangsi province showing the rather distorted and contorted tissue of the periderm (gray) embedded in an opaque ground mass. Vertical section × 45.

Fig. 2. Microscopic structure of a coal from Niuling, Chinhsien district in Kiangsi Province. Here the opaque ground mass is more predominate while the transparent cork tissue is more thin as compared with the previous section. Vertical Section × 45.

Fig. 3. Horizontal section of the periderm showing the polygonal-shaped cork cells. Loping, Kiangsi. × 37.

Fig. 4. Same as Fig. 3 more enlarged. × 100.

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Explanation of Plate II.

Explanation of Plate II

Fig. 1. Vertical section of the periderm showing the laminated, brick-shaped cells. Loping, Kiangsi. × 143.

Fig. 2. More enlarged view of the cells, Loping, Kiangsi. × 190.

Fig. 3. A piece of periderm as separated by maceration—showing horizontal view of the cells. Loping, Kiangsi. × 135.

Fig. 4. A cuticle separated by maceration from the coal of Niuling, Chinhsien, Kiangsi Province. The Stomata are distinctly shown. × 140.

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地質調查所沁園燃料研究室

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GRAPHICAL CLASSIFICATION OF CHINESE COALS

By
K. Y. King

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GRAPHICAL CLASSIFICATION OF CHINESE COALS

K. Y. KING

I. INTRODUCTION.

The proximate analysis of coals, that is, the determination of moisture, ash, volatile matter, fixed carbon and calorific value, is a much simpler method than the ultimate analysis, which involves the determination of elementary constituents of the coal. Comparing the time necessary for a complete analysis by the above two methods, one will at once appreciate the short procedure of proximate analysis for the estimation of the general composition of coal. From practical and commercial viewpoint, to make a comparative valuation of coal samples and to control the variation in quality of a particular supply, proximate analysis is undoubtedly the most useful method as it furnishes fairly accurate data necessary for determining the important properties of different varieties of coal. It not only saves time in approximate fuel valuation, but also need simple apparatus and common chemicals.

To distinguish between one variety of coal and another such as anthracite, bituminous and lignitic coals, it seems necessary to have some definite means of classifying coals according to their chemical and physical properties. The classification may be based on the characteristics of coals as revealed by proximate analyses, ultimate analyses, extraction with solvent, reaction with reagents, microscopic examination, destructive distillation or physical properties. The chemical composition given by proximate or ultimate analyses is more extensively used than the rest.

II. COAL CLASSIFICATIONS.

Instead of giving a full description of the methods of coal classification so far known, a summary showing the general features of the existing methods is tabulated (Table 1).

It is evident that each system of classification has its own particular merit for differentiating varieties of coal but none of them is applicable to all types of coal of different regions. Generally speaking, more use has been made of the proximate analysis because of its easy application, where strict accuracy is not to be expected. Special corrections[12] such as hydrogen and carbon

derived from water of constitution in ash-forming materials seem to be important. This still involves long and complicate analysis together with sufficient knowledge to apply such correction factors, so whether this can be adopted for general usage is still uncertain. It seems that the proximate analysis combined with the weathering property as shown in slacking test will be suitable for all round purposes. It is hoped that a complete workable procedure on slacking test as suggested by Fieldner[13] will soon be formulated and properly adapted to practical use.

Chemically, the reactivity index[14], a measure of oxidation on ulmin constituents, can be used with reasonable accuracy for gauging the ranks of coal. The recent substitution by the permanganate number[15] as suggested by Heathcoat and Francis has considerably reduced the experimental procedure; nevertheless, it remains difficult for commercial laboratories to adopt this much simplified but still complicated procedure for their fuel inspection. With the aid of the microscope, the coals may be resolved into ulmic, spore and algae types.[16] It is needless to say that much technique is involved in microscopic examination as well as its preparation; it may not be useful again for general work. As the purely spore and algae coals are only found in very limited quantity, such classification should be considered merely as a scientific one.

W. H. Wong[4] carefully compared the relative merit of all the classifications based on proximate analysis and finally concluded that Ashley's coal ratio or moisture combined ratio is better adoptable to the classification of Chinese coals. He suggested a new nomenclature for indicating the different types of coal of various geological ages. Limits of coal ratio are arbitrarily fixed according to the general characteristics of coal that are so far known.

TABLE II.

New Nomenclature Class	Rank	Coal Ratio	Symbol
Lignite		below 0.90	C
Lignitic Bitumite		0.90- 1.30	BC
Bitumite	Low Rank	1.30- 1.70	Bl
	Medium Rank	1.70- 3.00	Bm
	High Rank	3.00- 4.00	Bh
Anthracitic Bitumitic		4.00- 6.00	AB
Anthracite	Low Rank	6.00- 8.00	Al
	Medium Rank	8.00-10.00	Am
	High Rank	10.00-12.00	Ah

TABLE I.

Summary on Methods of Coal Classification[1,2]

Classification	Basis of Classification	Advantages and Disadvantages
Fraser's[1]	Fuel Ratio $= \frac{\text{Fixed Carbon}}{\text{Volatile Matter}}$	(1) Only proximate analysis needed. (2) Unsuitable for coals of lower coalification.
Dowling's[2]	Split Volatile Matter $= \frac{\text{Fixed Carbon} - \frac{1}{2}\text{ Volatile Matter}}{\text{Moisture} - \frac{1}{2}\text{ Volatile Matter}}$	(1) Requires only proximate analysis on "as received" basis. (2) Suitable merely for general classification.
Ashley's[3]	Coal Ratio or Moisture Combined Ratio $= \frac{\text{Fixed Carbon}}{\text{Moisture} + \text{Volatile Matter}}$	(1) Requires only proximate analysis on "as received" basis. (2) Suitable only for use classification.
Wong's[4]	Adopts Coal Ratio and advocates a new nomenclature for different types of coal.	Applicable to classify Chinese Coals in a general way.
Parr's[5]	Percent Volatile Matter and heating value of unit coal substance.	(1) Proximate analysis and sulphur determination required. (2) Applicable for U. S. coals.
Campbell's[6]	(1) Proximate analysis on ash-free basis or Carbon/Hydrogen Ratio. (2) Appearance and weathering property of coal.	(1) Ultimate analysis or proximate analysis and slacking test needed. (2) Gives an easy method for differentiating bituminous, subbituminous and lignitic coal from each other.
Seyler's[7]	Percent Carbon and Hydrogen in pure coal substance.	(1) Requires ultimate analysis. (2) Names proposed complicated. (3) Applies well to British coals.
Ralston's[8]	Percent composition (Carbon, Hydrogen and Oxygen) on a moisture, sulphur, nitrogen and ash-free basis.	(1) Complete ultimate analysis required. (2) Lines of demarkation not sharp.
White's[9]	(1) Percent oxygen on moisture and ash-free basis. (2) Oxygen/Hydrogen Ratio.	(1) Percent oxygen hard to determine. (2) Gives some idea as to coking properties of coal.
Regnault-Gruner's[10]	(1) Ultimate and proximate analysis. (2) Coking characteristics. (3) Chief Uses.	(1) Requires ultimate analysis and a knowledge of the behavior of coking properties and burning quality of coal. (2) Long but complete.
Twelfth International Geological Congress[11]	(1) Ultimate and proximate analysis (2) Coking and burning characteristics. (3) Physical properties.	(1) Requires both ultimate and proximate analysis and a knowledge of the chemical and physical properties of coal. (2) Classifies coals into the well-recognized commercial grades.

1. Modified after Haslem and Russel "Fuel and Their Combustion" McGrow Hill Co., p. 65, 1926.
2. An extended discussion of the different classification except Wong's is given by Moore "Coal", John Wiley and Sons pp. 105-122, 1922.

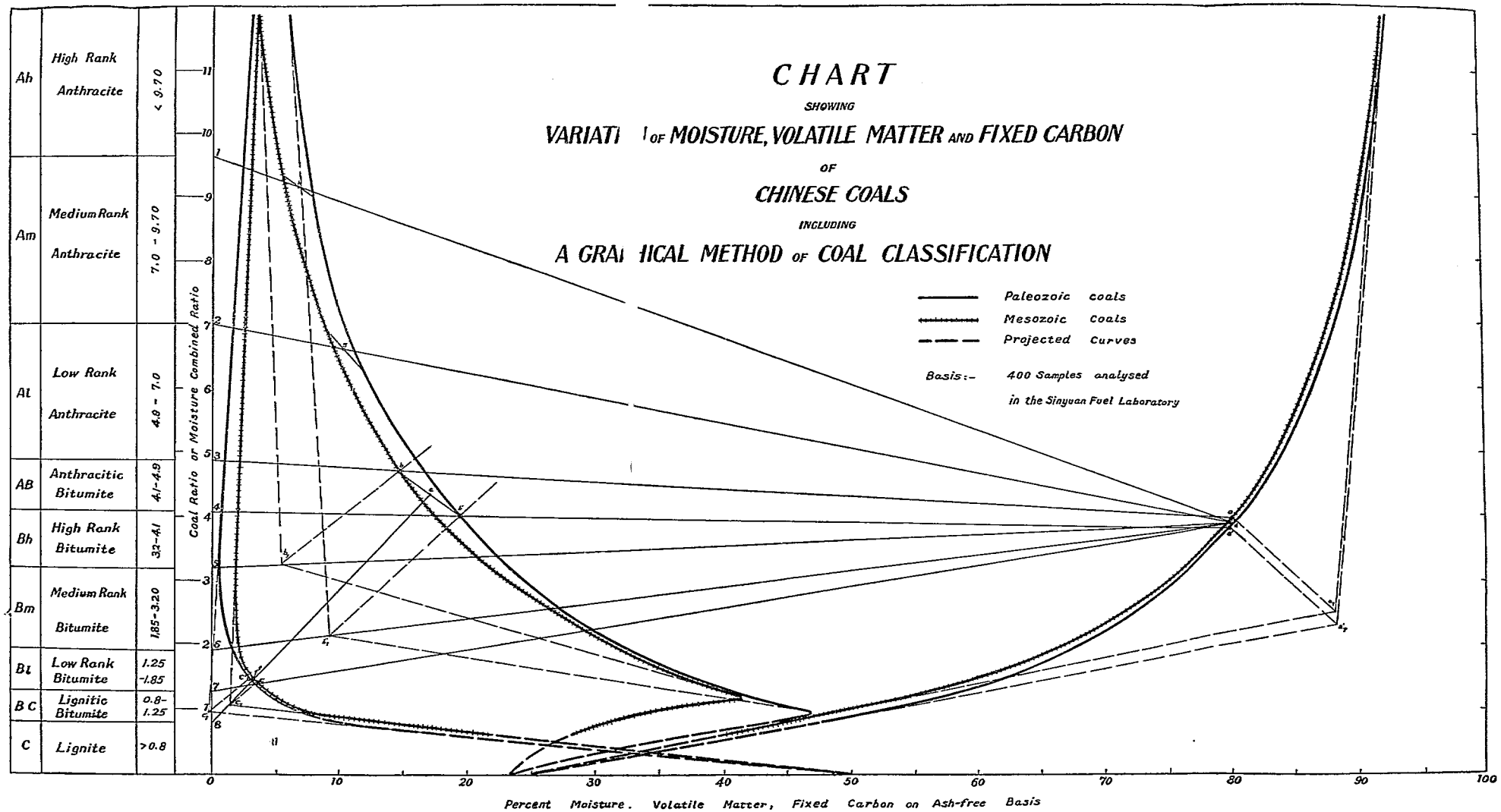
CHART
SHOWING
VARIATION OF MOISTURE, VOLATILE MATTER AND FIXED CARBON
OF
CHINESE COALS
INCLUDING
A GRAPHICAL METHOD OF COAL CLASSIFICATION
Paleozoic coals
Mesozoic Coals
Projected Curves
Basis:- 400 Samples analysed in the Sinyuan Fuel Laboratory
Ah High Rank Anthracite < 9.70
Am Medium Rank Anthracite 7.0 - 9.70
At Low Rank Anthracite 4.0 - 7.0
AB Anthracitic Bitumite 4.-4.9
Bh High Rank Bitumite 3.2-4.
Bm Medium Rank Bitumite 1.85-3.20
Bl Low Rank Bitumite 1.25 -1.85
B C Lignitic Bitumite 0.8- 1.25
C Lignite >0.8
Coal Ratio or Moisture Combined Ratio
Percent Moisture. Volatile Matter, Fixed Carbon on Ash-free Basis

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At any rate, the present graphical classification holds very well for differentiating the main divisions of coal. It is not intended to be final, and from time to time, careful application of these determined coal ratios will naturally offer a good assistance in testing its suitability. Other means may be incorporated with this classification. The best means will perhaps be the slacking test as suggested by Fieldner and others. This is quite likely a quick and simple test applicable to commercial laboratories where untrained workers are performing the fuel inspection work.

V. CONCLUSION.

As coals of different ranks are regarded as conglomerates there is no doubt that strict demarkation of coal ranks is difficult. Little overlapping in its proper grouping cannot be entirely avoided even in those classifications based on ultimate analysis.

The setting of coal ratios for gauging the ranks of coal as determined graphically should be considered as a simple and reasonable means for use classification and rough identification of coal ranks on account of its logical way of classifying coals.

Finally the author wishes gratefully to acknowledge credit to Director W. H. Wong for his valuable criticisms of the original manuscript, and to Prof. C. Y. Hsieh, his suggestions in constructing the graph.

Except for its high volatile matter (40% on ash-free basis). This coal should not be classed as Bl.

4. In thin section, Lincheng coal consists of large number of spores which are perhaps responsible for its high volatile constituents. Since only one sample is analysed, it is quite hard to give a hasty conclusion as to which class this coal should belong, but following the average results of the latest analysis reported by Lincheng Mining Company Feb. 1933, the coal ratio calculated is 1.67 and with 37% volatile matter. Accordingly this should be listed in Bl instead of Bm.

5. Kailan Mining Administration produces different grades of bituminous coals. Based on analysis from "The Ten Great Industries of China" 1916 and reports of South Manchurian Railway, Linsi produces Bh coal, Tangshan Bm and Machiakou Bl. The samples we have on hand are from Chaokochang and all the analyses showed that they are Bl. Considering the wide variation of coal ranks in Kaiping basin, a strict demarkation of Kailan coals is difficult, The tar and oil yield of Chaokochang coals is over 10%, about 2% higher than Chunghsing, a typical Bm and similar to Houfang and Tatung coals of Bl type, therefore it may be classed in Bl with reasonable ground.

6. Analysis of Chinghsing coal as reported by Chinghsing mine has a coal ratio of 2-2.8 therefore it belongs to Bm. The general opinion classifies it in the low volatile group but a coal containing a volatile matter of no less than 25%-33% should be considered as a medium volatile coal or Bm.

7. Liuhokou coal is distinctly Bh considering both its physical and chemical proporties. The only sample analysed may be of special case and could not be taken as final.

8. As only a single sample is available for analysis, the definite conclusion could not be drawn as to whether the Chechow coal is Al or Am.

The limits for classifying the different grades of anthracite and bitumite as already mentioned are arbitrarily chosen and whether the tangent-crossing points can be taken with advantage for differentiating the subdivisions is still a question. Yet in considering the physical properties, the limits for subdivision should remain as they are now and awaiting further revision when more coal samples are investigated.

coal ratio as set by Wong or the coal ratio as determined by the present graphical method. In the table coals are arranged in order of ranks as well as of geological age.

It is evident that the frequency of occurrence in the classification by graphical method seems to be more regular than by Wong's method, especially along the main divisions such as Changhsing which should be a proper Bl and Lincheng at least Bl but both of them would be classed as BC if Wong's old limits are used. However, five coals of Bm, 2 of Bh type according to Wong's classification have to be shifted one rank below while one Al to be moved to Am. It is rather difficult to conclude as to which proper rank these coals should belong, since most of them are lying very close to the dividing lines set by the graphical method. A discussion of these coals with reference to their general properties determined by methods other than proximate analysis and also the existing analytical data from various reliable sources will surely lead us to a reasonable and agreeable conclusion and reveal the fitness of the coal ratio as determined graphically.

1. Tangyuan coal is distinctly of humic type with well preserved woody structure. Though the cleavages are well developed, but they are not cubical. The streaks are brown and with many cracks on the surface of coal. As far as general appearance is concerned, this coal should be called Bl. According to the analyses given in The Manchurian Geological Mining Review, 1924, Tangyuan is classified into Bl rank.

2. Jurassic coals from Pinghsiang is widely accepted as Bm. Of the samples analysed, they all show quite high volatile matter and coal ratios calculated varying from 1.50-2.00, so that they are really right on the dividing limits. As the samples recieved are of crushed nature, it is hard to reveal their cleavages and laminations for macroscopic examination. This field situates very close to Leelin coal field which is distinctly a Bl type, therefore Pinghsiang may be closely connected to this field and exhibits similar properties of Bl coal to certain extent. In one case out of the six analyses given by Japanese Geological Survey 1912, it is reported with 46.50% volatile matter or a coal ratio of 0.97. This indicates there is a great difference in ranks of coal in the same field.

3. Hsuancheng coal resembles very close to Bm macroscopically with distinct alternate layers of bright and dull bands and cubical fractures.

TABLE IV.

Age	Notation as given by Wong[1]	Coal	No. of samples analysed in Sinyuan Fuel Lab.	Wong's Classification		Graphical Method	
				Notation	Frequency	Notation	Frequency
Tertiary	C	Zalainor Heilungkiang	4	C	4	C	4
Jurassic	Bl	Tatung, Shansi.	2	Bl	2	Bl	2
	Bm	Tangyuan, Heilungkiang.	4	Bl	4	Bl	4
	Bm	Pinghsiang, Kiangsi.	8	Bm	5	Bl	6
	Am	Mentoukou, Hopei.	10	Am	6	Am	6
Permian	Bl	Changhsing, Chekiang.	7	BC	6	Bl	5
	Bm	Hsuancheng, Anhui.	3	Bl	3	Bl	3
Permo-Carboniferous	Bl	Shengkeng-shan, Anhui.	27	Bl	16	Bl	21
	Bl	Chiawang, Kiangsu.	2	Bl	1	Bl	2
	Bm	Lincheng, Hopei.	1	BC	1	Bl	1
	Bm	Kaiping, Chao-kouchuang, Hopei.	19	Bl	13	Bl	18
	Bm	Chunghsing, Shantung.	5	Bm	5	Bm	5
	Bh	Chinghsing, Hopei.	6	Bm	6	Bm	6
	Bh	Liuhokou, Honan.	1	Bm	1	Bm	1
	Bh	Yenli, Hopei.	6	Bh	6	Bh	6
	Bh	Poshan, Shantung.	13	Bh	6	Bh	11
	AB	Tzechuan, Shantung.	1	AB	1	AB	1
	Al	Chechou, Shansi.	1	Am	1	Am	1
	Ah	Pingting, Shansi.	1	Ah	1	Ah	1

1. Based on analyses found in various publications.

TABLE III.

Classs and Rank	Coal Ratio	Physical characters
C	below 0.80	Brown to almost black, develops considerable cracks easily, non-coking, dull with brown streak.
BC	0.80- 1.25	Generally black, develops cracks easily resinous fracture and sometimes dull with brown to dark brown streak.
Bl	1.25- 1.85	Mostly laminated structure with luster varying from dull to shinny. Coking to non-coking in Carboniferous coal with well developed cleavages, Permian coals often coking and swelling, other younger coals moderate coking to non-coking. Streak dark brown.
Bm	1.85- 3.00	Very distinct banded structures with well developed cleavages. Strongly coking and mostly well swelling. Streak black but occasionally dark brown.
Bh	3.10- 4.10	Structure and cleavages very distinct, friable, nearly smokeless, coking with moderate swelling. Streak black.
AB	4.10- 4.90	Banded structure still distinct, shinny and hard, practically smokeless and feebly coking.
Al	4.90- 7.00	Little banded structure, less hard and lustrous than typical anthracite.
Am	7.00- 9.70	Both strong luster, hard and heavy, no banded and laminated structures.
Ah	9.70-12.0	

IV. Discussion.

In order to test the regularity on the frequency of occurrence of each rank within the set limits of coal ratio, another table No. 4 showing the relative frequency of several samples of some given coals according to the

there are also two points existing, with the Mesozoic one (point 7) below the Paleozoic. Since the difference is very small and there are more coals for the Mesozoic group existing in this range (lignitic coals of Paleozoic age are rarely found in China), the point 7 is better suited for differentiating the bitumite from lignitic coals.

It remains now to separate the bituminous coal of lignitic character and the real lignite. Since in these two types of coal, the variation of volatile matter and moisture is comparatively higher than fixed carbon, the curves of the former two constituents are therefore more concerned in their classification. Drawing lines through the point e (mean of b and b′) and f (mean of c and c′), an intercept 8 is obtained on the ordinate. This is now designated as the dividing point of lignitic bitumite and real lignite. So the main classification of Chinese coals will be; anthracite coal ratio of 4.90-12, anthracitic bitumite 4.10-4.90, bitumite 1.25-4.10, lignitic bitumite 0.8-1.25 and lignite below 0.80.

In order to subdivide the anthracite and bitumite which seem to have quite a wide range, another set of lines are arbitrarily drawn through the mean point d of a and a′ to four other points, h, g, (the mean point of two adjacent points which divide the upper part, above b and b′, of volatile matter curves into three equal divisions) and b, and b′ (the tangent points of the curve b and b′). The intercepts 1 and 2 divide the anthracite into three ranks and similarly 5 and 6 divide bitumite into three ranks. Avoiding the use of terms such as super-anthracite, semianthracite, semibituminous and the like the three fold division of *low, medium* and *high ranks* is assigned to each of these classes. Table III gives a complete scale of limits demarkating these classes and ranks as resulting from the graphic classification outlined in the above, together with the general appearance and physical characters of the coals belonging to the respective class and rank.

It results from the examination of a great number of coals that the macroscopic character of the hand specimens can often be taken for good indication in classifying at least the main divisions of coals. Such character should be especially observed on newly broken surfaces which give the actual sight of luster and cleavage. A ready recognition of the types of coal in such a manner will be very useful in the field where other means of identification are not available.

Logically, for the purpose of distinguishing anthracite from bituminous coal, the curves of fixed carbon and volatile matter should be concerned because in the higher ranks of coal there is little change in the percentage of moisture and only the volatile matter in relation to fixed carbon is much varied. That is why fuel ratio can be adopted for this range. When it comes to the lower ranks, the change between moisture and fixed carbon is proportionally larger than that of volatile matter with respect to fixed carbon. Therefore the former ratio, volatile matter and moisture, should be used to divide the bituminous coals and the still lower ranks such as sub-bituminous and lignite.

For the purpose of obtaining on the curves certain definite points which may serve at best as some sort of mid-point, tangent lines are drawn from both ends on each one of these pairs of curves. The points a, a′, b, b′, c, and c′, are thus determined. Straight lines are drawn from the crossing points ($a_T a'_T$ etc.) bisecting the angles formed by each set of tangents. Each of these bisecting lines will cut at one point on the curve on which the tangents are drawn. This point is chosen as the mid-point of that curve, six such points a, a′, b, b′, c and c′ are fixed in this manner on the six curves. These form the basis for the graphical classification. Straight lines are now drawn through the two points of corresponding geological group, that is the mid-points of fixed carbon and volatile matter, say of the Palæozoic age, or those of fixed carbon and moisture of the same age. With these, two intercepts on the ordinate are obtained for the Palæozoic group; the upper one dividing anthracite and bituminous and the lower one separates bituminous and lignitic coals. Similarly two more intercepts can be obtained by the mid-points on the curves of Mesozoic coals.

It is interesting to note that the dividing point 3 of anthracite and bituminous for the Mesozoic group is higher than the corresponding point 4 of the Palæozoic. Those coals having coal ratios between point 3 and 4 are quite close to anthracite as far as hardness and luster are concerned, yet they are often slightly coking and the banded structure is still distinct. They therefore constitute an intermediate type of coal rather than either of the anthracite or bitumite classes. Adopting the same nomenclature as suggested by Wong, anthracitic bitumite is thus assigned for this type of coal. When it comes to coal ratio limits for the bitumite and those lower than bitumite,

This system of classification has been applied to coals for years in China and is accepted as a useful means to differentiate various types of coal mined in this country. Wilson[17] after trying the various classifications to the coals known in Peiping market concluded that Wong's system is the most suitable.

III. Construction and Explanation of the Graph.

In the previous attempt of classification of Chinese coals, difficulty was particularly felt for the lack of reliable and comparable analysis, the data so far available were obtained from different laboratories with different methods and at times widely apart. Much uncertainty also arose from the fact that the limits of the coal ratio between classes and ranks were arbitrarily found without reference to any special basis.

During the past one and half years this fuel inspection laboratory has analysed over 400 coal samples from various mines by a tentative method based closely on the American procedure. Most of the samples are collected by our geologists and should therefore be considered as true samples. The analyses are reduced to ash-free basis and the calculation of coal ratio is made for each sample. A chart is constructed by plotting coal ratio as ordinate and volatile matter, moisture and fixed carbon on ash-free basis as abcissa.

It was H. S. Wang[18] who first thought to represent the analyses of Chinese coals to a rectangular diagram and found out the difference between the Palæozoic and Mesozoic coals which form two distinct groups.

Similarly, all the samples are divided up into two main geological groups, namely, Palæozoic and Mesozoic, in order to avoid unnecessary complication which would arise when coals of all geological periods are distinctively considered. The intention is to show the variation of the three main constituents moisture, volatile matter and fixed carbon of Chinese coals with reference to the coal ratio. Three pairs of curves representing each of the three constituents of quite remarkable smoothness are drawn. The moisture content of all the samples seems to be unusually low for all types of coal. From this graph, it is suspected that a graphical classification might be possible by passing suitable straight lines through certain definite points on the three sets of curves and the intercepts on the ordinate may be employed as a means to differentiate one type of coal from another.

分類法並未能有切實標準，往往適于此者，不合于彼，反不如實用分析法之迅速簡易也。且實際應用之結果，已足証明圖解分類與煤之物理狀態及燃燒性均有關係，於實用上亦甚有益也。

煤類	加水燃率	性質
褐炭	〇・八〇以下	色暗櫻黃至黑易起裂紋不粘結
褐性烟炭	〇・八〇至一・二五	色常黑時有裂紋劑裂面往往不平如松脂裂面
低級烟炭	一・二五至一・八五	色黑分亮暗層次甚多石炭紀煤有方形裂面或粘或不粘絕少賬性二疊紀煤大部粘而賬性高侏羅紀以下之煤粘性微或竟不粘
中級烟炭	一・八五至三・〇〇	亮暗層次之分甚顯兼有方形裂面粘性賬性均甚高
高級烟炭	三・〇〇至四・一〇	與中級烟炭相仿似稍亮質脆燃燒時少烟或無烟粘至稍粘而有賬性但不高
無烟性烟炭	四・一〇至四・九〇	亮暗層次亦分但較高級烟炭尤光亮而質亦堅硬粘性極微
低級無烟炭	四・九〇至七・〇〇	亮暗層幾不分較眞正無烟煤似稍暗稍鬆
中級無烟炭 高級無烟炭	七・〇〇至十二	爲尋常無烟煤或紅煤中級高級之分甚不易較之他種煤硬而且重

由此觀之，從圖解而定之分類與各種性質均有關連之處。雖高中兩級無烟煤分別甚微，其餘各類非特性質不相同，卽其外表亦互有分別。故在目力之下，亦有判別之可能。如對于驗煤有相當經驗者，則除少數特別煤外，各種類均可以目力觀察之，卽知其屬何類之大概。此法雖未能完全準確，但對于野外調查者，可當時得悉該煤之約歸何類矣。

（五）結論

今將此圖解分類法所定之標準燃率，與翁氏所定數比較之，則相差不遠，祇有烟煤無烟煤間之無烟性烟煤改動稍大。故以本所分析煤樣結果用此二法分類者，相差甚微。但如將翁著「中國石炭之分類」一文中所定之種類高下而研究之，其出入似稍大，其原因當在標本及分析方法之不同耳。茲參考他種試驗所得之結果，如低溫度蒸溜，薄片顯微鏡視察，及出產地位等，加入研究，則新得之標準，甚稱合式（參閱英文）。各地所產煤等級，稍有更動，並非貿然爲之，亦相當合理也。夫煤之結構複雜，卽使採自一時一處者，其分析結果亦或有出入，況用此簡易法鑑定之乎。但用他法分類，既耗費時間甚多，又需要複雜設備，而關于

煤，大都由本所同人所採集，煤樣既可靠，試驗方法復無歧異，雖成績僅四百餘種，但亦不可稱爲少數，用之於分類，或較彙集國內外各地試驗室之成績爲妥，蓋其出入較微也。

今將本所四百餘分析成績分爲中生代古生代兩種，用圖表明其揮發物水份及固定炭與加水燃率之互相關係（如圖中之粗線）。再在各綫上以切綫法（Tangents）得數交綫點，然後均分（Bisecting）其交綫所成之角度，則可得一中心點，于每綫之上（詳細製圖法及分配法見英文）。復又推測煤之成因以區別煤之總分類。夫由烟煤變成無烟煤，揮發物逐漸減少，其速率較之固定炭增加爲尤甚，水份之變化當甚微，故分別烟煤無烟煤，可僅取揮發物固定炭之中點。烟煤與褐性烟煤之別，首在水份之高下，次在固定炭之增減，故應用固定炭及水份兩中心點以分別之。褐炭及褐性烟煤之分別，常在揮發物與水份之上，因擬用此兩綫上之中心點定之。如將所定諸點以縱橫線連貫再引長此線，使之切在加水燃率之縱距綫上，則可得3.4.7.及8.四點。如此無烟煤烟煤之界限，凡爲中生代者在第三點，古生代者第四點，烟煤褐性烟煤之界在第七點，而無中生代古生代之分。第八點以下爲褐炭，亦無時代之別。第三第四點其間之煤，亞近烟煤而烟甚少，故稱之曰無烟性烟煤以示區別。以上爲總分類大概。又四七兩點之間距離甚大，如用交點 aT aT bT bT 照上法引畫橫綫，復得五六兩點爲分高中低三級烟煤，第三點以上，亦可用相似此法分一二兩點，以區別高中低無烟煤之用。若是則華煤共分九類，與翁氏所定者適相同，因沿用其名也（詳細理論見英文）。

（四）各分類與各煤性質關係

上述分類法與他種實用分析分類法特異。其所取材料完全根據分析所得之結果，及煤炭化之變遷，而定其類別，並未含有其他性質之觀察，雖對于小分類中，一時不能十分完備，但其總分類法似無勉強之處，于理論上亦相吻合。苟能日後華煤分析逐漸增多，再爲圖解之，當可比現時所定之標準燃率數尤爲確實。爲證明各點與其他性質是否有關連之處，特將各類煤之化學及物理性質比較，列表於後。

華煤圖解分類

金開英

(一)緒言

凡分析煤之水份，灰份，揮發物，固定炭，發熱量者，謂實用分析。此法較諸元素分析（乃測定煤中元素如碳，氫，氮，氧，硫，磷等）簡易甚多，其所用器械不繁，需時亦短，關于工商界所期要之煤質記載，或各煤田各煤層產煤優劣，均可一一判定。是以該分析既省時間，又得效果，于經濟應用諸方面，無不合用，因此各燃料試驗機關，往往以此爲鑑別各煤煤質惟一要法。

煤之種類不一，有褐煤烟煤無烟煤之分，又煤之變態無窮，常乏定則，因此其分類法亦繁瑣異常，有時因一試驗法之不足以分別其性質，而取他種方法輔助之，以爲分類標準。各種標準中尤以實用試驗爲最主要。因其方法既簡，成績復多，于分類比較上最爲便利也。

(二)分類法

此篇英文著述內，曾將關于元素實用兩分析爲煤分類基礎者，列入一表。凡各分類法之提要，以及其優劣均詳細載入，以供參考。各分類法對于華煤適用優劣之比較翁文灝氏亦經詳論，並自擬一分類法。翁氏分類法，乃用加水燃率之數而定煤類（原文見地質彙報第八號）。此分類法經本所歷年試用，尙爲合適。燕大教授衛爾遜將北平市場上所得煤樣詳加分析，用各種分類法試驗之，亦謂翁氏分類法之最適宜于華煤分類。但翁氏當時因分析缺乏乃雜取各出版物中不同機關之分析結果而酌量採用之。又其分類各數分界之標準缺少固定依據。此篇之意，在以較爲可靠之分析爲根據，用圖解法以定各類之分界點，期使翁氏所擬各類得有更實在及合理之依據。

(三)圖解分類法

近年來沁園燃料研究室，以實用分析法測驗國內各省之煤，已達四百餘種。此項分析乃純用同一方法之試驗者，其所分析之

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MICROSCOPIC STRUCTURE OF TZUHSIEN COALS AND ITS BEARING ON COKING PROPERTY

By

C. C. WANG

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

By C. C. Wang (王竹泉)

(*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 (峯峯村), however, an incomplete section (Fig. 1.) along a stream valley has been surveyed as described below:—

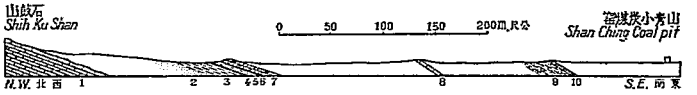


Fig. 1. Section of the Carboniferous strata, N. W. of Fengfengtsun. 1, Ordovician limestone; 2, Grayish white sandstone; 3, Bluish clay shale; 4, Hsiachia coal seam; 5, Bluish clay; 6, Taching coal seam; 7, Deep gray limestone with flint nodules (Taching limestone); 8, Grayish limestone (Hsiaoching limestone); 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 $\frac{1}{3}$	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 $\frac{2}{3}$	0.52	19.97	70.81	8.70	1.50	,,	7702 ,,
,,	Shanching-hsiaotan	Bh $\frac{4}{5}$	0.32	21.00	58.80	19.52	3.50	Caking & swelling	6795 ,,
Chungho Coal Mine	Toumei-hsiaotan	Bm $\frac{2}{5}$	0.55	24.60	53.86	20.99	1.20	,,	6801 ,,
,,	Tamei	Bh $\frac{3}{4}$	0.58	21.62	64.32	13.48	0.94	,,	7500 ,,
,,	Itsomei	Bm $\frac{4}{5}$	1.26	22.01	63.43	13.30	3.80	,,	7467 ,,
,,	Yehching-mei	Bm $\frac{3}{5}$	1.88	22.86	64.56	10.70	2.00	,,	7624 ,,

1. For the meaning of the sympbols, see W. H. Wong, Classification of Chinese coals. Bull. Geol. Sury. 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.

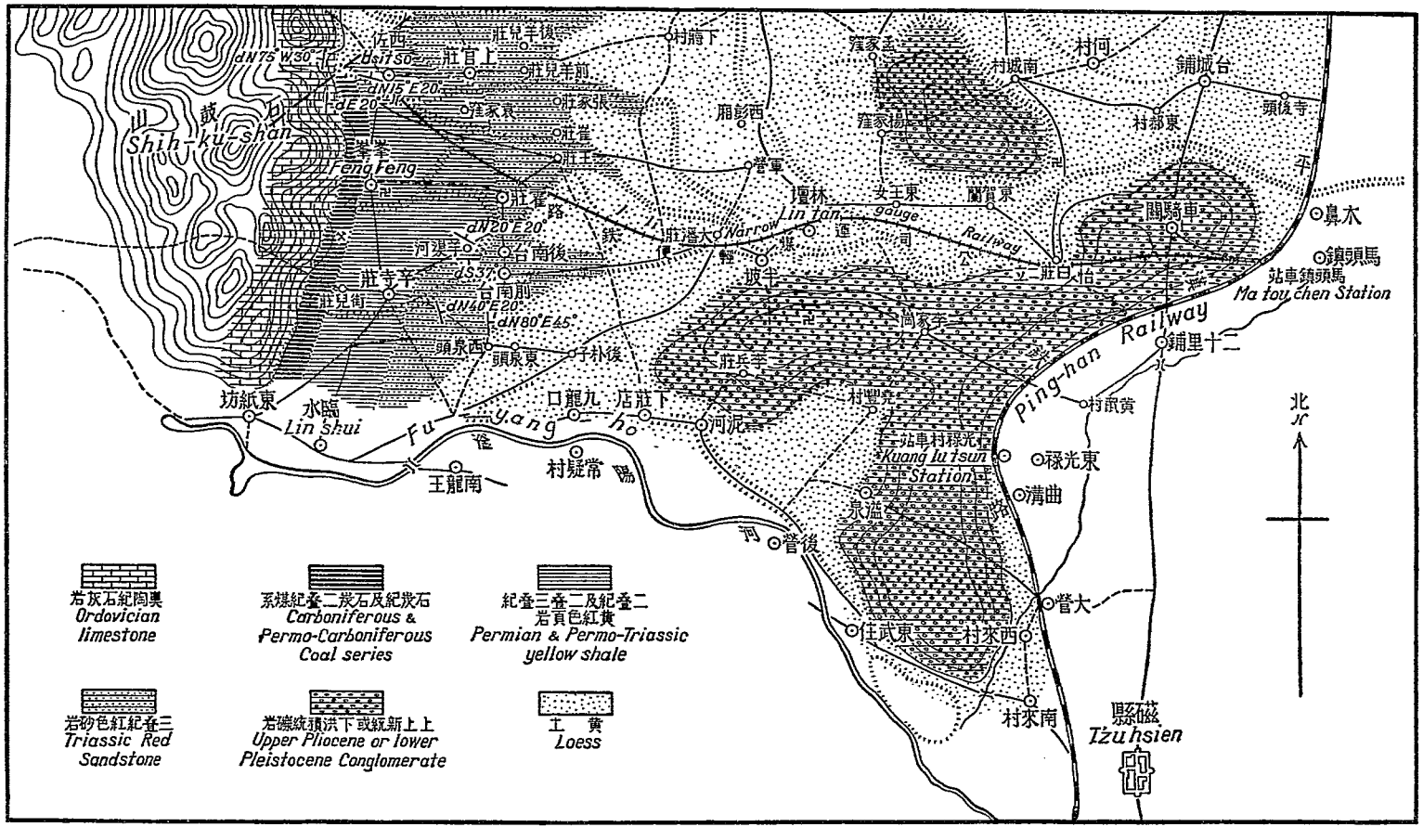
1 E. C. Jefery: Coal in relation to coke, Trans. Am. Inst. Min. Met. Eng. Vol. LXXI, pp. 149-164, 1925.

磁縣煤田地質圖

GEOLOGICAL MAP OF THE TZUHSIEN COAL FIELD.

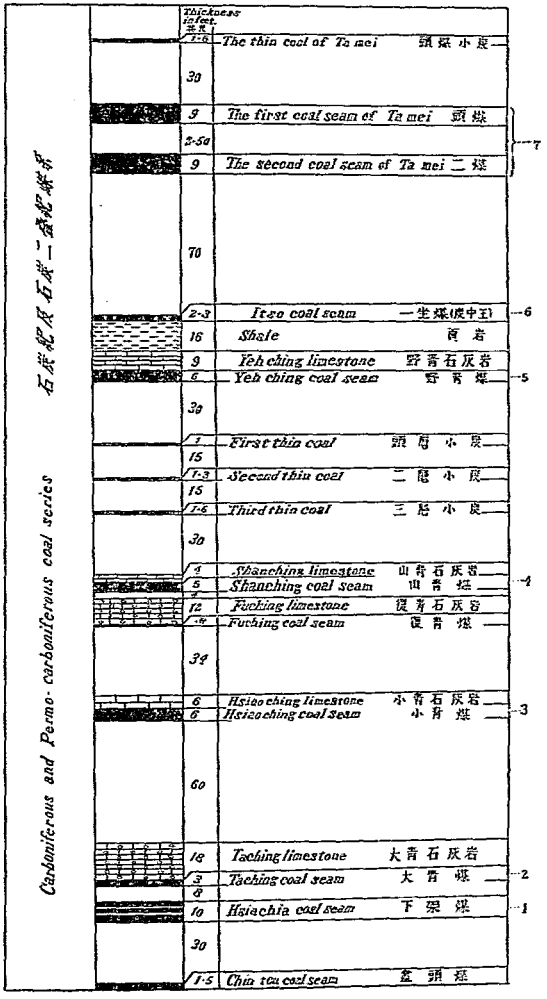
0 2000 4000 6000 8000 m.

P1. I.



西佐煤田煤層柱形圖 Pl. II.

Columnar section of the Heitso 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.

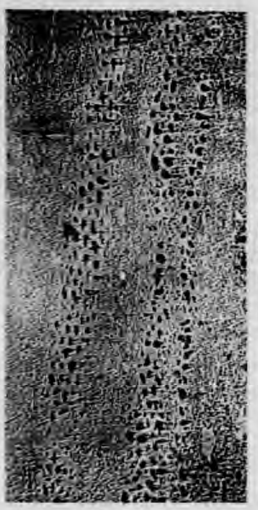


Fig. 2.

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.

地質調查所沁園燃料研究室

燃料專報

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磁縣烟煤顯微鏡下之結構及其與焦性之關係

王竹泉著

中華民國二十二年七月
實業部地質調查所印行

新園燃料研究室

燃料研究專報

CONTRIBUTION FROM THE SIN YUAN FUEL LABORATORY

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THE PLASTIC RANGE OF COKING COALS IN CHINA

BY

K. PING

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THE PLASTIC RANGE OF COKING COALS IN CHINA

By K. Ping

Introduction

In spite of constant researches on the constitution of coking coals, no definite conclusion has yet been arrived. So far as we know, coal is a conglomerate of chemical substances which on heating in the absence of air, give off gases and tars and leave behind a solid mass known as coke. Since the utilization of coke is of fundamental importance in mordern industry, and the properties of coke vary greatly with different sources of coal, a study of the physical characteristics of coal when subjected to thermo-treatment, has induced us to device a method adaptable for the prediction of coking properties.

This study has been extensively investigated and the various important schemes suggested for are stated below:—

Audibert studied the mechanism of coking by moulding powdered coal into cylinders and measuring their swelling lengths when subjected to heat at different temperatures. His results show that the progress of the change in length depends essentially on the nature of coal and on the rate at which the temperature rises.

Pieters[2] suggested a method for evaluating coke by the determination of the velocity of gas evolution of coal heated at a constant rate. His conclusion states that all good coking coals show a characteristic maximum in the velocity of the evolution of gas at about 480°C, and poorly coking coals are decomposed at a more regular rate.

An important series of investigations on the plastic state of coal has been done by Foxwell[3]. He suggested a method by means of which the resistance to a stream of gas passing through a coal column at different temperatures can be measured. Conforming to his idea, Layne and his coworkers[4,5] by using a similar method, have determined the plasticity of many American coals. The results obtained have led them to believe that when a coking coal is heated in an inert atmosphere, it tends to expand gradually due to the presence of moisture which forces the coal to swell. As the temperature is brought up to about 350-400°C, moisture is driven off, then the coal softens and rapidly shrinks. On further hating the coal beecomes plastic, evolving

gases and vapors which form blisters in the fused mass. The mass gradually hardens to coke with a cellular structure when the temperature is still increased.

The temperature interval beginning from the temperature at which gases and vapors evolve from the coal to where the coal hardens, is called the "Plastic Range".

In the present experiment, the method adopted by Layne and Hathorn is employed with a slight modification. It is in the hope that this method may serve a good purpose to predict the coking properities of Chinese coking coals.

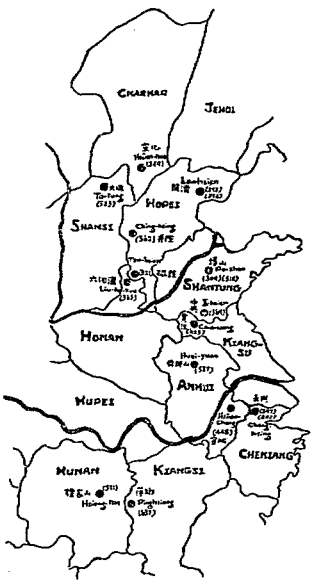

Fig. 1.

SAMPLES OF COAL TESTED

Seventeen coal samples were collected from the outstanding mines in different provinces. The localities, classifications as well as other specifications are listed in table I. The location of the mines is shown on the index map. (fig. 1).

TABLE I

Lab. No.	Locality	Company	Locality seam or Local Name	Geological Age *	Notation
309	Poshan, Shantung	Potung	Tatuanshiht'an	P-C	Bh
310	Poshan, Shantung	Potung	Siawtuanshiht'an	P-C	Bh
321	Tsuhsien, Hopei	Yili	Yitsomei	P-C	Bh
349	Hsüanhua, Charhar	Houfeng	Whole seam	J	Bl
362	Chinghsing, Hopei	Chinghsing	Fifth seam	P-C	Bm
365	Liuhokou, Honan	Liuhokou	——	P-C	Bh
369	Ihsien, Shantung	Chunghsing	Washed slack	P-C	Bm
373	Lanhsien, Hopei	K.M.A.	Washed slack (5th seam)	P-C	Bm
374	Lanhsien, Hopei	K.M.A.	Special washed slack	P-C	Bm
448	Hsüancheng, Anhui	—	Tawangtsun	P	Bl
523	Tatung, Shansi	—	Kakata	J	Bl
587	Shunkengshan, Anhui	Tatung	Average sample	P-C	Bl
591	Hsiangtan, Hunan	Yiuli	Tanchiashan	P	Bh
597	Changhsing, Chekiang	Changhsing	Tameidien	P	Bl
622	Changhsing, Chekiang	Changhsing	Kwanhsing	P	Bl
623	Chiawang, Kiangsu	Huatung	Upper seam	P-C	Bl
655	Pinghsiang, Kiangsi	Pinghsiang	Anyuan	J	Bl

* J-Jurassic
P-Permian
P-C-Permo-Carboniferous

APPARATUS

The apparatus used is closely similar to that described by Layne[4] and Hathorn. The assembly of the apparatus is shown in figure 2.

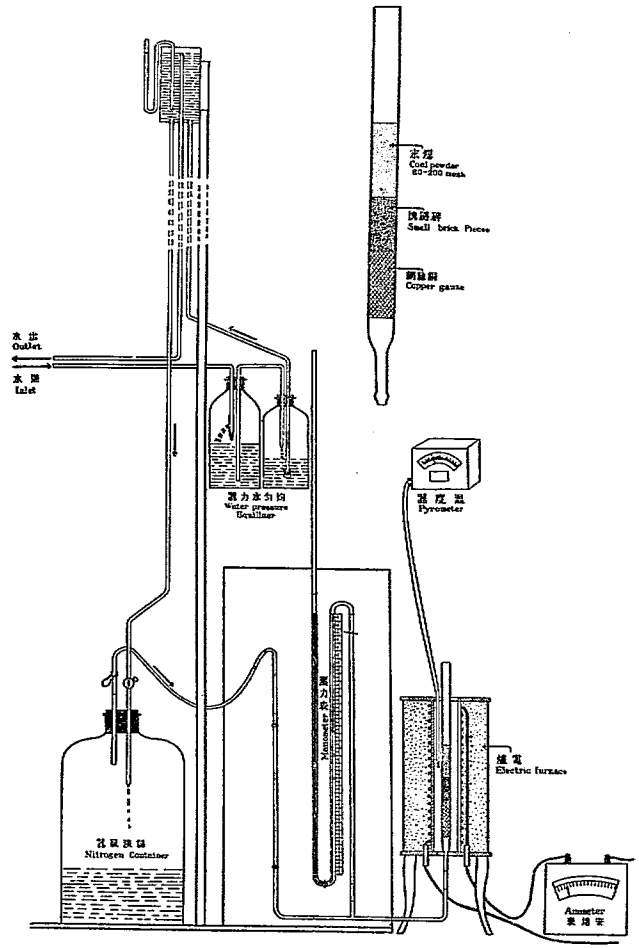
Coal powder
60-200 mesh
Small brick Pieces
Copper gauze
Outlet
Inlet
Water pressure Regulator
Pyrometer
Manometer
Electric furnace
Nitrogen Container
Ammeter

Fig. 2.

The pyrex tube (1 cm. and 20 cm. long) with a coil of reduced copper gauze placed at the lower end serves to hold the testing coal sample. It is inserted in an electric tube-furnace having a uniformly heated portion of 10 cm., where the rate of heating is controlled by means of two rheostats (not shown) and one ammeter, while the temperature is measured by a Cr-Al thermocouple and a high resistance pyrometer.

An inert gas, nitrogen, prepared from NH_4Cl and $NaNO_2$ is forced through the coal sample by a constant water head maintained at a height of 9 feet. Owing to the wide difference in water pressure, an equilizer has to be used to regulate the flow. It is composed of two large bottles; in one of them, there is a rubber tubing with an uniflow slit valve serving as the inlet of water. While in the other, a small nozzle which depresses the excess water when the pressure is too high. When the water is incidently out of supply or the pressure is less than that of the head, the excess water in these two bottles will be forced up to the head by the confined compressed air in the bottles. A manometer filled with water slightly colored with carmine is connected between the nitrogen holder and the pyrex tube containing the coal. This indicates the resistance to gas flow offered by the plastic state of coal particles in terms of gas pressure in mm.

Preparation of Samples

All the samples were crushed and pulverized carefully to make all the coal to pass through 60-mesh sieve (Tyler Standard). The coal powder is then sieved with a 200-mesh sieve. The portion that remains on the 200-mash sieve was mixed with pure sand sized 60-100 mesh, in the ratio of two parts to one by weight.

Procedure

Small brick pieces of the size 10-40 mesh, were charged on the wire gauze in the tube to make a two-centimeter column. The coal and sand mixture is then poured into the tube sufficiently to make a column of exactly 5.5 cm. which was reduced to exactly five centimeters by gentle tapping the coal column. At the outset, the furnace was heated to about 200°C quickly. The resistance of the rheostat was then increased to maintain the rate of heating to 4°C per minute. The resistance of the rheostat was gradually reduced so as

to increase the current to compensate the radiation of the furnace with rise of temperature.

When the temperature reached about 250°C the pyrex tube was inserted into the furnace and the lower end of the tube was connected to the nitrogen system. The stopcocks on the water head and gas passage were opened and the nitrogen in the container was displaced by water and forced to pass through the tube. The gas pressure was indicated by the manometer. In the course of the experiment, readings of temperature and pressure were recorded from time to time, At the end of the experiment, that is, after the pressure has dropped, the pyrex tube was drawn out, and the length of the coke column remeasured.

RESULTS

The critical points, the pressure, as well as the swelling coefficient were recorded and tabulated in table (II). The following graphs of different coals (Pl. I-IV) were obtained by plotting pressure against temperature.

EXPLANATION OF TABLE (II) AND GRAPHS

The coal particles in the coal column are separated from each other by very small spaces which, though allowing the passage of gas, give resistance to the flow. When the tube is inserted into the furnace and connected to the nitrogen system, the pressure as indicated by the manometer increases gradually until the pressure of the flow just counterbalances the resistance of the coal column. When the temperature rises, moisture begins to evolve, consequently the column is slightly expanded as indicated by a little increase in the gas pressure.[7] At the moment when the moisture is all gone a sudden reduction of the pressure results, owing to the shrinking of the column. This point is only apparent with a few of the coals and is termed as the initial softening point. As the temperature is gradually and uniformly increased, the coal softens, that is the organic matter firstly fuses to a viscous mass which by gravity flows down and clogs the interspaces of the particles, therefore blocks the flowing gas.[8] This is known as the transition point of fusion. Both of these changes (the change of fused state and that of the gas pressure) take place in a gradual manner. Further increasing of heat causes the fused mass to decompose into gases and vapors thus forms blisters and bubbles which force the fused mass to swell. Such behavior cannot be observed very clearly dur-

TABLE II.

Lab. No.	Initial Soften. Point	Fusion Point	Solidification Point	Pressure of Fusion Point	Pressure at Solid. Point (Maximun Pressure)	Swelling Coefficient
309	407°C	450°C	483°C	76.0 mm.	250 mm.	1.40
321	—	435°C	543°C	60.4 mm.	330 mm.	1.06
591	342°C	364°C	483°C	38.5 mm.	82 mm.	1.00
310	359°C	457°C	499°C	99.6 mm.	162 mm.	1.04
362	—	425°C	509°C	72.0 mm.	111 mm.	0.90
365	—	425°C	495°C	65.6 mm.	269 mm.	1.04
369	418°C	438°C	480°C	133.0 mm.	346 mm.	2.56
374	415°C	449°C	482°C	86.0 mm.	214 mm.	1.14
373	—	431°C	460°C	65.6 mm.	246 mm.	1.96
655	—	430°C	487°C	102.0 mm.	132 mm.	1.10
448	433°C	449°C	467°C	67.0 mm.	189 mm.	2.64
523	—	380°C	450°C	78.0 mm.	93 mm.	1.00
587	—	385°C	410°C	80.0 mm.	84 mm.	0.94
349	—	—	—	—	—	1.00
597	369°C	440°C	690°C	—	—	2.72
622	—	420°C	481°C	60.0 mm.	278 mm.	2.50
623	—	—	432°C	—	—	1.11

ing the experiment but it is very noticeable on the graph by a sharp change of slope of the curve. The viscous mass finally decomposes into compounds of high carbon content, in other words, the whole mass gradually graphitizes and cements the particles to form coke of cellular structure. During this stage, the carbonized column again opens up its passage to the flowing gas, and thence, the pressure on manometer suddenly drops. This transitional stage is termed as the solidification point.

Swelling coefficient is obtained simply by dividing the length of coke finally found by that of coal column of 5 cm.

Discussion of Results

1: On the prediction of coking quality of coals.

While the general principle involved in this experiment is quite simple, many difficulties are constantly met with in carrying out this experiment. Though the results obtained are quite interesting, yet they vary to a great extent with different coals. The curves shown herein represent the behavior of coals under thermal treatment as measured by their resistance to a constant flow of an inert gas.

Concret conclusion can hardly be drawn regarding the prediction of good metallurgical coke from these tests, yet a series of facts as shown on those curves are of interest. These might lead us to a general conclusion as to how the good coking coals, moderate coking coals, and non-coking coals may behave under such an experimental procedure. It seems that those coals which show great resistance to gas flow when plastic, that is, where the curves indicate highest pressures, give comparatively good cokes.

Moreover, good coking coals have smaller range of plasticity. Because, the small value of plastic range shows the ease of converting coal into coke. That is to say, the rate of rise of pressure or dP/dT has a very high value.

Basing upon the above two factors, we consider the ratio of the pressure difference to the plastic range may serve as a method for predicting the properties of coking coals. In accordance with this ratio the coals are arranged in table III:—

No. 362 (Pl. I, Fig. 1) produces a very compact coke, but it is poor in the plasticity test, since it shrinks, and leaves room for the passage of gas between the wall of the tube and the coal. So to coals which shrink on heat treatment, the plasticity test shows detrimental effect.

The curve of No. 597 (Pl. III, Fig. 6) is quite extraordinary. It may be due to the inadequacy of the uniformly heated portion of the furnace, for the high swelling of the coal. Thus, when the coal swells to the upper or cooler portion of the furnace, a part of the tar hardens to form a film which prevents the flow of gas, until sufficient pressure is attained to break up the filament. After the dropping of pressure a new film is formed again. The repetition of the formation of tar film results the odd shape of the curve. Aside from these two exceptions, most of the coking coals have the value well

TABLE III

Lab. No.	Locality or Company	Pressure Difference	Plastic Range	Value of P.D./P.R.
448	Hsüan Cheng	122 mm.	18°C	6.78
373	Kailan	180.4 ,,	29 ,,	6.23
309	Poshan	174 ,,	33 ,,	5.28
369	Chunghsing	213 ,,	42 ,,	5.08
374	Kailan	128 ,,	33 ,,	3.87
622	Changhsing	218 ,,	61 ,,	3.59
365	Liuhokou	230.4 ,,	70 ,,	3.29
321	Tzuhsien	269.6 ,,	107 ,,	2.52
310	Poshan	62.4 ,,	42 ,,	1.49
655	Pinghsiang	30 ,,	57 ,,	0.53
362	Chinghsin	29 ,,	84 ,,	0.33
523	Tatung	15 ,,	73 ,,	0.205
587	Shunkengshan	4 ,,	25 ,,	0.16
591	Tanchiashan	5 ,,	119 ,,	0.042
344	Hsüanhua	0 ,,	—	0.00

over one, and moderate and non-coking coals below 0.50. Considering the case of 655 which has been used for the production of metallurgical coke, the dividing line for good coking coals and feebly coking coals should be in the neighborhood of 0.50.

All the solidification points of these coals are somewhere around 480°C. This fact harmonizes with the results of Pieters[2] who observed that at this temperature the rate of evolution of gas is the greatest.

In comparing the coals that have been used for the production of coke, such as Chunghsing, Kailan and Poshan etc, we are in the opinion to say that those coals of recognized type for good coke agree with this test very well and ranked in the higher order in the table, those of medium coking coals as Liuhohou, Tzuhsien come next in order, while Tatung, Hsüanhua, known to be of very poor coking quality lie in the cellar of the list. Consequently, allowing for errors and inevitable difficulties in carrying out this experiment as experienced by many investigators, we believe such test may be of good

help for the prediction of coking properties of various coking coals mined in this country.

2. On the size of coal.

To our knowledge, the main trouble seems to lie in the samples prepared, because a part of the fine coal powder (below 200 mesh) is sieved out and unaccounted for in the test. They cannot be regarded as representative of the original coals.

It is of the common opinion, that coal has physically four constituents: fusain, durain, clarain and vitrain. In coking coal, clarain and vitrain are supposed to be the important constituents, without which good coke cannot be formed. They are rich in resinous substances soluble in pyridine and chloroform, so-called gamma compounds, which on being heated decompose and start the cementation of coke. Durain is poorly coking and fusain non-coking. Fusain is considered as the most friable component of the four and durain the hardest. Evidently fusain will crumble into powder on crushing. Clarain and vitrain are comparatively resistant to crushing and durain the least.

An attempt has been made to illustrate this fact:—

200 grams of coal No. 373 were all made to pass through a sieve of 10-mesh. The crushing of the coal was done very carefully, that is by repeated crushing and sieving. The crushed coal is further separated into four portions which are then weighed separately:—

Portions	Weight	Percentage
a. that passes through 10-mesh and remains on 20-mesh sieves	85 g.	42.5%
b. that passes through 20-mesh and remains on 60-mesh sieves	75 g.	37.5%
c. that passes through 60-mesh and remains on 200-mesh sieves	35 g.	17.5%
d. that passes through 200-mesh sieve	5 g.	2.5%
Total	200 g.	100.0%

Foxwell and Layne have chosen the portion of (b) for their experiment. Though it is their opinion that the coarseness of coal will get rid of the effect of packing, yet the coal taken may be merely 60% of the original coal. It seems that the larger pieces are rich in durain because it resists crushing the most and therefore a large part remains in the portion 10-20 mesh. Clarain

and vitrain the next in crushing strength, will be found in the portion (b) and it may show much better coking property than that of the original coal and other portions. Thus, No. 373 coal, was crushed and separated into a, b, c and d four portions. a, b, and c portions were tested for plasticity. Portion d is rejected owing to its extreme fineness. The results of testing on different portions are as follows:—

Portion	Initial Sof. Point	Fusion Point	Solidification Point	Maximum Pressure	Swelling Coeff.
a.	449°C	470°C	517°C	195.2 mm.	1.04
b.	—	435°C	479°C	294.0 mm.	2.40
c.	468°C	444°C	466°C	204.0 mm.	2.20
(O)	—	431°C	460°C	246.0 mm.	1.96

(O) is the original coal that made all to pass 60-mesh and remain on 200-mesh sieves.

Therefore this indicates that portion (b) contains major part of bright coal, the highly coking and swelling constituents of bituminous coals, while (a) consists mostly of durian and in (c), it is probably a mixture of bright coal and fusain.

Regarding the maximum pressure and the swelling coefficient, it seems that the values of the last one are the average of the above three, though the sample is about 90% of the original coal. We are inclined therefore to think that 60-200 mesh is more apt to give the representative values of coals. The slight packing we experienced does not seem to be of importance and alter the results greatly.

Conclusions

1. Seventeen coking coals were tested by the method of plastic range and their properties were studied.
2. This test is good for the prediction of the properties of coke to swelling coals. To coals which shrink on heating, this method cannot be applied.
3. The disadvantage of this method is that the samples prepared for the test are not the exact representatives of the original coals, only 90% of the sample is used in the test.

ACKNOWLEDGMENT

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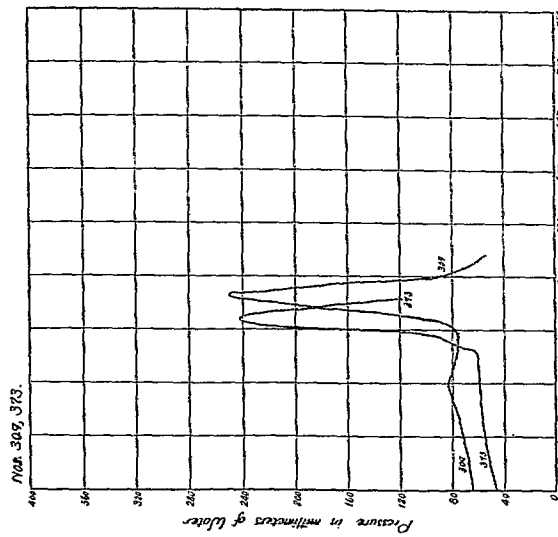
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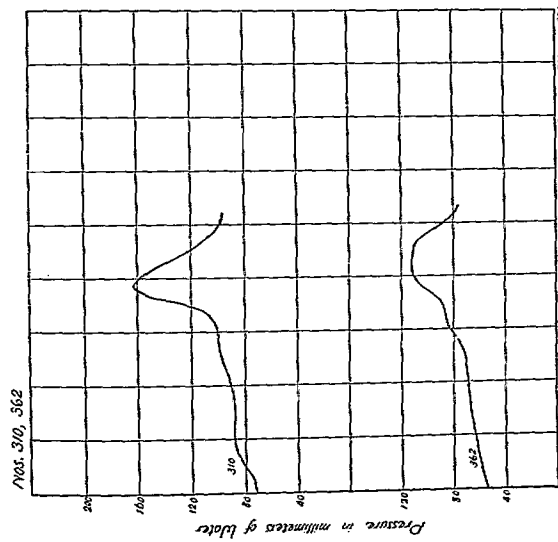
Pressure in millimetres of Water
Temperature in Degrees Centigrade
309
373
375
371

Fig. 2.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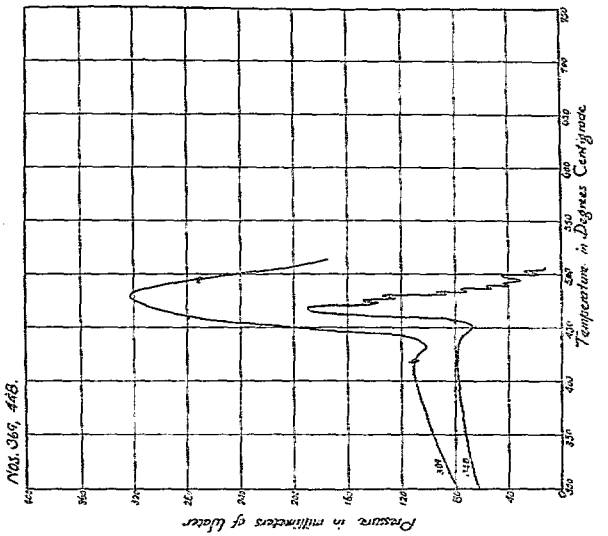
Pressure in millimetres of Water
Temperature in Degrees Centigrade
310
362

Fig. 1.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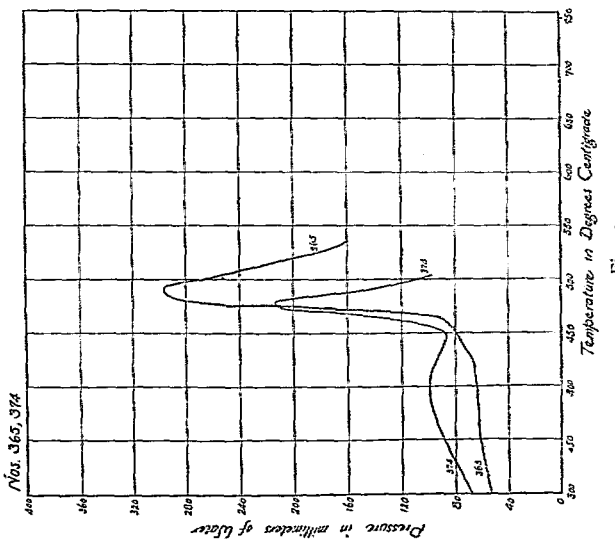
Pressure in millimeters of Water
Temperature in Degrees Centigrade
309
320

Fig. 4.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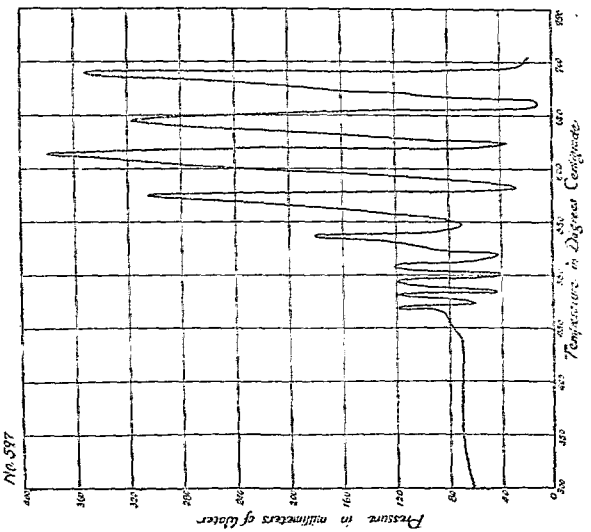
Pressure in millimeters of Water
Temperature in Degrees Centigrade
363
374
363

Fig. 3.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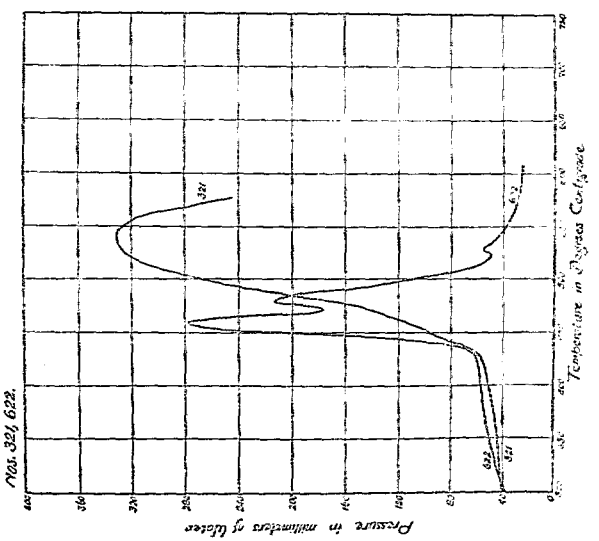
Pressure in millimetres of water
Temperature in Degrees Centigrade

Fig. 6.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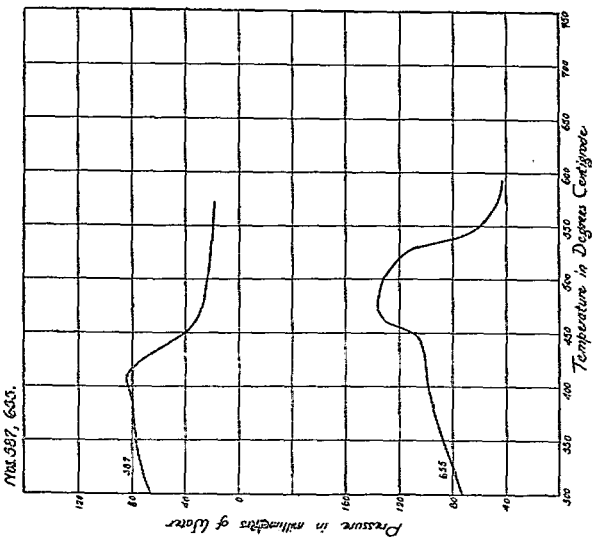
Pressure in millimetres of water
Temperature in Degrees Centigrade
321
622

Fig. 5.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Pressure in millimetres of Water
Temperature in Degrees Centigrade

Fig. 8.

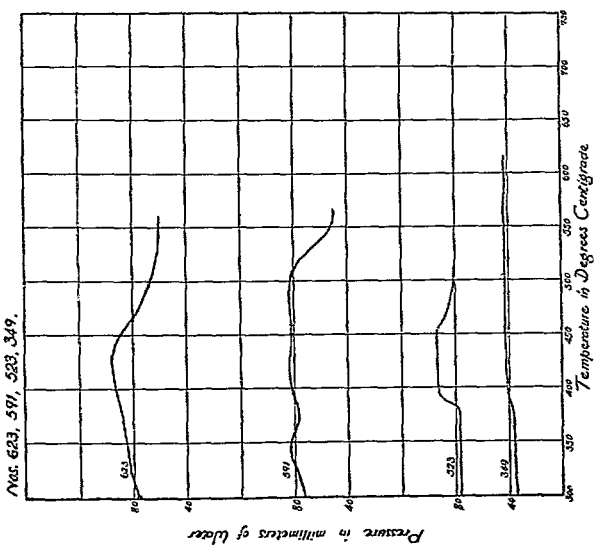
Nos. 623, 591, 523, 349.
Pressure in millimetres of Water
Temperature in Degrees Centigrade

Fig. 7.

六二三　賈汪　〇・〇　〇　〇・〇〇
三四九　厚豐　〇・〇　〇　〇・〇〇

第三六二號（井陘）煤所成之焦炭，質緊而堅，惟因其受熱收縮，煤柱與管壁相離，氣流可通，故得結果不佳。第五九七號長輿煤之曲線頗奇，或因此煤膨脹甚大，電爐內部熱度不均所致，煤漲時過電爐上部較冷處，凝結成膜，故阻氣流而壓力上升，溫度漸高，膜化而壓力降，更脹至上部而凝結，反復如是，以致形成此種曲線。除此兩種而外，可煉焦之煤，其粘性率均在〇・五以上，不成焦者在〇・五以下。以六五五號卽萍鄉煤，曾用以煉冶金焦炭者爲標準，則可煉焦與不可煉焦之煤之分割線，應在〇・五左右。我國烟煤之用於煉焦者甚多，而以開灤中興及博山所出之焦炭最著。表中所列上選者，適與實際相合。國內烟煤所不能煉焦者，如大同厚豐等處，亦均在表之末端。由此觀之，焦性之優劣，可以粘性率之大小爲定，其在五以上者爲特選，三五之間者爲上選，在〇・五以上二三以下者爲中選，其在〇・五以下者，則不能煉焦矣。

之速度），差誤始得減少，然於所得結果中歸納一預測焦性方法，實非易事。僅知煤於變粘時，能與氣流以大阻力，即氣壓所示之最高者，似可得較良焦炭。又煤之粘性程短者，焦性亦較佳，蓋粘性程短者，即示煤之易於變焦也。茲據以上兩點，焦性之優劣，似與氣壓成正比，與粘性成反比，故可以氣壓對粘性程之比定之，爲便利計，名曰粘性率。今將所試各煤依此率之大小，排列於下，其區別乃較明晰。

試驗號數	礦區或公司	壓力差	粘性程	粘性率
四四八	宣城	一二二。〇公蓋	一八度	六・七八
三七三	開灤	一八〇・四	二九	六・二三
三〇九	博山	一七四・〇	三三	五・二八
三六九	中興	二一三・〇	四二	五・〇八
三七四	開灤	一二八・〇	三三	三・八七
六二二	長興	二一八・〇	六一	三・五九
三六五	六河溝	二三〇・四	七〇	三・二九
三二一	磁縣	二六九・六	一七	二・五二
三一〇	博山	六二・四	四二	一・四九
六五五	萍鄉	三〇・〇	五七	〇・五三
五二三	大同	一五・〇	七三	〇・二〇五
五八七	舜耕山	四四・〇	二五	〇・一六
五九一	譚家山	五・〇	一九	〇・〇四二

三七三	———	四三一	四六〇	二四六	一・九六
六五五	———	四三〇	四八七	一〇二・〇	一三二	一・一〇
四四八	四三三	四四九	四六七	六七・〇	一八九	二・六四
五二三	———	三八〇	四五〇	七八・〇	九三	一・〇〇
五八七	———	三八五	四一〇	八〇・〇	八四	〇・九四
三四九	———	———	———	———	———	一・〇〇
五九七	三六九	四四〇	六九〇	———	———	二・七二
六二二	———	四二〇	四八一	六〇・〇	二七八	二・五
六二三	———	———	四三二	———	———	一・一一

（五）圖表說明

玻璃管中之煤末，雖可通氣，然對氣流有相當之阻力，故氮氣通過玻璃管時，氣壓逐漸增加，直至氣流壓力與煤末之阻力洽相平衡爲止。溫度漸昇，煤中水份發散，使煤稍漲，氣壓稍增，水份散盡，煤復收縮，氣壓亦下降，此種變化，僅顯於少數煤樣中，謂之始軟點。溫度昇高，煤乃軟化，其中有機質即融爲粘體，充塞煤末間之空隙，而氣流爲之所阻，故壓力上昇，此點謂之融化點。溫度再升，粘質遂分解爲氣體，而使煤體膨脹，此點於試驗時並不顯然，惟於曲線上可察曝變之灣折。溫度更高，則煤硬化而成多孔狀之焦炭，空隙復見，得使氣流通過，氣壓遂下降，此點謂之硬化點。

膨脹係數，即以試驗後煤柱長度除試驗以前煤柱長度，所得之商。

（七）討論

本試驗含理至簡，試驗時困難良多，所得結果，每有差誤，經長時試驗，更換手續，（如煤末之粗細，熱力增長及氮氣流通

試驗前各煤樣均磨碎，使通過六十孔之篩。復以二百孔篩篩去過細煤末，在六十孔篩下二百孔篩上之煤末，以重量二與一之比混以六十孔至一百孔之淨沙。（兩份煤一份沙）

試驗時先以十至四十孔之碎磚塊置於銅紗卷上，計兩公分高，然後放入煤沙混合物，使之洽長五公分。將電爐熱至二百度左右，調節電流，使爐中溫度每分鐘增加四度，俟溫度達二百五十度時，即將玻璃管置爐中，其下端與氮氣裝置連接，開氮氣裝置上下兩活塞，使氮氣以每分鐘十二至十五立方公分之速度，通過玻璃管。溫度增高，煤對於氣流之阻力，應時時由氣壓表錄下。試驗終，即壓力下降時，抽出玻璃管，再量煤柱之長度。

（四）結果

臨界點壓力及膨脹係數均列第二表。圖中曲線，係以壓力對溫度點成者。

試驗號數	始軟點	融化點	硬化點	融化時之壓力	硬化時之壓力即最高壓力	膨脹係數
三〇九	四〇七度	四五〇度	四八三度	七六・〇公釐	二五〇公釐	一・四〇
三二一	——	四三五	五四三	六〇・四	三三〇	一・〇六
五九一	三四二	三六四	四八三	三八・五	八二	一・〇〇
三一〇	三五九	四五七	四九九	九九・六	一六二	一・〇四
三六二	——	四二五	五〇九	七二・〇	一一一	〇・九〇
三六五	——	四二五	四九五	六五・六	二六九	一・〇四
三六九	四一八	四三八	四八〇	一三三・〇	三四六	二・五六
三七四	四一五	四四九	四八二	八六・〇	二一四	一・一四

三六二	河北	井陘	井陘	南大井第五層	二疊石炭紀	Bm
三六五	河南	安陽	六河溝		二疊石炭紀	Bh
三六九	山東	嶧縣	中興	洗煤	二疊石炭紀	Bm
三七三	河北	趙各莊	開灤	第五層洗煤	二疊石炭紀	Bm
三七四	河北	趙各莊	開灤	特別洗煤	二疊石炭紀	Bm
四四八	安徽	大汪村	水東		二疊石炭紀	Bl
五二三	山西	口泉				
		大格塔同			侏羅紀	Bl
五八七	安徽	舜耕山遠	大同	通煤	二疊石炭紀	Bl
五九一	湖南	湘潭	有利		二疊石炭紀	Bh
五九七	浙江	長興大煤山	長興		二疊紀	Bl
六二二	浙江	長興廣家	華東	上層	二疊紀	Bl
六二三	江蘇	銅山賈汪	萍鄉	洗煤	二疊石炭紀	Bl
六五五	江西	安源	萍鄉		侏羅紀	Bm

(三)　試驗用具及試驗法

用具與福氏所用者大致相同，其組成如圖第二圖（圖見英文內）所示。一徑一公分長二十公分之硬玻璃管，下端置一銅紗卷以承試樣置於電爐中。另有二電流調整器及一電流表，以調節熱率。爐中溫度則以鉻鎳合金熱偶（熱電對）及高溫計測定之。

氯氣（惰性氣體）一瓶，其上連接九尺高之水頭，用以壓瓶中之氣經過玻璃管者。一貯紅水之氣壓計，連於氯氣裝置與玻璃管之間，因煤承粘性狀態時，對於氣流之抵抗（或阻力），得以以一公厘之水柱爲單位之數表示之。

中國烟煤之粘性程試驗

賓果

（一）引言

工業發達，首重煉焦，尤重煉焦烟煤之選擇，蓋煉焦爐之構造及冶金之成敗，均視煉焦煤之優劣爲斷也　我國烟煤甚富，產地不同，性質亦異，欲知其可否煉焦，以及所得焦炭之優劣，非得加以試驗，不易明晰。

關於試驗煤之煉焦特性，方法甚夥　烟煤結構複雜，化學方法雖有應用之者效果所得，難而少功，因此多借重于物理方法，以其易於試驗而得結果較速也　茲擇主要數法略述以下，有以煤末製成小柱狀煤塊，加熱後察其膨脹之長短，以定其焦性者　有以煤加熱後，察其氣體發生速率以定優劣者　英人雷斯偉（Lessing）氏謂煤末於玻璃管中，通以惰性氣體，凡煤之粘結者受熱後，時起膨脹變化，將儲煤管中細孔水漏，而阻止通過之氣體　由其阻力之強弱，以測煤之粘結性　該氏謂煤熱至三百五十至四百度時，水氣放散，致煤軟化而收縮，再熱則膨脹，放出氣體，更熱則變硬而成多孔之焦炭　自煤軟化以至變硬時之溫度差，謂之粘性程（Plastic Range）　粘性程之長短與焦作者密切之關係　本試驗即採用此法，思其對於煉焦性質之預測，或可應用也。

（二）試驗煤樣

此次所試煤樣共十七種，其產地分布等列如下表　其礦區位置示於明細圖（見英文內）

試驗號數	省	縣	公司	俗名	時代	記號
三（）九	山東	博山	博東	大窪石炭	二疊石炭紀	Bh
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GEOLOGICAL SURVEY OF CHINA

No. 9 July, 1933

A LOW TEMPERATURE CARBONIZATION ASSAY OF SOME CHINESE BITUMINOUS COALS

BY

C. C. HSIAO

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LOW TEMPERATURE CARBONIZATION ASSAY OF SOME BITUMINOUS COALS

By C. C. Hsiao

(Research fellow of the China Foundation for the Promotion of Education and Culture)

Introduction

The primitive practice of burning coal in the raw state not only results in civic nuisance but also in fuel waste due to the loss of valuable products in the form of smoke. The need of fuel economy leads to the development of the carbonization process. When coal is subjected to heat treatment without access of air, its constituents undergo thermal decomposition into solid, liquid, and gaseous phases as shown by Lewes[1]:—

TABLE I

Constituents of coal	Decomposition products		
	Solid	Liquid	Gaseous
Humus bodies ——→	Carbon	Water	Carbon oxides
		Thin tar	Methane
Resinous bodies ——→	Carbon	Water	Carbon oxides
	Pitch	Rich tar	Ethylene
			Unsaturated hydro-carbons
Hydrocarbons ——→	Carbon	Heavy tar	Methane
	Pitch		Ethane
			Homologues.
Carbon residuum ——→	Unaffected by heat.		

The quality and quantity of these products for a particular coal depend upon the physical conditions, particularly the temperature, under which the carbonization is carried out.

High temperature carbonization as is used in the coke ovens has as its main aim the production of good metallurgical coke. Most of the primary tars are cracked at 700°C and up into fixed gases and lower aromatic compounds. Contact with incandescent coke surface catalyzes these secondary reactions. Low temperature tar, on the other hand, are characterized by the presence of chemically neutral paraffin hydrocarbons and acidic compounds of higher

phenol homologues. The former forms a mixture resembling paraffin base crude petroleum and is suitable for motor fuel. Benzol, formed by the secondary transformation[2] of primary tar, is practically absent. The great decrease in the free carbon content (from about 6.5% to 1%) further indicates that cracking is reduced to a minimum. The yield of tar at low temperature is approximately twice that obtained at high temperature with the simultaneous reduction of gas production.

The increasing demand for liquid fuels and the limited reserve of petroleum in some countries greatly stimulate the interest towards low temperature carbonization. The World War of 1914 gave an impetus to research in this field, as the need of a home source of petroleum substitute becomes urgent when foreign supplies are shut off. The British Board of Fuel Research established in 1917 and the Kaiser Wilhelm Institute fur Kohlenforschung in Germany all aimed at the investigation of converting coal into gasoline fuel-oil substitutes.

Complete estimate of our national oil deposit is still lacking. The figures[3] given by the U. S. Geological Survey (1,375,000,000 barrels) are yet short of practical evidence. Survey of the oil regions of Shensi and Szechuan shows that these natural resources are not very promising. The future of oil shale, though possible, is not yet certain. We are at present depending on foreign supply of gasoline, the import of which in 1931 amounted to 29,895,000 gallons. To meet the increasing need of automotive transportation, to insure our national defense, and to eliminate the tremendous national economic loss due to the import of foreign oil, the seeking for an oil substitute is no less important than the finding of oil deposits.

Of our total coal reserves, bituminous[3] coals are estimated to be approximately three fourths, amounting to 183,958,000,000 tons. The utilization of low temperature tar from carbonizing these coals may help the partial solution of the oil problem. While the practical application of low temperature carbonization necessitates a complete study of its technology, a preliminary knowledge of the behavior of the bituminous coals during such carbonization is essential prior to large scale experiment. It is the purpose of this work to determine quantitatively the yields of low temperature products and to ascertain something regarding their nature and prorpeties.

EXPERIMENTAL

Sources of coals used.

Sixteen samples of coal were tested, the sources and classification of which are given in Table II:—

TABLE II

Lab. No.	Sample No.	Locality	Mine	Seam	Classification.[4]
1	349	Chahar, Hsuanhua	Houfung	Chuantsun	Bl
2	319	Hopei, Tsuhsien	Yili	Toumei	Bh
3	321	,, ,,	,,	Itsomei	Bh
4	362	,, Chinghsing	Chinghsing	5th seam	Bm
5	373	,, Lanhsien	Kailan	5th seam washed slack	Bm
6	374	,, ,,	,,	Special washed slack	Bm
7	309	Shantung, Poshan, Heishan	Potung	Tatuanshihtan	Bh
8	310	Shantung, Poshan, Heishan	,,	Hsiaotuan-shihtan.	Bh
9	369	Shantung, Ihsien	Chunghsing	Washed slack.	Bm
10	523	Shansi, Tatung	Kakata	———	Bl
11	365	Honan, Liuhokou	Liuhokou	———	Bm
12	591	Hunan, Hsiangtan, Tanchiashan	Yuli	———	Bh
13	448	Anhuei, Hsuancheng	Tawangtsun	———	Bl
14	587	Anhuei, Huaiyuan, Shunkengshan	Tatung	———	Bl
15	597	Chekiang, Changhsing	Tameishan	———	Bl
16	623	Kiangsu, Chiawang	Huatung	Upper seam.	Bl

For the sake of convenience, reference of each coal will be made to its laboratory number throughout this paper. Table III records the proximate analyses of these coals.

TABLE III

Coal	Moisture (as received)	*Volatile matter* (moisture free basis)	*Fixed carbon* (moisture free basis)	*Ash* (moisture free basis)	Btu/lb	Total sulfur
1	1.96	36.72	49.37	12.91	11900	.74
2	.24	21.25	72.28	6.47	14675	.64
3	.32	21.25	73.88	4.97	14902	1.43
4	.14	23.73	64.98	11.29	13919	.78
5	.31	32.03	57.58	10.39	13745	.97
6	.78	31.49	56.17	12.34	12602	1.39
7	.41	21.37	67.72	10.91	13945	.85
8	.30	22.82	67.17	10.01	14087	.60
9	.40	31.87	61.21	6.82	14416	.79
10	2.00	36.35	59.21	4.34	14029	.57
11	.46	23.87	61.06	15.07	13239	.84
12	.62	22.22	71.33	6.45	14625	.65
13	.10	33.37	46.74	19.89	11426	5.47
14	1.49	33.59	52.99	13.42	12645	1.62
15	.48	33.60	45.81	20.59	11124	3.35
16	1.91	37.60	52.45	9.95	12609	—

Description of Apparatus.

In order to derive practical information from laboratory assay, the results of the latter must be reproduceable on a working scale. The low temperature carbonization test of the British Fuel Research Board as devised by Gray and King[5], fulfills this requirement. In addition to its rapidity of operation, the assay results may, within certain limits, be correlated[6] to those from a horizontal retort. With the exception of tar-oil which is only 60% of that obtainable from the assay, the ratios of the yields of coke, liquor, and gas are all in the neighborhood of unity. The apparatus, with slight modifications, is shown in figure I.

The distillation tube, made of pyrex glass, is about 30 cm. long and 2 cm. in diameter with a side tube leading to the condensing and scrubbing system. The electric furnace has a uniformly heated portion of about 6 in. at the center, the temperature of which is measured by an alumel-chromel thermocouple. Oil and liquor are collected in the graduated tube, while ammonia is absorbed by sulfuric acid. The U-tube containing a loose

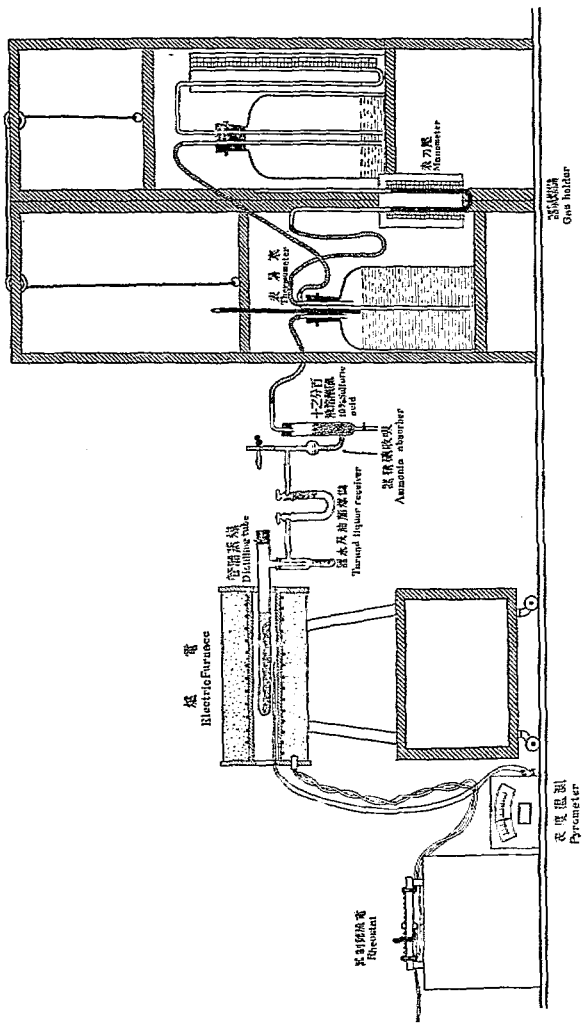

Manometer
Gas holder
Sulphuric acid
Ammonia absorber
Thermometer
Distilling tube
Electric Furnace
Pyrometer
Rheostat

Fig. 1.

plug of cotton helps to retain the tar mist carried off by the gas. The gas holder consists of two bottles filled with water saturated with coal gas from a previous experiment. When gas enters the first bottle, the displaced liquid flows into the second through a piece of rubber tubing, the volume of gas being represented by the rise of liquid level on the scale attached therewith. The constant pressure in the system is maintained by the device[7] of the chemists of the U. S. Steel Corporation. By levelling the movable train with the help of pulleys until the colored liquid in the two arms of the manometer are on the same level, the gas may easily be brought to atmospheric pressure.

METHOD OF OPERATION.

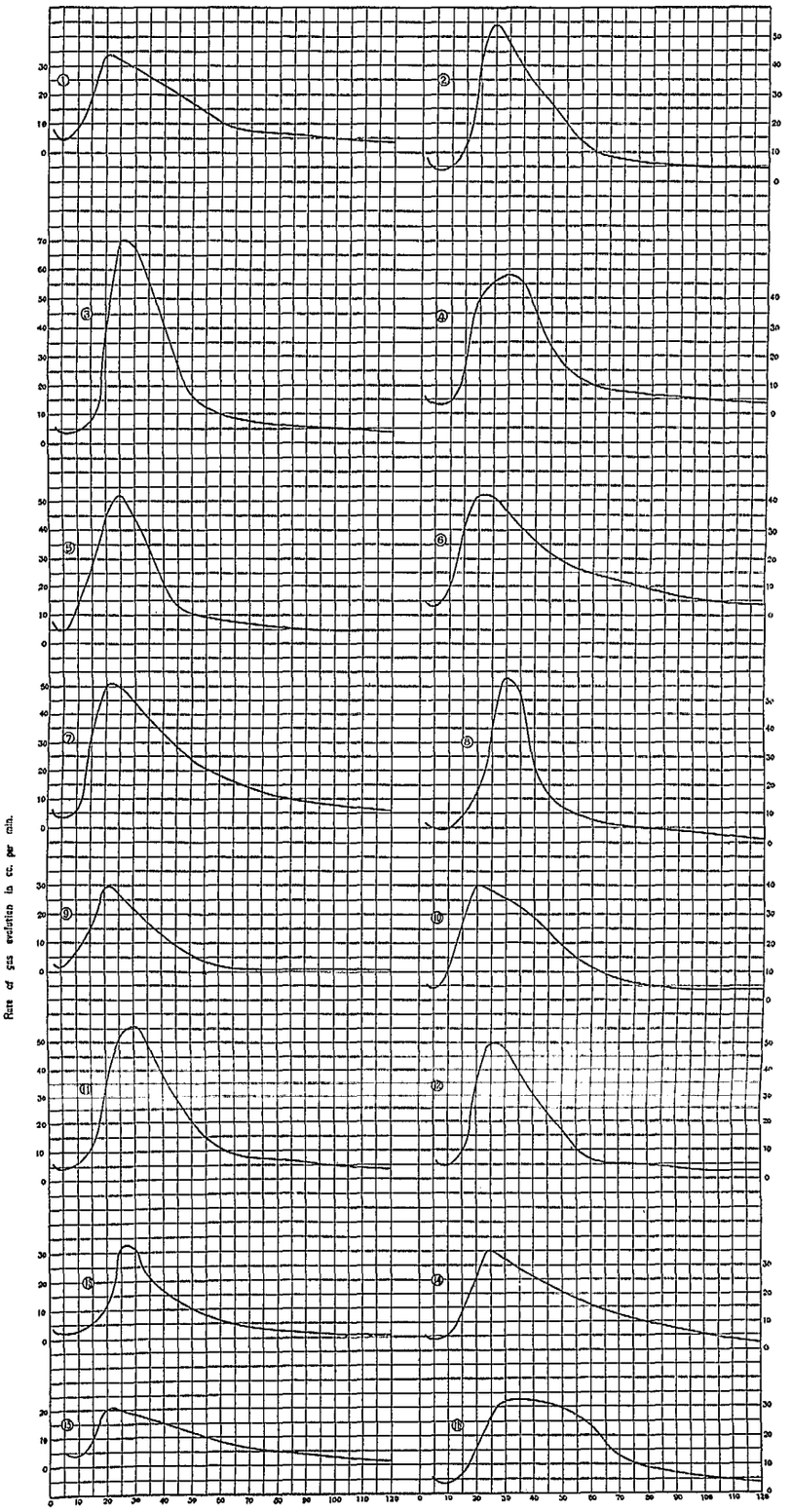
The coal samples were ground to pass through a 60-mesh sieve and were dried at 105-110°C for two hours. 20 grams of the sample were charged into the distillation tube, occupying 6 in. in length and about 2/3 of the tube diameter, and were held in position by a small amount of asbestoes. The charged tube was then connected to the rest of the apparatus and the furnace previously heated to 300°C was pushed into the position shown. The temperature of the furnace was gradually raised by adjusting the rheostat so that the ultimate temperature, 600°C, was reached in one hour. During this period, observations were made of the temperature at which oil and gas appeared and the rate of gas evolution. Heating at 600°C was continued for one more hour.

The yield of coke was arrived at by weighing the distillation tube before and after the experiment. The increase in weight of the graduated tube and the U-tube represented the total yield of oil and water. The volume of the aqueous portion was measured by dissolving the contents in CCl_4, the difference between this volume and the total volume being the volume of tar-oil. Assuming the specific gravity of liquor to be one, the weight of liquor and that of tar can be obtained. Dividing the weight by volume we got the specific gravity of tar-oil.

To get the yield of ammonia, the liquor was mixed with the 10% H_2SO_4 solution and was distilled after the mixture was made alkaline by strong NaOH. The distillate was collected in an excess of 1/10 N. HCl and titrated back against 1/10 N. NaOH.

Only the gas in each duplicate run was analyzed. The gas in the first test was contaminated by that from the previous coal sample and was used

Figure 11



to sweep out the apparatus by raising the levelling bottle and forcing the gas back through the open end of the distillation tube. The gas analysis was made by an Orsat apparatus together with the accessary explosion pipette, etc. for the determination of hydrogen and saturated hydrocarbons. From the composition of the gas, the specific gravity and consequently its weight were calculated.

Results of Experiments.

The carbonization results, calculated to percentage basis, are shown in Table IV. Coals 7, 9, 13 and 15 were of such swelling nature that the charges extended much beyond their original lengths of 6 inches. The extended portion, being kept at a lower temperature (limited by the condition of the furnace), retained part of the tar-oils undistilled. In each case the yield of oils ought to be greater and that of coke lower if no swelling occured. Coal 9, in particular, swelled to such an extent that the coke reached the exposed part of the tube covered by a layer of solidified mass of resinic tar, thus preventing further evolution of tar and gas. The yield of semi-coke was abnormally high. A ten-gram sample was later used, and the result was thought to be roughly comparable with other swelling coals.

The distillation of oil and gas in the case of coal 15 was not continuous. This behavior was traced to no other cause than the highly swelling nature of the coal which was only next to coal 9. The plastic coal, when pushed to cooler portion of the distilling tube, soon became semi-solidified, thus stopping the passage of both gas and oil. Further distillation could only be possible when, as a result of rise in temperature, the pressure of the volatile substances inside became high enough to break the solidified layer. The solidification was not so pronounced as to stop the distillation completely as in the case of coal 9.

It is hardly justifiable to compare the carbonization yields of the different coals due to the lack of a common basis for comparison. Due consideration must be given to the wide variation in ash content which was weighed with, and expressed as, coke. One should expect a close similarity in the distillation products of coals 1 and 10 if not for the fact that the former contains three times more ash than the latter. On the other hand, it is rather surprising that coal 15 with high percentage of volatile matter and low carbon content should yield the same amount of coke as, and only

TABLE IV

Coal Sample	Products of distillation at 600°C						sp. gr. of oils.	Vol. of gas (cc. at 15°C)	sp. gr. of gas (Air = 1)	Behavior on distillation
	Semi-coke	Oils	Liquor	NH_3	Gas	Total				
1	80.00	8.90	4.50	——	——	——	.928	6560	——	Oil vapor at 300°C, oil drops at 333°C, sustained gas evolution at about 355°C.
,,	80.50	9.15	4.45	.016	5.34	99.46	.948	6425	.677	
2	87.50	4.70	2.05	.028	5.43	99.71	.913	8530	.519	Oil vapor at 344°C, oil drops at 440°C, sustained gas evolution at 391°C.
,,	88.50	4.60	2.10	——	——	——	.885	8550	——	
3	86.00	5.45	1.10	——	——	——	.814	8685	——	Oil vapor at 382°C, oil drops at 402°C, sustained gas evolution at about 390°C.
,,	86.00	5.45	1.25	.065	6.42	99.19	.808	9810	.533	
4	85.50	6.00	2.05	——	——	——	.993	7985	——	Oil vapor at 343°C, oil drops at 374°C, sustained gas evolution at 380°C.
,,	86.00	5.80	2.00	.125	5.25	99.18	.952	8000	.534	
5	84.00	8.60	2.10	——	——	——	.951	7890	——	Oil vapor at 309°C, oil drops at 373°C, sustained gas evolution at about 330°C.
,,	84.00	8.80	2.35	.053	4.60	99.80	.952	8285	.452	
6	82.00	9.30	2.85	.054	6.41	100.61	1.010	9095	.575	Oil vapor at 292°C, oil drops at 375°C, sustained gas evolution at 337°C.
,,	81.50	9.10	2.85	——	——	——	.964	8815	——	
7	87.50	4.70	1.90	——	——	——	.832	11200	——	Oil vapor at 300°C, oil drops at 334°C, sustained gas evolution at 375°C.
,,	86.50	4.30	2.00	.125	7.50	100.46	.801	11795	.518	
8	88.00	5.35	1.25	.025	4.54	99.17	.982	7185	.515	Oil vapor at 342°C, oil drops at 400°C, sustained gas evolution at 465°C.
,,	89.00	4.90	1.50	——	——	——	.980	6820	——	

TABLE IV *Continued*

Coal Sample	Products of distillation at 600°C						sp. gr. of oils.	Vol. of gas (cc. at 15°C)	sp. gr. of gas (Air = 1)	Behavior on distillation
	Semi-coke	Oils	Liquor	NH_3	Gas	Table				
9	91.50	4.00	.80	———	———	———	———	3900	———	Oil vapor at 328°C, oil drops at 373°C, sustained gas evolution at 355°C.
*,,	87.00	7.50	.80	.055	4.58	99.94	.883	6930	.535	
10	78.00	10.40	4.00	.035	7.46	9.90	1.000	9065	.670	Oil vapor at 311°C, oil drops at 396°C, sustained gas evolution at about 356°C.
,,	77.50	10.75	4.05	———	———	———	1.003	9020	———	
11	87.50	4.85	1.90	———	———	———	.906	8295	———	Oil vapor at 356°C, oil drops at 393°C, sustained gas evolution at 393°C.
,,	87.50	5.20	1.85	.075	5.57	00.20	.913	8235	.551	
12	89.00	4.20	1.30	.060	4.66	99.22	.894	7985	.476	Oil vapor at 354°C, oil drops at 413°C, sustained gas evolution at about 413°C.
,,	89.00	4.50	1.00	———	———	———	.900	7665	———	
13	87.50	6.70	1.50	———	———	———	.870	4885	———	Oil vapor at 278°C, oil drops at 363°C, sustained gas evolution at 435°C.
,,	88.00	6.70	1.50	.011	3.80	100.01	.860	4825	.642	
14	80.50	10.55	3.60	.080	5.25	99.98	.971	7220	.592	Oil vapor at 314°C, oil drops at 374°C, sustained gas evolution at 374°C.
,,	81.00	10.40	3.15	———	———	———	.972	7260	———	
15	88.50	6.10	1.50	.029	3.58	9.971	.810	4460	.654	Oil vapor at 300°C, oil drops at 340°C, sustained gas evolution at about 420°C.
,,	89.00	5.95	1.40	———	———	———	.805	4255	———	
16	78.00	11.20	4.60	.046	5.99	99.84	.973	7650	.640	Oil vapor at 317°C, oil drops at 383°C. sustained gas evolution at 390°C
,,	77.50	10.80	4.50	———	———	———	.968	8005	———	

* on 10 gram sample

TABLE V.

Coal	Semi-coke		Oil		Gas		Liquor	NH
	%	(kg./ton)	%	(gals/ton)	%	(cu. ft./ton)	%	%
1	76.75	698	10.36	26.75	——	——	5.23	——
,,	77.40	704	10.64	26.92	6.21	2270	5.17	.019
2	86.70	789	5.02	13.20	5.81	2770	2.19	.030
,,	87.70	798	4.91	13.33	——	——	2.25	——
3	85.30	775	5.73	16.90	——	——	1.16	——
,,	85.30	775	5.73	17.02	6.76	3140	1.32	.068
4	83.70	761	6.76	16.33	——	——	2.31	——
,,	84.20	766	6.54	16.50	5.92	2740	2,26	.141
5	82.15	748	9.60	24.23	——	——	2.34	——
,,	82.15	748	9.82	24.80	5.13	2810	2.62	.059
6	79.50	723	10.61	25.22	7.31	3150	3.25	.062
,,	78.90	717	10.39	25.85	——	——	3.25	——
7	86.00	782	5.28	15.22	——	——	2.13	——
,,	84.80	771	4.82	14.47	8.41	4020	2.24	.174
8	86.70	789	5.95	14.53	5.05	2430	1.39	.028
,,	87.70	798	5.45	13.35	——	——	1.67	——
9	90.90	827	4.29	——	——	——	.86	——
,,	86.10	784	8.05	21.88	4.92	2280	.86	.059
10	77.00	700	10.87	26.07	7.80	2890	4.18	.037
,,	76.50	696	11.23	26.88	——	——	4.23	——
11	85.30	775	5.71	15.12	——	——	2.24	——
,,	85.30	775	6.12	16.10	6.56	2950	2.18	.088
12	88.30	803	4.48	12.06	4.98	2590	1.39	.064
,,	88.30	803	4.81	12.85	——	——	1.07	——
13	84.40	767	8.37	23.10	——	——	1.87	——
,,	85.00	773	8.37	23.39	4.74	1830	1.87	.014
14	77.40	704	12.19	30.08	6.06	2540	4.16	.092
,,	78.00	709	12.00	29.63	——	——	3.64	——
15	85.60	780	7.68	22.75	4.51	1710	1.89	.037
,,	86.18	784	7.50	22.38	——	——	1.76	——
16	75.60	687	12.42	30.62	6.65	2580	5.11	.051
,,	75.00	687	11.99	29.73	——	——	4.99	——

a little more oil than, coal 12 which is low in volatile matter and markedly high in fixed carbon. To afford a better correlation, the results are reduced to ash-free basis and are re-tabulated in Table V, in which are included the yields of coke in kilograms, oils in gallons, and gas in cubic feet per ton of coal carbonized.

The tar-oils are, in general, brownish black in color, fluid at room temperature, and become darker and more viscous on standing. In thin layers, the color ranges from orange to red. The tars from coals 1 and 10 differ from the rest in that they are thicker and less fluid. This is probably due to the presence of a large proportion of solid paraffins characteristic of younger coals.

The coke analysis (Table VI) was made primarily for determining the content of volatile matter. Of the highly swelling coals an average ground mixture of the coke sample taken out of the distilling tube is considered to be not representative on account of the presence of an extended portion which has undergone only partial distillation. Only that portion contained within six inches from the closed end of the tube was taken for analysis.

TABLE VI

Coke Analysis

Coke No.	Moisture	*Volatile matter*	*Fixed carbon* (Moisture-free basis)	*Ash*
1	.62	14.74	62.40	22.86
2	.70	11.67	73.73	14.60
3	.87	6.66	85.02	8.32
4	1.05	8.31	76.63	15.06
5	.97	8.21	79.82	11.97
6	.63	7.32	77.62	15.06
7	1.27	4.51	82.43	13.06
8	.69	6.35	80.90	12.75
9	.86	7.54	83.96	8.50
10	.95	11.86	82.21	5.93
11	.62	7.70	74.37	17.93
12	.65	7.00	85.41	7.59
13	.50	5.93	58.93	35.14
14	.85	10.01	75.12	14.87
15	.80	9.09	63 69	27.22
16	.47	9.47	78.62	11.91

The coke samples photographed to two thirds, and for coals 9, 15, 13 and 7 to one half, of their natural sizes are shown in Plates I and II. The order is in accordance with the relative swelling powers of the coals except the last two which are practically non-coking.

The cell structures of the semi-cokes are shown in Plates III and IV. Six typical samples of different degrees of porosity and with different sizes of pores were chosen. The photographs of cokes 8, 3, 14 and 4 were taken on the polished cross sections with a magnification of five. Sections of cokes 7 and 5 due to their fragibility were prepared by Rose's[8] method. The specimens of coke were first moulded with plaster of Paris and then polished. Cokes 9, 15 and 13 were so friable that they were broken to small pieces when discharged from the distilling tube. Even casting into gypsum mould will not reveal their original structure. Structurally 6 and 11 are more or less similar to 8, 12 to 14, 2 and 16 to 4.

The compositions of the gases appear in Table VII. The rates of evolution of gas for the different coals are graphically represented in figure II.

TABLE VII

Constituents of gas

Coal	CO_2	Illuminants	O_2	CO	C_nH_{2n+2} (Calculated as CH_4)	H_2	N_2 (diff)
1	12.80	3.20	1.90	10.30	36.50	23.60	11.70
2	4.68	2.12	1.10	2.70	44.70	32.25	12.45
3	4.90	2.10	2.62	1.68	48.00	29.60	11.10
4	4.80	2.10	1.28	2.22	53.10	26.80	9.70
5	5.45	2.80	1.25	2.85	41.20	41.80	4.65
6	6.40	2.62	1.73	3.35	57.20	21.48	7.22
7	3.05	1.25	3.10	2.30	50.40	29.00	10.90
8	4.60	1.63	3.47	2.20	43.60	33.50	11.00
9	4.70	2.50	3.05	2.05	45.60	30.40	11.70
10	13.30	2.70	1.18	7.42	45.32	20.45	9.63
11	3.85	2.15	4.65	1.50	47.50	27.40	12.95
12	3.08	2.22	1.40	2.40	50.26	33.55	7.09
13	15.20	3.45	1.95	1.80	53.20	21.20	3.20
14	8.10	3.40	1.55	4.55	52.40	22.73	7.27
15	8.70	5.80	1.95	1.65	56.70	14.12	11.08
16	7.60	3.18	1.84	7.38	52.40	17.10	10.50

Discussion of Results.

Oils.

Comparing the carbonization yields of the coals under investigation with those of British[5] and American[9] coals, one would notice that Chinese coals, on the average, are in no way inferior in the capacity of oil production, though some of the foreign coals may be better. The high yield of oil is associated with coals of high percentage of volatile matter and belonging to the class of low rank bitumite. Cases that may be cited are coals 1, 10, 14 and 16. The well-known good coking coals, being high rank bitumite or medium rank bitumite, show rather low figures of tar-oil. Thus the oils from coals 7, 8, 4, 2, 3 and 11 are only half as much as those from the four coals just mentioned. Exceptions to this fact are coals 5 and 6, which are known by experimentation to produce good metallurgical coke, yield also considerable amount of oil during low temperature distillation. Coal 9, alleged to be the best coking coal, might be expected to give high oil yield if not for its extremely swelling property.

It is known that the younger the coal[10] and the greater its oxygen content, the greater is the quantity of low temperature tar per unit of weight. To test this relationship, the tar yield is arranged in the order of the geological

Table VIII

Coal	Geological age	% of tar*
1	Bl Jurassic	10.50
10	Bl ,,	11.05
15	Bl Permian	7.59
14	Bl ,,	12.10
12	Bh ,,	4.65
16	Bl Permo-Carboniferous	12.21
13	Bl ,,	8.37
6	Bm ,,	10.50
9	Bm ,,	8.05
4	Bm ,,	6.65
11	Bm ,,	5.92
7	Bh ,,	5.05
3	Bh ,,	5.73

(* These figures are the averages of two values from Table IV).

age of the coal. It is interesting to note in Table VIII the general decrease in yield of tar accompanying the consolidation of the fuel. The irregularities of coal 15 and 13 can be accounted for by their high swelling property.

The small scale of the experiment has rendered the analysis of the oils difficult. Mere specific gravity would hardly reveal the actual quality of the liquid products. As distinct from high temperature tars which resemble one another to a great extent from whatever coal they may have been made, low temperature[10] tars follow variations in the character of the coal more closely. It is hard to predict the composition from the known results of other coals. The available data only help to show that the tar-oils thus distilled off had a specific gravity range of .8-1.0 and scarcely above 1. The natural inference is that there must be present an appreciable portion of light and low boiling fractions consisting of gasoline, kerosene, phenols, etc.

Direct use[11] of low temperature tars has been proved to be not practical. By proper separation and refining, good fuel oils and lubricating oils can be obtained as well as light and heavy naphtha which, when added to the spirit obtainable by scrubbing the gas, give a mixture very similar in property to a good quality petrol. Its application[11] to internal combustion engines has been carried out by the British Fuel Research Station and has been found to give satisfactory results. Very recently, the British Admiralty[11a] has placed a contract for twelve months with the Low Temperature Carbonization Ltd. for the bulk supplies of coal oil, which it is said, has the technical advantage of leaving no sediment and requiring no pre-heating. If we assume a 20% yield of spirit from low temperature tar and a 60% yield of laboratory assay results in large scale plant, one ton of "good" (referring to oil-producing capacity) coal would give 3-4 gallons of motor fuel, not including that from gas. The residual tar can further be utilized to produce tar-acids and paraffin waxes. The former (amounting to 15-28% to tar) is particularly useful in the manufacture of disinfectants owing to the presence of cresols, xylenols, and other higher phenols.

Semi-coke.

In order to insure commercial success, low temperature carbonization must find a market for the semi-coke which constitutes 75-90% of the carbonization products. From a chemical standpoint the outstanding feature of low temperature coke is the large proportion of volatile matter amounting to 5-15% as shown by Table VI. To this may be attributed many desirable pro-

perties of the material as a solid fuel. It is readily ignitible and maintains fire without special attention. It has high thermal value and radiation[12] efficiency. The smoke nuisance of raw bituminous coal is absent on account of the removal of tars and heavy hydrocarbons. Semi-coke is therefore ideal for domestic heating, especially for open fireplaces. Tests have also shown that when used in gas producer it has distinct advantage over anthracite[9] and gas[11] coke. Use of semi-coke for boilers is anticipated, though few data have been published regarding its steam-raising efficiency.

Not all the semi-cokes, however, are suitable for the purposes above mentioned. As household or industrial fuel, it is essential that the cokes should be in such a form as to be easily transported. They should also be strong enough to stand severe handling. Only cokes 4, 14, 2, 3, 12, 8 fulfill these requirements. In coals 10 and 1 there is not present enough binding material (which according to Illingworth[13] is the γ compound) to cement the coal particles into a coherent mass. The product cannot be used without briquetting, which will involve further cost. On the other hand, the binders in coals 9, 15, 13, 7.5, 6, 11 are probably in excess, causing excessive foaming and swelling and friability of the resultant product, (as shown by Plate I).

The highlg swelling coals, good as they may be for producing metallurgical coke, are not fit for low temperature carbonization. In addition to the lack of strength and coherency of the semi-coke there are other difficulties one would encounter in the design of retorts. The swelling would produce considerable pressure on the walls of the retort, liable to injure it or to shorten its life. The coke cannot be discharged with facility. Moreover, the plastic layer would retard the passage of gases and would hence subject tar vapors to contact with hot surfaces for a greater length of time. The effect is to offer greater opportunity for cracking our desirable product, the tar-oils.

The best raw material for low temperature carbonization is coal 14 in that it yields a large amount of tar and at the same time hard and coherent coke which occupies a smaller volume than the original coal. Coal 16 would be equally recommendable were its coke not slightly inferior. From the standpoint of financial returns it is best to apply low temperature carbonization to low-priced non-coking coals. One can not afford to produce oil from a coal like 6 at the expense of the good coke it may yield at higher temperature. If coals 1 and 10 are properly blended with highly fusible coals like 15, 13,

etc. the difficiency of binder in the former will be balanced against the excess in the latter without destroying the oil-yielding capacity. The residue from the blended charge will be sufficiently strong and free from retort annoyances.

Cell structure imparts to the semi-coke partly its ease in combustibility. As pointed out by Thau[14], the cell walls of semi-coke, after volatile matter is driven off are quite free from vitreous carbon and are highly reactive. It is to be noted in Plates III and IV, the large number of small pores entangled in the coke besides those big ones. As combustion proceeds more of those will be exposed, giving more available surface for oxidation. On account of its high combustibility, should it be possible to produce low temperature coke of sufficient crushing strength to make it usable for metallurgical purposes, to quote Thau, "it would be vastly superior to the best by-product oven coke known."

To predict the nature of high temperature coke frem the structure of low temperature ones is difficult owing to wide difference in conditions to which the two processes are subjected. Some correlations, however, seem to be possible. Beilby[15] has shown that coke structure is due to the evolution of gas bubbles from the fused or partially fused coal substance. When rigidity of cell wall sets in, bubbles cease to develop, and so is the structure, though gases may still evolve with rise of temperature. Since there are definite temperature limits (350°-450°C) of plasticity and since our experimental temperature is above these limits, it is reasonable to deduce that the high temperature structure is already stereotyped in this low temperature product. Slater[16] has attempted to determine the coking property of a coal by its swelling power. He observed that the best coking coals all gave highly swollen cokes in the laboratory tests, while the moderately or poorly coking coals gave decreasingly swollen cokes.

The two theories combined throw some light on the coking ability of the coals under investigation. Thus, coal 7 with high swelling power and giving a coke of large pores with thick cell wall is undoubtedly a very good coking coal. 9, 15, 13 cannot be differentiated by the extent of swelling, but structurally they are essentially different. The former has much thicker wall and is less fragile than the other two. 5, 6, 11 and 8, judging by their swelling power and structure can all give good metallurgical cokes, whereas 3, 12, 2, 16, 14 and 4 are markedly inferior in quality. It must be remembered that these

predictions, though may be of partial validity, should not be too much emphasized without reservation.

Gas and Other By-products.

The gases produced are invariably rich in saturated hydrocarbons, relatively low in hydrogen content with small percentages of carbon oxides and unsaturated hydrocarbons. Young coals like 1, 10, 13. 15 and 16 give more carbon dioxides and carbon monoxides than the older coals. The gas from coal 15 differs from the rest in that it contains 2-3 times more unsaturated hydrocarbons, making it particularly fit for illuminating purposes.

The large proportion of paraffins in the gases indicates high calorific value (usually more than 800 b.t.u. per. cu. ft.) for the thermal value of methane at constant pressure is 1012 b.t.u. per cu. ft. These rich gases are good enriching agents for water gas or other low grade gases produced by certain systems of high temperature carbonization.

The temperatures recorded in Table IV for the appearance of oil and gas and the curves showing the rate of gas evolution present some points of theoretical interest. Burgess[7] and Wheeler noticed five stages in the primary thermal decomposition of coal. As our furnace has been preheated to 300°C, the removal of occluded gases and combined water occurs almost instantaneously after the charged tube is put in. These gases together with carbon dioxide and some air expansion are represented by the first portion of the curve. The rate of gas then reached a minimum and attained a maximum within 20-30 minutes after heating. The temperature (350°-450°C) of sustained gas evolution which is almost simultaneous with the copious distillation of oil indicates the major decomposition of the coal conglomerate. The first appearance of oil vapor at 280°-350°C is not considered to be necessarily the splitting of coal proper. The rapid flatting out of the curve shows that there is no advantage of "stewing" the coal for an indefinite period since the increased quantity of gas to be obtained is small.

Little can be said about the composition of the liquor (varying from .8-4.5%) except that it smells strongly of phenol. The ammonia yield is small, ranging from a minimum of .011% to a maximum of .125% equivalent to 1.7 and 19.4 lbs. respectively of ammonium sulfate per ton of coal. This is only to be expected as the evolution of ammonia from coal begins below

300°C and ends above 1200°C. A great part of the nitrogen present is probably retained in the coke.

Technical Considerations.

As the experimental condition indicates, the correlation of the laboratory assay results to large scale experiment is limited to stationary, externally heated retorts. Many processes, however, resort to agitating devices or internal heating systems for accelerating the rate of carbonization and consequently reducing the operation cost. The effect of the change in conditions on the quality of the products is considerable. The semi-coke from a rotating cylinder is usually small in size, necessitating further treatment before use. The passing of hot gases through the coal charge dilutes the rich gas produced and reduces its calorific value. The slow transferring of heat as a result of the low temperature gradient maintained in addition to the intrinsic poor thermal conductivity of coal is one of the fundamental difficulties of low temperature carbonization. A satisfactory solution of the problem is essential to the success of any type of low temperature carbonizing plant.

Summary.

Sixteen samples of bituminous coal were tested for their behavior and yield of by-products during low temperature carbonization. It is found that coals from Shunkengshan and Chiawang are most suitable for the purpose, as they give a high yield of oil with a strong and coherent coke. Coals from Houfung, Tatung, and Kailan, though good for oil production, suffer from the disadvantage of yielding undesirable semi-cokes. Coals like Chunghsing, Hsuancheng, and Changhsing, due to their highly swelling nature, are not recommended. The information, essential to the design and plan for the large-scale application of such carbonization, was also used for predicting the coking properties of the coals.

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APPENDIX I

After the above paper had been completed, five more coal samples were received and tested. The results are here tabulated:—

Lab. No. of Coal	17	18	19	20	21
Sample No.	655	644	766	804	841
Locality	Kiangsi, Pinghsiang, Anyuan	Hunan, Liling.	Hunan, Hsianghsiang, Fengkwanshan	Hopei, Wanping, Chaitang.	Kiangsi, Loping.
Mine	Pinghsiang	Shihmenkou	Yali	Chaitang	Mingshan
Seam	Washed slack	Tachaomei, upper seam	First mine		
Classification	Bl	BC	BC	Bh	C
Geological age	Jurassic	Jurassic	Permian	Jurassic	Permian
Proximate analysis:-					
Moisture	.92	3.41	.32	1.01	.47
V.M. (Moisture-free basis)	30.66	40.63	35.05	20.95	63.02
F. C. (Moisture-free basis)	53.52	52.36	41.70	66.12	33.24
Ash	15.82	7.01	23.25	12.93	3.74
Sulfur	.54	1.27	—	—	—
B. t. u./lb.	13000	13400	—	13550	—
Carbonization results (ash—free basis):-					
Semi-coke					
(%)	79.20	73 10	85.70	85.10	54.28
kg. per ton	720	665	789	774	493
Oils					
(%)	9.15	14.48	6.39	5.92	33.05
gal. per ton	23.82	35.55	18.50	14.50	88.80
Sp. gr. of oils	.922	.978	.830	.981	.893
Liquor + NH_3 (%)	4.16	4.03	1.96	2.18	3.12
Gas					
(%)	7.45	7.85	4.99	6.50	8.11

Cu. ft. per ton	2905	2882	1820	2905	3044
Sp. gr. of gas	.635	.674	.679	.554	.660
Behavior on distillation:-					
Oil vapor at	329°C	356°C	259°C	386°C	259°C
Oil drops at	383°C	395°C	360°C	410°C	342°C
Sustained gas evolution at	453°C	426°C	430°C	461°C	409°C
Compositions of gas:-					
CO_2	6.78	10.15	8.70	3.65	6.00
Illuminants	3.20	3.65	3.90	2.17	8.10
O_2	2.02	1.40	2.20	1.13	2.90
CO	4.40	8.80	3.55	2.55	3.20
CH_4	66.10	60.40	59.30	63.40	58.60
H_2	10.83	11.10	10.25	19.05	11.20
N_2	6.67	4.50	12.10	8.05	10.00
Appearance of Coke:-					

17 Black, Coherent, moderately hard, slight shrinkage, little powder on surface.

18 Black coherent mass, very slight shrinkage, much powder.

19 Lustrous black, highly swelling, porous and friable, poor cell structure.

20 Black, coherent, hard, non-swelling, no powder.

21 Highly lustrous, highly swelling, very porous and friable, moderately good cell structure.

It is to be noted that coal 17 is moderately good for low temperature distillation, while coals 18 and 19 need to be blended in one way or another in order to make them fit for the purpose. The remarkable nature of coal 21 merits our particular attention. Aside from its exceedingly high fusibility and swelling (for which the experiment had to be run with a five-gram sample), the oil yield exceeds that of any other coal by more than two times. The oil is rather thin and is free from resinic portions indicating that the amount of solid paraffins is not large. But in view of the high percentage of unsaturated hydrocarbons present in the gas (8.10%), we may also expect high percentage of unsaturation in, and consequently poor quality of, the oil.

APPENDIX II

To remove the irregularities in Table VIII in the above paper. Coals 13 and 15 were subjected to further experiment by using ten gram sample. The results, together with the result of a ten gram sample experiment of coal 19, are shown below:—

Coal		13	15	19
Semi-coke	(Ash-free basis)	77.50	82.45	77.80
Oils		11.36	10.32	10.69
Liquor		1.87	1.76	1.95
Gas		8.53	5.16	9.76

With these data at hand, Table VIII is re-tabulated, including the results of the four additional coal samples:—

Coal	Geological age		% tar-oil
18 *Liling*	BC	Jurassic	14.48
1 Houfung	Bl	,,	10.50
10 Tatung	Bl	,,	11.05
17 Pinghsiang	Bl	,,	9.15
20 Chaitang	Bh	,,	5 92
21 Loping	C	Permian	33.05
19 Hsianghsiang	BC	,,	10.69
15 Changhsing	Bl	,,	10.32
14 Shunkengshan	Bl	,,	12.10
12 Tanchiashan	Bh	,,	4.65
16 Chiawang	Bl	Permo-Carboniferous	12.21
13 Hsuancheng	Bl	,,	11.36
6 Kailan	Bm	,,	10.50
9 Chunghsing	Bm	,,	8.05
4 Chinghsing	Bm	,,	6.65
11 Liuhokou	Bm	,,	5.92
7 Poshan	Bh	,,	5.05
3 Tsubsien	Bh	,,	5.73

Explanation of Plate I.

EXPLANATION OF PLATE I.

*9. Semi-Coke from Chunghsing coal. × 1/2. Lustrous, highly swollen and porous, with thick cell structure.

15. Semi-coke from Changhsing coal. × 1/2. Highly swollen, lustrous in places, porous but very friable.

13. Semi-coke from Hsuancheng coal. × 1/2. Highly swollen, lustrous in places, porous but friable.

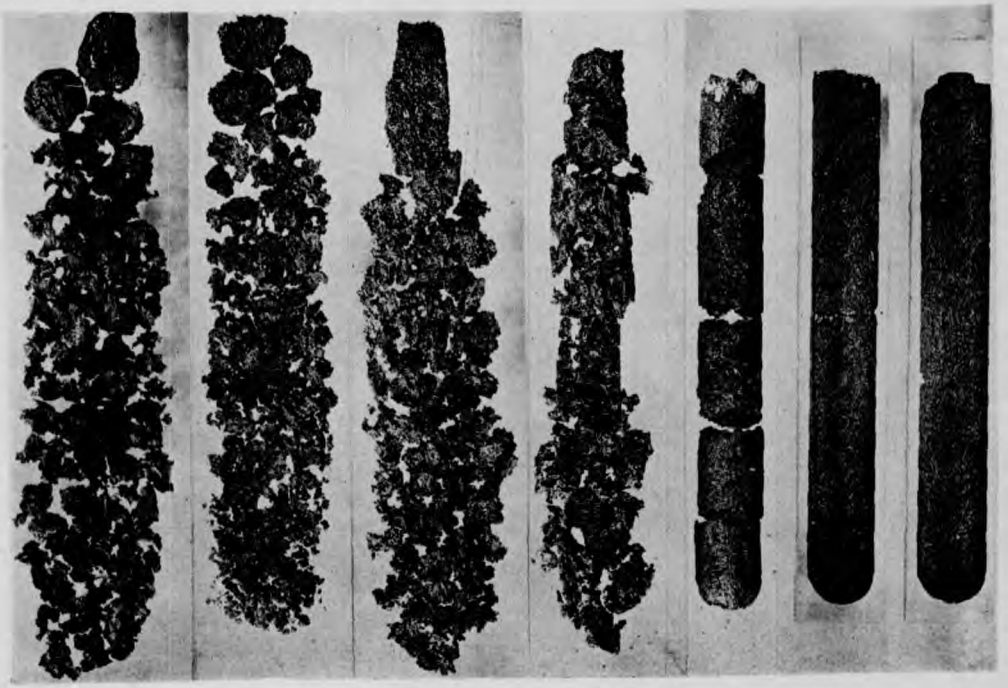
7. Semi-coke from Poshan Tatuanshihtan. × 1/2. Highly swollen, highly lustrous, hard and porous structure with thick cell wall.

5. Semi-coke from Kailan 5th. seam washed slack. × 2/3. Lustrous in places, swollen and porous with cross fracture.

6. Semi-coke from Kailan special washed slack. × 2/3. Grayish black, less swollen than 5 but harder, slight lustre in places.

11. Semi-coke from Liuhokou. × 2/3. Grayish black, little lustre in places, swollen, hard and porous.

* The number of each coke sample corresponds to the laboratory number of the coal from which it is derived. (see Table II).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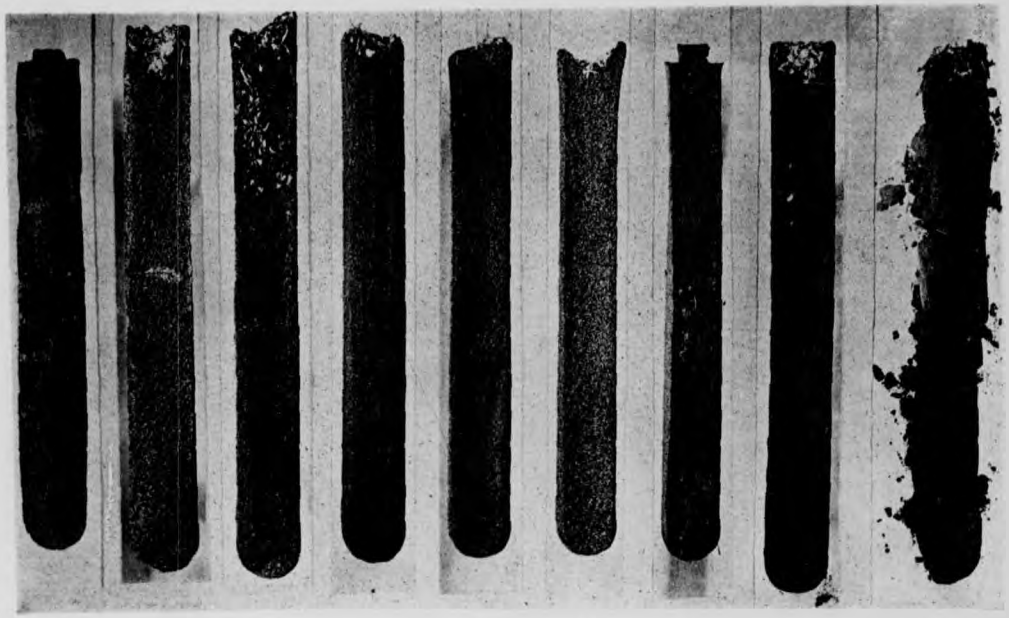
Explanation of Plate II.

EXPLANATION OF PLATE II.

3. Semi-coke from Tsuhsien Itsomei. × 2/3. Dull. grayish black. faint lustre in places, surface fracture noticeable, swollen, no powder.
8. Semi-coke from Poshan Hsiaotuanshihtan. × 2/3. Grayish black slightly swollen, hard and porous.
12. Semi-coke from Tanchiashan coal. × 2/3. Dull grayish black, no swelling, coherent and hard, little powder.
2. Semi-coke from Tsuhsien Toumei. × 2/3. Dull grayish black, hard and compact, slight shrinkage, little powder on surface.
16. Semi-coke from Chiawang coal. × 2/3. Black coherent mass, slight shrinkage, much powder.
14. Semi-coke from Shunkengshan coal. × 2/3. Grayish black, faint lustre in places, hard and compact, shrinking, no powder.
4. Semi-coke from Chinghsing coal. × 2/3. Dull grayish black, very hard and compact, shrinking, no powder.
10. Semi-coke from Tatung coal. × 2/3. Black coherent mass which forms powder by pressing with hand, no swelling.
1. Semi-coke from Houfung coal. × 2/3. Dull black mass which crumbles to powder at a touch, no swelling.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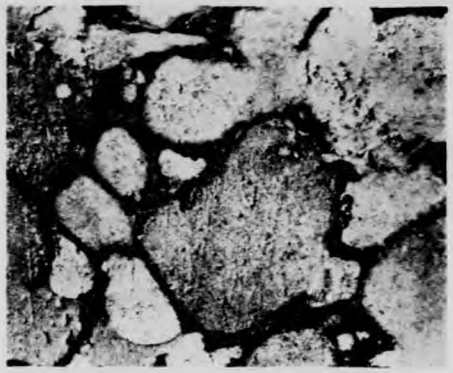
Explanation of Plate III.

EXPLANATION OF PLATE III.

7. Longitudinal section of semi-coke from Poshan Tatuanshihtan. × 5. The pores were filled with gypsum to show the cell structure of coke.
5. Longitudinal section of semi-coke from Kailan 5th. seam washed slack. × 5. Pores filled with gypsum.
8. Cross section of semi-coke from Poshan Hsiaotuanshihtan. × 5.

7



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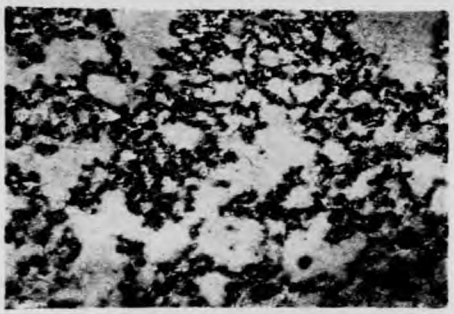

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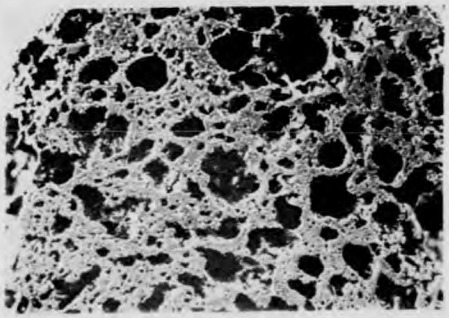
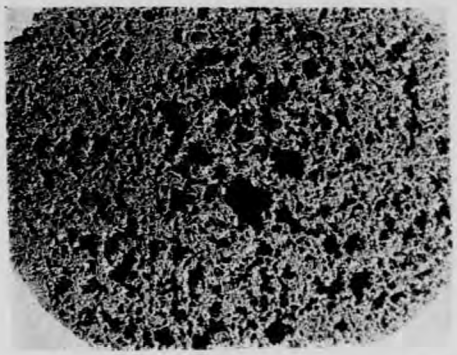


Explanation of Plate IV.

EXPLANATION OF PLATE IV.

3. Cross section of semi-coke from Tsuhsien Itsomei. × 5.
14. Cross section of semi-coke from Shunkengshan coal. × 5.
4. Cross section of semi-coke from Chinghsing coal. × 5.

3



14

4

開灤	Bm	二疊石炭紀	10·五0	
中興	Bm	二疊石炭紀	六·0五	
井陘	Bm	二疊石炭紀	六·六五	
六河溝	Bh	二疊石炭紀	五·九三	
博山	Bh	二疊石炭紀	五·0五	
磁縣	Bh	二疊石炭紀	五·七三	

（表中湘鄉長興宣城煤之產油量，係用十克煤蒸溜而推算所得。樂平煤產油量由五克煤蒸溜所得。）

氫	一〇·六三	一一·一〇	一〇·二五	一九·〇五	一一·一〇
氮	六·六七	四·五〇	一三·一〇	六·〇五	一〇·〇〇

附錄二

篇中第四表內，宣城長興二煤，因膨脹太甚，脂油未能全量蒸出，所產油量，證以煤之地質時代關係，似嫌略少。近復用煤一半，重加試驗，並加入附錄一內五種煤蒸溜結果，爰得一改正表如下：

煤	分類	地質時代	產油量（減灰百分數）
醴陵	Bc	侏羅紀	四·四六（百分數）
厚豐	Bt	侏羅紀	一〇·五〇
大同	Bt	侏羅紀	一一·〇五
萍鄉	Bm	侏羅紀	九·一五
齋堂	Bh	侏羅紀	五·九三
樂平	C	二疊紀	三三·〇五
湘鄉	Bc	二疊紀	一〇·六九
長興	Bt	二疊紀	一〇·三三
舜耕山	Bt	二疊紀	一三·一〇
譚家山	Bh	二疊紀	四·六五
賈汪	Bt	二疊石炭紀	一三·一三
宣城	Bt	二疊石炭紀	一一·三六

硫份	〇·七二	一·二七	〇·七九	一·二七	〇·七九	一·二七	〇·七九	一·二七	〇·七九
發熱量	一三〇〇〇	一三〇〇〇							
蒸溜結果(減灰)									
半焦炭(百分數)	七九·一〇		七三·一〇		七五·七〇		八五·一〇		四九·二六
(每噸公斤數)	一三一〇		六六五		七九六		七四四		四九三
脂油(百分數)	九·一五	一四·四八	一四·四八	六·三九	六·三九	五·九三	五·九三	三三·〇五	三三·〇五
(每噸加倫數)	三三·八三	三五·三五	三五·三五	一六·五〇	一六·五〇	一四·五〇	一四·五〇	八八·八〇	八八·八〇
油之比重	〇·九三三	〇·九六八	〇·九六八	〇·八三〇	〇·八三〇	〇·九六一	〇·九六一	〇·八九三	〇·八九三
水與磺精(百分數)	四·一六	一·四〇	一·四〇	一·九六	一·九六	二·一八	二·一八	三·一三	三·一三
氣(百分數)	七·四五	七·五五	七·五五	四·九〇	四·九〇	六·五〇	六·五〇	八·一一	八·一一
(每噸立方尺數)	二九〇五	二六二五	二六二五	一八二〇	一八二〇	二九五五	二九五五	三〇四四	三〇四四
氣之比重	〇·六三五	〇·六四四	〇·六四四	〇·六九六	〇·六九六	〇·五五四	〇·五五四	〇·六〇〇	〇·六〇〇
氣之成分									
炭二氧	六·七八	一〇·一五	八·七〇	三·六五	八·七〇	三·六五	一二·一七	八·一〇	一二·一七
不飽和炭氫化合物	三·一〇	三·六五	三·九〇	二·一〇	三·九〇	一·一三	一·一三	一二·九〇	一·一三
氧	二·〇三	一·四〇	二·一〇	一·四〇	二·一〇	一·四〇	二·一〇	三·二〇	二·一〇
炭一氧	四·四〇	八·八〇	三·五五	八·八〇	三·五五	二·三五	三·五五	三·二〇	三·五五
飽和炭氫化合物	六六·一〇	六〇·四〇	五九·三〇	六三·四〇	五九·三〇	六三·四〇	五九·三〇	五六·六〇	五九·三〇

合一・七至一九・四磅之硫酸鹽，大半氣質，多存留於半焦中未經任何變化。

結論

從實際方面着想，吾人果欲從事于大規模低温蒸溜試驗，則不能不對下列兩點，作愼重之考慮：(一)各種蒸溜產品之質量是否能與吾人所期望者相符？(二)產品有無銷路，俾使銷售代價，能超出蒸溜之費用？換言之，即低温蒸溜是否有商業上之可能性？然綜合二者觀之，亦不過爲技術方面之數個問題，即如何以最簡單，最賤之設備，獲得最多，最佳之產品。

歷來各國低温蒸溜失敗之最大原因，在未能重視蒸溜所用煤之個別特性，往往冀以一種固定設備，蒸溜各種性質迥異之煤炭，不論其爲不粘煤，高漲煤，或中漲煤，結果非損壞蒸溜設備，即產品不合實用。

茲篇試驗主要目的，即在鑒別各煤對於低温熱解之反應。特別可注意者，即最適于低温條件之煤，多爲習慣上次等煉製冶金焦煤，此種煤炭，即不能適于煉焦，當可利用于低温蒸溜。厚豐大同炭雖稍有缺點，不妨以混合煤方法改良之。至于低温蒸溜之另一大難點——煤之傳熱問題——則猶待更詳之試驗。例如熱之傳導，應由甑外，抑由甑內，甑之構造，應係不動，抑爲旋轉式，皆與蒸溜產品質量，有極大影響，詳加研究，俾底于成，液體燃料前途，庶有望乎。

附錄一

此篇脫稿以後，復收到煤樣五種，續加試驗，茲將其結果列下：

煤樣	萍鄉	醴陵	湘鄉	齋堂	樂平
實用分析					
水份	三・四一	四・三五	一・〇一	一・〇四	〇・四四
揮發物	三〇・六六	四〇・六三	三五・〇五	三〇・九五	三五・〇三
固定炭(減水)	三三・三三	三三・三六	四一・四〇	六六・一三	三三・三四
灰份	三五・六一	七・〇一	三三・三五	一一・九三	三・七四

碰縣一坐煤	四·九〇	二·一〇	二·六三	一·六八	四八·四〇	二九·六〇	一一·一〇
井陘	四·六〇	二·一〇	一·一六	二·三三	五二·一〇	二六·八〇	九·六〇
開灤第五層洗煤	五·四五	二·八〇	一·二五	二·六五	四一·一〇	四一·八〇	四·八〇
開灤特別洗煤	六·四〇	二·六三	一·一五	二·三五	五七·一〇	三一·四〇	七·三三
博山大碾石炭	三·〇五	一·二五	三·一〇	二·三〇	五〇·四〇	二九·八〇	一〇·八〇
博山小碾石炭	四·八〇	一·六五	三·四五	二·一〇	四五·六〇	三五·六〇	一一·八〇
中興	四·八〇	二·六〇	三·〇五	二·〇五	四五·八〇	二〇·四〇	一一·八〇
大同	三·三〇	二·八〇	一·一六	七·四三	四五·三五	二〇·四五	九·八五
六河溝	三·八五	二·一五	四·八五	一·六〇	四九·六〇	一八·四〇	一三·八五
譚家山	三·〇八	二·三三	一·四〇	二·四〇	五〇·一八	三五·三五	一一·〇〇
宣城	一五·一〇	三·四五	一·八五	一·八〇	五三·一〇		三·一〇
舜耕山	八·一〇	三·四〇	一·三五	四·三五	五三·四〇	三三·七五	七·一五
長興	八·八〇	五·八〇	一·八五	一·八五	五六·八〇	一四·三	一一·八〇
賈汪	七·八〇	三·一八	一·八四	七·一八	五三·四〇	一七·一〇	一〇·五〇

觀上表卽知各種低溫煤氣，大致相似。飽和炭氫化合物甚多，苟與水煤氣或劣質煤氣摻合，可使後者發熱量增高。氫之百分率較低，此原蒸溜品未經二度熱解之明證。厚豐，大同，宣城，舜耕山，長興，賈汪時代較新，炭二氧及炭一氧成分亦較他煤爲多，長興煤氣之不飽和炭氫體特高，最適爲燃燈之用。

在六百度下，硫精產量極微，最低者僅百分之〇·〇一一，最高不過百分之〇·一二五（參看第二表），以每噸煤計算，僅

惟數種半焦，性質甚劣，大同，厚豐二煤，加熱以後，不能黏結，焦悉成粉（圖版二）。中興，長興，博山大碾石炭，開濮，六河溝等焦質鬆脆易碎，輸運不便。蓋煤之適于煉焦（指高溫）者，率含多量O成份，熱至三百五十至四百五十度左右，即溶成粘性液體，分解氣體，不易蒸出，積成泡沫，向外推漲，半焦內多細孔，質至不堅。況膨漲壓力太高時，能損壞蒸溜甑之構造；原脂油與熱甑接觸太久，亦有分解之虞；半焦因漲填滿甑內，卸取至不易——種種實際困難，不易解決，故高漲煤炭恆不適爲低溫試驗。

低溫蒸溜之原料，當推舜耕山煤爲最佳，以其產油極多，煤經熱先漲縮，黏結成塊，卸取既易，焦力亦強。賈汪油量與舜耕山等，惟焦質稍差，開灤產油雖多，惜半焦太劣，不合實用。

低溫蒸溜目的，首在產油，半焦不過爲副產品，其價值遠遜於冶金焦。從經濟立場設想，最好用價值較低之煤，爲蒸溜原料。舜耕山，賈汪，厚豐，大同同非上等煉焦煤，最合爲低溫之用。厚豐，大同設能與長興或宣城高漲煤混合，則後者剩餘之O品，可補前者之不足，苟能配合適當，半焦當無鬆碎，不黏結，或不易卸取之病也。

半焦雖與高溫焦根本不同，然由半焦之形狀與內部結構及煤在蒸溜時所發生之現象不難推測其是否適宜於煉製冶金焦炭，詳見英文篇及圖版三四。

低溫煤氣及其他

煤氣成分見第六表

第六表　煤氣之成分

煤	炭二氧	不飽和炭氫化合物	氧	炭一氧	C_nH_{2n+2}	氫	氮
厚豐	三·六〇	三·一〇	一·六〇	一〇·三〇	三六·三〇	三三·三〇	一二·六〇
磁縣頭煤	四·六〇	二·二	一·一〇	二·六〇	四四·六〇	三三·三五	一三·四五

第五表　半焦之實用分析（滅潮煤樣）

半焦	水份	揮發物	固定炭	灰份
厚豐	〇.三一	一四.四四	六三.四〇	三一.六五
磁縣頭煤	〇.四〇	一二.九八	五七.三七	一四.〇五
磁縣一坐煤	〇.八八	六.六六	五五.〇三	八.三三
井陘	一.〇五	八.三三	六六.六六	二五.〇〇
開灤第五層洗煤	〇.九八	八.二二	七九.八三	一一.九八
開灤特別洗煤	〇.三五	七.三三	八四.四六	一四.〇〇
博山大窩石炭	一.二八	四.五一	六三.四五	三三.〇六
博山小窩石炭	〇.六八	六.三五	五〇.九〇	二三.三五
中興	〇.八六	七.五四	六三.九六	八.四〇
大同	〇.九五	一一.八六	八三.二一	五.九七
六河溝	〇.三一	七.四〇	八四.三八	七.九五
譚家山	〇.六五	七.〇〇	八五.四一	七.九四
宣城	〇.五〇	五.九三	八六.一四	三五.一四
舜耕山	〇.六五	一〇.〇一	七五.二三	一四.一八
長興	〇.八〇	九.〇八	六三.六八	二八.三三
賈汪	〇.四八	九.四八	八六.六三	二一.九一

煤	地質時代	產油量(百分數)
厚豐	侏羅紀	一〇·五〇
大同	侏羅紀	一一·〇五
長興	二疊紀	七·五九
舜耕山	二疊紀	一二·一〇
譚家山	二疊紀	四·六五
賈汪	二疊石炭紀	一二·二一
宣城	二疊石炭紀	八·三七
開灤	二疊石炭紀	一〇·五〇
中興	二疊石炭紀	八·〇五
井陘	二疊石炭紀	六·六五
六河溝	二疊石炭紀	五·九五
博山	二疊石炭紀	五·〇五
磁縣	二疊石炭紀	五·七三

半焦炭

半焦炭佔蒸溜產品百分之七五至九〇，大規模低溫蒸溜，商業上能否成功，當視焦炭之有無銷路而定。半焦與高溫焦最大不同之點，則在半焦含揮發物甚多（第五表），故雖不適于冶金，但易燃而無烟，發熱量甚大，射熱効率亦高，家庭爐竈用之，最爲合宜。工業上可爲發氣爐之燃料。

舜耕山	七七·四〇	七四四	二二·一九	三〇·〇六	六·〇六	二五四〇	四·一六	〇·〇五二
	七六·〇〇	七〇九	二二·〇〇	二九·六五			三·六四	
長興	七五·六〇	七六〇	七·六六	三三·七五	四·五一	一七一〇	一·九	〇·〇三七
	八六·一六	七六四	七·五〇	三三·一六			一·八六	
賈汪	七五·六〇	六六七	二三·四三	三〇·六三	六·六五	二五六〇	五·二一	〇·〇五二
	七五·〇〇	六六七	二一·九	二九·七三			四·九	

煤脂油

脂油色棕黑，在尋常室內溫度下爲液體，置久色較深，性亦較粘，油之薄層作棕黃或紅色。厚豐大同之油，較其他稍濃，並不易流動，蓋以煤之時代較近，固體石臘成分較多故也。

試驗用煤二十克，所得脂油，最多僅二至三立方生的，數量太少，分析甚難。僅就其比重（平均在〇·八至一·〇之間）觀之，其中必含有低沸輕油甚多，如汽油煤油等。假定汽油約佔百分之二十，而大規模廠產，約合試驗室產量百分之六十，則每噸產油較多之煤，約可出汽油三至四加倫，由煤氣內提取之輕汽油，尚未計入。英國燃料研究所曾將低溫提煉之汽油施用於內燃機器，成績甚佳。汽油以外，如煤油，柴油，滑物油，石臘，煤脂酸等，皆可逐步提取。煤脂酸約佔脂油百分之十五至二十五，係各種石炭屬酸之和，爲消毒良劑。

產油最多之煤，率富含揮發物，並屬低級烟碳，（此篇仍用翁氏分類法）如厚豐，大同，賈汪等是。蓋煤之地質時代愈近，氧份愈高，則產油亦愈多（第四表）。宣城，長興油量不能與時代關係符合者，則以其膨性太高，尚有餘油未能蒸出也。高級或中級烟碳，除開灤中興而外，如博山，井陘，磁縣，六河溝等，產油極少，雖適於煉焦，不宜爲低溫蒸溜之原料。

第四表　煤之產油量與其地質時代之關係

開灤第五層洗煤	八三・三五	七四九	九・六〇	三四・八〇	五・一三	二六・一〇	二・四三	〇・九五	〇・〇五	四四・〇	一・一
開灤特別洗煤	八三・三五	七四九	九・八三	三四・八〇	五・一三	二六・一〇	二・四三	〇・九五	〇・〇五	四四・〇	一・一
博山大磚石炭	八六・四〇	七七一	一〇・六一	三五・三三	七・三	三一・五〇	三・一五	一・三五	〇・〇五	四五・〇	一・一
博山小磚石炭	八六・七〇	七九八	一〇・九一	三五・三三	七・三	三一・五〇	三・一五	一・三五	〇・〇五	四五・〇	一・一
中興	八六・一〇	七四八	一〇・八〇	三一・八〇	四・九三	三三・八〇	三・〇六	一・三五	〇・〇五	四五・〇	一・一
大同	八七・〇〇	七八〇	一一・一三	三六・八〇	七・八〇	三六・九〇	四・一六	一・四三	〇・〇五	四五・〇	一・一
六河溝	八五・三〇	七五七	一一・一三	三五・一〇	六・三五	三九・五〇	三・一六	一・三五	〇・〇五	四五・〇	一・一
譚家山	八六・三〇	七四八	一一・四〇	三六・三〇	六・四〇	三九・五〇	三・一六	一・三五	〇・〇五	四五・〇	一・一
宜城	八五・四〇	七五八	一一・三〇	三五・六〇	四・四〇	三八・〇〇	三・一六	一・三五	〇・〇五	四五・〇	一・一

惟爐外溶煤之凝結不堅，蒸溜時僅呈忽斷忽續現象，不致使整個蒸溜停止。

(二)十六種煤之成分至不一致，揮發物有二一・二五及三七・六〇多少之不同，灰份有低至四・三四，高至二〇・五九者，灰不揮發，經熱不易變，與蒸溜後之炭渣合爲焦炭實　是灰份高者，半焦產量恆高，以百分計算，其他脂油煤氣等之產量，當必因之而低。第二表所列數字，似不能爲各煤互相比較之標準，例如厚豐與大同煤之實用成分頗相近，惟前者灰份，約高於後者三倍，故厚豐之油，少于大同，厚豐焦炭，多于大同。又如長興煤揮發物甚高，固定炭僅四五・八一，湖南譚家山煤揮發物不過二二・二二，固定炭有七一・三三，乃二者蒸溜產品數量極近。長興之油，僅略多于譚家山之油，證以常理，似有不合。第三表以滅灰煤爲計算標準，較適宜于比較各煤蒸溜產品之多寡，表中並附每噸煤各種產品之數量。

第三表　各煤低溫蒸之產品（以滅灰煤爲計算標準）

煤	半焦炭		脂油		煤氣	水	磷精
	百分數	每噸公斤數	百分數	每噸加倫數	百分數	每噸立方尺數	
厚豐	六六・七五	六六八	一〇・三六	二六・七五			五・二三
	七二・四〇	七二四	一〇・六四	二六・九三	六・二一	三二六〇	五・一七　〇・〇一九
磁縣頭煤	六六・七〇	六六九	五・〇二	一三・二〇	五・八一	二七八〇	二・一九　〇・〇三〇
	六七・七〇	六七八	四・九一	一三・三三			二・二五
磁縣一坐煤	六五・二〇	六七五	五・七三	一六・九〇			一・一六
	六五・二〇	六七五	五・三三	一七・〇二	六・七六	三四〇	一・三三　〇・〇六六
井陘	六三・七〇	六六一	六・六六	一六・三三			二・三三
	六四・二〇	六六六	六・五四	一六・五〇	五・九三	二七四〇	二・一六　〇・一四一

六河溝	九七·五〇	四·八五	一·九〇				〇·九〇六	八二九五	
	九七·五〇	五·二〇	一·八五	〇·〇五五	五·七七	一〇〇·二〇	〇·九一三	八三三五	〇·五五一
譚家山	九九·〇〇	四·二〇	一·三〇	〇·〇六〇	四·六六	九九·三三	〇·八九四	七九八五	〇·四六六
	九九·〇〇	四·五〇	一·〇〇				〇·九〇〇	七六六五	
宣城	九七·五〇	六·七〇	一·五〇				〇·八七〇	四八二五	
	八六·〇〇	六·七〇	一·五〇	〇·〇一一	三·八〇	一〇〇·〇一	〇·八八〇	四八二五	〇·六四三
舜耕山	八〇·五〇	一〇·五〇	三·六〇	〇·〇六〇	五·三五	九九·九八	〇·九一一	七三一〇	〇·五九三
	八一·〇〇	一〇·四〇	三·二五				〇·九二三	七三六〇	
長興	八六·五〇	六·一〇	一·五〇	〇·〇三九	三·三六	九九·七一	〇·八一〇	四四六〇	〇·六四四
	九九·〇〇	五·九五	一·四〇				〇·九〇五	四三五五	
汪賈	七七·五〇	一一·二〇	四·六〇	〇·〇四六	五·九九	九九·八四	〇·九二三	七六五〇	〇·六八〇
	七七·五〇	一〇·八〇	四·五〇				〇·九六八	八〇〇五	

第二表有數點略需解釋者：

（一）試驗所用電爐，僅中間六寸部份，能勻熱至攝氏六百度，因是每次煤樣，僅裝佔蒸餾管中六寸地位，並使管之六寸部份，與爐之勻熱部份相符（參看英文篇圖一）。煤性之膨脹與否，即以焦炭之形狀而定（參看圖版一二）。中興，長興，宣城，及博山大碾石炭四煤膨性極強，加熱以後，漸向管之空處推移，幾佔原煤地位之二倍，脹出之煤，溫度較低，脂油未能儘量蒸出，油之產量因爾略少，半焦炭產量略高。膨脹程度以中興爲最甚：一部份已溶之煤，因脹而被推送爐外，遇冷凝結，堅不可破，後出之油與氣，遂不能照常蒸溜，半焦產量太高。第二次試驗用煤一半，結果差可與他煤比（表二※）。長興煤雖有同樣高脹性，

磁縣頭煤	八七·五〇	四·七〇	二·〇五	〇·〇二八	五·四三	九九·七一	〇·九一三	八五三〇	〇·五一九
	八六·五〇	四·六〇	二·一〇				〇·八八五	八五五〇	
磁縣一坐煤	八六·〇〇	五·四五	一·一〇				〇·八八四	八六八五	
	八六·〇〇	五·四五	一·二五	〇·〇八五	六·四二	九九·一九	〇·八〇八	九六一〇	〇·五三三
井陘	八五·五〇	六·〇〇	二·〇五				〇·九九三	七九八五	
	八六·〇〇	五·八〇	二·〇〇	〇·一二五	五·三五	九九·一六	〇·九五二	八〇〇〇	〇·五三四
開灤第五層洗煤	八四·〇〇	八·六〇	二·一〇				〇·九五一	七六九〇	
	八四·〇〇	八·八〇	二·三五	〇·〇五三	四·六〇	九九·八〇	〇·九五二	八二八五	〇·四五二
開灤特別洗煤	八三·〇〇	九·三〇	二·八五	〇·〇五四	六·四一	一〇〇·六一	一·〇一〇	九〇九五	〇·五七五
	八一·五〇	九·一〇	二·八五				〇·九六四	八八一五	
博山大碬石炭	八七·五〇	四·七〇	一·九〇						
	八六·五〇	四·三〇	二·〇〇	〇·一二五	七·五〇	一〇〇·四六	〇·八〇一	一一七九五	〇·五一八
博山小碬石炭	八六·〇〇	五·三五	一·二五	〇·〇二五	四·五四	九九·一七	〇·九六二	七二八五	〇·五一五
	八九·〇〇	四·九〇	一·五〇				〇·九六〇	六六二〇	
中興	九一·五〇	四·〇〇	〇·八〇					三九〇〇	
	※八七·〇〇	七·五〇	〇·八〇	〇·〇五五	四·五六	九九·九四	〇·八六三	六九三〇	〇·五三五
大同	七六·〇〇	一〇·四〇	四·〇〇	〇·〇三五	七·四六	九九·九〇	一·〇〇〇	九〇八五	〇·六七〇
	七七·五〇	一〇·七五	四·〇五				一·〇〇三	九〇二〇	

磁縣怡立一坐煤	Bh	〇·三三	二·三五	七三·八六	四·九七	一四九〇三	一·四三	
井陘礦務局第五層	Bm	〇·一四	三三·七三	六四·九六	一一·二九	三九一九	〇·七六	
開灤第五層洗煤	Bm	〇·三一	三三·〇三	五七·五六	一〇·三五	三七四五	〇·九七	
開灤特別洗煤	Bm	〇·七六	三一·四五	五六·一七	一三·三四	三五〇三	一·三九	
博山大碾石炭	Bh	〇·四一	二一·三七	六七·七三	一〇·九一	三九四五	〇·六五	
博山小碾石炭	Bh	〇·三〇	三三·六三	六七·一七	一〇·〇一	四〇八七	〇·六〇	
中興洗煤	Bm	〇·四〇	三一·八七	六一·三一	六·八三	一四四一六	〇·八三	
大同口泉加疙塔	Bl	一·〇〇	五六·三五	五九·三三	四·三四	一四三九九	〇·三五	
六河溝	Bh	〇·四六	三三·八七	六一·〇六	一五·〇七	三三三九	〇·八四	
湘潭譚家山	Bh	〇·六三	三三·三三	七一·三三	六·四五	一四六三五	〇·四〇	
宣城大汪村	Bl	〇·一〇	三三·三七	四六·七四	一九·六九	一一四一六	五·四七	
懷遠舜耕山大通	Bl	一·四九	三三·五六	五三·九五	一三·四一	三六四五	一·六三	
長興大煤山	Bl	〇·四六	三三·六〇	四五·六一	三〇·五六	一一三四	〇·六一	
賈汪上層	Bl	一·九一	三七·六〇	五三·四五	九·五五	三六〇九	三·三五	

第二表　攝氏六百度下蒸溜產品（以一百克煤爲計算標準）

煤	半焦炭	脂油	水	硇精	煤氣	總	油之比重	氣之容積	氣之比重
宣化厚壘	八〇·〇〇	六·九〇	四·三〇				〇·九二六	六五六〇	
	八〇·三〇	九·一五	四·四五	〇·〇一六	五·三四	九九·四六	〇·九四六	六四三五	〇·六七四

中國烟煤低溫蒸溜之試驗

蕭之謙

近代機器用途日廣，液體燃料之需要亦日增，汽車飛機滑水艇等，無一不恃汽油柴油等爲動力之來源。產油不富之國家感於經濟上仰賴外給之不利，及戰爭時國防之重要，遂不得不於探索油田外，另求石油代替品，以補天然原料之不足　烟煤之高低溫蒸溜遂由理論研究進而爲工業上應用。

高溫蒸溜以產優質冶金焦爲主；煤在攝氏千度以上，原煤脂油大半因熱分解成氣體，或因煳炭氫化合液體。低溫蒸溜則最高溫度僅六百度，原油產量約多于高溫者二倍，油質亦較良，多直接炭氫化合物，提煉以後，性質頗似石油。

我國石油儲量，就歷年調查之結果，並非甚富　年來油類燃料，殆無不依賴他國；據海關報告，二十年進口汽油，竟約達三千萬加倫　彌補漏巵，歷因國防，除積極開採固有石油，及發展油頁岩工業外，低溫蒸溜，殆亦當世之急需也。

低溫蒸溜爲最近較新試驗，工程技術方面之困難，未經解決者良多　茲篇所載，偏重各種烟煤在低溫下各種產品之數量，附及各項產品之性質，藉以測定其是否適宜于低溫蒸溜　至於工程設備等，則猶待較大規模試驗也。

蒸溜儀器，參照英國燃料研究所專報第一號所載，略加修改（詳見英文篇內）　試驗煤樣計十六種，其實用分析見第一表，蒸溜結果見第二表。

第一表　煤之實用分析（試溜煤樣）

煤樣	類別	水份	揮發物	固定炭	灰份	發熱量	總硫份
宣化煤礦全層	Bl	一·九六	三六·七三	四九·三七	一三·九一	一二九三	〇·七四
磁縣怡立頭煤	二	〇·三四	三一·二五	五二·二六	六·四七	一四六七五	〇·六四

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燃料研究專報第九號
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中國烟煤低溫蒸溜之試驗

蕭之謙著

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A STUDY ON COKING PROPERTIES OF SHENGKENGSHAN COAL BLENDED WITH OTHER BETTER COKING COALS

BY

K. Y. KING

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A STUDY ON COKING PROPERTIES OF SHENGKENGSHAN COAL BLENDED WITH OTHER BETTER COKING COALS.

K. Y. KING.

ABSTRACT.

The purpose of this study is to find the possibility of the Shengkengshan coal for the production of metallurgical coke for the proposed iron and steel industry on lower Yangtze.

Agglutinating power, low temperature carbonization, and horizontal gas retort tests have been applied to verify the possibilities of different coal blends.

Conclusions drawn are based upon the results of the tests that it seems hopeful to blend Shengkengshan coal with 40% better coking coals to produce blast furnace coke.

It is found also that medium grade bitumites§ (Bm) blend better with low grade bitumites (Bl) than the high grade bitumites (Bh).

INTRODUCTION.

Most of the coking coals in China are situated in the northern part of this country. Though there are coal fields in the central and southern part, their characters are not quite known and therefore the suitability of these coals for the manufacture of blast furnace coke has to be carefully studied.

The success of the proposed iron and steel works on the lower Yangtze using the iron deposits in that district[1] as recently planned by the Government depends largely on the availability of cheap and good coke produced from coals located not too far away.

A good blast furnace coke together with cheap transportation are always essential to an iron and steel industry. To lower the first cost in transportation, a coal field close to the iron deposit is undoubtedly desirable. Naturally the coal fields of Chinhsien and Hsuancheng in Anhui[2] producing a medium bituminous coal came first into consideration, but their high content in ash

§ For the significance of these names, see W.H. Wong: Classification of Chinese coals, Bull. Geol. Surv. China, No. 8, 1926.

and sulphur together with insufficient reserve as maintained by geologists should place this field at best as a secondary source of supply. The coking properties of the Liehshan and Luichiakou coal fields of northern Anhui[3] are yet little known and proper investigation is now under way for their evaluation.

The Shengkengshan coal field[4] is easy to reach and situated not far from the proposed plant site somewhere near Pukow. The coal is of a low grade bituminite (Bm)[5] and possesses a medium variety of coking quality, ranging from moderate coking to non-coking. Using 100% of this coal for coke manufacture seems to be impossible; but coal blends with a better coking coal will naturally improve its quality.

The Chunghsing coal of Ihsien, south Shantung, has long been regarded as one of the best coking coals in China. It possesses not only high agglutinating power, but also is low in ash. The coke from this coal produced in native bee-hive ovens has been known for its excellent quality. The mine is not far from Shengkengshan and therefore the two coals can be easily brought together. Coal from Kailan mines also proves to be of high agglutinating power; the chief drawback in this coal is its high ash content. If the special washed coal is used, the ash content may be considerably lowered. Though it is far away from lower Yangtze, its location can afford a cheap transportation by water route.

It was therefore suggested that blending Shengkengshan coal with a part of Chunghsing or Kailan coal in certain suitable proportion might result in a good mixed coal for blast furnace coke. If it is possible, though at present it still needs further confirmation by large scale test, to produce a desirable metallurgical coke in this manner, the rather inferior coking coals from Shengkengshan can be utilized for useful purposes, and on the other hand, there will be a great saving of excellent coking coal from other mines. Excellent coking coals in China are rather limited, so economical conservation should be considered.

Studies along this line have been made for sometime and the following is an account of the work which has been done so far.

The study of this subject was carried out in three different parts, namely, (1) Agglutinating test, (2) Low temperature carbonization assay and (3) Horizontal gas retort carbonization. The procedures and observations of the experiments are described in the following.

TEST FOR MEASURING THE AGGLUTINATING POWER OF COAL.

Since 1870 Richtets[6], 1895 Campredon[7] proposed to test the agglutinating power of coal, many observers have thoroughly investigated on this subject. A good summary on this subject is fully given by S. M. Marshall, and B. M. Bird[8] so that it is unnecessary to review them again. In general the tests involve "the carbonization under standard conditions of a small sample of carefully prepared coal, either alone or mixed with inert material, and some tests of the resulting coke buttons which serve to indicate the agglutinating value of the coal"[9]; the inert material used being either quartz, electrode carbon or coke.

After careful consideration of the used methods and availability of apparatus and materials, the following procedure is choosen for the agglutinating test on the coals and coal blends used for this study.

Inert material employed in the test being a high temperature coke with a maximum of 2.2% volatile matter. This type of coke is readily available on the market. Large quantities are purchased for storage to minimize the variation of coke obtained at different times. The cokes are grounded to pass 40 mesh (Tyler Standard) and retain on 60 mesh sieve. Above 40 and under 60 should be discarded. Samples are carefully taken and analysed.

A part of the coal samples are sampled and supplied by the mines. They have been securely packed in cans and boxes during transport. Another batch of samples are collected by Mr. Y. S. Chi of our Survey. They are packed in sacks of about 200 lbs each. Owing to heavy rain in the summer season, these samples have been considerably weathered. All the samples are air dried at room temperature and pulverized to pass 60 mesh sieve in Braun Pulverizer and stored in glass bottles with a metal clamp lid. Proximate analysis of coal is then made with their respective percentages shown in the attached tables (I and II). Some proximate analyses of the same type of coal supplied by other laboratories are also included.

The proportion of 1:6.6 that is 1 part of coal to 6.6 parts of coke is adopted after a series of experiments. This ratio of coal and coke will produce a loose button which crumbles to touch by fingers when made from a very feebly coking coal. The total weight of the sample button before carbonization weighs 11.5 grams (10 grams coke and 1.5 gram coal). 20 samples of coke of 10 grams each are weighed out and then another set of 20 samples of coal of 1.5 gram each. One sample of coke and another of coal are carefully and intimately mixed. The mixture is then transferred into a 30 cc crucible and a weight of 5 kilograms is applied for 1 minute after leveling of the surface. The empty space in the crucible is filled with coke of 20-40 mesh sieve.

The furnace is electrically heated and in the form of a muffle. The furnace is heated to 960°C before the crucibles are put in. The time of carbonization is set at 10 minutes. The temperature in the furnace should reach 950°C within 5 minutes after the crucibles are put in. The crucibles are laid aside for about 20 hours before crushing. The weighing and mixing of the buttons are usually performed in the morning and the carbonization in the afternoon. The next morning, the buttons are crushed for estimating the agglutinating value (Plate III).

The testing is made on a very simple apparatus shown in the figure (Plate II). The value is ascertained by the number of times the carbonized button can stand the force of a metallic plate weighing 140 grams dropping from a distance of 6 cm. This test is not at all satisfactory for many reasons and therefore changes are now being made. It is intended to apply an increasingly steady force by using lead shots or iron shots for crushing such as used in testing cement briquets. This should give more readable values than the number of blows as now indicated.

A comparison of the coking values of Table I and II, there seems that the samples, except No. 587, collected by Y. S. Chi have in general a lower value than those supplied by the mines. The values for blends are still lower, this is mainly due to the difference of Chunghsing coal used. As I have mentioned, the tremendous amount of rain in the summer 1932 should have played an important part in the weathering of coal. Since the coal samples were stored in sacks and considerable time was required during the transport,

and besides this batch of sample weighed over two tons, it was very hard to store them indoors at the time of heavy rainfall. Consequently more weathering has occurred.

With the exception of 2nd seam South, the ash percentage of all the new samples are much higher, but its difference does not affect the agglutinating value very much. A striking difference is noted between the samples from Tatung Mining Co. Of the former samples collected by the mines had no sign of coking at all while the new sample (average sample) shows a little better than all the other ones.

Low Temperature Assay.

Gray and King of the British Fuel Research Board[10] have devised a laboratory method for evaluating the approximate by-products of coal. This method has been recognized as a good test for indicating the coking character of coal[11]. In lack of apparatus for this test, a still smaller coal assay method is devised and used. The general principle is altogether the same as the 20 gram assay.

This method consists of a pyrex tube of 20 cm long 2.5 cm diameter holding a coal sample of 10 grams. The tar collector is a part of U-tube. The gas-washing tube is simply made from two cheap type pipettes bending in such a manner as to be easily connected to the tar collector on one end and gas holder on the other. A large bottle of 3-liter capacity is employed as the gas holder. The gas entering at the top displaces the water which is saturated with coal gas from previous tests. The displaced water flows to a leveling bottle of 2 liter capacity.

The operation is very simple. A ten gram sample (dried at 105°C) occupies the lower three-fifth of the tube and is connected to the tar collector which is dry and empty. Eight cc of normal sulphuric acid is charged into the ammonia absorption tube for the absorption of ammonia and other basic gaseous compound that are coming through. This is connected next to the tar collector.

The pyrex tube filled with the prepared sample is inserted partly into an electric tube furnace which is heated to 300°C beforehand after the current is raised. The temperature is gradually increased. The rate of heating is so

arranged that at the end of 1 hour, the furnace attains a temperature of 600°C, which is measured by a base metal thermocouple. This temperature 600°C is maintained for another hour or more until the gas evolution is practically ceased. Usually one hour at 600°C is sufficient for complete gas evolution. The total time of carbonization is 2 hours and 10 minutes.

The volume of gas can be easily measured by the calibrated scale on the bottle. The total volume of gas is collected to 15°C as saturated gas. The tar, liquor and gas are not carefully estimated since they have no direct connection on the whole experiment.

The general arrangement of the apparatus and also some of the cokes formed are shown in accompanied photographs (Plate, I 2, IV, V). A description of the resulting low temperature coke and a comparison of the coke and the coke button from volatile matter determination are fully given in Table III.

CARBONIZATION IN HORIZONTAL GAS RETORT.

After initial testings in the methods described, a decision was henceforth made that a larger sample of blends should be used for testing their suitability for coke manufacture. My colleague, Mr. Y. S. Chi, was so kind to have collected nine new samples about 400 lbs each on a special trip. It was quite unfortunate that during this year heavy rainfall in North China has resulted in washing out all the fine particles from the coal in the sacks.

Preliminary tests of these samples showed little difference with the old ones inspite of the fact that they are considerably weathered. Subsequently they were all ground to pass 1/4" in Braun laboratory crusher and intimately mixed by hand with Chunghsing dust in the proportion of 4 to 6, that is, 40% Chunghsing and 60% Shengkengshan. The sieve analysis of two samples after crushing is shown below.

Sample	Chunghsing	Shengkengshan
on 1/4"	77%	25%
on 10 mesh	16%	40%
under 10 mesh	7%	35%

Two lean blends with 70% Shengkengshan were also mixed for testing.

The test was made at the Horizontal gas retort of Peiping Union Medical College. The retort is made of fire brick and lour in a bench. By not disturbing the gas generation of P.U.M.C., by-product estimation was abandoned entirely and only coke was concerned. It took 8 hours for heating a charge of 300 lbs at a maximum temperature of 900°C. The charging and discharging were made by hand.

Owing to many difficulties the conditions for carbonization are differed from those of standard carbonization. Therefore the retorts were not fully charged, temperature was lower than usual and the time was limited only to eight hours.

Nevertheless, the tests were made, and slightly shiny surfaced cokes (Plate VII) were produced. The coke appears quite hard and difficult to break. Shatter and tumbler tests are unavailable for testing the coke strength here; only the analysis is performed. The results are shown in Table IV. Examining the coke by Rose Method[12], there are numerous black and very hard infusible particles cemented in the cokes of fairly porous structure (Plate VIII$_2$). Ash determination on these particles shows that they contain as high as 40% ash. Accordingly, they are the ash forming material and probably could be washed out if coal cleaning plant is provided.

In one sample, that is 40-60 mixture of Chunghsing and Tatung, the infusible particles are only present in small quantities. The structure of this sample is different from the rest and possesses a quite uniform cell structure (Plate VIII 1 & 2). But the surface remains dull as others, except it feels a little harder and more porous.

According to the observations on coke structure, it seems that the ash content has an important bearing on the porosity as well as the hardness of coke. In all cases, the smaller the ash content, the more porous is the structure.

DISCUSSION.

Both coals from Chunghsing and Kailan of the *Bm* type are taken as excellent coking coals in this country. And those of Tzuhsien and Liuhokou of the Bh type, as far as the native bee-hive oven tests have shown, are also

of good coking quality. The chief difference between these two types of coal lies in the fact that the former two are highly swelling coking coal and the latter are only of moderate swelling. This can be shown very evidently by carbonizing the coals at 600°C in the carbonization test.

Furthermore, Shungkengshan coal (Bl type and poorly coking) blends with either Chunghsing or Kailan up to 50% showed still noticeable swelling in the carbonization test, while these blends of Tzuhsien and Liuhokou do not form quite shiny but loose coke at the temperature of 600°C. When the agglutinating test is applied, Tzuhsien and Liuhokou blends even at the amount of 60% coking coal showed little evidence of coking, and cracked very easily at the test. On the other hand, blends made of 30-40% Chunghsing or Kailan and 70-60% Shungkengshan medium coking coal shows considerable strength of agglutination and the values can be compared with those of 100% Tzuhsien and Liuhokou.

In evidence of these facts, the excessive swelling in coking coal proves to be not entirely necessary in the coke formation, but would be very useful in blending the poorly coking coals. The normal swelling coking coals such as Liuhokou and Tzuhsien are merely good for producing coke by itself and of no advantage for blending other coals. In other words, low volatile bituminous coking coals of the Bh type are only good for making coke alone while Bm coals or medium volatile bituminous coking coals are useful for blending purpose depending on their special property of excessive swelling. By this manner, that is, blending with a coking but non-swelling coal, the excessive swelling can be somehow eliminated with a result of having a normal swelling and good coking coal. Tests made with Kailan coal give very similar results which proves that either Kailan or Chunghsing coal might be used for the same purpose.

The general appearance of low temperature coke from 40% Chunghsing 60% Hwainan (2nd hole, 1st seam) of Shungkengshan is quite similar to that of Liuhokou (Plate VI) any even the agglutinating values are alike. Blends richer in Chunghsing (50% up) shows considerable swelling, giving a coke quite shiny, and can be easily crushed owing to the porosity of the coke. Blends with lower percentage in Chunghsing (20% down) give a mass of jet black color.

compact, little shiny in places, quite fissury and non-swelling. Chunghsing in 10% gives a coke of little difference to 0% Chunghsing or 100% Shungkengshan coal. Basing upon these evidences from the tests, one might say that the blends made of 40% Chunghsing, 60% Shungkengshan would produce a desirable coke for blast furnace. However, only large scale experiment in coke oven will definitely prove its suitability for metallurgical coke and assure the practical ratio for constituting the blend. This seems rather expensive for experimental purposes. Consequently, arrangement is made with Peking Union Medical College to use their gas retort for testing. This is, of course, not quite as satisfactoriiy as ovens, yet its indication will probably justify further experiments on full scale coke ovens.

Since Shungkengshan coals include a wide variation of coking quality in different regions and also in different seams, assurance should be obtained first as to whether that seam which proves to be promising under test is of considerable reserve, or other seams may prove to possess similar property and can be used along with it. Of the six samples (No. 483-488) differing in seams, supplied by the Hwainan Coal Mining Administration of Shungkengshan, the third seam of the 4th hole west in the south and 1st seam, probably also the 3rd seam of the 4th hole west in the north (designations according to original labels) are of the same general property as that of the 2nd hole 1st seam. This gives a more wide limit in the coal reserve that might possibly be blended with other coking coals of highly swelling nature in the ratio indicated. Low temperature assay and agglutinating value test show evident similarities between these three coals of the 4th hole west and that of the 2nd hole 1st seam. All these were made in the proportion of 40% Chunghsing 60% Shungkengshan.

Coals from Tatung Mining Company of Shungkengshan seem to be of inferior coking quality. Tests on the individual samples from different seams showed feebly coking quality, while of the average sample No. 432 has no sign of coking at all.

Among the samples collected by Mr. Y. S. Chi, the average sample of Tatung coal stood out as the best coking quality of the whole lot of Shungkengshan coals. Not only the agglutinating value is high, but also the general

appearance of coke, hardness, porosity as well as the ash content are better than others. Probably the ash forming material such as shale and slate hinders the coking quality of the others. This is shown in the analysis, the higher the ash content, the lower the agglutinating number. It is therefore suggested, if these coals were washed, they might improve the coking quality of the coal a good deal. Float and Sink test will be applied to new samples to verify this point.

All the other samples are moderate coking, but none can be compared with that of Tatung both in the original coal and coal blends. Perhaps, the general characters of Shungkengshan coal are alike and the chief differences are mainly due to the percentage of ash content and the relative presence of durain and vitrain in the coal.

In the mean time, due to the difference of the samples collected at different times and also the wide variation of weathering conditions, due to difficulties in transporting the samples from one place to another (it took practically two months to transfer Mr. Chi's samples from the mine to Peiping); due to handicap in apparatus for crushing and mixing large quantities of coals, large scale experimental test at regular coke ovens (Chinghsing Coking Plant of Shihchiachuang, Hopei) as originally planned does not seem to be worthwhile. But, according to the tests so far made, there still lies a strong hope that Shungkengshan coal can be used for a more noble purpose after being mixed with better coking coals. This purpose is the production of blast furnace coke for iron and steel industry on lower Yangtze.

Hsuancheng and Chinghsien coals are quite promising for blast furnace coke as far as the samples have shown in the test. It seems that Hsuancheng coal has a higher agglutinating value than Chinghsien, but, one weathered sample showed no sign of coking at all. At any rate, these two fields are of little importance as their total reserves are not yet sure and these coals are generally too high in sulphur and ash. Their utilization must wait for further investigation.

SUMMARY.

a. Coal from different seams of different Shungkengshan coal mines collected at different times are not alike in their coking properties.

b. In the first batch of samples, 1st seam S. No. 2 hole and 3rd seam S, 1st seam N and 3rd seam N of 4th hole of Hwainan Mining Administration produce a coking coal of non-swelling nature but form compact and hard mass of coke.

c. 40% Chunghsing or Kailan coal used in blending the above four coals could produce a good coke comparable in shape and swellness with the coke produced from Liuhokou or Tzuhsien coals alone.

d. Coals from Liuhokou and Tzuhsien are not good for blending but those of Kailan and Chunghsing are very good for blending poor coking coals because of their special property of excessive swelling.

e. Tatung coal of Shungkengshan was not investigated seam by seam. The average sample as tested can hardly form any coke even with the ratio of the blend increased to 60% coking coal, but a new sample showed a much better coking quality, even better than all the other samples from the same field. The new sample collected by Chi should be considered as the representative sample.

f. Tests in horizontal gas retort indicate that the new Tatung average sample mixed with 40% Chunghsing coking coal produces a quite desirable coke according to the general appearance.

g. Aside from inefficient transportation facilities and shortage of proper machanical appliance, a trial test on a large scale plant seems worthwhile.

h. Hsuancheng and Chinghsien coals look quite promising for the production of metallurgical coke except for their high ash and sulphur content. But this conclusion is based only on a few samples under test.

i. The medium grade bitumite (Bm) such as Chunghsing and Kailan coals are far better for blending purpose than high grade bitumite (Bh) from Liuhokou and Tzuhsien on account of the excessive swelling character.

ACKNOWLEDGEMENT.

The writer is indebted to Chief Engineer Alston of P.U.M.C. who helped in making the gas retort test and my colleague Mr. Y. S. Chi who made a special trip to Shungkengshan and carefully collected nine new samples for the test. Thanks are also due to Miss T. C. Hung who assisted in the coal analysis.

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TABLE I

Proximate Analysis and Agglutinating Values of Shungkengshan Coals and their Blends.

(Coals supplied by mines)

Lab. No.	Sample No.	Coal provenance	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Heating values (calories)	Agglutinating value
		Hwainan Coals							
483	1	west 4th hole 1st seam S	2.42	33.75	48.53	15.30	——	6577	crumbles
484	2	,, 2nd ,, S	1.74	33.47	39.63	25.16	——	5558	,,
485	3	,, 3rd ,, S	2.11	36.32	48.67	12.90	——	6713	2
486	4	,, 1st ,, N	2.05	39.60	48.54	9.81	——	6712	2
487	5	,, 3rd ,, N	2.15	40.35	48.35	9.15	——	6667	1
488	6	,, 4th ,, N	2.55	36.95	49.30	11.20	——	6765	1
433	7	2nd hole 1st seam S	1.45	36.62	50.41	11.52	0.54	6841	2
355	8	1st hole	2.49	37.32	51.61	8.58	0.90	7029	—
356	9	2nd hole	1.75	37.93	51.70	8.62	0.85	7083	—
357	10	4th hole	2.91	36.46	52.88	7.75	0.68	7252	—
	11	(1) Hwainan	3.30	32.59	50.91	13.20	1.26	6615	—
		Chunghsing, mixture,							
	12	90% 433, 10% 369	1.29	36.56	51.10	11.05	——	7004	2
	13	80% 433, 20% 369	1.14	36.07	52.37	10.42	——	7258	5
	14	70% 433, 30% 369	1.00	35.83	53.44	9.73	——	7247	4
	15	60% 433, 40% 369	0.84	35.46	54.60	9.09	——	7403	5
	16	50% 433, 50% 369	0.78	34.82	55.83	8.57	0.61	7501	5
	17	40% 433, 60% 369	0.61	33.89	57.69	7.81	——	7712	7
	18	90% 433, 10% 374	1.25	37.97	49.18	11.60	——	6769	2
	19	80% 433, 20% 374	1.19	37.47	49.70	11.64	——	6771	2
	20	70% 433, 30% 374	1.13	37.20	49.85	11.82	——	6765	3
	21	60% 433, 40% 374	1.01	36.76	50.31	11.92	——	6745	5
	22	50% 433, 50% 374	0.93	36.28	50.28	12.01	——	6906	5
	23	40% 433, 60% 374	0.73	35.26	54.89	12.12	——	7074	7
	24	70% 433, 30% 365	1.28	31.52	54.33	12.87	——	7227	3
	25	60% 433, 40% 365	1.24	30.54	54.81	13.31	——	7171	2
	26	50% 433, 50% 365	1.20	30.56	54.79	13.45	——	7272	2
	27	40% 433, 60% 365	1.14	30.26	54.95	13.65	——	7248	3
	28	70% 433, 30% 319	1.15	31.25	57.03	10.57	——	7633	2
	29	60% 433, 40% 319	1.05	30.40	58.37	10.18	——	7642	2
	30	50% 433, 50% 319	0.98	28.92	60.10	10.00	——	7703	2
	31	40% 433, 50% 319	0.84	27.21	62.45	9.50	——	7780	2
		Chunghsing, Mixture,							
	32	60% 483, 40% 369							1
	33	60% 484, 40% 369							2
	34	60% 485, 40% 369							5
	35	60% 486, 40% 369							4
	36	60% 487, 40% 369							3
	37	60% 488, 40% 369							3
342	38	Tatung, 1st seam	2 70	41 85	42.68	12.77	0.62	6200	——
343	39	,, 2nd ,,	3.12	36.54	54.14	6.20	0.60	7027	——
344	40	,, 2nd ,,	2.94	37.33	52.73	7.10	0.74	7108	——
345	41	,, 3rd ,,	2.43	36.61	54.80	6.16	1.10	6990	——
346	42	,, 4th ,,	2.96	35.85	50.77	10.42	0.75	6884	——
347	43	,, 8th ,,	1.76	28.93	45.80	23.51	1.50	5857	——
432	44	,, average	1.73	33.49	42.78	22.00	——	5954	crumbles
	45	(1) ,, 1st ,,	2.24	31.42	48.54	17.80	0.73	5901	——
	46	(1) ,, 4th ,,	1.17	36.87	45.46	16.50	1.10	6280	——
	47	(1) ,, 5th ,,	0.70	37.74	50.07	10.80	0.74	5784	——
	48	(2) ,,	3.56	32.27	44.59	19.58	1.21	6722	——
447	49	Hsuanch'eng, Anhui.	0.25	30.20	44.48	25.07	6.37	6063	13
448	50	,, ,,	0.10	33.34	46.68	19.88	4.58	6394	12
449	51	Chinghsien, Anhui.	0.27	26.83	57.40	15.50	0.71	7307	9
450	52	,, ,,	0.20	28.22	58.06	13.06	0.71	7469	6
319	53	T'zuhsien, Hopei.	0.36	21.01	69.46	8.24	——	7075	5
365	54	Liuhokou, Honan.	1.07	23.68	60.05	15.20	——	7284	5
366	55	Chunghsing, Shangtung, (Tats'ao)	0.50	28.20	58.50	11.80	0.66	7504	——
367	56	Chunghsing, Shangtung, (Siaots'ao)	0.38	29.68	58.64	11.30	1.16	7627	——
368	57	Chunghsing, Shangtung, (not washed)	0.24	30.82	58.76	10.18	—— 0.95	7734	——
369	58	Chunghsing, Shangtung, (washed slack)	0.40	31.75	61.05	6.80	——	7990	21
374	59	Kailan, Hopei. (special washed)	0.42	31.98	55.20	12.40	——	7435	20
	60	60% 369 40% 432							2
	61	60% 374 40% ,,							2
	62	60% 365 40% ,,							2
	63	60% 319 40% ,,							1

1. Analysed by a Laboratory in Germany

2. Analysed by Chaiotung University, Shanghai

TABLE II.

Proximate Analysis and Agglutinating Values of Shungkengshan Coals and their Blends

(Samples collected by Y. S. Chi)

Lab. No.	Sample	Coal provenance	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Heating value	Agglutinating value
582	64	3rd seam N. 4th hole west (a) (c), Hwainan	1.77	32.51	51.32	14.40	0.60	6900	1
580	65	3rd seam N. 4th hole west (b), Hwainan	1.22	38.43	43.75	16 60	——	5907	2
579	66	1st seam N. 4th hole west (a), Hwainan.	1.64	37.06	47.79	13.51	0.39	6326	2
577	67	1st seam N. 4th hole west (b), Hwainan	1 40	38.34	46.06	14.20	——	6374	2
583	68	2nd seam S. 4th hole west, Hwainan	1.70	30.88	52.77	14.65	1.83	6865	2
578	69	3rd seam S. 4th hole west (a), Hwainan	1.60	32.32	45.38	20.70	——	6157	crumble
581	70	3rd seam S. 4th hole west (b), Hwainan	2.15	36.13	39.77	21 95	2.29	5479	crumble
584	71	Mixed coals from 2nd seam S. & 3rd seam N. 4th hole W., Hwainan	1.87	30.46	51.91	15.76	0.87	6815	1
585	72	Mixed coals from 3rd seam S & 3rd seam N. 4th hole W., Hwainan	2.04	32.58	48.59	16.79	1.11	6470	2
586	73	3rd seam S. 2nd hole E., Hwainan	2.20	31.10	52.00	14.70	0 85	6920	1
587	74	Tatung average.	1.49	33.03	52.20	13.28	0.66	7011	3
596	75	Chunghsing dust.	0.80	30.42	55.43	12.35	1.71	7570	19
		Chunghsing Mixtures							
	76	40% 596 60% 587	1.19	32.91	53.14	12.76	——	7140	4
	77	40% ,, 60% 586	1.10	30.52	53.06	15.32	——	7331	3
	78	40% 596 60% 585	1.40	31.93	51.47	15.20	——	6921	2
	79	40% ,, 60% 584	1.87	30.46	51 91	15.76	——	6765	1
	80	40% ,, 60% 578	1.57	30.01	50.97	17.45	——	6675	1
	81	30% ,, 70% 581	2.12	32.44	50.94	14.50	——	6821	1
	82	40% ,, 60% 583	1.83	30.05	55.86	12.26	——	7365	2
	83	40% ,, 60% 577	1.37	37.13	48.44	13.06	——	6610	4
	84	30% ,, 70% 579	1.32	34.15	49.46	15.07	——	6700	4
	85	40% ,, 60% 580	0.61	30.56	55.78	13.05	——	7304	4
	86	40% ,, 60% 582	1.87	30.46	51.91	15.76	——	6806	2

TABLE III.

Comparison of General Appearances of Coke Button and Low Temperature Coke.

(Coal supplied by mines)

Lab. No.	Coal Provenance	Appearance of coke Button	Appearance of Low Temperature coke at 600°C
483	Hwainan Coal Mine, Shungkeng-shan, Anhui, 4th hole, west 1st seam S.	Dull grey-black, very, slight surface fusion. No swelling.	Dull black, coherent very fragile, no swelling, little powder,
484	Hwainan Coal Mine, Shungkeng-shan, Anhui, 4th hole, west 2nd seam S.	Grey, slight surface fusion, very slightly swollen.	Dull black, coherent, very fragile; no swelling, no powder.
485	Hwainan Coal Mine, Shungkeng-shan, Anhui, 4th hole west 3rd seam S.	Steel grey, with granular and partly fused surface, slightly swollen.	Grey black, lustrous in places, hand and compact mass, no swelling.
486	Hwainan Coal Mine, Shungkeng-shan, Anhui, 4th hole, west 1st seam N.	Grey, partly fused surface, swollen.	Grey black, lustrous in places, very compact, fissurous, no swelling.
487	Hwainan Coal Mine, Shungkeng-shan, Anhui, 4th hole, west 3rd seam N.	Dull grey, slight surface fusion, practically no swelling.	Grey black, compact & fissurous, no swelling.
488	Hwainan Coal Mine, Shungkeng-shan, Anhui, 4th hole, west 4th seam N.	Dull grey-black, very slight surface fusion practically no swelling.	Dull black, coherent, very fragile, no swelling, little powder.
433	Hwainan Coal Mine, Shungkeng-shan, Anhui, 2nd hole, 1st seam S.	Steel grey, with granular and partly fused surface, slightly swollen.	Grey black, lustrous in places, hard but fissurous, no swelling.
432	Tatung Coal Mine, Shungkeng-shen, Anhui, average sample.	Black, loosely coherent, slight swelling.	Black powder mostly, little particles loosely coherent.
447	Shuitung Kuankuon, Tawang-ts'un, Hsuanch'eng, Anhui.	Steel grey, lustrous, fused furface, considerably swollen.	Grey black, strong lustre, considerably swollen.
448	Shuitung Kuankuon, Tawang-ts'un, Hsuanch'eng, Anhui.	Similar to 447.	Same as 447
449	Huamit'ang, Ching Hsien, Anhui.	Similar to 447.	Grey black, strong lustre swollen.
450	Yenkungt'ang, Ching Hsien, Anhui.	Similar to 447.	Same as 449.
329	Yili Company, Hsitso, T'zu-hsien, Hopei. Top coal.	Silver grey, strong lustre, fused surface, swollen.	Grey black, lustrous, fairly hard but porous, swollen.
365	Liuhokou, Honan.	Steel grey, lustrous, fused surface and swollen	Grey black, lustrous, hard and swollen.
369	Chunghsing Company, Shantung, washed slack.	Silver grey, strong lustre, fused surface, considerably swollen.	Lustrous, much swollen and with hard porous structure.
374	Kailan Mining Co., Kaiping, Hopei special washed slack.	Same as 369, more swollen.	Similar to 369 with still porous structure.
A	60% 369, 40% 433	Grey black, lustrous, fused surface and swollen.	Lustrous in places, much swollen and with hard porous structure.
B	50% 369 50% 433	Grey black, lustrous, fused surface swollen.	Lustrous, hard, swollen porous.
C	40% 369 60% 433	Similar to B but not so swollen.	Similar to 365 but more lustrous.
D	30% 369 70% 433	Similar to C, but less swollen	Grey black, lustrous in places fissurous, little swollen.
E	20% 369 80% 433	Similar to D, little swollen.	Grey black, lustrous in places, fissurous, no swelling.

TABLE IV.

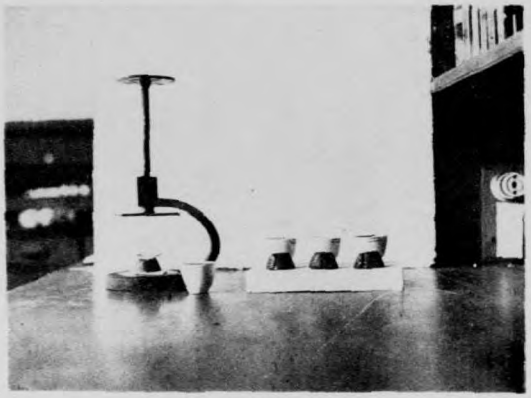
Analysis of Cokes produced in Gas Retort

Lab. No.	Samples	Moisture	Volative matter	Fixed carbon	Ash
1	40% 596[1] 60% 587[2]	1.45	2.37	78.01	18.17
2	40% 596 60% 586[3]	0.95	6.07	76.53	16.45
3	40% 596 60% 585	1.09	4.56	72 94	21.41
4	40% 596 60% 584	1.70	3.72	76.03	18.55
5	40% 596 60% 578	2.15	2.68	76.67	18.50
6	30% 596 70% 581	1.94	4.38	76.02	17.66
7	40% 596 60% 583	2.05	3.95	74.25	19.75
8	40% 596 60% 577	0.48	6.74	75.51	17.27
9	30% 596 70% 579	1.69	2.46	75.71	20.14
10	40% 596 60% 580	1.37	3.20	74.86	20.57
11	40% 596 60% 582	1.14	2.14	77.65	18.07

1. Chunghsing dust.

2. Tatung average sample collected by Chi.

3. All other samples from Hwainan, Shungkengshan collected by Chi.



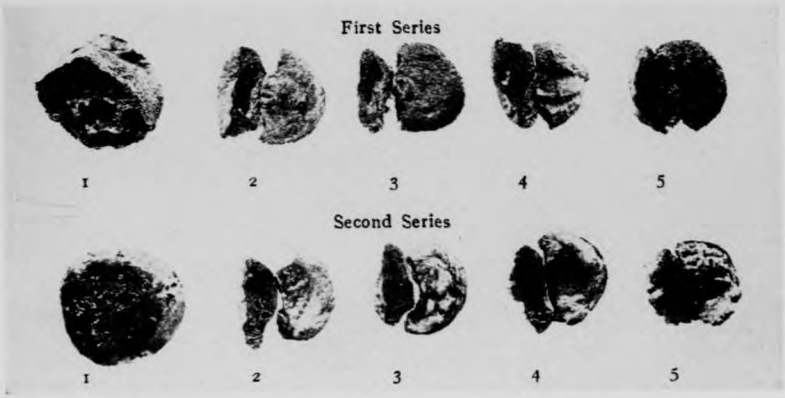
1

Testing apparatus for Agglutinating Value of Coal showing crucibles used in carbonization and the button under test as well as the crushed buttons. Note the cracks.

2

An assembly of apparatus for the Low Temperature Carbonization Test showing the electric tube furnace, tar collector, ammonia absorber, gas holder, leveling bottle, thermo-couple, pyrometer and ammeter.

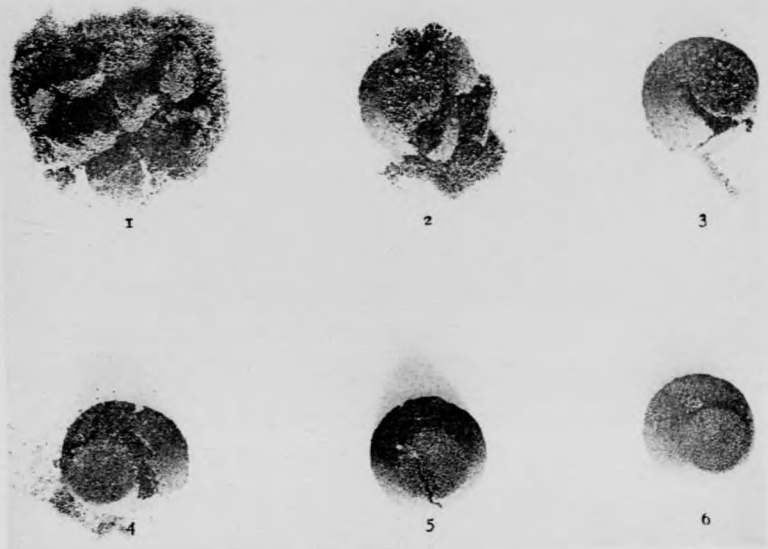
Comparison between Coke Buttons of Coal and Coal Blends resulting from Volatile Matter Determinations.



First Series: (1) 100% Chunghsing, (2) 60% Chunghsing, 40% Hwainan, (3) 50% Chunghsing, 50% Hwainan, (4) 40% Chunghsing, 60% Hwainan, and (5) 30% Chunghsing, 70% Hwainan. Note the excessive swelling of Chunghsing Coal and the gradual decrease in swellness as the amount of Hwainan coal increases.

Secondary Series: (1) 100% Kailan, (2) 60% Kailan, 40% Hwainan, (3) 50% Kailan, 50% Hwainan, (4) 40% Kailan, 60% Hwainan, and (5) 30% Kailan, 70% Hwainan. It seems that the Kailan coal gives more lustre than Chunghsing coal, otherwise, the difference is only slight.

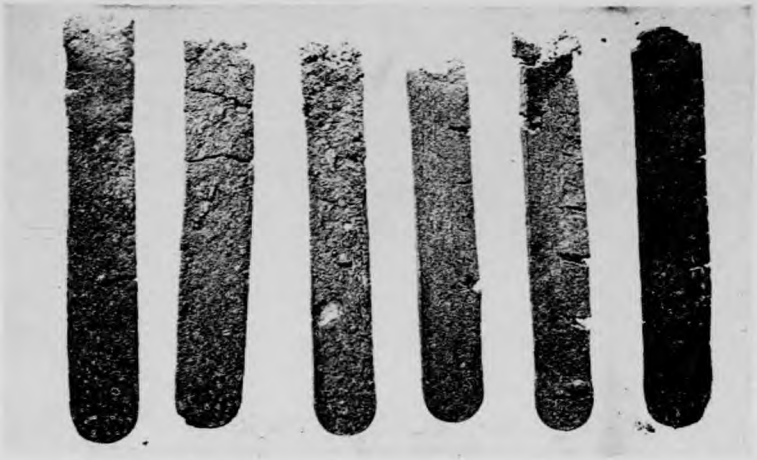
Agglutinating Value Test Buttons.



1.—Shungkengshan coal (100%)
2.—Shungkengshan coal (55%), Chunghsin coal (45%)
3.—Shungkengshan coal (50%), Chunghsin coal (50%)
4.—Shungkengshan coal (45%), Chunghsin coal (55%)
5.—Shungkengshan coal (40%), Chunghsin coal (60%)
6.—Chunghsin coal (100%)

Note the difference in shape between the coking characters of 100% coals and their blends.

Low Temperature Coke Buttons from Different Hwainan Coal Seams produced in L. T. C. Test (Coal supplied by mines)



1.—1st seam S. 4th Hole West, loosely coherent mass and slightly swollen.

2.—2nd seam S. 4th Hole West, similar to 1.

3.—3rd seam S. 4th Hole West, hard and compact coke little swollen and surface fusion. This is perhaps the best coking coal among all the Hwainan coals tested.

4.—1st seam N. 4th Hole West, hard and compact coke slightly swollen and very little fused surface.

5.—3rd seam N. 4th Hole West, hard and compact coke quite fissury, little fused surface, very similar to the 2nd seam S, No. 2 Hole.

6.—4th seam N. 4th Hole West, loosely coherent mass but stronger than No. 1 and 2, slightly swollen and very little fused surface.

Low Temperature Coke Buttons from different proportions of Chunghsing and Hwainan, Shungkengshan coals.

1 2 3 4 5

1.—60% Chunghsing (washed coal) 40% Hwainan (1st seam S No. 2 hole,) considerably swollen with hard porous structure, quite lustrous.

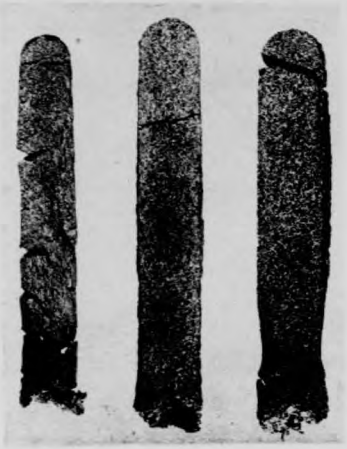
2.—50-50 Blend of Chunghsing and Hwainan, much swollen with hard and porous structure, Lustrous in places.

3.—40% Chunghsing and 60% Hwainan, much swollen with a very uniform hard and porous structure. Lustrous in places. This structure is very similar to that of 100% Lu-ho-kou.

4.—30% Chunghsing and 70% Hwainan, little swollen, quite fissury but hard coke. Lustrous in places.

5.—20% Chunghsing and 80% Hwainan, slightly swollen, hard and compact coke with little lustre. Quite fissury and very similar to the original 100% Hwainan Coal.

Comparison between L. T. C. test cokes obtained.



1 2 3

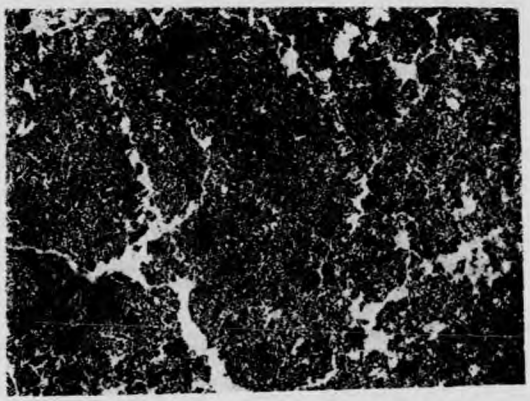
1. 100% Hwainan coal (1st seam S. 2nd Hole) Note its fissury structure. The coke as a whole is quite hard and compact. Little porosity. Surface fusion small and lustrous in places.
2. 60% Hwainan Coal and 40% Chunghsing coal, normally swollen, quite porous and hard. Fused surface and lustrous. Its cell structure is fairly uniform.
3. 100% Liuhokou coal, being known as a good coking coal. The general structure and the porosity appears very similar to No. 2 coal blend (60% Hwainan and 40% Chunghsing) except that of Liuhokou is little more swollen than the blend.

1

Gas retort coke from 33% Volatile matter and 12.8% Ash. "Coal Mixture" of 40% Chunghsing coking coal and 60% Tatung poorly coking coal ½ full size.

1

Retort coke from coal mixture of 40% Chunghsing coal and 60% Tatung coal of Shungkengshan. *Cells filled with white composition.* × 1.



2

Retort coke from coal mixture of 40% Chunghsing coal and 60% Hwainan (1st seam N. 4th hole west) of Shungkengshan cells filled with white composition. × 1. *Notice the high* ash (40%) black particles.

之成功，本篇之結論克以更爲證明也。

份Bl（舜耕山）六十份時，其合煤粘性可與 Bh（磁縣或六河溝）幾相等。推原其故，蓋因 Bm 煉焦煤中之膨性特高耳。膨性特高於煉焦固有益，但亦不必如此之膨脹，否則磁縣六河溝煤不可製焦炭矣。Bh 之本身可以製焦，其無補於合煤，乃因其膨性之不足耳。是以 Bm 之特膨性，非獨可以本身製焦，並可補他煤粘膨兩性之不足者，如 Bl 類。Bh 煤祇能單獨煉焦，對於合煤毫無補益，此中與開灤之所以可貴也。

舜耕山煤各層優劣固不相同，其粘性亦復不一律，其原因則不得而知。計君所取者，知爲渠親自採集者，當最可靠，惜爲雨水淋洗，致不能代表淮南礦務局各井各層煤樣。各礦所送驗者亦不差，惟不知其採集法如何耳。最奇者爲大通統煤，其先後煤樣性質之差，出乎意外。淮南各層煤粘性之不同，或由灰份所致，蓋據分析所得，灰份之高者粘度則低，而反是者則稍高。如此論可證實，則洗煤機之設備，當有補益於舜耕山各煤之粘性也。

吾國可煉焦之煤，其加水燃率大都在一·六至三·六之間，其最低度似不能在一·六以下。今舜耕山烟煤之加水燃率皆不出一·四，理當不可煉焦，如其合煤在一·六以上當有煉焦希望，但此不可概論之。苟其燃率在一·六以上，而又兼有粘性在五六度之間者，大約俱有煉焦希望，否則恐難製焦。

大規模試驗，爲證明此研究實爲不可少者，然舜耕山處於津浦路，而井陘煉焦廠則遠在石家莊，又非平漢路不能達，苟欲實地試驗，其數量約不在二十噸以下，運輸上當感受困難，（此次運二噸淮南煤至北平時，共計十餘日之久，致各煤遍受雨淋，亦是此故。）況井陘煉焦廠，又無碎煤機器，而淮南煤大約均爲大塊，用人工打碎，恐又須虛費時日，（此次軋煤，乃用本所備有之小碎煤器，費事費時不少，欲將二十噸之多在本所試驗室內軋碎，勢所不能，）如不軋碎，用大塊煉焦，理所不許。況此次乃爲合煤試驗，不軋碎則不能混合，不混合則不克將各成份參勻，其結果較之小規模者當更不可靠。但煤質複雜，勢不可完全倚賴小規模試驗，爲確實證據也。

工業上試驗，往往由小而中，由中至大，今中小兩試驗俾可暫告結束，所待者乃正式煉焦試驗，甚盼早日得有相當方便，使

其膨脹性亦高，半焦之色澤亦亮，中興開灤粘度何以高至二十而舜耕山之煤祇有兩度者，蓋皆因膨脹性之分別故耳。至於何種物質能使其有脹性及粘性，則現時尚在試驗中，不敢斷言，大約或與煤中松香樹脂及炭輕兩質化合物有密切關係。磁縣六河溝二煤，已知其粘度不高，故其膨脹性亦遠不如中興，今舜耕山中興合煤第二十八號已知其粘度與磁縣者相仿，但尚不知其他性質，據此試驗，乃悉其他種性質均相仿，而其光澤復勝之。因此可重伸前說，第二十八號合煤卽四十份中興煤六十份舜耕山煤之煉焦性當不在磁縣之下，磁縣煤既可煉焦，則合煤第二十八號之可製成冶金焦炭，亦無疑矣。（半焦狀態比較見附圖第四五六版）定揮發物時所剩之焦塊狀態（見附圖第二版）雖亦可分出優劣，但不如半焦之顯明，再粘度與炭焦狀態比較，較之與焦塊更爲吻合。又裂痕與質之鬆硬等，在半焦上均能現出，並可察其副產品之多寡，故低溫蒸溜法于此種研究似較合宜。

夫小規模試驗結果，往往與正式煉焦爐者不同，此種困難已屢見聞之矣。各國試驗煉焦均主張用正式爐試驗，然所費太鉅，不易實行，此次因各種關係，亦未能用大爐證明，前已述及矣。協和煤氣廠所產之合煤焦，經一度試驗之後，雖較小規模者易得要領，但未能確實證明此合煤焦是否適於冶金，祇知所產焦有堅鬆兩種，其最堅者爲大通統煤（42號），最鬆者爲西四井南三槽乙種煤（45號）及北三槽甲乙丙三種（48及49號）。其堅鬆固未能與粘度同高下，然大致尚不差。（焦見附圖第七版）將煤磨成平面再摩入白粉後，焦中細孔顯現，其結構情形與井壁之剖面亦不過如此，惟發見小黑點甚多，鑲嵌於焦內，（見附圖第八版圖二）乃檢出分析之，始知其爲高灰份物約百分之四十。大通統煤所成之焦，小黑點較少，（見附圖第八版圖一）因此其焦堅硬，因此推想高灰份物之與焦，或有妨礙，亦難言也。

（五）結論

中興開灤磁縣六河溝四處煤皆可煉焦，就中以中興爲最著名，據翁氏分類法，前兩者應列 Bm，次二者 Bh。Bh Bm 之分別固在其揮發物之多寡，或可以其膨脹性區別之。（恐祇限於煉焦煤而已）膨性高者爲 Bm，其較低者爲 Bh，此外之 Bl，大半僅稍粘而已，於煉焦不宜。但將中興磁縣混入於舜耕山（Bl）煤中，則 Bl 煤粘性可得增加。在 Bm （中興或開灤）四十

2	全右惟無不粘粉末	全右惟稍現膨性	微
4	色深灰兼有光澤，團結而不膨，質硬而緊，	色如鋼灰，溶結點稍多，稍膨，	二
7	全右惟有裂紋	全右	二
10	全右惟無光澤	全右惟無膨性	一
13	狀態與第一號同	色暗灰，溶結點少，微有膨性，	一
16	狀態與第四號同	與第三號同	二
18	黑色，幾不粘，粉末甚多，	黑色稍有粘結性	無
20	鋼灰色，甚光亮，膨脹性極強，質多孔，	銀灰色，甚光亮，塊面完全溶結，脹性極強，	廿一
22	全右惟質更多孔	全右惟脹性更強	廿
23	深灰色，光澤亦亮，而膨脹性亦強，	鋼灰色，光亮，塊面溶結，膨脹性強，	十三
24	深灰色，光澤高，有膨脹性	全右	九
25	深灰色，有光澤，質硬而多孔，有脹性，	與二十號同惟膨脹性特差	五
16	全右	與二十三號同惟脹性不及	五
29	色灰而有光澤，脹性甚強，質硬而多孔，	深灰色有光澤，溶結點多，脹性高，	五
28	與二十六號相同惟更亮	與廿九號同惟脹性不如	五

細察第二表半焦狀態，始知各煤性質完全不同，而對於膨脹性及光澤尤顯而易見，其最可注意者，卽凡煤之粘度高者，

煙煤能有幾何。宜涇煤田儲量如何現尚不明，但其硫份過高，常在百份之五左右，雖其粘性亦高，對於冶金當不合宜，暫可不論。碭縣六河溝之煤可以製成焦炭爲冶金之用，所成之焦色澤硬度等均尚佳好，而其煤本身粘度則不甚高，約在「五」左右。照上述經驗，則煤之能製焦炭者，其粘性固不必十分過高，約在「五」度即可，今舜耕山煤粘度祇在一二之間，如能參入他種高粘性煤，將其粘度提高至五度，理應可得一煉焦煤如碭縣六河溝者。是以將中興開灤煙煤及其他者逐步分配混合於舜耕山煤，製成焦塊，以壓力試其粘度。試驗結果已擇其主要者列入附表，如將其結果詳細比較，（第一表二十五至三十四號）乃知中興或開灤四十份合舜耕山東井南一槽煤六十份，可得與碭縣六河溝粘度相仿之合煤，其成份各五十份時，粘度仍舊，並不見混。如用碭縣六河溝與之混合，雖成分增至五十份，其粘度仍如舜耕山原煤。故可斷言中興開灤之有益於合煤煉焦，而碭縣六河溝則否。

舜耕山煤層甚多，各層應有其特別性質。茲爲鑒定各層煤粘度是否相同，故將各層用四六成份混合試驗，（第一表三十至四十一號）始知各層煤粘度頗有出入，西四井之南三槽及北一槽與所試之東井南一槽相同，餘則均不如之。再各次所採之煤，粘度亦多出入，尤以大通統煤爲最甚，一則粘而一則不粘，此蓋因採集法之不同耳。大概論之，舜耕山各層固各具特別性質，而大致相似。就淮南礦區而言，西四井南三北一兩槽及東二井南一槽之煤爲上選。大通公司之煤並未將其各層次序研究，所試驗之兩種統煤，相差太多，不敢斷言，然亦決不致無合煤之可能也。

合煤成份之比例既可用粘度試驗法定之，以粘度之高下爲標準，然煤之膨脹性，焦性，及焦炭色澤等，均不能同時顯出，於是乃利用低溫乾蒸溜法試驗之，其主要成績，均列入第二表，

第二表

號數	半焦狀態	粘度
1	色暗黑，團結無膨性，質鬆有不粘粉末	色暗深灰，溶結點甚少，不膨脹，	微

40	合 26	六十份 四十份	二十三號						三
41	合 27	五四十份	二十八號						二
42	合 31	四六十份	十九號	三八・二三	六一・七七	一二・九一	一・五七	Bl	四
43	合 37	四六十份	三號	三五・〇二	六四・九八	一二・五〇	一・七五	Bm	二
44	合 35	四六十份	五一號	三七・〇四	六二・九六	一七・七四	一・六二	Bl	一
45	合 36	四六十份	六號 廿一	三八・九〇	六一・一〇	一四・八三	一・四八	Bl	一
46	合 39	四六十份	八號 廿一	四〇・八四	五九・一六	一五・一九	一・四〇	Bl	四
47	合 38	四六十份	九號 廿一	四三・四三	五六・五七	一三・二三	一・二六	BC	二
48	合 41	四六十份	十一號 廿一	三七・〇四	六二・九六	一六・〇七	一・六〇	Bl	二
49	合 40	四六十份	十二號 廿一	三五・三二	六四・六八	一三・二二	一・八五	Bm	四
50	合 32	四六十份	十七號 廿一	三六・五五	六三・四五	一五・五二	一・六八	Bl	三

（四）研究成績及其比較

揮發物分析時所餘剩之焦或團結或否，照普通經驗，對於煤之粘結力，當可知其大概，（見附圖第二版）但因所用煤量既微，蒸溜時粘亦不免過速，（祇七分鐘）因此成績往往頗有出入，祇能察其大略耳。壓力試驗結果，雖未能十分符合，但大體不差。中興開濬粘度最高，宣城涇縣次之，磁縣六河溝又次之，舜耕山者則幾不粘，（見第一表未行粘性）由此可深信中興開濬煙煤之可以製煉冶金焦而舜耕山煤則不能煉焦。蓋煤能製焦者，其粘性當愈高愈好，舜耕山煤既缺團結性，自屬不能成焦。但煉焦之煤，其粘性應有一限度，決不能謂非具高粘性者不可。中興開濬煤爲國內所不可多得者，如捨中興開濬煤不能煉焦，則國內之煉焦

24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
四四九	三一九	三六五	合3	合4	合5	合9	合10	合11	合19	合15	合21	合22	合23	合24	合25
安徽涇縣費眉堂	河北磁縣怡立公司頭煤	河南六河溝	七十份 三十份 二十六號	六十份 四十份 二十六號	五十份 五十份 二十六號	七十份 三十份 二十六號	六十份 四十份 廿六號	五十份 五十份 廿六號	五十份 五十份 廿五號	五十份 五十份 廿六號	六十份 四十份 二十一號	六十份 四十份 二十二號	四十份 四十份 二十四號	六十份 四十份 二十七號	四十份 六十份 二十號
三一・八五	二二・七二	二八・一五	四〇・二一	三九・四五	三八・五〇	四二・七八	四二・二一	四一・六三	三二・四六	三五・八二					
六八・一五	七七・二八	七一・八五	五九・七九	六〇・五五	六一・五〇	五七・二二	五七・七九	五八・三七	六七・五四	六四・一八					
一五・五四	六・四七	一五・〇七	九・八三	九・一六	八・六四	一一・九七	一二・〇五	一二・一三	一〇・一〇	一三・六四					
二・一二	三・一一	二・四三	一・四五	一・五一	一・五七	一・三〇	一・三四	一・三四	二・〇一	一・七三					
Bm	Bh	Bm	Bl	Bl	Bl	Bl	Bl	Bl	Bm	Bm					
九	五	五	四	五	五	三	五	五	二	二	一	二	五	四	三

8	五七九	全右	北一槽甲	四三・六八	五六・三二	一三・八〇	一・二四	BC	二														
9	五七七	全右	北一槽乙	四五・四三	五四・五七	一四・八〇	一・一七	BC	二														
10	四八七	全右	北三槽	四五・四九	五四・五一	九・三五	一・一四	BC	一														
11	五八二	全右	北三槽甲及丙	三八・七八	六一・二二	一四・六〇	一・五〇	Bl	一														
12	五八〇	全右	北三槽乙	四六・七六	五三・二四	一六・八〇	一・一〇	BC	二														
13	四八八	全右	北四槽	四二・八四	五七・一六	一一・九六	一・二五	BC	一														
14	五八四	全右	南二槽及北三槽統煤	三六・九八	六三・〇二	一六・三〇	一・五七	Bl	一														
15	五八五	全右	南三槽及北三槽統煤	四〇・一四	五九・八六	一七・二一	一・四一	Bl	二														
16	四三三	全右	東二井南一槽	四二・〇八	五七・九二	一一・六八	一・三三	Bl	二														
17	五八六	全右	東二井南三槽	三七・四二	六三・五八	一五・〇五	一・五六	Bl	一														
18	四三二	安徽舜耕山大通煤礦統煤		四三・九一	五六・〇九	二三・三〇	一・二二	BC	無														
19	五八七	全右統煤（樣較新）		三八・七五	六一・二五	一三・四二	一・五一	Bl	三														
20	三六九	山東中興洗煤		三四・二一	六五・七九	六・八二	一・九一	Bm	二十一														
21	五九六	全右煤末		三五・〇三	六四・九七	一二・三五	一・八一	Bm	十九														
22	三七四	河北開灤特別洗煤		三五・九六	六四・〇四	一二・三四	一・七二	Bm	二十														
23	四四七	安徽宣城大汪村		四〇・四四	五九・五六	二五・一四	一・四七	Bl	十三														

此次所試驗之原煤共四十種，合煤又四十種，舜耕山煤樣佔大部，該煤共分兩種，其一來自該處之大通煤礦，其二來自淮南礦務局。各處煤樣有礦廠送驗者，然大都爲本所許榮森君所採集。大通煤礦煤樣，時優時劣，係檢樣時之不一其法，抑各層煤之區別甚廣，則不得而知。淮南煤樣則不然，優劣顯因層次關係而分，且不同時採集煤樣，其區別甚少。許君所採集者，爲量最大，適值夏雨之時，全部樣煤被水淋者多次，其一部份煤末由儲煤袋中冲出，其大塊者亦不免風化，致未能實在代表該煤田煤質，甚爲可惜。中興煤有洗煤末洗煤及煤末之別，開灤樣爲特別洗煤，磁縣六河溝宣城涇縣等煤樣亦皆本所所採集者。合煤樣，首先自一份粘煤九份低粘煤起，次第混合，至一份低粘煤九份粘煤爲止。至得六七份低粘煤，三四份粘煤之數爲合式之比例。其餘合煤樣，均依照此例配合之，分析之。各樣均經過實用分析後，再加於各種試驗。茲特將各原樣煤及主要合煤樣之詳細產地，純揮發份，純固定炭，濕潮樣灰份，種類記號，及試驗號分列以次，

第一表

號數	化驗室號數	產地	純揮發份	純固定炭	濕潮樣灰份	加水燃率	種類記號	粘性
1	四八三	舜耕山淮南礦 西四井 南一槽	四一・〇二	五八・九八	一五・六七	一・三四	Bl	微
2	四八四	全右 南二槽	四五・七九	五四・二一	二五・六〇	一・一三	BC	微
3	五八三	全右 南二槽	三六・九二	六三・〇八	一四・九〇	一・六二	Bl	二
4	四八五	全右 南三槽	四二・七三	五七・二七	一三・二八	一・二七	BC	二
5	五七八	全右 南三槽甲	四一・六〇	五八・四〇	二一・一〇	一・三四	Bl	微
6	五八一	全右 南三槽乙	四七・六六	五二・三四	二二・九〇	一・〇四	BC	微
7	四八六	全右 北一槽	四四・九三	五五・〇七	一〇・〇一	一・一七	BC	二

來或有更改之處。

（二）低溫蒸溜試驗—壓力試驗法，祇能測定煤之團結力高下，至於膨脹性焦性等，則當以蒸溜試驗察定之，此法已經採用於英德兩國，以測計煤之副產品。但本室之重要目的，並不在此，故其儀器裝置法（見附圖第一版圖二）雖相彷彿，而意旨頗各不同。茲將其試驗法加以說明，將七分對徑八寸長硬玻璃試管一根，在口端下邊加一長管，以容油及氣之流出。十克原煤或合煤鋪平，置於管之一邊，長約三寸。其所用電爐，爲一管狀式者，將電爐燒熱至三百度時，即將貯煤管插入，漸漸增高其溫度，約每分鐘五度左右，至六百度爲止。在六百度時，再蒸溜一小時，其油氣兩體亦同時流入相當玻璃器皿，並定其多寡，作爲副產品記錄。所成之半焦，經冷却後，由管中取出，察其膨脹性團結性及焦之色澤與裂痕等。然後將各種半焦之性質，互相比較，以甄別其優劣。

（三）煤氣爐試驗—爲證明上述兩試驗結果是否可信，當用大規模煉焦爐試驗之。但我國正式大煉焦爐，現時祇井陘煉焦廠有之，曾一度與之商借，已蒙慨諾，嗣因所費煤樣太多，及運輸與機器之不便，遂暫中止。土法煉焦需煤亦多，取費亦復不廉，故暫用本市協和醫學校煤氣爐。此爐雖未能盡善，但其需煤少而又近在城內，試驗時大有方便之處，遂決與之商用。是爐爲橫式，共分四穴，每穴可容煤約四百磅，最高熱度祇能到攝氏九百度，較之正式爐約低三百度。煉焦時每穴各置三百磅合煤末，其合煤各成分，先在本所試驗室將各原樣煤，用小碎煤機壓碎，然後稱出各成份數量，次第混合，裝入蔴布袋運至協和煤氣廠。其煤末之送入爐穴，均用人工，爐之熱度已於四日前燒起，故試驗時其最高度已達九百矣。煉焦時間爲八個鐘頭，本擬延長至十二個，因其穴口封閉法不嚴密，恐空氣內侵，燃及焦炭，遂止於八小時。焦炭取出之際，即用凉水冲滅，以免燃燒。冷却後檢出一小部份，送回本所試驗室研究之。破碎試驗，爲試焦法之最得用者，但本所無之，故祇可視焦炭裂痕之大小，微孔之虛密而已。其法迺將焦炭磨成一平面，其縫內孔內均擦入白粉，如此則焦黑而孔及痕俱白，一目了然，其優劣可由此判別之。

（三）煤樣說明

合煤法不能製煉。

今舜耕山之煤已言明爲 B1 類，又其粘性微而絕無膨脹性，故擬用合煤法製煉焦炭。所合之煤，應首還中興開濬，次及磁縣六河溝。中興於地勢論爲最合宜，開濬雖遠處北方，但可水運，亦不能稱爲不便。磁縣六河溝煤田，其路程較遠，然亦舜耕山鄰近具上好粘性烟煤之最便者。因是本試驗所以選此四煤爲混合微粘不膨之舜耕山烟煤也。

(二)試驗法

本所所用試驗煉焦方法共分三種。其一二兩種，規模甚小，其用意在辨別各混合煤之能否煉焦，及測定各煤之混合比例，其第三種爲證明一二兩種所得結果，是否有效，故其試驗較大。茲將各試驗法及其結果分述如下，以資考證，

(一)壓力試驗—小規模試驗，其種類亦繁，大都未能得要領，由尋常定揮發物時所餘剩焦炭之粘結與否而斷言之，雖用之甚夥，然往往不能得準確成績。現據各方試驗，均以烟煤之能黏結純沙或淨炭之多寡，有則用同量沙或淨炭與碎煤之團結力，以計其煉焦性。此法雖用之者衆而且久，但尚無一定試驗法，今特採用此意而暫定下列試驗方法。各種烟煤小塊經乾燥後，用磨煤器磨細，過每寸六十眼之銅篩，盛入嚴密玻璃瓶內，其合煤樣均用準確天秤配齊，裝於同樣瓶中。試驗粘性時所需之混雜物，當可用淨炭或純沙，但平地附近均不易覓得，故改用井陘焦炭，是炭廉而易得，現已備有大宗，俾每次試驗時，其性不致相差過遠。配樣時將炭磨細過篩，而祇取其在每寸四十孔篩以下在六十孔篩以上者，亦貯存於瓶內。在試驗之先，將十一克半井陘焦炭盛入三十cc乾蒸鍋，再加一克半原煤或合煤，用牛角棒和勻之，漸加五千克重量於其上，爲時準一分鐘，使煤及焦炭成塊狀。乾蒸鍋空餘處，用二十孔以下四十孔以上篩出之焦炭末盛滿之，鍋上再覆以磁蓋，然後置入電爐內，其熱度爲九百四十度至九百七十度之間，用電氣計量器測定之。十分鐘後取出，置于鐵板上冷却之，二十句鐘後，用下列方法以定其粘性強弱。其法(其儀器見附圖第一版圖一)乃將所成煤膠結塊平放於鐵板上，每塊之上下蓋一層紗布，然後將一四百克重之金屬，自六生的高壓下之。其塊之堅硬，即該煤或合煤之粘結性，以其能耐此壓力數次甄別之。上述方法，雖試驗已久，其結果亦稱準確，但尚未能盡善，將

安徽舜耕山烟煤煉焦之試驗

金開英

（一）緒言

實業部有設立鋼鐵廠於揚子江下游附近之計畫，其目的在開發安徽南部鐵礦，是以需煉焦煤甚殷。但我國可煉焦烟煤，大部蘊藏於北方，如山東之博山中興，河北之開灤井陘，河南之六河溝，遼寧之本溪湖等，其在南方者，除江西萍鄉外，餘如安徽之宣城涇縣，湖南之譚家山，浙江之長興，雖或爲煉焦烟煤，但究屬若何，及其儲量等等，尙須待調查試驗而後可知。中興烟煤爲國內現在煉焦煤中之最佳者，其黏性特高，揮發物約在百分三十有幾。其焦質堅硬。微孔亦多，對於冶金當甚相宜。該礦離揚子江下游不遠，又有津浦運輸之便，應當首選。其儲量豐富，而黏性特高，如此上好烟煤，在國內頗不易得，今用之單獨煉焦，滋爲可惜。苟可利用其高黏結性，與他種微有黏性烟煤摻合而煉焦，倘能得可用之冶金焦炭，非特可節省中興上等煉焦煙煤，並得多利用不能煉焦煙煤，乃一舉兩得之計也。

安徽懷遠縣舜耕山，蘊藏低級煙煤甚富，其揮發物約在百分四十左右，雖其各層煤性質互有出入，總言之則其黏性極微，又無膨脹性，所成之焦，質鬆而色澤不佳，因此是煤之單獨煉焦，可謂絕無希望。但從地勢而論，幷不計及其煉焦等因，該煤田應較中興爲優，蓋其與現時暫定鋼鐵廠地址爲最接近，如能用鐵道連接，由懷遠縣一直南下，其運輸之便，當爲上乘。因此之故，本所採用合煤之法，改良該煤黏性及膨脹性，以期能得可煉冶金焦而其價值又廉之煤。

合煤煉焦之法，各國沿用已久，其意義或在改良其煉焦性，或增加焦炭之硬度。（日人所經營之本溪湖煉焦廠亦應用是法製煉）凡沿用是法者，應得具高粘性之煤爲主，無粘性者爲副，或稍粘者爲主，高黏者爲副。我國烟煤約分三類，卽 Bh 高碳烟炭，Bm 中碳烟炭，及 Bl 低碳烟炭是也。Bl 煤粘性固高，但膨脹性甚微，如磁縣六河溝井陘等，然亦兼有高膨脹性煤如山東博山之烟煤。Bm煤大部兩性俱兼，如中興開灤萍鄉等。Bl 煤則粘膨二性具差，舜耕山賈汪大同各煤俱屬此類，長興煤亦在 Bl 之例，但其膨性則甚高。故凡選擇粘膨兩性之煤，當集中於 Bm，而粘性一種者則用 Bh 。用 Bl 烟煤單獨煉焦，當不合式，恐非用

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ON THE OCCURRENCE OF SPHÆROSIDERITE IN A SUBBITUMINOUS COAL FROM HSIAN COAL MINE, LIAONING PROVINCE§

BY

C. Y. HSIEH* (謝家榮)

(Contribution from the Sinyuan Fuel Laboratory No. 7a)

(With two plates)

1. INTRODUCTION.

Mr. T. F. Hou, geologist of the National Geological Survey of China brought back in 1931 from Liaoning province, a specimen of subbituminous coal in which are included patches or aggregates of small oolites. This interesting specimen was given to the writer for microscopical investigation. Both polished and thin sections were made and the result of microscopical study shows that these oolites are composed chiefly of siderite or ferrous carbonate and what is of more interest is that practically every oolite has in its center a piece of wood fiber which shows more or less well preserved structures. Such oolitic siderite containing plant remains is called in German, "Sphærosiderite".

Sphærosiderite and its related forms such as coal balls of dolomitic composition etc. are of frequent occurrence in coal seams of Germany, England and other European countries. They are comparatively rare in American coal fields, as description of them is scanty among the literature. As both sphærosiderite and coal balls contain frequently well preserved plant tissues, they are therefore considered by Palæobotanist as the best material for the study of the anatomy of the ancient plants. In fact most of our knowledge in regard to the internal structure of the Palæozoic plant life have been derived from such a study.

In view of its value in palæobotanical investigation, the discovery of the first occurrence of sphærosiderite with plant tissues among the Chinese coal seam, is therefore of special interest to deserve a short description as follows:

2. FIELD OCCURRENCE.

The Hsian coal mine is located about 3 km north of Hsian city in

§ Manuscript received—August 1932.

* Geologist, Geological Survey of China, Professor of Economic Geology, National University of Peking.

Liaoning Province. The principal coal seam worked is seam No. 3 (counting from below upwards) which has a thickness of about 5 m. At the North end of the No. 1 open cut Mr. Hou found a lenticular layer of sphærosiderite about 1.5 ft. in thickness. It lies in the upper part of the coal seam, and is not far from the earth surface. The layer is limited both above and below by bands of vitrain of bright luster. The lateral extension of the sphærosiderite is rather limited, a length of about 30 m. has been traced by Mr. Hou. According to Mr. C. C. Wang,[1] the age of the coal series belongs to Cretaceous, though some Japanese geologists have claimed it to be Jurassic.

The Sphærosiderite is gray in color when it is fresh and yellowish to brownish when it is weathered. The oolitic structure becomes especially evident on the weathered surface. The distribution of oolite seems to be quite irregular, it is found both in vitrain and in the ash-rich bands of durainic composition.

Chemical analysis on a carefully prepared sample of the oolite has been made by K. Y. King who reported the following result:

Total Fe as FeO	51.62%
Organic matter	2.62
Carbon dioxide	30.95
Insoluble matter	1.06
Hydroscopic water	none

The above composition agrees closely with the formula $FeCO_3$, therefore its identification as siderite is proved beyond any doubt. The small content of organic and insoluble matter shows that the siderite is fairly pure. The insoluble matter consists essentially of clayey material as is shown on microscopic examination.

Chemical analysis on the Hsian coal made by the Geological Survey of China gives the following composition:

Moisture	10.25	Volatile matter	33.81	Fixed Carbon	51.50
Ash	4.44	Color of ash, brownish		Calorific Power	6956.

It is therefore a kind of subbituminous coal very near to the coal of Fushun.

[1] C. C. Wang, Geology of some coal fields in Liaoning and Kirin Provinces, Bull. Geol. Surv. No. 13, 1929.

3. Study of Thin Section.

The sphærosiderite is rather uniform in sizes, being varied from 1-1.5 mm in diameter. Under the microscope, the siderite occurs in rounded form and from center outwards, there may usually be distinguished three zones (Plate 1, Figs. 1 & 2): (a) a central portion with brownish colored wood fiber (b) an intermediate zone of almost pure siderite which is coarse fibrous to prismatic and is concentrically arranged. Under the crossed nicols, the siderite granule shows spherulitic extinction. (c) a thin marginal zone of rotten and badly crushed wood, showing no distinct structure.

The Sphærosiderites are embedded in a ground mass of coaly matter which is either pure and homogeneous or is thoroughly infiltrated by quartz grains. In the well made thin section, the coaly mass is usually translucent and shows in some cases also well preserved woody structures. This latter structure in the ground mass and that of the siderite are generally similar and are parallelly oriented, except that the tracheids in the center of the siderite are more widely spaced and less compressed as compared with those in the ground mass (See Fig. 2, Pl. I).

The above relation indicates probably that siderites were formed as a result of replacement on twigs or pieces of wood during the time when the entire wood was not yet crushed and coalified.

In certain part of the section the central wood fibers of different sphærosiderites are not parallel to each other and the woody structure of the groundmass is also not parallel; in such cases, it may probably indicate their formation by gradual growth on irregularly and orderlessly scattered tiny bits of woods, the latter acted as precipitation agent.

The degree of preservation of the wood fibers is also extremely varied; some fiber is practically uncrushed and therefore all structures such as tracheids, medullary rays and perhaps also bordered pits may be distinctly observed, while in the other cases, the fibers have been crushed, contorted indicating that stress before sideritization was already in activity.

In the horizontal sections of the wood fibers, the cells may be polygonal, rectangular or irregular, depends, as a rule, on the degree of crushing. Some

fibers having their cells filled by mineral matter are comparatively less crushed and show therefore still the original rectangular forms and seriate arrangement (Fig. 1. Plate II).

The tracheids in the ground mass, when the section is thin enough to be observable, are found usually to be a little curved when they come to meet the siderite nucleus (See Fig. 2, Pl. I). This relationship shows clearly that sideritization preceeds coalification and its accompanied compression, a conclusion harmonized with what reached by previous workers.

4. Study of polished section.

Several polished sections of the specimens were prepared and they were examined under a Leitz ore microscope by the reflected light.

When examined by ordinary light or with the use of one nicol only, the polished surface shows no well marked structure. The reflecting color of both the siderite and the wood fibers are nearly the same, so a discrimination of them under the microscope was impossible. But when the nicols are crossed or still better when a drop of oil is introduced between the polished surface and the oil immersion objective, the cellular structure of the wood fiber becomes at once very distinct; the latter also shows a brownish color contrasted with the gray color of siderite. The three zones, namely the central wood fiber, the intermediate siderite and the marginal rotten zone are then as clear as observed in the thin section

Exactly the same kind of structure may be observed when the polished section be examined by oblique illumination; the wood fiber will then be colored brown while the siderite as well as the ground mass will be black.

At one place, it is observed an aggregate of 20 or more oolitic siderites containing all in their center a bit of wood fiber which show similar and parallelly orientated cellular structures. This relation conclusively proves that oolitic siderites were formed by replacement of a formerly homogeneous piece of wood. Fig. 2, Pl. II, shows very well the orientated woody fibers in different oolites.

From the form and orientation of the cellular structure in the central wood fiber of the siderite oolite, we may roughly divide the polished section in-

to several quarters, each of them shows the same orientation of the vegetale tissues. These different quarters evidently represent different piece of individual wood, which may vary greatly in sizes from a few millimeters to one or more centimeters in length or width, as can be seen from Fig. 3, Pl. II.

The ground mass of the oolitic aggregate is composed of coaly matter which is much dessiminated with quartz infiltrations. In the ash-rich bands, the quartz is exceptionally abundant; it occurs either as irregular grains or as thin veinlets of lamellar forms, the lamelle being perpendicular to the direction of the veinlet. To the naked eyes, the lamellar quartz looks not unlike fibrous gypsum.

The polished section of the vitrain band shows under the microscope to be an almost structureless and homogeneous mass, but some indication of cellular structure can often be seen, especially oil immersion objective is used. This structure represents extremely crushed tracheids with inclusions of rounded particles perhaps resin canals. Some faint indication of medullay ray can also be observed. Under the crossed nicols, the vitrain is, however, isotropic, so that it shows no structure whatsoever.

Very distinct and rather beautifully preserved woody structure is obtained when the vitrain is etched with chromic acid. By this treatment, the surface of the vitrain is soon coated with a thin film and which exhibited under the microscope very distinct structure. It is no doubt that here the wood belongs to some kind of Conifer. From the general structure of the wood, it seems very likely that the vitrain band has been derived from the same kind of coniferous wood as that formed the central nucleus of the siderite oolites.

5. Origin of Sphærosiderite.

From the above study of both the thin section and the polished section, it becomes clear that the sphærosiderite of Hsian coal mine was formed as a result of replacement of woody stems or twigs at a time when the plant material had not yet quite decayed. Hydrous iron oxide (limonite) is abundant in swamp water, and under the reducing condition of the plant-rich swamps or bog, the iron will easily be reduced to form the soluble ferrous carbonate. According to R. Potonie this solution when meeting the woody material, will be absorbed by

it, and after reacted with lignin in the wood, soon became a kind of colloidal solution. The gradual precipitation and coagulation of the colloidal solution in the woody cells will produce oolitic forms which was called by Potonie[2] the "Gerinuungstruktur".

The above explanation is nothing more than a hypothesis, as the so-called "Gerinuungstruktur" of Potonie is a very problematical thing. The detailed process of oolitic formation and gradual replacement of the wood is yet not clear. But there is one thing quite certain that the oolite was not formed by concentric growth on a piece of wood fiber (the usual explanation of concentric formation), but as replacement in pieces of woods of greatly varied sizes.

Owing to the minuteness of the woody fibers and the incomplete preservation of cellular structures, the exact nature of the wood can hardly be determined. However, in view of the narrowness of the medullary ray and the rounded bordered pits, this wood in question may be compared with the *Xenoxylon* found at Hsiachiakou in Hsüanhua Hsien and in many of other coal fields of northern China.

[2] R. Potonie, Einführung in die allgemeine Kohlenpetrographie, p. 106, 1924.

Explanation of Plate I

Explanation of Plate I.

Fig. 1. Three sphærosiderites occur near together in the thin section. The woody fibers of the three concretions are all parallel to each other while in the ground mass the tracheid shows a little curved forms when it comes to meet the siderite. The structure represents a tangential section of the wood. × 36. Thin section.

Fig. 2. Same as Fig. 1 on higher magnification. The tracheids and the medullary rays in the wood are very well shown. × 62. Thin Section.

Fig. 1.

Fig. 2.

Explanation of Plate II.

Explanation of Plate II.

Fig. 1. *Horizontal section of the woody fibers in sphærosiderite.* The cells are of polygonal shape with lumens completely silicified so that they have suffered very little from compression. × 62. Thin section.

Fig. 2. Photograph of polished section shows the distribution and general structure of the sphærosiderite in the Hsian coal. According to the orientation of the woody fibers, the section may be roughly divided into several quarters, each represents a single piece of wood stem from which sideritization gradually took place. × 2.5.

Fig. 3. A portion in Fig. 2 much enlarged, shows more distinctly the parallel alignement of the wood fibers. × 6.5.

Fig. 1.

Fig. 2.

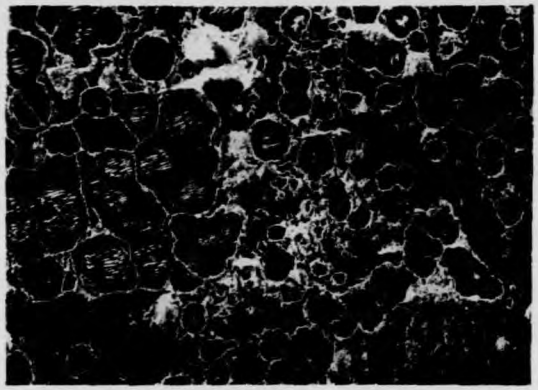

Fig. 3.

A REMARKABLE OCCURRENCE OF FUSAIN AT LUNGCHUANHSIEN, CHEKIANG PROVINCE§

By

C. Y. HSIEH* & K. CHANG* (謝家榮，張更)

(Contribution from the Sinyuan Fuel Laboratory of the Geological Survey, No. 7b).

(with two plates and one text figure)

1. INTRODUCTION.

During his short visit to the Geological Institute of Academia Sinica in Shanghai in 1931 the senior author noticed among the coal collection there some remarkable specimens of fusian collected several months ago by the junior author. These specimens in the size of several centimeters square or more, are made up of homogeneous fusain which shows to the naked eye a silky luster of black and dull color and a distinctly cellular structure. According to the junior author, the fusain occurs as lenticular bodies or pockets in a volcanic series, which fact indicates beyond doubt that it has been formed from the charring of woods following the volcanic eruption. As there has been within recent years controversy theories and serious discussions about the origin of fusain, a finding showing its undisputed origin is therefore highly interesting and is worthy of mentioning.

2. OCCURRENCE.

The fusain lenses are found on the slope of Chenkanshan (陳坑山), five li North of Taotaichên (道太鎮) or 2 or 3 li west of Yangtoutsün (垟頭村), in eastern Lungchuanhsien (龍泉縣) at a distance of about fifty li from the district city, Chenkanshan is a hill of about 300 m. in elevation with an upper steeper slope and a lower gentle one. Fusain, in the forms of pockets, veins or lenticular layers is exposed at the base of the upper steeper slope. Largest pockets so far observed show a length of about 8-9 m. with a maximum thickness of about 10 cm. It is intercalated in greenish tuffaceous rhyolite.

Similar coal seams are reported to occur at about 10 li West of Taotaichên at a place called Chikoutsun (溪口村). Although this occurrence was

§ Manuscript receive in August 1932.

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** Member of the Geological Institute of Academia Sinica.

not visited personally, it seems very likely that it belongs to the same type of deposit as found at Chenkanshan.

Fig. 1 is a sketch of the Chenkanshan section showing the successive layers of rhyolite and the intercalated pockets of fusain. The lowest rock exposed at this hill is a grey rhyolite (a) containing some quartz phenocrysts and above it is a layer of brown rhyolite (b) with practically no quartz grains visible to naked eyes. The uppermost formation is a greenish tuffaceous rhyolite forming here

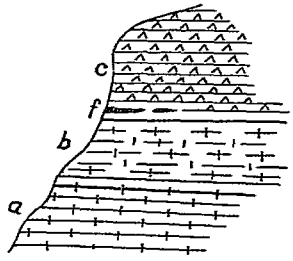

Fig. 1.

a steeper slope than the other two. Fusain lenses are found nearly in the lowest part of the tuffaceous rhyolite; at the contact between the fusain and the rhyolite, the rock is frequently marked by a black color of glassy appearance which indicates probably the result of rapid chilling with at the same time the introduction of coaly matter as intermixtures.

Lithologically, the formation just described bears a close resemblance with the great rhyolite formation of Western Chekiang, its geological age has been determined on paleontological ground to be Upper Cretaceous. Similar age may therefore be assigned to the rhyolite series of Lungchuanhsien.

3. Physical and Chemical Characters.

The fusain forms rather compact and coherent mass, but on breaking, it is easily separable into fibrous or powdered forms. The color is black with a

dull but a somewhat silky luster. Fibrous structure is distinctly observable to naked eyes. Determination of specific gravity and porosity by Miss T. C. Hung gives the following results:

True sp. gravity	= 1.960
Apparent sp. gravity	= 1.930
Porosity	= 1.53%

According to Lange[1] the specific gravity of fusain varies from 1.272—1.86. In the report of the U. S. Bureau of mines, Davis[2] determined the specific gravity of one sample of fusain to be 1.53. From this record, we can see that our specimen of fusain has the highest specific gravity, a fact, evidently to be explained by the presence of abundant infiltration of mineral matter essentially quartz.

Chemical analysis of the fusain shows the following composition:

Analysis by	Moisture	Volatile matter	Fixed carbon	Ash
Geological Institute of Academia Sinica	9.39%	11.58%	50.90%	28.64%

4. Microscopical study.

Both polished section and thin section of the fusain show under the microscope well preserved woody structure. Fig. 1 Plate I shows a horizontal section of the specimen, in which the radial arrangement of the woody cells is very well shown. One characteristic feature is the extremely small sizes of the woody cells which amount to 15 μ in tangential and 12 μ in radial directions. The thickness of the cell wall is about 3 μ. The lumens are almost entirely filled by quartz, which shows in polished section a gray color and a slightly

1. The. Lange, Die praktische Bedeutung und der technische Wert der Faserkohle in O. Stutzer's "Fusit", pp. 101, 1929.
2. Joseph D. Davis, Fusain, Information Circular No. 6115, Bureau of Mines, originally published in Mining Congress Journal, March 1929, pp. 197-200.

higher relief as compared with the coaly matter. Medullary ray is not distinct on the horizontal section. There are abundant radial lines closely resembling rays, but as they have been all replaced by quartz, exact determination of their nature is not possible. It is believed that narrow rays are certainly present, but as a result of mineralization, they have been mostly obliterated.

The thin section of the fusain shows equally well the woody structure. Here the infiltrations or veinlets of quartz becomes admirably shown. Another way to identify quartz infiltration is by immersing crushed fragments of fusain in oil; then, the rod-like, prismatic form of the quartz, a pseudo-form derived from the woody cells, is very characteristically shown.

The structure of annual growth can be very well seen from the horizontal section. It is marked by alternation of more crushed spring wood and the less crushed autumn wood, the latter, is, as a rule much narrower.

Fig. 3, plate II is a longitudinal section of the fusain, showing somewhat crushed and distorted tracheids. The pittings have been mostly mineralized and are therefore obliterated. In certain rare cases, pits resembling bordered pits are observed as shown in the accompanied illustration. These pits are extremely small, not exceeding $3 \times 4\ \mu$ in diameter.

It is certain that the wood herewith described belongs to some kind of Conifer; owing to advanced mineralization and imperfect preservation of detailed structures, its specific determination is almost impossible.

5. ORIGIN.

In recent years there has been much discussion among coal petrographers in regard to the possible origin of fusain.[3] According to one school fusain is nothing but charcoal that has been burned during forest fire. This fire was brought about incidently by lightening, spontaneous combustion or other natural causes, a phenomenon occurs not infrequently also in the present time. The other school maintains, however, that origin other than forest fire is equally

3. O. Stutzer, Fusit, Vorkommen, Entstehung und praktische Bedeutung der Faserkohle (fossile Holzkohle), 1929.

feasible for the formation of fusain. As it has been proposed for instance, that dehydration or decay under deep burial i. e. under anerobic condition may eventually convert woody components of the coal into fusain. Recently, Laupper[4] has demonstrated that "Heukohle" i. e. hay charcoal may be produced in hay stacks by prolonged decay and decomposition. Such hay charcoal often shows well preserved cellular structure and therefore quite similar to fusain. The action of sulphuric acid on wood will also produce charcoal-like substance, although the presence of such acid in appreciable quantity in swamps is yet to be proved. On the other hand, Bode[5] has recently summarized all the arguments and evidences favoring the forest-fire theory which according to him should be the only possible explanation of the origin of fusain.

By the forest-fire theory, fusain may be considered as primary in origin, i. e. to say fusain has been already in existence while the coal was in formation, whereas by the latter theory, fusain formed simultaneously with the coalification process of the coal bed, in other words, it is of secondary origin.

The occurrence of lenticular layers or pockets of fusain in volcanic series at Lungchuanhsien in Chekiang province has provided us an undisputed evidence in favour of the first hypothesis, namely, fusain has been formed not through the chemical reaction, but by the action of burning. Instead of forest fire brought about by lightening etc. as the only cause, our case has shown that volcanic eruption may under certain condition produce sufficient heat for the conversion of wood into charcoal.

We may therefore interprete our occurrence in the following words: During upper Cretaceous time there occurred repeated volcanic eruptions and the stream of lava encountered in the vicinity of Chenkanshan some drifted woods. As the lava was so hot, that the wood became at once charred to form natural charcoal or fusain. When later lava or tuff coming down, the fusain will be buried and finally became included in the volcanic series. Since the woods

4. G. Laupper, Die Schaden der Landwirtschaft infolge Selbstentzündung der Heustocke. Genf, 1926, Geogr. Gesellsch.
5. H. Bode, Die Fusitbilding vom Standpunkt der Waldbrandtheorie, Glückauf, no. 7, Jahrgang 1930.

were of drifted origin and were distributed usually in scattered and irregular manner, so the fusain formed is necessary in the form of lenticular layers or pockets; no regular and persistent beds are therefore to be expected from this kind of deposit. During or after the process of carbonization, solution carrying SiO_2 from the lava gradually worked into the cellular spaces of the wood and there be deposited as quartz infiltrations. This explains why we have in this specimen an exceptionally abundant quantity of quartz impregnations.

Explanation of

Plate I.

PLATE I

Fig. 1. Several lenticular bodies of fusain (marked by hammer) occurring in a volcanic series of Upper Cretaceous age. Chenkanshan, Taotaichên, Lungchuanhsien, Chekiang Province. Photographed by K. Chang.

Fig. 2. Fusain occurring in more or less continuous layers in volcanic series. Same locality. Photographed by K. Chang.

Fig. 1.

Fig. 2.

Explanation of Plate II.

PLATE II

Fig. 1. A piece of fusain showing rather distinctly its fibrous structure. Reduced about one half.

Fig. 2. Microphotograph of polished section of fusain showing distinctly the cellular structure which represents clearly a horizontal section of the wood of the Coniferous variety. × 160.

Fig. 3. Longitudinal section of the wood showing extremely small bordered pits. × 120.

Fig. 1.

Fig. 2.

Fig. 3.

THINNED POLISHED SECTION OF COAL, A NEW TECHNIQUE IN COAL PETROGRAPHY*

By C. Y. Hsieh (謝家榮)

(*The Geological Survey of China*)

Contribution from the Sinyuan Fuel Laboratory No. 7c.

(*with two plates*)

Contents.

1. Introduction.

Opinions often differ among coal petrographers as to the relative advantages of the thin sections and the polished sections. In reality both of them are useful and they should be used simultaneously in order to get a clear and exact idea about the microstructures of the coals studied. It is needless to say that the thin section of coal is always far more superior than the polished one for the former is apt to give more distinct view of the structures represented. Nevertheless, in the case of coal extremely rich in opaque matter, the use of thin section alone is often not enough to show all the detailed structure, so that the polished sections method will be helpful. In his study of the Elkhorn coal bed, Thiessen[1] has microphotographed a number of splint and semi-splint coals in which opaque matter forms predominate part and therefore besides the transparent spores, cuticles, etc. there shows very little structure in the ground mass. To study the occurrence, form, and detailed structure of the opaque matter, the use of polished section is consequently of great help.

* Received for publication Dec. 1932

1. Thiessen, R., Geo. C. Sprunk, H. J. O'donnell, Microscopic study of Elkhorn coal bed at Jenkins, Letcher county, Ky. Tech. paper 506, Bur. of Mines, 1931.

On the other hand, the study of polished section alone gives usually considerable uncertainty especially in regard to the nature of the cellular bodies which may be a charred wood i. e. fusain or a less humified xylon showing still well preserved structure. The question can be immediately settled if the cellular body could be studied by the transmitted light; in that case fusain will appear perfectly black, while humified wood will be red or dark red in color.

Now, if both thin sections and polished sections of a coal be prepared and studied, considerable difficulty may still arise as how to make exact correlation and comparison between the structures observed by both processes. Therefore it is the opinion of the writer that if by certain means the two processes could be combined into one, then there should present no difficulty in the accurate identification of most of the constituents contained in the coal.

The writer is indebted to Mr. K. Y. King, chief chemist of the Geological Survey of China for many of his helps and suggestions throughout the work.

2. The Thinned Polished Sections.

The writer was much impressed by the bright idea recently proposed by Donnay[2] on the making of thinned polished sections. This new technique involves the polishing of one side of the chip before mounting and to grind the other side to the standard thickness by the usual way. It is in fact just a reverse process of what was formerly suggested by Tolman and Rogers[3] who gave the polishing of the surface, however, after the slice has been mounted and ground to the required thickness. No cover glass was used as polishing plays the same rôle. Such sections were called by Donnay, the polished thin section.

It is clear that by the method of Donnay, the polished side after final grinding will face to the mounted slide, and this will make both observation and good focussing impractible. In order to make the polished side facing the cover

2. Donnay, J. D. H., Thinned polished sections, Econ. Geol. Vol. 25, No. 3, 1930, pp. 270.

3. Tolman, C. F., A. F. Rogers: A study of the magmatic sulfide ores, Stanford University Press, 1916, pp. 75-76.

glass, a process of transfer of the thin rock piece is necessary, and the covered section is finally remounted on another mounting glass.

Owing to the internal reflection in cover glass, and the consequent blurring effect of the image, the examination of polished section with glass cover on it gives usually no sharp focus. In order to overcome this difficulty, Donnay recommended the use of oil immersion objectives. By the introduction of a drop of cedar oil or glycerine between the slide and the lens, there resulted in the production of an approximately uniform refractive medium (i. e. Canada balsam, cover glass, cedar oil or glycerine) between the polished section and the lens, and it is then possible to obtain a perfectly sharp focus. Only low power oil immersion objective can be used, the 8 mm lens being considered as most convenient.

3. The Preparation of Thinned Polished Section of Coal.

It is evident from the above description that the Donnay's method of thinned polished sections could also be well applied to coal, except that the process of transfer which owing to the fragile nature of the coal slice is almost impossible. With some modification, the writer has finally succeeded in preparing a number of thinned polished sections of coal which can be studied both in reflected and in transmitted light. Our method may be briefly described as follows:

The processes involved in the making of thin sections of coal followed largely those proposed by Thiessen[4], except that in case of compact and tough coal which contains a high content of volatile matter, and consequently its grinding to the required thinness being of less difficult, such preliminary steps of water proofing the slice by paraffin can in most cases be avoided. Canada balsam alone may be used as the mounting medium, though the mixture with certain parts of marine glue as recommended by Thiessen gives certainly better results.

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4. I am indebted to Drs. Thiessen and Fieldner for their kind advice in regard to the making thin sections of coals.

Having been ground on iron and glass plates with carborundum and fine emery respectively, the plain surface of the coal block must again be rubbed on a piece of Belgium hone and then polished on a rotating disc covered with billiard cloth. Alundum (Tonerde) is used as the polishing material. The polishing must not be too long, as otherwise relief will be produced and final thinning of the slice will be diffcult. The polish surface is then mounted on a small piece of mounting glass with Canada balsam or a mixture of balsam and marine glue. The other side of the slice is then further ground at first on iron plate with coarse carborundum and then on glass plate with fine emery. As soon as the edges of the slice or such constituents in the coal like macrospores, resinous bodies etc. begin to appear transparent, the slice must then be rubbed on a piece of yellow Belgium hone (extra fine grade) until the whole slice becomes transparent. The small mounting glass with coal slice is finally remounted on another mounting glass of the standard size.

The thinned polished section of coal thus prepared has evidently its polished side to face the thick mounting glass, the latter is now also used as cover glass. For comparatively low magnification with the use of the 12 mm Leitz oil immersion objective such section gives already sufficiently sharp image for microscopic examination. For higher magnification as for instance, with the 8 mm objective, because of the great thickness of the cover glass, sharp focussing is in most cases impossible, and therefore we must have the polished surface of the coal to face the standard thin cover glass. This is done by the following way:

Mount the cover glass to coal block by means of Canada balsam or a mixture of marine glue and Canada balsam depending upon the nature of coals. Until this is perfectly dry and hard, mount cover glass side of the block to a small mounting slide. The whole thing consisting of a mounting slide, a cover glass and a thin coal block is now ground by the usual method until the required thinness is arrived. The whole thing with a thin slice of coal on the cover glass is again mounted on another mounting glass of the standard size. As soon as the Canada balsam becomes perfectly dry, apply a little heat to the side of the small mounting slide until this can be slipped around and finally taken away. The finished slide will now have the polished side facing cover glass and which can be cleaned and studied.

The procedure just described is of course rather tedious and troublesome. It involves considerable skill and is not always successful in all the time. For practical purpose this is however not quite necessary, because all the detailed structures can be well seen by the use of low power 12 mm oil immersion objective. The above procedure is therefore only recommended where high power examination with 8 mm objective or still higher is required.

4. Method of Examination.

The arrangement used by the writer for examining the thinned polished section by both transmitted and reflected lights consists of a Leitz ore Microscope[5] and a Monla lamp for the reflected light and another lamp for the transmitted light.

In actual examination both sources of lights should be connected and by the shading of the finger or by a piece of thick paper, any one source of them can be easily cut off, and the section be examined under pure transmitted or reflected light. It has been found, however, that best view can often be obtained when both lights are used simultaneously and what is better when a green filter is used with the reflected light; in this way the spores etc. will appear bright red while the xylonic elements and fusain green and vitrain a dark red color. With Panchromatic plate, distinct microphotographs showing detailed structures of the spores etc. as well as of the opaue matter may be obtained. A few of the microphotos thus taken is illustrated in plate I, and plate II.

5. Application of the Method.

As has already been discussed, neither thin section nor polished sections should be dispensed with for an accurate microscopic study of coal, so any method to produce a combination section, must therefore be of utmost importance. The thinned polished section of coals as just described is an attempt to fulfill this urgent need longly sought for by coal petrographers.

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5. Preferably the microscope is also equipped with reflecting mirror, condensor system and diaphragm. If these are not available, any reflecting mirror and diaphragm from a polarizing microscope can of course be easily fixed on it.

The principal application of the combination sections may be summarized as follows:

(1) To permit a sure discrimination between fusain[6] and xylonic elements showing cellular structures.

(2) To give detailed view of the structures in the opaque matter.

(3) To afford quick and accurate correlation and comparisons between structures observed in thin section as well as in polished sections.

(4) To permit the determination of the nature, distribution and occurrence of the mineral matter in the coal. It shows especially well the mutual relationship between the mineral matter and the opaque matter such as fusain etc.

(5) To get a permanently preserved polished section. The glycerine or cedar wood oil on the cover glass can be easily swept off, and repolishing of the section is therefore avoided.

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6. In this connection it may be noted that by the use of oil immersion, the study of polished section of coal alone can also make such discrimination, though it is not as sure as with the present method see writer's paper on "Some new methods in coal petrography" Bull. Geol. Soc. Vol. 9, No. 3, 1930.

Explanation of Plate I.

EXPLANATION OF PLATE I.

Fig. 1. Microphotograph of thinned polished section of coal by transmitted light only, showing alternation of fusain (f) and vitrain (v) and a few resinous body (white). Hokeng, Heilungkiang. × 90.

Fig. 2. The same as Fig. 1 but photographed by both transmitted and reflected lights. The cellular structure in fusain becomes now very distinctly shown. × 90.

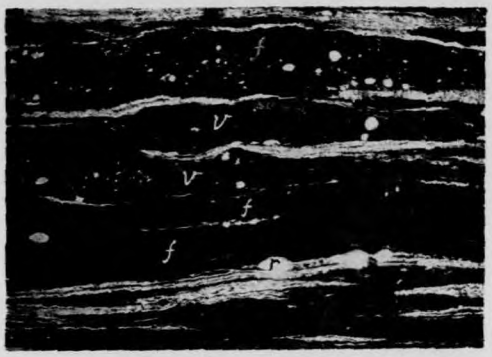

Fig. 1.

Fig. 2.

Explanation of Plate II.

EXPLANATION OF PLATE II.

Fig. 1. Microphotograph of thinned polished section of coal showing microspores (s), macrospores (s_1), thin layers of vitrain (v) and a ground mass of opaque matter. Shenkengshan, Huiyuanhsien, Anhui. × 80.

Fig. 2. The same as fig. 1 but photographed by both transmitted and reflected lights. The opaque ground mass is now resolved into an aggregate of fragments or particles of fusain (f) showing distinct cellular structure. × 80.

Fig. 3. Microphotograph of thinned polished section of coal from Shenkengshan, Anhui showing macrospores (s_1), microspores (s), vitrain (v) and a ground mass chiefly composed of cellular particles or fragments of fusain. × 170.

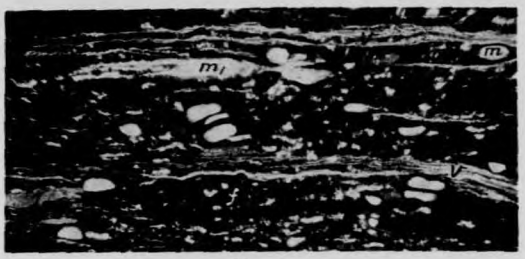

Fig. 1.

Fig. 2.

Fig. 3.

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MICROSTRUCTURES OF SOME CHINESE ANTHRACITE

By
C. Y. Hsieh

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MICROSTRUCTURES OF SOME CHINESE ANTHRACITE

By

C. Y. HSIEH (謝家榮)*

(Contribution from the Sinyuan Fuel Laboratory No. 6)

(With 4 Plates)

CONTENTS.

1. PREVIOUS WORKS ON MICROSCOPY OF ANTHRACITE.

The existing method of coal petrography seems to be well adaptable only to bituminous or lignitic coals; in the case of anthracite, because of its extreme opacity to light and resistency to most chemical solvents, no satisfactory method has yet been developed so as to enable the determination of all its detailed structures.

Perhaps the first attempt of devising new method for the microscopical study of anthracite was the flame etching method of Turner and Randall.[1]

§ Read at the 9th Annual Meeting; Manuscript received in Nov. 1932.

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1. Turner, H. G. and Randall, H. R., A preliminary report on the microscopy of anthracite coal, Jour. Geol. Vol. 31, 1923, p. 306-313.
Turner, H. G., Microscopical structure of anthracite. Trans. A. I. M. E. Vol. 71, 1925, p. 127-148.

These two authors used a blowpipe flame as the etching reagent. By passing such a flame on the usually polished surface of anthracite, the latter will soon be covered with a thin coat which, under a reflecting microscope, will show sometimes well preserved vegetal tissues and structures.

The principle of Turner and Randall's method is, however, not new. As early as in 1836, Goeppert[2] has already noticed the effect of the burning off of the organic substances and the preservation of the vegetal structures in the remaining ash. His work was followed by Reade in 1837 and Ehrenberg and Bailey in 1846. The conclusion of Bailey is especially worth mentioning, as he has already correctly interpreted his results by saying that anthracite is nothing but bituminous coal which has lost its volatile matter.

Although the method was derived from the application and modification of some older principle, the flame-etching method has still its merit in that the original banded structure as well as the numerous vegetal tissues in anthracite was first visible after the works of Turner and Randall.

By the use of chromic acid as the etching reagent, Seyler[3] has obtained woody structures as well as exines of macrospores in some of the Welsh anthracite. According to the experience of the writer, however, the etching by chromic acid seems to be applicable only to the bituminous and lignitic coals, whereas for anthracite, this reagent is generally too weak to give satisfactory results.

2. THE APPLICATION OF POLARIZED LIGHT TO THE STUDY OF ANTHRACITE.

In a previous paper on "Some new methods in coal petrography"[4] the writer has described some of the results in the using of polarized light to coal

2. For detailed statement on historical development of coal research, see: Stopes, M. C. and R. V. Wheeler, Monograph on the constitution of coal, Dept. of Scientific and Industrial Research, 1918.
3. Seyler, C. A.: The microscopical examination of Coal, Phys, and Chem, Surv, of National Coal Resourses No. 16, 1929.
4. Fuel Bulletin No. 2, published in Bull. Geol. Soc. China, Vol. 9, No. 3 pp. 311-328, 1930.

research. Among many different applications of this new method, it has been found that the study of anthracite gives in most cases the best result.

As we know coal is an amorphous rock and consists of material chiefly of colloidal nature. Consequently it must be isotropic, i.e. dark between crossed nicols and showing no change of color or color intensity when the stage is rotated. In actual case, however, this is not always true. On account of intense dynamic metamorphism and consequently internal molecular rearrangement, most of the coal and especially anthracite, has been so changed as to show more or less anisotropism between crossed nicols. This anisotropism is most distinct and marked in the case of anthracite, whereas in bituminous coals, this property may vary from faint and unnoticeable to strong and well marked as the case may be. It is chiefly due to this anisotropic character of anthracite, that we are now able, by the use of polarized light, to detect its original banded structures and structures showing original cellular forms or grain boundaries.

When examined by the oridinary light, the polished section of anthracite shows usually an homogeneous and structureless vitrain in which are intercalated here and there few lenses or fragments of fusain. This is the most typical structure of anthracite and in fact it is the chief microscopic character by which the anthracite may be clearly distinguished from the bituminous coals. Now with the use of polarized light and crossed nicols, an entirely different view is obtained. Instead of homogeneous and structureless, the polished surface of anthracite shows in most cases alternating bands of vitrain, xylon, durain and fusain, just the same as in bituminous coals. The durain is composed of a fine aggregate of spore exines, cuticles, woody debris etc, the exact identification of which is, in most cases, not possible. The bands of xylon are generally well recognizable, except that the cells have been intensely crushed and displaced so that a *granulated* or *cataclastic* structure is usually shown. This granulated structure is most characteristic as to give evidence of what an enormous pressure the coal has suffered in its changing from bituminous coal to anthracite. Besides these, the polarized light is able to reveal the incipient woody structure in an apparently structureless vitrain, to trace the transition from fusain to fused fusain and then finally to homogeneous vitrain, and in one case also contortion and folding of the coaly matter which becomes only visible when the upper

nicol is crossed. All these structures are well illustrated in the accompanied microphotographs and are to be described in the following paragraphs.

During the present investigation, a few section of anthracite has been etched according to the method of Turner and Randall. They show, under the microscope, striations, dots or lamellæ suggesting the presence of varied cellular structures. And when the upper nicol is closed, there shows at once the most distinct structure and what appears to be most remarkable is that every striation, dot or lamella in the etched section conforms precisely with what seen under the polarized light and crossed nicol. This illustrates how closely agree the results of the method of etching and that of polarized light.

While etching by either blowpipe flame or other chemical means (as chromic acid) may achieve the same result, but the method of polarized light, in view of its simplicity in procedure and distinctness of the images, should be considered as superior to any of the other methods so far proposed. Moreover, it is often difficult with the etching method to decide from which portion has the structure in question been derived; in other words, it is difficult to compare the etched structure with that of the unetched one, whereas in the polarized light method, the comparison is a very simple matter.

The Leitz Ore Microscope equipped with both polarizer and analyser has been found to be best suited for microscopic study of anthracite. A strong source of light must be used, otherwise the anisotropism will be so weak as to be unnoticeable. Throughout the present work, a Leitz Liliput arc lamp* of 4-5 Amp. was used, and in order to increase the light intensity, no filter of any kind should be inserted during observation.

At last a few word may be said about the microphotography of anthracite under crossed nicols. As the reflecting power of coal surface is usually very weak and as most of the light will be cut off after the insertion of the upper nicol, so the image obtained will usually be so faint as to make microphotography an extremely difficult task. Focussing must always be done on a plain glass with the help of a magnifying lens, as on ground glass back, the faint image will practically be unvisible. No filter of any kind was used and oil immersion is sometimes desirable as to give a more uniform illumination. Exposure varies

*A monla lamp, though of slightly weaker intensity, gives equally good results.

from 8-30 minutes all depending upon the light condition as well as the manification. In some cases the image was so faint that even by the use of longer exposure, say 30 minutes, it was still impossible to get a good picture; this is especially so in the case of higher magnification.

3. Simple polishing method versus etching or polarized light methods.

In a recent paper on the microstructure of anthracite, Duparque and Fanshawe[5] still insisted on the simple polishing as the most effective method of investigation. The well polished section of anthracite when examined under ordinary light will show of course cellular structure of fusain or partly transformed xylon. These are evidently the structures represented in the illustrations of the work just mentioned. In order to show incipient woody structure of the vitrain or the distinctly banded structure of the anthracite as a whole, resort must be made to some other better methods, and among which the polarized light method seems to be the best that has ever been tried.

The following demonstration shows very well the value of polarized light method to coal research. A polished section of an anthracite from Lienchen district in Fukien Province was made. This when observed under ordinary light, i. e. without the insertion of either polarizer or analyser, appears in the main as an homogeneous vitrain, with here and there short twigs or lenses of fusain which can be well identified by its cellular structure and high relief (*Fig.* 1, Pl. I).

With the insertion of either one of the nicols, a banded structure becomes faintly shown (Fig. 2, Pl. I). The layer of vitrain exhibits a light gray color and the color becomes brightest, when the elongation direction is perpendicular to vibration direction of either one of the nicols. In other words, the vitrain has different capacity of reflection, being greatest along a direction perpendicular to the bedding planes of the coal.

Under parallel nicols, i. e. with the insertion of two nicols but having their planes of vibration in parallel position, the result is the same as with one nicol only, except that the light intensity becomes somewhat reduced.

5. Duparque, A. and Fanshawe, J., La Structure Microscopique des Anthracites. Soc. Géol. du Nord, Ann. LV, 1930, pp. 111-138.

Distinct banded structure and anisotropism of the anthracite are shown when the polished surface is examined under crossed nicols (Fig. 3, Pl. I). Most of the layers seem to show a parallel extinction, i. e. the extinction position being parallel to either vibration directions of the nicols and giving maximum intensity of light when the layers are at 45° with the vibration planes of the nicols.

The above description of the optical character of a polished section of anthracite shows clearly that great difference exists between investigation under ordinary light and under polarized light. With the above method, we can observe at most the fusain lenses, the partly altered xylon, the ash particles or lenses and perhaps some vaguely defined cellular structures. With the use of polarized light and with one nicol (or two nicols in parallel position) only, the visibility of the microstructure has improved already to a marked degree as can be seen from a comparison of fig. 1 & fig. 2 in the accompanied illustration, but the *real structure of anthracite can only be observed when the two nicols are closed*. By this way, the original banding as well as many of the vegetal tissues in the anthracite could be seen just as distinctly as in the case of bituminous coal.

4. Vegetal tissues and structures observed in the Chinese anthracite.

Since it is possible with the new method of study to observe the real microstructure in anthracite, so a systematic investigation of some of the well known Chinese anthracite was taken up by the writer. The object of this study is firstly to show how much the polarized light method can be of service to the coal petrographical research, especially in the study of anthracite, and secondly to identify, as far as possible the vegetal tissues and structures in the anthracite. Besides, attention is also paid to such broad relationship as it may occur between microstructure and chemical composition or between microstructure and geological age of the anthracite.

Over fifty specimens of Chinese anthracite derived from six different provinces have been studied. For each specimen at least two polished sections, one vertical and one horizontal were made. They were studied at first under

the parallel nicols and then under the crossed nicols; the difference in structure between the two procedures were observed and noted. The description of different specimens studied is summarized in table II at the end of this article. It is hoped that a fairly good idea can at least be obtained from a study of this widely distributed material.

Since anthracite represents the end product of coal formation, the preservation of vegetal structure in it is therefore bound to be fragmentary and imperfect. Without the application of polarized light, the detect of any real structure in anthracite is in fact almost impossible. The following vegetal structures have been observed in the Chinese anthracite under crossed nicols:

a) *Woody structure*:—This appears to be the most important and frequent structure observed in the Chinese anthracite. In the best preserved state as seen in the anthracite seam No. 3 of Mentoukou, Hopei province, all details such as bordered pits, medulary rays etc. (Fig. 3 & 4, Pl. III) are distinctly shown. In the usual case, the woody structure is generally shown by tracheids which may be completely crushed and granulated or practically undeformed showing still the forms of cells with middle lamellæ lying between. The middle lamella becomes in most cases extremely fine and narrow indicating what a great amount of fusion and compression the two adjacent cells have received. The lamella shows an exceptionally bright luster which is particularly well shown under higher magnification with oil immersion. Some distinctly preserved middle lamella is seen in an anthracite from Hsiaolungtaikou, Chaitang basin in Hopei province.

In an anthracite from Tsihsien, Shansi province, some incipient woody structure is beautifully shown under crossed nicols. The woody nature of these bands is already noticeable in ordinary light from the distribution of fine pits and ash particles but it becomes clearly shown when the upper nicol is inserted in. As can be seen from the microphotograph (Fig. 4, Pl. I) the woody lamina occur in wavy form; it represents therefore some oblique section of the wood.

Some of the woody-like structures in anthracite may belong to peridium or to some other tissues, but on account of the intense crushing, their exact identification becomes usually extremely difficult.

b) *Resinous bodies*:—Resinous filling in lenticular or rounded shape is not uncommon in the Chinese anthracite studied. A best example is seen in the anthracite of Laohuyen, Lienchen district, Fukien province.[6] This is found in a series of lenticular to egg-shaped cells which are believed most probably to be the resinous filling of some parenchymatous cells. From the lenticular shape of the body, it is evident that the resin must have suffered considerable compression, a condition likely to be encountered during anthracitization. In lignite or bituminous coals because of less compression, the resinous bodies are usually slightly compressed or not affected at all. As an example, we may refer to the rectangular-shaped resinous bodies[7] in the lignite of Wulunghsien in Kirin province.

c) *Exines of microspores and macrospores*:—In the present investigation, special care was taken to look for exines of both microspores and macrospores. The result is that in certain kind of coal, they are surely present, but in most cases are either poorly preserved or have been broken up to such a form as to render their recognition extremely uncertain. In view of the intense pressure and comparatively high temperature prevailing during anthracitization, the sporic material is likely to be destroyed, so their perfect preservation in anthracite is, according to principle, not to be expected. On the other hand, Seyler has found after etched with chromic acid, some comparatively well preserved macrospore in a Welsh anthracite. The macrospore exines figured by both Turner and Duparque are not so distinct and are likely to be of other origin.

In our specimens, somewhat well preserved macrospore exines have been detected in the anthracite from Liangshuiching, Tating district and Tashuikou, Kueiyang district, all of Kueichow province. In the former specimen, there occurs frequently bands or laminæ of gryish yellow in color and which show usually curved, looped or fusi-formed shape, a feature suggesting strongly to be

6. See Pl. 11, in "Some New Methods in Coal petragraphy."
7. See Fig. 2, Pl. 1 in Contribution from Sinyuan Fuel Laboratory, No. 4, "On the Vegetable Tissue and Flora in the Chinese Coal & their Geological Significence."

the exines of macrospore (Fig. 3, Pl. IV). These spore exines are distinctly anisotropic under crossed nicols.

In the coal of Tashuikou, a bright and yellow colored, lenticular body may represent also some exines of macrospores.

Exines of microspore are still more difficult to be definitely identified. In the anthracite from Fanchang district in Anhui province, the polished section shows frequently numerous tiny streaks or lenses representing probably the much altered and humified spore exines or other bituminous matter. Similar occurrence of tiny streaks is found also in the anthracite of Tienlukou, Tatung district, in Shansi province.

d) *Cuticles*:—Owing to the much fused and humified character of the anthracite, surest identification of cuticle is not possible. In the anthracite from Fukien, Anhui and Kueichow, there occurs frequently long and fine lines or laminæ showing brilliant color under crossed nicols. They are supposed to be cuticles.

The principal components of anthracite, according to their origin and structure, may be distinguished into the following divisions:

a) *Euvitrain*:—In microscopical study of anthracite under ordinary light, the whole mass, except a few lenses of fusain or ashes, may be considered to be composed of structureless vitrain. But this vitrain when examined under polarized light and crossed nicols, is again resolved into many different components with some showing beautiful structures while others is entirely structureless and homogeneous. To this latter component which shows no structure even under polarized light and crossed nicols and which represents evidently product of complete jelification and humification, the name *euvitrain*, an old term originally proposer by Potonie, is herewith applier. The amount of euvitrain in an anthracite increases with the degree of anthracitization and roughly speaking it is directly proportional with the amount of fixed carbon. So in an anthracite with highest content of fixed carbon or with least content of volatile matter will show most development of euvitrain.

b) *Clastoxylon*:—In bituminous coal there occurs frequently bands or lenticles of woody material which shows distinct cellular structure in polished section. This was called by Duparque *xylon* in distinction from vitrain which

is entirely structureless and homogeneous. In natural cases transitional forms between vitrain and xylon are frequently found, and these were called by Duparque *xylo-vitrain*.

In the anthracite probably the most abundant constituent is a lenticular layer or band which appears perfectly structureless in ordinary light but showing beautiful woody structure under crossed nicols. On close study it is observed that the cells are generally intensely crushed and granulated resulting in a kind of structure which is much more intricate and fragmentary than the so called arc structure (Bogenstruktur) commonly observed in bituminous coals. That these bands have been derived from some woody material, in other words of xylonic origin, seems of no doubt, but on account of the advanced coalification, the material has been so humified or jelified that it shows no structure at all in the ordinary light. But at the same time the strong metamorphic effect of the anthracitization process has converted an otherwise amorphous mass into an anisotropic one with the result that under the crossed nicols, owing to different optical behavior of the different cellular particles, a marked structure is obtained. Such structures are shown in the accompanied microphotos especially in Fig. 1 & Fig. 2, Pl. II & Fig. 1, Pl. III, etc.

Owing to the fact that such structures just described differ greatly both in optical character and in origin from the ordinary xylon and moreover that they seem to be confined only to anthracite, a special name must be given. For this reason, I propose herewith the name *clastoxylon* to indicate such strongly compressed and anisotropic but in ordinary light entirely structureless bands or lenticles of chiefly xylonic origin.

The highest magnification that we can use to observe the clastoxylon in crossed nicols is about 200-300 X (under oil immersion) and the highest magnification for microphotography is only about 200 X. Beyond this limit the image becomes usually so hazy that no clear structure can be observed. On the other hand the structure is generally of a very fine type and in order to get a more detailed and exact view of its make up, a much higher magnification than just specified is required. In this respect there is needed more careful study and further research.

The clastoxylon is widely distributed in practically all the anthracite studied. It is more abundant in the so called ligno-cellulosic type of anthracite as will be discussed below.

c) *Metadurain*:—A third constituent in anthracite is herewith called metadurain. It is in fact a durain as can be seen from its inhomogeneity in composition under crossed nicols but in ordinary light it appears just as structureless and homogeneous as the ordinary vitrain. On careful study under crossed nicols, the metadurain is seen to be made up of a fine mixture of many different materials including bits of woody cells, resins, ashes, and in some coals also remains of macrospores and microspores exines. The isolated bits of woody cells shows not infrequently a bright line in the tracheid, representing perhaps the much humified middle lamella. Cuticle is conspicuously rare in all the metadurain studied.

d) *Fusain*:—The fusain in anthracite exhibits no special features except that most of the lenticle seems to show a very vaguely defined border. On careful observation this border may present all kinds of transitional forms to vary from a sharply defined to one where the fusain passes imperceptibly into the structureless vitrain. This seems to be just in contrast with what is usually observed on the fusain in bituminous coal.

No matter what hypothesis we may advocat for the origin of fusain, the fact is here clear that fusain has usually a less sharply defined border in anthracite than in bituminous coal. And this fact may be taken to indicate probably that fusion or humification during the process of anthracitization has been responsible for the formation of this ill-defined border in fusain.

Another noteworthy feature of the fusain is its isotropic character which is almost perfect in most cases. When the upper nicol is crossed, it can be seen that all lenticles or bands of fusain become darker in color if not entirely extinct, and when the stage is rotated, this darker color remains unchanged.

The isotropic character of fusain seems to be a very important feature, and by it we may safely distinguish between fusain and xylon in polished section, as both of them show well preserved cellular structure under the microscope, so

that a sure distinction without the help of other diagnostic character may become sometime extremely difficult.

5. RELATION BETWEEN MICROSTRUCTURE & CHEMICAL COMPOSITION.

Owing to the preliminary nature of study and lack of sufficient number of accurate chemical analysis, definite relationship between microstructure and chemical composition of anthracite has not yet been wholly worked out. It appears quite certain, however, that such relationship must exist and further research is needed for its through solution.

Our present study has brought out at least three outstanding features which may be briefly discussed as follows:

a) *Anisotropism and degree of anthracitization*:—As has been stated above both lignite and bituminous coal are isotropic under crossed nicols, whereas in anthracite, owing to the intense metamorphism and its consequent internal rearrangement, a marked anisotropism is usually shown under the microscope. On the other hand it has been observed that the more fusion or alteration a clastroxylon or a metadurain has received, the more homogeneous or structureless will it become under the crossed nicols. In other words a clastoxylon or a metadurain will gradually be transformed into an euvitrain in course of progressive coalification. This means that anisotropism increases from bituminous coal to anthracite only up to certain limit and beyond that when a coal has reached its highest degree of coalification, i. e. an anthracite containing the highest content of fixed carbon, owing to the increase of the amount of euvitrain, its anisotropism appears as to be markedly decreased. Thus in the anthracite of Tsiokeng in Fukien province, (see table I) which contains 92% of fixed carbon and only 6% of volatile matter, shows under the crossed nicols to be markedly less anisotropic as compared with other anthracite. The same is true in the case of anthracite from Chaitang which contains only 2.73% volatile matter and 97.27% of fixed carbon. Thus we may roughly figure on the content of fixed carbon (ash & moisture free basis) from a microscopic study of its degree of anisotropism.

b) *Presence or absence of sporic material in anthracite and its relation with the content of volatile matter*.—As will be discussed below anthracite

may be divided into ligno-celluslosic type and cutinic type, the latter is characterized by a large amount of spores etc. Theoretically speaking, this latter type will contain at the same time the highest content of volatile matter. On the other hand, progressive coalification may devolatilize simultaneously the sporic constituents in anthracite, so eventually both the ligno-cellulosic and the cutinic type of anthracite may arrive at almost the same composition with equal amount of volatile matter.

In table I is listed the chemical analysis together with microscopic characters of all anthracite studied. A glance at the table will show at once the relationship between the presence or absence of spore and the amount of volatile matter. Thus all the coal classed as Cutinic II & in which certain amount of spore exines, resins or cuticles etc. has been detected by the microscopic investigation, shows upon chemical analysis to contain usually a higher content of volatile matter. Only in rare instances anthracite with abundant cutinic substance is poor in volatile matter and this may perhaps be explained by the progressive coalification process which has devolatilized the sporic constituents in the anthracite.

c) *Nature, amount & occurrence of ashy matter in anthracite*:—In regard to the kind of mineral matter in anthracite, its relative amount and its mode of occurrence, the microscopic examination gives usually very satisfactory result. Especially the method of oil immersion will render possible the specific identification of such minerals like quartz, calcite, gypsum etc. The occurrence of the mineral matter whether as infiltrations in clastoxylon, fusain or as lenticles, bands or again as isolated grains or patches in the ground mass, our microscopic view gives in all cases the best informations. Finally some approximate idea about the ash content of the anthracite may be gained from microscopic study alone which may act as guide to later chemical investigation.

6. Relation between microstructure and geological age.

In my paper on the "Vegetable tissues & flora in Chinese coal & their geological significance" some criteria has been proposed by which major geological age of a coal may be roughly determined from microscopical study alone. These rules hold especially well with lignite and bituminous coal; in

the case of anthracite, owing to its advanced coalification and the obliteration of most of the structures, such determination is often extremely difficult. Yet some rough idea about the major geological division may be obtained from the amount of macrospore or microspores exines; their presence especially in large amount indicate probably a Palæozoic age.

The above criterium can be applied very well to our present investigation. Practically all the anthracite of Permian age from Kueichow province is characterized by the presence of a large amount of macrospores as well as microspores, although both of which present in no case such distinct structure as observed in bituminous coal. Some spore-like substances are also found in the anthracite of Pingting (No. 22) and Tzehsien (No. 24) both of which are also of Palæozoic age. On the other hand all the Mesozoic anthracite of Fukien province is characterized by the conspicuous absence of any sporic matter. Of course the exines of spores etc. may be completely destroyed by the processes of anthracitizations, so that their absence does not necessarily indicate a Non-Palæozoic age, but the presence of abundant amount of the same especially the exines of macrospores is in any way an undisputable evidence for age determination.

7. Mechanical deformation in anthracite.

The fact that clastoxylon presents usually a finely granulated structure under crossed nicols, and that rarely does the lenticle or band of the same show any sign of bending, crushing or dislocation, a condition of incipient or plastic deformation must therefore be inferred as one of the most important mode of deformation during anthracitization. This incipient deformation must have been accomplished while the coal bands were somewhat in colloidal or paste-like condition, a condition easily attainable under great pressure and comparatively high temperature at great depth. Another way of deformation is the bending, crushing or dislocation of consolidated or compacted coaly bands or masses, which may be called hard-rock deformation.

The phenomenon of hard-rock deformation is sometimes also observed in anthracite. Thus the different lenticles or bands of xylon, fusain and euvitrain may be crushed or dislocated. But the most remarkable de-

formation of this kind is seen in a kind of powdered anthracite, widely distributed in Southern China especially in the provinces of Hunan, Fukien and part of Hupeh. In Western Hills of Peking and in Tachingshan of Suiyuan, such powdered anthracite are also found. These coals occurring in beds of irregular thickness are composed almost entirely of a fine aggregate of coal sand, (in the size of one mm or less) the latter has been derived undoubtedly from the grinding and crushing of an once already consolidated anthracite.

The distribution of powdered anthracite[8] in China seems to have immense geological significance and needs to be thoroughly studied. At present we know that it is more abundant in South than in North China, but in the Western Hills of Peiping and in the Tachingshan area of Suiyuan, where tectonic movement played a special role, powdered anthracite is also found. On the other hand in the much less disturbed regions like the different coal basins of Shansi and Shensi, this kind of anthracite is conspicuously rare or absent. Thus from the distribution of the powdered anthracite, we may define certain kind of tectonic province within which the mountain making force was specially intense and frequent so that the coal contained therein has been not only anthracitized but badly crushed and fragmented.

At last a few words may be said about the method of investigation of this special coal. Because of the friable nature of the powdered anthracite, the preparation of polished section needs evidently some preliminary treatment. The coal must at first be boiled in a dish with evaporated Canada balsam, and when the entire mass has been thoroughly impregnated with this embedding medium, it is taken out and after perfectly cold and hardened, it is then ready for cutting and grinding.

8. A SYSTEM OF CLASSIFICATION.

All classification of coal so far proposed is based chiefly on chemical composition; very little attention seems to have been paid on the utilization of microscopical character as a basis of coal classification.

8. Powdered anthracite (in German Trümmerkohle) is widely distributed in Europe especially in Switzerland, France, Austria and certain parts of England. All these occurrences are closely related with intense orogenic movements. See O. Stutzer, Die wichtigsten Lagerstätten der Nichterze, Zweite Auf. 1923, p. 248.

Seyler, in his petrographical classification of coal[9] was perhaps the first one to have adopted the scheme just stated. In his system however no detailed classification is given for anthracite.

In the recent work of Duparque,[10] anthracite or anthracitic coal is divided into two types; a) *Charbons Ligno-cellulosique gélifié* is the most common and widely distributed type and is characterized by the predominance of vitrain (la houille amorphe or pâte) and lignified body (corps figurés lignifiés).

b) *Charbons de cutine*, this is extremely rare and is characterized by the presence of spore exines, cuticles etc. in which cutine forms an important constituent.

The above classification of Duparque with some modification may be well applied to the Chinese anthracite. Instead of considering the type "charbon de cutine" as an extremely rare one, its distribution among the Chinese example seems to be not entirely uncommon. Thus all the anthracite of Kueichow province may belong to this type. In its complete form, our system of classification runs as follows:

9. Seyter, A. C. Petrography and the classification of Coal. Presidential address given before the South Wales Institute of Engineers, Jan. 21, 1931.

10. Loc. cit.

Types		Characteristics	Distribution in China.
1. Ligno-cellulosic anthracite.	Higher carbon type.	Clastoxylon, fusain & with a higher content of euvitrain (Isotropic). Anthracite of highest coalification.	Tsiokeng, Shaowuhsien, Fukien province.
	Lower carbon type	Clastoxylon, fusain, euvitrain etc. Anisotropic constituent predominate.	Hopeh, Shansi, Fukien etc.
2. Cutinic anthracite.	Lower volatile matter type.	Spores, cuticles etc. largely destroyed & humified.	Anhui & part of Shansi Anthracite in Kueichow.
	Higher Volatile matter type	Spores, cuticles etc. not yet entirely humified.	
3. Powdered Anthracite.	————	Fine aggregates of coal grains which may be isotropic or anisotropic. Products of hard rock deformation.	Fukien, Hunan, Hupeh, Parts of Hopeh & Suiyuan

9. On the origin of anthracite.

Among the older views on the origin of anthracite there were two controversing hypothesis: according to one school there is complete gradation in chemical composition from lignite to anthracite and the latter is formed from the former thru metamorphic action; this action may be brought about by either of the following causes:

(1) folding or thrusting of the coal bearing series produced a stress which devolatilized the inclosed coal seams.

(2) Pressure exerted as a result of long & deep burial.

(3) Contact with an igneous body may produce local thermal metamorphism and the conversion of bituminous coal into anthracite.

(4) Fractures, joints etc. produced in the overlying rocks during orogenic movement may facilitate the devolatilization of the coal seams below and consequently the formation of anthracite.

All these causes postulate a secondary origin as the principal factor of anthracite formation.

According to another school, secondary causes are not the principal factor required. There are some primary causes such as (1) initial difference in vegetal constituents or (2) difference in length of exposure of the vegetal matter to oxidation before burial may both act as the fundamental factors. Without the introduction of microscopical study of coal, it was often difficult to make definite decision between either of the two hypothesis.

With the development of the science of coal petrography, we are now able to observe the microstructures and constituents of coal in a very exact and definite way. Coal geologists are at present almost unanimously agree on the first hypothesis by considering that no initial difference in vegetal constituent seems to have existed between the bituminous coal and the anthracite. Among the recent workers who hold this view are Turner, Jeffrey, Stach, Legraye etc. On the other hand, the view of Duparque is a little different, he maintained that since most of the anthracite he studied belongs to the ligno-cellulosic type, it appeared to him as if this composition be particularly fitted for anthracite formation. In other word initial composition, according to Duparque, may play still an important rôle. At the same time, Duparque admits that in certain rare cases, anthracite may also be formed from coal rich in spores etc. a composition similar to the usual bituminous coal containing higher content of volatile matter.

The present investigation shows in many of the Chinese anthracite, broken remains of macrospores as well as much compressed and altered microspores. So on the whole the vegetal constituents of anthracite differs no greatly from that of the bituminous coal, the latter includes both the coal of cutine and the coal of ligno-cellulose. It requires therefore no special kind of bituminous coal from which to form the anthracite, and our investigation thus seems to confirm the usually accepted hypothesis of considering secondary causes as the principal factor of anthracite formation.

10. Summary & Conclusion.

1. A brief description is given on the application of polarized light to anthracite study. It has been definitely demonstrated that real microstructure in anthracite can be obtained conveniently and efficiently only by this method.

2. A total of over 50 specimens of Chinese anthracite was studied. The object of this study was not only to test the validity of our new method, but to observe and interprete of what structure one may be obtained among the Chinese anthracite.

3. Four important components in anthracite have been recognized, these are *clastoxylon, metodurain, euvitrain* and *fusain*.

4. Owing to advanced coalification, vegetal structures in anthracite are only partly preserved and are mostly observable only under crossed nicols. Woody structure of varied forms seems to be most important, while spores, cuticles etc. are also observed.

5. According to microstructure, the Chinese anthracite may be classified into 3 types: (1) Ligno-cellulosic anthracite.

(2) Cutinic anthracite.

(3) Powdered anthracite.

The cutinic anthracite is usually of Palæozoic age and carries, theoritically speaking, a higher content of volatile matter, but progressive coalification may produce a type slightly lower in volatile matter. Among the ligno-cellulosic anthracite, two subdivisions may also be recognized: one is characteristic of higher carbon, the other is of lower carbon content. The former is the product of advanced coalification and shows under the microscope the predominance of the structureless euvitrain. The powdered anthracite was formed by mechanical deformation after anthracitization.

6. The result of the present study seems to prove that initial composition of vegetal matter plays no important rôle in anthracite formation, as both the coal of cutine and the coal of ligno-cellulose may equally well produce anthracite of similar composition.

TABLE I. CHEMICAL COMPOSITION AND MICROSCOPIC CHARACTERS OF SOME CHINESE ANTHRACITE. * I High Carbon or Low Volatile Matter Type

† II Low Carbon or High Volatile Matter Type

No.	Locality	地點	Pure coal basis Volatile Matter %	Fixed Carbon %	Ash %	Geological age	Microscopic characters	Classification
1.	Laohoyen, Liencheng, Fukien	福建連城老虎岩	7.97	92.02	9.37	Jurassic	Euvitrain, clastoxylon, fusain, a little metadurain with cuticles & broken macrospores.	Ligno-cellulosic I*
2.	Tsiaokeng, Shaowu, ,, ,,	邵武焦坑	6.39	93.61	7.12	,,	Euvitrain predominats, also clastoxylon. Comparatively few structure.	,, I
3.	Tungtzeyen, Lienchen ,, ,,	連城童子岩	4.50	95.27	7.00	,,	Anisotropic coal fragments.	Powder anthracite
4.	Lihshan, Kienou, ,, ,,	建甌縣梨山	2.94	97.07	4.11	,,	Alternating euvitrain and clastoxylon, more or less fragmentary with numerous veinlets of quartz.	Ligno-cellulosic I
5.	Hsiamei, Chungan, ,, ,,	崇安下梅	2.49	97.53	19.59	,,	Extremely rich in fusain.	,, I
6.	Chinanfan, Lungyen, ,, ,,	龍岩溪南坊	5.33	95.17	6.24	,,	Crushed angular fragments of 1 mm or less in diameter, anisotropic.	Powder anthracite
7.	Liangshuiching, Tating, Kueichow.	貴州大定涼水井	20.78	79.30	37.10	Permian	Metadurain predominates with macro- & microspore exines, resins, fusains & clastoxylon.	Cutinic II†
8.	Tashuikou, Kueiyang, Kueichow.	,, 貴陽大水溝	8.52	91.48	27.03	,,	,, ,, ,,	,, II
9.	Tingshancheng, Tungtze, Kueichow.	,, 桐梓鼎山城	8.40	91.60	14.68	,,	Metadurain & euvitrain in alternation with abundant exines of spores. Fusain is present.	,, II
10.	Chengchiachai, Tungtze, Kueichow.	,, ,, 陳家寨	4.22	95.78	36.65	,,	Essentially euvitrain with ash bands and a few form suggesting cuticles & macrospores.	,, I
11.	Wayaopu, Tungtze, Kueichow.	,, ,, 瓦窯坡	5.98	94.02	21.34	,,	Similar to No. 13 with few grains of pyrite.	,, II
12.	Hsiaotun, ,, ,, ,,	,, 小屯	4.31	95 69	25.74	,,	Chiefly euvitrain, some fusain, rich in ash. Spore exines are present.	,, I
13.	Chichiatien ,, ,, ,,	,, 齊家田	5.37	94.63	20.44	,,	Euvitrain predominats, some metadurain with cuticles & spore exines. Xylon consp. rare. Ash is abundant.	,, II
14.	Tienkouwan, Tsunyi, ,, ,,	遵儀田溝灣	7.32	92.68	16.94	,,	Ash rich anthracite shows no well marked structure.	Ligno-cellulosic I?
15.	Kuangtasung, Laiyang, Hunan	湖南耒陽廣大生	7.85	92.20	9.45	Permo-Carbon	Isotropic coal fragments and some fusain.	Powder anthracite
16.	Tzemenchiao, Hsianghsiang, Hunan.	,, 湘鄉梓門橋	9.38	90.61	5.23	Lower-Carbon	Fragmentary aggregates of euvitrain & fusain of different sizes.	,,
17.	Shihlung, Laiyang, Hunan.	,, 耒陽石壟	6.87	93 09	8.86	Permo-Carbon	,,	,,
18.	Tashingchung, Fanchang, Anhui.	安徽繁昌大信冲	6.13	93.81	13.60	Permian	Euvitrain & metadurain the latter contains cuticles, spores, etc., also clastoxylon.	Cutinic II
19.	Taochung, Fanchang, Anhui.	,, ,, 桃冲	9.09	90.91	9.10	,,	,,	,, II
20.	Kwangmiaoping, Chingmen, Hupeh.	湖北荊門關廟坪	13.78	86.27	17.55	Permo-Carbon	Euvitrain & metadurain in alternation, the latter is rich in cuticles & spores. Xylon & fusain are rare.	,, II
21.	Tanshanwan, Yangsing, Hupeh.	,, 陽新炭山灣	15.01	85.04	16.60	,,	Fragmentary aggregates of practically isotropic substances.	Powder anthracite
22.	Tienlukou, Pingting, Shansi.	山西平定鐵爐溝	3.35	96.70	8.92	,,	Euvitrain, clastoxylon & metadurain in which a few cuticles & spores is present.	Cutinic I
23.	Kienchang Co., ,, ,, ,,	,, 建昌公司	7.22	92.73	12 11	,,	,, ,, ,,	,, I
24.	Paochin Co., Tsehsien, ,,	,, 澤縣保晉公司	8.72	91.50	8.75	,,	Chiefly clastoxylon & euvitrain showing distinct woody structure. Some fusain.	Ligno-cellulosic II
25.	Hsiaolungtaikou, Chaitang, Hopei.	河北磁堂小龍太溝	12.23	87.80	15.83	Jurassic	Euvitrain clastoxylon & fusain in alternation.	,, II?
26.	,, ,, ,, ,, ,,		2.73	97.27	5.86	,,	Chiefly euvitrain showing no marked structure.	Ligno-cellulosic I
27.	2nd seam, Wangpingtsun, Hopei.	河北王平村二層煤	5.82	94.22	11.62	Permian	Euvitrain, clastoxylon & fusain in alternation.	,, I
28.	4th seam, Wangpingtsun, Hopei.	,, ,, 四層煤	16.68	83.28	57.52	,,	,, ,, ,,	,, II
29.	Panchiao, Wangping, Hopei.	,, 宛平板橋新鼎高琉	3.04	96.96	23.41	,,	Subangular fragments embedded in still continuous layers of anthracite.	Ligno-cellulosic I
30.	,, ,, ,, ,, ,, ,,	大祥煤	3.66	96.34	8.37	,,	Transitional type between fragmented & not fragmented. Alternating euvitrain & metadurain, the latter contains large amount of macrospores.	Cutinic I
31.	,, ,, ,, ,, ,, ,,	窗次塊	4.83	95.17	11.50	,,	Clastoxylon, euvitrain, fusain.	Ligno callulosic I
32.	1st seam, Mengtoukou, ,,	,, 門頭溝一層煤	5.03	95.45	13.25	Jurassic	Clastoxylon euvitrain & fusain in alternation. Clastic cellulosic structure is distinctly shown. A few spore is present.	Ligno cellulosic I
33.	3rd seam, Mengtoukou, ,,	,, 門頭溝三層煤	8.06	92.43	14.90	,,		,, II
34.	Changkouyu, Fanshan, ,, Hopei.	,, 長溝峪二李峪	8.37	91.63	12.60	,,	Essentially euvitrain with some xylon no marked structure can be seen.	,, II
35.	,, ,, ,, ,, ,,	新豐窑	10.81	89.19	26.54	,,	Alternation of euvitrain & clastoxylon, the latter shows beautifull and well preserved structure.	,, II
36.	,, ,, ,, ,, ,,	西蘆窑	7.08	92.92	20.52	,,	Fragments, grains, etc. of anisotropic euvitrain which shows no marked structure.	Powder anthracite
37.	Shuikouping, Yuenlien, Szechuan.	四川筠連水口坪	5.78	94.22	34.18	Permian	Essentially fusain embedded in mass of euvitrain with some humified xylon.	Ligno cellulosic I
38.	Lungwan, Hunghsien, Szechuan.	,, 珙縣龍灣北山	4.22	95.78	12.55	,,	Essentially euvitrain, certain bands of which are rich in ash. Pyrite grains are present.	,, I

Explanation of Plate I.

PLATE I.

Fig. 1. Microphotograph of a polished section of anthracite seen under ordinary light. It shows a lenticle of fusain embedded in a structureless vitrain; this is all what can be seen. Loc. Liencheng, Fukien Province, × 90.

Fig. 2. The same spot in the same anthracite but seen under polarized light and with one nicol only. The structureless vitrain begins already to display a kind of banded structure in which an alternation of homogeneous and inhomogeneous layers are clearly shown. Immediately above the lenticle of fusain on the right there is a lenticular body shows some kind of cellular structure. The appearance of fusain remains unchanged in this picture. Using one nicol or two nicols in parallel positions. × 90. Same locality.

Fig. 3. The same spot as above but seen under polarized light & with nicols crossed. An entirely different appearance is obtained which is composed of several thin layers of euvitrain (remains structureless and homogeneous even under crossed nicols) in alternating with metadurain, the latter is essentially made up by woody debris and degradation matter. The cellular structure of the lenticular body on the right central portion becomes more clearly shown. Fusain is isotropic under crossed nicols, so its structure becomes disappeared and remains dark in all position when the stage is rotated. Same locality. × 90.

Fig. 4. Cellular structure representing evidently an oblique section of some kind of wood becomes visible only under crossed nicols of polarized light. Polished section of Anthracite from Tsihsien, Shansi. × 130.

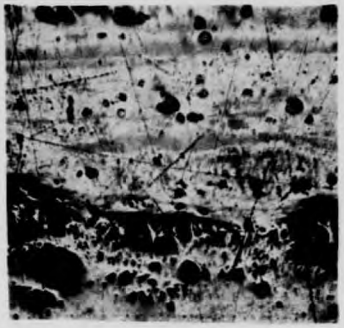

Fig. 1

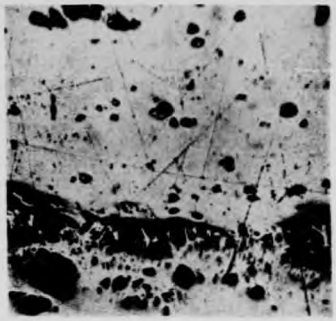

Fig. 2

Fig. 3

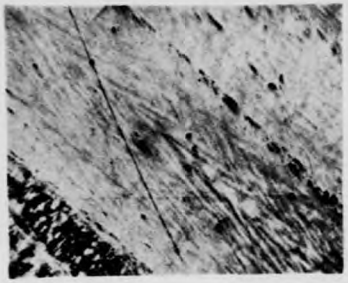

Fig. 4

Explanation of Plate II.

PLATE II.

Fig. 1. Polished section of anthracite from Liencheng, Fukien, showing the remarkable banded structure of euvitrain (structureless band) and clastoxylon. This banded structure becomes visible only by using polarized light and crossed nicols. × 80.

Fig. 2. The same kind of banded structure seen in an anthracite from Mentoukou, Hopei province, seam No. 1. It shows however better preservation of the woody structure in which the tracheids as well as bordered pits can be distinctly seen. Some bands showing indistinct cellular structure is the much crushed clastoxylon, × 160.

Fig. 1

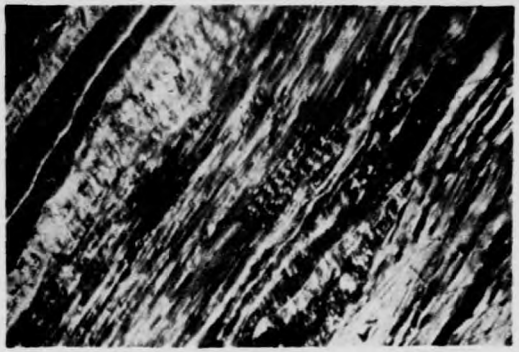

Fig. 2

Explanation of Plate III

PLATE III.

Fig. 1. Banded structure in anthracite showing alternation of fusain (f) and xylon (x). The thin bright line or lamina may be euvitrain or cuticle. The xylon represents evidently some longitudinal section of woody material in which the cells are only slightly crushed. Liencheng, Fukien province. × 80. Crossed nicols.

Fig. 2. Xylon with distinct cellular structure merges gradually into vitrain with thin streaks and finally into an entirely structureless vitrain. Anthracite from Wangpingtsûn, Hopei province. × 80. Crossed nicols.

Fig. 3. Longitudinal section of wood in anthracite becomes visible only in polarized light and crossed nicols. The wood has suffered apparently little compression, as both the tracheid and the bordered pits are nicely preserved. Seam No. 1 of the Mentoukou Colliery, Hopei province. × 120.

Fig. 4. Same as Fig. 3 under higher magnification. × 240.

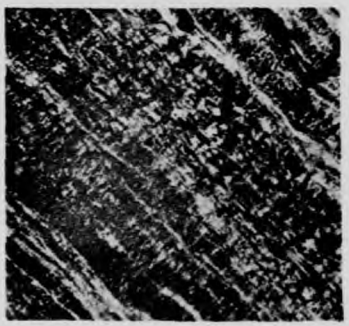

Fig. 1

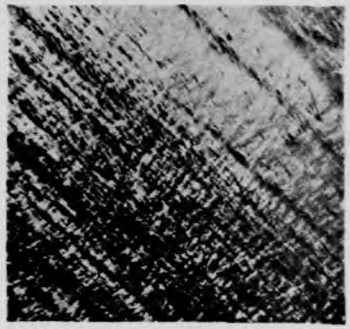

Fig. 2

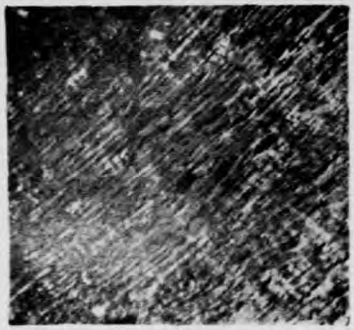

Fig. 3

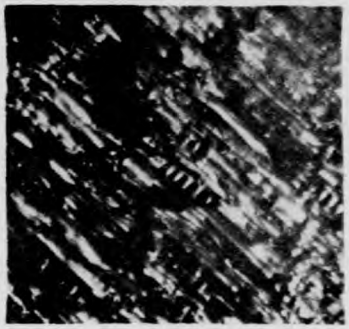

Fig. 4

Explanation of Plate IV

PLATE IV.

Fig. 1. Microphotograph of metadurain in an anthracite from Liangshuichin, Tating, Kueichow province. The bright, loop-like laminæ in the right central portion is supposed to be exine of a macrospore. The ground mass is composed of woody debris, degradation matter and ash grains. × 120. Crossed nicols.

Fig. 2. Metadurain in an anthracite from Mentoukou colliery, seam No. 1. It is composed in the main of woody debris, ashy matter embedded with numerous thin laminæ of euvitrain. × 160. Crossed nicols.

Fig. 3. The bright laminæ forming lenticular loops are supposed to be exines of macrospores which are exceptionally large sized in this coal. The groundmass is chiefly degradation matter scattered with numerous grain of ashy material, Liangshuichin, Tatinghsien, Kueichow province. × 90.

Fig. 1

Fig. 2

Fig. 3

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燃料研究專報第九號
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中國無烟煤之顯微鏡研究

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地質調查所新園燃料研究室

燃料研究專報

CONTRIBUTION FROM THE SIN YUAN FUEL LABORATORY

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No. 5 June, 1932

CHEMICAL ANALYSIS OF SOME CHINESE CRUDE OILS

By K. Y. KING

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No. 10.	Sulphur Forms in Chinese Coking Coals, by K. Y. King & T. S. Chang. (in preparation)	

CHEMICAL ANALYSIS OF SOME CHINESE CRUDE OILS

K. Y. KING.

With the inadequate equipment yet available in our laboratory we have to rely upon the following simple methods which, though imperfect in many respects, may be good to give some general indication on the composition of the crude oils samples collected by our geological colleagues in the course of their field work. This procedure is a modification of the method employed by the Bureau of Mines, U. S. A. for the fractional distillation of oil. The modifications we made are not for the perfection of the method but in order to solve the practical difficulties as well as to suit the available apparatus.

Most of the crudes studied are collected by Messrs. H. C. Tan and C. Y. Li, geologists of our Survey during their recent visit to Szechuan. This covers both the operating and non-operating, the productive and non-productive oil fields in that province. Some of them were collected from brine wells in the same province. Practically all the brine producing regions in Szechuan are also oil producing but in very different degrees of richness. The geological conditions of the Szechuan oil fields will be later reported on by Messrs. Tan and Li.

Only one Shensi oil is fractionated and another one from Kansu. The Shensi sample came from the Yenchang oil well which is comparatively the largest producer in China. The oil sample from Kansu was collected several years ago by Mr. C. Y. Hsieh from Yumen, at the westernmost extension of that province.

The general procedure for fractional distillation is briefly described in the following. A pear-shaped copper flask with a column filled of aluminum turnings and a pyrex tube as represented by the figure is employed for distilling and in all cases little difficulty was experienced for foaming and priming though the crudes are not dehydrated. The heating was done by a local made furnace which gave a steady and strong flame and can be manipulated very easily. Every 25 cc of distillates was collected in graduated cylinder for specific gravity determination. All the data are condensed in the following two tables (I & II), one showing the locality and the specific gravity of original crudes, and the other the distillation data.

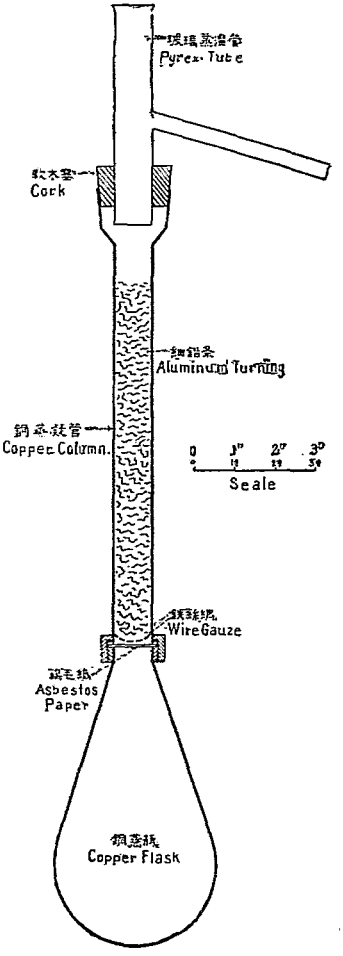

玻璃蒸溜管
Pyrex Tube
軟木塞
Cork
細鋁条
Aluminum Turning
銅柱筒管
Copper Column.
0 1" 2" 3"
Scale
鐵絲網
Wire Gauze
石棉紙
Asbestos Paper
銅蒸瓶
Copper Flask

TABLE I

No.	Location	Well Name	Color	Sp. gr.
1	Tsuliutsing, Szechuan	Sze Fu	Dark green (R)[1]	.8394
2	" , "	Tung Shun	Green (R)	.8660
3	" , "	Tung Ch'ang	Dark green (R)	.8585
4	" , "	" "	" (R)	.8587
5	" , "	Tsi Fu	" (R)	.8748
6	" , "	" "	" (R)	.8752
7	" , "	Fu Lung	" (R)	.8775
8	" , "	" "	" (R)	.8780
9	" , "	Tung Teh	" (R)	.8650
10	Kungtsing, Szechuan	Hung Lung	Reddish (T)[2]	.8310
11	" , "	" "	" (T)	.8372
12	Tsechung, Szechuan	Lu Chuan	Brownish (R)	.8393
13	" , "	" "	Light brown(T)	.7750
14	Loshan, Szechuan	Ho Er Kan	Dark Brown(R	.8340
15	Pahsien, Szechuan	Yen P'o	Black (R)	.9134
16	Yumen, Kansu	Sheng Tsai Chin Pao	Black (R)	.8961
17	Yench'ang, Shensi.		Black (R)	.8840

According to U. S. Bureau of Mines R. I. 2806, the different fractions such as gasoline and kerosene, etc., can be estimated by noting the specific gravity of the distillates collected at different temperature range. Following this method, the next table III is calculated for estimating the constituents.

1. Reflected Light
2. Transmitted Light

TABLE II

	First Drop	Below 200°C	200-250°C	250-275°C	275-300°C	Above 300°C
1	95°C	17.68%	16.34%	9.66%	9.00%	49.00%
2	80	6.41	23.80	26.02	17.00	25.23
3	95	3.75	11.25	11.00	10.50	64.20
4	90	3.67	12.25	11.20	10.33	63.40
5	85	5.00	9.00	8.34	12.00	64.95
6	80	5.00	10.80	9.70	11.00	65.00
7	75	3.23	7.50	6.00	8.50	75.00
8	76	3.24	7.34	6.00	8.34	77.70
9	75	4.00	9.72	8.55	13.32	63.50
10	90	0.54	6.21	13.52	13.50	68.40
11	90	0.54	6.60	14.00	14.50	66.50
12	80	16.02	10.68	8.00	11.00	55.00
13	75	70.50	14.50	← 13.50% →		
14	85	20.00	15.33	7.33	18.00	40.00
15	78	1.68	6.67	5.33	15.68	70.00
16	75	16.55	8.60	10.47	21.33	44.80
17	80	10.70	6.22	9.33	7.00	66.60

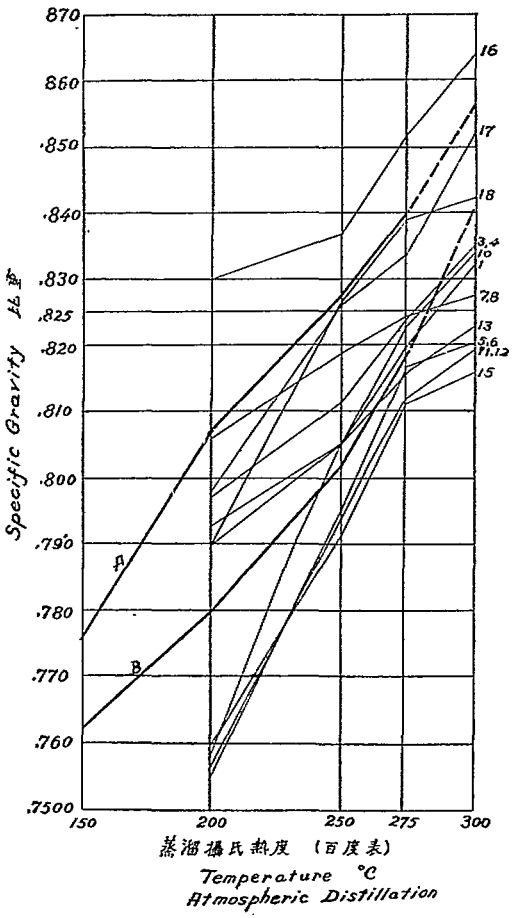
It is noted that No. 13 is quite an extraordinary one giving very unusual percentage of gasoline fraction. According to the original label, this is a washed crude, therefore this may be the topped fraction from steam distillation of No. 1 from the same locality. In all the 17 samples, except No. 13, they all show low percentage of gasoline and high in either kerosene or fuel oil in general.

TABLE III

	Gasolene		Kerosene		Fuel Oil		Fraction above 300°C	
	%	Sp.Gr.	%	Sp.Gr.	%	Sp.Gr.	%	Sp.Gr.
1	17.68	.7575	26.00	.8041	9.00	.8317	49.00	.8861
2	6.41	.7996	49.82	.8180	17.00	.8006[1]	25.23	.8530
3	3.75	.7830	22.25	.8144	10.50	.8351	64.20	.9054
4	3.67	.7845	23.00	.8140	10.33	.8362	63.20	.8997
5	5.00	.7920	29.33	.8148	——	——	64.95	.8983
6	5.00	.7924	31.50	.8145	——	——	65.00	.8976
7	3.23	.8058	13.50	.8200	8.50	.8274	75.00	.8872
8	3.34	.8064	13.34	.8204	8.34	.8270	77.70	.8880
9	4.00	.7898	18.27	.8138	13.32	.8334	63.50	.8893
10	0.54	——	33.23	.8084	——	——	68.40	.8360
11	0.54	——	35.10	.8130	——	——	66.50	.8340
12	16.02	.7558	29.68	.8238	——	——	55.00	.8689
13	70.50	.7553	14.50	.7972	——	——	13.50	.8364
14	20.00	.7543	40.66	.8051	——	——	40.00	.8780
15	——	——	——	——	13.68	.8420[1]	85.60	.9135
16	16.55	.7976	——	——	38.40	.8440	44.80	.9378
17	10.70	.7892	——	——	22.65	.8360	66.60	.9056

The percentage of fuel oil may be increased to some extent if the "fraction above 300°C" is vacuum distilled.

1. Indicating cracking.


.870
.860
.850
.840
.830
.825
.820
.810
.800
.790
.780
.770
.760
.7500
Specific Gravity 比重
150
200
250
275
300
蒸溜攝氏熱度 (百度表)
Temperature °C
Atmospheric Distillation
A
B
16
17
18
3,4
10
1
7,8
13
5,6
11,12
15

Basing upon the facts (R. I. 2806, U. S. Bureau of Mines pp. 3-4) that if the specific gravity of 250-275°C fraction is 0.8250 or lower, the oil can be considered as paraffin base and if it is between 0.8250 and 0.8600, the oil has a mixed or intermediate base. When this distillate measures above 0.8600, the crude is of asphalt base, the following Table IV, is given for comparison. It can immediately tell that of all the crudes studied, 14 samples belong to paraffin base, 3 to mixed base and none to asphalt base.

TABLE IV

Fraction collected 250-275°C

No.	%	Sp. Gr.	Base
1	9.66	0.8205	Paraffin
2	26.02	0.8230	"
3	11.00	0.8244	"
4	11.20	0.8238	"
5	8.34	0.8170	"
6	9.70	0.8120	"
7	6.00	0.8240	"
8	6.00	0.8234	"
9	8.55	0.8227	"
10	13.52	0.8065	"
11	14.00	0.8075	"
12	8.00	0.8164	"
14	7.33	0.8106	"
15	5.33	0.8518	Mixed or Intermediate
16	10.47	0.8334	" " "
17	9.33	0.8390	" " "

In this study, all the distillation are carried out under 300°C for avoiding any cracking that might occur above this temperature. Even though, two cases are noted showing slight cracking at 285°C. Partial vacuum distillation will be further conducted on the reserved portions of residue, i. e. "fractions above 300°C".

Handbook of Petroleum Industry, David T. Day
John Wiley & Sons Inc.
American Petroleum Industry, Bacon & Hamor
McGraw Hill Company.

十六	甘肅玉門縣	○•八三三四	混合	
十七	陝西延長縣	○•八三九○	混合	

附注　石蠟質 Paraffin Base

混合質 Intermediate Base

四川石油除巴縣外均列入於石臘質。巴縣石油黑且厚，與甘肅陝西者彷彿，均入混合質內。由此觀之國內重要石油均不在土濕青質之列，但其汽油成份較尋常石臘質石油爲低，或其天然如此，抑所用之油樣其中一部份已爲空氣日光蒸出則不得而知。但石臘質石油其汽油部份大半在百分二十左右，然亦有在百分之一十以內者，故亦不能確定四川等石油已有所蒸出。現祇求其儲量豐富，則各油用途不同，不可因汽油成份稍低，即謂無採取之價值也。

參考書

本所地質專報丙種第二號一百十一頁至一百十四頁

美國鑛務局出版物兩種(U.S. Bureau of Mines)

Report of Investigation 2805, 1927

Bulletin 207, 1922

美國標準局出版物兩種(U.S. Bureau of Standards)

Miscellaneous Publication 97, 1929.

Circular 154, 1924 Table 3

油樣基質表（表五）

化驗數號	地名	比重（250–275°C間所得蒸溜物）	油之基本質
一	四福井	○•八二○五	石蠟
二	東盛井	○•八二三○	石蠟
三	同昌井	○•八二四四	石蠟
四	同昌井	○•八二三八	石蠟
五	積福井	○•八一七○	石蠟
六	積福井	○•八一二○	石蠟
七	富龍井	○•八二四○	石蠟
八	富龍井	○•八二三四	石蠟
九	同德井	○•八二二七	石蠟
十	灴龍井	○•八○六五	石蠟
十一	灴龍井	○•八○七五	石蠟
十二	資中羅泉井	○•八一六四	石蠟
十四	樂山河洋坎	○•八一○六	石蠟
十五	巴縣顏坡石油溝	○•八五一八	混合

據各成份之多寡而言當以四川河洪坎及資中之石油爲最佳，其汽油成份既多，煤油亦不弱，而油渣又復不少則汽油煤油潤油等均可由此產出。四川自流井四福井及甘肅陝西者次之。柴油用途當不及煤油，況其價值亦稍遜之，則柴油多者（如甘陝石油）似不及煤油多者（四福井）爲貴。然陝西汽油柴油雖亞於甘肅，而其潤油成份則過之。（按甘肅陝西石油當不感玉門延長兩油田，今所分析者不足以代表其全省石油，僅限於所採油樣而論耳。）其餘各石油又次之。其汽油成份太低尤以貢井者爲最，惟煤油潤油則不在少數。四川資中水洗油似已蒸溜過者，因其汽油多而油渣少，但其詳情不明，姑置不論。餘如煎過油等等與原油幾相同或其所謂煎過者乃將水油泥各份澄清而已，大半質厚原油不用火力恐不易澄清，故煎過之原油水量微而少泥，但其成色及成份均與原油中分出之石油相等，因用火之故稱之曰煎，否則焉能得同樣成份乎。（四川原油均多泥，非澄清不可，在工業上極不相宜，殆因由鑿井汲出故然。）

石油現共分三類曰石蠟質基（Paraffin Base）土瀝青質基（Asphalt Base or Naphthene Base）及混合質基，（Intermediate Base or Mixed Base）。其名之來源無非自石油內所含之基質（Base）不同而已。石蠟質石油含土瀝青甚少而其大部份均爲臘類，氫炭化物（Paraffin Hydrocarbons）可用（$C_n H_{2n+2}$）化學公式代之。土瀝青質石油經蒸溜後常餘煤脂（Pitch）或土瀝青渣，其渣內物質大都不外（$C_n H_{2n}$）公式。至於混合質者乃界於其間，兩類俱全之石油耳。由工業眼光觀之，三類之中以石蠟質石油爲最佳，既可產出潤油，兼可得汽油等等。至於混合質亦可得不少汽油及潤油。土瀝青質石油除得潤油及柴油而外，別無可取之物，因此不甚重要。

鑑別之法互有不同，其最簡易者當首推美國鑛務局之比重法其例如下。在二百五十度至二百七十五度所蒸出部份其比重在〇•八二五或〇•八二五以下者爲石蠟質，〇•八六以上者爲土瀝青質，在〇•八二五及〇•八六〇之間爲混合質。

據其報告所得此例屢試屢驗，除一部份少數石油之外，餘均合式可用。茲將此法以定國內各石油基質如下。

四	三・六七	・七八四五	二三・〇〇	・八一四〇	一〇・二三	・八三六二	六三・四〇	・八九九七
五	五・〇〇	・七九二〇	二九・三三	・八一四八	—	—	六四・九五	・八九八三
六	五・〇〇	・七九二四	三〇・五〇	・八一四五	—	—	六五・〇〇	・八九七六
七	三・二三	・八〇五八	一三・五〇	・八二〇〇	八・五〇	・八二七四	七五・〇〇	・八八七二
八	三・三四	・八〇六四	一三・三四	・八二〇四	八・三四	・八二七〇	七七・七〇	・八八八〇
九	四・〇〇	・七八九八	一八・二七	・八一三八	一三・三二	・八三三四	六三・五〇	・八八九三
十	〇・五四	—	三三・二三	・八〇八四	—	—	六八・四〇	・八三六〇
十一	〇・五四	—	三五・一〇	・八一三〇	—	—	六六・五〇	・八三四〇
十二	十六・〇二	・七五五八	二九・六八	・八二三八	—	—	五五・〇〇	・八六八九
十三	七〇・五〇	・七五五三	一四・五〇	・七九七二	—	—	一三・五〇	・八五六四
十四	二〇・〇〇	・七五四三	四〇・六六	・八〇五一	—	—	四〇・〇〇	・八七八〇
十五	—	—	—	—	一三・六八	・八四二〇	八五・六〇	・九一三五
十六	一六・五五	・七九七六	—	—	三八・四〇	・八四四〇	四四・八〇	・九三七八
十七	一〇・七〇	・七八九二	—	—	二二・六五	・八三六〇	六六・六〇	・九〇五六

1　祇代表石油中之一部份，油渣內尙可提取柴油

2　油渣內含有柴油，潤油及凡士林等並非渣滓也

＊　似已有分裂物質(Cracking Product)故比重較低

爲合理。蓋沸點往往不能代表各部份之分別，其比重之別常相差太遠。（如汽油之比重約在〇・八〇左右，其沸點約在二百度左右，如其沸點集在二百度而比重則在・八二或・八三以上者，決不能稱之爲汽油，）因此故沸點與比重當並用之以定各蒸溜物，似較妥協。今應用下列暫定規則以區別各石油之蒸溜物。

（一）在二百度以前所蒸出而其比重在〇・八二五以下者爲汽油。

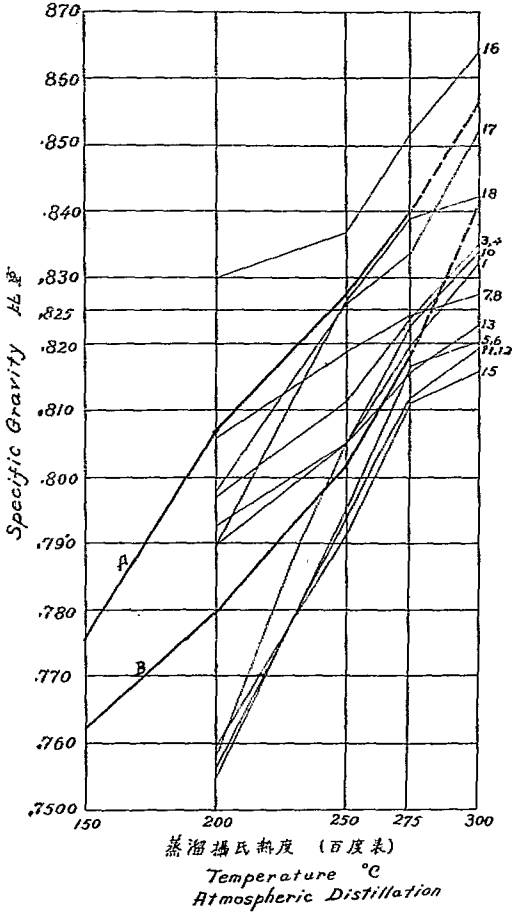
（二）在二百度二百七十五度三百度等各部份，其比重如在〇・八二五以下者爲煤油，在〇・八二五以上者爲柴油。

（三）三百度以上部份即名之油渣。

照此暫定之例其汽油部份約可代表工業上所用之汽油（其最高沸點爲二百十五度），至於油渣則其中仍含柴油凡士林及石蠟等尙多，祇因現在無法研究，置之不論。其實所含有用物質種類繁多，並非渣滓也。如用高熱度蒸之常有分裂物（Cracking Product）發見，既不能謂之自然成份（Original Fraction）又不可稱之爲蒸溜部份（Distilling Fraction）於分析上有大關係，（四川東盛井石油及巴縣石油在二百七十五度至三百度所蒸溜物其比重較二百七十五度者爲低，如將此部份重複蒸溜之則二百度二百五十度及二百七十五度各部份均有，故可斷定其中已有分裂物。）如欲分析之則非在眞空情形中爲之不可。在三百度以下已有此類情形發現，三百度以上之成份勢不可在空氣壓力境界內蒸溜之可無疑矣。今按暫定規則計算所得各部份列表如下。

油樣成份表（表四）

號數 化驗	汽油 百分率	汽油 比重	煤油 百分率	煤油 比重	1柴油 百分率	1柴油 比重	2油渣（三百度以上） 百分率	2油渣（三百度以上） 比重
一	一七・六六	・七五七五	二六・〇〇	・八〇四一	九・〇〇	・八三一七	四九・〇〇	・八八六一
二	六・四一	・七九七六	四九・八二	・八一八〇	一七・〇〇	*・八〇〇六	二五・二三	・八五三〇
三	三・七五	・七八三〇	二二・二五	・八一四四	一〇・五〇	・八三五一	六四・二〇	・九〇五四



附註　圖中A及B乃美國石油基質之標準今特附此以供參考

A爲混合質石油之蒸溜結果

B爲石蠟質者之結果

三	九十五	三・七五	一一・二五	一一・〇〇	一〇・五〇	六四・二〇	
四	九十	三・六七	十二・二五	一一・二〇	一〇・三三	六三・四〇	
五	八十五	五・〇〇	九・〇〇	八・三四	十二・〇〇	六四・九五	
六	八十	五・〇〇	一〇・八〇	九・七〇	十一・〇〇	六五・〇〇	
七	七十五	三・二三	七・五〇	六・〇〇	八・五〇	七五・〇〇	
八	七十六	三・二四	七・三四	六・〇〇	八・三四	七七・七〇	
九	七十五	四・〇〇	九・七二	八・五五	一三・三二	六三・五〇	
十	九十	〇・五四	六・二一	一三・五二	一三・五〇	六八・四〇	
十一	九十	〇・五四	六・六〇	一四・〇〇	一四・五〇	六六・五〇	
十二	八十	一六・〇二	一〇・六八	八・〇〇	一一・〇〇	五五・〇〇	
十三	七十五	七〇・五〇	一四・五〇	↑——	一三・五〇	——↓	
十四	八十五	二〇・〇〇	一五・三三	七・三三	一八・〇〇	四〇・〇〇	
十五	七十八	一・六八	六・六七	五・三三	一五・六六	七〇・〇〇	
十六	七十五	一六・五五	八・六〇	一〇・四七	二一・三三	四四・八〇	
十七	八十	一〇・七〇	六・二二	九・三三	七・一〇	六六・六〇	

夫石油乃一極複雜有機物質，蒸溜時常有不確實之處。再各部份分類之標準又復不同，尤以汽油成分爲最。以一百五十度沸點以下爲汽油者有之，以二百度沸點爲汽油者亦有之。煤油柴油等亦然。但由實際而論則常以沸點及比重兩種標準同時鑒定之較

雖構造不同而其尺寸則彷彿，彼既聲稱可用，則本所所用之蒸溜法當不遠遜也。最難者國內大石油蒸溜鍋尙未備，美國原油又無從獲得，未能畧爲比較，是爲憾耳。尋常化學用蒸瓶，其頸太短，蒸凝不易，似不相宜。即使用之，其汽油煤油部份往往過低，柴油增高決不能與工業實驗相頡頏。每次試驗樣量似不能太少，二百立方生的應爲最低度，有機物質之蒸溜大半有此困難，應加注意也。

各油份之比重乃用韋氏天秤法（Westphal Balance）定之，定時溫度隨便或十五度或三十度不等。定畢後用溫度與比重對照表校正之，俾比重均在攝氏表十五度有奇或法氏表六十度正。其各部份（如汽油煤油等）之比重則用下列公式計算而得。

$$\text{No. of } cc_1 \text{ (Fraction 200–250)} \times Spgr_1 = \text{甲}$$

$$\text{No. of } cc_2 \text{ (Fraction 250–275)} \times Spgr_2 = \text{乙}$$

$$+\ \text{No. of } cc_3 \text{ (Fraction 200–275)} \times Spgr_3 = \text{丙}$$

$$\therefore \frac{\text{丙}}{\text{No. of } cc_3} = Spgr_3 \text{(Fraction 200–275)}$$

此計算法當較幷合各部份而定者爲準，毫無失去油份之慮，故擇用之。

今用上述長頸紫銅瓶方法蒸溜，其所得各部份皆由其沸點甄別之，共分五種，列表如下。

油樣蒸溜表（表三）

化驗號數	蒸溜開始溫度（攝氏表）	二百度以下（百分率）	二百度至二百五十度	二百五十度至二百七十五度	二百七十五度至三百度	三百度以上
一	九十五	十七・六八	十六・三四	九・六六	九・〇〇	四九・〇〇
二	八十	六・四一	二三・八〇	二六・〇二	一七・〇〇	二五・二三

三	九十五	三・七五	一一・二五	一一・〇〇	一〇・五〇	六四・二〇
四	九十	三・六七	十二・二五	一一・二〇	一〇・三三	六三・四〇
五	八十五	五・〇〇	九・〇〇	八・三四	十二・〇〇	六四・九五
六	八十	五・〇〇	一〇・八〇	九・七〇	十一・〇〇	六五・〇〇
七	七十五	三・二三	七・五〇	六・〇〇	八・五〇	七五・〇〇
八	七十六	三・二四	七・三四	六・〇〇	八・三四	七七・七〇
九	七十五	四・〇〇	九・七二	八・五五	一三・三二	六三・五〇
十	九十	〇・五四	六・二一	一三・五二	一三・五〇	六八・四〇
十一	九十	〇・五四	六・六〇	一四・〇〇	一四・五〇	六六・五〇
十二	八十	一六・〇二	一〇・六八	八・〇〇	一一・〇〇	五五・〇〇
十三	七十五	七〇・五〇	一四・五〇	↑——	一三・五〇	——↓
十四	八十五	二〇・〇〇	一五・三三	七・三三	一八・〇〇	四〇・〇〇
十五	七十八	一・六八	六・六七	五・三三	一五・六六	七〇・〇〇
十六	七十五	一六・五五	八・六〇	一〇・四七	二一・三三	四四・八〇
十七	八十	一〇・七〇	六・二二	九・三三	七・一〇	六六・六〇

夫石油乃一極複雜有機物質，蒸溜時常有不確實之處。再各部份分類之標準又復不同，尤以汽油成分爲最。以一百五十度沸點以下爲汽油者有之，以二百度沸點爲汽油者亦有之。煤油柴油等亦然。但由實際而論則當以沸點及比重兩種標準同時鑒定之較

雖構造不同而其尺寸則彷彿，彼既幸稱可用，則本所所用之蒸溜法當不遠遜也。最難者國內大石油蒸溜鍋尙未備，美國原油又無從獲得，未能暢爲比較，是爲憾耳。尋常化學用蒸瓶，其頸太短，蒸凝不易，似不相宜。即使用之，其汽油煤油部份往往過低，柴油增高決不能與工業實驗相頡頏。每次試驗樣品似不能太少，二百立方生的應爲最低度，有機物質之蒸溜大半有此困難，應加注意也。

各油份之比重乃用韋氏天秤法（Westphal Balance）定之，定時溫度隨便或十五度或三十度不等。定畢後用溫度與比重對照表校正之，俾比重均在攝氏表十五度有奇或法氏表六十度正。其各部份（如汽油煤油等）之比重則用下列公式計算而得。

$$\text{No. of cc}_1\ (\text{Fraction } 200-250)\times \text{Spgr}_1 = \text{甲}$$

$$\text{No. of cc}_2\ (\text{Fraction } 250-275)\times \text{Spgr}_2 = \text{乙}$$

$$+\ \text{No. of cc}_3\ (\text{Fraction } 200-275)\times \text{Spgr}_3 = \text{丙}$$

$$\therefore\ \frac{\text{甲}+\text{乙}+\text{丙}}{\text{No. of cc}_3} = \text{Spgr}_3(\text{Fraction } 200-275)$$

此計算法常較幷合各部份而定者爲準，毫無失去油份之虞，故擇用之。

今用上述長頸紫銅瓶方法蒸溜，其所得各部份皆由其沸點甄別之，共分五種，列表如下。

油樣蒸溜表（表二）

化驗號數	蒸溜開始溫度（攝氏表）	二百度以下（百分率）	二百度至二百五十度	二百五十度至二百七十五度	二百七十五度至三百度	三百度以上
一	九十五	十七・六八	十六・三四	九・六六	九・〇〇	四九・〇〇
二	八十	六・四一	二三・八〇	二六・〇二	一七・〇〇	二五・二三

七	深綠色質甚厚油味輕	○・八七七五	一○七九○
八	深綠色質甚厚油味輕	○・八七八○	一○七八五
九	深綠色質薄油味輕	○・八六五○	一○八三○
十	深黃色帶紅質薄油味輕	○・八三一○	一○九四五
十一	深黃色帶紅質薄油味輕	○・八三七二	一○九二三
十二	櫻色帶綠質尙薄油味甚重	○・八三九三	一○九一五
十三	深黃櫻色質甚薄油味甚重	○・七七五○	一一一四○
十四	櫻色質甚厚油味甚重	○・八三四○	一○九三五
十五	黑色帶綠質尙薄油味輕	○・九一三四	一○六五○
十六	黑色質厚油味輕	○・八九六一	一○七二○
十七	黑色質厚油味輕	○・八八四○	一○七六五

* 參閱美國標準局出版物 Miscellaneous Publication No. 97, pp. 16—17.

此銅瓶之容量在七百立方「生的」左右不宜滿儲以三百立方「生的」油量時爲最宜，過滿則過油之容水多者常易冲溢，過少則不易蒸溜。二百立方「生的」似爲最低數，三百五十爲最高度。無水之油則多至四百五十「生的」亦無妨。（按石油內之水份有兩種，一爲清水與石油判然若兩層，分之極易。一爲雜水 Emulsified Water 藏於石油中，甚難取出，非火力及化學方法不能提取之。）經試驗之成績二百立方「生的」及三百立方「生的」石油蒸溜所得之成份甚相似，卽其比重亦相差不遠，雖此不足以證明此蒸溜法完全適宜，但已可斷定此法能得相同之結果。至於是否與工業實驗成績相合，則未可知也。美國鑛務局所用之銅瓶

較純淨，而所分各部份亦較爲確實。管上玻璃管原擬亦用紫銅，但金屬易於傳熱，如全用銅恐熱度表因其傳熱性而不準故改用玻璃（此玻璃乃由破 Pyrex 蒸瓶鋸下者）。接口處用軟木裹，大者約可用兩三次，小者可十倍次之多。各部裝置完畢後尙應其透漏，故凡接口處均以洋蜜及黃鉛粉調滿塗之保其緊密不透。所用凝水器（Condenser）即蒋常大號者（管長二十四英寸）以柏蘭 Pyrex 玻璃爲佳。發熱器乃北方家用之白泥爐價廉物美，使用時亦復異常便利。爐頂上裝銅瓶瓶週稍有四小鐵片，火足時則去之，不足時則覆之，如遇太不足時（即熱度在二百八十至三百度間）即加用火酒噴燈以補其火力。

蒸溜時常遇石油內水份冲出，如逢此事發生則用小火將水份（及多數油質）逐漸蒸出，去火凝冷之，然後將水份分出。其所帶出之油質重復灌入銅瓶蒸溜之。此舉甚覺煩瑣，然亦不得已之事。其他去水方法雖不乏，然皆不如此法之簡便，雖費時較長而實行時便利多矣。

油樣性質表（表二）

化驗號數	油成色	原油比重	*發熱量 (Cal)
一	深綠色質薄油味輕	○•八三九四	一○九一五
二	綠色質甚厚油味輕	○•八六六○	一○八三○
三	深綠色質尙薄油味輕	○•八五八五	一○八六○
四	深綠色質尙薄油味輕	○•八五八七	一○八六○
五	深綠色質甚厚油味輕	○•八七四八	一○七九五
六	深綠色質甚厚油味輕	○•八七五二	一○七九五

七	四川自流井雷家冲富龍井	原油	全右	
八	全右	煎過油	全右	
九	四川自流井大坟堡同德井	原油	翁所長	
十	四川貢井扇子嘴灯龍井	原油	譚錫畴先生　李春昱先生	
十一	全右	煎過油	全右	
十二	四川資中羅泉井	原油	全右	
十三	全右	水洗油	全右	
十四	四川樂山河洋坎	原油	全右	
十五	四川巴縣顏坡石油溝	原油	丁文江先生	
十六	甘肅玉門上赤金堡南六十里	原油	謝家榮先生	
十七	陝西延長縣	原油	延長官辦石油廠	

石油分體蒸溜（Fractional Distillation）爲現今油類工業上最重要方法，小規模試驗時亦常採用之，然其成績往往與工業實驗者不相符合。所異者無非在試驗器械之不同其原則則一也。美國鑛務局曾有海波（Hempel）法，據稱極爲準確能與工業成績相仿，然反此說者亦不乏人。

本所此次研究法因各石油樣量不多，不能作較大之蒸溜，而祇限於在四百立方「生的」c.c. 之下，故即擬採用海波法。旋因器械購備之不便玻璃之易於破碎，乃改用紫銅蒸瓶，其形狀及尺寸等均註明英文篇內之附圖，不另贅述。銅瓶及蒸凝管相連處祇用二分厚鷄毛紙（Asbestos Paper）墊之，即能嚴密。蒸凝管內滿盛鋁片，一可阻止泡沫上冲，二可增加蒸凝面積，石油分體自

苟能設法將無煙煤化爲油屑以補吾國天然石油之不足，未始非善策也。煙煤之油類提取當屑可能，但低溫度蒸溜試驗宜特別研究以期有成。

國內油田最著者爲陝西北部，民國初年美孚煤油公司曾得特許權探勘石油經探鑽數處均未成功。聞該公司探鑽地點祇有七處，其深度自二千至三千尺，故尚有研究之價值不得謂絕無希望也。甘肅與陝西毘連，其油色及質地均與陝西所產相似，其面積不及陝西之大。四川產鹽之處甚多，鹽井中常發見石油及氣體物質，當地人民均以產鹽爲主要工業，而未曾特別注意石油。其產量向不富饒。近年來本所送派專員入川調查，採有油樣十餘種，出自貢井自流井資中樂山巴縣等處。其地質儲量等譚錫畸李春昱兩君將另有詳細報告。新疆省亦有油田，其質量尚不得而知。貴州泡木冲一帶在晶洞內發見石油，其含油量似無多希望。總之吾國石油量多寡尚未能完全明曉但既有油苗歷歷在目，決不能因探鑽之未遍，而斷定其有無。石油地層地質複雜在未經充分鑽探以前即專家亦不能切實確定。因此吾國石油儲量究竟此時亦未便先行斷言，但油苗發現既多其希望自當較大也。

油樣產地表（表一）

化驗號數	產地	油名稱	採集者
一	四川自流井桂花山四福井	原油	譚錫畸先生　李春昱先生
二	四川自流井老林冲東盛井	煎過油	仝右
三	四川自流井甕塘同昌井	原油	仝右
四	仝右	煎過油	仝右
五	四川自流井白家灣積富井	原油	仝右
六	仝右	煎過油	仝右

中國石油之成分

金開英

當今之世工業繁興，動力之源厥在燃料。燃料所資，初用草木，繼以煤炭，現乃及於石油。石油者蘊於巖石層內而爲液質，故有此名，其體小利於致遠，其性柔滑不膩於器之方圓，至於含熱力多而渣滓少，較之草木煤炭均有過之無不及也。今試擇其優點種別列敘於次。

(甲)石油原油如鑛中所得未經製鍊者其用處頗狹，迨蒸溜一過鑑別所含輕重各質而其效斯廣。

(一)汽油 Gasolone 精細原動力機之最要燃料

(二)煤油 Kerosene 燃燈裹物及種種生熟之用

(三)柴油 Fuel Oil 大小汽鍋及巨方原動機均能合用水陸咸宜

(四)潤油 Lubli ant 爲保持動機軸桿等令溫度平均不易磨損

(五)石臘 Paraffin 再分厚薄以製凡士林藥膏及洋燭各品

(乙)石油及其副產品既如上述種種然猶僅擇其要者言之，更細分別其品物幾至無窮。煤油一項所含熱力較諸煤約多百分之四十。前曾言及運輸之便而且價廉。但就已出鑛之煤相比，若從開採時說起其難易亦處迥別。蓋石油出處一經探得即可通下一長鐵管，用抽力機或壓氣機均能將石油取出。既出鑛外即可藉鐵管送至製鍊廠內，再從事蒸溜分別矣。

是以各國關於世界石油之蘊藏非常重視。惟恐用之或竭，試驗種種方法從含油頁岩內提取石油。並設法化煤爲油，所獲成績尚優。但因成本浩大，所產油價現尚不能與天然石油相抗衡。然各國爲國防計仍努力試驗，每年耗費資財不可勝數。吾國所有油田向少開採，如其儲量豐富則所需各油類自應由天然石油內提煉。否則爲自給計亦亟應研究頁岩內提油及化煤爲油各法，極力圖之，庶不居人後。頁岩內有油質國內除遼寧熱河廣東外，其他尚少發現。無煙煤則吾國蘊藏極富，滿佈各方。況此類煤用途有限

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金開英著

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ON THE VEGETABLE TISSUES AND FLORA IN THE CHINESE COAL AND THEIR GEOLOGICAL SIGNIFICANCE

BY C. Y. HSIEH

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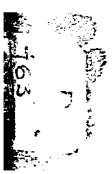

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ON THE VEGETABLE TISSUES AND FLORA IN THE CHINESE COAL AND THEIR GEOLOGICAL SIGNIFICANCE*.

By C. Y. Hsieh. (謝家榮)

(*Contribution from the Sinyuan Fuel Laboratory, No. 4.*)

1. Introduction

Although the vegetable origin of coal has been recognized as early as in the beginning of 18th century, our knowledge in regard to the nature and kind of tissues which formed such an important part in the constituent of coal, was not known until very recently. With the introduction of the microscopic study of coal in either thin section or polished section, the coal investigators are now in a position to identify certain kinds of tissues in a more or less definite way.

During his visit to Germany in 1929, the writer had the opportunity to work with Prof. Gothan on the microscopical study of coal. A total of about hundred specimens of coal derived from 19 different provinces of China were studied. The result** of this study thus started in Berlin and continued in Peiping will be published in several papers, and the present one on the "Vegetable tissues & flora in the Chinese coal and their geological significance" constitutes the first of the series.

The writer wishes to acknowledge his best thanks to Prof. W. Gothan, Prof. R. Potonie, and Dr. H. Bode of the Prussian Geological Survey for their valuable suggestions and criticisms during his work in Berlin. To Prof. Gothan, the writer is indebted especially for his kind help rendered in the identification of several vegetable tissues and the fossil wood *Xenoxylon*.

2. The material

As has been stated, a total of about hundred specimens of Chinese coals were used for microscopic study. These coals were largely furnished by the Geological Survey of China in Peiping; a few of them was also sent by the Geological Survey of Kwangtung and Kwangsi.

* Received for publication March 1932

** Part of the result on the etching structure of coal has already been published by the Prussian Geological Survey "Ätzstrukturen in der Kohle" Arb. aus dem Inst. f. Paläobotanik u. Petrogr. der Brennstein, Bd 2, Heft 1, 1930.

The geological age of the coals, under the present study varies from Carboniferous to Tertiary. With respect to geographical distribution, our specimens are derived from almost the whole China, with the exception of a few provinces, like Sinkiang, Sikang, Chekiang, etc. Our collection covers also the complete range in quality from lignite up to anthracite. Thus a fairly good idea on Chinese coals can be obtained from the study on these widely distributed specimens.

3. METHODS OF STUDY

Four methods were used in the present investigation, namely:

(1) The study of thin section by the transmitted light.

(2) The study of polished section by the reflected light.

(3) The maceration.

(4) The etching.

The best thin section of coal can be made either by the Jeffrey's microtome method[1], or by the method of Thiessen. By the first method the coal must at first be treated with concentric fluoric acid and then washed thoroughly by dilute alkali or a solution of alkali in alcohol. Owing to its tedious procedure and somewhat complicate technique, this method was not employed in the present investigation.

While polished section method has been almost exclusively used, a few thin sections were also made. The writer has found that by following somewhat the same procedure of Lomax[2], fairly good sections of coal, which are thin enough to show all the details, can be made. The principle of Lomax's new method is that instead of grinding the coal section on the glass plate, he used a piece of oil stone as the grinding tool by which the different bands of the section are carefully ground one after another. In this way, the already thinned part of the coal can be kept from further grinding.

In making the polished section of coal, I have adopted the method developed in the Prussian Geological Survey as has been fully described by Stach[3]. Fine powder of aluminum oxide (Tonerde) was used as the material for final polishing.

The maceration method, a familiar method in botanical and paleobotanical research, has been applied with some success in the present investigation.

Exines of spores, cuticles, wood fibers, fusain etc. can in this way be isolated and studied under the microscope. The Schulze's reagent, i. e. a mixture of potassium chlorate and concentric nitric acid (sp. gr. 1.40), was used as solvent for maceration.

The Seyler's method[4] of etching by using a mixture of chromic acid and sulphuric acid has given excellent result. More than twenty specimens Chinese coals ranging in quality from lignite to anthracite were etched and from which different structures of woody tissues, bark tissues, cork cells, parenchymatous cells, epidermis of leaf etc. were obtained. Thus our result has fully demonstrated the value and necessity of etching as a means to detect microstructure in coal, especially in the homogeneous and structureless band of the vitrain. Without etching, many of the structures are not possible to observe.

Lastly, the application of polarized light to the study of polished section of coal as recently proposed by the writer[5], may be mentioned. This method is especially adaptable to the investigation of anthracite. Some excellent structures similar to those obtained by Turner and Randall[6] after flame etching have recently been observed among the Chinese coal under crossed nicols*. A full account of it is reserved for a later paper.

4. Description of Vegetable Tissues.

In the Chinese coals, the vegetable tissues are composed of many different kinds, and in most cases are well preserved. Even the cell contents of the epidermal cell of a leaf are sometimes clearly recognizable. On account of lack of sufficient material for comparison, no attempt is made to identify the different tissues or flora specifically. In some cases, however, broad distinction as, for example, between the Coniferous wood and the Angiospermous woods, can be easily made.

The following is a short description of the various tissues identified among the Chinese coals.

(1) *Cell content and cell filling:*—Rounded granules, probably coalified cell contents are abundantly present on the cuticles separated by maceration from coal seam No. 12 of the Chaokuochuang Colliery in Kaiping coal basin.

* a Leitz ore microscope (Mop) is used for this kind of study.

These granules (Fig. 1, Pl. I) are about 5 μ or more in diameter. In general they have a linear arrangement, being parallel to the longer axis of the cells; but irregularly disposed granules are also frequently seen. The location of the granules with reference to cell walls are also varied; mostly they lie inside the cells, but not infrequently they are located just on the boundary between two cells.

Similar granules in better preservation have been found by the writer from the Jurassic coals of Mudsetou on the right bank of Kialingkiang in Szechuan Province.

The resinous matter is a kind of cell filling, being especially abundant in the cells of Coniferous wood. Owing to its resistent nature, the resin is commonly preserved in the coal.

The preservation of resin either in its original position i. e. filling up the wood parenchyma, or in isolated and displaced state is a common feature of the Chinese coal.

Original resinous filling in the wood tracheids is found in the lignite of Hanwanshan, Wulunghsien in Kirin Province. In this coal, a great number of wood is represented, which shows already distinct woody structure in polished section without etching. In the longitudinal section of the wood, the cells are sometimes so intensively compressed and decayed that their original form could hardly be recognized. Among the tracheids, one can see numerous rectangular to lenticular shaped wood parenchyma cells with resinous filling. These resinous bodies could stand the compression much better than the woody cells, so that they maintained practically their original form without being disturbed. (Pl. I, Fig. 2). The resinous nature of these bodies are best displayed when the polished section is observed under oil immersion or still better when using the polarized light and with upper nicol crossed. Under these conditions, a yellow color and vitreous luster is beautifully shown which proves conclusively their resinous nature. Same result could be obtained when the section is viewed by oblique illumination.

In the bituminous coals of Hokang in Heilungkiang and Chimingshan in Hopei, resinous bodies in the tracheids are abundantly shown after being etched with chromic acid. These structures are illustrated in Fig. 3, Pl. 1. Both of these coals belong to upper Jurassic age.

Isolated resinous body of rounded to irregular shape is commonly observed, especially in the coals from Tawenkou, Shantung; Chiawang, Kiangsu; Fushun, Fengtien and several other districts. The resin in the coal of Tawenkou is remarkable because of its extremely irregular and elongated form, being about 4 *mm* in the whole length. The Chiawang coal is characterized by a great abundance of irregularly shaped bodies which become especially distinct when studied in thin section (Fig. 4 Pl. 1). The higher content of volatile matter in this coal is most likely due to these resinous ingredients.

(2) *Tracheids and woody tissues:* The tracheids and woody tissues of the coniferous or angiospermous woods are preserved in the Chinese coals in various ways and which may be distinguished into the following types.

a) The best state of preservation is that when the wood has been burned by natural forest fire, and occurring in the form of so called fusain, in which all details such as bordered pits, medullary rays etc. may be observed. Fusain is widely distributed in the coals of all ages and of all ranks, and most of them show excellent preservation of cellular structure. In the coal of Hokang in Heilungkiang, twigs or bands of fusain are very common; in one of these twigs there shows clearly the structure of annual ring (Fig. 5, Pl. I. & Fig. 1, Pl. II.). As can be seen from the illustration, the cells of the spring wood have been badly crushed, while that of the autumn wood, because of their thicker walls of the cells, and consequently more resistant to destruction, have suffered practically no compression. In this way, the cells of spring wood and autumn wood could be easily distinguished, and the structure of annual ring is well displayed.

b) Infiltrated structure—Another mode of preservation of the woody structure is that when the cells have been infiltrated by ashy matter; the latter was not coalified, so that their original structures could be retained. Such infiltrated xylain, as it may be called, is commonly met with in the Chinese coal, especially in the coal from the Linhsi colliery, seam No. 9 and Chaokouchuang colliery, seam No. 12. Many of the coals from Shansi province, such as Tienwutsun in Wutai (Fig. 2, Pl. II), Linyu in Taiyuan, show also very beautiful infiltrated structure.

c) After etching—A great number of the woody components of coal, because of advanced coalification, have destroyed all structures they may ori-

ginally have had and now changed into a structure-less and homogeneous mass to which the name Eu-vitrain has been suggested by Dr. R. Potonie. In some cases, however, an homogeneous vitrain can be made to show structures after certain process of etching. One of the best methods of etching is by a mixture of chromic acid and sulphuric acid, devised some years ago by Dr. Seyler. Thus very beautiful structures showing tracheids and woody cells have been obtained in the vitrain of the coals from Hokang, Chimingshan, Fushun, Hsian etc. by etching with the Seyler's reagent. Before etching the vitrain was practically homogeneous and structure-less.

The subbituminous coal of Pataohao in Chinhsi Hsien, Fengtien Province is composed of broad bands of vitrain embedded in a durainic mass. The vitrain shows some kind of wood structure even without etching, but it becomes more distinct after being etched with the Seyler's solution. Fig. 3, Pl. II represents a longitudinal section lying somewhat obliquely between the tangential and the radial positions. The tracheids and the medullary rays are particularly well shown. Even the spiral striation of the tracheids is clearly brought out by etching as can be seen from the illustration (Fig. 4, Pl. II).

Another etched structure showing tracheids, medullary rays, etc. is represented in a coal from Hsian coal mine, Hsian Hsien in Fengtien Province. Under the microscope, the vitrain shows, in most cases, some faint indications of structure which is not, however, distinct enough to warrant a correct interpretation. But the woody structure becomes distinctly shown after etching. Many different section of tangential, horizontal and oblique positions are represented, one of which is illustrated in Fig. 5, Pl. II, which is a tangential section and in which the tracheids and the medullary rays are manifestly shown.

A remarkable structure is found in the coal of Chimingshan. It is an oblique section of wood showing distinct preservation of annual rings as is shown in fig. 1, Pl. III. This piece of wood measuring in total 6 mm long and 2 mm wide represents altogether 13 annual rings. As usual the spring wood is more compressed than the autumn wood, as can be roughly seen from the illustration.

d) *By maceration*—As has been stated above, wood fibers etc. can be separated from the coal by maceration, and thus permitting detailed investiga-

tion of their structures under the microscope. In the best preserved state, these fibers show distinctly the bordered pits, simple pits, medullary rays and other details by which the specific nature of the wood can be accurately determined.

The lignite of Hanwangshan, Wulung Hsien in Kirin province has yielded, by maceration, a great number of wood fibers which show in most cases good preservation of structures. Small and rounded bordered pits (of the modern type) rather densely placed in two or three rows are distinctly shown (Fig. 2 Pl. III). The pits of each row are not alternately arranged, but are one against the other. Some radial section is also found in which are shown somewhat indistinctly the small and lenticular shaped simple pits. Wood parenchyma cells filled by resins are commonly observed.

A piece of angiospermous wood (Fig. 3. Pl. III) has been isolated by maceration from the coal of Fengtien province. It shows clearly the presence of vessels with the characteristic pits on the walls and in some cases even the perforated end walls of the vessels are also preserved. Such perforated end walls may be detached from the main vessels and occur consequently as isolated plates among the different macerated products. The identification of the true nature of these perforated plates was at first quite uncertain, they were not known until the whole vessel in its complete preservation had been found.

(3) *Parenchymatous cells:*—The walls of the parenchymatous cells generally consist of pectin and cellulose. Both of these are weak and easily destructible when subjected to process of coalification, yet it is surprising to find that in many of the Chinese coals studied, these cells are often nicely preserved.

The best preserved cells of this kind are found in the coal from Kaiping basin, Hopei province (Fig. 4, Pl. III), especially from seam No. 12 of the Chaokuochuang colliery. Isolated fragments of the parenchymatous cells are also commonly observed to form minor constituents in the durain.

Although the cellular structure of the parenchymatous tissue is usually distinctly observable; in some cases, because of the advanced coalification, it has been largely obliterated, and will reappear only after etching.

(4) *Scalariform tissues:*—Tissue showing the scalariform thickening of the cell wall is commonly met with in the coals of Penchihu, Tawenkou,

Peitaotze (Shansi) and the Linhsi (Hopei) colliery. In the last named coal, scalariform tissue occurs as fragments in the sideritic concretions. In the coal of Peitaotze, the tissue has been almost wholly replaced by ashy matter, yet its characteristic form is still well preserved. A very well preserved tissue of this kind is found in the maceration product from the coal of Tawenkou in Shantung, shown in Fig. 5, Pl. III.

As the scalariform tissue is in general more characteristic for Pteridophyta, its existence in a coal may be regarded therefore, as a criterion suggesting Palaeozoic age of the coal.

(5) *Stone cells:*—Stone cell, on account of its thick wall and resistant nature, will naturally be saved from destruction, and consequently be preserved as a tissue in the coal. K. Yasui[8] has found many good examples of stone cells in Japanese coal. In Chinese coal, stone cells are also present, as for example, in the coal from the Kaiping basin.

(6) *Bast fiber:*—In her study on the Japanese coals, Yasui[8] has found bast fiber as another common tissue in the coal, although this has not yet been generally recognized by other coal investigators. In view of the lignified nature of the cell wall, the preservation of bast fiber in coal is quite to be expected.

In the present investigation of Chinese coals, bast fiber is rather rarely observed. It is found in the coals of Hokang in Heilungkiang and Chimingshan in Hopei; both of these coals are of Upper Jurassic age.

The preservation of bast fibers in the coal of Hokang is of special interest, as both horizontal and longitudinal sections of the same are well represented. Fig. 1, Pl. IV, is a horizontal section in which bast cells are interbedded with the more pressed parenchymatous tissues of the bark. The bast cell is characterized by very thick cell wall and small lumen. Consequently it is very resistant and in most cases, seems to have suffered little compression and maintains practically its original shape. The small lumen of the cell is now represented either by a small dot or by a narrow line, according to the amount of compression it has received. The radial wall of the cell is convex in shape exhibiting consequently a characteristic and easily recognizable form. Fig. 2. Pl. IV is a microphoto of the same section but

under higher magnification, in which the narrow lumen, the middle lamellae and the convex shaped radial wall are distinctly shown. The longitudinal view of the bast fiber together with the interbedded parenchymatous tissue is shown in Fig. 3, Pl. IV.

Practically the same structure as just described, but less perfect in preservation, is observed in the coal from Chimingshan in Hopei. This and many other structures which are similar in both cases, have raised the question as whether the two coal fields are contemporaneous in geological age.

Some bast fibers have also been found in a coal from Tutai in Szechuan[7], though their preservation are not as perfect as in the other two coals.

(7) *Cork cells:*—Recent investigation has shown the cork cell as a frequent tissue in the coal, especially in coal of younger age and lower rank such as lignite or brown coal. In view of the fact that cork cell is composed of the suberized cell wall and constitutes one of the most resistant part of the plant, the preservation of the same as a tissue in coal, is therefore, a matter of no wonder.

In the Chinese coal, cork cells are also frequently found, either as isolated pieces and fragments in the attritus or being still attached to some vitrain to form the bark of a twig. Most of the cork cells are visible only after etching, and the structure becomes sometimes more distinct, when it is etched for a slightly longer time, say, five minutes or more in the chromic acid solution.

Cork cells are abundantly present in the coals of Fushun in Fengtien and Kiufengshan and Hokang in Heilungkiang (Fig. 4, Pl. IV); in the former coal, Iwasaki[9] has obtained the same result by etching with tetralin. The coal of Kiufengshan contains a great amount of cork tissues which come out especially well when the coal is etched for about half a minute.

Some cork cells are also found in the coals of Hokang, Chimingshan and outer Mongolia.

(8) *Cuticles and leaf parenchyma:*—Cuticle, i.e. the outer cutinized layer of the epidermal cell, forms one of the commonest constituents in the Chinese coal. In vertical section of the coal, the cuticle appears as wavy or indented line, the indentation being due to the protruding edges of the cutinized

walls. Because of the resistant character of the cutin, the cuticle is generally well preserved, and by the use of maceration method, it can be isolated and studied.

Nearly all the Chinese coals investigated contain some cuticle and in the coals of Mesozoic or Tertiary ages from Jehol, Mongolia and Heilungkiang, the cuticle is especially abundant. In the bituminous coal of Peipiao, in Jehol, the cuticle forms an important constituent, especially in seam No. 3. In this coal the cuticles are usually crowded together to form a band of $\frac{1}{2}$ cm or more in thickness in which nothing but cuticles of various sizes are found (Fig. 1, Pl. V). From its high relief and finely striated aspect in the polished section, the cuticle-band is clearly noticeable even to naked eye.

Although cuticles are commonly met with in the coal, complete preservation of leaf parenchyma with cuticles still attached on them is, because of the easily destructible nature of the latter, only rarely observed. In the coal of Yuanpaoshan in Jehol, the writer has been fortunate enough to find complete section of a leaf limited both above and below by cuticles. This is shown in fig. 2, Pl. V in which besides the serrated cutinized walls, the epidermal cells are also distinctly preserved. The mesophyll, however, is not shown.

The best way to study the detailed structure of the epidermal cells in a cuticle is by maceration. Fig. 3, Pl. V, represents a cuticle separated by maceration from the coal of Nalaha in outer Mongolia. The irregularly shaped epidermal cells are well shown together with excellent preservation of stomatic openings which are exceptionally abundant in this particular leaf. A cuticle with rectangular shaped epidermal cells is commonly found in the Permo-Carboniferous coal of northern China, such as Linchen, Kaiping etc. in Hopei province.

With respect to the structure of the epidermal cells, the cuticles from the Chinese coals can be divided into three groups:

a) The epidermal cells are of rectangular shape, being bordered by straight cell walls (Fig. 3, Pl. V.).

b) The epidermal cells are of rectangular, polygonal or irregular shapes and are bordered by cell walls showing remarkable dentation or undulation (Fig. 4, Pl. V).

c) The epidermal cells are of polygonal shape but are bordered by straight cell walls.

The coals of Permo-Carboniferous age contain generally the cuticles of the type (a) i. e. rectangular cells with straight cell walls, while those of Jurassic age, as for instance, the coals of Pinghsiang in Kiangsi province and Hsüanhua in Hopei province, the irregular cells with undulated walls are most common, though to some extent the cuticles of the type (a) are also found. The late Mesozoic and Tertiary coals contain, in most cases, the cuticles of polygonal shape with straight walls. Thus some approximate idea about the age of the coals may be gained from a study of the cuticle alone.

(9) *Spores and pollen grains:* The exines of both microspores and macrospores and pollen grains, because of their resistant nature are also frequently preserved in the coals. As a result of stress from the overlying load, the spores are usually compressed in the direction perpendicular to the bedding planes. Consequently, in the vertical section of the coal, they generally appear as flattened lenses or tiny streaks showing no detailed structures, while in the section parallel to beds, a horizontal view of the spores is obtained.

But the best way to study the morphological characters of the spore exines is by maceration, by which the spores can be isolated and photographed. All details such as the tri-radiate ridge or marking, the sculpturing or ornamentation on the surface, the outgrowth and the tubercles of the spores etc. may be observed.

In Chinese coals, the exines of macrospores are rarely found; only in the following coals, they are found to be fairly common. These are the coals from T'angchiachuang in Hungyuan Hsien, Shansi; Shakuotun in Chinhsihsien, Fengtien; Kaiping, Hopei; Tawenkou in Taianhsien, Shantung; Shungkengshan, Anhui; Chiawang in Tungshanhsien, Kiansu. All these coals are of Permo-Carboniferous age. A few exines of macrospores have been also observed in the Mesozoic coal of Pinghsiang in Kiangsi province; this seems to be the only exception, so far as we know, where exines of macrospores are found in younger coal than Palaeozoic.

The macrospores from the coal of Shakutun in Fengtien ary very characteristic; in vertical section they have a length varying from 64 to as much

as 1.69 mm and with generally a very thin wall reaching only about 12 μ in thickness (Fig. 5, Pl. V). They are frequently wrinkled at many places, so that in vertical section a double layered or "Zangen" structure is resulted. In the horizontal section, the macrospore gives an entirely different appearance, an example of which is shown in Fig. 1, Pl. VI. Macrospores showing almost the same structures and forms as here described have also been found in the coals of Kaiping in Hopei, Shungkangshan in Anhui and Chiawang in Kiangsu. On this ground we can conclude that such complicately wrinkled and thin-walled macrospore exines are widely distributed in the Permo-Carboniferous coal basin of the whole China.

The macrospore exines in the coal from T'angchiachuang, Hunyuan Hsien in Shansi are of special interest. These spores are generally of enormous sizes; in one case they were 3.36 mm long and 48 μ thick for their wall. Another characteristic feature is the existence of peculiar shaped rounded tubercles which are found attached on almost the whole surface of the exines. From figs 3 & 4, Pl. VI, we can further notice that these spores have suffered comparatively little compression, so that they are not pressed together, but to form lenticular loops in the vertical section.

In the coal near Tawenkou in Shantung, macrospores of enormous sizes with round tubercles are also found, an example of which is shown in Fig. 5, Pl. VI. In its entire length, this macrospore is 3.71 mm long, the thickness of its wall is about 52 μ. The tubercles are very complicate in form, being attached to the wall almost all the way through the whole length. Besides, the spore shows also the characteristic double layered structure. Morphologically speaking, the macrospore of Tawenkou is quite similar to the one just described in previous paragraph.

On the other hand, exines of microspores are commonly observed among the Chinese coals; they are especially abundant in the coals of Permo-Carboniferous age. The most typical is the coal of Kaiping, in Hopei province. Similar occurrences of microspores are found in the coals of Shakuotun in Fengtien, Shungkungshan in Anhui, Chiawang in Kiansu, Tienwutsun, (Wutaihsien) Huangshantsun (Wukwanhsien) and T'angchiachuang (Hunyuanhien) in Shansi, Hsitzeyao (Ninyanghsien) and Tawenkou (Taianhsien) in Shantung. The exines of microspores separated by maceration from the

coal of Shakutun is shown in Fig. 1, Pl. VII. Regarding their morphological characters, the microspore exines from the Shakuotun coal may be divided into four types as follows:

a) Perfectly round b) Round spores with a sculptured surface c) More or less triangular in shape and with a ring. (Fig. 1, Pl. VII) d) A very small spore having a diameter of only 18 micra and occurring generally in aggregated forms. The latter is probably spore of some fungi.

It is almost impossible to distinguish between the exines of the microspores and the pollen grains either in thin section or in polished section; only by maceration is such a distinction possible. In the Tertiary coals from Kirin, Heilungkiang, Kuangsi and Fushun in Fengtien, many pollen grains are surely in existence. A very characteristic pollen grain with two air sacks resembling therefore the type of Pinus is found by maceration from the coals of Kongyao in Kirin and Fushun in Fengtien.

(10) *Sclerotium & hyphae of Fungi:*—Sclerotium, i.e. the compact mass of mycelia of some fungi in passing into a vegetative resting stage was first discovered by Jeffrey and Crysler in a lignite from Brandon, Canada. Since then, similar structures have been repeatedly found in coals of other countries, as Germany, Japan etc. They are especially characteristic for the younger coals of lignitic composition.

During the present investigation with the Chinese coals, Sclerotium is found to be a common constituent in practically all the lignitic coals of the Tertiary age. It has been found in the coals of Fushun in Fengtien (Fig. 3, Pl. VII) Loutouhotzekou, Kangyaochên, Hanwangshan in Kirin, Niutzeshan in Kwangtung and a lignitic coal of unknown locality in Kwangsi (Fig. 4 Pl. VII). So far as the Chinese materials are concerned, no sclerotium has ever been observed in coals older than the Tertiary, though some European authors have claimed their occurrence even in Carboniferous coals.

The sclerotium can be easily identified from its rounded to lenticular shape, and reticulated or alveolated structures. It consists of a rather thick outer wall, and a comparatively thinner wall for the internal chambers or spores. It is usually extremely small in size, being about 98 μ in diameter. In the coal of Fushun, the same structure has also been noticed by Iwasaki[9], but he named it as the reticulated bodies.

Fungi hyphae is found in the maceration product from a lignite in Kwangsi. It is interesting to note that such structure, though delicate in form, is extremely resistant, having survived from the intense processes of coalification and metamorphism, it is now again unaffected by the Schulze's reagent.

Both sclerotium and hyphae are principally composed of Chitin, a material of extremely strong resistence; consequently they are often nicely preserved in the coals.

5. THE FLORA THAT CAN BE IDENTIFIED.

The science of coal petrography has, until now, not yet developed to such a stage as to permit accurate identification of the flora contained in the coal beds. The reason is partly due to the lack of completely preserved tissue for a full identification and partly is also due to the imperfectness of our knowledge in regard to the microscopical anatomy of the ancient flora. Intensive research along that line is therefore urgently needed.

It is not intended for the present preliminary investigation to make accurate identification of the different floral elements that have contributed to the formation of Chinese coal beds. On the other hand, some of the tissues observed or isolated from the coal are so nicely preserved that a complete identification of their genus or even species is possible.

Most of woody pieces observed either in their charred forms (fusain) or in the unburned state, belong generally to the coniferous group. In the best preserved state, the wood shows also bordered pits, medullary rays and other details.

The detailed structure of the woods can be best seen by maceration. By that method the wood fibers can be separated and studied under microscope. According to Gothan[10], two kinds of bordered pits of the coniferous woods may be distinguished:

(1) The Araucarian type, i.e., the pits are closely packed together and with alternating arrangement. They are, with a few exceptions, the characteristic forms for the Palaeozoic formations.

(2) The younger or modern type in which the pits are perfectly rounded and more or less separated are found in all formations younger than Palaeozoic.

The only exception is the wood *Xenoxylon*, the index fossil of Upper Jurassic, in which the bordered pits are more near to the older or Araucarian type, rather than the modern one.

The broad relation between the forms of the bordered pits and the geological age discussed above holds especially well in the study of the Chinese coals. In the maceration products of the coal of Yutaishan in Hopei, Hanwangshan in Kirin and an unknown locality in Kwangsi, wood fibers showing modern bordered pits are abundantly found. All these coals belong either to Jurassic or to Tertiary in age. On the other hand, wood fibers isolated from the coal of Shakuotun, which is of Permo-Carboniferous in age, bordered pits of the older or the Araucarian type are observed.

The wood fibers isolated by maceration from the coals of Hokang and Yuanpaoshan show such detailed structure that they may be specifically determined to belong to the genus *Xenoxylon*, a genus founded by Gothan[12] in 1908. As can be seen from the accompanied illustration in fig. 6, Pl. VII, this wood is characterized by the big egg-shaped simple pits (Eiporen) in the medullar ray and vertically flattened and therefore more or less rectangular shaped bordered pits in the tracheids. The *Xenoxylon* of Yuanpaoshan shows closely arranged bordered pits and which should therefore be compared with *Xenoxylon latiporosm* of Gothan, while that of Hokang, the bordered pits are not so densely located; this latter character seems to approach the species *Xenoxylon phyllocladoidese* Gothan. Owing to lack of sufficient sections (only radial sections are present in the maceration products) for detailed examination, a definite identification of the species is not possible.

A similar occurrence of the fossil wood *Xenoxylon* was found by H. S. Wang of the Geological Survey from Hsiachiakou, Choluhsien in Hopei province and which has been recently described by Prof. C. Y. Chang[13]. Here the wood occurs as isolated fragments, twigs, or part of a trunk in a tuffacious sandstone of upper Jurassic age. In the later collection by Mr. S. W. Wang of the Survey there has been found some large trunks, the largest specimen attaining about two feet in diameter. According to Prof. Chang this wood shows all the essential characters of the typical *Xenoxylon* except a few point of no great importance such as the presence of wood parenchyma, the Bars of

Sanio, an occassional biseriate ray etc. Accordingly, Prof. Chang has made a new species, the *Xenoxylon hopeiense* for this remarkable occurrence.

According to Prof. Gothan the fossil wood *Xenoxylon* has a wide distribution; it has been found in Poland, Germany (Salzgitter), Spitzbergen, Konig Karlo Land, and Yorkshire in England. The geological age of the wood, so far as is known, belongs to upper Jurassic or Lowest Cretaceous. This agrees perfectly well with our occurrences in China, as the geological age of the formation at Hsiachiakou has been fairly determined, from other evidences, to belong to the same horizon.

The above discussion shows clearly the coniferous wood as an important constituents in the Chinese coal. On the other hand, wood of the Pteridophyta which certainly have contributed a great part to the formation of the Palæozoic coal, are found only in a few instances. Their presence can be inferred from the structure of the scalariform tissue which is common in all these coals studied, and which can be seen either in the polished section, or in the maceration products.

The activity of fungi in most of the Tertiary coals, is also a noteworthy phenomenon. Their presence is clearly indicated by the numerous sclerotites, the hyphae, and the fungi spores.

6. GEOLOGICAL SIGNIFICANCE OF MICROSCOPICAL STUDY OF COAL

It is needless to say that microscopical study of coal has important bearing on its geological and economical problems. The identification of tissues and flora in the coal constitutes only one phase of the study, but sometimes even this phase alone, is enough to give important geological conclusions.

Owing to the preliminary nature of our study, such important problems as the correlation of coal seams, the constitution of coal, the origin of coal, etc. will not be considered. Only two points, which are of special importance geologically, will be discussed as follows:

(1) *Coal structure and geological age:*— It has been a familiar method to the geologist, that in order to determine the geological age of a coal seam, one has to rely upon fossils (either plant or animal) contained in its associated strata. Before the development of the microscopical study of coal, no

geologist will believe that a study of the coal alone will throw light on its geological age. Now with the development of new technique, the coal petrographer is able to see through the unknown darkness, and to formulate some broad relations[13] between the coal structures and the major geological divisions as Palæozoic, Mesozoic or Tertiary. This relation holds especially well with the study of Chinese coal.

So far as our present investigation goes, the following criteria has proved to be of value in the broad determination of the geological age of coals:

A. CRITERIA INDICATING PALAEOZOIC AGE OF COAL:

a) The presence of an immense quantity of microspore exines together with some of abundant exines of macrospores. The only exception to this rule is the coal of Pinghsiang of Lower Jurassic age in which abundant exines of microspores and a few macrospores have been observed.

b) Presence of wood fibers with bordered pits of the Araucarian type. The wood *Xenoxylon*, the index fossil of Upper Jurassic is perhaps the only exception to this rule.

c) Epidermal cells of the cuticles are generally characterized by straight cell walls. The cuticles isolated from the coals of Kaiping, Linchen, Shakuotun etc. agree perfectly well with this rule.

d) Presence of the scalariform tracheids of the Pteridophyta.

B. CRITERIA INDICATING MESOZOIC OR TERTIARY AGE OF COAL.

a) Presence of Angiospermous wood. This is indicated by the presence of the vessels or the end plate of the vessel. Generally Tertiary.

b) Presence of annual ring which can be seen either before or after etching. Mesozoic or Tertiary. Some Permian woods are said to show also distinct preservation of annual ring, but this is only exceptional case rather than usual.

c) Presence of wood fiber with bordered pits of the modern type. Mesozoic or Tertiary.

d) Presence of cuticles with undulated epidermal cell walls. Mesozoic or Tertiary.

e) Presence of the wood fiber belonging to genus *Xenoxylon*. This is the surest indication of Upper Jurassic age.

So far as my own observation with the Chinese coals goes, the preservation of cork tissues and the presence of Sclerotites seems to point to Tertiary age of the coal, as these tissues have not yet been seen in coals older than that period.

(2) *Geological condition during coal formation:*—The study of tissues and flora in the Chinese coal has furnished us some evidences by which the general geological condition for the coal forming period may be traced. First of all we may consider the activity of fungi in many of Tertiary coals in China, their presence being clearly indicated by the abundant sclerotites, the hyphae and the fungi spores. As is well known in Botany, sclerotium develops only under a dry surrounding, so we may picture a rather dry condition, under which were deposited most of our Tertiary coals. Same explanation has been advocated by Gothan and others for the condition of brown coal formation in Germany as in this coal sclerotites are also of frequent occurrence. Another fact which may be considered as supplementary argument for the above interpretation, is the poor preservation of the cuticles in most of the younger coals studied. As we know, dry condition facilitates oxidation and decomposition, so this explains itself why younger coals contain frequently poorly preserved cuticles.

On the other hand, the usually excellently preserved tissues including cuticles, spores, parenchymatous cells etc. in most of the Palaeozoic coals in China is a noteworthy phenomenon. This fact together with the absence of any indication of the action of the microorganisms in the coal indicates strongly that a pre-existing destruction of the vegetable tissues did not take place, and the coal-forming condition must be a specially favorable one for their preservation. A wet surrounding probably under constant covering of water must have been the prevailing condition during the coal forming periods of Permo-Carboniferous time in China.

7. SUMMARY

1. Altogether about one hundred specimens of coal from 19 different provinces of China proper and two specimens from Mongolia were studied. In quality, these coals vary from lignite to anthracite, and in age they belong to different formations of Tertiary, Cretaceous, Jurassic and Permo-Carboniferous.

2. Four methods of investigation, namely, the thin section, the polished section, the maceration and the etching have been used in the present investigation.

3. A great number of vegetable tissues and organs such as parenchymatos cells, stone cells, wood tracheids, scalariform tracheids, bast fiber, bark parenchyma, epidermal cells sometimes with cell contents, cork cells, fungi hyphae, sclerotites, spore exines, pollen grains etc. have been detected in the coals studied.

4. One of the exceptionally well preserved wood fibers has been definitely identified to belong to *Xenoxylon*, an index fossil for upper Jurassic formation. This coniferous wood is now known to be widely distributed in the Mesozoic coal basin of Northern China.

5. From the presence of fungi activity in the Tertiary coal a rather dry condition for the coal forming period may be advocated. On the other hand, the usually excellently preserved state of the various tissues in the Palaeozoic coals postulates a contrary condition i.e. a wet surrounding and probably under constant covering of water.

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Explanation of Plate I.

PLATE I.

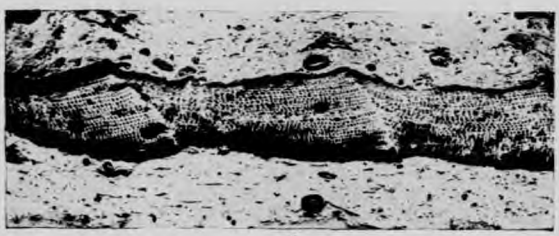
Fig. 1. Granules in epidermal cells, evidently representing some coalified cell content. Chaokuochuang Colliery, Kaiping coal basin, Hopei province. × 488, Maceration products.

Fig. 2. Extremely crushed tracheid with resinous filling in the wood parenchyma. Hanwangshan, Kirin, Polished section of a lignite. × 224.

Fig. 3. More or less crushed tracheids with lenses or pockets of resinous matter. Etched polished section of a subbituminous coal, Hokang, Heilungkiang × 210.

Fig. 4. Irregular and detached resinous bodies in bituminous coal of Chiawang, Kiangsu province. × 60 Thin section.

Fig. 5. Fusain showing distinct structure of annual growth. Bituminous coal of Hokang, Heilungkiang × 34. Polished section.



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Explanation of Plate II.

PLATE II.

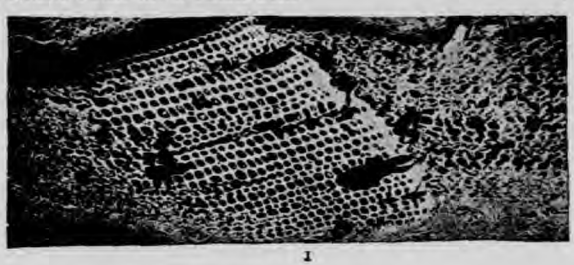
Fig. 1. Same as Fig. 5 under higher magnification × 110.

Fig. 2. Wood structure preserved by ash infiltration, Bituminous coal from Tienwutsun, Wutai district, Shansi. × 110. Polished section.

Fig. 3. Etched polished section showing tracheids, bordered pits, and medullary rays of a wood. Subbituminous coal of Peitaoho, Chinhsien, Fengtien. × 107.

Fig. 4. Same section as Fig. 8 showing spiral striation in the tracheids. Etched polished section. × 107.

Fig. 5. Woody structure brought out after etching. Bituminous coal of Hsian, Fengtien. × 118.



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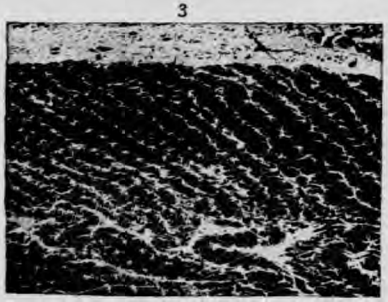

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Explanation of Plate III.

PLATE III.

Fig. 1. An oblique transverse section of a wood showing several annual rings. Etched polished section. Chimingshan, Hsüanhua district, Hopei province. × 67.

Fig. 2. Wood fiber showing bordered pits (modern type) and resinous filling: Separated by maceration from a lignite of Hanwangshan, Wulung district, Kirin province. × 220.

Fig. 3. An angiospermous wood with vessels separated by maceration from the sub-bituminous coal of Fushun, Fengtien. × 32.

Fig. 4. Parenchymatous cells partly replaced by ash. Chaokuochuang, Kaiping coal basin, Hopei province. × 65. Polished section.

Fig. 5. Scalariform tissue, separated by maceration from the bituminous coal of Tawenkou, Shantung × 166.

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Explanation of Plate IV.

PLATE IV.

Fig. 1. Etached polished section showing the bast fiber and bark parenchyma in horizontal view. Hokang. Heilungkiang. × 108.

Fig. 2. Same as Fig. 1 under higher magnification. × 450.

Fig. 3. Longitudinal view of the bast fiber and bark parenchyma. Etched polished section, Hokang, Heilungkiang. × 210.

Fig. 4. Cork tissue in the coal of Hokang, Heilungkiang. × 210.

Fig. 5. A durain extremely rich in cuticles. Peipiao, Jehol, × 58. Vertical Section.

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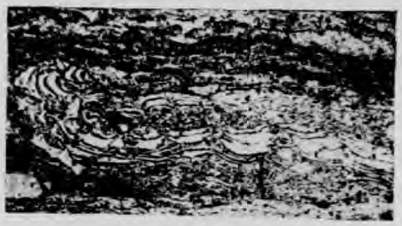

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Explanation of Plate V.

PLATE V.

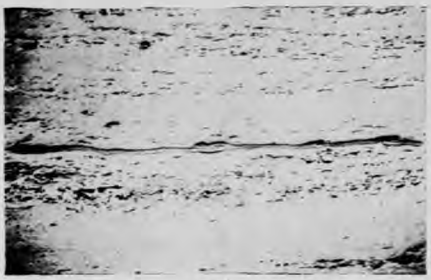
Fig. 1. Cross section of a leaf showing distinct structure of cuticle and epidermal cells after etching, Yuanpaoshan, Jehol. Polished section. × 118.

Fig. 2. A well preserved cuticle with distinct stomatic opening, isolated by maceration from the coal of Nalaha, Mongolia. × 106.

Fig. 3. Cuticle showing rectangular cells and straight cell walls. A few stomatic opening can be indistinctly seen. By maceration from the coal of Lincheng, Hopei. × 180.

Fig. 4. Cuticle with rectangular cells and undulated cell walls. Isolated by maceration. Yuanpaoshan, Jehol. × 220.

Fig. 5. General microstructure of coal from Shakuotun, Fengtien, showing abundant microspore exines and a peculiar macrospore in the center. × 60. Polished section.



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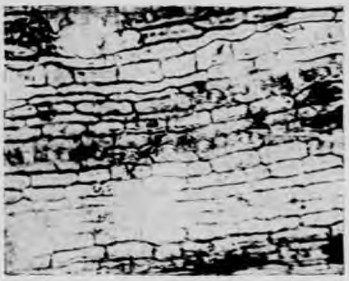

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Explanation of Plate VI.

PLATE VI.

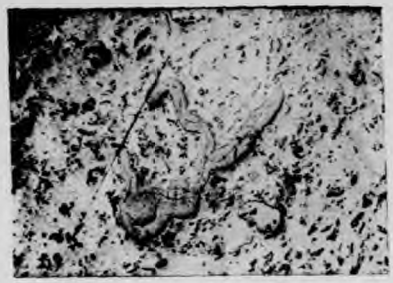
Fig. 1. Macrospore in horizontal view, Shakuotun, × 56, Polished section.

Fig. 2. General microstructure of the coal from Tangchiachuang, Hunyuan district, Shansi, showing numerous slightly pressed microspore exines and a big macrospore with tubercles in the center. × 50, polished section.

Fig. 3. Another view of the macrospore under higher magnification. Tangchiachuang, Shansi. × 98. Polished section.

Fig. 4. An extraordinary large sized macrospore exine showing numerous tubercles on the wall. Tawenkou, Taian district, Shantung, × 60. Thin section.

Fig. 5. Horizontal view of microspore exines, Chaokuochuang, Hopei. × 128. Polishod section.



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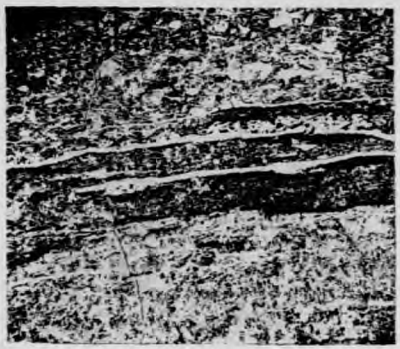

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Explanation of Plate VII.

PLATE VII.

Fig. 1. Exines of microspores from the maceration product of the Shakuotun coal, Fengtien. Note the tetrasporic marking and the ring. × 105.

Fig. 2. Maceration preparation showing several exines of microspores, Tawenkou, Shantung. × 90.

Fig. 3. Sclerotium in the coal of Fushun. Fengtien, × 400. Polished section.

Fig. 4. Sclerotium in the coal of Kwangsi. × 105. Polished section,

Fig. 5. A group of rounded, oval or lenticular bodies occurring in the mids of the woody tissue; they are probably the spores of some fungi. Etched section, Fushun, Fengtien. × 118.

Fig. 6. *Xenoxylon* isolated by maceration from the coal of Yuanpaoshan, Jehol. × 106.

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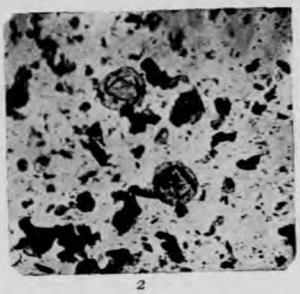

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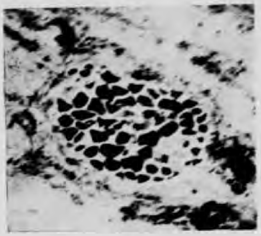

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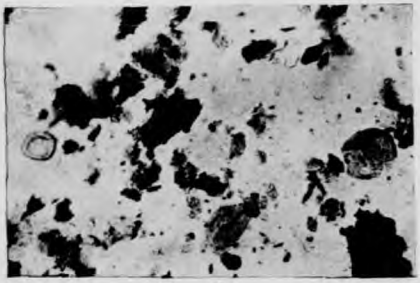

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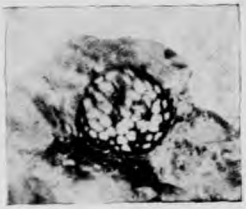

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謝家榮著

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CONTRIBUTION FROM THE SIN YUAN FUEL LABORATORY,
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THE COKING PROPERTY OF THE POSHAN COAL OF SHANTUNG

BY C. C. WANG

GEOLOGIST OF THE GEOLOGICAL SURVEY OF CHINA

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THE COKING PROPERTY OF THE POSHAN COAL OF SHANTUNG

(Summary)

By C. C. Wang.

GEOLOGY

The geology of the coal field of Poshan and its adjacent fields has been surveyed and described by my colleague Mr. H. C. Tan in a report in the Bulletin of the Geological Survey of China, No. 4, Oct. 1922. This report was accompanied by an excellent geological map on the scale of 1:100,000 surveyed topographically and geologically by Mr. Tan. I shall, however, propose certain modifications as result of my field observations in 1928 and 1931.

The lower and middle parts of the "Palæozoic coal series" of Mr. Tan are difficult to be differentiated and better to be combined into one and called Carboniferous and Permo-Carboniferous coal series. This is the coal measure of the region under study, and its stratigraphy is well comparable to the equivalent formation which I have formerly studied in Shansi province. On the other hand, the overlying yellow shale of Permian and Permo-Triassic age is a distinct formation which I can see no reason to include in the coal measure. Practically it is more important to make it a separate series, as it contains the bauxite bed which I shall describe in the following paper.

According to Mr. Tan's survey, the Poshan-Tzuchuan coal field is limited on the west by a great fault or horizontal displacement by which the eastern continuation of the coal field known as the Changchiu field is abruptly shifted ten kilometers northward. I revisited this part of the coal field in 1928 with Mr. C. C. Liu and found that there exists really no such a fault. The Changchiu field is really continuous with the Poshan-Tzuchuan field and separated only by the turning of strike due to a fold of the strata. On the other hand, the vertical fault NE of Heishan has been essentially confirmed.

For the other points of general geology, especially for the geological map, the reader is referred to Mr. Tan's report and my next paper on the bauxite shale. The present paper is chiefly concerned with the different coal seams and their respective composition.

COAL SEAMS

The coals from the northern fields extending from Tahuangti (Tzuchuan) westward to near Poshan city and to Changchiu locally known as Siao-shan-tan are generally not good for coking. The coking coals only occur in the southern area, south of the district city of Poshan, namely Heishan and Hsiho fields. They are locally called Ta-shan-tan. Of the two latter fields, the Heishan field is by far larger than the other one. The Plate I shows the whole field already entirely covered by mining claims. In this field there exist altogether 19 coal seams within a total thickness of strata of 250 meters (see Plate II). Out of these ten seams are workable. The following table summarizes the local name of these seams, their respective thickness, and the area of their distribution and reserve, the seams being arranged in ascending order, i. e. the highest on top.

No.	Coal seam	Average thickness	Area	Reserve
10	Chitzutan	0.7 meter	5.400,000 sq. m	4,914,000 tons
9	Tatuanshihtan	1.5	id.	10,530,000
8	Siaotuanshihtan	0.8	id.	5,616,000
7	Siaohuangshihtan	0.6	6,930,000	5,405,40.)
6	Huishihtan	1.2	10,440,000	16,286,400
5	Tahuangshihtan	1.2	11,840,000	18,740,400
4	Yusingtzutan	0.7	13,860,000	12,612,600
3	Siaoshihtan	1.0	16,000,000	20,800,000
2	Tashihtan	2.0	id.	41,600,000
1	Chiakangtan	1.2	id.	24,960,000

The numbering of the coal seams in the above table is added by the author specially for this summary for practical convenience in the following discussion. The seams are only known to the local miners by their particular names which designate definite properties in their mind.

From the above table the total reserve of the Heishan field is 161,464,800 tons, which essentially confirms the estimate previously made by Mr. Tan in his report published in 1922.

The Hsiho field contains only the five lower coal seams nos. 1-5 totalling about 5 meters in thickness over an area of 8,400,000 square meters. The reserve is thus calculated to be 54,600,000 tons. This is again in the same order of magnitude as Mr. Tan's estimate. But my figures are in both cases a little higher,

CHEMICAL ANALYSES OF THE COALS.

The coal samples collected by me in the summer of 1931 have been fully analysed under the supervision of Mr. K. Y. King, the chief chemist of the Geological Survey. The results are tabulated below.

I. COALS FROM THE HEISHAN FIELD.

	Coal seam	Class.[1]	Moist.	Vol. mat.	Fix. C.	Ash	Sulphur	Coke	Heat value
No.	2	Ah^{4}_{4}	0.70	19.60	63.18	16.52	3.40	caking & swelling	7100 Cal.
	3	AB^{3}_{2}	0.40	17.94	76.56	5.50	2.50	caking & slight swelling	8286
	4,	Bm^{3}_{3}	0.40	23.00	67.38	9.22	1.60	caking & swelling	7871
	5	Bh^{1}_{3}	0.39	20.42	70.87	8.32	0.13	caking & swelling	7975
	8	Bm^{4}_{3}	0.30	22.76	66.96	9.98	3.00	caking & swelling	7833
	9	Bh^{1}_{3}	0.41	21.29	67.43	10.87	0.51	caking & swelling	7741

II. COALS FROM THE HSIHO FIELD.

	1	Bh^{1}_{3}	0.64	19.25	68.15	11.96	0.22	slightly caking.	7628
	2	Bh^{5}_{4}	0.50	16.72	65.66	17.12	6.3	,,	7206

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

3	AB^{3}_{3}	0.24	17.32	74.16	8.28	2.4	caking & swelling	7986
4	AB^{3}_{2}	0.60	16.35	76.22	6.82	2.5	sl. caking	8097
5.	Bh^{3}_{3}	0.40	18.54	70.13	10.93	2.2	caking & sl. swelling.	7770

It can be seen that the coals from the Hsiho field are all high in sulphur except the lowest seam No. 1 which is however not very well caking.

In the Heishan basin, the seam No. 5 is low in ash as well as in sulphur contents according to the analysis and therefore would be a good coal for metallurgical coke. But from the experience of the local coke manufacture, this seam too is known to have a high sulphur content. In view of the result of the analyses, it is hoped that part of this seam may still be utilizable. The seam No. 9 is a high rank bituminous coal of medium grade very low in sulphur, and therefore constitutes an excellent coking coal; this is well confirmed by the local coke ovens. Besides, this seam is a thick one easily workable. The seam No. 8 which is much thinner shows much more sulphur in analyses, but in practice, it is often mixed with the No. 9 for coke manufacture. Its sulphur can probably be washed off. The mixture of the coals No. 9 and No. 8 after washing gives the following analysis.

Moist.	Vol. mat.	Fix. C.	Ash	Sulphur	Coke	Class	Heat Value
0.26	23.90	66.86	8.98	0.54	cak. & swelling	$Bm\frac{1}{3}$	7919 Cal.

Coal of the No. 3 seam from the both fields is also used for coking, although both the coal and the resulting coke are high in sulphur.

CHEMICAL ANALYSES OF THE COKES

Different kinds of coke produced in the Poshan district have also been analysed in the Survey laboratory with the following results:

I. Cokes made with coals from the Heishan field.

Coal used	Mines	Moist.	Vol. mat.	Fix. C.	Ash	Sulphur
3	Tungfeng	0.59	2.21	86.94	10.26	2.40
6	Potung	1.11	2.51	65.08	31.30	0.67

9 + 8	Yuseng	0.38	1.17	79.43	19.02	0.06
9 + 8	Tungbo ord.	0.36	0.90	81.46	17.28	0.84
9 + 8	„ sieved	0.14	1.22	81.84	16.80	0.72
9 + 8	„ washed	0.04	1.08	86.22	12.66	0.69
9 + 8	„ spec.	0.06	1.16	87.78	11.00	0.68

II. Cokes made with coals from the Hsiho field.

3	Yuseng	0.08	1.90	89.28	8.40	2.7
4	Tunghsing	0.32	1.90	84.70	13.08	1.9

From the above tables it can be seen that only cokes made with coal seams No. 3 and Nos. 9—8 washed have their ash content near or below 12%, while all the others are much more ashy. All the cokes from the Hsiho field are too sulphurous with their sulphur content all above 1.3%, while the cokes from the Heishan field are all below this limit and therefore good for the blast furnace use except that from No. 3.

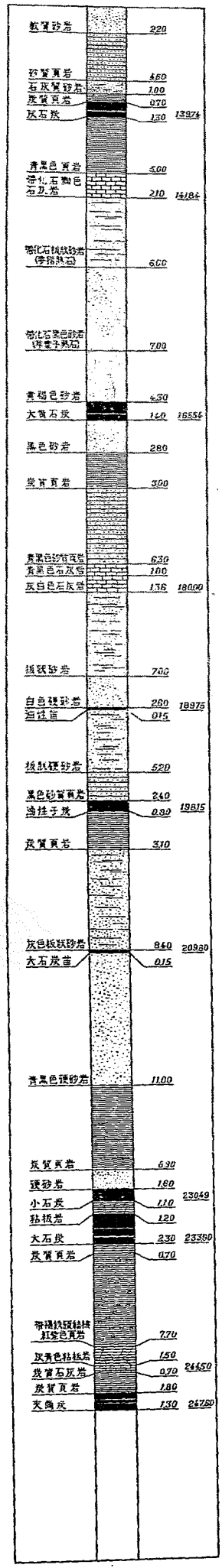
CONCLUSION

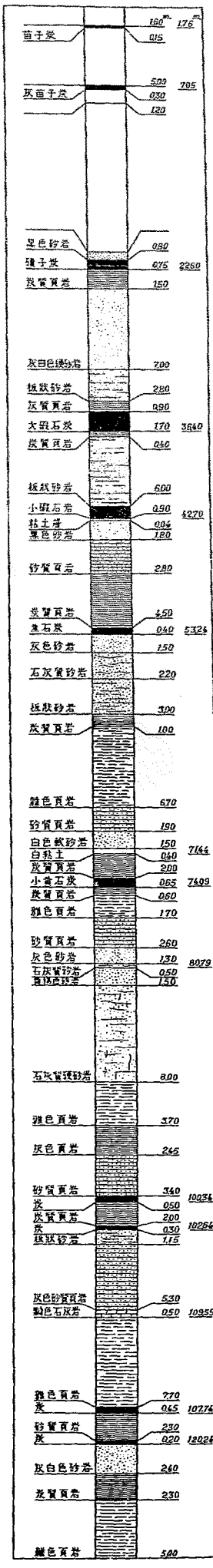
Although the Poshan coal fields contain enormous reserve of bituminous coals mostly coking, yet by far not all the seams can be used for metallurgical coke. The seam No. 9 locally known as Tatuanshihtan of the Heishan basin is the best coking coal which can yield excellent blast furnace or foundry coke even mixed with No. 8 coal which shows to the analyses comparatively more sulphur. The reserve of these coal seams which can be used for the manufacture of metallurgical coke only amounts to about 15,000,000 tons.

The Heishan coal field is favorably situated near the Tsinan—Tsingtao railway with which it is already connected by a branch line. Its coal or the coke from this coal basin can be easily exported through Tsingtao to Japan or to the Yangtze Valley where it is much needed.

Details of the present mining and coke manufacturing industries are given in the Chinese text.

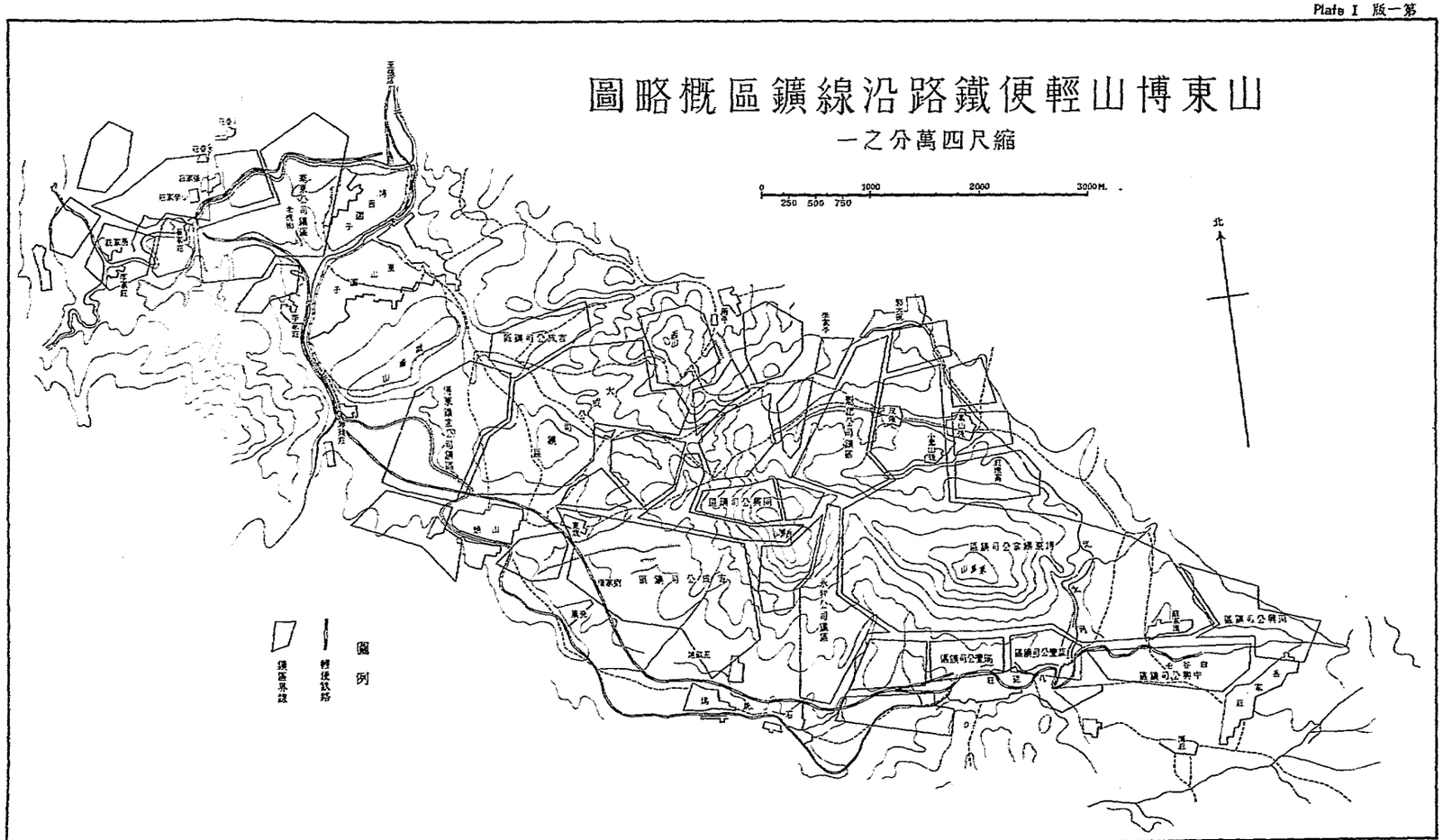
山東博山縣黑山煤田地層柱形圖
COLUMNAR SECTION OF THE COAL SEAMS AT HEISHAN COAL FIELD, POSHANHSIEN, SHANTUNG.





博山東輕便鐵路沿線鑛區概略圖

縮尺四萬分之一



三　利用大小礦石炭混合鍊焦，若能將煤內所含比重較大雜質較多之劣煤，用水洗除，則可得較優美之焦炭，本地名爲洗焦，倘再加以百分五之無烟煤，所鍊之焦尤爲優良，本地名爲特別洗焦。

四　大小礦石炭混合所製之洗焦及特別洗焦，質頗優良，不惟宜於冶鐵，且宜於鎔鐵。

五　博山全煤田儲量極爲豐富，但鍊焦最佳之煤居如大小礦石炭，則其儲量亦不過一千數百萬噸，並非甚多。

司，所採之煤悉爲大石炭與小石炭，不過悅昇公司兼採少許羅珠炭，同興公司兼採少許大黃石炭與油性炭耳。

運輸

膠濟鐵路之張博支線，直達於博山縣城。自博山縣城至黑山煤田二十餘里之運輸，則恃輕便鐵路，名爲博山輕便鐵路公司。係商辦，資本約一百二十萬元。計有車皮一百八十輛，小火車頭十個，每車可容煤三噸，每列車爲十五輛，計可載煤四十五噸，每日約可往返十二次至十四次，計可運煤六七百噸。博東公司鑛廠距博山車站約二十里，每噸煤運費爲一元五角，裝卸費在內。距博山車站二十五里之每噸煤運費爲一元七角。茲考輕便鐵路之運輸力既有限，各煤鑛公司之產額，不得不受其限制，且運費太高，亦足爲鑛業發達之障礙。聞有人倡議改輕便路爲大鐵路，以便膠濟路之車可以直達鑛廠，如此議諒見諸事實，於黑山煤田鑛業之發達，當大有裨益。

由張博支路之大崑崙車站至西河煤田，亦築有輕便鐵路，專爲運煤之用，名爲西崑輕便鐵路。計長二十五里，資本約八十萬元，係悅昇公司獨力經營。計有車皮三十輛，車頭四個，每車可裝煤二十噸，每列車爲五輛，計可運煤一百噸，每日運輸可往返六七次，每噸煤運費爲一元五角，裝卸費歸運煤者自理。

結論

茲將此次調查所得主要之點，分列於左，以便易於考核。

一　鍊焦之煤只限於大山炭，產於黑山與西河煤田。凡小山炭產於博山淄川章邱一帶之煤田者，率不能鍊焦。

二　在黑山煤田可採之煤層有十，本地皆曾與以專名，自下至上數之曰，夾崗炭大石炭小石炭油性子炭大黃石炭灰石炭小黃石炭小硬石炭大硬石炭碩子炭等。就中除夾崗炭與碩子炭外，其餘皆曾用以鍊焦，但鍊焦最佳之煤，應首推大硬石炭，或大硬石炭與小硬石炭之混合炭。西河煤田無灰石炭小黃石炭硬石炭與碩子炭等煤層，可採之煤爲羅珠炭（即夾崗炭）大石炭小石炭油性子炭大黃石炭等。羅珠炭在西河有變薄之趨向，大石炭在西河多不能鍊焦，故西河煤遠不如黑山煤之較適宜於鍊焦。

裝置西式鍊焦爐，係長方形，皆用耐火磚砌成。計有小爐十四座，每座可裝煤二千二百斤，能鍊焦一千五百四十斤。有大爐十五座，每座可裝煤四千二百斤，能鍊焦二千九百四十斤。統計每爐可鍊焦六成五至七成。所鍊之焦分四種。(一)普通焦，即將收買之原煤末，裝入於西式爐內所鍊之焦。(二)改良焦，即將原煤末透過鐵絲篩，分出煤中所含之大塊劣煤，此種劣煤大抵係接近煤層底盖之煤，每含雜質及灰份較多，用透過鐵篩煤末所鍊之焦爲改良焦。(三)洗焦，將原煤末先透過鐵篩，除去所含之大塊劣煤，再用水將透過之煤末冲洗，如此則劣煤之細塊，固其比重較大，亦可分出，以冲洗之煤所鍊之焦爲洗焦。(四)特別洗焦，以上三種皆用原來煤末，不過改良焦與洗焦則加以過篩與冲洗耳。特別洗焦則係用原來之煤塊，碎爲細末，再經以過篩與冲洗之手續，如此則劣煤完全絕跡，復加以百分五之無烟煤(青貢)，如此所鍊之焦則稱爲特別洗焦。普通焦在博山出售每噸約值洋十五元，改良焦洗焦及特別洗焦多運往青島銷於日本。

鑛業

此次調查既專注重於鍊焦，所述之鑛業，亦皆限於黑山與西河煤田。察博山輕便路沿綫鑛區概略圖，知黑山煤田鑛區林立，全煤田悉劃入鑛區。(參閱附圖第一版)惟鑛區雖多，並未全部開採，調查時黑山煤田最大之公司，爲博東煤鑛公司，係中日合辦，資本一百五十萬元，中日各半。公司內設董事九人，中國方面占五人，總理爲中國人。鑛廠內計有斜井一座，斜深約二千尺，直深約五百尺，陞降機一架係二百五十匹馬力，又電機廠一座。統計每日可出煤三百噸，開輕便鐵路運輸，如不發生困難，每日產額尚可增加。煤井上工人約二百名每日工資約五六角，井內工人約四百名，每日(按二十四點鐘計)工資約一元。所採之煤屑爲大小碳石炭及碴子炭。博東公司之西爲永和公司，統係中國人開採，所採之煤爲大小石炭。博東公司之東爲同興公司，所採之煤爲灰石炭黃石炭及大石炭。永和公司之西爲同豐公司，其鑛區原係吉成公司呈領，現與吉成公司合辦，仍稱同豐公司，所採之煤爲黃石炭灰石炭及大小石炭。同豐公司之西北爲大成公司，所採之煤爲大石炭與小石炭。永和公司之北，居黑山之陰者爲悅昇公司，係租借魁記公司鑛區，所採之煤爲碳石炭。此皆爲黑山煤田內較著公司之較著者。西河煤田內較著之煤鑛爲悅昇公司與同興公

適用於冶鐵。以此爲衡則西河煤田內之焦，似皆含硫過高，惟黑山煤田除小石炭焦外，其餘所含硫分悉在百分之一以下，於冶鐵皆尙適用。以焦內所含之硫份與煤內所含之硫份相比較，可以推知鍊焦時硫分已一部被消滅。

焦內所含燐份之關係，每視所用冶鐵爐之種類及所製鍊鐵之性質而不同，有時焦內燐份須勿過一定限制，有時稍多亦不爲害。黑山與西河焦之燐分，皆未加以化驗，以理度之大約亦不至甚高。博山烟煤之是否可以煉冶鐵之焦，其關鍵似重在硫份及灰份也。

用以鎔鐵之焦炭名爲鑄造焦（Foundry Coke），其需要之成分，與一般冶鐵焦稍有不同。普通鑄造焦之揮發份須勿過百分之二，固定炭須勿少於百分之八十六，灰份勿過百分之十二，硫份須勿過百分之一。硫份極關重要，過高大非所宜，最好在百分之一以下。燐份在鑄造焦中似無關重要，但燐份低者恆被歡迎。以上成分之標準與黑山西河之焦質化驗表相較，可知只有洗焦與特別洗焦最適宜於鑄造之用，其他或因固定炭太低，或因灰分過高，或因硫分太多，均非甚宜於鑄造之品。

統察在黑山與西河兩煤田，本地對於煤質焦性之經驗及本所對於煤質焦性化驗之結果，大抵西河之煤遠不如黑山之煤。黑山煤田內鍊焦最佳之煤爲大礦石炭，但大礦石炭與小礦石炭混合，用水冲洗之後，亦可得佳焦，如東和公司（礦區分布見附圖第一版）所鍊之洗焦與特別洗焦，卽其表證也。據煤質化驗表，除礦石炭外大黃石炭似亦頗宜於鍊焦，不知何以本地有人謂此層煤不宜於鍊佳焦，此爲化驗結果與本地說法不同之點。按焦質化驗之結果，大抵以大小礦石炭混合所製之洗焦與特別洗焦爲最佳，不惟適宜於冶鐵鑛，且適宜於鑄造鐵，此大可注意者也。

土法鍊焦之窯呈圓形。其工作方法大抵先掘一地坑，圓徑約丈許深約二三尺，用煤將土坑塡滿，並高出於地面約二三尺，形如饅頭，內修風道，鍊焦時所供之養氣，僅足逐出煤之揮發份。每燒焦一窯，需時兩星期，方能將焦炭取出。惟燒焦時可置許多窯於一處，同時燃燒，同時啟窯。每窯平均可容煤一萬斤，約可出焦五六千斤。

博山縣城附近東和鍊焦公司係日本人設置，聞資本約三十萬元，其所用之煤爲礦石炭，悉向黑山博東煤鑛公司收買。該公司

地點	焦名	水份	揮發分	固定炭	灰份	硫份
黑山同豐公司	小石炭焦	○・五九	二・二一	八六・九四	一○・二六	二・四○
黑山溥東公司附近洞牌地	灰石炭焦	一・一一	二・五一	六五・○八	三一・三○	○・六七
博山東和公司	普通焦	○・三六	○・九○	八一・四六	一七・二八	○・八四
博山東和公司	改良焦	○・一四	一・二二	八一・八四	一六・八○	○・七二
博山東和公司	洗焦	○・○四	一・○八	八六・二二	一二・六六	○・六九
博山京和公司	特別洗焦	○・○六	一・一六	八七・七八	一一・○○	○・六八
黑山悅昇公司	桃峪花嶺石炭焦	○・三八	一・一七	七九・四三	一九・○二	○・○六

(二)西河煤田焦質化驗表

地點	焦名	水份	揮發分	固定炭	灰份	硫份
西河悅昇公司	小石炭焦	○・○八	一・九○	八九・二八	八・四○	二・七○
西河同興公司	油性炭焦	○・三二	一・九○	八四・七○	一三・○八	一・九○

佳焦需要之成分，每因用途而稍有岐異。先就灰份言之，冶鐵爐(Blast Furnace)所需之焦可含灰份約由百分之八至百分之十六，但最佳者祇含灰分百分之十以下，百分之十二以上者，每不受歡迎。蓋冶鐵爐中用含灰分多之焦與純良之礦，其結果等於用含灰分少之焦與低劣之礦也。在黑山與西河煤田之各煤層中，含灰量之較可適用者，爲小石炭焦洗焦及特別洗焦，灰份皆在百分十二左右，或以下，其他則似含灰份太高。

次就硫份論之，冶鐵焦炭之硫，應勿過百分之一・三，最好在百分之一以下，含硫在百分之一・五至一・七五者，有時已不

由右列二表可知黑山與西河煤田內之煤層，大部似含硫份稍高，在西河尤著，幾全在百分之二以上，灰份在西河煤田亦似略高，故西河煤田之煤質遠遜黑山。大黃石炭本地人恆謂含硫份高，據此炙化驗之結果，西河之大黃石炭，含硫雖不少但比他層似亦不特別高，而黑山之大黃石炭，含硫反特少，爲中淨高碳烟煤之硫量甚低者，應係鍊焦冶鐵佳煤之一。大石炭與小石炭雖本地皆曾用以鍊焦，並有人以小石炭所鍊之焦爲佳者，化驗之結果雖亦證明其可以鍊焦，但皆含硫太高。黑山煤田之大碾石炭與小碾石炭爲本地鍊焦最重要之煤層，化驗之結果亦證明其適宜鍊焦，惟小碾石炭硫分似仍過高，而大碾石炭爲中淨高碳烟煤之硫分甚低者，當爲黑山煤田內鍊冶金焦最佳之煤層，此分析研究及本地經驗所同爲證明者也。小碾石炭雖含硫略多，但與大碾石炭混合，用水冲洗之後，似硫分亦可減少，茲將博山東和鍊焦公司之洗煤分析，表列於左，以資比較。

大小碾石炭混合洗煤化驗表

地點	煤名	類別	水份	揮發份	定炭	灰份	硫黃	焦性	發熱量
博山東和公司	洗煤（大小碾石炭混合）	$Bm\frac{1}{3}$	〇·二六	二三·九〇	六六·八六	八·九八	〇·五四	粘結膨漲	七九一九克洛利
仝上	洗碴	$Bm\frac{1}{5}$	〇·三四	一七·七〇	三三·四四	四八·五二	〇·五六	粘結略膨漲	四四〇五

由右可知大碾石炭與小碾石炭混合之洗煤與洗碴，俱含硫分甚低，此頗似硫在煤內至少有一部份與煤質混合不密，易爲水所冲去也。用洗煤及他煤層所鍊之焦，亦經本所燃料研究室分析，成份如左。

（一）黑山煤田焦質化驗表

地點	焦名	水份	揮發份	固定炭	灰份	硫份

地點	煤層	類別	水份	揮發分	炭灰份	硫黃	焦性	發熱量
東公司	黑山博	小煅石炭	Bm^4_3	〇·三〇	二二·七六	六六·九六	九·九八	三·〇〇	粘結	七八三三
東公司	黑山博	大煅石炭	Bh^1_3	〇·四一	二一·二九	六七·四三	一〇·八七	〇·五一	膨粘結	七七四三
和公司	黑山永	煅石炭	AB^3_3	〇·三五	一七·三八	七二·八七	九·四〇	二·〇	粘結	七八八六

(二)西河煤田內煤質化驗表

地點	煤層	類別	水份	揮發分	炭灰份	硫黃	焦性	發熱量
昇公司	西河悅	夾崗炭	Bh^1_3	〇·六四	一九·二五	六八·一五	一一·九六	〇·二二	略粘結	七六二八 克洛莉
昇公司	西河悅	大石炭	Bh^5_4	〇·五〇	一六·七二	六五·六六	一七·一二	六·三	略粘結	七二〇六
昇公司	西河悅	小石炭	AB^3_3	〇·二四	一七·三二	七四·一六	八·二八	二·四	粘結膨漲	七九八六
興公司	西河同	小石炭	AB^3_3	〇·五〇	一六·八一	七三·九七	八·七二	二·三〇	略粘結漲膨	七九四六
興公司	西河同	油性炭	AB^3_2	〇·六〇	一六·三五	七六·二三	六·八二	二·五	略粘結	八〇九七
興公司	西河同	大黃石炭	Bh^3_3	〇·四〇	一八·五四	七〇·一三	一〇·九三	二·二	粘結膨漲略	七七七〇

經驗，在黑山煤田雖可鍊焦之煤有八層，而大石炭與灰石炭每夾有頁岩薄層，開採時不易分出，鍊焦時當亦不利。油性子炭鍊焦時所餘熔渣甚多，黃石炭則開含硫黃太高。故以鍊焦之優劣言，八煤層之中當首推大硼石炭小硼石炭及小石炭三層爲佳，但小石炭層較薄，產量不能甚多，故鍊焦最重要之煤層，應推大硼石炭與小硼石炭二層。在西河煤田僅有下八層，無硼石炭，故該煤田鍊焦最重要之煤層，當推小石炭。此就本地鍊焦經驗所得之結果而論定者也。

至此次調查所採集各煤層之煤樣焦樣，曾經本所燃料研究室詳細化驗，更足藉以互相闡明，以爲改良鍊焦之根據。茲將煤樣化驗之結果列表於左。（關於煤質類列之記號及名詞參閱翁著中國石炭之分類見地質彙報八號）

（一）黑山煤田內煤質化驗表

地點	煤層名	類別	水份	揮發份	定炭	灰份	硫黃	焦性	發熱量
黑山後池大成公司	大石炭	AB^4_3	〇·三八	一七·二六	七一·七六	一〇·六〇	二·九〇	粘結不膨漲	七七六七（克洛利）
黑山同興公司	大石炭	Bh^4_4	〇·七〇	一九·六〇	六三·一八	一六·五二	三·四〇	粘結漲	七一〇〇
黑山後池大成公司	小石炭	AB^3_2	〇·四〇	一七·九四	七六·五六	五·五〇	二·五〇	粘結不膨漲	八二八六
黑山同興公司	油性炭	Bm^3_3	〇·四〇	二三·〇〇	六七·三八	九·二二	一·六〇	粘結漲	七八七一
黑山同豐公司	大黃石炭	Bh^1_3	〇·三九	二〇·四二	七〇·八七	八·三二	〇·一三	粘結膨漲	七九七五

小石炭	一・〇公尺	全	上	二〇・八〇〇・〇〇〇
油性子炭	〇・七公尺			一二・六一二・六〇〇
大黃石炭	一・二公尺			一八・七四〇・四〇〇
灰石炭	一・二公尺			一六・二八六・四〇〇
小黃石炭	〇・六公尺			五・四〇五・四〇〇
小硬石炭	〇・八公尺			五・六一六・〇〇〇
大硬石炭	一・五公尺	全	上	一〇・五三〇・〇〇〇
碛子炭	〇・七公尺	全	上	四・九一四・〇〇〇

統計黑山煤田共儲煤達一六一・四六四・八〇〇噸。惟煤田開採既久，已採出之煤，爲最當亦不少，然無論如何，儲藏之煤量，似應可達一萬萬噸。

西河煤田較黑山煤田面積既小，所含可採之煤，又僅下五層，其儲煤最當亦較貧。茲假定此五層煤之總平均厚度爲五公尺，則全煤田之面積爲八・四〇〇・〇〇〇平方公尺，應儲煤五四・六〇〇・〇〇〇噸。除去已採出之煤，應尚儲煤五千萬噸。

鍊焦研究

博山縣境之煤，本地向有大山炭與小山炭之分。小山炭即指博山淄川章邱一帶煤田內之煤，雖爲烟煤而不能鍊焦。大山炭即黑山西河之煤，十煤層中除夾矸炭與碛子炭外，其餘八層本地皆會用以鍊焦。考小山炭之煤層，傾斜甚爲整齊，構造亦不複雜，其不能鍊焦之原因，大抵由於接近侵入火成岩而受變質作用所致。博山煤田附近煤層有時受變質較深，而竟變爲無烟煤，本地名爲青貢。黑山西河煤田，由平面地質圖觀察即可知其距侵入火成岩頗遠，其受變質作用應甚微，故大部能鍊焦。但據

五十九	黑色頁岩	七・七公尺	六十	灰色砂岩	六・七公尺
六十一	燋石炭	○・四公尺	六十二	炭質頁岩	四・五公尺
六十三	砂質頁岩	二・八公尺	六十四	黑色砂岩	一・八公尺
六十五	小礫石炭	○・九公尺	六十六	板狀頁岩	六公尺
六十七	炭質頁岩	○・四公尺	六十八	大礫石炭	一・七公尺
六十九	炭質頁岩	○・九公尺	七十	板狀砂岩	二・八公尺
七十一	灰白色硬砂岩	七公尺	七十二	炭質頁岩	一・五公尺
七十三	磧子炭	○・七五公尺	七十四	黑色砂岩	○・八公尺

由右表可知煤層之總數，在此柱形圖內共達十有九層。但其中厚度不及一尺或僅達尺許者，約占九層。實際上此種薄煤層不能開採，毫無實業之價值，而可供採取者亦僅十層，與前所述略同。

儲量

此次對於各煤層係分層研究其各別性質，故儲量亦宜分層各別估計，俾知各種煤質儲藏量各有若干。

含煤岩系在滔川博山以及章邱一帶煤田，露布既廣，煤量當亦甚豐富。惟此次之調查，偏重於黑山西河可煉焦之煤田，茲將黑山西河煤田內各煤層蘊藏之量，分別計之，表列於左，以期知其約數。各煤之比重，皆假定爲一・三，以便易於計算。

黑山煤田儲量約計表

煤層	平均厚度	露布面積	儲藏量
夾岡炭	一・二公尺	一六・〇〇〇・〇〇〇平方公尺	二四・九六〇・〇〇〇噸
大石炭	二・〇公尺	全上	四一・六〇〇・〇〇〇

二十三	青黑色砂質頁岩	六・三公尺
二十五	黑色砂岩	二・八公尺
二十七	黃褐色砂岩	四・三公尺
二十九	黝色石灰岩	二・一公尺
三十一	灰石炭	一・三公尺
三十三	石灰質砂岩	一公尺
三十五	軟砂岩	二・二公尺
三十七	灰白色砂岩	二・四公尺
三十九	砂質頁岩	二・三公尺
四十一	雜色頁岩	七・七公尺
四十三	灰色砂質頁岩	五・三公尺
四十五	炭層	〇・三公尺
四十七	炭層	〇・五公尺
四十九	雜色頁岩	六・一五公尺
五十一	黃灰色砂岩	三・三公尺
五十三	雜色頁岩	二・三公尺
五十五	炭質頁岩	二公尺
五十七	白色軟砂岩	一・五公尺

二十四	炭質頁岩	三・〇〇公尺
二十六	大黃石炭	一・四公尺
二十八	黑色砂岩（含化石）	一三公尺
三十	青黑色頁岩	五公尺
三十二	炭質頁岩	〇・七公尺
三十四	砂質頁岩	四・六公尺
三十六	雜色頁岩	七・三公尺
三十八	炭層	〇・二公尺
四十	炭層	〇・四五公尺
四十二	黝色石灰岩	〇・五公尺
四十四	板狀頁岩	一・一五公尺
四十六	炭質頁岩	二公尺
四十八	砂質頁岩	三・四公尺
五十	石灰質硬砂岩	八公尺
五十二	砂質頁岩	二・六公尺
五十四	小黃石炭	〇・六五公尺
五十六	白色粘土	〇・四公尺
五十八	砂質頁岩	一・九公尺

大煤石炭		一・四至一・八公尺
岩層距離		十一至十四公尺
磧子炭		〇・六至〇・九公尺

由右表可知自最下之夾崗炭至最上之磧子炭，其間岩層之總厚度不過二百餘公尺，故所述之十煤層，皆可於一竪井內同時採取。

博東煤鑛公司在黑山煤田對於煤層曾作一柱形圖。此雖不能完全代表各煤田內煤層相互之關係，然各煤田內煤層之大致情形頗可以由此柱形圖得其梗概。茲將該柱形圖表述於左，以資參考，岩層次序自下而上述之。（參閱本篇附圖第二版）

一	夾崗炭	一・三公尺	二	炭質頁岩	一・八公尺
三	炭質石灰岩	〇・七公尺	四	灰青色粘板岩	一・五公尺
五	紅紫色頁岩含褐鐵鑛結核	七・七公尺	六	炭質頁岩	〇・七公尺
七	大石炭	二・三公尺	八	粘板岩	一・二公尺
九	小石炭	一・一公尺	十	硬砂岩	一・六公尺
十一	炭質頁岩	六・九公尺	十二	灰色硬砂岩	二・〇〇公尺
十三	大石炭炭苗	〇・一五公尺	十四	灰色板狀砂岩	八・四公尺
十五	炭質頁岩	三・一公尺	十六	油性子炭	〇・八公尺
十七	黑色砂質頁岩	二・四公尺	十八	板狀硬砂岩	五・二公尺
十九	油性炭苗	〇・一五公尺	二十	白色硬砂岩	二・六公尺
二十一	板狀砂岩	七公尺	二十二	灰白色及黑色石灰岩	二・三六公尺

層距離，表列於左，以便易於比較。表之次序係自下至上敘之。（參閱本篇附圖第二版。）

煤層	厚度
夾崗炭	一至一・五公尺
岩層距離	九至十四公尺
大石炭	一・五至二・五公尺
岩層距離	○至二公尺
小石炭	一公尺上下
岩層距離	二十八至三十五公尺
油性子炭	○・六至○・九公尺
岩層距離	三十至三十三公尺
大黃石炭	一至一・四公尺
岩層距離	二十二至二十六公尺
灰石炭	一至一・四公尺
岩層距離	六十二至六十八公尺
小黃石炭	○・五至○・八公尺
岩層距離	二十八至三十二公尺
小礦石炭	○・七至一公尺
岩層距離	五至八公尺

遺跡甚夥，在刁虎峪附近有二煤窰於調查時尙在出煤，不過煤系之上有時覆蓋土壤稍厚，似無重要斷層夾於其間。故章邱煤田與淄川博山一帶煤田實一連續之煤田，似並未受平推斷層分割也。博山縣城東南黑山西河一帶煤田內之地質構造，大致呈淺向斜層狀。惟黑山東北山坡岩層斷裂，其斷層面在八陡村北極爲明顯，沿河流構成一小瀑布，走向爲東南西北，傾斜幾近直立，仰側居斷線之東北，黑山反居斷層之旁側，大抵屬一正斷層。其上下移動之斷距雖不甚大，但斷綫之可尋者，由黑山之東北山坡向東南經岳莊與戴莊之東北，走入與陶紀石灰岩，延長達二十餘里。

煤層

淄川博山一帶之煤田，本地用土法開採甚早，認識甚切，對於各煤層皆曾予以專名。凡本地精於煤窰業者，率能知煤之層數及其相互之位置，甚至有用手摸煤，察其色澤組織，即知其來自何煤層者。故本地人對於煤層之意見，往往頗有參考之價值。但此種人對於煤層知識，率由於終身業煤之經驗得來，只限於其業煤之區域。曾工作於黑山煤田者，至西河煤田則茫然不解，熟悉西河煤田內煤層之情形者，至博山煤田則莫辨其層序，蓋富於經驗，無於學識，經驗只限於一隅，不能融以學理而三隅反也。統計煤田內煤層發育完備時，本地恒謂有十六層，固有上八層下八層之分。博山煤田與黑山煤田內煤層層數頗完備，西河煤田則僅有下八層。各煤層之厚度，及其間相隔岩層距離，恒因煤田之位置，而頗有差異。且煤之層數，雖達十六七層之多，而實際可資開採者只十層。此十層之煤，屬於下八層者計六層。自下而上曰夾崗炭，大石炭，小石炭，油性子炭，大黃石炭，及灰石炭等。此六煤層就厚度言，以大石炭爲最厚，就煤質優劣言，本地恒謂小石炭爲最佳，且大石炭與小石炭中間僅隔頁岩數尺，有時合爲一煤層。夾崗炭在西河煤田，則改稱爲羅珠炭。十層之煤屬於上八層者計四層，自下而上曰小黃石炭，小硬石炭，大硬石炭，磧子炭等。此四煤層就煤層之厚度言，以大硬石炭爲最厚，就煤質之優劣言，本地恒謂大硬石炭與小硬石炭爲最佳，有時此二煤層合爲一層，可以同時開採。統考下八層之煤，恒與砂岩頁岩及薄層石灰岩相間，即岩系之組織，爲海成層與陸成層相間。上八層之煤，則只間以砂岩與頁岩，即岩系之組織皆屬陸成層。此上八層與下八層岩系組織及成因之異點也。茲將可採十煤層中間之岩

，是以本報告不採用古生代之廣泛名辭。本煤系除分佈於淄川博山章邱一帶外，在博山縣城東南黑山西河附近，露布亦甚廣。

三、二疊紀及二疊三疊紀黃紅色頁岩　石炭紀及石炭二疊紀煤系之上，爲二疊紀及二疊三疊紀黃紅色頁岩。本岩系相當於譚君所稱之古生代煤系上部，其最特異之標識，爲黃色與紅色頁岩間以少許薄層砂岩，不含煤層，在野外極易與含煤系區分。本岩系內含植物化石甚夥，在山西於相當之層內曾經系統的採集與鑒定，（參閱拙著山西保德地層及那珠著山西太原地層詳考皆印於地質彙報第四號）故其時代頗爲確定。且本系合鋁石頁岩，就經濟地質方面觀察，本岩系甚重要，亦應獨立一系，其分布之區域，與含煤系相同。

四、三疊紀白色石英岩與紅色砂岩　此砂岩呈厚層狀，僅間以少許紅綠色頁岩，相當於譚著所謂石英砂岩層與紅色砂岩層。本岩系在山西於相當之層內尚未發見化石，大抵由於岩層沉積時之氣候，不適於動植物繁殖所致。惟其岩層位置既位於二疊三疊紀黃紅色頁岩與下侏羅紀煤系之間，其時代似應屬於三疊紀。本岩系之分佈，大部現露於淄川博山間沿張博鐵路附近。

五、下侏羅紀煤系　三疊紀砂岩層之上，爲下侏羅紀煤系，相當於譚著之中生代煤系。在調查區內僅分布於淄川縣城西北變衣鋪萬年溝山王莊一帶，沿岩層露頭往往有舊煤窰遺跡。

六、侏羅白堊紀紅色斜層砂岩　此斜層砂岩相當於譚君之紅綠砂岩系。其特別之標識，爲斜層結構甚著，且多呈薄層狀，易與三疊紀之紅色砂岩區分。在調查區域內，本岩系僅露布於淄川縣城西北東明水孟里莊一帶，直覆於下侏羅紀煤系之上。

七、基性侵入火成岩　基性火成岩在博山與淄川西北露布甚廣。岩石呈黑色，大部屬安山岩與輝綠岩等。

地質構造

淄川博山一帶煤田附近之地質構造，從前調查者恒謂淄博煤田與章邱煤田中間係一大平推斷層"(Horizontal displacement)，以致二煤田不相連接，作者兩次考察所得結論稍有不同。作者曾由博山北關沿西山之麓，經黃莊吳宅刁虎峪桃園以達章邱煤田附近之磁窰塢一帶，見石炭紀及石炭二疊紀煤系沿山麓露布，層序尚爲清晰，大致傾斜東向約近三四十度。且沿煤系露頭舊煤窰

山東博山烟煤煉焦研究

王竹泉

緒言

中國北部煤之蘊藏雖富，可煉焦之煤並不甚多，佳焦尤爲稀見。近來因鋼鐵廠之計畫，而研究及於煉焦烟煤之供給。山東膠濟路一帶以博山煤爲最良烟煤，但對於煉冶金焦之可能究竟如何，迄今尚無具體調查。二十年夏竹泉愛奉實業部派至博山煤田考察煉焦情形，對於各煤層及土法所煉焦炭皆經詳細考察。所採標本，並經本所燃料研究室詳細化驗。茲將野外考察所得及本所化驗結果，分述於左，並互相比較，加以論斷焉。

地質系統

博山縣附近地質，於民國八年曾經譚錫疇君及瑞典人安特生君調查，並著有報告，印於地質彙報第四號。譚君將地層自下而上分爲六系，即(一)奧陶紀石灰岩，(二)古生代煤系，(三)石英砂岩層，(四)紅色砂岩層，(五)中生代煤系，(六)紅綠砂岩系等。民國十六年竹泉同劉君季辰因考察鋁鑛之便，曾至博山煤田，因見岩層之性質，與山西煤田附近之地層完全相似，乃將地層重分於左，以便易與作者前在山西研究之地層相比較，抑亦較合於通行之系統也。譚君之地質圖，經複加考察後，亦有略爲修改之必要，故亦另繪附入鋁鑛報告內，閱者可取以爲本篇之參考。

一、奧陶紀石灰岩　此爲中國北部分布最廣之岩層，每構成煤田之底床。博山煤田之東南與西北，及黑山煤田之四周，此石灰岩顯露頗多。因其抵抗風雨之侵蝕力較含煤岩系稍強，恒組成崇峻山嶺，遠望之頗易與含煤岩系區分。

二、石炭紀及石炭二叠紀煤系　此系相當於譚君所稱之古生代煤系下部與中部。因煤層皆含於本系之內，岩層大致呈灰黑色，野外調查時極易辨識，故特別爲一系。又因本系內之動植物化石，在山西他煤田已研究甚詳，確知其屬於石炭紀及石炭二叠紀

沁園燃料研究室
燃料研究專報第三號
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SOME NEW METHODS IN COAL PETROGRAPHY

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SOME NEW METHODS IN COAL PETROGRAPHY

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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, whereas 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 "Ätzstruk-

turen 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 newly 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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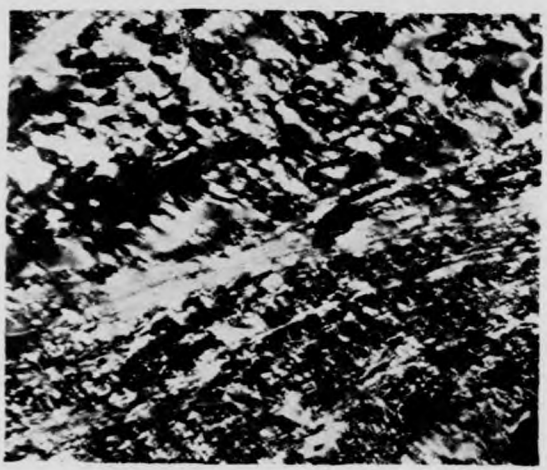
Explanation of Plate I

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

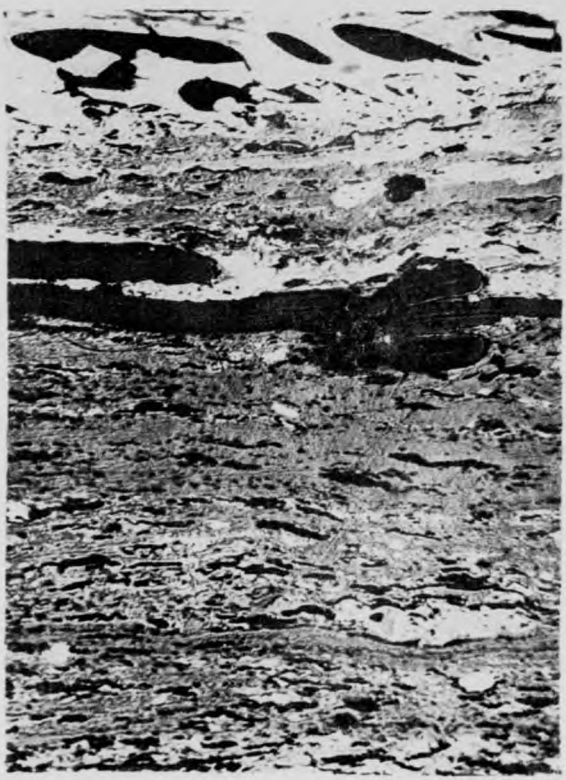
PLATE III

Vertical crossed section of a bituminous coal as seen under oil immersion. The microspore exines (small lenticular bodies of black color) and the groundmass (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.



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A PRELIMINARY PETROGRAPHICAL STUDY OF THE PEIPIAO COALS

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GEOLOGICAL SURVEY OF CHINA

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A PRELIMINARY PETROGRAPHICAL STUDY OF THE PEIPIAO COALS.

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(*Contribution from the Sin Yuan Fuel Laboratory, No. 1.*)

1. INTRODUCTION.

The Peipiao coal field is situated about 90 li North of the Chaoyang city, eastern Jehol and is connected with Chin Hsien, a station on the Peking-Mukden railway by a branch line of about 170 li. The region is characterized by a moderately dissected mountain range which runs roughly in a N. E.—S. W. direction.

Since 1921 the Peipiao coal field is being developed by the Peipiao Coal Mining Company. Under the able management of its first director Dr. V. K. Ting and its present director Mr. T. A. Yuan, this mine has been turned into a profitable enterprise and is now yielding a production of more than 360,000 tons annually.

The geology of the Peipiao coal field has been studied at first by Dr. V. K. Ting and afterwards detailedly mapped by Mr. H. C. Tan[1] and Dr. W. H. Wong[2]. To Dr. Wong we owed to his discovery of several overthrusts of considerable magnitude,—a discovery of prime importance to the well understanding of the Chinese tectonics. The geological interest of the region is further enhanced by the existence of two volcanic series between which the coal formation of Jurassic age is found. A petrographical study of the volcanic rocks collected by Mr. H. S. Wang[3] in this region has been recently made by P. C. Wang[4]. In regard to the mining condition and technical development of the mine, we have the report of Mr. P. H. Lay[5], mining engineer of the said company.

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1. T'an, H. C., Geology of the Peipiao coal field, Chaoyang district, Jehol, Bull. Geol. Surv. China No. 8, 1926.
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3. Mr. Wang's report on the geology of the Peipiao region is in course of preparation.
4. Wang, P. C., The volcanic rocks in Peipiao region, Bull. Geol. Soc. China. Vol. 8, No. 4, 1929, p. 343.
5. Lay, P. H., Engineering report on Peipiao Colliery, Mining & Metallurgy (Chinese) Vol. 1, No. 1, p. 129, 1927.

It is interesting to note from the above mentioned that the Peipiao coal field, though its systematic development being dated from comparatively recent time, has furnished us a good deal of scientific informations and became now one of the best known coal fields in China. On the other hand, a petrographical knowledge of its coals produced, which from the genetic point of view is of fundamental importance, is unfortunately still lacking. With a view to fill up this gap of knowledge, the present work is intended.

The writer wishes to thank the authorities of the Peipiao Coal Mining Co. for the sending of specimens and various other informations.

2. THE COAL SEAMS.

According to Mr. Lay's report there are more than ten seams of coals encountered in the bore holes and underground but among which only eight are considered as workable. Among these seams, the seams No. 7 and No. 8, because of their high content in ashes are now not worked. Their average chemical composition[1] is listed below with notations[2] indicated:

No. of Seam	Moisture	Volatile matter	Fixed Carbon	Ash	$\frac{C}{M+V.}$	Notation
	%	%	%	%		
No. 3 (1st level)	2.31	29.60	53.20	14.84	1.66	Bl_4
No. 3 (2nd level)	2.65	27.35	52.45	17.54	1.74	Bm_4
No. 4 (1st level)	2.08	30.67	53.10	14.15	1.61	Bl_4
No. 4 (2nd level)	1.96	31.25	53.09	13.63	1.59	Bl_4
No. $4\frac{1}{2}$	4.00	26.84	39.68	29.48	1.28	BC_3
No. 5 (1st level)	3.10	29.40	51.50	14.71	1.58	Bl_4
No. 5 (2nd level)	2.01	29.20	51.00	17.60	1.63	Bl_4
No. 6	1.50	26.50	51.00	21.00	1.82	Bm_5
No. 7	1.00	33.50	33.00	32.50	0.95	BC_3

3. MICROSCOPIC AND MACROSCOPIC CHARACTERS.

In the following description of the microscopic characters of coals, the writer has adopted the somewhat modified nomenclature of Stopes[3] proposed by the Prussian Geological Survey in Berlin. In this nomenclature the term Clarain is discarded, because it does not show much difference both chemically

1. Taken from Mr. Lay's unpublished report on the Coal Seams in Peipiao field.
2. Wong, W. H., Classification of Chinese Coals, Bull. Geol. Surv. China, N. 8, 1926, p. 33.
3. Stopes, M., On the four visible ingredients in banded bituminous coals, Proc. Roy. Soc. Ser. B. Vol. 90. No. 633, p. 483, 1919.

and microscopically from durain, the latter as we understand now is used to indicate all inhomogenous layers in the coal, no matter whether it is made up of spore exines or of cuticles or of any other constituents.

To describe the various degrees of humification of the woody materials in the coal, the writer is preferred to use the terms xylain and xylo-vitrain of Duparque[1] rather than the eu-vitrain and pro-vitrain of Potonie[2], the former nomenclature seems to give a much clearer understanding.

After having stated the defination of the terms used in this article, I may now proceed to describe the different coals studied.

Seam No. 3.

Macroscopic character: This is a finely laminated coal composed essentially of durian with thin intercalations of vitrain and several lenses of fusain. The coal is light, seems to contain little ash. It breaks easily to roughly parallelopiped fragments of various sizes.

Microscopic character: Under the microscope the vertical section of the coal is seen to be composed almost entirely of durain which is characterized by a great abundance of woody materials in the forms of fusain, xylain and xylo-vitrain. In some section practically no cuticle is observed while in others it is very abundant. Some resinous matter in rounded to lenticular fragments showing high relief and grayish color is present.

Fusain forms usually long lenticles of considerable sizes attaining sometimes one centimeter or more in length. It can be clearly recognized by the naked eyes from its high relief, dull appearance and fibrous form. Under the microscope fusain shows very well preserved cellular structure, the cells are usually neatly preserved and have apparently suffered no or little compression. Both transverse and longitudinal section of the fusain is encountered in the vertical section. The cells are generally infiltrated by ashy matter which gives a dark and dull appearance under the microscope. It is perhaps due to this infiltration that most of the higher ash content of fusain is to be accounted for. Pyrite replacing the cells is also frequently observed.

Xylain has a lower relief, but brighter luster than fusain. It exhibits no well marked relief on the polished section when seen by naked eye or by a

1 Duparque, Andrè, Le rôle des tissus lignifiés dans la formation de la houille, Extr. Ann. de la Soc. Geol. du Nord T. LI p. 51, 1926.

2 Potonie, R., Zur Kohlenpetrographie und Kohlenentstehung, Z. d. D. Geol. Ges Bd. 78, 1926.

lens as this is the case with fusain. Under the microscope, xylain shows also a well preserved cellular structure; in this respect it resembles fusain and can only be distinguished from its relief and luster; the former character is best to see by the use of a hand lens. In the sections examined, xylain forms usualy long or short lenses of various sizes. It is generally bordered by a structure-less zone of thin xylovitrain. Pieces of woody matter showing transition from xylain to xylo-vitrain are frequently observed.

The durain is composed essentially of a ground mass (pate fondamental of Duparque) in which are embedded numerous thin lenses, fragments or small grains of xylovitrain and fusain. Both groundmass and xylovitrain are homogenous and structureless, but they can be distinguished by the fact that xylovitrain is higher in relief, brighter in luster and distinctly yellow in color, while the groundmass assumes generally a gray to bluish tint.

In the section just described there exists very few cuticle or microspore exines. According to Duparque, a structure like this should be called clarain, instead of durain, but as we are not intended to make minor distinction of this kind the name durain is used throughout this paper.

In another section from the same specimen, the microscopic structure gives quite a different picture. The groundmass is characterized by the presence of numerous microspore exines, and in certain portion it is crowded with cuticles of immense sizes. This is the typical durain, using the definition of Duparque. Other woody material like fusain, xylain and xylovitrain are equally abundant, and the cellular structure in fusain and xylain is equally well preserved as in the other section.

The occurrence of cuticle is of special interest. It is usually crowded together to form a band of $\frac{1}{2}$ cm or more in thickness, in which nothing but cuticles of various sizes are found. The thickness of the cuticle varies naturally with the orientation of the section; thus it varies from a mere fine line to as much as 10 microns. By naked eye the presence of cuticle band is already noticeable from its high relief and long-striated aspect of the polished section.

In the coals studied, the microspore exines are not so abundant as commonly seen in the coals of Palaeozoic age. They are extremely minute in size, being only a few microns in length and could hardly noticeable unless examined carefully and by the use of small aperture.

Microscopic characters of the horizontal section: The microscopic view of the horizontal section depends of course much upon the position along which

the section is cut. It shows in one case an homogenous groundmass embedded with numerous small fragments or fine grains of xylainic and fusainic material, the latter is generally higher in relief. In another case the section is crowded with abundant pieces of fusain or xylain with well preserved cellular structure. As a rule the cells seem to have suffered little compression. Infiltration of ashy matter in the cellular spaces is a common phenomenon, and it is perhaps due to this reason that the cells have been rendered hard and resistent so as to show little signs of mechanical strain.

Thin section: The study of thin section confirms the existence of numerous bands, lenses or chips of fusain which together with cuticles and small lenticular bodies of resin are embedded in a reddish brown vitrainic groundmass. The resin shows a brilliant reddish brown color and is very transparent in the thin section.

Seam No. 4.

This is a hard and compact coal like seam No. 3. It is heavier than seam No. 6. It breaks into an uneven fracture, this character being also somewhat similar to seam No. 3.

Under the microscope: The coal is seen to be composed essentially of durain with a few intercalations, of vitrain which is more developed here than in any other coals studied presently. The vitrain attains sometimes a thickness of 2 mm or more.

As usual, the durain is made up principally of woody materials with subordinate representation of microspore exines, cuticles and a few resinous bodies, the whole series of material being embedded in an homogenous groundmass The woody material occurs mostly in the form of xylovitrain, i. e. a much transformed xylain with its cellular structure almost entirely obliterated. It can still be recognized as such from its high relief and not infrequently the presence of numerous cavities suggesting the original cellular spaces. Fusain is also present, but rather rare. Besides, there presents a fragmentary material with thick cell walls occurring either in single isolated cells or in one or two rows of a series of cells. Some of the cells assume a form very like bast fiber which has been produced by etching in the coal of Hokong and Chimenshan[1] while in others the cell walls of which are so thick that they may be called stone cells. Such cell generally shows a higher relief and distinct

1. Hsieh, C. Y., Ätzstrukturen in der Kohle, Arb. Institut f. Paläobotanik u. Petrographie der Brennsteine, Bd 2, Heft 1, pp. 25, 1930.

bright lustre than ordinary xylain. When examined by naked eye or by a lens it shows a sub-metallic lustre of gray color, so it can not be fusain.

Seam No. 4½.

Macroscopically, this is a compact and hard coal showing distinct banding of bright and dull layer, the latter is an ash-rich components weathered generally to yellow or brownish color, evidently due to the presence of iron. It breaks into regularly formed parallelpiped fragments.

Under the microscope,— Vertical section: This is composed essentially of durain intercalated here and there with extremely abundant lenticles of fusain showing distinct cellular structures. In the durain is present a great amount of xylainic debris or isolated rows of cells showing distinct relief and bright lustre of yellow color; also some cuticles and microspore exines, and a few resinous bodies. Most of the woody material here occurs in the forms of fusain and xylain; xylovitrain is present only in subordinate way. The cellular structure in both fusain and xylain has suffered some degree of compression, so that arc structure is common. It seems that well formed, uncrushed cells have not been observed; a feature similar to seam No. 6, but unlike seam No. 3. The more abundance in xylain than xylovitrain in this coal distinguishes it from seam No. 6.

Stone cells, bast fiber and other thick walled cells of indeterminate nature are very abundant in this coal occurring either in unburnt (xylain) or in burnt state (fusain); the latter form of preservation seems to be more common.

Another characteristic feature of this coal is the ash-rich beds which show under the microscope a great amount of woody debris embedded in a dark grey groundmass of inorganic origin. The debris is of different sizes and is composed of a great variety of tissues.

Horizontal Section: The horizontal section reveals a great abundance of fusain and xylain forming either large pieces of several mm. long or small irregular fragments embedded in a bright ground-mass. Cuticles of wrinkled or folded forms are found but they are only subordinately represented.

The ash-rich layer shows under the microscope to be an aggregete of xylainic and fusainic material embedded in a groundmass containing greyish spots or masses of ashy matter.

Seam No. 5.

The horizontal section of this coal shows a great abundance of leaves, often wrinkled and folded giving thus a most complicate appearance, being bounded in all cases by cuticles of irregular outlines. In some part of the section it seems to be made up essentially of large pieces of xylainic to xylo-vitrainic materials with cellular structure more or less clearly shown.

The vertical section shows also a great abundance of cuticles and spore exines embedded in a bright groundmass. The cuticles are often contorted and curved. The coal seems to have suffered some movement during or after its formation, as is evidenced by the displacement and discontinuity of the cuticle bearing layers. Crushing of the beds is also commonly seen. Both fusain and xylain are present, but they are not so abundant as in other coal. A richness in small lenticular fragments or grains of resin is very characteristic for this coal. It is more gray in color and higher in relief as compared with xylainic constituent. The recognation of resin can be best made by using polarized light[1] or still better under oil immersion; in this way the internal reflection color of brown or yellow is distinctly shown.

From the above description it seems clear that seam No. 5 is unique in its abundance in cuticles or sporic matter and in its great reduction in woody materials such as are the case with the other seams previously described.

Seam No. 6.

This is also a finely laminated coal, but less hard and compact as compared with seam No. 3. It is much crushed showing abundant slickensides and cleavages while bedding planes being only indistinctly shown.

Under the microscope the vertical section is seen to be composed almost entirely of durain with a few thin intercalations of vitrain, the thickness of which reaches only 20—40 microns. The durain is composed in the main of lenses or fragments of xylo-vitrain, in which cellular structure has been mostly obliterated, but can still be inferred from the form and distribution of cavities which occurs abundantly in it. Moreover, the xylovitrain has a distinctly higher relief than the ground mass or the common vitrain. Xylain and fusain showing distinct cellular structure are also present, but they are not so abundant as in coal of seam No. 3. In addition, the cells have generally

1. See the next article in this Bulletin by C. Y. Hsieh on "some new methods in coal petrography."

suffered some compression, so that arc structure is commonly observed. Transition from xylain to xylovitrain is also observed. In some pieces of fusain, especially those of large sizes, there occurs some well preserved, uncompressed cells together with intensely crushed ones; this suggests very likely the structure of annual ring, which the author has repeatedly seen among the Chinese coals of Jurassic or more younger ages.

In the durain there occurs some exines of microspores, small grains of detached fusain, xylain or xylovitrain and here and there rounded to irregular-shaped resinous bodies.

In some part of the section, cuticles are observed, but they are far less abundant and not so crowdly spaced as in the coal of seam No. 3. Bast fiber and bright, fragmentary cells are also present but are not very abundant.

In some other polished section made from the same specimen, there shows great development of an homogenous groundmass in which are embedded numerous fragments of xylovitrain (or vitrainic debris) some exines of microspores and cuticles and several lenticles or fragments of fusain, lenticles the latter show sometimes a well preserved and uncompressed cellular structure. The cell walls are often replaced by pyrite. Some beds of one or more mm. in thickness are exceptionally rich in small ash grains which make the coal to exhibit a dirty appearance.

The similarity of this coal with some of the previously described is very great, but some distinction is still noticeable. Firstly, the woody material is here found to be mostly in a state of more advanced transformatien; fusain and xylain with somewhat distinct cellular structure are certainly present, but they have generally suffered some compression and transformation, so that arc structure and xylo-vitrain are found to be more common. Moreover, cuticles are not so abundant in this coal; this character distinguishes it from the seam No. 3.

4. Maceration

In order to know more detail about the botanical constituents preserved in the coal, a study by maceration method is the best means. This method is now being used in a large extent by coal investigators and has yielded in some cases surprising results. The coal to be studied must be pulverized first; the fine powders are then immersed in a solution of concentric nitric acid (sp. gr. 1.40) and potassium chlorate. The time of treatment varies with

the nature of the coal and in the case of Peipiao coals, I have left them in the solution for about 4-5 days. The residues are then washed throughly, and treated again with ammonia for ten to twenty minutes. Practically all the humic substances are dissolved by ammonia while fusain, mineral grains and what is most important, the cutinized substances such as exines of spores, cuticles etc. can be picked out and studied under the microscope.

The maceration products from the seam No. 3 and No. 6 are very similar; they are composed in the main of isolated wood fibers showing sometimes distinct structures such as bordered pits, medullary rays etc; also some fusain and cuticles. Exines of microspores are only rarely found, though they are certainly present. Epidermal cells of the cuticle are generally well preserved, showing a long streatched, rectangular forms. The best preserved cuticles showing distinct cell structures and stomata are seen in the coal from seams No. 4 and 4½, of which an example is given in the illustration. Wood fibers and fusain are equally abundant in these coals while microspore exines are rare. The maceration product of seam No. 5 shows only some badly preserved cuticles and unidentifiable tissues.

From the above maceration study, it is concluded that the vegetable tissues forming the bulk of the Peipiao coals are composed in the main of the woody elements and cuticles, while sporic constituents are conspicuously rare. The forms of the epidermal cells in the cuticles as well as the structure of the wood fiber present some striking resemblance in all the coals studied, so that they afford no means by which to distinguish or to correlate the different coal seams from a maceration study alone.

5. Conclusion.

The present study is merely a petrographical description of six principal coal seams found in the Peipiao coal field. As the "exact location [1] of the specimens studied are in most cases unknown, and systematic collection of coals from one place to another is not yet available, any discussion about the horizontal variation in microstructure and botanical constituents of the coals is therefore not the scope of the present work. A detailed study to show horizontal variation is, however, of fundamental importance, as it furnishes the only means to interpret the mode of conditions under which the coals in different parts were formed. It is hoped that such a study shall be taken up

1. The Peipiao authority has consented to send such a collection in the near future

by the Fuel Laboratory in the near future.

From the previous microscopical and maceration study, it is concluded that the Peipiao coals are made up principally by woody constituents and cuticles together with some fragmentary cells of bast fiber, some stone cells characterized by extraordinary thick cell walls especially abundant in Seam No. 4, whereas sporic matter, resins etc. are conspicuously rare (Only abundant in Seam No. 5). Among the woody materials, three different forms of preservation may be distinguished; namely fusain, a charred wood, xylain, a humified wood showing still distinct cellular structure and xylovitrain, a more advanced transformation of woody material with complete obliteration of most of the cellular structures.

Another important conclusion brought out by the previous microscopic study is the constant association of ashy matter in fusain, the former is almost always present occurring as infiltration in the cells of the latter. Therefore, if we can develop some means to separate out more or less completely the fusain particles from the coals, it will decrease the ash content and consequently improve the quality of the coal to a considerable extent. Perhaps the coking quality of the coal can also be improved in this way as is believed by most of the recent coal investigator.

Synoptic table showing characters of the Peipiao Coals.

No. of Seam	Macroscopic characters	Microscopic characters.							
		Cuticles	Microspores Exines	Fusain	Xylain	Xylovitrain	Resinous matter	Other Tissues	Sp. Gr.
Seam No. 3	Finely laminated durain with thin vitrain and numerous lenses of fusain. Fracture uneven, very light.	Extremely abundant, often crowded to form a band of high relief.	Not abundant.	Abundant, cells often infiltrated with ash or pyrite generally not crushed, occurring in large lenses.	Very abundant, cells generally not compressed or crushed	Very abundant, often in large lenticles.	Rare		1.29
Seam No. 4	Finely laminated durain with more developed vitrain; fusain is rare. Fracture uneven, more heavy than seam No. 3.	Not abundant to rare.	Not abundant.	Not Abundant, cells generally uncompressed occuring generally in narrow lenses.	Abundant, cells generally uncompressed;	Very abundant, in small or larger lenticles or bands.	Rare	Bast fiber, stone cells are rather abundant.	1.32
Seam No. $4\frac{1}{2}$	Distinctly banded coal of bright and dull layers, the latter is an ash rich component weathered generally to yellow or brown (due to iron) Fracture even, breaks into parallelopiped fragments.	Not abundant	Not abundant.	Extremely abundant, cells generally compressed to form arc structure.	Abandant, cells generally compressed to form arc structure.	Not abundant.	Rare	Same as Seam No. 4	1.37
Seam No. 5	A semi-bright much crushed coal showing undistinct banding. Rather soft and friable, breaks into small irregular fragments.	Very abundant generally folded and contorted.	Very abundant.	Very rare, cells generally uncompressed.	Present.	Present.	Common to abundant.	Some fragmentary cells with thick walls are present.	1.28
Seam No. 6	Finely laminated durain with thin vitrain and some fusain; fracture uneven, less compact and is a little heavier than seam No. 3, with which it closely resembles otherwise.	Abundant	Not abundant	Common, cells sometimes compressed showing arc structure sometimes uncompressed.	Common, cells generally compressed.	Very abundant, generally forming small grains, and lenses rarely long lenticles.	Rare	Bast fiber present, but not abundant.	1.30

Explanation of Plate I

EXPLANATION OF PLATE I.

Microphotographs of polished sections of coal.

Fig. 1. A transverse section of fusain showing well preserved cellular structure perhaps of a coniferous wood. Annual ring is here distinctly marked. (See the horizontal demarcation in the center). Seam No. 3. × 100.

Fig. 2. Pieces of fusain in coal seam No. 3 showing thin walled cells filled almost entirely by ash infiltration. The ash content of the coal is probably largely derived from this infiltration. × 90.

Fig. 3. Vertical section of coal from seam No. 4 showing its general microstructure. This coal is characterized by an abundance of xylovitrain which occurs generally in fragmentary state. White, xylovitrain; gray, groundmass or vitrain. × 100.

Fig. 4. Vertical section of coal from seam No. 4 showing a portion with abundant cuticles. The bands both above and below in the figure are xylovitrain with woody structure indistinctly shown. × 90.

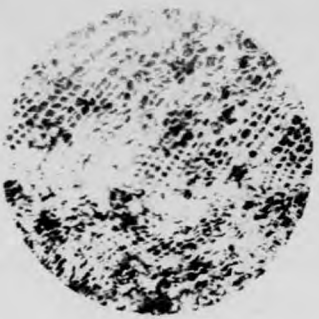

Fig. 1. Coal Seam No. 3
x 100

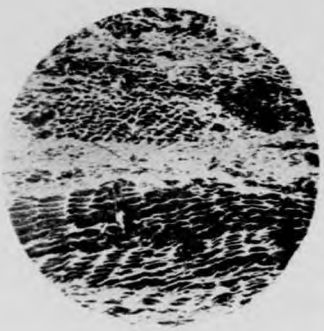

Fig. 2. Coal Seam No. 3
x 90

Fig. 3. Coal Seam No. 4
x 100

Fig. 4. Coal Seam No. 4
x 90

Explanation of

Plate II

EXPLANATION OF PLATE II.

Microphotographs of polished sections except Fig. 8 which is a maceration preparate.

Fig. 5. Vertical section of coal seam No. 4, showing several bands of xylain exhibiting a more bright lustre and higher relief than the ordinary one. × 100.

Fig. 6. Several bands of fusain embedded in a groundmass of vitrain. Seam No. $4\frac{1}{2}$. × 100.

Fig. 7. Vertical section of coal of seam No. 5 showing an entirely different aspect from other seams. It is characterized by a richness in resinous matter and a durain with fairly abundant microspore exines. The exceptionally higher content of volatile matter in this coal is perhaps due to this reason. One of the large resinous fragments is shown in the upper left corner. × 100.

Fig. 8. A cuticle as isolated by maceration from coal seam No. 3. It shows a long stretched, rectangular epidermal cells. × 80.

Fig. 5. Coal Seam No. 4.
x 100

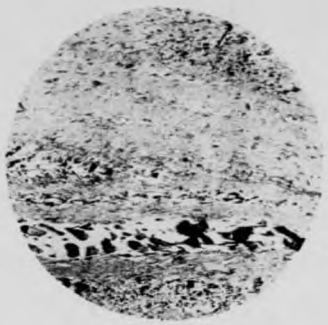

Fig. 6. Coal Seam No. 4½
x 100

Fig. 7. Coal Seam No. 5.
x 100

Fig. 8. Coal Seam No. 3.
Maceration preparate, x 80.

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北票煤之煤岩學初步研究（英文）

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