THE OIL SHALE DEPOSIT OF FUSHUN, MANCHURIA

By

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With 13 Plates and 38 Text-Figures

CONTENTS

INTRODUCTION

The Fushun oil shale field lies about 56 kilometers northeast of Mukden, Manchuria. The oil shale bed at Fushun has, genetically, a close relation to the coal seam on which it rests conformably. The present paper gives an account of geological, petrographical, and chemical studies of the Fushun oil shale, and also a close relation between the oil shale and the coal seam from the standpoints of sedimentation of bitumens embedded in the oil shale, is mentioned.

The previous works on the geology and petrography of the Fushun coal seam and oil shale, are those of Professor M. Yokoyama(1), J. Palibin(2), T. Kido(3), N. Fukuchi(4), R. Florin(5), J. Makiyama(6), Shigeru Yabe(7) S. Endô,(8) C. Iwasaki,(9) J. Takahashi(10), K. Uwatoko,(11) J. E. Hawley,(12) K. Uwatoko(13), S. Oka(14) T. Iki.(15) In preparing the present paper on geology of the Fushun oil shale field, large use has been made of the studies by the writers above mentioned.

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(1) M. YOKOYAMA: The geological age of the Fushun coal field. Jour. Geological Society of Tokyo, Vol. 13, No. 144, 1906. (Japanese)

(2) J. PALIBIN: Fossile Phlanzen aus den Kohlenlagern der von Fushun in der Sudlichen Mandshurei. 1906. Separat abdruck aus den Verhandlungen der Kaiserili:hen Russischen Mineralogischen zu St. Petersburg. Zweite Series Band XLIV, Lief. I.

(3) T. KIDO: The geology of the Fushun coal field. Manchuria Geological and Mining Review, No. 18, 1912. (Japanese)

(4) NOBUYO FUKUCHI: Geology of the Fushun coal field. Manchuria Geological and Mining Review, No. 21, 1913. (Japanese)

(5) R. FLORIN: Zur Alttertiaren flora der sudlichen Mandshurei von Rudolf Florin in Stockholm. Geological Survey of China, Paleontologia Sinica, Series A, Vol. I. Facicle I. 1922.

(6) J. MAKIYAMA: Geology of Fushun. Japanese Jour. of Astronomy and Geophysics, Vol. 11, No. 2, 1924.

(7) Shigeru YABE: Geology of the Fushun coal field. Manchuria Geological and Mining Review, No. 64, 1925. (Japanese)

(8) Seido ENDÔ: Paleogene plant fossils from the Fushun coal field. Journal of Geography, Vol. 38, No. 453, 1926. (Japanese)

(9) Chozô IWASAKI: Fushun coal and its geological significance. Technical Report, Tohoku Imperial University, Vol. 8, No. 1, 1928.

(10) J. TAKAHASHI: Significance of the micro-crystals of carbonates in bituminous shales. Bull. Amer. Assoc. Petroleum Geologists, Vol. 13, No. 10, 1929.

(11) K. UWATOKO: Bitumens of the Fushun oil shale. Manchuria Geological and Mining Review, No. 72, 1929. (Japanese)

(12) J. E. Hawley: Generation of oil in rocks by shearing pressures. Bull. Amer. Assoc. Petroleum Geologists, No. 4, Vol. 13, 1929.

(13) K. UWATOKO: An evidence of cycle of sedimentation of bitumens of the Fushun oil shale. Jour. Geological Society of Tokyo, Vol. 37, No. 441, 1930. (Japanese)

(14) S. OKA: Origin and properties of the Fushun coal. Sekitan Zihô, Vol. 4, No. 10, 1927. (Japanese)

(15) T. IKI: On the oil shale. Jour. Mining Institute of Japan, Vol. 36, 1920. (Japanese)

ACKNOWLEDGMENTS

The present writer has studied the Fushun oil shale, in Berlin, under the direction of Dr. R. Potonié and Dr. H. Hellmers, of the Preussischen Geologischen Landesanstalt, in 1928. He has visited the Fushun field twice in 1928 and in 1929 to observe the geological occurrence of the oil shale and also to collect specimens for the laboratory studies at the Geological and the Chemical Laboratories of the Hokkaido Imperial University.

The present writer gratefully acknowledges indebtness to Dr. R. Potonié and Dr. H. Hellmers, for their kindness in the laboratory works during the studying of the present writer in Berlin in 1928.

He is also indebted to Professor Tsunenaka Iki, of the Tokyo Imperial University, for his constant sympathy and advice during the progress of the work. President Dr. H. Murakami, Mr. Shigeru Yabe, and Mr. M. Kawada, of the Geological Survey of the South Manchurian Railway Company, and Messrs. I. Katayama and K. Imidzu, of the Fushun Coal Mining Research, gave facilities for studying. Professors T. Yoshimachi, Y. Hori, and T. Fukutomi, of the Hokkaido Imperial University, gave also facilities for studying. Lecturer T. Nemoto, Mr. I. Nakaya, and Mr. A. Kannari, of the Department of Geology and Mineralogy of the Hokkaido Imperial University, also gave assistance during the progress of the work.

GEOLOGY

Of those rocks occurring at the Fushun coal field, the sedimentary rocks are generally found through the field. The igneous rocks are dominant in effusives, such as olivine dolerite, andesite, liparite, and diabase.

A. Sedimentary Rocks

1. Mesozoic Formation

The Mesozoic formation is locally developed in the central and eastern parts of the filed, on which the Tertiary formation unconformably rests. The Mesozoic sediments are composed of tuff, black shale, slate, mudstone, limestone, and sandstone. In the upper part of the formation, andesite flows are found, and in the lower part of the formation, flows of porphyrite and liparite are interbedded. Occasionally, the formation is intruded by sheets and dikes of diabase and dolerite.

2. Tertiary Formations

The Tertiary formations are developed in the southern part of the field, resting unconformably upon the granite gneiss which is the foundation rock of this region. Tertiary sediments are composed of green shale, brown shale (oil shale), coal seams, coaly shale, black shale, tuff, and sheets of olivine dolerite. The general strike of the formation extends East to West, dipping northward 20 to 40 degrees.

A number of plant fossils are found at the base of the brown shale (oil shale) near the boundary between the coal seam and the oil shale, being determined by Professor Mataziro Yokoyama (see p. 115) as follows:

Osmunda sp.
Thya cf. borneolis Hr.
Parrotia cf. priestina Ett.
Quercus sp.
Salix sp.
Sequoia cf. langsdorfii Br.

J. Palibin (see p. 115) has described the following plant fossils.

Aspidium cf. meyeri Hr.
Osmunda torelli Hr. ?
Glyptostrobus ungeri Hr.
Sequoia langsdorfii Brongn.
Populus glandulifera Hr.
Carpinus grandis Ung.
Fagus foremiae Ung.
Juglans acuminata A. Br.
Planera ungeri Ett.

R. Florin (see p. 115) also has described the following fossils.

Lygodium kaulfussii Hr.
Dryopterites sp. ?
Osmunda lignitum (Giebel) Stur
Sequoia langsdorfii (Brongn.) Hr.
Glyptostrobus europaeus (Brongn.) Ung.
Populus glandulifera Hr.
Juglans sp. ?
Cf. carpinus grandis Ung.

Alnus kefersteinii Ung.
Corylus MacQuarii (Forb.) Hr. ?
Dryophyllum dewalquei Sap. et. Mar.
Fagus feroniae Ung. ?
Cf. zelkova ungeri Kovatz
Cf. Panax longissimum Ung. ?
Cf. Viburnum nordenskijöldi Hr.

Seido Endô (see p. 115) has also determined a number of plant fossils as follows :—

Osmunda lignitum (Giebel) Stur
Lygodium kaulfussii Hr.
Glyptostrobus europaeus (Brongn.) Hr.
Sequoia langsdorfii (Brongn.) Hr.
Myrica banksiaefolia Ung.
Dryophyllum dewalquei Sap. et Mar.
Fagus feroniae Ung.
Viburunum speciosum Knowlton
Banksia saffordi (Lesq.) Berry
Dryandra brongniartii Ett.
Cinnamomum scheuchzeri Hr.
Betula prisca Ett.
Alnus kefersteinii Goepp.
Alnus incana rotundifolia Schmalh.
Quercus drymeja Ung.
Quercus lonchites (Kovatz) Ung.
Planera ungeri Kovatz
Panax longissimum Ung
Nyssidium fusiforme Hr. (Fruits)
Comptoniphyllum anderssonii (Florin)
Corylus insignis Hr.
Corylus MacQuarii (Forb.) Hr.
Carpinus grandis Ung.
Populus grandulifera Hr.
Ficus occidentalis Lesq.
Rhus pyrrhae Ung.
Hedera M'clurii Hr.
Flabellaria sp. ? (Fragment)
Taxodium sp. ? (Cones)
Libocedrus sp. ?
Cf. Acasia mirophylla Ung. (Fruits and Leaves)

Cf. Cassia hyperborea Ung. (Fruits and Leaves)
Cf. Crataegus kornerupi Hr.
Feildenia bifida Hr. ?
Cf. Juglans hydrophyla Ung. ?
Celastrus borealis Hr. ?
Cf. Quercus breweri Lesq.
Cf. Celastrus persei Ung.
Viburnum sp.
Populus sp. ?
Cf. Ficus morloti Ung.
Cf. Pyrus euphemes Ung.
Cf. Celastrus andromedae Ung.
Dryophyllum yunnanense Colani

J. Palibin stated in 1906, under his consideration of the fossil plants above mentioned, that the age of the coal measures of the Fushun field is Oligocene. R. Florin also regarded the geological age of the Fushun coal field as Upper Eocene or Oligocene.

The Tertiary formation is divided into two groups; the upper and the lower parts.

The lower part of the Tertiary formation is composed mainly of volcanic products, such as tuff and olivine dolerite, and also of black shale, coaly shale, and coal seams, as is shown in Figure 1 of the columnar geological section at the coal washing place at the Fushun colliery.

The upper part of the Tertiary formations is economically important, being mainly composed of the main cool seam, the oil shale, and the green shale, as are shown in the following figures of the profiles of the field.

The coal seams are developed, striking from East to West, dipping northward with the range from 20 to 40 degrees. The thickness of the coal seams varies locally, showing one or two meters at the eastern part of the field, and about 100 meters at the western part of the field, as are shown in figures of the following pages. The coal seam is interbedded with shales and sandstones called "Bota" which are mainly developed in the lower part of the coal seam. The "Kabary" (Pseudocannel coal) which is mentioned in the following chapter, is mostly developed in the upper part of the coal seam.

The brown shale (oil shale) which rests conformably on the coal seam, is mentioned in detail in the following chapter.

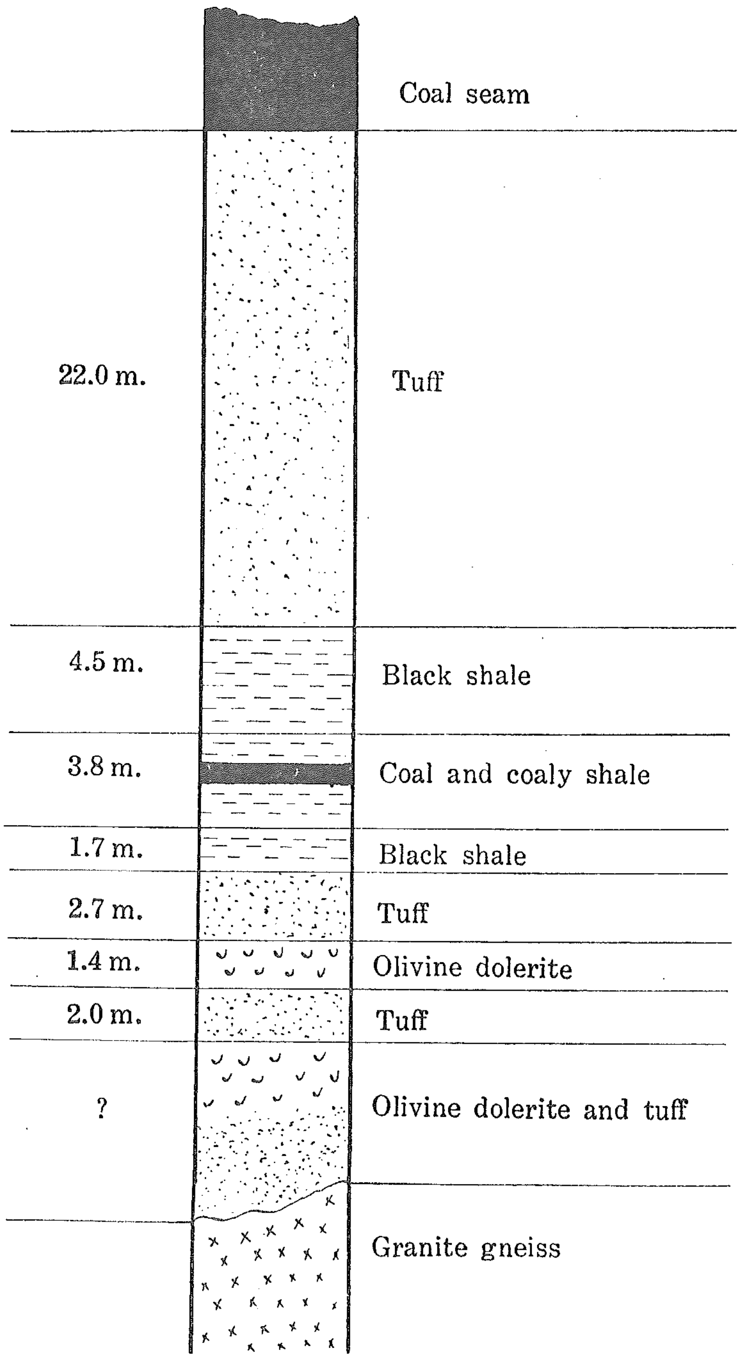

Fig. 1. Geological section of the Lower group of the Fushun Tertiary coal bearing formation at Kojôshi (古城子) colliery.

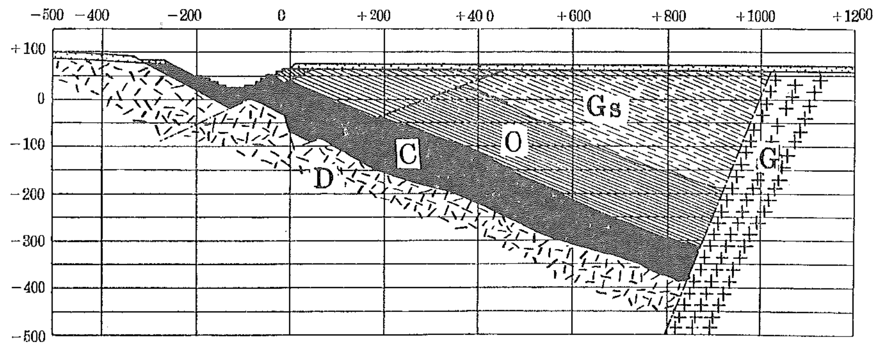

Fig. 2. Structure section of the Fushun coal field along north-south line through a point 600 meters west of zero point in Plate I. Dimensions in m.. G, granite gneiss; Gs, green shale; O, oil shale; C, coal; D, dolerite and tuff.

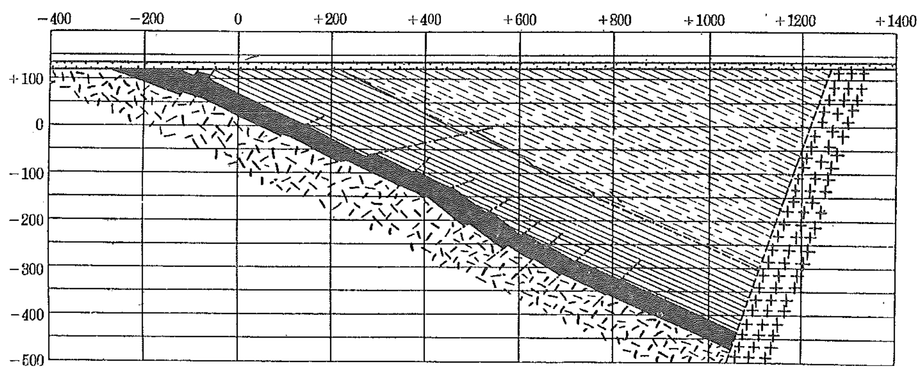

Fig. 3. Structure section of the Fushun coal field along north-south line through a point 2727 meters east of zero point in Plate I. Dimensions in m..

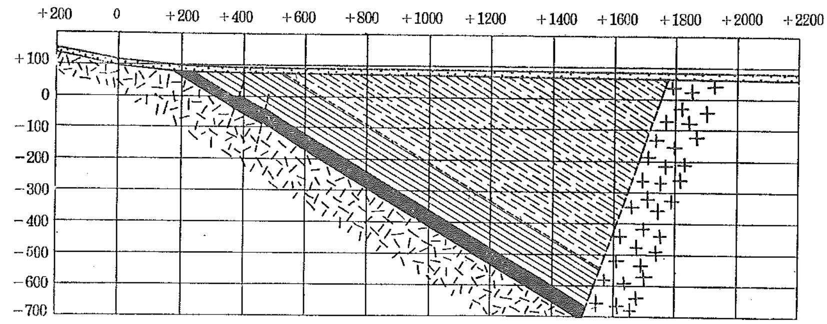

Fig. 4. Structure section of the Fushun coal field along north-south line through a point 6545 meters east of zero point in Plate I. Dimensions in m. .

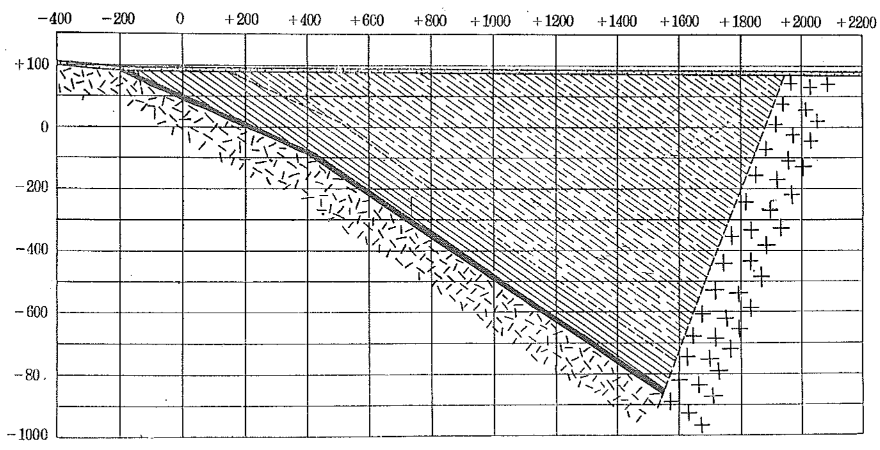

Fig. 5. Structure section of the Fushun coal field along north-south line through a point 12090 meters east of zero point in Plate I. Dimensions in m. .

The green shale occurs in the northern main part of the Fushun coal field. It covers the oil shale bed conformably, representing a thin alternation of the oil shale and the green shale at the boundary between them. The exposure of the green shale at the surface is only observed at the central part of the field, near Tôgô-ko (東鄉坑) and Ôyama-ko (大山坑). But it extensively develops unconformably immediately below the Quarternary sediments, being shown by the diamond boring method, as is shown in Plate I of the solid geological map at sea level, which had been prepared by the Fushun Tankô. The green shale is found in homogenous compact masses, without any interbedding laminae with other rocks except the thin alternation of the oil shale and the green shale at the boundary between them. The thickness of the green shale is not measured accurately, because the upper part of the formation has been weathered and eroded away by water. But its thickness may be measured by the diamond boring method as more than three times that of the oil shale bed, as is shown in figures of the geological profiles of the coal field above mentioned.

The fresh hand specimen is uniformly light green in colour, although when decomposed by weathering it alters to grayish light green colour. The rock is usually cut by small veins and veinlets of calcite ranging from about 0.1 up to half millimeter in thickness. The rock is so strongly calcareous that one can prove it easily by one drop of hydrochloric acid.

Under the microscope, there is not observed any grain of mineral as a component mineral, except the grains of the secondary crystal of rhombohedral calcite about 0.02 millimeter in diameter. Occasionally, the crystal grains of calcite are tinged a reddish brown colour with iron oxide. Minute grains of quartz and felspars about 0.002 millimeter in diameter are also found. A small flake of biotite 0.06 millimeter in length and 0.01 millimeter in width is observed. This is the one only coloured mineral that is seen in the thin section of the green shale. In pleochroic halos the direction of stronger absorption is parallel to the cleavage cracks. The matrices, which are the main part of the green shale, are composed of those submicroscopic grains of the minerals which may be a colloid sediment with non-stratified uniform texture.

The green shale is extremely different in chemical characters from the oil shale, the former is a calcareous rock, while the later is an argillaceous rock. The colour of the green shale also differs from that of the oil shale. The fresh hand specimen of the green shale is macroscopically grayish green in colour, while the oil shale is brownish black to black in colour. Under the microscope in thin section, the former is gray to opaque, and one can not recognize any grain of green minerals upon which the green colour of the shale depends. But the result of chemical analysis of the rock shows a large content of magnesia and iron from which the green minerals of the green shale may be derived.

The chemical analysis of the green shale and the oil shale has been made at the Central Experimental Works of the South Manchurian Railway Company. The specimens were taken from the fresh samples of the boring cores at the colliery. The following table is from S. Midzuuchi.(16) The analysis has been againt the ash after ignition for volatile matters.

	I	II	III	IV
	Wt. %	Wt. %	Wt. %	Wt. %
SiO_2	44.00	51.75	51.77	51.11
Al_2O_3	10.90	20.72	25.31	23.02
Fe_2O_3	13.30	9.56	10.12	10.87
FeO	1.00	....	....	....
MnO	0.30	....	....	....
MgO	2.80	4.85	1.04	1.56
CaO	11.00	7.00	7.28	8.21
Na_2O	1.10	....	....	....
K_2O	1.00	....	....	....
P_2O_5	0.26	....	....	....
CO_2	12.60	....	....	....
Ig. loss	1.20	....	....	....
Total	99.46	93.88	95.52	94.77

As is shown in the above tables of the chemical analyses of the green shale, iron, alumina, and magnesia are rich, from which the coloured minerals of the green shale might been derived.

No. I, the chemical analysis of the above table, has been done by A. Kannari, of the Department of Geology and Mineralogy, Faculty of Science, of Hokkaido Imperial University, against the surface exposed sample collected by the present writer at the Ôyama-ko (大山坑) at Fushun coal field.

B. Igneous Rocks

Of those igneous rocks occurring in the fields, the granite gneiss is widely distributed as a basal rock of the region, Porphyrite, ande-

(16) S. Midzuuchi: Chemical analysis of the residue of the Fushun oil shale. Report of the Central Experimental Works, S.M.R. Co., Series 10, No. 13, 1924. (Japanese)

site, liparite and dacite occur in dikes or intrusive and extrusive sheets intruding into the Mesozoic formation.

Olivine dolerite, which is mostly in close relation to the coal seam and the oil shale occurs in the Tertiary formation in intrusive sheets in the lower part of the Tertiary sediments, upon which the coal seam and the oil shale are resting. The rock is macroscopically medium granulitic and compact in texture with black colour. Holocrystalline minerals of lath-shaped plagioclases with a length up to three millimeters, are observed with grains of crystals of augite and olivine of about one millimeter diameter, through the rock. Under the microscope, the component mineral of the rock, are the lath-shaped crystals of plagioclase, the glanular crystal of augite and olivine, by which a typical ophitic structure is formed as is shown in Figure 44. Occasionally the lath-shaped crystals of holocrystalline plagioclases are seen as phenocrysts with a zonal structure in polarized light. It is a striking character that the brown glassy matter is seen in interstitial patches between the crystals of plagioclases and other minerals. Plagioclase, which shows a fresh appearance, is found to be labradorite, showing lath shape, with albite and occasionally pericline twinning, with a small amount of inclusions such as patches of dark coloured glassy matter, and small masses of augitic matter. Common augite, having ophitic texture with plagioclases, is present in irregular crystal grains with a diameter of about one millimeter, showing a distinct cleavage. The colour is seen as light yellowish-brown with weak pleochroism. Most of the crystals are fresh within an inclusion of crystal grains of magnetite. Olivine, which is one of the characteristic minerals of the rock, is also found in irregular crystal grains of about one millimeter diameter, sometimes fresh but usually replaced by green or yellowish-brown serpentine along cracks which developed irregularly. Crystal grains of magnetite are also found in slices, but not so abundantly as seen in other typical basaltic rocks. In addition to the foregoing minerals, there are irregular-shaped spaces of brown colour occupying the interstices between the felspars and other mafic minerals. These spaces consist, in general, of glassy matter containing numerous needles, of apatite and other longulitic minerals.

The chemical analysis of olivine dolerite at the Fushun coal field which had been done at the Geological Survey of the South Manchurian Railway Company, is referred, in the following table, after Shigeru Yabe.[17]

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(17) Shigeru YABE: Manchuria Geological and Mining Review, No. 64, 1925, p. 35. (Japanese)

	Wt. %	Mol. numb.
SiO_2	45.44	753.6
Al_2O_3	17.14	167.7
Fe_2O_3	2.83	17.7
FeO	9.37	130.4
MnO	1.60	22.6
CaO	12.41	221.2
MgO	2.25	55.8
TiO_2	3.10	38.7
P_2O_5	0.59	6.7
K_2O	2.23	23.7
Na_2O	1.68	27.1
H_2O	0.89	....
Total	99.53	

OIL SHALE

A. General Statement

1. Definition of bitumen

Bitumen and kerogen are defined variously by many writers. Cunningham Craig,[18] Steuart,[19] Gavin,[20] Smith,[21] Takahashi[22] Engler and Höfer,[23] Holde,[24] R. Potonié,[25] and others have considered and defined the meaning of the term bitumen.

But, generally speaking, the term bitumen is used for the organic matters soluble in solvents, and the term kerogen is used for the insoluble organic matters, but on the other hand, the term bitumen has been considered in the wide sense including organic matters both soluble and insoluble. But recently it has been found that some stable bitumens may be extracted practically by the use of suitable solvents under certain physical conditions, as for example in the experiments

(18) E.H. Cunningham Craig: Kerogen and Kerogen shale. Jour. Inst. Petroleum Tech., June, 1616.

(19) D. R. Steuart: The oil shale of Lothians. 3rd ed., Scotland Geological Survey, Mem., 1912.

(20) M. J. Gavin: Oil shale. Bull. 210, U.S. Bureau of Mines, 1924.

(21) R. G. Smith: Asphalt. Handbook of the Petroleum Industry, by D. T. Day and others, New York, 1922.

(22) J. Takahashi: The marine kerogen shale from the oil fields of Japan. Science Report, Tohoku Imperial University, Japan. Vol. 1, Series 3, 1922.

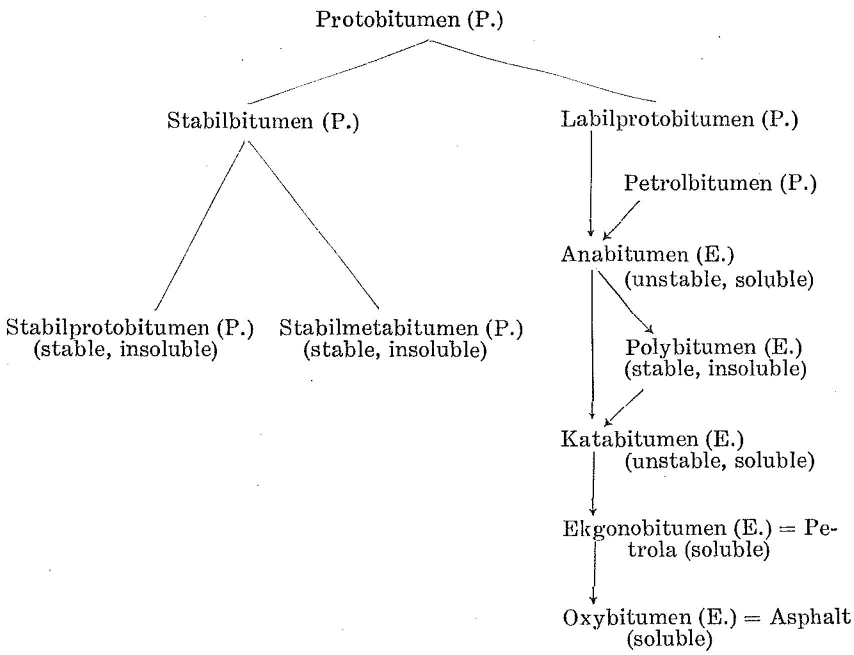
(23) C. Engler and H. v. Höfer: Das Erdöl. 1913.

(24) D. Holde: Handwörterbuch der Naturwissenschaften. Bd. 1.

(25) R. Potonié: Beziehungen zwischen bituminosen Gestein und Erdöl. Situngsberichte der Geol. Landesanstalt, Heft 1, 1926.

by Hawley[26]. Therefore, this definition is not technically correct for all bitumens.

The present writer has considered the meaning of the term bitumen in the following suggestions. In a narrow sense it includes organic matters soluble in benzol at temperatures up to their boiling point under atmospheric pressure. Therefore, it includes inflammable natural gases from oil and coal fields and also gases from marshy swamps, and it also includes liquid and solid oils from oil, and oil shale fields. In the wide sense, in addition to the bitumens in a narrow sense above mentioned, the term includes organic matters insoluble in benzol at temperatures up to their boiling point under atmospheric pressure, from which, however, will be yielded substances soluble in solvents by thermal treatment. Therefore, it includes stable organic matters such as cutin derived from epidermus, suberin derived from cork, cellulose, lignin, resins, waxes, humic substances, which are contained in oil shales, peats, boghead coals, cannel coals, bituminous



Kerogen = Polybitumen (E.) = Stabilbitumen (P.) + Polybitumen (E.) derived from Labilprotobitumen (P.)

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(26) J. E. HAWLEY: Generation of oil in rocks by shearing pressures. Bull. Amer. Assoc. Petroleum Geologists, Vol. 13, No. 4, 1929.

coals, dysodiles, coaly shales. It includes also stable organic matters insoluble in solvents, which are embedded in bituminous shales from oil fields.

Kerogen (Gestein-or Fest-bitumen) is considered as solid bitumen insoluble in solvents, from which will be yielded matters soluble in solvents, after thermal treatment.

According to the Engler and Potonié's idea of the meaning of bitumen, it will be classified as is mentioned on the above page.

2. DEFINITION OF OIL SHALE

A number of writers, Gavin,(27) Conacher,(28) Ashley,(29) Thiessen,(30) Steuart,(31) Cunningham Craig,(32) Winchester,(33) McKee,(34) Day(35) and others, have variously defined the meaning of the term oil shale.

It is, however, difficult to define oil shale quantitatively, because oil shale is a member of groups of sapropelitic rocks which contain organic matters of sedimentary origin, and there are no sharp boundaries between them. But Gavin has defined oil shale, considering the ash content for distinguishing oil shale from coals, and Day also has defined oil shale chemically, considering the content of ash, voltatile matters, and fixed carbon for distinguishing oil shale from peat, cannel coal, boghead coal, lignite, bituminous coal, and anthracite. These definitions of the meaning of oil shale have, however, seemed to be, more or less, quantitatively considered.

As Day has stated that the definition of an observer whose experience has been limited geographically will not apply to other oil shales from other countries, the definition of oil shale should be to be purposely broad and inclusive, covering the entire field of oil shales, as for examples, those from Esthonia, Sweden, Scotland, England,

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(27) M. J. GAVIN: Oil shale. Bull. 210, U.S. Bureau of Mines, 1924.

(28) H. R. J. CONACHER: A study of oil shales and torbanites. Trans. Geol. Soc. Glasgow, Vol. 16, Pt. 2, 1917.

(29) G. H. ASHLEY: Cannel coal in the United State. Bull. 659, U. S. Geol. Surv., 1918.

(30) R. THIESSEN: Origin and Composition of certain oil shales. Economic Geology, Vol. 16, 1921.

(31) D. R. STEUART: Oil shales of Lothians. Part III, Mem. Geol. Surv. Scotland, 3rd ed. 1912.

(32) E.H. CUNNINGHAM CRAIG: Origin of oil shale. Roy. Soc. Edinburgh Proc., Vol. 36, 1916.

(33) D. E. WINCHESTER: Oil shale of the Rocky Mountain region. Bull. 729, U.S. Geol. Surv., 1923.

(34) R. H. MCKEE: Shale oil. Chemical Catalogue Company, New York, 1925.

(35) David Eliot Day: Oil shale. Handbook of the Petroleum Industry, by D. T. Day and others, New York, 1922.

Germany, France, Spain, Servia, Italy, Tyrol, Switzerland, Tasmania, New South Wales, Burma, South Africa, China, Manchuria, Korea, Japan, Alaska, California, Utah, Nevada, Wyoming, Colorado, Ohio, Kentucky, Indiana, Tennessee, New Brunswick, Brazil, and other countries.

The present writer has considered that the main points of the definition are on the basis of the petrographical properties of the oil shale, and also are based on the amount of bitumen contained in it, from which will be yielded gases, or liquid and solid hydrocarbons by any method of treatment. Therefore, the term oil shale is to be defined as all sedimentary rocks which may be petrographically classed as shale which contained bitumen (defined in the wide sense by the present writer) which will yield hydrocarbon compounds by certain methods of treatment. Therefore, the meaning of this definition may include those of both Thiessen and Day.

B. Geological Occurrence

The Fushun oil shale occurs extensively at the Fushun coal field, as is shown in Plate I. It covers the coal seam conformably and is covered conformably by the green shale. The thickness of the oil shale varies locally, showing about 120 meters at Kojôshi (古城子), 130 meters at Ôyama-ko (大山坑), 140 meters at Tôgô-ko (東鄉坑), 180 meters at Roko-dai-ko (老虎台坑), 115 meters at Bantatsuya-ko (萬達屋坑), 130 meters at Shinton-ko (新屯坑), 115 meters at Rhuhô-ko (龍鳳坑), 117 meters at Toren-ko (塔連坑). Generally speaking, the Fushun oil shale is uniformly developed ranging from about 100 meters to 200 meters in thickness, from west to east, although it varies locally at the central part of the coal field. The boundary between the oil shale and the coal seam shows a sharp line in contact. But there is found a large amount of coaly fragments and plant fossils at the base of the oil shale bed, and at the western part of the field, the oil shale interbeds with coal seams at their boundaries.

The oil shale occurs, however, apparently in uniform argillaceous, fine grained masses. It is composed of various types of oil shales, showing an alternation of the rich and poor oil shales.

C. Petrographical Characters

1. Macroscopical characters

Generally, the Fushun oil shale, looks like a homogenous fine-grained argillaceous shale showing dark brown to black in colour. There are distinct differences between the rich and poor oil shales, the most rich oil shale is distinctly distinguished from the poor oil shale in which microcrystals of siderite mainly dominate as an essential component of mineral of the shale, while the most rich oil shale contains almost no grains of siderite.

The Fushun oil shale is generally petrographically classified into four classes: (1) the most rich oil shale, (2) the medium rich oil shale, (3) the poor oil shale, (4) the siderite bed, which will be mentioned respectively in detail in the following chapters.

The typical Fushun oil shale, is a fine-grained compact massive argillaceons shale with blackish-brown colour as above mentioned. The streak on unglazed porcelain has brownish colour. Specific gravity, about 2.0. On clipping, it may be curled moderately by an edge of a piece of glass. On weathering it alters to gray in colour and becomes more or less scaly. It usually yields about 6 percent of oil on distillation. It also occasionally includes curious nodules, coaly fragments, and resinous substances, which are recognized with the naked eyes.

2. Microscopical characters

The Fushun oil shale is petrographically classified into four groups according to the grade of oil content, as above mentioned, and there are also different characters among them in thin section under the microscope. But common characters of the Fushun oil shale are also observed.

The Fushun oil shale is found in uniform texture under the microscope, being composed of mineral grains and bituminous and non-bituminous organic matters. Of these grains of minerals embedded in the oil shale, siderite, quartz, felspars, and marcasite are mostly dominant in quantity.

Siderite enters dominantly into the composition of almost all the Fushun oil shales except the most rich oil shale which contains more than 14 percent of oil. The mineral occurs in granular grains of crystals of rhombs embedded uniformly through the rock. The grains of crystals of siderite are exteremly minute in diameter having a range from 0.001 to 0.04 millimeter. Therefore, it is difficult to determine their optical characters accurately. But the index of refraction is so high that all grains of siderite look as if they were floating on other minerals and organic matters. Double refraction is also strong. According to Takahashi,[36] the refractive indices nearly coincided with

(36) J. Takahashi: Significance of the microcrystals of carbonates in bituminous shales. Bull. Amer. Assoc. Petroleum Geologists, Vol. 13, No. 10, p. 1377, 1929.

those of siderite, The grains of siderite are usually found in disseminated grains, but also they are often found in crystal aggregates in the oil shale. Siderite increases in quantity with the decrease of oil content in the shale. That is, the most rich oil shale is most scanty in content of siderite, while the poor oil shale is dominated by it.

It is also interesting that the grains of siderite are deposited in alternation with the oil shale beds, therefore the siderite bed represents an evidence of cycles of sedimentation. Siderite is also found in thick aggregates around the curious black phosphorous nodules, as is shown in Figure 49. It increases in quantity with grains of marcasite near the center of the nodule, as is mentioned in detail in another chapter. It is also a striking character that the most rich oil shale often contains nothing of crystal grains of siderite.

Marcasite is also great in quantity next to siderite. This mineral occurs in disseminated microscopical globules about 0.01 millimeter in diameter through the rock, but occasionally it is found in aggregates, as is shown in Figure 65. Opaque, and black in colour, but in polished section, grayish white in reflected light with metallic luster. Marcasite is usually found in embedded microglobules in the sapropelitic rocks. Generally speaking, it is a striking character that most of the grains of marcasite are spherical globules like micronodules. This mineral may be melnicovite which has been described by Doss[37] as a modification of iron disulphide that is now being formed in the mud at the bottom of water basins of fresh and salt waters by agencies of bacteria. Microglobules of marcasite are also found in the coaly shales interbedded with the Fushun coal seam. Marcasite is also met with around the curious black phosphorous nodules which are embedded in the oil shale. In this case, the grains are generally irregular in form and do not show such definite microspherical globules as those of others embedded in the oil shale.

Quartz is found also usually dominant next following marcasite. The grains are also very minute in size with a range from 0.01 millimeter to 0.025 millimeter in diameter, but occasionally there are recognized some large angular grains which may be angular fragments of pyroclastic materials showing about 0.3 millimeter in diameter, with irregular inclusions, such as brown glass and gasses, as is shown in Figure 45. Fragments are colourless.

(37) BRUNO DOSS: Ueber die Natur und Zusammensetzung des in Miocänen Tone des Gauvernements Samara auftretenden Schwefelleisens. Neues Jahrb., Beil. Band 33, 1912.

Submicroscopical grains of quartz and kaolinized minerals, may exist composing a matrix as cementing substances between the grains of minerals and organic materials. But these matrices are not recognized distinctly in thin section under the microscope, because of tinging by the brownish colour of bitumen. But the result of chemical analysis of ash after expulsion of volatiles, shows some amount of silica and alumina.

Felspars occur in angular fragments in the oil shale. This mineral amounts to a very small quantity disseminated through the rock. The fragments are colourless. Among these felspars, plagioclase and orthoclase felspars are both met with, but it is difficult to ascertain their optical properties, because they are too minute in size and are closely covered by mineral matrix and organic substances.

The organic substances, which are the most important materials of of the Fushun oil shale, from some of which oil may be extracted on distillation, may, for purposes of description, be divided into two groups: (1) the carbonaceous matter, (2) the bituminous matter.

Carbonaceous matters are the substances derived from plant fragments, being dominant in free carbon and non-bituminous substances. Therefore, it does not yield oil on distillation, and is also distinguished from other bituminous coaly matters by microchemical methods in thin section under the microscope. Fragments are irregular in form, black in colour, opaque and often reveal wood tissue structure in thin section, as is shown in Figure 47. Carbonaceous matter is usually found in the poor oil shales particularly in those laid down immediately above the coal seam. Especially such matter is abundantly found in the coaly shale interbedded with the coal seam, as is shown in Figure 46. The fragments in the oil shale are, however, occasionally macroscopical in size. In thin section made perpendicular to the bedding plane, it shows irregular forms with elongated edges parallel to the bedding plane, with a range from 0.015 millimeter to about one millimeter in diameter.

Bitumens are the most important substances, from which oil will be extracted on distillation. Those bitumens occurring in the Fushun oil shale, are those of humic substance, resins, waxy substances, and cutin.

Humic substance occurs in lenticular but usually in irregular elongated forms with a range from 0.01 millimeter up to 2 centimeters in length, as is shown in Figure 56. Humic substance is also found in aggregates of small globules ranging from 0.005 millimeter up to 0.02 millimeter in diameter. Humic substance is dark reddish-brown in colour, translucent in thin section under the microscope, dark between crossed nicols. Its refractive index is lower than that of Canada balsam. Humic substance also yields oil on distillation. The percentage of oil content in the Fushun oil shale may depend upon the amount of humic substance in the shale. That is, the percentage of oil content increases with the amount of humic substance in it, indicating a close relation between them, as is shown in the following table and Figure 6. The measurement of fragments of humic substance is by vertical lineal method(38) in thin section which had been made perpendicular to the bedding plane of oil shale.

Sample nos.	Humic substance in %	Oil in %
1	9.6	4.88
2	8.0	4.80
3	5.4	9.02
4	18.7	15.33
5	15.4	11.93
6	10.0	9.01
7	9.2	6.42
8	6.6	5.60
9	8.5	4.29
10	10.4	6.51
11	11.2	8.78

As is indicated in Figure 6, humic substance in the oil shale roughly shows in proportion to the amount of oil. Therefore, humic substance may be considered as one of the indicators for prospecting the rich oil shale at the Fushun colliery.

Resins are also found in disseminated globules, or in spherical forms through the rock, showing a range from about 0.2 millimeter up to 4 millimeters in diameter. Generally speaking, in thin section perpendicular to bedding plane, the resins are found in rounded, lenticular forms under the microscope, as is shown in Figures 57 and 59, and occasionally they occurs in folded structure. Most resins embedded in the coaly shales and coal seams, are spherical or ellipsoid in form like grains of globules of dark brownish colour. Under the microscope, the resins in the oil shale are translucent, yellowish brown in colour, dark between crossed nicols. Microscopic minute globules of resins are covered by other bituminous matrices, therefore, it is difficult to dis-

(38) ELLIS THOMPSON: Quantitative Microscopic analysis. Jour. Geol., Vol. 38, No. 3, 1930.

tinguish a resin by form, colour, and other optical properties, but it is easily distinguished by a microchemical process. The microscopic structures of spherical resins, are, more or less, heterogeneous in texture, showing aggregated structure of scroll work or cloudy form with irregular inclusions, such as minute coaly fragments, or patches of grains of quartz, or siderite, as is shown in Figures 58 and 60. As the resin occurs geologically irregularly in the oil shale, it can not be

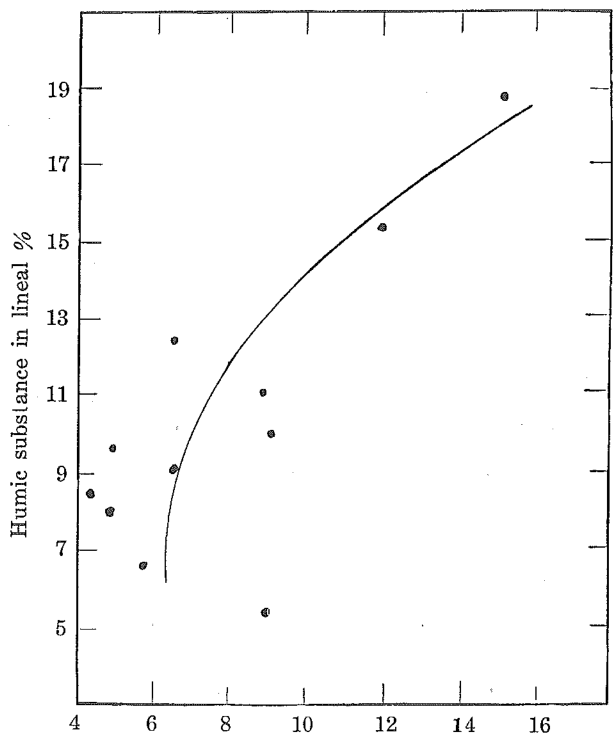

Fig. 6. Oil content in %

considered as one of the indicators for prospecting the rich oil shale at the Fushun colliery, although it is one of the bitumens that yields oil on distillations.

Cutin derived from epidermus of plants, is also one of the stable bitumens which are recognized abundantly as spores and pollens in the oil shales from Ohio, Kentucky, Scotland, and other countries. The Fushun oil shale also contains spores and pollens which are the fossil bitumens derived from epidermus, but they are very rarely found. Under the microscope in thin section perpendicular to bedding plane, spores are generally found in elongated and lenticular form of 0.3 millimeter diameter in the Fushun oil shale. They are yellowin colour, dark between crossed nicols. Cutin is usually recognized, microchemically, by mezeration method of Schulzes solution, and it comes out floating on other substances in the oil shale. Cutin may be regarded also a negligible indicator for prospecting the rich oil shale at the Fushun oil shale colliery, because it may be stated that there is so small amount of cutin that there could not be found any relation between the amount of cutin and the oil content in the Fushun oil shale, although cutin is also one of the important bitumens that will yield oil on distillation.

Suberin derived from the cork of plants, is also mentioned as being met with in the oil shale, but in the Fushun oil shale it can not be recognized microscopically nor microchemically in thin section under the microscope. These bitumens, such as cutin and suberin above mentioned, are, however, important substances on yielding oil on distillation. They are rather negligible in the Fushun oil shale.

Wax is prepared from bitumen extracted, as Montan wax, from Thuringian lignite in Germany, as is mentioned by Lewkowitsch and Warburton.[39] But it is difficult to distinguish it petrographically in thin section under the microscope. In studying the Fushun oil shale, it is also very difficult to distinguish it from other solid bitumens, such as humic substance, resins, and cutin. But by microchemical process, the present writer has distinguished a certain kind of bituminous substance which may be a solid bitumen different from those bitumens of humic substance, resins, and cutin, above mentioned. This bitumen may be a waxy substance which will yield oil on distillation. The products of extraction from the Fushun oil shale on distillation dominate in amount of paraffin[40] which is one of the essential constituents of hydrocarbon compounds of the Fushun shale oil, which usually is derived from the waxy substances. Such substances, which may be met with in the Fushun oil shale, occur as matrix filling up the space between minerals and other solid organic substances. They show, in thin section, light brownish and yellowish brown colour, but are colourless to grayish white after mezeratian by microchemical methods. They are dark between crossed nicols. Their refractive index is lower than that of

(39) LEWKOWITSCH and WARBURTON: Chemical technology of oils, fats, and waxes. London, 1923.

(40) N. TANAKA: Chemical costituents of the Fushun shale oil. Rept. Central Experimental Works, South Manchurian Railway Co., Series 10, Rept. 13, p. 629, 1925. (Japanese)

Canada balsam. This substance is not affected by acids. After treatment by acua regia, and a mixture of hydrofluoric acid and concentrated sulphuric acid, the mineral matters in the thin section under the microscope are observed to be all dissolved, and only the stable bitumens, such as humic substance, resins, cutin, and waxy substance remain to be seen under the microscope. Of these many kinds of bitumens remaining in the thin section, waxy substance is most abundant with light grayish white colour. This waxy substance is not determined, quantitatively, in thin section under the microscope. Therefore, the present writer can not state any definite relation between the amount of waxy substance and the percentage of oil extracted from the Fushun oil shale on distillation, although it yields aboundant of oil on distillation.

3. MICROCHEMICAL EXAMINATION OF OIL SHALE

Microchemical examination of the Fushun oil shale has been made, being based on the methods of Potonié,[41] Behrens-Kley,[42] Schneider,[43] Walton,[44] Schulzes,[45] Ohara,[46] Emich,[47] Stach,[48] Seitz-Gothan,[49] Kräusel,[50] Anderson,[51] Lomax.[52]

(a) Determination of mineral matters by mezeration methods

(1) MINERALS SOLUBLE IN AQUA REGIA

Of those mineral matters found in the thin section of the Fushun oil shale under the microscope, such as siderite, quartz, marcasite,

(41) R. POTONIÉ: Der Mikrochemische Nachweis fossiler kutinisierter und verholzter Zellwände. Jahrb. Preuss. Geol. Landesanstalt, Bd. 41, Teil 1, 1920.
(42) BEHRENS-KLEY: Mikrochemische Analyse. Leipzig, 1921.
(43) H. SCHNEIDER: Die botanische Microtechnik. Jena, 1922.
(44) J. WALTON: On a new method of investigating fossil plant impressions or incrustations. Ann. of Bot., Vol. 37, 1923.
(45) P. SCHULZES: Der Nachweis und die Verbreitung des Chitins. Zeitschr. f. Morphol. u. Oekol. d. Tiere, Bd. 2, 1924.
(46) K. OHARA: Ueber die Mikrochemie der Lignit. Brounkohle, Nr. 37, 1925.
(47) FRIEDRICH EMICH: Lehrbuch der Mikrochemie. München, 1926.
(48) ERICH STACH: Kohlen-petrographisches Praktikum. Sammulung naturwissenschaftlicher Praktika, Bd. 14, 1928.
(49) SEITZ und GOTHAN: Paläeontologisches Praktikum. Berlin, 1928.
(50) RICHARD KRÄUSEL: Die Paläeobotanischen Untersuchungsmethoden. Jena, 1929.
(51) D. B. ANDERSON: Ueber die Struktur der Kohlenchymzellenwand auf Grund mikrochemischer Untersuchungen. Planzenphysiologischen Institut der Universität Wien. Nr. 268 der 3 Folge, 1927.
(52) J. LOMAX: The microstructure of a coal seam. Fuel Research Board Technical Paper. No. 11, Department of Scientific and Industrial Research, London, 1925.

felspars, and free carbon, the grains of siderite and microglobules of marcasite, are both dissolved in aqua regia at normal temperature, but quartz, felspars, free carbon, and stable bituminous substances, remain undissolved to be seen under the microscope.

In determination of the microminerals in the oil shale, the procedure is as follows: the Canada balsam in the thin section is dissolved in xyrol and then the section is washed with a mixture of equal volume of alcohol (96%) and benzol at their boiling points to separate the bituminous substance such as some of the resins soluble in them. After treatment with xyrol and a mixture of alcohol and benzol, the preparate of the oil shale is put carefully in aqua regia for 24 hours to take out the mineral matters, such as siderite and marcasite. There after, the preparate should be well washed with running cold water for 24 hours. The section is fixed in glycerin on an objective glass. During the procedure above mentioned, some of the unstable bitumens are oxydized as oxybitumen, and some are dissolved. Minerals soluble in aqua regia, are also dissolved. Under the microscope, minerals such as quartz, felspars, and free carbon, and stable bitumens such as humic substance, waxy substances, some resins, and cutin, still remain undissolved and visible to be seen.

(2) Minerals Soluble in a Mixture of Hydrofluoric Acid and Concentrated Sulphuric Acid

The thin section of the oil shale which had been treated by aqua regia mezeration above mentioned, is placed in a platinum crucible, and the mixed solution, of hydrofluoric acid and concentrated sulphuric acid is carefully poured into it. The crucible is then placed on a water bath for 24 hours to remove the silica and silicates in the preparate. After treating with acids, the preparate should be again washed very carefully continuously with cold running water for about 40 hours. And then the section is fixed with glycerin on an objective glass. By these treatments above described, all minerals except some small fragments of free carbon, are dissolved. The stable bituminous substances, such as only reddish brown humic substance, yellowish and coreless resins, and yellowish or brownish cutin, are observed under the microscope. Other unstable and soluble bituminous substances and mineral matters did not remain to be seen.

(3) Determination of Free Carbon

After treatments of mezeration methods above mentioned, the preparate is seen under the microscope to contain only small fragments of free carbon as mineral matter. For determining of these black substances as the fragments of free carbon, the preparate is then placed carefully in Schulzes solution (a mixture of 20 parts of nitric acid of 1.16 in density and 3 parts of potassium chloric acid). If the black fragments in the thin section were graphite, it is oxidized and converted into a yellowish transparent scaly substance called graphitic acid. This distinguished graphite from amorphous free carbon. But the fragments still remain black in colour, therefore, these small fragments are amorphous free carbon.

(b) Extraction of Bituminous Substances by Solvents

The bituminous substances, such as oily matters in the Fushun oil shale, are extracted by benzol and a mixture of alcohol and benzol. The apparatus of extraction of bitumens at any temperature is shown in Figure 7, which is prepared by the present writer.

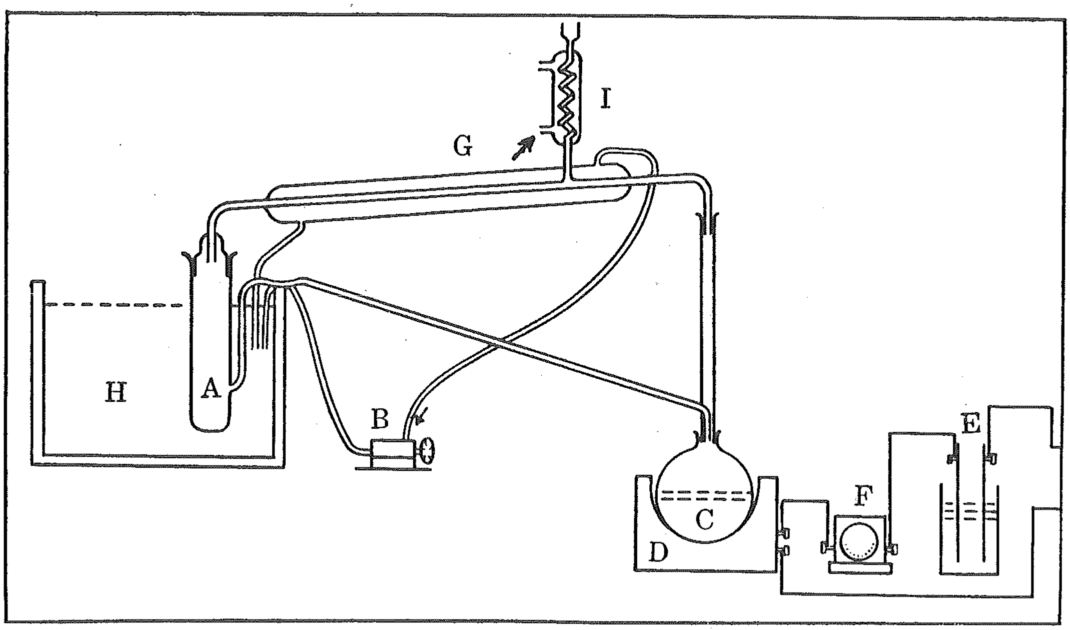

Fig. 7. A Sample
B Pump
C Solvent
D Electric heater
E Resistance box
F Ampere meter
G Condenser
H Thermostat
I Condenser

Benzol or a mixture of alcohol and benzol, are used for solvents to extract bituminous substances in the oil shale. 10 grams of sample powdered less than 170 in mesh, is weighed into a cylindrical paper filter and is placed in A. The extraction is commenced at the normal temperature and finished at the boiling point of the solvents. The amount of bitumens extracted by the solvent at the temperature of every ten degrees in Centigrade, is weighed. Thus, the oily substances are extracted by benzol, as is shown in an accummulative curve in Figure 8, some kinds of resins and other bituminous substances are also extracted by a mixture of equal quantities of benzol and alcohol (96%), as is also shown in an accummulative curve in Figure 8. One may see that the amount of bitumens extracted by benzol is much smaller than that of the substance extracted by a mixture of alcohol and benzol.

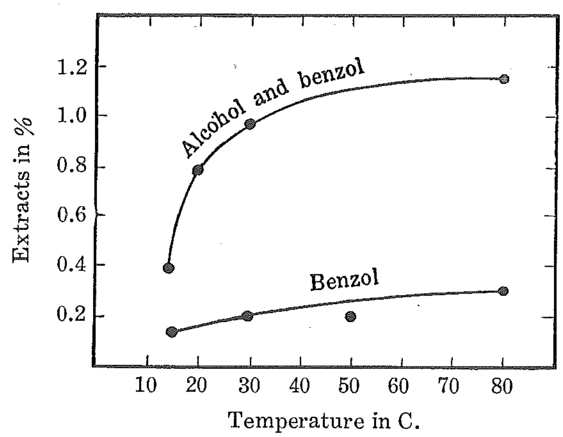

Fig. 8. Accumulative curves of extracts by solvents.

If the oil shale is treated with alcohol only, the amount of extraction is about 0.590 in percent. That is, the amount of both alcohol-extracted and benzol-extracted bitumens is much smaller in percent than that of the bitumens extracted by a mixture of alcohol and benzol. This may depend upon the difference between the dissolving agencies above mentioned. After these treatments with the solvents, the stable bitumens called kerogen or Gestein-bitumen remain.

(c) Determination of Bitumens by Mezeration Methods

(1) Schulzes Mezeration

Of those stable bitumens observed in the Fushun oil shale, such a bitumen as cutin derived from epidermus, is not dissolved in Schulzes' solution, and it remains as spore in the preparate. A thin section parallel to the plane of sedimentation is placed in xyrol to remove Canada balsam, and then the preparate is replaced carefully for 24 hours in Schulzes' solution of a mixture of 20 parts nitric acid of 1.16 density and 3 parts of potassium chloric acid. Then the preparate is fixed in glycerin on the objective glass for examination under the microscope. It is found that the thin section treated by Schulzes' mezeration contains only silica and silicate minerals of quartz, felspars, and a small amount of fragments of free carbon. The grains of carbonate mineral of siderite and sulphide mineral of marcasite, are all dissolved into solution. The bituminous matter like humic substance which are abundant in the Fushun oil shale, are also removed and there remain only stable bitumens like cutin and waxy substances. Generally speaking, cutin, like spore and pollen, is very small in quantity. The present writer, rarely, found only one mezeration product which may be spore and pollen in the Fushun oil shale, as are shown in Figures 62, 63, and 64. Thus, the bitumen as spore and pollen derived from epidermus are very scantily found in the Fushun oil shale, although they are observed abundantly in the Kentucky, Scotland, and Posidonian oil shales under the microscope.

(2) Diaphanol Mezeration

The method of diaphanol mezeration is used to determine cutin, suberin, and cellulose in the oil shale. The preparate is washed with xyrol to remove Canada balsam as above described, and is placed it in diaphanol (chlordioxydessigsäure) in a glass bottle in the sunshine for about two weeks. During that time the section alters its colour from dark to light. After about two weeks in the sunshine, the preparate is very carefully washed with cold running water for two days. Then it is fixed in glycerin on an objective glass. Of these mineral matters found in thin section of the Fushun oil shale, the minute grains of siderite and microglobules of marcasite, which are dominantly observed embedded in the preparate, are all dissolved away in diaphanol by mezeration, and are not to be seen under the microscope. Silica, silicate minerals, and free carbon only are found. Those bitumens which remained in the preparate, are grayish white in colour but partly are brownish yellow in colour. If those bitumens were, even partly, cellulose they would alter to violet or dark violet by the colour reaction method with chlotinjod, but since they still maintain the original colour, they are not cellulose. These brownish yellow substances are cutin which alters to violet by Gentiana violet.

(d) Determination of Bitumen by Colour Reaction Methods

(1) DETERMINATION OF CUTIN

Cutin derived from epidermus, is a very stable bitumen left as spore and pollen in the sedimentary bituminous rocks. After treatment of a thin section of the oil shale by the diaphanol mezeration method, the preparate is then coloured with Sudan III. If the thin section contains cuticulous bitumens such as spore and pollen, they alter to reddish-brown in colour with grade of bituminization of the epidermus. But cuticulous bitumen is very rarely found in the Fushun oil shale.

(2) DETERMINATION OF SUBERIN AND CHITIN

A similar method, as in the case of determination of cutin, is used for the determination of suberin derived from cork, but it is not found in the Fushun oil shale.

Chitin, which is a stable bitumen derived from the animal plankton, is also proved by the colour reaction of Lichtgrün S. after diaphanol mezeration, but it was difficult to determine it in the Fushun oil shale although there is a small amount of nitrogen (0.14 to 0.84 in per cent) in the Fushun oil shale, which may have been derived from chitin of animal plankton in the fresh water. But on the other hand, nitrogen in the oil shale may have been derived from the protein of vegetable matters.

(3) DETERMINATION OF CELLULOSE

For determination of cellulose in the Fushun oil shale, a similar method of diaphanol mezeration, as in the case of cutin, is used in this case. The preparate is washed with cold running water after mezeration, and is coloured with chlotinjod to find out cellulose, showing usually violet colour, but it is not found in the Fushun oil shale.

(4) Determination of Resins

Resins and resinates, which are found in the thin section after treatment with a mixture of alcohol (96%) and benzol at their boiling points, are insoluble proving them to be stable fossil resins and resinates in the Fushun oil shale.

The preparate of the oil shale is placed in xyrol to remove Canada balsam. Thereafter, the thin section is carefully wrapped with thin filter paper and placed continuously for 24 hours in A in Figure 7 to remove some of the resins and resinates soluble in a mixture of alcohol (96%) and benzol at their boiling points. The preparate is then placed in aqua regia, and then in a mixture of hydrochloric acid and concentrated sulphric acid for 24 hours to remove mineral matters in the thin section. There remain only minute fragments of free carbon in the preparate under the microscope. The preparate is washed very carefully with cold running water for about 24 hours to remove acids. The preparate is then again placed in Schulzes' solution and diaphanol to remove humic substance, after which it is again washed very carefully with cold running water for more than 24 hours to remove acid solution. In this case, the acid solution should be completely removed in water, because it bleaches the colour of reagents which will come next for colour reaction.

Then, one piece of the preparate is treated with alcoholic solution of Sudan III, and the other piece, with alcoholic solution of Gentiana violet, to determine the bitumens remaining in the thin section. All bitumens left in the thin section, are coloured reddish brown by Sudan III. But some of the bitumens are not coloured violet by Gentiana violet, and still retain their original yellowish or light brownish-yellow colour. These bitumens of yellowish or light brownish-yellow colour, are resins and resinates which are some of the stable bitumens in the Fushun oil shale. These resins and resinates occur in lenticular and elongated forms parallel to the plane of sedimentation, with a range from 0.1 millimeter to 4 millimeters in diameter. To check these yellowish bitumens, a thin section of a piece of megascopic resins found in the Fushun coal seam, is treated by the same procedure as above outlined. The same result of the examination is obtained to prove that these yellowish bitumens are truly resins or resinates.

(5) Determination of Waxy Substance

Wax and waxy substance, which are derived from vegetable matters, are occasionally found in the Tertiary coal such as Montan wax in the Brown coal in Germany. A certain bitumen with light grayish white colour which may be one kind of waxy substance, is found in thin section of the Fushun oil shale under the microscope after microchemical treatment. The preparate of the oil shale is treated with xyrol to remove Canada balsam, and then with a mixture of alcohol and benzol, and also with tetralin, to remove some bitumens in the oil shale. The preparate is next treated by mezeration methods of aqua regia, a mixed solution of hydrofluoric acid and concentrated sulphuric acid, Schulzes' solution, and diaphanol, to remove mineral matters and bitumen, such as humic substance. After these procedures, the section is washed very carefully with cold running water. The preparate still contains bitumen of yellowish or light-brownish yellow colour. These yellowish bitumens are mostly resins or resinates as above mentioned, but the grayish white substance is certain kind of bitumen which is coloured reddish brown with Sudan III, and violet with Gentiana violet. This substance is dark in polarized light, and is irregular in forms like the cementing matter between minerals and bitumens. It is insoluble in alcohol, in benzol, in a mixture of benzol and alcohol, and in tetralin, at their boiling points, and is not also affected by aqua regia, a mixture of hydrofluoric acid and concentrated sulphuric acid, Schulzes' solution, or diaphanol. It was coloured with Sudan III and Gentiana violet to be proved as bitumens which are most dominantly found in the Fushun oil shale. But the substance is not such a bitumen as cutin, suberin, chitin, cellulose, lignin, resins, humic substance, or solid oily substance, as above mentioned. Therefore, it may be some kind of waxy substance which is usually found as vegetable wax in the Tertiary coal. It is also one of the striking characters that the shale oil extracted from the Fushun oil shale on distillation, is abundantly dominated by the amount of paraffin which is usually derived from waxy substances.

4. Microchemical Examination of Kabary

Kabary occurs in the upper part of the coal seam at the western part of the Fushun coal field. It varies from thin beds up to 2.5 meters in thickness. Kabary is macroscopically very compact in texture. Black in colour. Streak, dark brownish-black. Luster, submetallic to resinous. It is used only for making domestic wares. Chemically, it is dominant in volatile matters, as is shown in the following table privately communicated by Shigeru Yabe, a Geologist of the Geological Survey of the South Manchurian Railway Company:

	Wt. %
Moisture	3.39
Volatile matter	53.10
Fixed carbon	35.01
Ash	8.48
Sulphur	0.828
Calorific value	7370 in B. T. U.
Specific gravity	1.250

Under the microscope, Kabary contains a small amount of minute grains of quartz and microglobules of maroasite disseminated through the rock.

Organic substances, which are met with in the Kabary, are mostly humic substances of reddish-brown colour, and also carbonaceous matters of black colour. Resinous substances of yellowish and yellowish-brown colour, are also found in spherical or lenticular, and elongated forms parallel to the plane of sedimentation. Microspores are occasionally found in elongated form parallel to the plane of sedimentation.

However, Kabary, macroscopically, resembles a cannel coal or boghead coal, microscopically, it is a Pseudocannel coal which is a mixture of "Glanzkohle" and "Mattkohle." The microchemical examination of the Kabary was carried out with the same process as above described in the case of the oil shale. The result of the examination proves that the Kabary contains also the same bituminous substances as those of the oil shale, such as resins, humic substances, cutin, and waxy substances. Of those bitumens, the resins, humic substances, and waxy matters are mostly dominantly found in the Kabary, which are also abundantly found in the Fushun oil shale. Therefore, the present writer may state that the bitumens in the Kabary are similar to those of the Fushun oil shale.

5. Microchemical Examination of Vitrit

Vitrit of Fushun coal seam, which is usually derived from a fundamental substance such as humic substance, is examined in thin section under the microscope. This is mostly composed of humic substance with reddish brown colour, and also a small amount of resins and microspores are met with. Microchemical examination of the thin section of vitrit of the Fushun coal, which was carried on with the same procedure as in the case of the oil shale and Kabary, also proves that it contains abundance of humic substance, and a small amount of resins, cutin, and waxy substance, which are the same bitumens as those in the oil shale and Kabary above mentioned.

6. Microthermal Examination of Oil Shale

To observe microscopically the dissociation phenomena of bitumens of the oil shale, several small fragments are heated in an open tube of hard glass in an electric combustion furnace, filled with carbon dioxide to protect the oxidation of bitumens on heating. The fragments are heated from normal temperature and gradually raised to 550 degrees in Centigrade which is the ultimate temperature on dry distillation. During the thermal examination in carbon dioxide, a slight white yellowish fume comes out of the tube at 250 degrees, and it slowly increases with the temperature, at 400 degrees, it reaches its maximum, and then it gradually decreases until at 550 degrees the fume ceases to come out. This white yellowish fume is a vapour of oil to be condensed to oil on cooling. Several thin sections are prepared from the fragments and examined under the microscope.

The thin section of the fragments heated to 250 degrees Centigrade, showed, in general, darker colour through the slice than that of the fresh specimen. Humic substance of reddish brown colour, which are dominant in the preparate, became deep red in colour. Humic substance and resins, still kept their original forms, being never deformed by heat. The thin section of the fragment heated to 350 degree Centigrade, showed, in general, darker colour through the slice compared with that of the former slice heated to 250 degrees. Humic substance became more dark in colour, the matrix which may be dominant in waxy substances, became also dark in colour. The thin section of the fragment heated to 400 degrees Centigrade with maximum evaporation of volatile matters, showed generally a blackish-brown colour. All bitumens altered to carbonaceous matters with blackish-brown colour. But they still maintained the original forms. The thin section of the fragments heated to 550 degrees, showed black colour through the slice. All bitumens, such as humic substance and those in matrix, altered completely to amorphous black carbon, but they never were deformed by heat, keeping their original form.

According to the result of the microthermal experiment on the oil shale, it may be stated that the bitumens embedded in the oil shale, partly yield gaseous matters which may be condensed to oil on cooling and partly remain as fixed carbon with ash, and they never are deformed from their original forms on heating.

7. Nature of the Bitumens of the Fushun Oil Shale

The result of the petrographical examination of oil shale, Kabary, and vitrit from the Fushun coal field, is summarized as follows:

Humic substance is mostly found in vitrit and Kabary, and more or less, in smaller amount in oil shale.

Resins are dominant in Kabary, and not so much in vitrit and oil shale.

Cutin is found in a very small quantity in oil shale, but is occasionally found in Kabary and vitrit.

Waxy substances are mostly met with in oil shale and Kabary, but to a small amount in vitrit.

Other bituminous substances, such as cellulose, chitin, and suberin, are found in negligible amounts in oil shale, Kabary, and vitrit from the Fushun coal field.

We may say that the bitumens which are found in oil shale, Kabary, and vitrit from the Fushun coal field, are petrographically the same substances under the microscope.

Mineral matter such as minute grains of siderite is abundantly found only in the ordinary Fushun oil shale and is never met with in the most rich oil shale, Kabary, and vitrit of the Fushun coal field.

Micro-globules of marcasite are found in oil shale and Kabary but not in vitrit.

Silica and silicate minerals, which compose the matrices of oil shale, are also found in the Fushun oil shale, but are seen in very small amount in Kabary and vitrit.

D. Classification of the Fushun Oil Shale

The Fushun oil shale, generally speaking, occurs in masses with uniform texture and colour. But there is a great variation in petrographical and chemical properties with the geological occurrence of the oil shale. The present writer has classified the oil shale into four classes from the standpoint of petrographical characters and the amount of oil content as follows: (1) the most rich oil shale, (2) the medium rich oil shale, (3) the poor oil shale, (4) the siderite bed.

1. THE MOST RICH OIL SHALE

Macroscopical characters.

The most rich oil shale yields oil from 10 to 15 in percent on distillation. The fresh hand specimen of the oil shale is slightly brownish black or black in colour with streak of dark brown. On weathering it still maintains grayish black or black colour and never alters to brown or reddish brown like other poor oil shales. Therefore, one can easily differentiate the most rich from the poor oil shale by the colour of the weathered surface of the oil shale outcropping at the Fushun oil shale colliery. Particularly, at the outcrop of the fault line, the most rich oil shale still shows black colour with greasy luster on the slicken sides of the blocks of the fault breccia and it never changes its original black colour to reddish brown on weathering, while with the poor oil shale its original dark chocolate colour weathers to reddish brown by oxidation of iron compounds. It certainly depends upon the large content of the iron compounds such as siderite and marcasite in the poor oil shale. But the rich oil shale contains too small amount of iron compounds to change its colour from black to reddish brown by oxidation, and also contains much of the bituminous substances which serve to protect the iron compounds from oxidation on weathering. Bituminous substances, which are macroscopically recognized on the fresh surface of the most rich oil shale, are such as coaly substance that is called vitrit derived from humic substance. Coaly fragments are, generally speaking, lenticular in form, with a range from one millimeter to three or four millimeters in diameter, black in colour, and in luster, submetallic to resinous. Coaly fragments which are recognized in the poor oil shale developed immediately above the coal seam, are, generally, derived from woody tissue, while those in the most rich oil shale, are mostly derived from humic substances which are dominantly found microscopically in a thin section of the most rich oil shale.

Spherical grains of resins are also occasionally observed in the most rich oil shale, with a range from one millimeter to two millimeters in diameter. The fresh surface shows angular faces with brownish colour. Luster, resinous. Brittle. Translucent in transmitted light. They are also rich in the coaly shale interbedded in the coal seam.

Of those mineral matters, such as siderite, quartz, felspars, and iron sulphide, embedded in the most rich oil shale, iron sulphide, such as marcasite, are macroscopically recognized in aggregates.

The most rich Fushun oil shale is rather smaller than other poor oil shale in density. It ranges from 1.800 to 1.932. Generally, it may be recognized that the oil shale decreases in density with the increase of oil in content.

The tenacity of the oil shale could not be recognized as an indicator for prospecting the rich oil shale, because the Fushun oil shale occurs in compact masses and never shows any bedding platy parting. But there may be some quantitative results of the tenacity of the oil shale as an indicator of the rich oil shale, if the specimens were examined as an artificial plate. The rich oil shale may be more flexible than the poor oil shale from the stress of the pressure as shown in the examination of the platy rich oil shale from Scotland. But the present writer has no quantitative data of that quality of the Fushun oil shale.

The curling structure, on clipping the oil shale with a piece of glass, shows also, generally speaking, the content of oil in the rock. The most rich Fushun oil shale also curls on clipping with a piece of glass, while the poor oil shale never curls and falls to powder. The edge of a piece of glass plays the role of curling the oil shale better than that of a knife. The surface of the rich oil shale scratched by a piece of glass, is resinous in luster, while that of the poor oil shale is earth dull.

Microscopical characters.

The most rich oil shale contains a large amount of humic substance and waxy substances which cement the spaces between minerals and other organic substances as matrices, from which oil may be extracted on distillation. Mineral matters are small in quantity, particularly, the minute crystal grains of siderite are very seldom to be seen. Rough angular grains of quartz and micro-globules of marcasite, are, generally, met with in less amount than in the poor oil shale. The oil shale which developed immediately below the green shale, is also a very rich oil shale which is composed mainly of humic substance and waxy substances, as is shown in Figure 54, yielding more than 13 percent oil. In thin section of the most rich oil shale perpendicular to the bedding plane, a large amount of fragments of humic substance are to be seen arranged parallel to the plane of sedimentation, as is shown in Figure 52. It is also a characteristic feature that the crystal grains of siderite embedded in the rich oil shale are much smaller than those of the siderite beds. The former grains show about 0.01 millimeter in diameter, while the later grains show about twice that.

a. Iron Compounds, as the Secondary Minerals on the Weathered Surface of the Most Rich Fushun Oil Shale

Ferrous sulphide, ferrous sulphate, and basic ferric sulphate, are to be seen on the weathered surface of the most rich oil shale exposed at the colliery. Particularly on a fine hot dry day after wet weather, one can easily recognize the white or gray rock which is coated with these secondary minerals, as is shown in Plates IV and V. But on a wet day these minerals disappear dissolved in water.

Iron sulphide is observed, as one of the secondary minerals coating the surface of the most rich oil shale. This mineral is observed only on the weathered surface of the most rich oil shale at the colliery. Therefore, this is one of the most prominent reading minerals for prospecting of the rich oil shale. The coating mineral is black in colour, submetallic to dull. It has a range from 0.5 millimeter to one millimeter in thickness, as is shown in Figure 55. The thickness of the coating mineral becomes great during the weathering. It is ferrous sulphide in chemical composition, therefore, it is a secondary product which has altered from iron disulphide like marcasite to ferrous sulphide by oxidation on weathering of the rich oil shale. The chemical reaction may occur slowly in the atmosphere as the oxidation of iron disulphide to ferrous sulphide as follows:

$$Fe\,S_2 + O_2 = Fe\,S + SO_2$$

Iron sulphate is also one of the secondary minerals coming next to iron sulphide on the surface of the most rich oil shale. This is produced from iron sulphide on weathering. It is in the form of a fine minute needle crystal of iron sulphate, about one centimeter in length. In addition to this, there is also found a minute short prismatic crystal, with more or less faint yellowish brown colour, on the weathered surface of the most rich Fushun oil shale. Of these two secondary minerals, the needle crystal may be ferrous sulphate which might have been altered from ferrous sulphide on weathering as follows:

$$FeS + 2O_2 = FeSO_4$$

The other short prismatic mineral may be basic ferric sulphate which might have been altered from ferrous sulphate on weathering as follows:

$$4FeSO_4 + O_2 + 2H_2O = 4Fe(OH)SO_4$$

The optical properties of these secondary minerals are described in the following pages.

Ferrous sulphate is found usually in acicular crystals about one-fifth millimeter to four millimeters in length. Cleavage, imperfect. Colour, slight differing shades of green. Pleochroism none. It contains inclusions such as gases showing well defined short or elongated elliptical cavity, arranged parallel to the long axis as is shown in Figure 9. Optically, biaxial and positive.

$\alpha'=1.473$, $\beta'=1.476$, $\gamma'=1.482$, by immersion method. $c' \wedge z'=40°$.

The indices of refraction are given as follows :

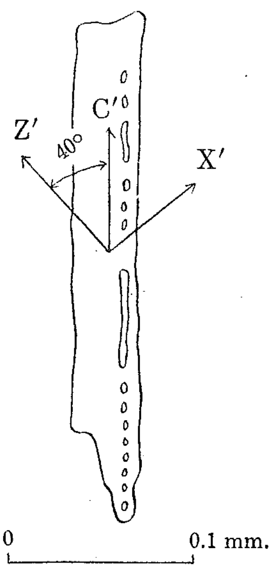

Fig. 9. Crystal of ferrous sulphate.

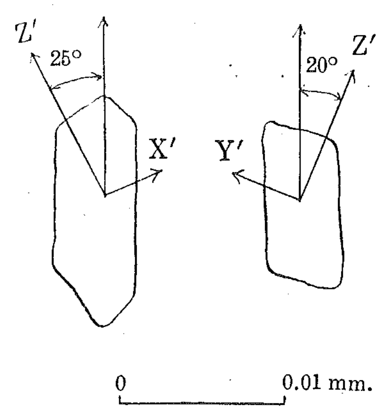

Fig. 10. Crystals of basic ferric sulphate.

I		II		III	
α	1·471	α'	1.473	α'	1.472
β	1.478	β'	1.476	—	
γ	1.486	γ'	1.482	γ'	1.482

I. Melanterite, after N. H. and A. N. Winchell.[(53)]

II. Ferrous sulphate on the weathered surface of the most rich Fushun oil shale.

III. Ferrous sulphate ($FeSO_4.7H_2O$) of Merk's chemical reagent.

As above mentioned, this ferrous sulphate from Fushun oil shale field may be "melanterite".

Basic ferric sulphate is usually found in well defined minute short prismatic crystals. Crystals are about 0.01 millimeter in length, as is shown in Figure 10. Cleavage, imperfect. Pleochroism, faint. X'= light brownish yellow, Y'=pale yellow, Z'=light greenish yellow. Absorption, $Z'>X'>Y'$. Inclusion, rare. Optical character, indistinct. $\alpha'=1.525\pm3$, $\beta'=1.547\pm3$, $\gamma'=1.569\pm1$, by immersion method.

The known minerals of basic ferric sulphates having analogous indices of refraction, are as follows:

	I	II	III	IV	V
α	1.531±3	1.506~1.540	1.527	{1.525 {1.533	1.526
β	1.546±3	1.528~1.550	1.547	{1.540 {1.534	1.532
γ	1.597±3	1.575~1.600	1.572	{1.565 {1.575	1.583
System	Orthorhombic	Orthorhombic	Monoclinic	Orthorhombic ?	

I. Copiapite ($2Fe_2O_3 . 5SO_317H_2O$) of artificial crystal.[(54)]

II. Copiapite ($2Fe_2O_3 . 5SO_318H_2O$).[(55)]

III. Copiapite ($2Fe_2O_3 . 5SO_318H_2O$).[(56)]

IV. Fibroferrite ($Fe_2O_3 . 2SO_310H_2O$).[(57)]

V. Castanite ? ($Fe_2O_3 . 2SO_38H_2O$?).[(58)]

(53) N. H. and A. N. WINCHELL: Elements of optical mineralogy. Part III, 1929, p. 125.

(54) E. POSNJAK and H. E. MERWIN: Jour. Amer. Chem. Soc., Vol. 44, 1922, p. 1979.

(55) N. H. and A. N. WINCHELL: Elements of optical mineralogy. Part II, 1927, p. 109.

(56) E. S. DANA: Text-book of mineralogy. 1926, p. 638.

(57) E. POSNJAK and H. E. MERWIN: ibid., p. 1977.

(58) E. POSNJAK and H. E. MERWIN: ibid., p. 1977.

As are above mentioned, it will be considered that the mineral is nearly similar to copiapite or fibroferrite. But the system of this mineral is to be considered as monoclinic or even triclinic from its opitical properties. A further study is required to obtain detailed results.

These minerals, such as ferrous sulphide, ferrous sulphate, and basic ferric sulphate, above mentioned, are very important characteristic products of the most rich oil shale, being considered an indicators of the rich oil shale at the Fushun oil shale colliery.

2. The Medium Rich Oil Shale

This is an oil shale which yields from 6 to 10 percent oil on distillation, and is an economically valuable shale for extracting oil. The colour of the fresh hand specimen is slightly brownish black. Streak, grayish brown. On weathering the shale alters slightly grayish white in colour but is never brown like other poor oil shales. This grayish white colour is also dependent upon the secondary oxidizing products of iron compounds as those of the most rich oil shale as above mentioned. The slicken-side of the blocks at the fault zone is also never altered to reddish brown in colour by the secondary iron oxide derived from iron carbonate and iron sulphide which are dominant through the rock. But it still maintains its original grayish black colour, which is certainly due to the large content of bituminous substances which protect the iron compound from oxidation. The coaly fragments which are often observed in the most rich oil shale as above mentioned, are also very rarely met with. These coaly fragments are vitritic material derived from humic substance, like those in the most rich oil shale. The resinous substance is macroscopically absent in the rock. The weathering products, which are recognized abundantly on the surface of the most rich oil shale exposed at the colliery, are never recognized on the surface of the medium oil shale. But the grayish white coloured coating substance is observed. This may be the same material as those which are recognized on the surface of the most rich oil shale, although it is a very thin coating. However, this white grayish coating on the surface of the medium rich oil shale is also one of the importart indications for prospecting the medium rich oil shale, while ferrous sulphide, ferrous sulphate, and basic ferric sulphate are the indicators of the most rich oil shale. The density of the medium oil shale varies from 1.851 to 2.277. As above mentioned, the density of the oil shale, generally speaking, depends upon the content of oil in the shale, that is, the smaller in density, the more rich in the content of oil in the shale. On clipping of the medium rich oil shale with the edge of a piece of glass, the product does not curl like that of the most rich oil shale as already described, but rather it becomes powder. This depends upon the content of oil in the shale. The luster of the surface of the medium oil shale scratched by a piece of glass, is, more or less, resinous in reflected light, but never bright as that of the most rich oil shale. The tenacity of the medium oil shale is never so highly regarded as to be used for determination of the medium rich oil shale, because the oil shale is not so rich content of oil.

Finally, the present writer would add a few statements on the difference between the macroscopic characters of the most rich and medium rich oil shales at the Fushun colliery, The macroscopic physical characters of these oil shales are different, but one can easily differentiate the most rich oil shale from the medium rich oil shale by the secondary weathering products on the surface of the shale outcrop in the atmosphere. The most rich oil shale has a thick and heavy coating of iron compounds on the surface exposed in the atmosphere, while the medium rich oil shale shows only a very thin grayish white coating on its surface.

The mineral components and bituminous substances, which are met with in the medium rich oil shale, are generally similar to those of the most rich oil shale above described. But those materials are different in quantity compared with those of the most rich oil shale. Minerals, such as siderite, quartz, felspars, marcasite, are more largely found in the medium rich oil shale than in the most rich oil shale. Particularly, micro-crystal grains of siderite are very small in quantity in the most rich oil shale.

3. The Poor Oil Shale

The poor oil shale, which contains less oil than 6 percent, is dark brown or chocolate in colour. Streak, grayish brown. The texture of the shale is also fine grained and compact, but, more or less, coarser than that of the rich oil shale. Coaly fragments are also occasionally observed in the poor oil shale. Some of them are of the same materials as those fragments of the rich oil shale, which are vitritic coal derived from humic substance. Lenticular fragments are found megascopically parallel to the plane of sedimentation. But some fragments of coaly substances of the poor oil shale are derived from wood tissue, as is shown in Figure 47. The poor oil shale which developed immediately above the coal seam, contains a large amount of fragments of wood tissue. Resinous substances are not recognized in this poor oil shale. The weathering products, such as coating of iron compounds on the surface of the most rich oil shale, are never recognized on the surface of the poor oil shale. But reddish brown iron oxide is observed on the surface of the shale as the oxidation product of iron carbonate which is dominant in the poor oil shale. Particularly on the slicken-sides of the blocks of the fault breccia exposed at the surface, the iron minerals alter to iron oxide with reddish brown colour. This reddish brown colour of iron oxide on the weathering surface of the shale, is one of the most important indicators of the poor oil shale which generally contains less than 6 percent of oil. Density of the poor oil shale is generally larger than that of the rich oil shale, showing a range from 1.880 to 2.696. The curling product on clipping of the poor oil shale with a piece of glass, shows the content of oil in the shale. In the case of the poor Fushun oil shale, the clipping product is powder instead of a curl as that of the rich oil shale, that is, the poor oil shale is rather brittle, because of containing much mineral matters. The luster of the scratched surface of the poor oil shale is earthy to dull, while that of the rich oil shale is resinous. The tenacity of the poor oil shale is useless, because it is so poor in oil that the flexibility is neglegible for determing the grade of oil content. Mineral components, which are met with in the poor oil shale, are abundantly dominant in minute grains of siderite. Other mineral matters, such as quartz, felspars, and marcasite, are also recognized in the oil shale. Of those bituminous substances which are recognized in the poor Fushun oil shale, vitrit is, more or less, dominant. But, generally speaking, the bituminous substances are very small in quantity in the poor oil shale, as is shown in Figure 50.

4. The Siderite Bed

Siderite is, generally speaking, found in extremely minute crystal grains disseminated uniformly through the most of the Fushun oil shales. It occurs also in crystalline aggregates, in crystalline nodules, being embedded in the coaly shale which is interbedded with the coal seam at the Fushun colliery. Siderite exists also in massive crystalline beds alternating with the oil shale.

It is a striking character that the most rich oil shale, particularly the oil shale which developed immediately below the green shale, is almost scanty in siderite, although it is commonly contained through the most of the Fushun oil shales. The present writer may state, concerning the occurrence of siderite, that the amount of siderite in the oil shale will represent definitely the grade of oil content of the Fushun oil shale. That is, siderite increases with the decrease of oil content of the oil shale, and finally it passes into the siderite bed which is composed of grains of siderite with very small amount of other minerals and organic matters. These siderite beds occur alternating with oil shale beds and showing an evidence of cycle of sedimentation of them. Siderite beds range from several millimeters to more than ten centimeters in thickness, showing light brown in colour with extremely fine grained compact texture,

Under the microscope, the rock is composed of extremely minute grains of crystals of siderite ranging from 0.001 millimeter to 0.04 millimeter in diameter, as is shown in Figure 51. However, many large nodules of siderite embedded in the coaly shale which interbedded with coal seam, consist of large grains of crystals showing radial aggregates of Rhombs of carbonate with a range from 0.02 millimeter to 0.31 millimeter in diameter, as is shown in Figure 48. Each crystal grain of siderite is so minute that it is impossible to determine its optical character accurately.

The chemical analysis of the siderite bed, which was made by A. Kannari, at the Department of Geology and Mineralogy, Faculty of Science, Hokkaido Imperial University, shows also the characteristic of the siderite bed as follows:

	Wt. %
SiO_2	8.60
TiO_2	0.24
Al_2O_3	....
Fe_2O_3	11.87
FeO	47.90
MnO	0.59
MgO	0.68
CaO	0.50
Na_2O	0.63
K_2O	0.42
CO_2	25.60
Ig. loss	2.80
Total	99.83

E. Macroscopical Inclusions Embedded in the Oil Shale

1. Black Phosphorous Nodule

Curious nodules are found in the oil shale at the colliery of the western part of the field. They occur, generally, in the poor or medium oil shales near the coal seam. But the microscopical nodule is also found in the rich oil shale. The macroscopical large nodule in the oil shale occurs in elongated or spherical lenticular forms, showing a range from one centimeter to 25 centimeters. Inside of the nodule, there is included a black spherical core with vitreous luster. Hardness of the core is about from 4 to 5. It occasionally contains something like the remains of animal skelton. The interior structure of the nodule is shown in Figure 49. Part (a), core of the nodule, is spherical in form. Compact but brittle. Fracture, concoidal. Colour, black. Luster, waxy to dull. Streak, brown. Specific gravity, 2.138. Hardness, 4 to 5. Opaque, but in thin section yellowish brown in colour by transmitted light. Dark between crossed nicols. It effervesces with hydrochloric acid. Under the microscope, minute crystal grains of calcite are seen to have filled up the cavities in the core, showing yellowish brown colour. Minute crystals of siderite and marcasite are also found disseminated through the core.

The chemical analysis of the core (part a) which was made at the Geological Survey of South Manchurian Railway Company, is cited here from S. Yabe,[59] as follows:

	Wt. %
Moisture	0.960
Volatile matter	8.270
Fixed carbon	1.350
Ash	90.645
Sulphur	0.707
Total	101.932

The chemical analysis of the ash of the core (part a), above mentioned, is also given in the following table by S. Yabe.

(59) S. Yabe: Geology of the Fushun coal field. Manchuria Geological and Mining Review, No. 64, 1923. (Japanese)

	Wt. %
SiO_2	1.020
Al_2O_3	44.729
Fe_2O_3	trace
MnO	0.728
CaO	9.320
MgO	0.408
P_2O_5	32.549
Na_2O	0.552
K_2O	0.188
Total	89.494

As is shown in the above table, the percentage of phosphoric acid is prominant.

Part (b), the outer zone of the core as shown in Figure 49, is dull in luster. Colour, dark grayish brown. Hardness, about 4. The chemical analysis of this zone is cited from S. Yabe, as follows:

	Wt. %
Moisture	1.470
Volatile matter	3.520
Fixed carbon	1.090
Ash	75.920
Sulphur	0.977
Phosphate	0.205
Total	83.182

Under the microscope, this part contains a great many micronodules of marcasite, covering the outside of the core, and filling up the cavities in the core.

Part (c), the outer side of the nodule in Figure 49, is occupied by the ordinary oil shale with fine grained compact texture. Luster, dull. Colour, blackish brown. Streak, brown. Specific gravity, 2.452. Hardness, from 2 to 3.

Under the microscope, minute crystals of siderite with a range from 0.005 millimeter to 0.2 millimeter in diameter, are found abundantly in minute disseminated grains through the rock. The elongated form of vitritic coal which is derived from humic substance, are observed being parallel to the plane of sedimentation. The fragment shows reddish brown in colour. The bituminous substance cementing the spaces between the grains of minerals and the fragments of vitritic substances, are also observed as of yellowish colour. The micro-nodules of marcasite and the fragments of crystals of quartz and felspars are also found in small disseminated grains through the rock.

The chemical analysis of a specimen of part (c) has also been made by S. Yabe at the Geological Survey of the South Manchurian Railway Company, as follows:

	Wt. %
Moisture	2.270
Volatile matter	24.160
Fixed carbon	3.070
Ash	69.700
Sulphur	1.386
Phoshoric acid	0.147
Total	100.733

There occur also some nodules in which a porous grayish substance like the remains of animal skeleton is contained. The remains of skeleton in thin section is yellowish brown in colour in transmitted light, and crystalline in polarized light. Double refraction rather weak, while index of refraction is high. Parallel extinction to the long axis

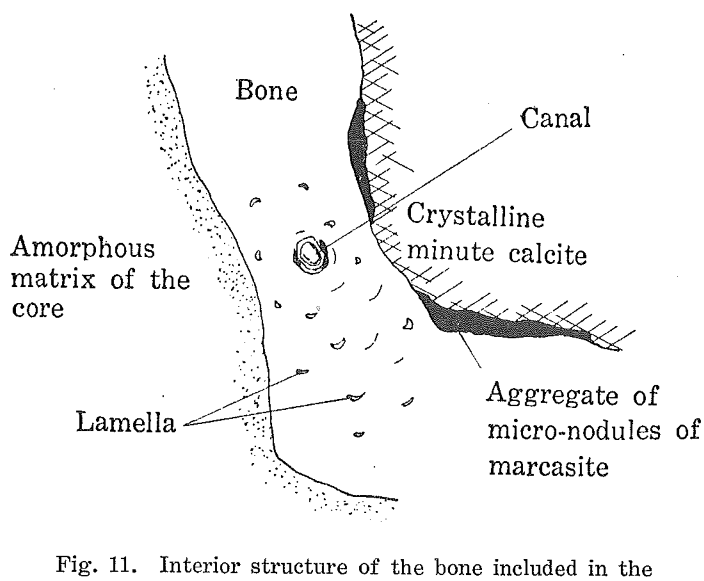

Fig. 11. Interior structure of the bone included in the black phosphorous nodule in the Fushun oil shale. Magnified 265 diameters.

of the skeleton is also recognized. This may be dependent upon the optical properties of secondary minerals which have metasomatically replaced the bone with calici-phosphoratic minerals. Some part of the bone which is included in the core, shows Havers's lamella and canal of interior structure of bone as is depicted in Figure 11.

These curious phosphorous nodules in the oil shale, may not be considered as one of the indications for prospecting of the rich oil shale at the Fushun colliery, because there is not any relation between the oil shale and its geological occurrence.

2. Coaly Fragments

Coaly fragments are often recognized in the oil shale with the naked eyes, although microscopic minute fragments derived from humic substance are also found embedded in the oil shale. They are black in colour with metallic luster. Brittle like other pieces of vitrit of the black coal. They occur throughout all kinds of the Fushun oil shales. But, generally, the coaly fragments embedded in the rich oil shale are smaller in size than those of the poor oil shale. The large fragments of coal might have been derived from wood tissue or pieces of Graminaceous plant with irregular outline of several centimeters in length. The small coaly fragments less than one millimeter in length, are elongated and lenticular in form. They are all vitritic coal which has been derived from humic substance.

The poor oil shale developed immediately above the coal seam, contains abundant fragments of coaly substances. These found embedded in the rich oil shale, are, as already mentioned, lenticular and spherical in form, parallel to the plane of sedimentation. Thin section vertical to the plane of sedimentation of the oil shale is shown in Figure 56. The coaly fragments therein are all reddish brown in colour in transmitted light under the microscope, while those fragments derived from wood tissue are black to opaque under the microscope. These coaly substances of vitrit derived from humic substances yield oil on distillation of the oil shale. They are all dark between crossed nicols. Generally, it may be said that the coaly fragments which are observed megascopically embedded in the poor oil shale, may have been derived from the wood tissue, and that those embedded in the rich oil shale may have been derived from humic substance. Microstructure of vitrit embedded in the oil shale, shows heterogeneous in texture like aggregates of minute globules of humic substance ranging from 0.005 millimeter to 0.02 millimeter in diameter. The oil content of the rich oil shale increases with the amount of vitritic coal fragments contained. Therefore, there is a close relation between the content of oil and the content of coaly fragments derived from humic substance which is one of the most prominent bitumens in the oil shale, from which oil will be extracted on distillation. In this respect, coaly fragments like vitrit are indicators for prospecting of the rich oil shales at the Fushun colliery.

3. Globules of Resins

Resinous substances, like amber, are often found in the coal seam at Fushun. Such are used for making of smoking pipes and other small pieces of hand work. They may be several centimeters in maximum diameter. But the resinous substance is rarely found in the oil shale, particularly, large grains as those found in the coal seam, are never found in the oil shale, although microscopic minute grains of resinous substance are often found in the oil shale. Generally, it is elongated and spherical in form as shown in Figures 57 and 59. Fracture, concoidal. Luster, resinous. Hardness, 2 to 2.5 Colour, brown. Translucent with yellowish brown colour in transmitted light. Dark between crossed nicols. Minute inclusions such as angular grains of quartz and remains of organic matters are observed under the microscope. Microstructure of the resinous substance is rather heterogeneous, showing aggregate structure of scroll work or cloudy form with inclusions above mentioned, as shown in Figure 58 and Figure 60. Resinous substance is never considered to be an indicator of the rich oil shale, although it is one of the bitumens in the oil shale, from which oil will be yielded on distillation, because the geological occurrence of resins has not yet been definitely considered.

F. General Chemical Characters of the Fushun Oil Shale

1. Chemical Analysis of Oil Shale

The amount of oil extracted from the Fushun oil shale on distillation varies from 0.27 to 15.33 in percent, with an average of about 6. The oil content of the oil shale shows a close relation to the geological occurrence of the shale. The following Table I shows the result of the chemical analysis of the Fushun oil shale made by the present writer. The specimens were sampled continuously with spacing mentioned in the table. 300 grams of the specimen of the oil shale (4 to 8 in mesh), were placed in a retort of 520 c.c. capacity to be distilled on a gas burner.

TABLE I

Sample No.	Spacing between samples in cm.	Distillation analysis, %				Volatilization analysis, %			N. %
		Oil	Water	Residue	Gas & loss of ignition	Volatiles without water	Fixed carbon	Ash	
1	0	4.88	5.33	85.33	4.46	14.67	10.00	75.33	0.603
2	30	4.80	6.66	83.03	5.51	16.97	8.22	74.71	0.505
3	10	9.02	4.33	80.63	6.02	19.37	8.96	71.94	0.624
4	44	15.33	5.00	74.66	5.00	25.34	14.84	59.82	0.848
5	40	11.93	2.80	81.18	4.09	18.82	14.87	66.31	0.729
6	28	9.01	5.00	81.90	4.08	18.10	11.46	70.44	0.519
7	30	6.42	6.00	83.66	4.91	16.34	8.24	75.42	0.433
8	26	5.60	5.00	84.23	5.17	15.77	8.71	75.52	0.377
9	58	4.29	6.66	84.33	4.92	15.67	9.13	75.20	0.383
10	46	6.51	5.66	83.00	4.83	17.00	9.49	73.51	0.504
11	54	8.73	6.66	79.43	3.18	20.59	9.44	69.99	0.626

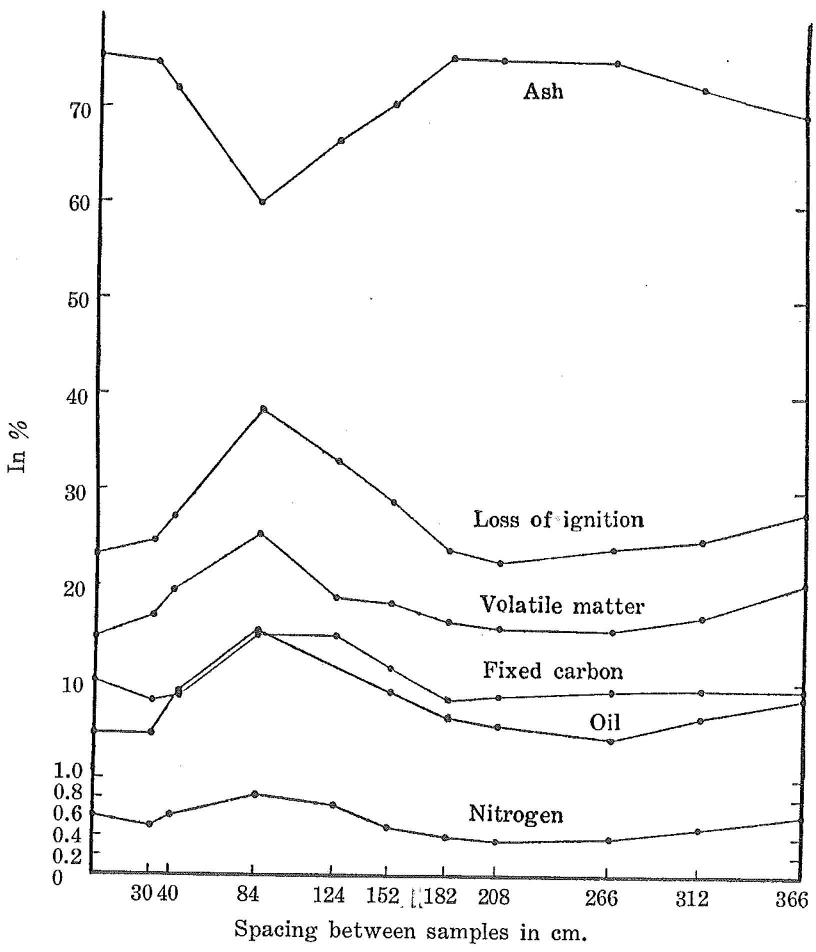

Figure 12.

A chart, Figure 12, was drawn, on which were plotted points representing the relation: percent composition of the oil shales to the spacing between samples. It is a striking character that there exists a close relation between the amount of extraction from the oil shale sample and its geological occurrence as is shown in Figure 12.

2. Chemical Analysis of Ash

Ash of the Fushun oil shale has been analysed by many chemists, showing the variation from 69.09 to 84.61 in percent, with an average 77.80. Chemical constituents of the ash of the oil shale vary with the mode of geological occurrence of the oil shale. The following table shows the result of analysis of ash of the Fushun oil shales.

	I	II	III		
	Wt. %	Wt. %	Variation Wt. %		Average Wt. %
SiO_2	59.70	61.18	66.27	57.86	62.47
TiO_2	0.30	....	....	....	....
Al_2O_3	19.20	24.65	25.13	18.66	22.08
Fe_2O_3	14.10	10.19	16.59	7.90	10.64
MnO	0.30	0.37	....	....	....
MgO	1.60	0.67	1.87	0.41	1.65
CaO	1.50	1.27	2.31	0.99	1.26
Na_2O	0.09	0.16	....	....	....
K_2O	0.53	0.49	....	....	....
P_2O_5	0.64	....	....	....	....
SO_3	....	1.01	....	....	....
Ig. loss	1.50	....	....	....	....
Total	99.46	99.99			

In the above tables of the chemical analysis of the Fushun oil shales, No. I shows the result of analysis by A. Kannari, of the Department of Geology and Mineralogy, Faculty of Science, Hokkaido Imperial University, against the poor oil shale sampled at the Fushun colliery by the present writer, No. II, by Kurihara and Uyehara,(60) and No. III, by S. Midzuuchi, against 49 samples of ash of the Fushun oil shale.(61)

(60) K. Kurihara and K. Uyehara: A study of the Fushun oil shale. Jour. Fuel Society of Japan, Vol. 2. No. 8, 1923. (Japanese)

(61) S. Midzuuchi: Chemical analysis of the residue of the Fushun oil shale. Central Experimental Works of South Manchurian Railway Company, Report 13, Series 10, 1925. (Japanese)

3. Relation of Oil Content to Water Content

Relation between oil and water both extracted from the Fushun oil shale on distillation has been already studied by T. Kimura, S. Midzuuchi, and T. Itoh.[62] They have already stated that there is no definite relation between them. The present writer has been given the new data of the results of chemical analysis of the Fushun oil shale by K. Imidzu.[63] The present writer has drawn a chart, Figure 13, on which were plotted about four hundred points representing the relation between oil content and water content. But there is not any definite relation between them. The water content of the Fushun oil shale varies from 2.3 to 9.5 percent, with an average of 5.39 percent.

4. Relation of Oil Content to Residue

Residue of the Fushun oil shale on distillation is also large in content. The result of the chemical analysis which had been made by K. Imidzu,[63] was given to the present writer. A chart, Figure 14, was drawn by the present writer, on which were plotted about four hundred points representing the relation between oil content and residue. Generally speaking, as is drawn in Figure 14, residue increases in percent with the decrease of oil content. The residue varies from 78.25 to 92.80 in percent, with an average of 86.32 percent.

5. Relation of Oil Content to Ash Content

Ash content of the Fushun oil shale is also large in percent. T. Kimura[62] and K. Kurihara[60] have also mentioned the large amount of ash of the Fushun oil shale. The relation between oil content and ash content is, generally, stated that oil content increases with the decrease of ash content. A chart, Figure 15, drawn by the present writer, on which were plotted about four hundred points based upon the results of the chemical analysis by K. Imidzu,[63] shows also the general relation between oil content and ash content of the Fushun oil shale. The ash content varies from 69.09 to 84.61 in percent, with an average 77.80 percent.

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(60) K. Kurihara (see p. 162).

(62) T. Kimura, S. Mizuuchi, and T. Itoh: A study of the Fushun oil shale. Central Experimental Works of South Manchurian Railway Company, Report 6, Series 10, 1923. (Japanese)

(63) K. Imidzu: Chemical analysis of the Fushun oil shale. Private Mimeograph paper No. 2, 1929. (Japanese)

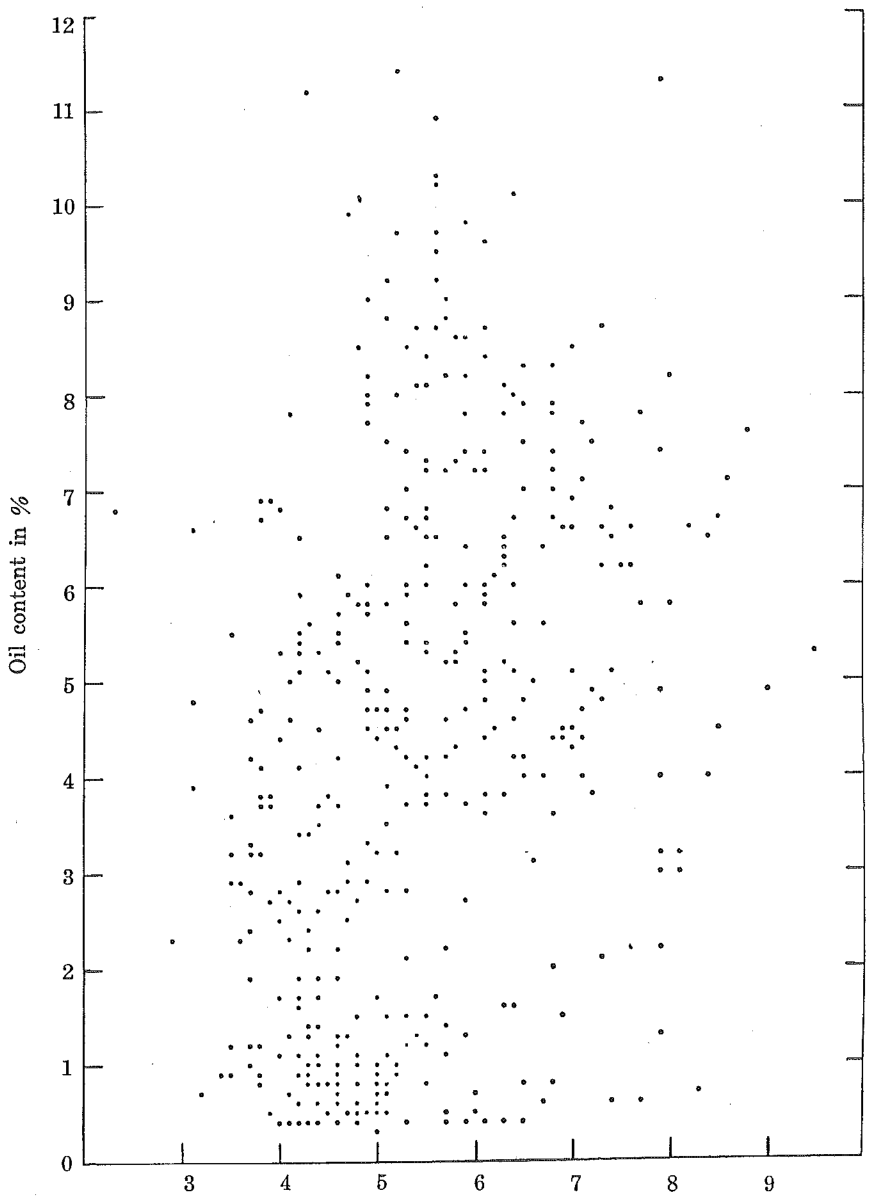

Fig. 13. Water in %

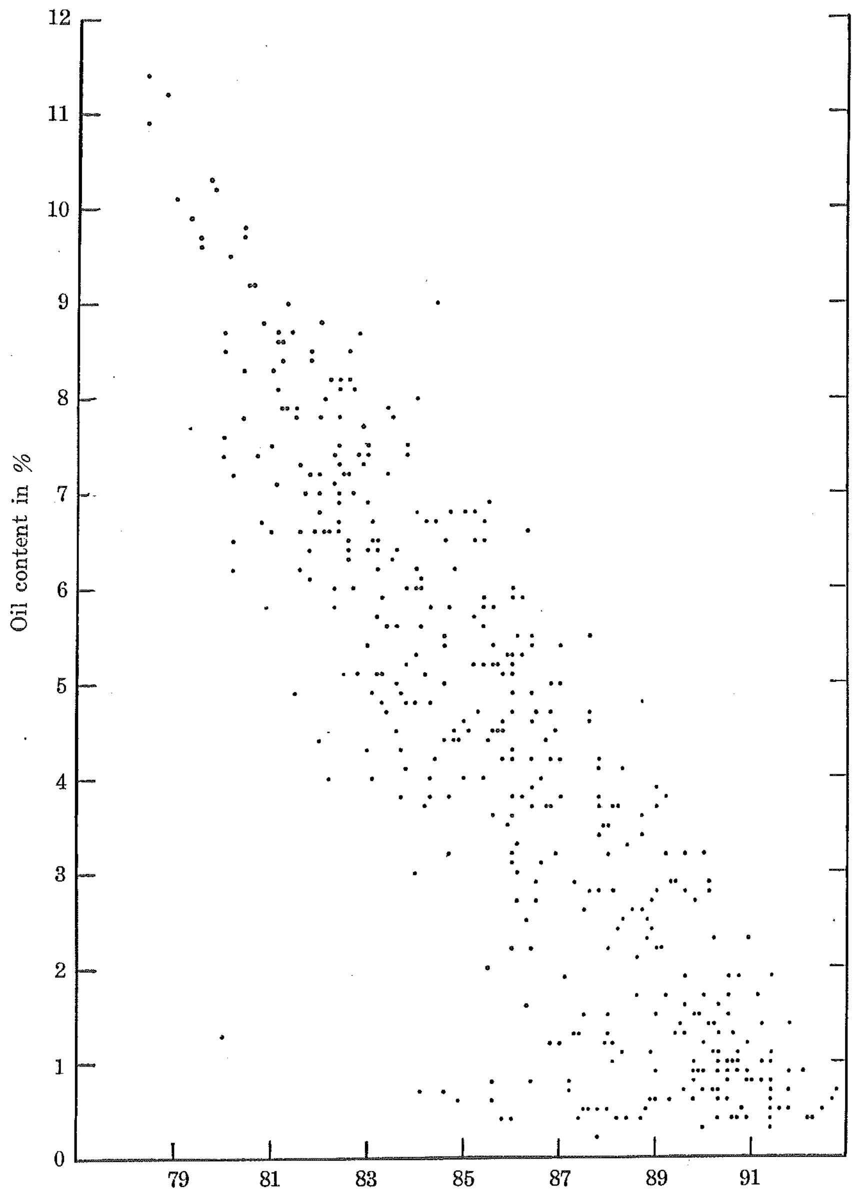

Fig. 14. Residue in %

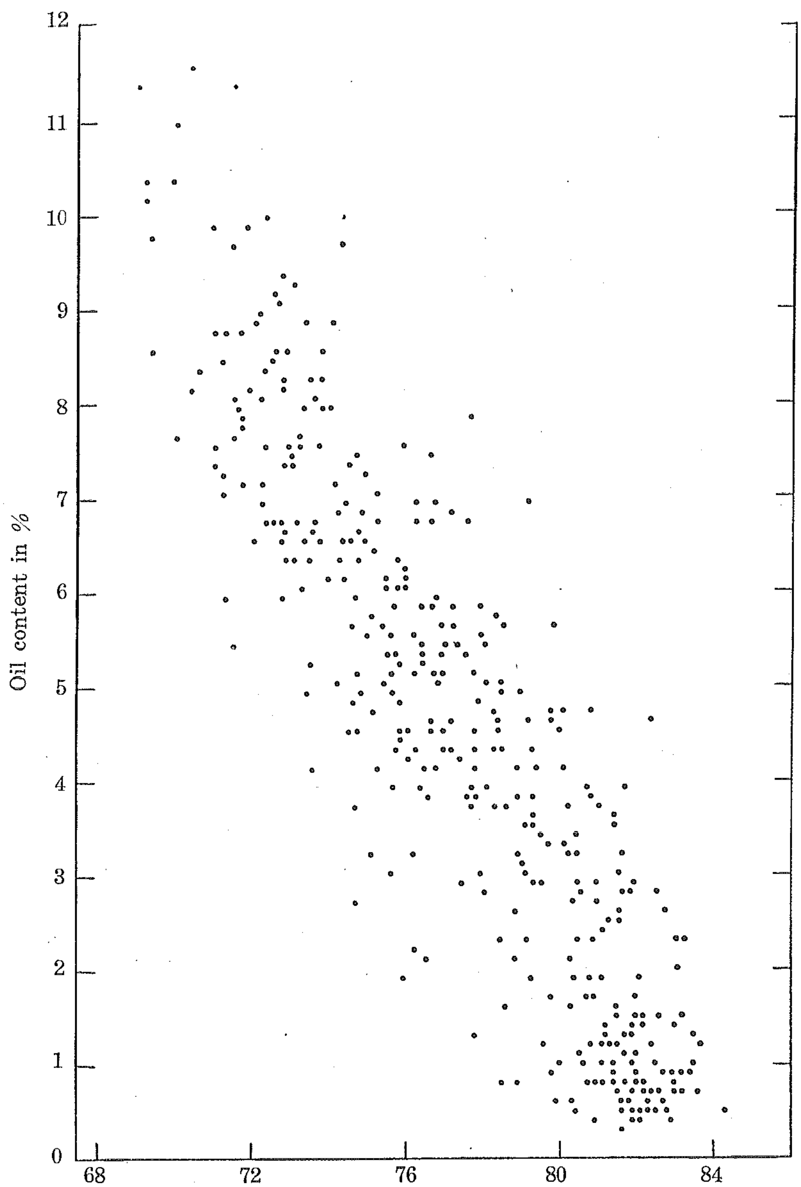

Fig. 15. Ash in %

6. Relation of Oil Content to Volatile Matter

Volatile matter of the Fushun oil shale is not very large in content, showing a variation from about 11 percent to 29.5 percent, with an average 17.28 percent, as is mentioned by T. Kimura.(62) But, generally speaking, volatile matter matter increases with the increase of oil content in percent. The present writer has also examined the volatilization analysis of the Fushun oil shale by Standard method,(64) and may state that the volatiles increase with the increase of oil content in percent as is shown in Figure 12.

7. Relation of Oil Content to Fixed Carbon

Fixed carbon has also been estimated previously by T. Kimura(62) and K. Kurihara.(60) The former observer has stated that fixed carbon varies very roughly with the increase of oil content. The present writer also has examined the volatiles of the Fushun oil shale by Standard method.(64) A chart, Figure 12 was drawn, which shows, generally, that fixed carbon is proportional to oil in content, The fixed carbon varies from 1.77 to 13.24 in percent, with an average 3.96 percent.

8. Relation of Oil Content to Loss of Ignition of Residue

Loss of ignition of residue left after distillation, is mainly dependent upon the content of free carbon. This is, however, not the true content of fixed carbon of the oil shale. Relation between oil content and loss of ignition of residue is also discussed by T. Kimura,(62) showing an indefinite relation between them. The present writer also may state that there is no definite relation between them, considering the result which has been offered by K. Imidzu.(63) A chart Figure 16, drawn by the present writer, on which were plotted about four hundred points, represents an irregular relation between oil content and content of loss of ignition of residue. The loss of ignition of residue varies from 2.13 to 14.80 in percent, with an average 8.55 percent.

9. Relation of Oil Content to Nitrogen Content

Nitrogen is one of the important constituents of the Fushun oil shale used to produce nitrogenous manure as a byproduct of the oil

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(60) K. Kurihara and K. Uyehara (see p. 162).
(62) T. Kimura, S. Mizuuchi and T. Itoh (see p. 163).
(63) K. Imidzu (see p. 163).
(64) Jour. Ind. and Eng. Chem., Vol. 9, No. 1, 1917.

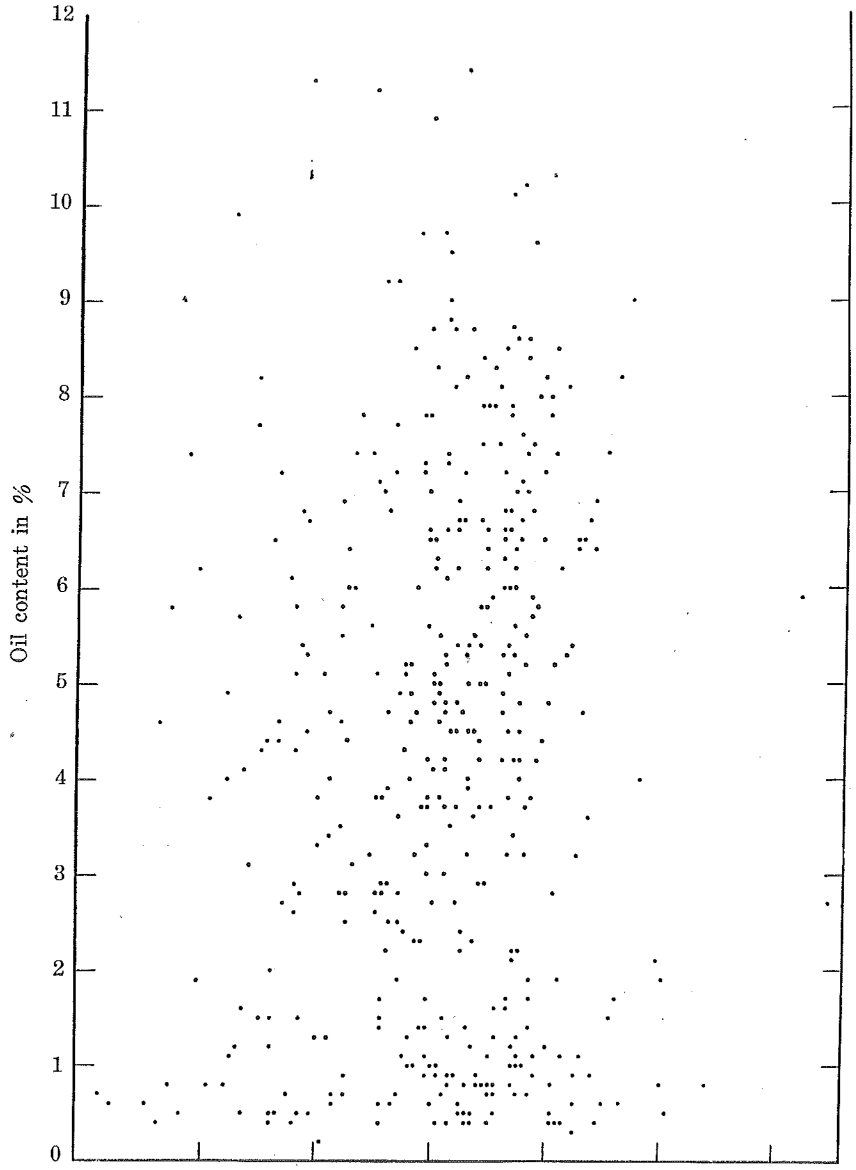

Fig. 16. (Residue—ash) in %

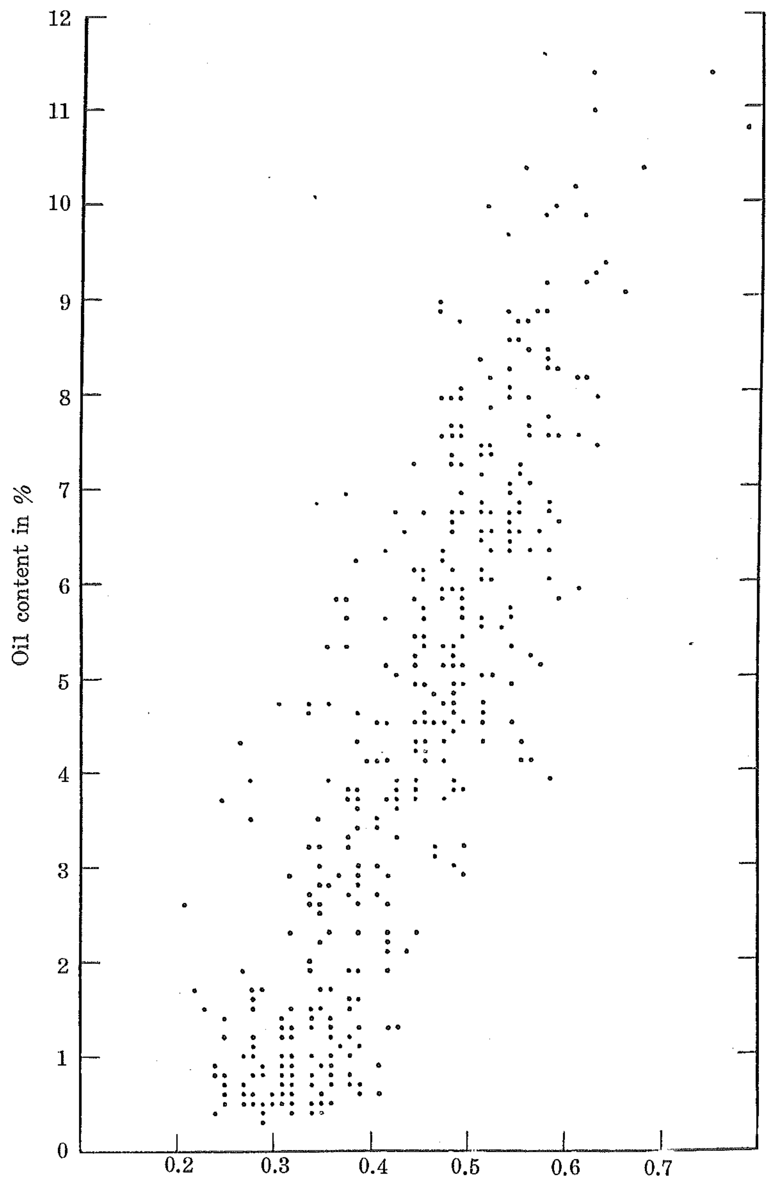

Fig. 17. Nitrogen in %

shale works. The Fushun oil shale and coal, generally speaking, show a large content of nitrogen in percent, representing a variation from 0.21 percent to 0.74 percent, with an average of 0.436 percent. The result of the chemical analysis of the Fushun oil shale which has been made by K. Imidzu,(63) shows a close relation between oil content and nitrogen content. A chart, Figure 17, drawn by the present writer, on which were plotted about four hundred points based upon the result of determination of nitrogen of the Fushun oil shale by K. Imidzu, shows that the oil content increases with the increase of nitrogen content in percent. The chart, Figure 12 shows also the result of the determination of nitrogen by the Kjeldahl's method,(65) which had been carried out by the present writer, representing also a close relation between oil content and nitrogen content. That is, nitrogen content increases with the increase of oil content.

10. Relation of Oil Content to Specific Gravity

The specific gravity of oil shale, generally speaking, decreases with the increase of oil content. This is also an important physical property of oil shale for determining its grade in the field. The specific gravity of the Fushun oil shale is generally large compared with that of typical oil shale from Utah, Colorado, Scotland, and Estonia. A number of chemists and geologists have examined the specific gravity of the Fushun oil shale. The specific gravity varies from 1.80 to 2.68, with an average 2.17. A chart Figure 18, drawn by the present writer, on which were plotted more one hundred points following the results of examination of the Fushun oil shale by T. Kimura(62) shows a close relation between oil content and the specific gravity, representing the increase of oil content with the decrease of specific gravity.

11. Relation of Ash Content to Specific Gravity

Generally considered, the specific gravity of oil shale has a close relation to ash content as it has to oil content. The specific gravity of oil shale increases, generally, with the increase of ash content. Figure 19, drawn by the present writer, on which were plotted more than one hundred points, represents a relation between the specific gravity of

(62) T. Kimura, S. Mizuuchi and T. Itoh (see p. 163).
(63) K. Imidzu (see p. 163).
(65) Jour. Chem. Soc., Vol. 67, 1895.

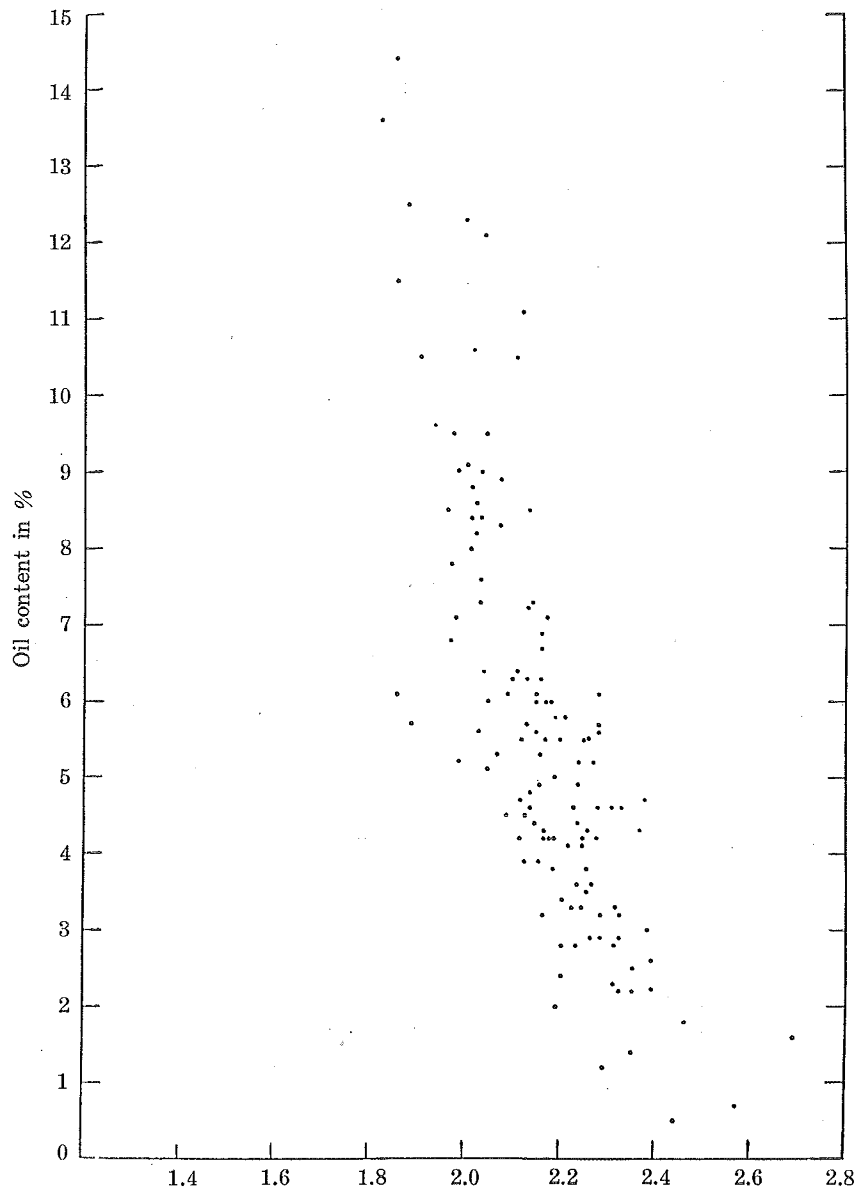

Fig. 18. Specific gravity.

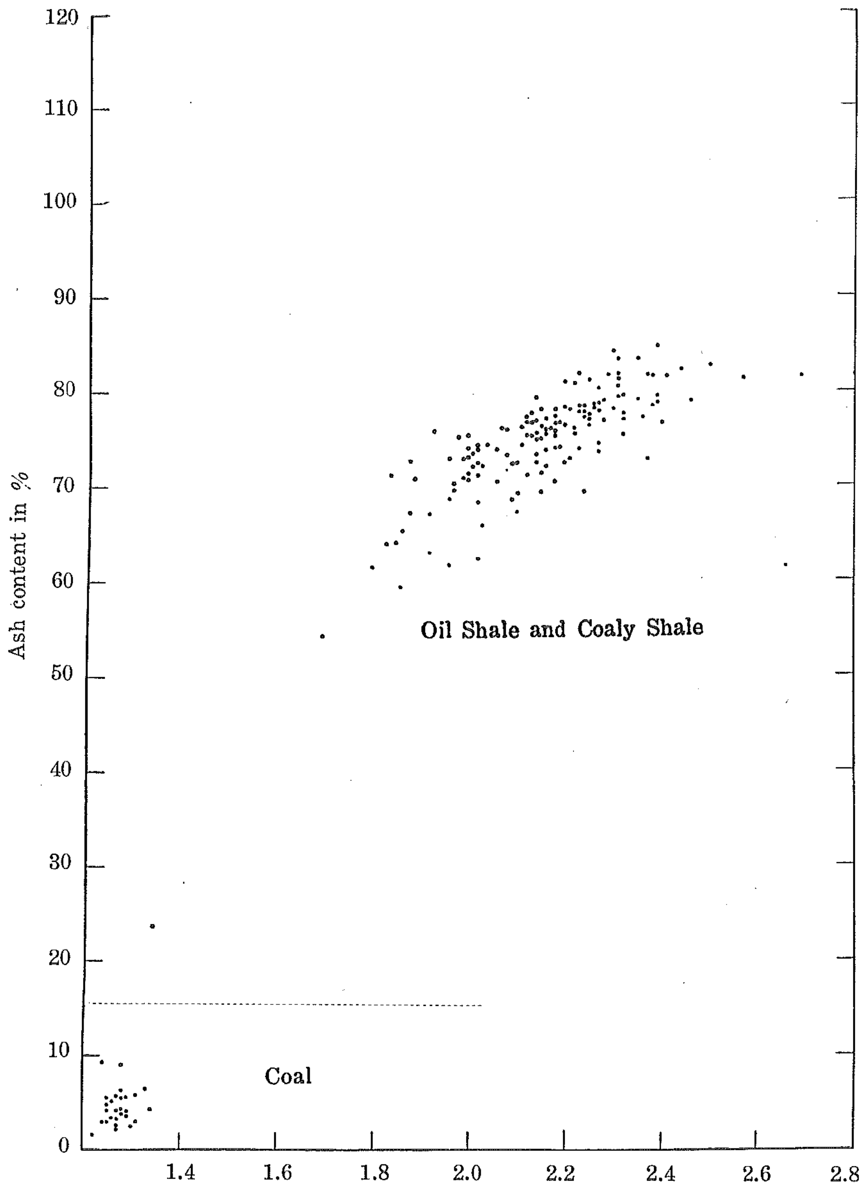

Fig. 19. Specific gravity.

the Fushun oil shale, coal, snd coaly shale and the ash content of them, which have been determined by T. Kimura[62] and the present writer. As is shown in Figure 19, the specific gravity increases also with the increase of ash content.

12. THE RATIO OF VOLATILES TO FIXED CARBON TO ASH

According to D. Eliot Day,[66] the sapropelitic rocks such as bituminous coal, cannel coal, boghead coal, lignite, and oil shale, from

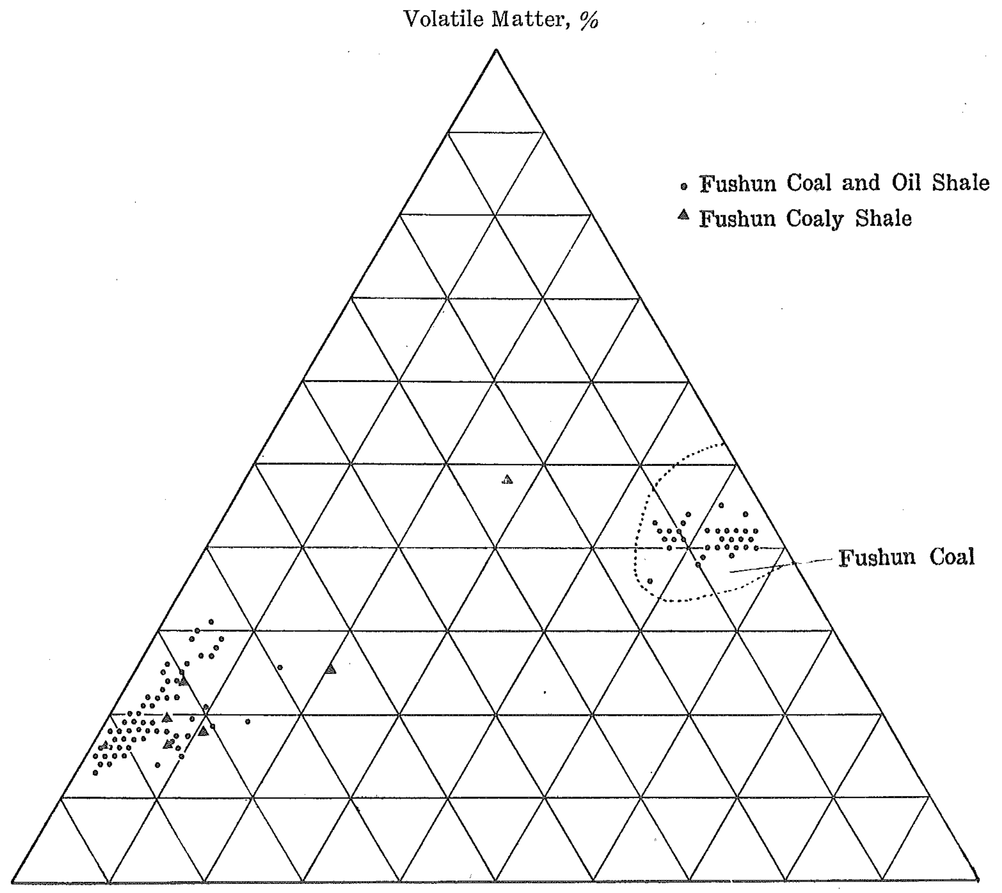

Fig. 20. Triangular diagrams, volatiles to free carbon to ash.

(62) T. KIMURA, S. MIZUUCHI and T. ITOH (see p. 163).

(66) DAVID ELIOT DAY: Oil shale. Handbook of the Petroleum Industry, by D.T. Day and others, New York, 1922.

which oil may be produced by destructive distillation or by the action of solvents, are classified according to the ratio of volatiles to fixed carbon to ash. It is also said that the fixed carbon content of oil shale is fairly constant and relatively low, never more than 20 percent, and that the variation from low grade to high grade shale is due to increase of volatiles at the expense of ash, and that the low fixed carbon content, seems to be outstanding point of difference between the average shale and coal. The Fushun oil shale and Fushun coal are also included within the classification by Day, but there are many coaly shales called "Hard coal" at Fushun, interbedded with coal seams. This is a certain variety of coal with a large amount of ash, and also with carbonaceous

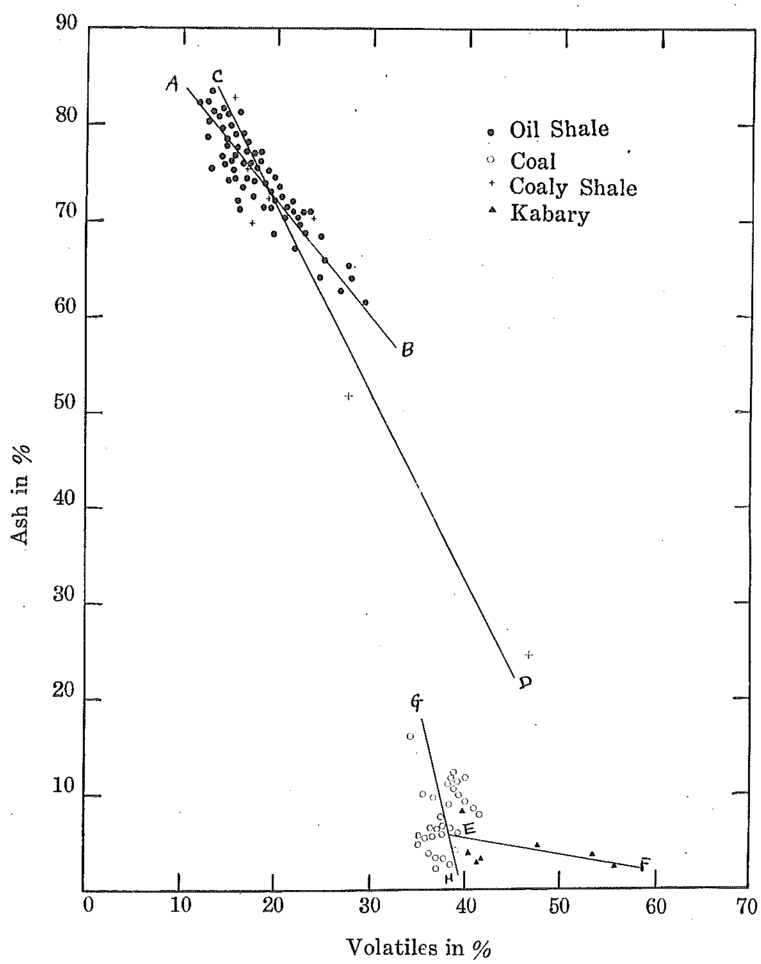

Fig. 21. Relation of percent volatile to percent ash.

and bituminous substances from which oil may be produced on distillation. Therefore, these rocks also belong to the category of oil shale in a wide sense, as is shown in Figure 20, although some of them are out of the boundary of 20 percent of fixed carbon determined by Day.

A triangular diagram, as is shown in Figure 20, shows no definite relation between oil shales, coals, and coaly shales. But a chart Figure 21, drawn by the present writer, on which were plotted points representing the ratio: percent volatiles to percent ash, shows, more or less, a definite relation between oil shales, coals, coaly shales, and Kabary (psuedocannel coal), which occur at the Fushun coal field. A fairly definite line AB on chart Figure 21 was drawn to represent the Fushun oil shales of various grades of oil content. Points representing coaly shales from the Fushun coal field also indicate a line CD on chart Figure 21 which is intersected by line AB, showing that in a certain case there is not any difference between oil shale and coaly shale. The points on this chart representing the Fushun coal, indicate a definite group which has no relation to the line AB. That is, there is no relation between oil shales and coals. But certain kinds of coaly shales which dominate in volatiles, with a small amount of ash, may coincide with the Kabary (pseudocannel coal), showing a certain relation to the group of coals.

According to the consideration of the ratio: percent volatiles to percent ash, there is, more or less, a distinct sharp classification of the oil shales, coaly shales, and coals occurring at the Fushun coal field.

G. Dissociation Phenomena of Oil Shale, Resin, Vitrit, and Siderite

For measuring the loss of weight on ignition, Honda's Thermobalance[67] has been used in the present experiment. The change in weight during the heating was measured under the atmospheric pressure and the room temperature.

(1) Oil Shale

Eleven specimens of the Fushun oil shale which are used in the present experiment, are the same samples which had been used in the chemical analysis of oil content described in the previous chapter. The

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(67) Kôtaro Honda: On the Thermo-balance. Kinzoku no Kenkyu, Vol. 1, No. 6, p. 543, 1924. (Japanese)

manner of the dissociation indicated by the variation in weight of the oil shale, varies with the content of oil, as is shown in the following figures. Figures 25 and 26, representing the most rich oil shale, indicate a large amount of loss of weight in percent. The samples contain a large amount of inflamable matters from which oil will be yielded on distillation. The poor oil shale, as are shown in Figures 22, 23, 28, and 29, indicate comparatively a small amount of loss of weight in percent. That is, they yield a less amount of inflamable matters from which oil will be yielded on distillation. Generally speaking, it is said that the amount of loss of weight of the Fushun oil shale on heating varies with the grade of the oil shale, that is, the greater the loss of weight on heating, the more rich in oil on distillation. But it is also noticeable that the dissociation loss of weight of the Fushun oil shale included the loss of weight of siderite abundantly embedded in the most rich Fushun oil shale, which is discussed in the following pages. As shown in Figures from 22 to 32, there is practically no change in weight during the heating from 20 degrees Centigrade. At about 80 degrees, the change commences and it proceeds slowly until about 180 degrees, where it ceases a little while. During this change of temperature, water and some of the volatiles in the oil shale, are lost. At about 200 degrees C., the second change occurs rapidly until about 500 degrees and from about 500 degrees there is no change in weight. During the

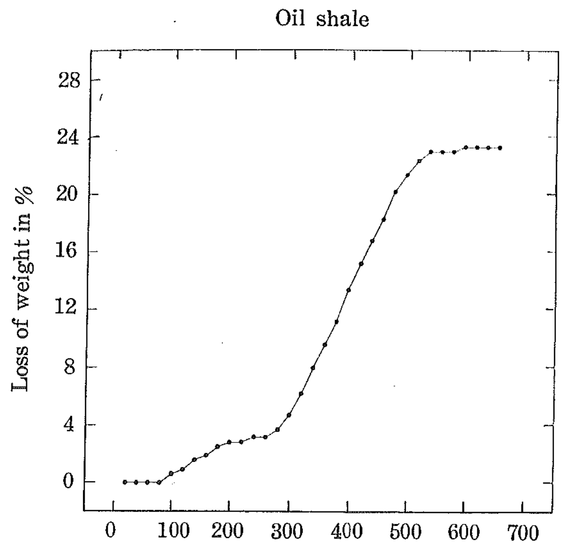

Fig. 22. Temperature in C.

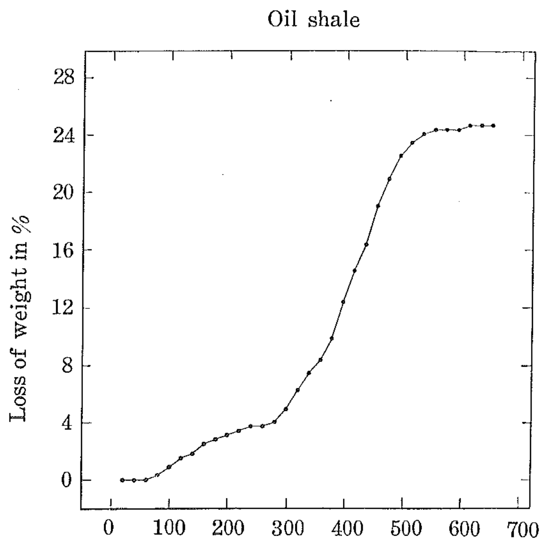

Fig. 23. Temperature in C.

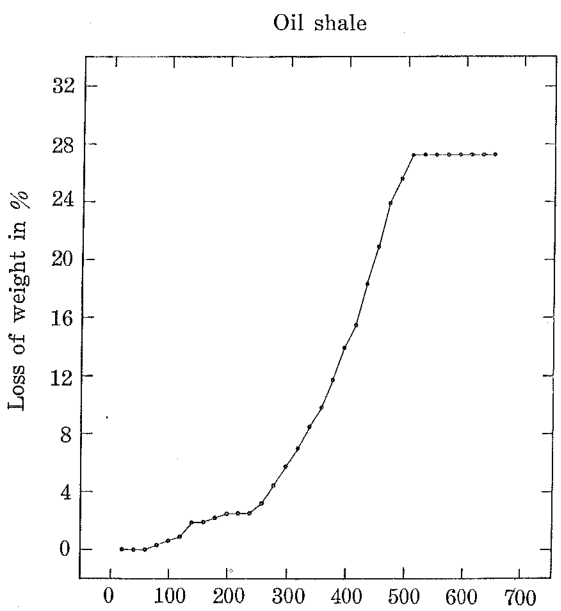

Fig. 24. Temperature in C.

Oil shale

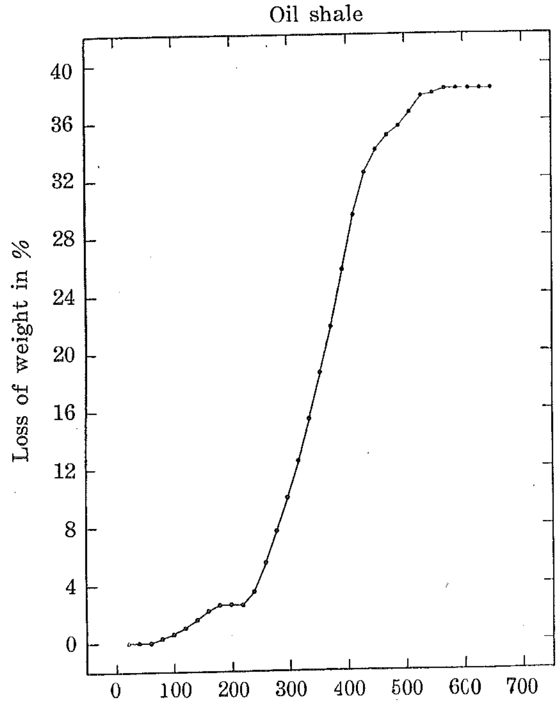

Fig. 25. Temperature in C.

Oil shale

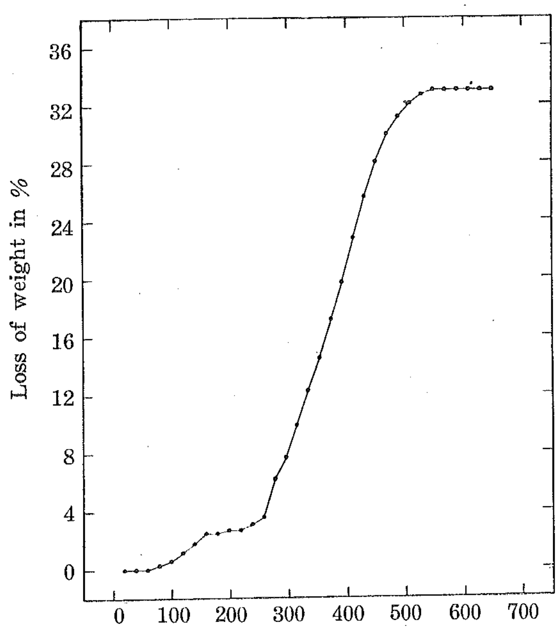

Fig. 26. Temperature in C.

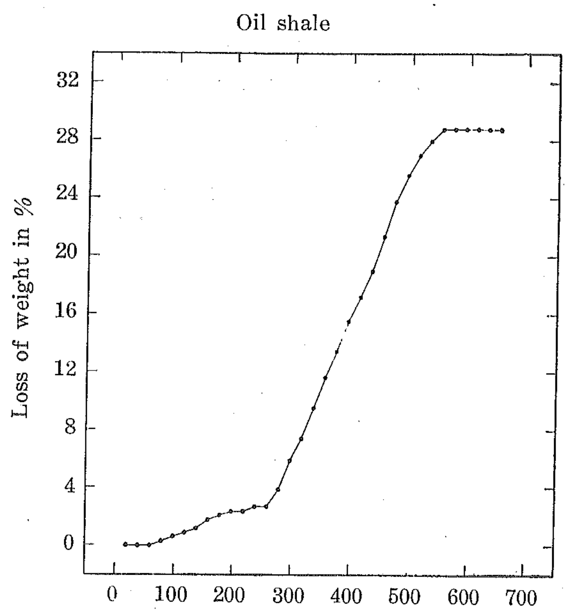

Fig. 27. Temperature in C.

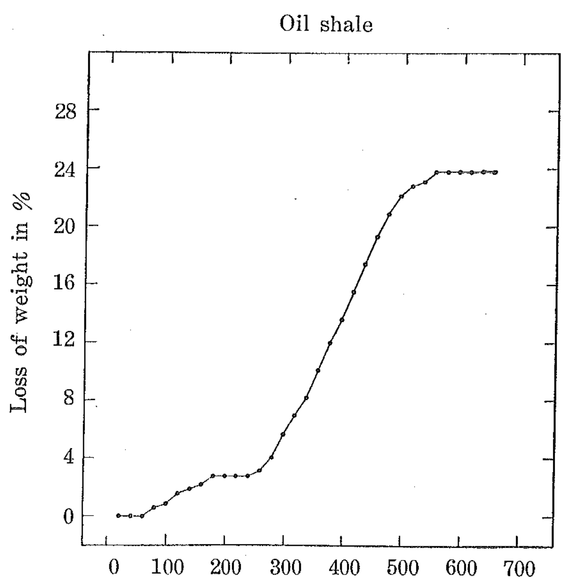

Fig. 28. Temperature in C.

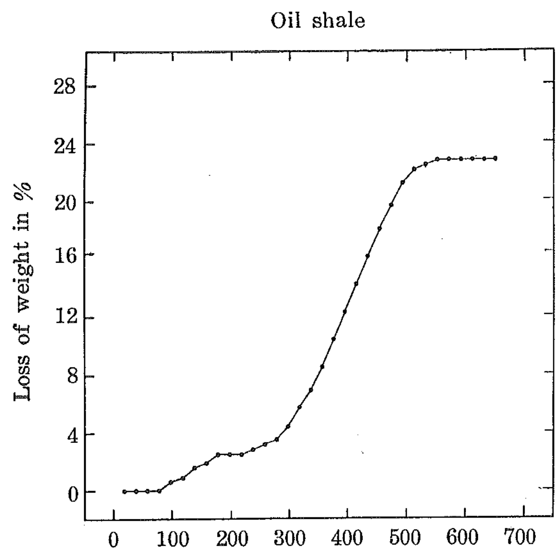

Fig. 29. Temperature in C.

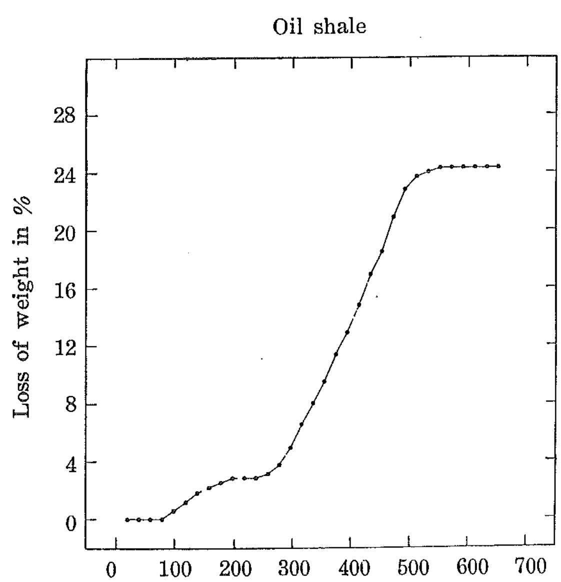

Fig. 30. Temperature in C.

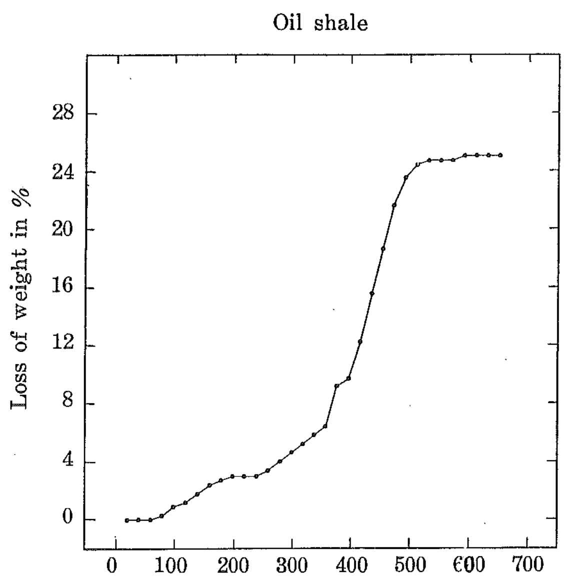

Fig. 31. Temperature in C.

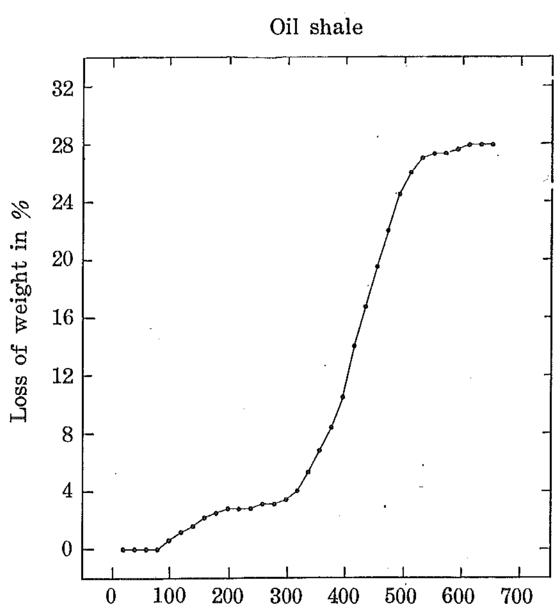

Fig. 32. Temperature in C.

heating from 200 degrees to 500 degrees, almost all bituminous substances in the oil shale are also lost. According to the results of these dissociation experiments, we may state that the bitumens soluble in solvents at their boiling points under atmospheric pressure may be lost before a temperature of about 200 degrees C. is reached and the stable bitumens insoluble in solvents, such as waxy substances and humic substance dominant in the Fushun oil shale may be lost during the heating from 200 degrees to 500 degrees C. As are shown in the above figures of dissociation phenomena, it is a striking character that the curves on charts Figures 22, 23, 30, 31, and 32, are similar to each other in form, representing the similar character of the oil shales, with the almost equal amount of loss of weight on heating. This is also an evidence of repetition of the occurrence of the same kind of oil shale to show a cycle of sedimentation.

(2) Resin

The specimen of resin used in the present experiment, is taken from a piece of large megascopic fragment of resin found in the coal

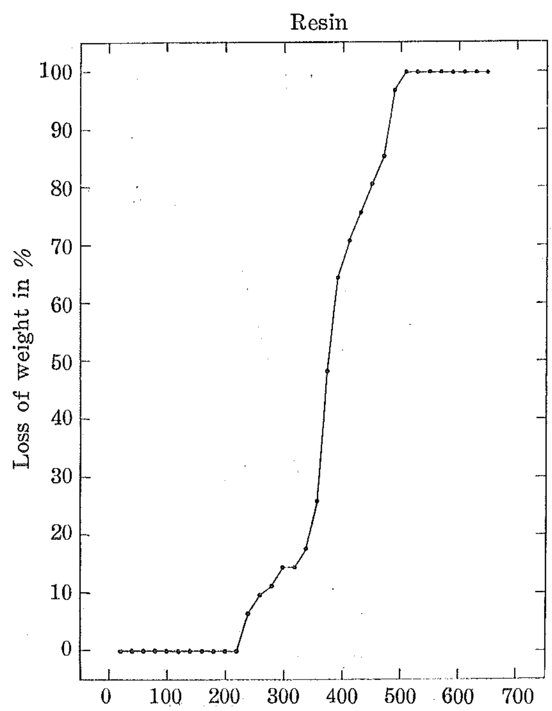

Fig. 33. Temperature in C.

seam at the Fushun colliery. As is shown in Figure 33, there is no change in weight during the heating from 20 degrees to 240 degrees C. At about 240 degrees the change commences and it proceeds very rapidly until 500 degrees C., showing a change absolutely different from those of vitrit and oil shales. That is, we may say that there is no water and almost nothing of ash in resin with 99.90 percent in loss of weight.

(3) VITRIT

The specimen of vitrit used in the present experiment is taken from a piece of the fresh fragment of vitritic coal of Sakura-sô (櫻層) at Oyama-ko (大山坑) at the Fushun coal field. As is shown in Figure 34, there is also no change in weight during the heating from 20 degrees to 60 degrees C. At about 80 degrees the change commences and it proceeds until 180 degrees. During this change water and light bituminous substances are lost. At about 240 degrees C. the second change commences and it proceeds rapidly until 520 degrees, showing

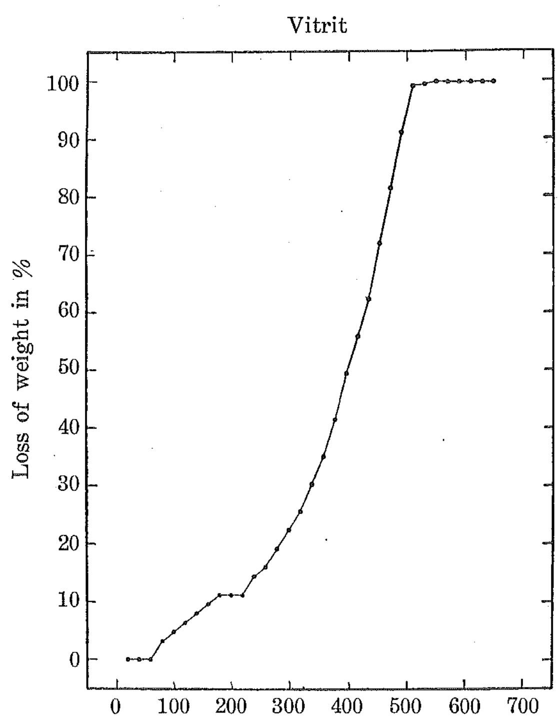

Fig. 34. Temperature in C.

a change absolutely different from those of oil shales. That is, the vitrit is almost completely composed of humic substance with very small amount of ash, showing 99.98 percent in loss of weight. From about 500 degrees C., there is no change in weight.

(4) SIDERITE

The specimen of siderite used in the present experiment is taken from a fragment of the nodule found in the coaly shale at the Fushun colliery. As is shown in Figure 35, there is no change in weight during the heating from 20 degrees to 260 degrees C. At about 280 degrees the change commences and it proceeds rapidly until 420 degrees C. At about 540 degrees there is a small change in weight. During this small second change, some impurities of other minerals in the siderite nodule may have been decomposed on heating. In the present experiment, as is shown in Figure 35, the loss of weight of siderite on heating, is 29.42 in percent. The pure siderite, iron protocarbonate, $FeCO_3$ = Carbo-dioxide 37.9 and iron protoxide 62.1 = 100.[68] Therefore, it may be said that the specimen of siderite used in the present experiment may be a mixture of siderite and other impurities.

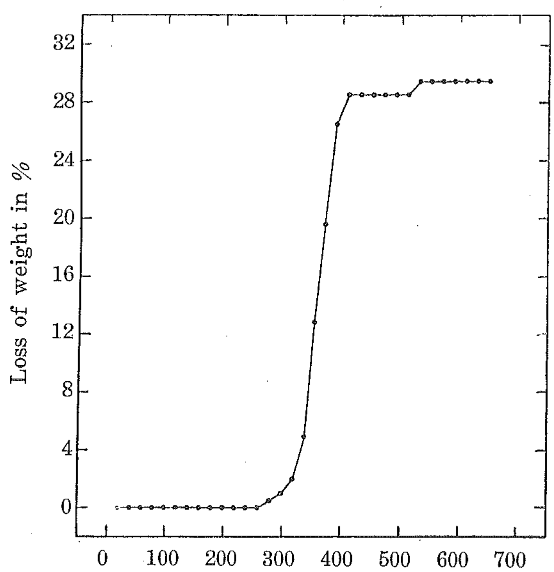

Fig. 35. Temperature in C.

(68) E. S. DANA: A Text-book of Mineralogy. New York, 1922.

Finally, we may say that the dissociation phenomena of the Fushun oil shale above mentioned, have a close relation to those of vitrit, resin, and siderite, which are dominantly contained in the Fushun oil shale.

H. ORIGIN AND SEDIMENTATION OF THE FUSHUN OIL SHALE

In discussing the origin of oil shale, there are three question : (1) the nature of organic materials of the oil shale, from which oil may be extracted by a certain method, (2) the sedimentation of organic materials, (3) the bituminization of organic materials during geological time. The present paper gives an account of the discussion on the first two questions, the nature and the sedimentation of organic materials of the oil shale.

Previous discussions on the sources of the organic materials called bitumen embedded in the oil shale, from which oil may be extracted on distillation, are those of Newton,[69] Cadell,[70] Carne,[71] Ells,[72] Scheibener,[73] Steuart,[74] Engler and Höfer,[75] Jeffery[76] [78], Zallesky,[77] Cunningham Craig,[79] Klever,[80] Winchester,[81] Conacher,[82]

(69) E. F. NEWTON : On Tasmanite and Australian white coal. Geol. mag., Vol. 2, 1875.

(70) H. M. CADELL : The oil shale of Lothians. Trans. Inst. Min. Eng., Vol. 22, 1901.

(71) J. E. CARNE : The kerosene shale deposits of New South Wales. Memoirs Geol. Surv. New South Wales, Geology, No. 3, 1903.

(72) R. W. ELLS : Joint report of the bituminous or oil shales of New Brunswick and Nova Scotia. Bull. 55, Canada Dept. Mines, 1909.

(73) EDMUND SCHEIBENER : Die Schieferkohlen von Morswill. St. Gallen, 1911.

(74) D. R. STEUART : The oil shale of Lothians. Memoirs Geol. Surv. Scotland, 2nd ed. 1912.

(75) C. ENGLER and HÖFER : Das Erdöl. Leipzig, 1913.

(76) E. C. JEFFERY : On the composition and qualities of coal. Econ. Geol., Vol. 9, 1914.

(77) M. D. ZALLESKY : On the nature of Pila the yellow bodies of boghead and a sapropel of the Ala-Koal Gulf of Lake Balkhash ; Extrait du tome 33, Bull. du Comite Geol., St. Petersburge. Nr. 248, 1914.

(78) E. C. JEFFERY : The mode of origin of coal. Jour. Geol., Vol. 23, 1915.

(79) E. H. CUNNINGHAM CRAIG : Origin of oil shale. Royal Soc. Edinburgh Proc., Vol. 36, 1916.

(80) H. H. KLEVER : Erdölbitumen und Kohlbitumen. Naturw. Ver, Karsruhe, Bd. 27, 1917.

(81) D. E. WINCHESTER : Oil shale in northwestern Colorado and adjacent area. Bull. 641, U.S. Geol. Surv., 1917.

(82) H. R. J. CONACHER : A study of oil shales and torbanite. Trans. Geol. Soc., Glasgow, Vol. 16, Part 2, 1917.

Ashley,[83] Bowen,[84] Stopes and Wheeler,[85] Murphy,[86] Strahan,[87] Kemper,[88] Zallesky,[89] Potonié,[90] Lindenbein,[91] Thiessen,[92] Trager,[93] Kimura,[94] Takahashi,[95] Day,[96] Haas,[97] Gavin,[98] Marcusson,[99] Ritter,[100] White and Standnichenko,[101] Winchester,[102] Bradley,[103] Reid,[104] Cotter,[105] Potonié,[106] Spielmann,[107] Stach,[108] Thiessen-

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(83) G. H. ASHLEY: Cannel coal in the United State. Bull. 659. U.S. Geol. Surv., 1918.

(84) C. F. BOWEN: Phosphatic oil shales near Dell and Dillon, Montana. Bull. 661, U.S. Geol. Surv., 1918.

(85) M. C. STOPES and R. V. WHEELER: Monograph on the constitution of coal. Dept. Scientific and Industrial Research, London, 1918.

(86) D. I. MURPHY: Manufacture of mineral oils from alum shales. Commerce Report, Bureau of Foreign and Domestic Commerce, London, 1919.

(87) A STRAHAN: Special reports on the mineral resources of Great Britain. Memoirs of the Geol. Surv., Vol. 3, 1920.

(88) G. H. KEMPER: Deposits of oil shale in Bulgaria. Commerce Report, Bureau of Foreign and Domestic Commerce, London, 1920.

(89) M. D. ZALLESKY: Ueber einen durch eine Zyalge gebideten marine Sapropel silusischen Alters (kuckersit). Zentralbl. f. Min., Geol. und Paläeont., Nr. 5 u. 6, 1920.

(90) H. POTONIÉ: Die Entstehung der steinkohle, 6 Aufl., Berlin 1920.

(91) H. LINDENBEIN: La Kuckersit. Archives des sciences physiques et naturelles 5 Periode, Vol. 3, 1921.

(92) R. THIESSEN: Origin and composition of certain oil shales. Econ. Geol., Vol. 16, 1921.

(93) E. H. TRAGER: Kerogen and its relation to the origin of oil. Bull. Amer. Assoc. Petroleum Geologists, Vol. 8, No. 3, 1921.

(94) T. KIMURA: A study of the Fushun oil shale. Central Experimental Works, South Manchurian Railway Company, Report 1, Series 10, 1922. (Japanese)

(95) J. TAKAHASHI: The marine kerogen shales from the oil fields of Japan. Science Reports Tohoku Imperial University, III, 1922.

(96) D. T. DAY: Oil shale. Handbook of petroleum industry, Vol. 1, p. 834, 1922.

(97) P. HAAS: Monographie der Oelschiefer des deutschen Lias. Brounkohle, Nr. 34. 1922.

(98) M. J. GAVIN: Oil shale. Bull. 210, U.S. Bureau of Mine, 1922.

(99) J. MARCUSSON: Struktur und Bildung der Haiminsäuren und Kohlen. Zeitschr. f. angew. Chem., 36, 1923.

(100) E. A. RITTER: Distillation of oil shale at Puertollano, Spain. Jour. Eng. and Min., Vol. 115, 1923.

(101) DAVID WHITE and STANDNICHENKO: Some mother plants of petroleum in the Devonian black shales. Econ. Geol., Vol. 18, No. 3, 1923.

(102) D. E. WINCHESTER: Oil shale of the Rocky Mountain Region. Bull. 729, U.S. Geol. Surv., 1923.

(103) W. H. BRADLEY: Oil shale and micro-organisms. Amer. Jour. Science, Vol. 8, 1924.

(104) A. M. REID: The oil shale resources of Tasmania. Tasmania Geol. Surv. Min. Resources, Vol. 8, 1924.

(105) C. de P. COTTER: The oil shale of Eastern Amherst, Burma. Records of Geol. Surv. India, Vol. 55, 1924.

(106) R. POTONIE: Einführung in die allgemeine Kohlenpetrographie. Berlin, 1924.

(107) P. E. SPIELMANN. Bituminous substances. London, 1925.

(108) E. STACH: Sporen und sporenähnliche Gebilde in der Kohle. Glückauf, Nr. 48, 1925.

White-Crouse,(109) Bradley,(110) Thiessen,(111) Standnichenko and White,(112) Potonié,(113) Carruthers,(114) McKee and Manning,(115) Potonié,(116) Bradley,(117) Standnikoff.(118) The results of these author's works suggest to us that there are a great many kinds of bitumens of oil shale and its derivatives. Therefore, we can classify the oil shale into several types from the standpoints of the nature and sedimentation of the bitumens of oil shales.

1. Source of the Fushun Oil Shale

The nature of the Fushun oil shale has been already petrographically described in the preceding chapters of the present paper. They are bitumens derived from the fine fragments of vegetable matters, which had been transported allochthonously in suspended state by water. These substance are also found in Kabary and vitrit in the coal seam to show that the bituminous substances contained in the oil shale and coal at the Fushun field, are all the same in nature, and the amount of them and the condition of sedimentation, are the only main points in which they differ each other. In the case of the formation of the Fushun oil shale, the minute fragments of the vegetable organic matters which later altered to bituminous substances, were transported with mineral matters in suspended state by water. The results of the chemical analysis of the Fushun oil shale, shows that there is present

(109) Thiessen-White-Crouse: Oil shale of Kentucky. Kentucky Geol. Surv., Series 6, Vol. 21, 1925.

(110) W. H. Bradley: A contribution to the origin of the Green River Formation and its oil shale. Bull. Amer. Assoc. Petroleum Geologists, Vol. 9, No. 2, 1925.

(111) R. Thiessen: Origin of the boghead coal. Prof. Paper 132, U. S. Geol. Surv., 1925.

(112) T. Standnichenko and David White: Microthermal observations of some oil shales and other carbonaceous rocks. Bull. Amer. Assoc. Petroleum Geologists, Vol. 10, No. 9, 1926.

(113) R. Potonie: Beziehungen zwischen bituminösen Gestein und Erdöl. Situngsberichte der Preussischen Geol. Landesanstalt, Heft 1, 1926.

(114) R. G. Carruthers: The geology of the oil shale fields. Memoirs Geol. Surv., Scotland, 3rd ed. 1927.

(115) R. H. McKee and Paul D. V. Manning: The genesis of oil shale and its relation to petroleum and other fuels. Oil Bulletin, Jan., 1927.

(116) R. Potonie: Allgemeine Petrographie der Oelschiefer und ihrer Verwandten. Berlin, 1928.

(117) W. H. Bradley: Neue Beobachtung über Algen als Urmaterialien der Bogheadkohlen und -schiefer. Zentbratl. f. M., Abt. B. Nr. 5, 1929.

(118) Georg Stadnikoff: Die Entstehung von Kohle und Erdöl, Schriften aus dem Gebiet der Brennstoff-Geologie, Bergakademie Freiberg, Sa., 5/6 Heft, 1931.

some amount of nitrogen, as is shown in Figure 17, which is usually found in animal matters, but it may be said that this nitrogen has been derived from the protein of the vegetable matter. The following table shows the content of nitrogen in the coal at the Fushun coal field.

N. in %	Locality
1.25	Kojôshi-ko (古城子坑)
1.75	Senkinsai-ko (千金寨坑)
1.60	Ôyama-ko (大山坑)
1.85	Tôgô-ko (東鄉坑)
1.90	Rôkodai-ko (老虎台坑)
1.80	Bantatsuya-ko (萬達屋坑)
1.90	Shinton-ko (新屯坑)
2.10	Ryuhô-ko (龍鳳坑)

The content of nitrogen above mentioned, is generally large compared with that of other coals with variations from 0.7 percent to 1.7 percent. This nitrogen is also considered to be derived from the protein of the vegetable matter which was transformed into coal.

2. Evidence of Cycle of Sedimentation of the Fushun Oil Shale

The Fushun oil shale exposed at the colliery, appears to be a uniform and homogenous massive shale, but it has different petrographical characters with depth, showing a repeating alternation of the rich oil shale and the poor oil shale, which offers evidence of cycles of sedimentation or a varve structure of oil shale. In the following pages, there are stated some evidences of the varve texture of the Fushun oil shale.

a. Vertical Distribution of Oil in the Fushun Oil Shale

On the previous pages, the present writer has classified the Fushun oil shale into four classes, as those of the most rich oil shale, the medium oil shale, the poor oil shale, and the siderite bed, of which the repeated alternation of the rich and poor oil shales is composed. As is shown in Plate II, the amount of oil is variable in percent with depth. That is, the rich and poor oil shales are alternately repeated showing a cycle of sedimentation of bitumens which will yield oil on distillation. This cycle of sedimentation of bitumen may not depend only upon the condition of supplying of source of bitumen, but also upon the paleoclimate and the mechanism of the sedimentation of suspended fragments of organic matters in fresh water. Plates II and III, are prepared from the results of chemical analyses of the Fushun oil shale which had been made by T. Kimura[(119)] and K. Imidzu,[(120)] to show a relation between oil yielding and the depth of samples from which oil is extracted on distillation.

As shown in Plates II and III, there is, generally, a sudden change in content of oil of the oil shales. This may depend upon the condition of sedimentation of bitumens in fresh water. It is also a striking character that the oil shale developed immediately above the coal seam is generally very poor in content of oil, but the oil shale developed immediately below the green shale is generally very rich in content of oil. These fluctuations of oil content from the top to the bottom of the oil shale bed mainly depend upon the cycle of sedimentation of bitumens and also upon the mechanism of sedimentation of bitumens and minute fragments of minerals in fresh water.

b. Horizontal Distribution of Oil in the Fushun Oil Shale

As is ahown in Plates II and III, the rich oil zone of the oil shale is developed horizontally in an area about 900 or more meters in length from West to East at the colliery. The oil shale which developed immediately above the coal seam, is very poor in content of oil as stated already in the above pages. This poor oil shale is also uniformly widely distributed horizontaly above the coal seam through the field. The most rich oil shale developed immediately below the green shale, is also widely developed through the field. Under general consideration of the distribution of oil in the Fushun oil shale, the oil shale of the western part of the field is more rich in content of oil than that of the eastern part of the field. That is, the bitumens embedded in the oil shale, from which oil will be extracted on distillation, are more abundantly deposited at the western part of the field than at the eastern part, and on the other hand, it may be said that the mineral

(119) T. Kimura: A study of the Fushun oil shale. Report of the Central Experimental Works, Rept. 6, Series 10, 1923. (Japanese)

(120) K. Imidzu: Chemical analysis of the Fushun oil shale. Private mimeograph Paper No. 2, 1929. (Japanese)

matters are dominant at the eastern part of the field. It may also be said that the materials, of which the Fushun oil shale is composed, have been transported from the eastern side of the Fushun basin to the western side. The mineral matters have been deposited mainly at the eastern part of the basin and the organic substances transported toward west and deposited there, where we found the rich oil shale at the colliery, as is shown in Plate I.

c. Sedimentation of Humic Substance

Humic substance, as a fundamental substance in the composition of vitrit is dominantly found embedded in the Fushun oil shale. The most rich oil shale developed immediately below the green shale, is mainly composed of humic substance. Generally, the humic substance has a close relation to the amount of oil in the oil shale.

A quantitative microscopic analysis of the humic substance observed in the thin section perpendicular to the plane of sedimentation of the Fushun oil shale, is made by the vertical lineal measurement method, as is shown in the following Table III and Figure 36.

Table III.

Sample No.	Spacing between samples in cm.	Humic substance in lineal %	Oil yield in Wt. %
1	0	9.6	4.88
2	30	8.0	4.80
3	10	13.4	9.02
4	44	18.6	15.33
5	40	15.4	11.93
6	28	10.0	9.01
7	30	9.2	6.42
8	26	5.8	5.60
9	58	6.6	4.29
10	46	10.4	6.51
11	54	11.2	8.73

As above mentioned in Table III and Figure 36, the humic substance occurs, more or less, in rhythmical curve, showing a repeating of rich and poor contents of humic substance with depth.

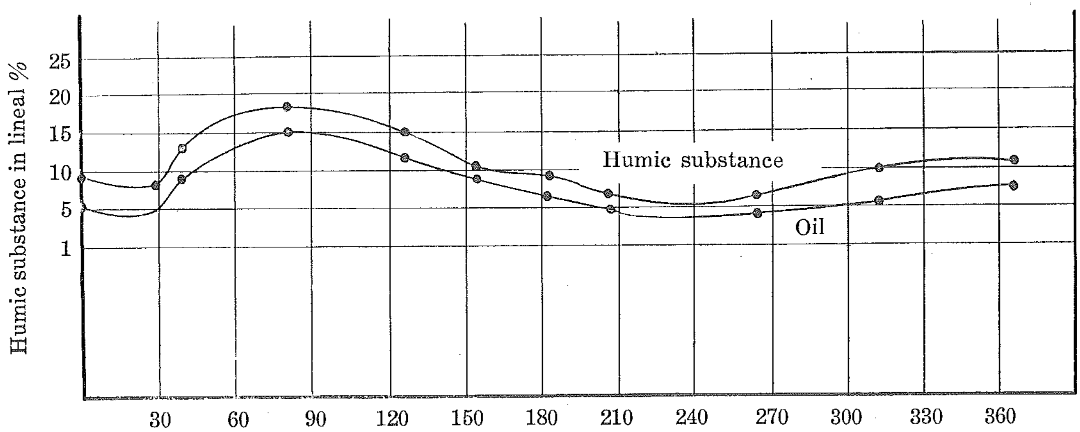

Fig. 36. Spacing between samples in cm.

d. Sedimentation of Nitrogen Compounds

Nitrogen in the Fushun oil shale, has also a close relation to the oil yield, as is shown in Figure 17. That is, the amount of nitrogen in the oil shale is proportional to the content of oil extracted on distillation. Generally speaking, nitrogen increases in quantities with the amount of oil. The amount of nitrogen shown in Table IV, is prepared from the result of chemical analysis of the boring core of the oil shale by K. Imidzu, which is referred on page 189.

As is indicated in Figure 37, nitrogen is found, generally speaking, showing roughly an evidence of cycles of nitrogen content in the oil shale with depth, while nitrogen is poor in content at the base of the oil shale developed immediately above the coal seam.

e. Sedimentation of Siderite

Micro-crystal grains of siderite embedded in the Fushun oil shale are found, however, abundantly in thin section under the microscope. But, it is a striking character that in the occurrence of siderite there is a close relation between the amount of crystal grains of siderite and the oil content of the oil shale. That is, the most rich oil shale is almost lacking in siderite, while the poor oil shale is very abundant in it, and passing to the siderite bed where is an increase of the amount of siderite. The amount of siderite is measured quantitatively by vertical lineal measurement analysis in thin section under the micro-

TABLE IV

Sample No.	Depth from surface in meters	Oil	Nitrogen
1	26.64— 29.64	11.33	0.644
2	29.64— 32.64	5.10	0.504
3	32.64— 35.64	6.76	0.588
4	35.64— 38.64	7.73	0.588
5	38.64— 41.64	4.06	0.402
6	41.64— 44.64	2.09	0.420
7	44.64— 47.64	7.77	0.532
8	47.64— 50.64	4.07	0.560
9	50.64— 53.64	2.86	0.504
10	53.64— 57.64	6.58	0.602
11	57.64— 60.64	6.56	0.714
12	60.64— 63.64	4.46	0.518
13	63.64— 66.64	4.08	0.574
14	66.64— 69.64	3.10	0.470
15	69.64— 72.64	10.94	0.644
16	72.64— 75.64	9.91	0.532
17	75.64— 78.64	11.25	0.756
18	78.64— 81.64	9.28	0.650
19	81.64— 84.64	5.80	0.602
20	84.64— 87.64	4.34	0.560
21	87.64— 90.64	9.01	0.672
22	90.64— 93.64	5.84	0.504
23	93.64— 96.64	7.02	0.546
24	96.64— 99.64	6.93	0.504
25	99.64—102.64	4.12	0.462
26	102.64—105.64	3.80	0.448
27	105.64—108.64	3.55	0.392
28	108.64—111.64	3.39	0.406
29	111.64—114.64	2.98	0.392
30	114.64—117.64	2.93	0.420
31	117.64—120.64	1.29	0.336
32	120.64—123.64	4.48	0.448
33	123.64—126.64	0.73	0.378
34	126.64—129.64	1.02	0.364
35	129.64—132.64	1.19	0.378
36	132.64—135.64	1.35	0.364
37	135.64—138.64	0.48	0.252
38	138.64—141.64	0.47	0.350
39	141.64—144.64	0.81	0.336
40	144.64—147.64	0.50	0.308
41	147.64—150.64	0.53	0.266
42	150.64—152.60	0.83	0.294

scope, and the vertical distribution of crystal grains of siderite in the oil shale which is sampled vertically at the colliery, is shown in Table V and Figure 38.

As is evident in Figure 38, siderite occurs, more or less, rhythmically, showing a repetition of rich and poor amount of siderite with depth. That is, siderite embedded in the Fushun oil shale is found in cycles of sedimentation, although there may be also a small cycling sedimentation of siderite in each one cycle, as is shown in Plate XIII.

TABLE V

Sample No.	Spacing between samples in cm.	Siderite in lineal %
1	0	23.7
2	28	27.7
3	28	50.4
4	28	6.0
5	20	6.0
6	20	33.5
7	20	34.2
8	20	48.0
9	20	65.5
10	20	43.0
11	20	67.3
12	20	52.6
13	20	78.2
14	20	93.0
15	20	42.3
16	20	63.4
17	20	82.8
18	20	51.7
19	20	41.9
20	20	46.0
21	20	41.4
22	20	29.2
23	20	31.2
24	20	51.1
25	20	29.4
26	20	43.7
27	20	36.8
28	20	60.5
29	20	77.6
30	20	76.8
31	20	60.7
32	20	72.8

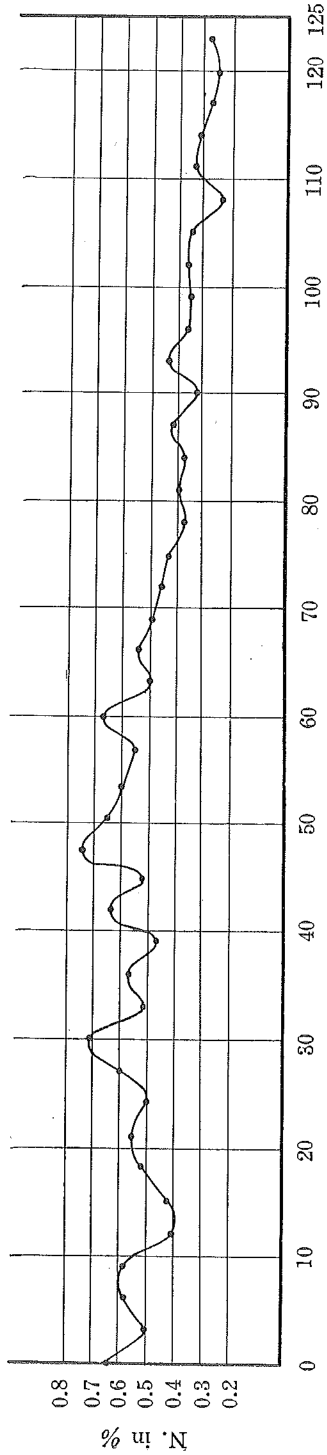

Fig. 37. Spacing between samples in m.

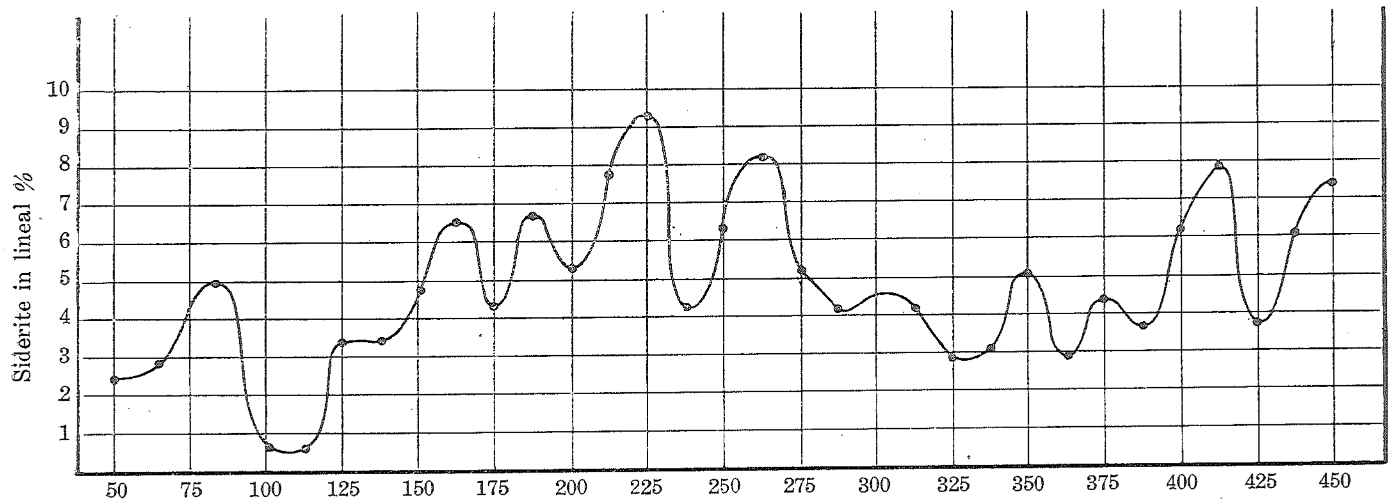

Fig. 38. Spacing between samples in cm.

3. Conditions of Deposition of the Fushun Oil Shale

Although we very often found microfragments of angular quartz and felspars in the thin section of the Fushun oil shale under the microscope, which might be fragments of pyroclastic materials, as is shown in Figure 45, the Fushun oil shale is principally composed of the terrigenous and argillaceous sediment with organic matters mainly of bituminous substances. From the standpoint of the paleontological study on the flora and fauna, as are described in the previous pages, the Fushun Tertiary sediments may be said to have been deposited in fresh water in a basin of granite gneiss.

As is stated in the above pages, the Fushun Tertiary sediment shows an evidence of cycles of sedimentation. That is, the materials, which had been dominated in organic matters, were, periodically transported from the land. After the deposition of the tremendously big deposit of coal seam of more than 100 meters thickness, the sedimentation of the oil shale commenced to deposit continuously under uniform but periodical paleoclimate. It is also a striking character that the materials of the mineral matters and organic substances, of which the Fushun oil shale is composed, are almost the same in nature from the begining to the end of sedimenting of the oil shale, and are only variable in quantity with depth. When the material was transported to the place where the water was still, they commenced to deposit in fresh water.

(a) Deposition in Fresh Water

The deposition of clay and minute fragments of organic matters takes place in very different ways in fresh or in salt water, and the laws controlling their deposition, are, generally, those of the flocculation of dipersed suspensions.[121]

In salt water, extremely minute fragments of glass, quartz,[122] and clay[123], are electro-negative colloid and can be flocculated by positively charged ions. The natural organic matter added to the terrigenous sediments consists also largely of colloidal substances, such as

(121) H. Freundrich: Colloid and capillary chemistry. London, 1926.

(122) Elissafoff: Zeitsch. Physical Chem., 79, s. 385, 1912.

(123) W. C. Dayhuff and D. R. Hoogland: The electrical charge on a soil colloid as influenced by hydrogen ion concentration and by different salts. Soil Science, Vol. 18, p. 401, 1924.

the soil organic matter. Soil organic matter (largely humic substance) has generally a protective effect on the flocculation of clay.[124] Protoplasm which is often abundantly found in water, is typically in the form of cellular units. The observations of Kühne,[125] Velten,[126] and Hardy[127] all indicate that in weak electric fields there is a cataphoretic migration of protoplasmic particles toward the cathod, and their results speak for the positive charge of the colloid elements of protoplasm. Protoplasm in water may be considered as the source of the labilprotobitumen.

In fresh water free from electrolytes, deposition, however, results from the settling of each particle separately, the rate of sinking being dependent upon the size and density of the particle, provided there is no disturbance by convection currents, variation in temperature, and other factors that influence the velocity of sinking. If the density of all mineral constituents of the Fushun oil shale is very nearly the same, it may be assumed without any considerable likelihood of error, that the all particles of the same size sink at the same rate. If the particle is assumed a spherical grain, the velocity of falling of a particle is estimated by Stoke's law.[128] But in this case the particle should in fresh water be less than 0.0228 centimeter[129] in diameter.

$$V=\frac{2}{9}\ \frac{a^2(d_1-d_2)g}{y}$$

a ....Radius of particle.
d_1....Density of falling particle (2.6495...Quartz)
d_2....Density of medium (0.9982...Water at 20°C.)
y ....Viscosity of medium (0.01006...Water at 20°C.)
g ....Gravity (980).

(124) SVEN ODEN: Die Koagulation der Tone und die Schutzwirkung der Humussäure. Jour. Landw., 67, s. 177, 1919.
M. I. WOLKOFF: Flocculation of soil colloidal solution. Soil Science, 1, p. 585, 1916.

(125) W. KÜHNE: Untersuchungen über das Protoplasma und die Contractlität. Leipzig, 1864.

(126) W. VELTON: Einwirkung stromender Elektrizität auf die Bewegung des Protoplasma. Sitzugsber. d. k. Akad. d. Wiss. Wien, Math.-Naturwiss. Classe, Vol. 73, 1876.

(127) W. B. HARDY: Note on differences in electrical potential within the living cell. Jour. Physiol., Vol. 47, p. 108, 1913.

(128) G. STOKES: Mathematical and Physical Papers. Vol. III, 1850.

(129) LAMB: Hydrodynamics. 5th edition, p. 567, 1924.

The rate of sinking of a quartz particle is shown in the following table.

	Radius in cm.	Velocity per second in cm.	Time of sinking one cm. in sec.
Silt	0.01	3.5961	0.2780
	0.001	0.035961	27.8000
Mud	0.0001	0.00035961	2780.0000
	0.00001 (0.1 μ)	0.0000035961	278000.0000
	0.000001	0.000000035961	27800000.0000

The increase of rate of sinking with the increase of the grain, is expressed quantitatively by the above table. If the suspension is perfectly uniform and grains are equal, the rate of deposition on the bottom is directly proportional to the amount of solid matter suspended, and inversely proportional to the thickness of the log of water, but independent of time. In other words, the more matter suspended and the thinner the layer of water, the quicker the deposition of sediment, which is the same in each unit of time. It is difficult in non-uniform system, that is, when particles of varying size are suspended at the same time, as in all natural clay suspensions. The amount of suspended matter and the thickness of water layer has the same effect as before, but the rate of deposition also varies with time, as each group of grains settles at its own definite face. Grains of each size, of course, begin to reach the bottom at one time, but the bulk of each group of grains settles separately, the coarsest first and then the finer in order of size. In the case of deposition of the Fushun oil shale, of mineral constituents of the Fushun oil shale, crystal grains of siderite dominantly embedded in the oil shale settled first to form the siderite bed as the basal sediment of one group of terrigenous transported matters. The organic substances of smaller density, settle later to form the top sediment of one group, representing the most rich oil shale bed. Again the next group of sediments comes on the top of the most rich oil shale of the former group, showing a sharp line at the boundaries between two groups, as is shown in Plate XIII. In one bed of the oil shale, the mineral matters, such as grains of siderite, quartz, felspars, and others, dominate at the base of the bed and gradually they decrease in quantity upwards, while the organic matters increase reversely, and finally at the top of the bed, there is one horizon which is very rich in organic substances and also in very extremely fine grains of clay which compose the matrix of the oil shale. Thus, the rich and the poor oil shales are alternating, showing a cycle of sedimentation. According to the result of study on sedimentation of the Fushun oil shale, the present writer may state that it was deposited in fresh water of a lake basin, and during the deposition, a small amount of pyroclastic matters was mixed with the terrigenous sediments.

I. Geological Relation between the Fushun Oil Shale and the Coal Seam

To explain the geological relation between the oil shale and the coal seam, the present writer has described it briefly from the standpoint of the geological occurrence, the petrographical characters, and the condition of sedimentation of the oil shale.

As is already stated, in the previous pages of the present paper, the geological occurrence of the Fushun oil shale has a close relation to that of the coal seam. That is, the Fushun oil shale conformably rests on the coal seam, generally, with a sharp line at the boundary between them. But at the western part of the Fushun coal field, at the Kojôshi (古城子) colliery, there is a transition point from the coal seam to the oil shale representing an alternation of them. Coaly fragments, carbonaceous matters, are also dominant in the oil shale near the coal seam. The coaly shales dominant in mineral matters, occurs interbedding with coal seam. But these shales generally occur in the lower part of the coal seam, and are quite different from the oil shale which alternates with the coal seam at the boundary between them. Mineral matters contained in the coaly shale are, however, pyrogenetic in nature. It may be said that after deposition of the coal seam the oil shale commenced to deposit conformably on the coal seam, and the coal seam is composed of only organic matters with a very small amount of ash, while the oil shale is composed of a mixture of organic and mineral matters. The result of petrographical study on the bitumen found in the oil shale and coal of Fushun field, as is mentioned in the previous pages of the present paper, suggests to us that the bitumens are quite similar to each other, showing as humic substance, resins, waxy substances, and cutin. The bitumens embedded in the Kabary interbedded with the coal seam, are also quite similar to those of the oil shale. Therefore, we may say that the bitumens embedded in the oil shale, and the coal seam, from which oil will be extracted on distillation, are quite the same together in nature. That is, there is no geological gap during the deposition of the oil shale and the coal seam, showing a complete conformable relation between them.

The conditions of sedimentation of the oil shale and the coal seam also show a close relation between them. The Fushun coal seam, at first, was deposited on the bottom of a fresh water basin. The organic substances which altered to coal, had been transported mostly in a suspended state of fragments of vegetable matters in water, although there are found some macroscopical fragments of wood tissues in the coal seam. Particularly, the Kabary is almost completely derived from small fragments of humic substances, resins, waxy substances, and a very small amount of mineral matters transported in suspended state. After the big deposit of the coal seam of more than 100 meters thickness, the minute fragments of vegetable matters have been still transported in suspended state in water with increasing of mineral matters to form oil shale. And there also occurred a periodical sedimentation of bitumens to show a varve structure of the oil shale. We may also say that, if there had been no deposition of mineral matters which are now found in the oil shale, the Fushun oil shale might have become a coal seam, as a successive coal seam of the present Fushun coal seam. The relation of the oil shale to the coal seam is not only geologically and petrographically interesting to geologists, but also chemically to chemists, because the shale oil extracted from the Fushun oil shale, is, more or less, similar in composition, to that of the tar oil from the Fushun coaly shales interbedded with the coal seam.

J. Position of the Fushun Oil Shale in the Petrographical Classification of Oil Shale

With regard to the result of the petrographical study of sapropelites, such as black shale, cannel coal, boghead coal, oil shale, bituminous coal, and other bituminous shales, a number of writers have already reported. R. Potonié[130] has also recently, however, classified the sapropelites petrographically. The present writer has made also a classification based upon the nature and the condition of sedimentation of bitumens embedded in the rocks, as follows:

Petrol-bitumen

1. Autochthonous bitumen
   Oil shale from Californian oil fields.

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(130) R. Potonié: Allgemeine Petrographie der Ölschiefer und ihrer Verwandten. Berlin, 1928.

Bituminous shale from Japanese oil fields.
Paleozoic stink kalk in Germany.
Bituminous Fusulina limestone from Spitzbergen.
Oil shale from Aleksinac, Servia.

2. Allochthonous bitumen
Oil shale from Colorado, which dominate in oily bitumens.

Coal-bitumen

1. Autochthonous bitumen
Boghead coal, Kuckersite, Kerosene shale.
2. Allochthonous bitumen
Cannel coal, Tasmanite, Pseudocannel coal, Brown coal, Bituminous coal, Oil shales from Scotland, Sweden, Kentucky, Ohio, Fushun, Korea, China, Germany, Japan.

Petrol-bitumen mentioned above in the present paper, is similar to that bitumen of Potonié, which would have become petroleum in a certain geological condition. It includes the bitumens derived from the labilprotobitumen by R. Potonié, and also it includes Engler's polybitumen derived from the labil-protobitumen by Potonié. Petrol-bitumen is not only found in the marine bituminous rocks, but also in the continental bituminous rocks in fresh and brackish waters.

Autochthonous bitumen is the bitumen which has been derived from the organic remains accumulated at the place, where the organism grew and fell.

Allochthonous bitumen is the bitumen which has been derived from the organic matters accumulated as the result of transportation by water.

Coal-bitumen mentioned in the present paper, includes bitumens insoluble in solvents, such as cutin, suberin, resins, humic substances, cellulose, lignin, and some kinds of waxy substances, which are usually found in coals. These bitumens are mostly allochthonous and coincide with stabilprotobitumens by R. Potonié, and also with some kinds of Engler's polybitumens derived from non-labilprotobitumens. These highly stable bitumens are found in the continental and also occasionally in marine sediments.

Autochthonous bitumens of coal-bitumen are mostly derived from marine vegetable organisms, like algae, which are abundantly found in boghead coals and kuckersite under the microscope. These autochthonous coal-bitumens are similar to the stabilmetabitumen by R. Potonié, and also to some kinds of Engler's polybitumen.

The oil shale and its derivatives which are classified upon the basis of the nature and the condition of sedimentation of bitumens above mentioned, do not show sharp boundaries between them, because these sedimentary sapropelites are variable in constituents on account of sources and conditions of sedimentation of bitumens. Therefore, a certain oil shale, often, contains both petrol-bitumen and coal-bitumen. For example, the Fushun oil shale mainly contains coal-bitumen but also a small amount of oily bitumen soluble in benzol, which might have been derived from a certain petrol-bitumen. But the Fushun oil shale, as is mentioned above, belongs to the category of the oil shale which contains allochthonous coal-bitumen.

K. Determination of the Fushun Oil Shale

1. Macroscopic Methods

Of those characters to determine the Fushun rich oil shale, the weathering secondary product on the surface of the oil shale exposed at the colliery, is the most convenient and effective material for prospecting of the rich oil shale. The weathering products, such as ferrous sulphide, ferrous sulphate, basic ferric sulphate, and iron oxides, are produced respectively on the surface of the oil shale. Iron sulphide and iron sulphate are found coating the surface of the most rich oil shale at the Fushun colliery, as is mentioned in the above chapter.

Ferrous sulphide, at first, comes out on the surface of the rich oil shale, with black colour, and then on fine days after wet weather, fine acicular crystals of ferrous sulphate white in colour are next produced on the surface of the ferrous sulphide, as is shown in Plates IV, V, VI. Basic ferric sulphate which derived from ferrous sulphate by oxidation, is also found in short prismatic crystals of light yellowish-white colour on the surface of ferrous sulphide. These secondary minerals of iron compounds are observed on fine days from far distance, as is shown in Plate IV. On wet day these white substances of iron compounds disappear dissolved in water. Iron oxide with reddish or reddish brown colour, is found on the surface of the poor oil shale, particularly, the slicken-sides of the block of the fault breccia in the fault zone, are deeply coloured reddish brown by it derived from siderite dominantly occurring in the poor oil shale, while the rich oil shale still shows the original black colour. The medium rich oil shale shows also gray in colour with a very thin coating on the surface exposed in the open air, which may be some weathering products derived from the oil shale.

Specific gravity of the Fushun oil shale has also some relation to its oil content, as is shown in Figure 18, showing a general increase of oil content with the decrease of specific gravity of the oil shale. Therefore, the specific gravity of the oil shale is used to determine the Fushun rich oil shale. But this method is not practical at the Fushun colliery, because it is difficult to determine practically the fluctuation of the specific gravity of the oil shale in the field.

Colour of the Fushun oil shale, generally speaking, may be considered for the determination of the rich oil shale. The rich oil shale is black or brownish deep black in colour, while the poor oil shale shows chocolate colour, particularly the deformed oil shale at the fault line shows its characteristic colour by the weathering products, as already mentioned. That is, the poor oil shale, which is generally rich in siderite, shows brown or reddish brown colour of iron oxide, while the rich oil shale still maintains the original black colour on the slicken side of the block of the fault breccia. Thus, the colour of the Fushun oil shale is practically considered for distinguishing the rich oil shale from the poor oil shale, considering also the weathering products of iron compounds above mentioned. But it is often difficult to determine the exact difference between oil shales with a small amount of oil content in them.

The streak of the oil shale on unglazed pottery, shows also a general qualititive difference among oil shales. The rich oil shale shows deep gray colour, while the poor oil shale, gray brown colour, and, generally speaking, the colour of the streak varies from grayish brown to grayish black with the increase of oil content.

Texture of the oil shale is also applied to determine the rich oil shale. The rich oil shale contains a small amount of mineral matter, and particularly is poor in large grains of mineral matters, while the poor oil shale is rich in mineral matters of large dimension, therefore, the fineness of the texture of the oil shale shows also the grade, the more fine in texture, the more rich in bitumens which will yield oil on distillation.

Clipping of the oil shale by edges of a piece of glass, also shows the grade. The rich oil shale curls on clipping by the edge of a piece of glass, while in the case of the poor oil shale, it falls to powder. This method is practically used in the field to determine the rich oil shale.

Spitting method for determining of the rich oil shale is also practically used in the field. If the fresh surface of the oil shale is wet by one drop of spit with finger, the drop keeps, for a long while, a sharp margin on the surface of the rich oil shale, but on the surface of the poor oil shale the sharp margin of spit soon deforms outward.

Tenacity of the platy oil shale is also usually practically applied for determination of the rich oil shale, but in the case of the Fushun oil shale, it is not practically used for the determination, because the Fushun oil shale occurs in compact masses without any platy joint. But if the platy specimen is artificially made parallel to the plane of sedimentation, tenacity tests may be practically applied to estimate the tenacity of the oil shale.

2. Microscopic Method

Microscopic methods for determining of the Fushun oil shale are also practically used in the laboratory. The rich oil shale is scanty in microcrystal grains of siderite under the microscope, but the poor oil shale is dominant in them, and the oil content decreases with the increase of siderite, as is mentioned already in the previous pages of the present paper. Humic substances with reddish brown colour are also rich in the rich oil shale, and they increase with the oil content as is shown in Table III and Figure 36.

SUMMARY

Of those sedimentary rocks developed at the Fushun coal field, the Tertiary sediments are widely distributed, resting unconformably on the Mesozoic sediments.

The Tertiary formations (Oligo-Eocene) are classified into two groups; (1) the lower group which is composed mainly of flows of olivine dolerite, tuff, black shale, coaly shale, (2) the upper group which is composed mainly of the principal coal seam, oil shale, and green shale.

The oil shale bed rests conformably on the coal seam, with monoclinal structure striking from East to West, dipping northward at 20 to 40 degrees.

The oil shale occurs in non-stratified fine-grained compact masses. Colour, dark brown to black. Mineral matters embedded in the oil shale are of minute crystal grains of siderite, quartz, felspars, mar-

casite, and clay matrices cementing the spaces between minerals and bitumens.

It is a striking character that the most rich oil shale contains almost nothing of minute crystal grains of siderite which is usually abundant in the most of the Fushun oil shales.

Organic matters also are found under the microscope to occur in minute fragments. They are of humic substance, resins, cutin, waxy substances, which are insoluble in solvents.

But a small amount of bitumens soluble in solvents is extracted at their boiling points under atmospheric pressure. Of those bitumens embedded in the Fushun oil shale, humic substance and waxy substances are mostly dominant in quantity.

It is also a striking character that the bitumens embedded in the Fushun oil shale are similar to those in the coal seam and Kabary which conformably occur immediately below the oil shale.

The Fushun oil shale is classified into four classes; (1) the most rich oil shale, (2) the medium rich oil shale, (3) the poor oil shale, (4) the siderite bed. The Fushun oil shale contains macroscopical inclusions such as black phosphorous nodules, coaly fragments, and globules of resins.

It is also a striking character that the rich oil shale outcrop at the Fushun colliery, has oxidation products of iron compounds such as ferrous sulphide, ferrous sulphate, and basic ferric sulphates, on the weathered surface of the rich oil shale. They are derived from the iron disulphide, such as marcasite and pyrite, embedded in the oil shale. Particularly, on a hot dry day after damp weather, one can easily observe such products on the surface of the most rich oil shale at the colliery. These minerals of white or grayish colour, are important indicators of the most rich oil shale at the colliery.

The Fushun oil shale was deposited in fresh water, representing a varve structure of sedimentation of an alternation of the rich and the poor oil shales.

The oil shale developed immediately above the coal seam is very poor in oil, showing less than 6 percent of oil content, while the oil shale developed immediately below the green shale is very rich in oil, showing more than 10 percent of oil content. The intermediate oil shale developed between those rich and poor oil shales above mentioned, presents an alternation of the rich and the poor oil shales, showing a varve structure of sedimentation of bitumens.

The amount of oil extracted from the Fushun oil shale on distillation, varies from 0.27 to 15.33 in percent, with an average 5.66 percent.

Ash of the Fushun oil shale is, generally speaking, large in content, showing a variation from 69.09 to 84.61 in percent, with an average 77.80 percent. It increases with the decrease of oil content.

The water content varies from 2.3 to 9.5 in percent, with an average 5.39 percent. It varies without regularity in relation to the amount of oil content.

The residue varies from 78 25 to 92.80 in percent, with an average of 86.32. It increases with the decrease of oil content.

The volatiles vary from about 11 percent to 29.5 percent, with an average 17.28 in percent. They increase, generally, with the increase of oil content in percent.

The fixed carbon varies from 1.77 to 13.24 in percent, with an average of 3.96. It increases with the increase of oil content.

Nitrogen varies from 0.21 to 0.74 in percent, with an average of 0.43; it increases with the increase of oil content.

Specific gravity varies from 1.80 to 2.68, with an average 2.17; it increases with the decrease of oil content, and it also increases with the increase of ash content.

GEOLOGICAL SOLID MAP OF THE FUSHUN COAL FIELD, AT SEA LEVEL.

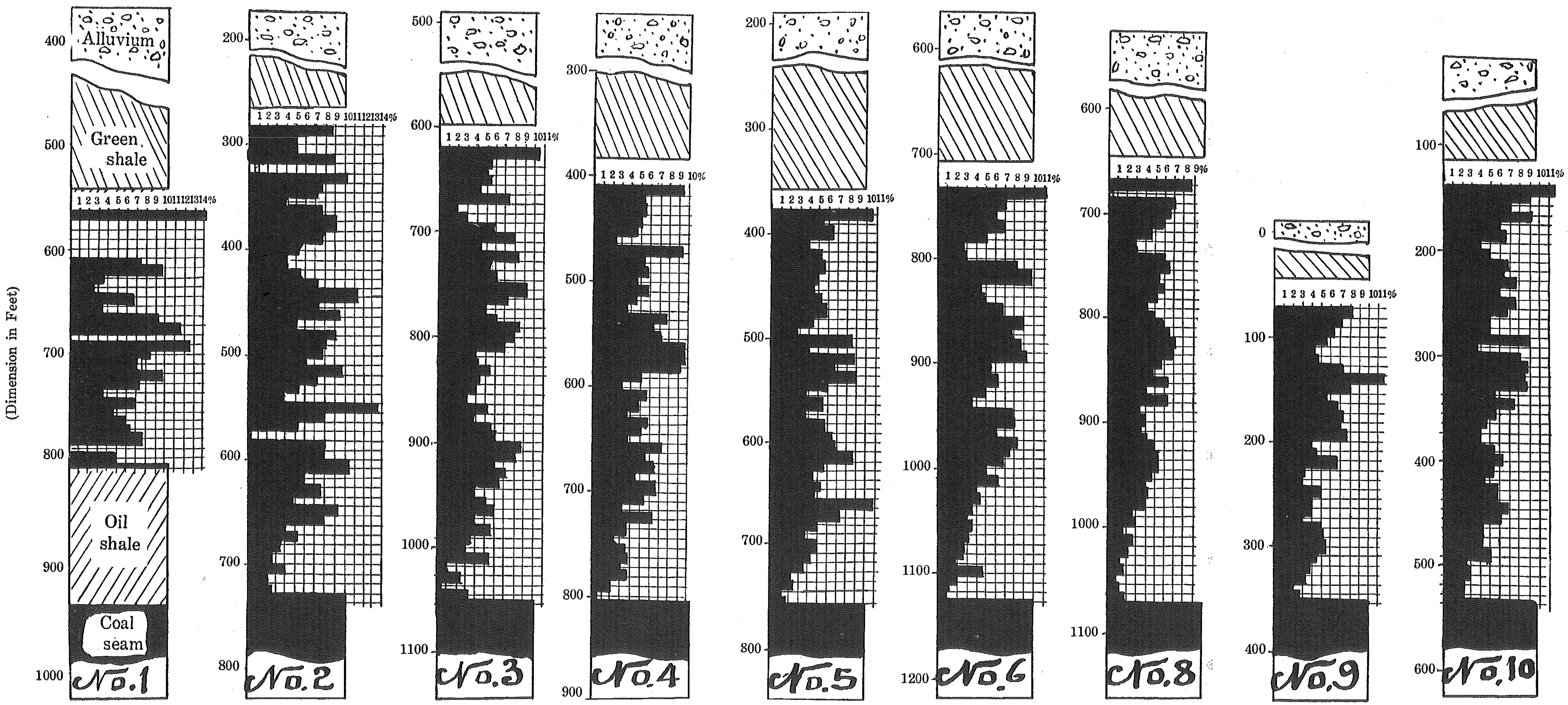
Explanation
- Granite gneiss
- Green shale
- Oil shale
- Coal seam
- Lower Tertiary
- Dolerite and tuff

K. Uwatoko: The Oil Shale Deposit of Fushun, Manchuria.

OIL YIELD AND DEPTH OF OIL SHALE BORING CORES,
SHOWING AN EVIDENCE OF CYCLE OF SEDIMENTATION OF RICH AND POOR OIL SHALES AT THE FUSHUN COLLIERY.
POOR OIL SHALES IMMEDIATELY ABOVE THE COAL SEAM.

K. Uwatoko: *The Oil Shale Deposit of Fushun, Manchuria.*

OIL YIELD AND DEPTH OF OIL SHALE BORING CORES, SHOWING THE RICH OIL CONTENT IMMEDIATELY BELOW THE GREEN SHALE.



K. Uwatoko: The Oil Shale Deposit of Fushun, Manchuria.

Plate IV

Explanation of Plate IV

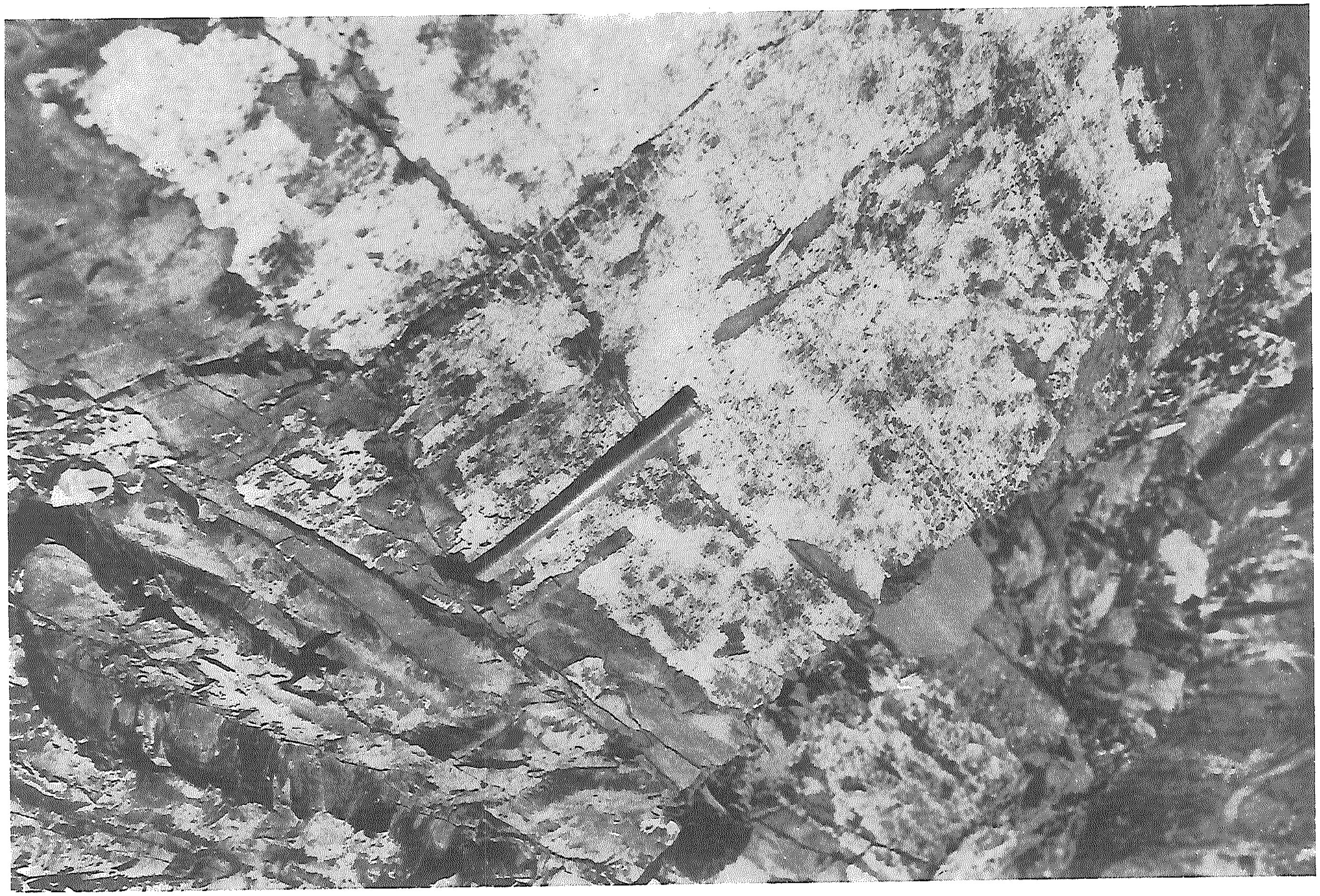
The most rich oil shale is shown with secondary iron minerals in white colour on its weathering surface at the Fushun colliery.

K. Uwatoko: Fushun Oil Shale.

Plate V

Explanation of Plate V

Secondary iron minerals are shown in white colour on the weathering surface of the most rich oil shale at the Fushun colliery.

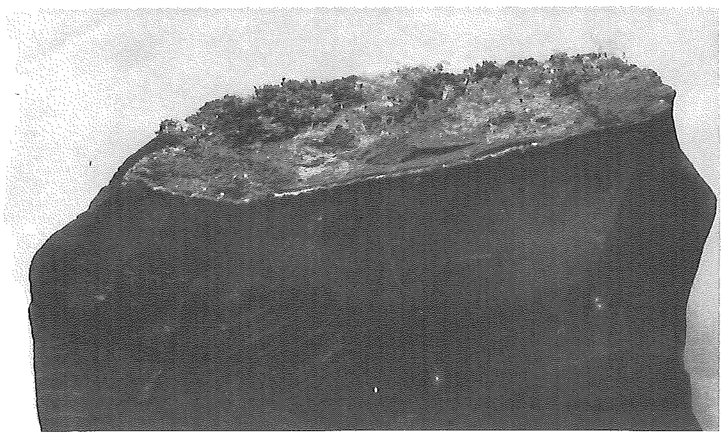


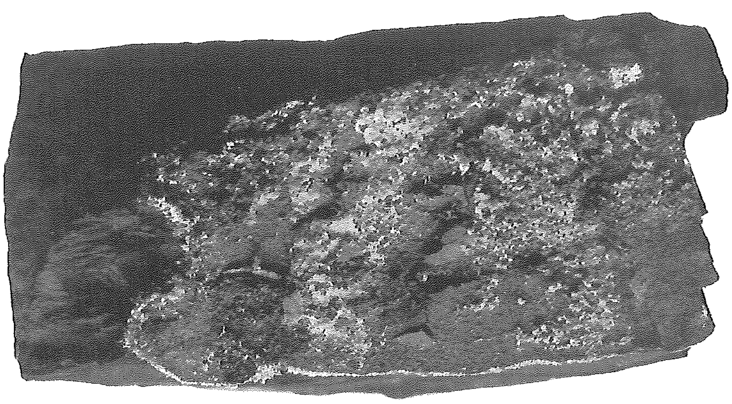
K. Uwatoko: Fushun Oil Shale.

Plate VI

Explanation of Plate VI

Secondary iron minerals on the weathering surface of the most rich oil shale at the Fushun colliery. Natural Size.





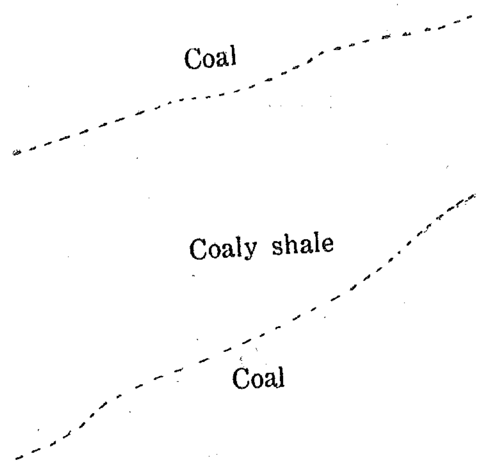
K. Uwatoko: Fushun Oil Shale.

Plate VII

Explanation of Plate VII

Fig. 41. Coaly shale at the Fushun colliery.

Fig. 42. Fushun colliery.


Coal
Coaly shale
Coal

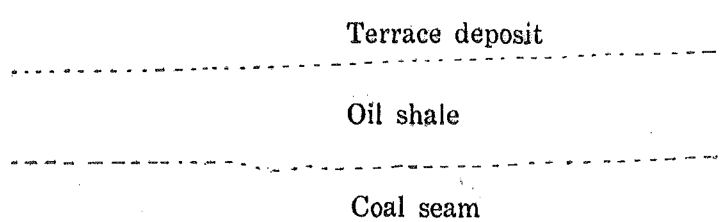

Terrace deposit
Oil shale
Coal seam

Fig. 41.

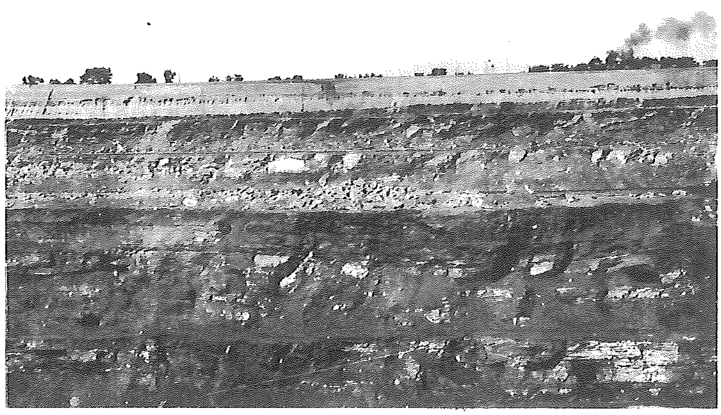


Fig. 42.

K. Uwatoko: Fushun Oil Shale.

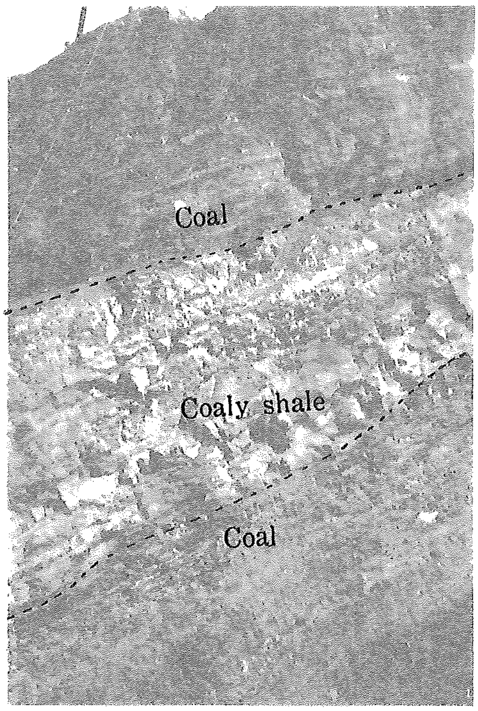


Fig. 41.

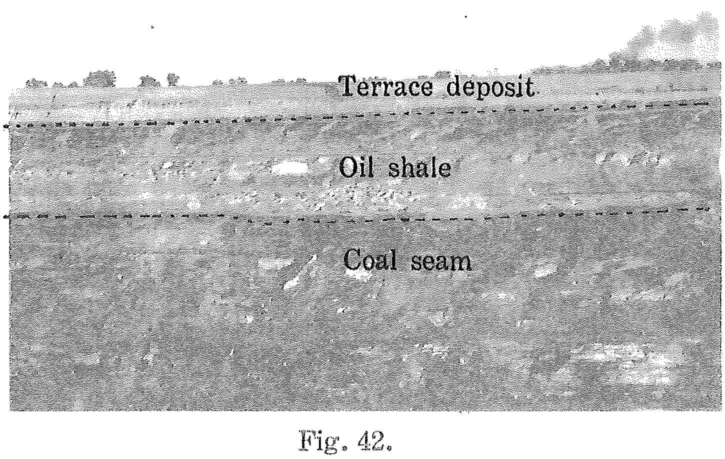


Fig. 42.

Plate VIII

Explanation of Plate VIII

Fig. 43. The Fushun colliery. The oil shale bed (light part) rests on the coal seam (dark part).

Fig. 44. Olivine dolerite, showing a ophitic structure. F, felspar. P, pyroxene. O, olivine. Magnified 30 diameters.

Fig. 45. Angular quartz grain in the Fushun oil shale. Magnified 60 diameters.

Fig. 46. Wood tissue in "Bota." Magnified 16 diameters.

Fig. 43.

Fig. 44.

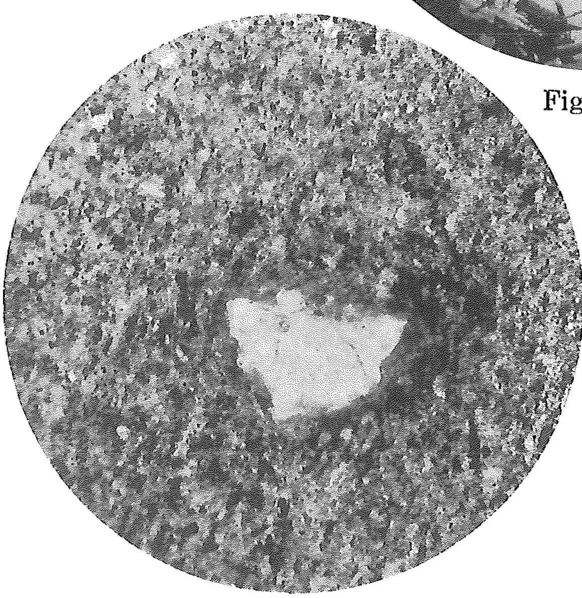


Fig. 45.

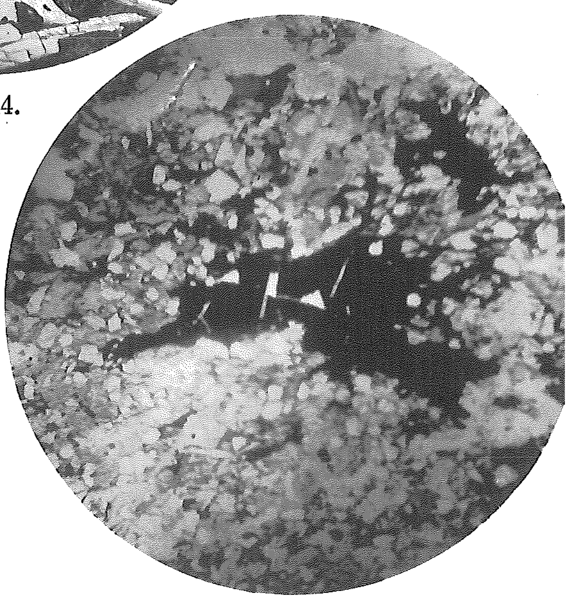


Fig. 46.

K. Uwatoko: Fushun Oil Shale.

Plate IX

Explanation of Plate IX

Fig. 47. Wood tissue in the Fushun oil shale. Horizontal section. Magnified 250 diameters.

Fig. 48. Siderite nodule. Magnified 70 diameters.

Fig. 49. Black phosphorous nodule. A, core of the nodule. B and C, outer zone of the nodule. Natural Size.

Fig. 50. The poor Fushun oil shale. The dark spots are bituminous. Cross section. Magnified 160 diameters.

Fig. 51. Siderite bed, showing micrograins of siderite. Horizontal section. Magnified 160 diameters.

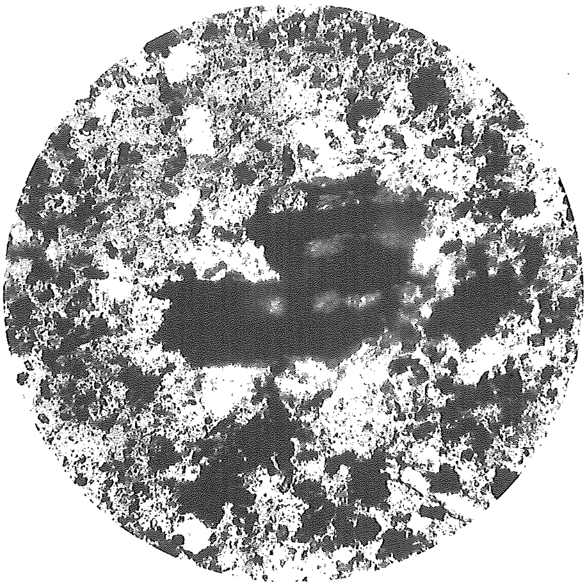


Fig. 47.

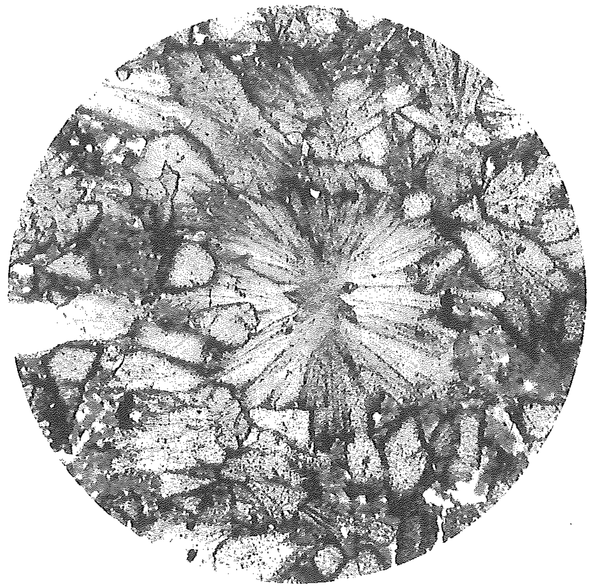


Fig. 48.

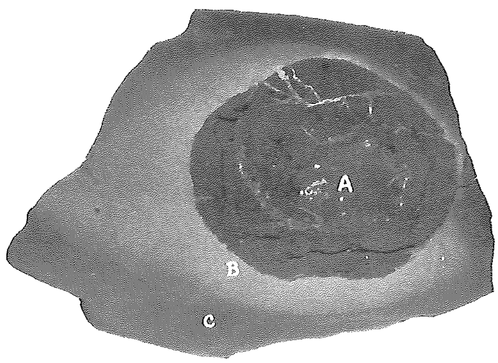


Fig. 49.

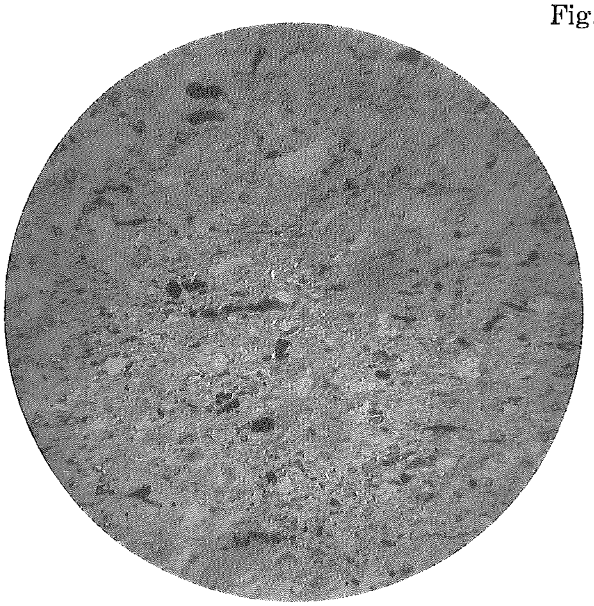


Fig. 50.

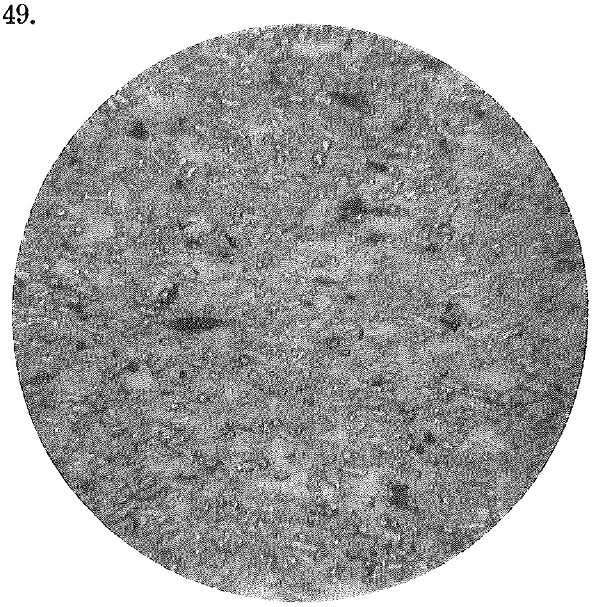


Fig. 51.

K. Uwatoko: Fushun Oil Shale.

Plate X

Explanation of Plate X

Fig. 52. The most rich Fushun oil shale. Cross section. H, humic substance. Magnified 60 diameters.

Fig. 53. The most rich Fushun oil shale. Cross section. H, humic substance. R, resinous substance. Magnified 60 diameters.

Fig. 54. The most rich Fushun oil shale developed immediately below the green shale, showing groups of varves distorted by pressure. The dark bands consist of humic substance. Cross section. Magnified 160 diameters.

Fig. 55. Ferrous sulphide coating on the rich oil shale. Cross section. F, ferrous sulphide. O, oil shale. Magnified 30 diameters.

Fig. 56. Rich Fushun oil shale. Cross section. H, humic substance.

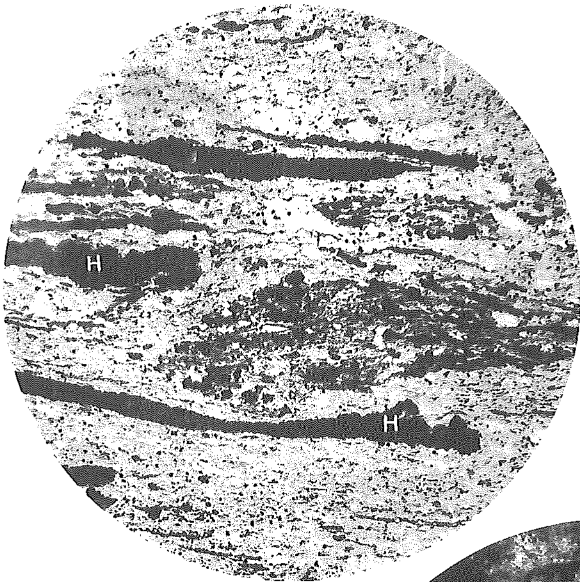


Fig. 52.

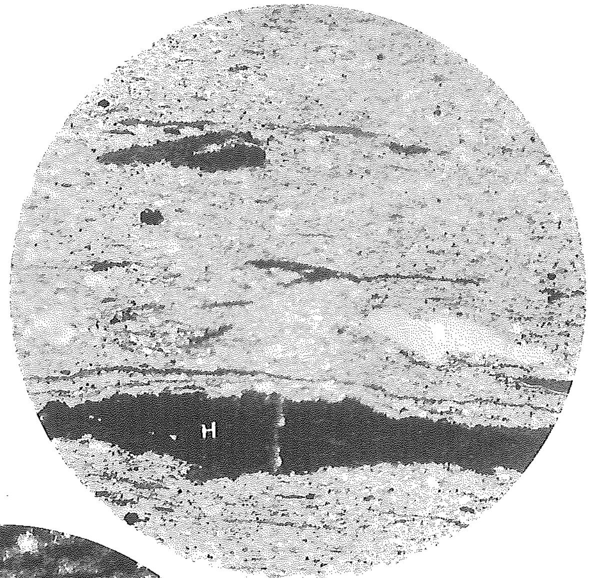


Fig. 53.

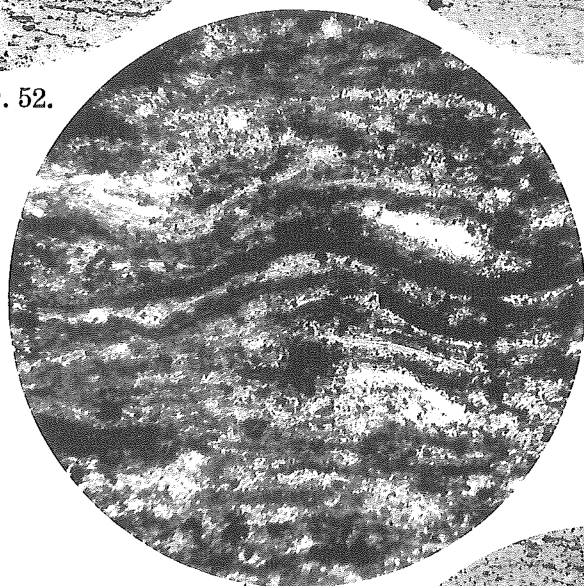


Fig. 54.

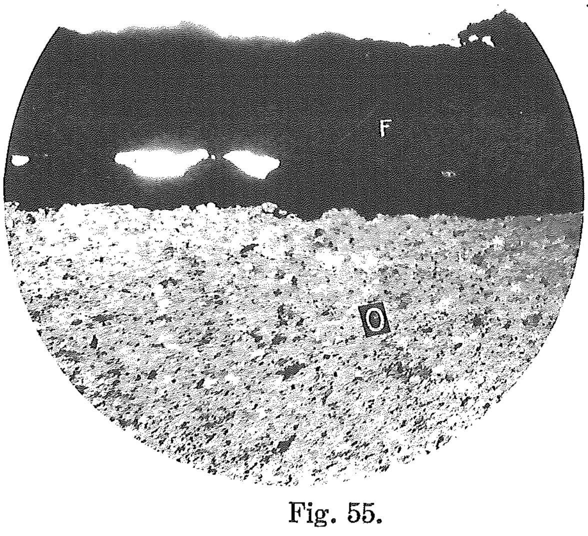


Fig. 55.

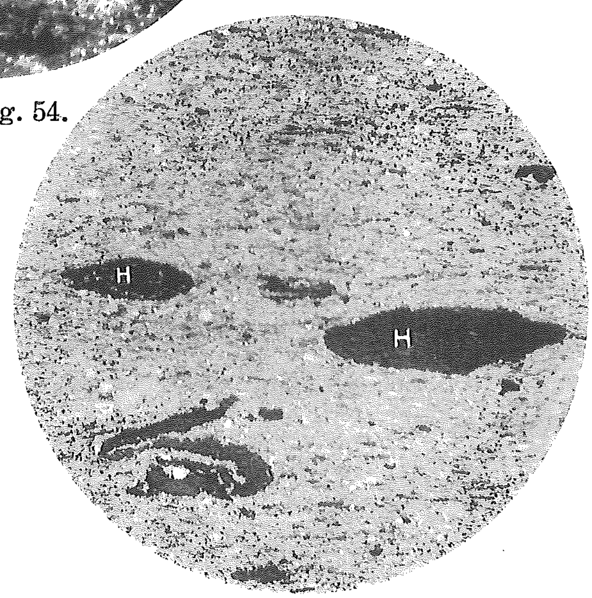


Fig. 56.

K. Uwatoko: Fushun Oil Shale.

Plate XI

Explanation of Plate XI

Fig. 57. Resinous globule in the Fushun oil shale, showing elliptical shape. Cross section. Magnified 16 diameters.

Fig. 58. Microstructure of the resinous substance in the Fushun oil shale, showing scroll works. Horizontal section. Magnified 140 diameters.

Fig. 59. Resinous substance in the Fushun oil shale, showing spherical shape. Horizontal section. Magnified 116 diameters.

Fig. 60. Microstructure of the resinous substance in the Fushun oil shale, showing cloudy structure. Cross section. Magnified 60 diameters.

Fig. 61. Organic remains in the Fushun oil shale. Cross section. Magnified 60 diameters.

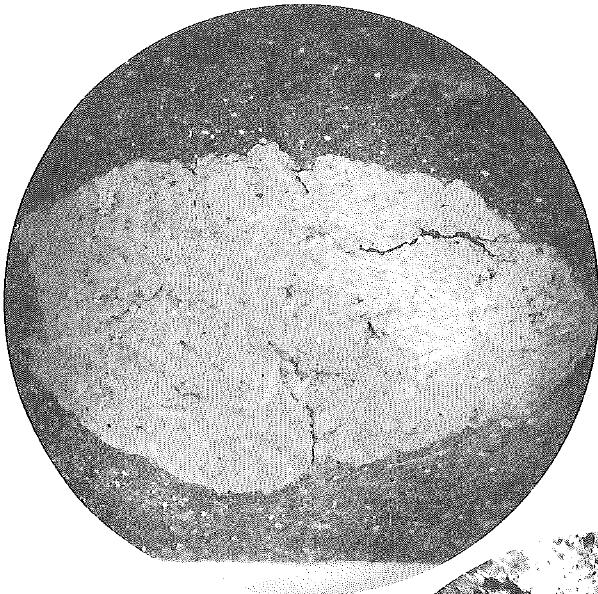


Fig. 57.

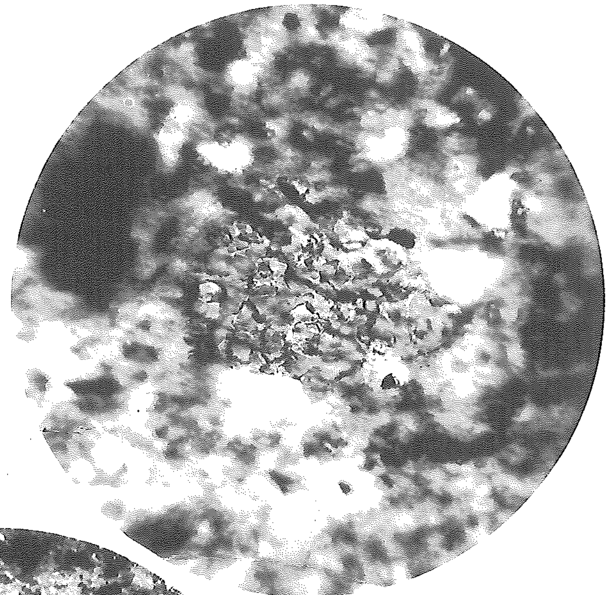


Fig. 58.

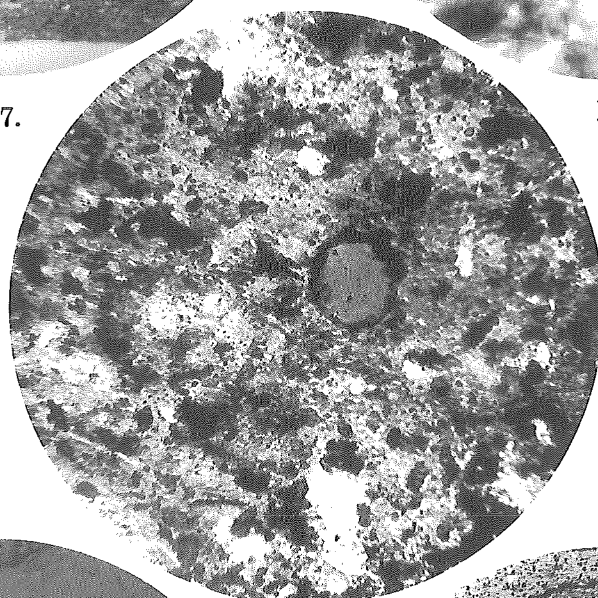


Fig. 59.

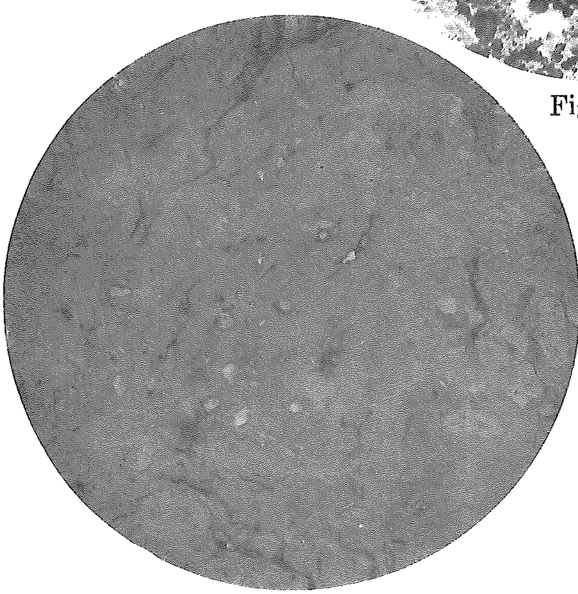


Fig. 60.

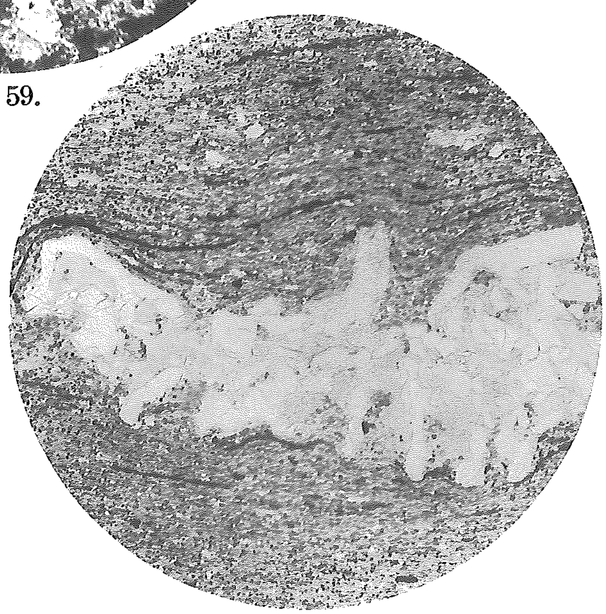


Fig. 61.

K. Uwatoko: Fushun Oil Shale.

Plate XII

Explanation of Plate XII

Fig. 62. Pilz spore after mezeration of the Fushun oil shale. Magnified 250 diameters.

Fig. 63. Conifer pollen after mezeration of the Fushun oil shale. Magnified 400 diameters.

Fig. 64. Pollen after mezeration of the Fushun oil shale. Magnified 250 diameters.

Fig. 65. Marcasite microglobules in the Fushun oil shale. Cross section. Magnified 200 diameters.

Fig. 66. Marcasite microglobules in the Fushun oil shale. Horizontal section. Magnified 250 diameters.

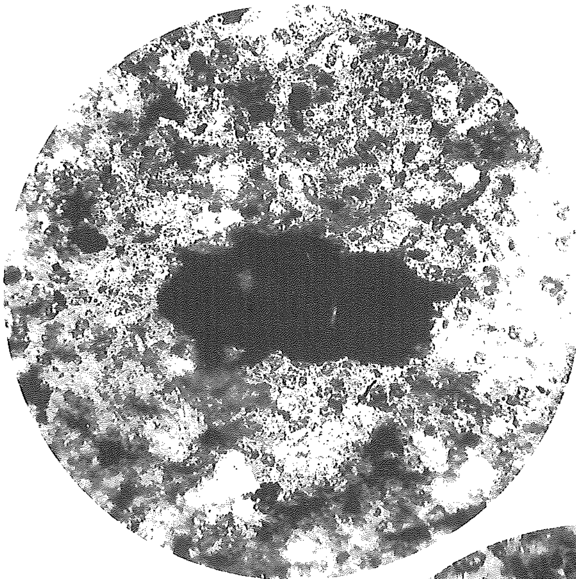


Fig. 62.

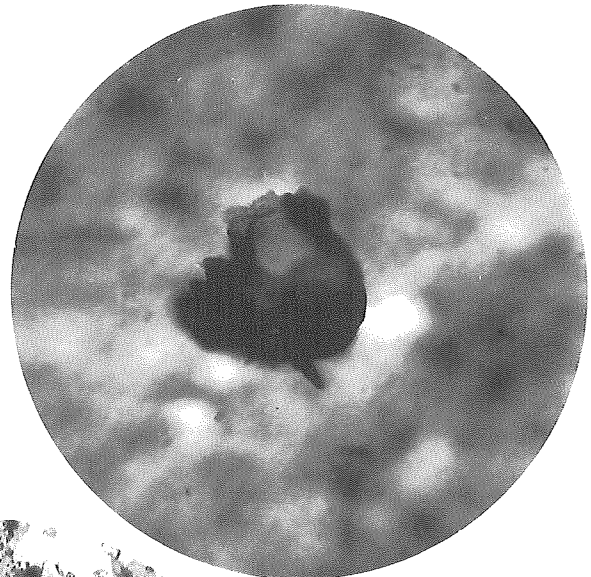
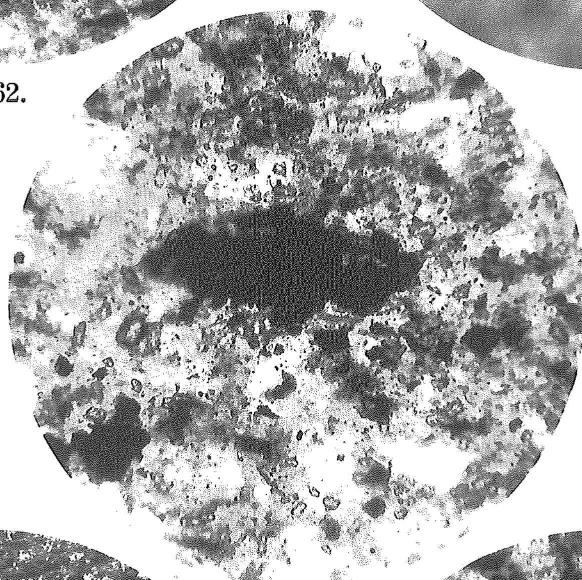


Fig. 63.



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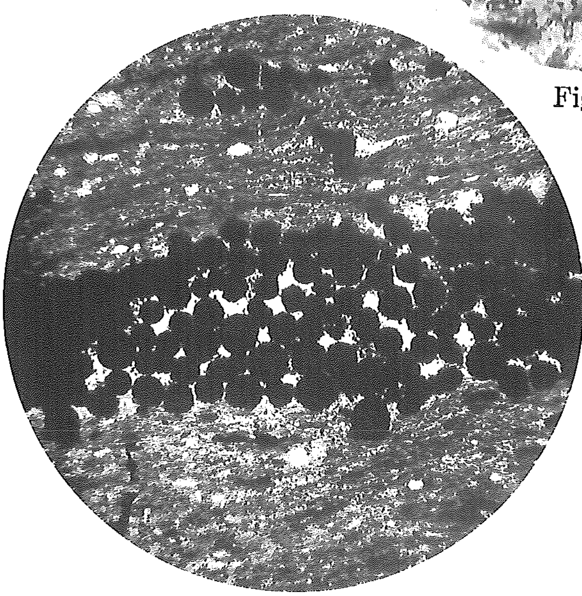

Fig. 65.

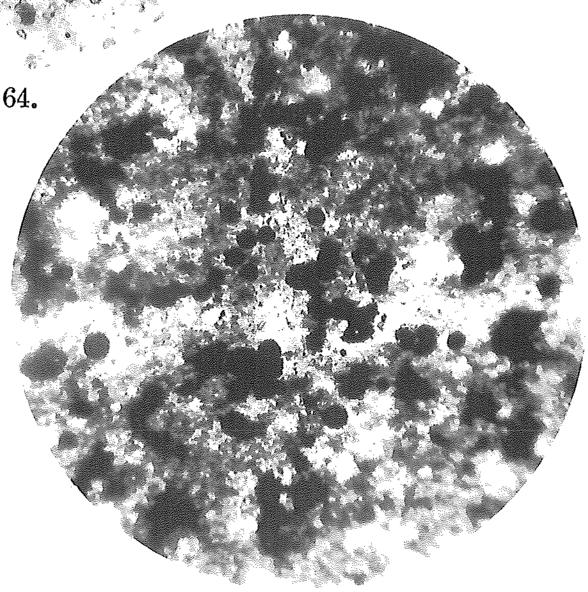

Fig. 66.

K. Uwatoko: Fushun Oil Shale.

Plate XIII

Explanation of Plate XIII

Varves of the Fushun oil shale. The darker parts of the rock contain the most organic matter, while the lighter parts contain the most grains of siderite, the later always comes with a sharp line immediately above the former, and it passing gradually into the darker parts.

Figs. 67 and 68 show specimens of the cores of the diamond boring for prospecting the oil shale at the Fushun colliery.

Figs. 69 and 70 show handspecimens collected by the present writer at the Fushun colliery. Natural size.

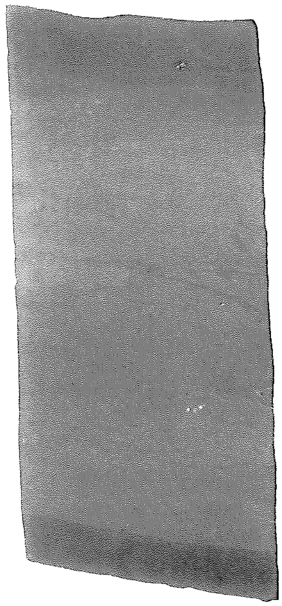

Fig. 67.

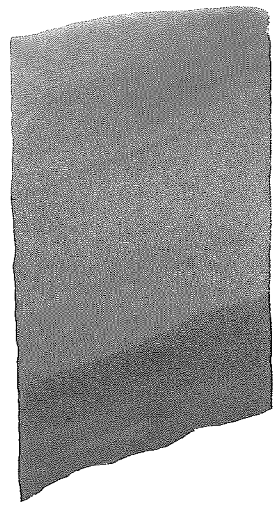

Fig. 68.

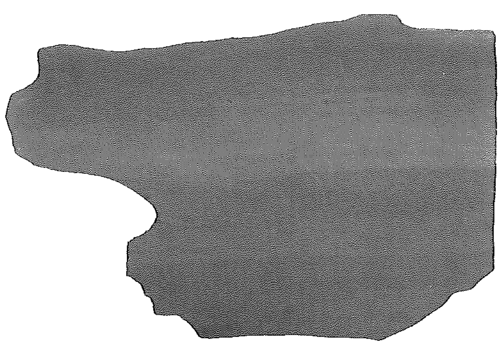

Fig. 69.

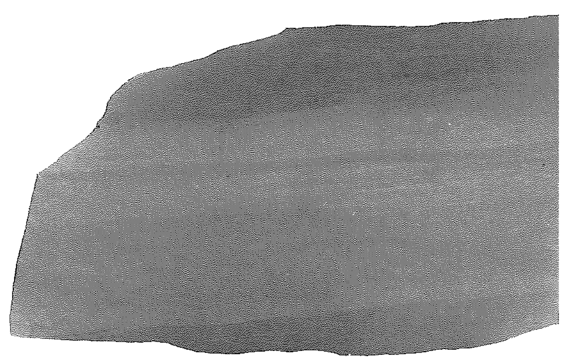

Fig. 70.

K. Uwatoko: Fushun Oil Shale.