Intrusive Rocks and their Influences on Coal-Seams, Chikuhō Coal-Field, Japan.

By Torajirō Ueji.

Contents.

Abstract.

The author treats of the occurrences and the petrographical properties of the intrusives, their influences on coal-seams and some suggestions on the utilization of the metamorphosed coal in Chikuhō coal-field in this paper.

Several thick coal-seams in the lower part of the coal-bearing Tertiary in the field are intruded with the igneous dykes and sheets of pyroxene-andesite or olivine-basalt. The coal, which is strongly influenced by these intrusives, is lower in volatile matters and higher in carbon and ash than are such as those of anthracite, and has been changed into graphite in the extreme case. A property of the decrepitation on heating is one of the characteristics of the coal. Macerations can be observed near the contact, and materials from the intrusives have been supplied to the coal. Abundant micro-pores and veins, containing quartz, chalcedony, opal, calcite and zeolites, also can be observed in the thin sections of such metamorphosed coal. Although oxygen and hydrogen in the coal decrease in inverse proportion to the proximity of the intrusives, those elements rather increase a little in amount instead of reaching a minimum when the coal is in direct contact with the rocks.

The author concluded that the phenomenon of the contact-metamorphism of coal by intrusives in this region can not be explained completely by a simple thermal effect only, but some substances such as water-vapor, gases and hydrothermal solutions from the intrusives have been supplied to the coal in the high pressured conditions underground.

Introduction.

The Chikuhō region, one of the largest coal-fields in Japan, lies in the northern part of Kyūshū Island. Its center Nōgata, stands at about 33°44′ N.L., 130°44′ E.L. The river Onga runs northward through the region, draining two basins of Kaho and Tagawa, and empties itself into the Corea-Channel. (Fig. 1) The coal-field is about 48 km. in length, 12 to 21 km. in width and the area is about 787 sq. km. The geological age of the coal-bearing strata is the Paleogene Tertiary. This bears about 40 workable coal-seams, (Fig. 2) and coals belong to the bituminous type of low grade. The yearly output of coal in the field is about 13 million tons, 40% of the whole production in Japan.

It is a striking phenomenon, that the intrusive sheets widely extend in the coal-beds, mostly in the southern half of the region. The stratigraphical geology of the region has been studied during the past 40 years by several geologists such as Dr. S. Suzuki,[1) 2)] C. Kido and S. Matsuda,[3)] Dr. K. Inouye[4)] and Dr. T. Nagao,[5)] while some of the

1) Suzuki, S., Explanatory Text on the 1 : 200,000 Geological Map of Fukuoka Sheet. (in Japanese), Imp. Geol. Surv. Japan, Tōkyō, 1894.

2) Suzuki, S., Geological Explanatory Text on the Coal-Field in Buzen and Chikuzen. (in Japanese), Jour. Geogr. Tōkyō, Vol. VI–VII, 1894–1895.

3) Kido, C. and Matsuda, S., Geological Report on the Coal-Field of the Chikuhō 4 Districts. (in Japanese), Min. Inspect. Off. Fukuoka, 1904.

4) Inouye, K., The Coal Resources of the World. Inq. XII Internat. Geol. Cong., Canada. Vol. I, 1913, pp. 339–331., Also, Coal in Japan, (in Japanese), Rep. of the Geol. Surv. Japan, No. 42, 1913, PP. 203–232.

5) Nagao, T., Explanatory Text on the Geological Map of Chikuhō Coal-Field. (in Japanese), Chikuhō Coal Min. Corp., Wakamatsu, 1929.

Fig. 1.

General map of Chikuhō coal-field, northern Kyūshū, Japan.

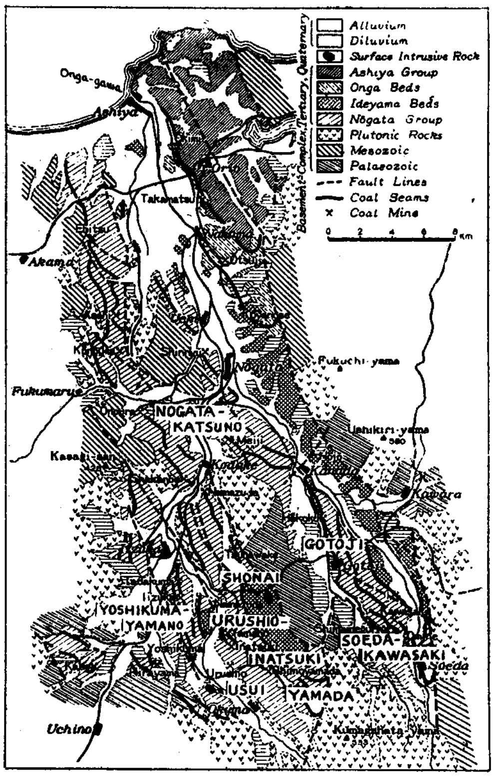
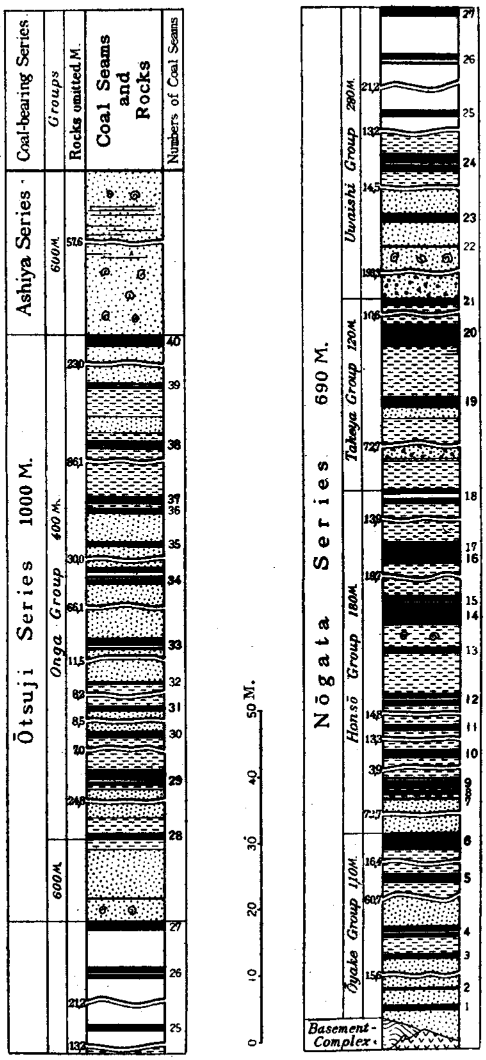


Fig. 2.

Columnar section of main coal-seams in the Chikuhō coal-field, northern Kyūshū, Japan.



intrusive rocks was reported by some petrographers, such as Prof. K. Yamada,[1] N. Fukuchi[2] and Prof. T. Katō.[3] Yet unfortunately with any complete study of these intrusive rocks in this region, we are not provided.

The study of these intrusive rocks is a matter of no small importance to the coal mining industry in this region. For the coal that lies in immediate contact with the intrusive rocks is considerably metamorphosed, and has a strongly decrepitating character on heating and the coal thus metamorphosed and decrepitated is quite unfit for manufacturing and other purposes at present. The regular methods of mining are not to be adopted, when the intrusive sheets extend in the coal-beds, for these sheets lie in irregular thicknesses and extensions.

The writer of this paper has investigated the intrusive rocks and the metamorphosed coal in this coal-field during the last several years. He gratefully acknowledges his indebtedness to Prof. T. Ogawa and Prof. S. Nakamura, for their kindness in guiding him in the laboratory work. He is also indebted to Prof. T. Otagawa, Prof. G. Kurauchi, of the Kyōto Imperial University, for their constant sympathy and active advice during the progress of the work. Mr. S. Ishiwatari and Mr. S. Noda, the directors of the Chikuhō C. M. C., provided various facilities for this work, Mr. T. Kumasaki and Mr. N. Tanaka of the Department of Mining and Metallurgy of the Kyōto Imperial University, did not spare their assistance towards his researches, for which he is under much obligation.

Historical Review.

The coal metamorphosed by intrusive rocks

1) Ueji, T., A Study on the Igneous Rocks and their Specimens in Chikuhō Coal-Field by late Prof. K. Yamada. (in Japanese), Jour. Chikuhō Coal Min. Corp., Vol. XXIII, No. 277, 1926, pp. 3–13.

2) Fukuchi, N., The Rocks which have given the Metamorphic Action upon Coal in the Chikuhō Coal-Field. (in Japanese), Jour. of the Geol. Soc. Tōkyō, Vol. XI, No. 126, 1904, pp. 81–91.

3) Katō, T., Geological Note on Yabakei and Volcano Hikosan. (in Japanese), Pub. Earthq. Inv. Com., Japan, No. 85, 1916, pp. 48–49.

was first discovered in the Amakusa coal-field in 1856,[1] and later in the Chikuhō region in our country. These metamorphosed coals are known as "Senseki" the decrepitating coal. Dr. S. Suzuki[2] classified them into two kinds by the content of ash, he holds that these differences had come from the action of heat from the intrusives.

Recently Dr. A. Naitō[3] studied the utilization of the Senseki from Takashima colliery, but he did not extend his notice to the nature of the metamorphism of coal. The contact-metamorphic phenomenon of coal has never been treated carefully in Japan.

We have had several papers during the past sixty years on these problems in European, American and other foreign countries.[4] A. Lassaulx[5] analysed some brown coal influenced by basalt in the Meissner coal-field, and observed that the volatile matter in that coal is much lower than in the other coal. A. Uthemann[6] studied the distribution and the occurrence of the intrusive rocks and their metamorphic phenomena of coal in the same coal-field. He observed prismatic structures of the coal near the intrusive rocks and found that such coal was higher in its amount of ash and specific gravity. G. Rath[7] reported such a kind of coal as "Natürlicher Koks" in the Fünfkirchen coal-field and he ascribed its higher specific gravity to the mechanical mixtures of coal and the intrusive rocks. W. Schuckmann[8] reported that the higher specific gravity and some ash in such coal might be due to the compression in addition to the mechanical mixture of coal and the intrusive rocks. A. Allport,[9] W. Topley,[10] J. Prestwich[11] and H. Briggs[12] reported the intrusive rocks in several coal-fields in Great Britain. E. T. Dumble[13] reported "Natural Coke" in Mexico, also N. M. Fenneman,[14] J. B. Eby[15] and G. C. McFarlane[16] in the Colorado coal-field. Most of these American papers treat the contact-metamorphism of coal by intrusives as a baking phenomenon, and among the last McFarlane concluded from the character of its porosity that the temperature of the intrusive sheet was probably about 1000°C. J. A. Taff[17] studied that the amount of the volatile matter contained in the natural coke was higher than in the artificial coke.

The microscopical study of the coal metamorphosed by intrusives was carried out by H. Winter[18] and W. P. Evans[19] and others with a reflected light; they observed some woody structures and the crushed structures on polished sections of the coal.

The electrical conductivity of the contact-metamorphosed coal was measured by Gümbel[20] in 1873. He observed a weak current in the coal laid at 3 centimeters distance from the margin of basalt, but there was no flow in the coal laid 5

1) Kurimoto, R., The "Senseki" in the Chikuhō Coal-Field. (in Japanese), Jour. Geogr. Assc., Vol. 1, No. 2, 1885, pp. 106-120.

2) Suzuki, S., A Characteristic Coal in the Chikuhō Coal-Field. (in Japanese), Geogr. Jour. Japan, Vol. IV, No, 45, 1892, p. 396.

3) Naitō, A., Recently Discovered Soft Coal, Metamorphosed by Intrusives as Domestic Fuel. World Pow. Confer. 2nd, Meet. Tōkyō, No. 16, 1929, pp. 1-20.

4) Ueji, T., References on the Intrusive Rocks and their Influences upon Coal-Beds in Foreign Countries. (in Japanese), Jour. Chikuhō Coal Min. Corp., Vol. XXV, 1929, No. 304 and No. 305.

5) Lassaulx, A., Ueber die durch Basaltkontakt veränderten Braunkohlen von Meissner. Ann. d. Phys. u. Chem., Bd. CXLI, 1870.

6) Uthemann, A., Die Braunkohlen-Lagerstätten am Meisner, am Hirschberg und am Stellberg. Abh. d. König Preuss. geol. Landesanstalt. Neu. Fol., Heft 7, 1892.

7) Rath, G., Kontaktverhältnisse zwischen Kohle und einem basischen Eruptivgestein bei Fünfkirchen. Neu. Jahrb. f. Min. I, 1880, S. 274-277.

8) Schuckmann, W., Beiträge zur Kenntnis der Braunkohle des Westerwaldes. Braunkohle, Jahrg. XXIII, Nr. 14 u. 16, 1924.

9) Allport, A., On the Basalt of South Staffordshire. Geol. Mag. Vol. VI, No. LVII. 1869, p. 115.

10) Topley, W., and Lebour, G. A., On the Intrusive Character of the Whin Sill of Northumberland. Quart. Jour. Geol. Soc., Vol. XXXIII, 1877, p. 416.

11) Prestwich, J., Geology, Chemical Physical and Stratigraphical. Vol. 1, 1885, pp. 398-402.

12) Briggs, H., Alteration of Coal-Seams in the Vicinity of Igneous Intrusions and Associated Problems. Trans. Inst. Min. Eng. Vol. LXXXIX, pt. 4. 1935, pp. 187-219.

13) Dumble, E. T., Natural Coke of the Santa Clara Coal-Field. Sonora, Mexico. Trans. Amer. Inst. Min. Eng., Vol. XXIX, 1899, pp. 545-549.

14) Fenneman, N. M. and Gale, H. G., The Yampa Coal Field, Rout Count, Colorado. Bul. U. S. Geol. Surv. No., 285, 1906, p. 226.

15) Eby, J. B., Contact-Metamorphism of Some Colorado Coal by Intrusives. Trans. Amer. Inst. Min. and Met. Eng., Vol. 71, 1925, pp. 246-252.

16) McFarlane, G. C., Igneous Metamorphism of Coal Beds. Econ. Geol., Vol. XXIV, 1929, p. 9.

17) Taff, J. A., Natural Coke in the Wasatch Plateau. Science N. S., Vol. XXIII, 1906, p. 696.

18) Winter, H., Die mikroskopische Untersuchuug der Kohle im auffallenden Licht. Braunkohle, Jahrg. XXIV, 1924, S. 605-613.

19) Evans, W. P., Microstructure of New Zealand Lignities. Lignites Subjected to the Action of Igneous Intrusions. Fuel, Vol. VII, No. 2 and No. 9, 1927.

20) Gümbel, C. W., Die durch ein Eruptivgestein verkokte Kohle von Mährisch-Ostrau. Verh. d. K. K. geol. Reichsanst., Wien, 1874, S. 55.

centimeters apart from it. Recently K. Arndt[1] and Fr. Fisher[2] examined the same test; they did not observe an electric current in their sample, because such coal contained hydrogen and several other volatile matters. H. Winter[3] reached the same conclusion to the volatile matters in such metamorphosed coal by his study of the coal, he thought the temperature that caused the metamorphic action upon the coal must have been about 700°C. H. Briggs assumed that the probable temperature would, as a rule, be under rather than over 1000°C in the Whin sill, Scotland.[4]

Author's Aim and Methods of Investigation.

The present writer's aim was to investigate the essential properties of the intrusive rocks, the contact-metamorphosed coal and the actual nature of the phenomenon of the metamorphism of coal by intrusives.

The writer studied the occurrences and distributions of the intrusive rocks and the metamorphosed coal, for they are intimately connected with the coal-mining in this field. Also, he investigated the petrographical character of the intrusives, for it is important in understanding the actual metamorphic phenomenon of coal. He studied the structures and mineral constituents of the metamorphosed coal by the petrographical methods, and he tried to make the distinction clear between the normal bituminous and the metamorphosed coal. He tried to solve the origin of the decrepitating character of the metamorphosed coal while at the same time trying to ascertain the physical properties such as specific gravity, porosity and hardness of the coal.

It is a matter of importance to know the chemical properties of the coal, for we can solve the questions of the nature of the metamorphism and the utilization of the coal by its chemical compositions. He analysed the coal following the methods of the proximate and the ultimate analysis. He studied the physical and chemical properties of ash, for they are not only important in the study of the essential property of coal but also in the practical use of it.

Occurrences and Distributions of Intrusive Rocks and Metamorphosed Coal.

Distributions of the Rocks on the Surface.

Most intrusive rocks are distributed underground although a few of them are exposed on the surface of the region, making volcanic hills, igneous dykes and intrusive sheets.

Volcanic hills. Ichimuro-yama, 150 meters high, stands in the Shōnai district, Kaho-basin. We find the olivine-basalt at the top of the dome-shaped hill. Kompira-yama, 120 meters high, rises in the plain, in the Usui district, Kaho-basin. It is an eroded volcanic cone of olivine-basalt. About 700 meters east from the cone, there stands a small hill of bronzite bearing pyroxene-andesite. Suribachi-yama, 214 meters high, stands in the Yamada district, Kaho-basin. It looks like a mortar turned upside down, just like a conide type of a volcano, but nearly the whole of the hill, except the top, is composed of the sedimentary rocks of Tertiary age.

There are some other small volcanic patches in the northern part of the Chikuhō region, but these volcanic rocks have apparently no obvious connection with the coal-beds in the field.

Igneous dykes and Intrusive sheets. One of the largest of the igneous dykes which expose themselves on the surface of the field is in the south of Gotōji town, Tagawa-basin, The dyke extends east and west, crossing Chūganji stream, and is about 90 meters in width. The intrusive sheets expose sometimes along the several outcrops of the coal seams. But most of them are thinner than 1–2 meters and they are very often weathered to loamy clay.

Distributions of the Rocks in the Coal-Seams.

Boring records. The underground distributions of the intrusive rocks have been tested by several bore-hole surveys, especially in the Nōgata coal-bearing series. The records of 60 borings are shown diagramatically in Fig. 3, No. 1.

As seen in the figure, there are distributed abundant intrusive rocks in the Honsō group, a division of a middle part of the Nōgata coal-bearing series. The inspection of the writer has shown that the intrusive rocks are distributed more widely than in the above records. (Fig. 3. No. 2.) The numberings of coal-seams in Fig. 3 correspond to those of the columnar section in Fig 2. The investigator classified the region containing the underground intrusive rocks into the following eight districts.

Yamada district. This district occupies the southeastern corner of Kaho-basin. Several coal-seams extend northwest as far as Inatsuki district. There are many collieries working actively, Kami-

1) Arndt, K., Die Bestimmung des Graphitgehaltes in graphitierten Elektroden. Elektrotech. Z. Jahrg. XLIII, 1922, S. 966–967.

2) Fisher, Fr. und Pfleiderer, G., Abh. der Kohle, Vol. IV, 1919, S. 394., "Die Veredelung der Braunkohle durch Basaltkontakt. Braunkohle, XXIV, Jahrg. Nr. 29, 1925, S. 656."

3) Winter, H., Die Veredelung der Braunkohle durch Basaltkontakt. Braunkohle, XXIV, Jahrg. Nr. 29, 1925, S. 653–658.

4) Briggs, H., loc. op. cit., 1935, p. 193.

Fig. 3.

Distributions of the intrusive rocks in the coal-seams.

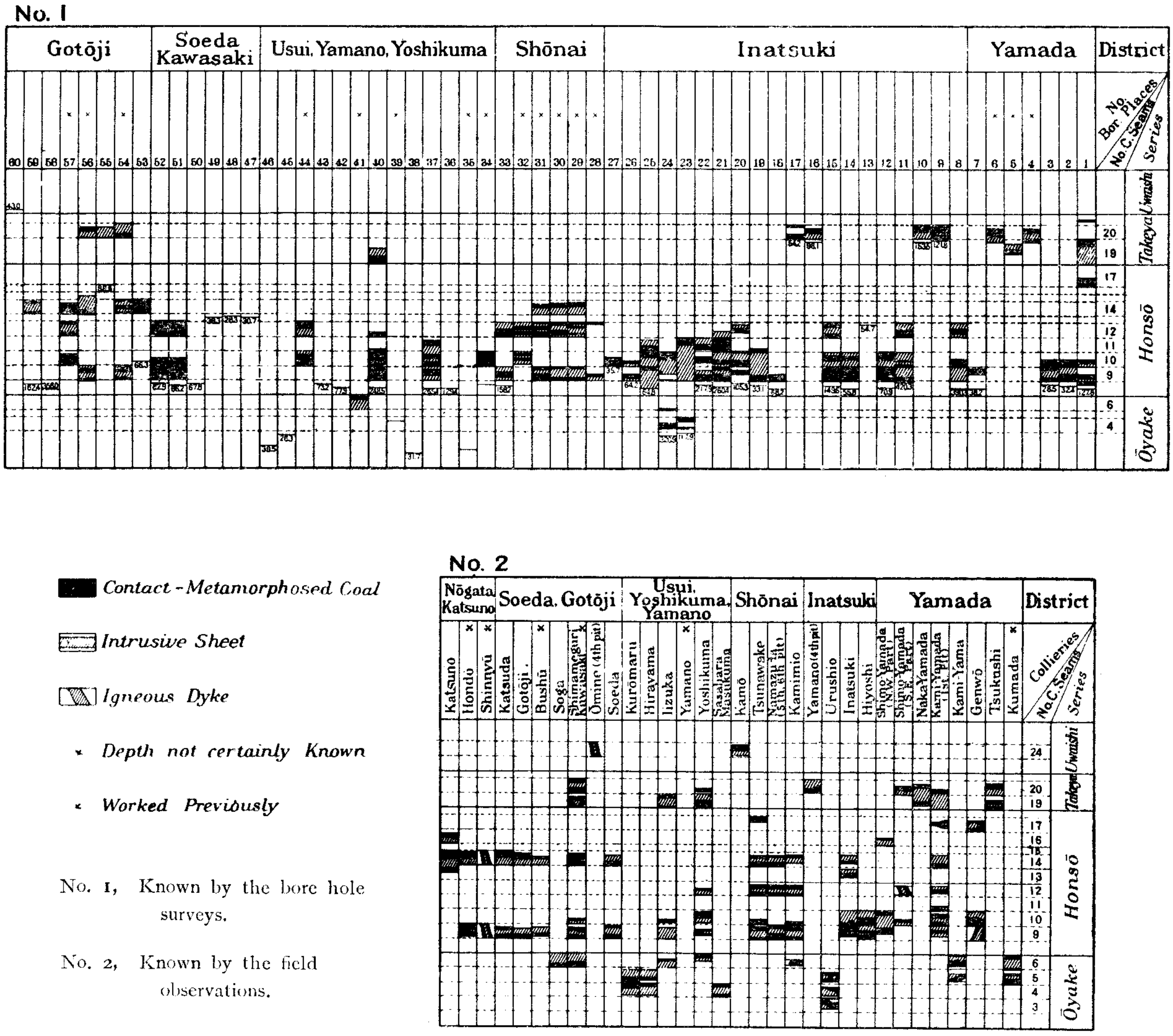
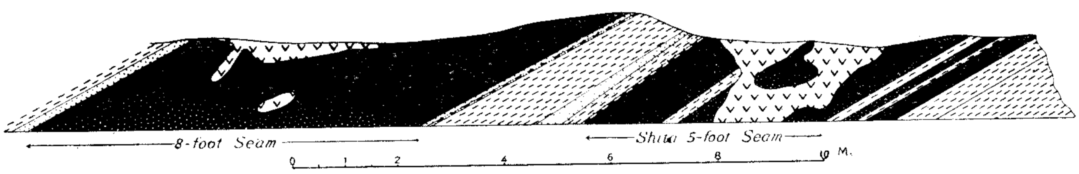


Fig. 4.

Intrusive sheet. Kami-yamada colliery, Yamada district.



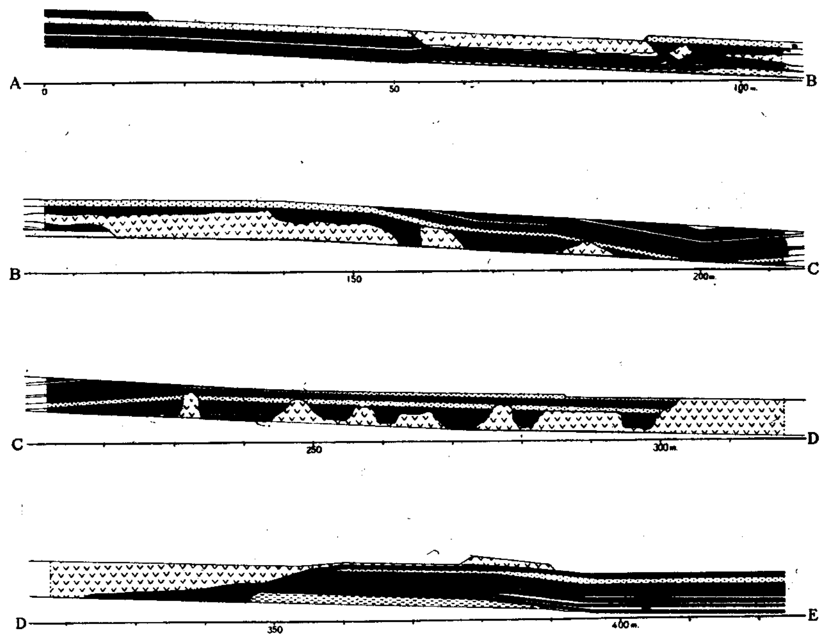
yamada being the largest one in the district. The intrusive sheets extend widely in No. 9 and No. 10 seams, that is, the Shita 5-foot seam and 8-foot seam. (Fig. 4) Also these intrusives extend in the several other thicker seams, such as No. 11, No. 12, No. 14, No. 16, No. 19 and No. 20. Generally speaking, the intrusive sheet spreads more extensively in the thicker than in the thinner seams, for example, the No. 10 and No. 14 seams have wider distributions than do any other thinner ones.

Two coal-seams, No. 19 and No. 20 are being worked in Naka-yamada colliery. The intrusive sheet thrust itself in No. 19 seam at first and then extends into No. 20 seam by a fault which occurred before the time of the igneous intrusion. There are two parallel faults running NW-SE, making horst in Shimo-yamada colliery. The coal-seams in the horst part are almost free from the large intrusive sheet, constituting the main workable part of the colliery. But several coal-seams in the outer sides of the horst are intruded by various extensive sheets.

Moreover, above the intrusive sheets, there occur more than 10 igneous dykes, running N 70° W, N 45° W. etc. in Yamada district. The longest one is, 2.2 Kilometers in length; it extends from Kami-yamada to Shimo-yamada. The direction of the dyke runs parallel to a fault. It is noteworthy that dykes sometimes swell up into the coalseams when they cross themselves, and very often they turn into sheets.

Fig. 5.

Occurrence of the intrusive sheet, Yamano colliery, Inatsuki district.



Urushio-Inatsuki district. This district is the northwest extension of the former district. Among several collieries, Urushio, Inatsuki, 4th pit Yamano are famous for their production of coal. The intrusive sheet, extending from the western part of the district, gave the metamorphic action to the several coal-seams of the Ōyake group at Urushio colliery, and the sheet from the south metamorphosed the coal of the Honsō group at Inatsuki colliery. The intrusive sheet in the 4th Pit Yamano colliery gave the strong metamorphic action to the coal of the Takeya group. The intrusive sheet in No. 10 seam encroaches upon the coal-bed and the coal in the upper seam (No. 9) is metamorphosed by the influence of the sheet. No. 20 seam in the Takeya group is being worked at 4th Pit Yamano. The extension of the intrusive sheet in that coal-seam is an oval shape with its longer axis. 1.2 km. The central part of it occupies all the coal-seam, although the marginal part only intrudes into the upper part of the seam. Its occurrence in the working place of No. 34 tunnel in that coal-seam is shown in Fig. 5.

Shōnai district. This is the northern extension of the former district. Several large collieries such as Kamimio, Namazuta, Akasaka, Tsunawake and Kamō are at work there. The main three seams of the Honsō-group, No. 9, No. 12 and No. 14, are intruded by the extensive intrusive sheets in the district. The general occurrence of a sheet in the coal-seam No. 12 is shown in Fig. 6 as measured in the coal-pit. Sometimes coal is piled up at one place by the movement of the sheet, and makes the coal-seam thicker than 5 meters in lenticular shapes.

Fig. 6.

Intrusive sheet in a coal seam. Tsunawake colliery, Shōnai district.

Rocks and Coal	Coal Seam	Thickness
Shale		Meters 1.061
Sandstone		0,242
Coaly Shale		0,212
M. Coal		0,121
I. Sheet		0,183
M. Coal		0,242
Intrusive Sheet		1,575
Metamorphosed Coal		0,940
Coaly Shale		0,121
M. Coal		0,727
I. Sheet		0,061
M. Coal		0,454
Coaly Shale		0,455
M. Coal		0,121
Coaly Shale		0,061
Shale		

Usui district. This is situated in the southern end of Kaho-basin, including Mt. Kompira, a small volcanic hill. There are few important collieries in the district, but some small ones are working temporarily at the coal metamorphosed by the intrusives.

Yoshikuma-Yamano district. There is great fault in the eastern border of the district, sharply dividing it from the Inatsuki district; another great fault runs nearly through the middle of the district in a NW-SE direction, dividing the district into two parts eastern and western parts.

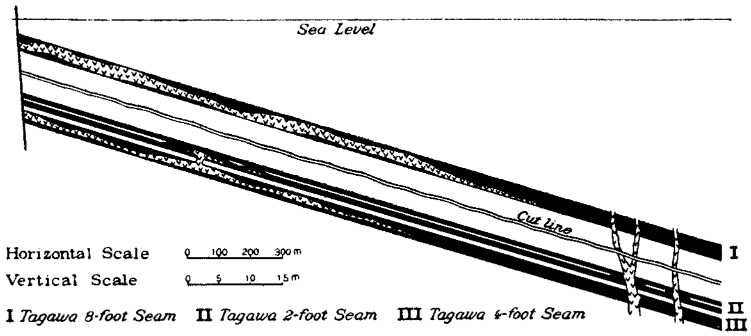
Yoshikuma colliery is one of the largest in the district, working at the several coal-seams in the coal-bearing beds of Ōyake, Honsō and Takeya groups. Some of the intrusive sheets in the district extend to the north to Iitsuka colliery. The intrusive sheets of No. 9. (3-foot) No. 14 (5-foot) and No. 19 (Urada) seams are well known by the minors.

Soeda-Kawasaki district. In Tagawa-basin, the coal-seam No. 9 and No. 14 in the Honsō group and No. 20 seam in the Takeya group are important on account of their thicknesses and their qualities. The intrusive rocks are of more density in the northern part of the district, such as abandoned pit of Kawasaki colliery and in the working pit of Shimameguri colliery.

Gotōji district. The quality of coal in the seams in the coal-bearing Honsō group is getting better. But the only drawback in these better coal-seams is the wide extension of the intrusive

Fig. 7.

Intrusive sheets. Tagawa colliery, Gotōji district.



sheets. These sheets extend from the south to the neighbourhood of Gotōji town in No. 9 (Tagawa 4 foot) seam, and to Hōkoku colliery in No. 14 (Tagawa 8 foot) seam. The east and west profile of these two sheets near Gotōji town is shown in Fig. 7.

Nōgata-Katsuno district. The district includes the central part of Chikuhō coal-field, with the city of Nōgata as its center. The thick intrusive sheets are found in the coal-seams near Katsuno colliery. The metamorphosed coal is heaped up to some ten meters by the movement of the sheets in some parts of the colliery.

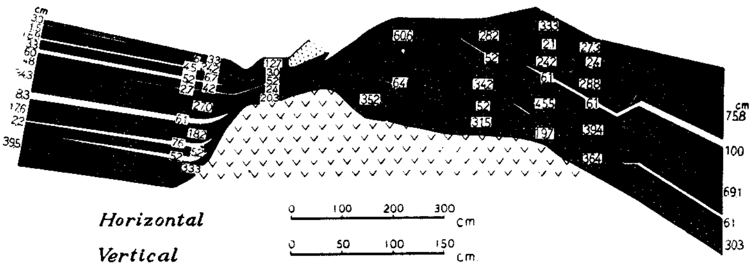
Occurrence of Metamorphosed Coal.

The metamorphosed coal occurs in the margin of the intrusive rocks and can be classified into three occurrences mainly, as follows :—

In a margin of the intrusive rocks. The coal lying within several meters from the margin of the intrusive rocks is commonly metamorphosed and differs in its physical and chemical properties from normal coal. The intrusive sheet sometimes

Fig. 8.

Intrusive sheet in the foot-wall of a coal-seam. Kamō colliery, Shōnai district.



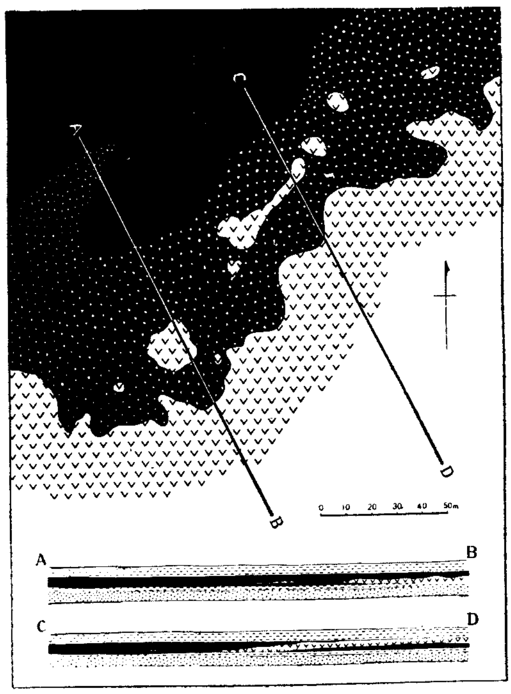
extends beneath the hanging-wall, or the foot-wall (Fig. 8) or along the middle part of the coal-seam. The coal-seam, in such formation, becomes thinner and almost all the coal is metamorphosed. The thicker the intrusive sheet becomes lenticularly the thinner the coal-seam.

In a lenticular masses. Sometimes the coal is heaped up at one place by the strong pressure of the intrusion, and the seam is swollen up several meters thick making a lenz or pool. The largest lenz in the field is recorded above 60 meters in vertical thickness at the thickest part in Nōgata-Katsuno district.

Thin layers. Some metamorphosed coal occurs between the normal coal-seams, forming thin layers, usually 3 to 10 centimeters in thickness. Such layers of the metamorphosed coal can be traced more than 70 meters from

Fig. 9.

Margin ot the intrusive sheet. Tagawa colliery, Gotōji district.

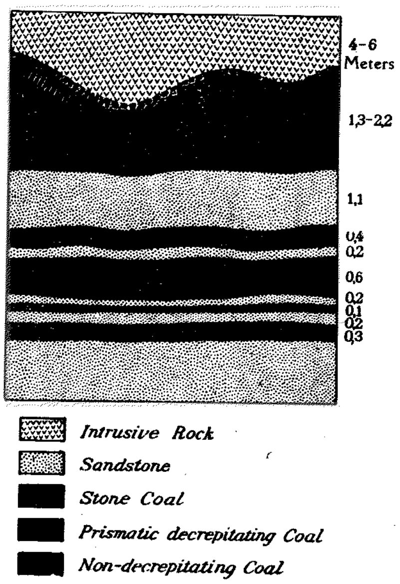


the margin of the intrusive sheet. (Fig. 9)

Prismatic structure. Sometimes the columnar joints are found in the metamorphosed coal. Its slender pentagonal or hexagonal prisms being sometimes six centimeters or more in diameter, and twenty centimeters in length. This characteristic structure is a contraction joint, such as is frequently produced in the volcanic lava, which is compact or homogeneous in its texture. (Fig. 10)

Fig. 10.

Prismatic structure of the metamorphosed coal.
Inatsuki colliery, Inatsuki district.



Petrography of Intrusive Rocks.

Types and the Classification of the Rocks.

The types of the intrusive rocks above mentioned can be classified into the following three types by their structure, texture, mineral composition and chemical properties. (Table 1)

1. Hornblende-trachyandesite.
2. Pyroxene-andesite.
3. Olivine-basalt.

Hornblende-trachyandesite. The rock is only found in the Yamada district, Kaho-basin. The typical locality of the rock is No. 16 seam at Genwō colliery. The rock is light grey in colour, but light greyish green when weathered. The texture of the rock is fine grained and compact with some porphyritic phenocrysts of the barkevikitic amphibole. (Fig. 11) A great number of lath shaped plagioclases, with trachytic structures, can be observed under the microscope. An average composition of the phenocrysts of plagioclases is 45–46% in anorthite-molecules, that is a class of andesine-labradorite in the classification of the mineral.

Pyroxene-andesite. The rock is widely distributed in the field, and can be classified into four types by the composition of the component minerals as shown in Table 1.

The rhombic-pyroxene-bearing pyroxene-andesite distributes at Usui-district, southern Kaho-basin, (Fig. 12) Soeda-Kawasaki district (Fig. 13) and Gotōji district in Tagawa-basin. The bronzitic rhombic-pyroxene, with a bastite structure is the

Table 1.

Classification of the intrusive rocks and their essential minerals.

Classification of Rocks / Structures and Minerals	Hornblende-trachyandesite	Pyroxene-andesite				Olivine-basalt
		Bronzite-bearing	Hornblende-bearing	Mica-bearing	Olivine-bearing	
Structure	Trachytic	Andesitic	Doleritic, Trachytic	Doleritic	Andesitic, Doleritic	Doleritic, Trachytic
Plagioclase	An 45–46	An 47–48	An 59	An 60.25	An 65.5	An 69.5
Amphibole	Hornblende (Barkevikitic)	—	Hornblende (Basaltic)	—	—	—
Monoclinic-pyroxene	Augite	Augite (Diopsidic)	Augite (Diopsidic)	Augite (Diopsidic)	Augite (Diopsidic)	Augite
Rhombic-pyroxene	—	Bronzite	—	—	—	—
Mica	Biotite	Biotite (rare)	Biotite	Biotite (abundant)	Biotite (rare)	Biotite (rare)
Olivine	—	—	—	—	Olivine (Phenocryst)	Olivine (Phenocryst, Groundmass)
Quartz	Quartz	Quartz (rare)	Quartz, Chalcedony	Quartz	—	—
Magnetite	Magnetite	Magnetite (rare)	Magnetite (rare)	Magnetite (rare)	Magnetite (rare)	Magnetite
Apatite	Apatite	Apatite	Apatite	Apatite	Apatite	Apatite

Fig. 11.

Hornblende-trachyandesite. ×25.

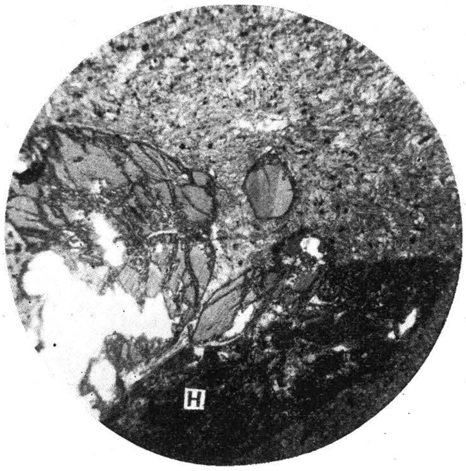


Fig. 12.

Pyroxene-andesite. ×11.

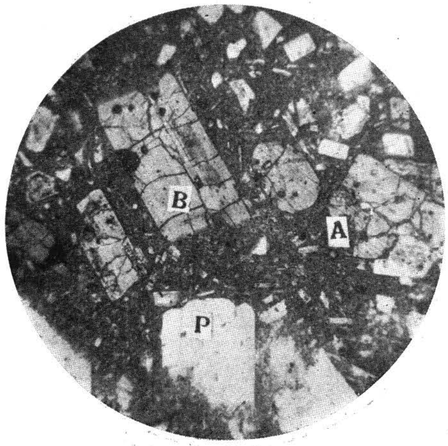


Fig. 13.

Pyroxene-andesite. ×40.

Fig. 14.

Pyroxene-andesite. ×25.

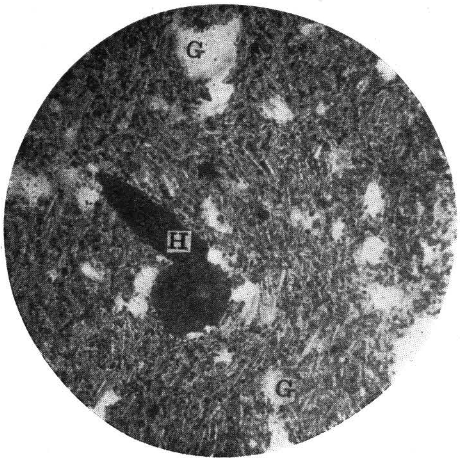


Fig. 15.

Pyroxene-andesite. ×30.

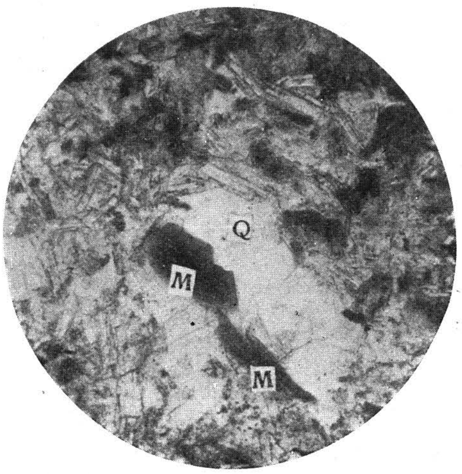
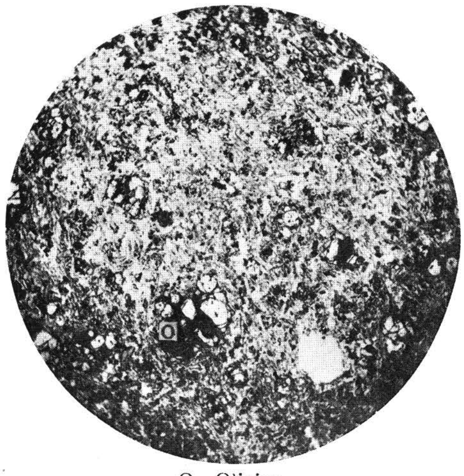


Fig. 16.

Pyroxene-andesite. ×25.

H...Hornblende.
B...Rhombic-pyroxene.
G...Volcanic glass.
M.. Mica.
A ..Monoclinic-pyroxene.
P...Plagioclase.
Q...Quartz.

Fig. 17.
Olivine-basalt.



O...Olivine.

characteristic mineral in the rock, and the rock has sometimes a structure of the Sanukitoid.

Hornblende-bearing pyroxene-andesite distributes in the southern part of the Kaho-basin in the field making the intrusive sheets or dykes. Abundant crystals of basaltic hornblende, with needles or prismatic shapes, are found in the dark coloured rock. (Fig. 14)

Mica-bearing pyryxene-andesite. Nōgata-Katsuno district is the typical locality of the rock. (Fig. 15) Although most of the pyroxene-andesite in the field have some crystals of mica, commonly the mineral is found more abundant in this type of intrusive rocks.

Olivine-bearing pyroxene-andesite distributes in the upper part of the coal seams in the coal bearing strata or northern part in the field. The structure of the rock is the andesitic to the basaltic sometimes having the phenocrysts of olivine. (Fig. 16).

Olivine-basalt. Olivine-basalt is found on the isolated small hills, e. g. Ichimuro-yama and Kompira-yama. The microscopical characteristics of the rock is fine grained in its texture, doleritic and trachytic in its structure. The crystals of olivine are scattered abundantly as phenocrysts and groundmasses. (Fig. 17).

Microscopical Characteristics of Plagioclases in the Rocks.

The author chose nineteen fresh phenocrysts of plagioclases in each different intrusive rock-sections, and studied the optical properties of them by the methods of Fedrow's universal-stage.[1]

Table 2.
Anorthite percentages of plagioclases.

Methods / Measurements / Specimens No.	Method of 2V			Method of Cleavage ‖ (010)			Method of Cleavage ‖ (001)		
	2V	Optical Character	An%	2V	Optical Character	An%	2V	Optical Character	An%
I	80	+	46	79	+	47	.	.	.
II	78	+	48½	.	.	.	79	+	47
III	.	.	.	80	+	46	.	.	.
IV	78	+	48½	.	.	.	.	.	.
V	.	.	.	78¼	+	48	.	.	.
VI	78	+	48½	.	.	.	.	.	.
VII	78	+	59⅓	77½	+	59	.	.	.
VIII	.	.	.	77¼	+	58	.	.	.
IX	76	+	57	.	.	.	.	.	.
X	81	+	61½	82¾	+	63	.	.	.
XI	76	+	57	.	.	.	.	.	.
XII	80	+	60¾	79	.	60	.	.	.
XIII	.	.	.	80¼	+	61	.	.	.
XIV	84	+	63½	.	.	.	.	.	.
XV	84	+	,,	.	.	.	.	.	.
XVI	85	+	64½	80¼	+	61	.	.	.
XVII	85	+	,,	90	±	68	.	.	.
XVIII	.	.	.	88½	+	67	.	.	.
XIX	.	.	.	85½	+	72	.	.	.

Each specimens are contained in the following rocks:—
I. Hornblende-trachyandesite, II–VI. Bronzite-bearing pyroxene-andesite, VII–IX. Hornblende-bearing pyroxene-andeiste, X–XIV. Mica-bearing pyroxene-andesite, XV–XVII. Olivine-bearing pyroxene-andesite, XVII XIX. Olivine-basalt.

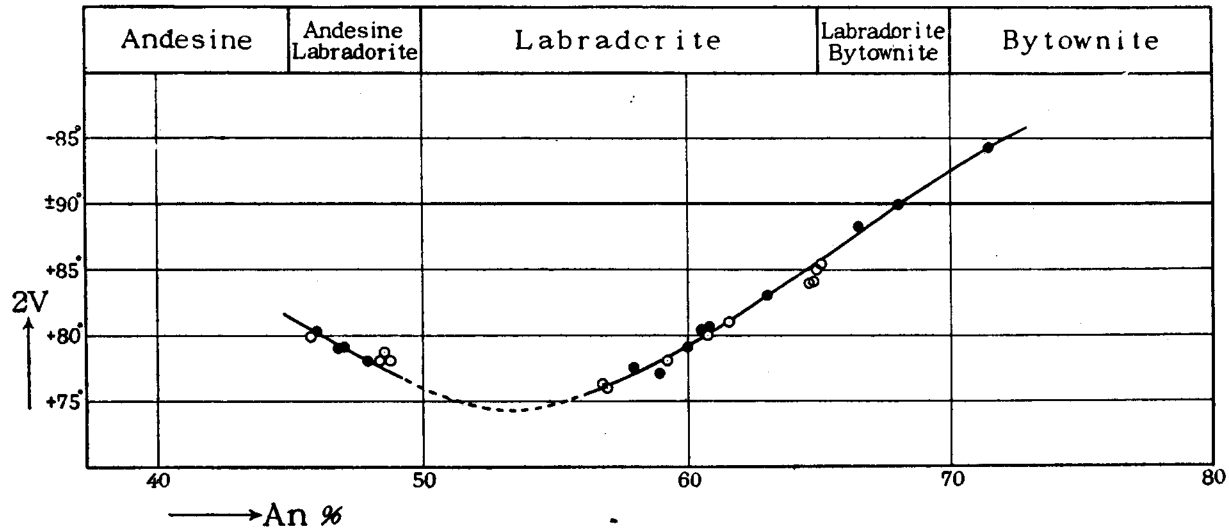
1) Fedrow, E., Eine neue Methode der optischen Untersuchungen von Krystallplatten in polaren Lichte. Tschermak Mit. Petr. Min., Vol. XII, 1891, S. 505-509, u. Universaltheodolitemethode in der Mineralogie und Petrographie. Zeitsch. Kryst., Vol. XXI–XXII, 1893–1894.

As shown on Table 2, the percentage of the molecules of anorthite in the plagioclases increases from the sample No. I to No. XIX, or in other words these plagioclases vary from andesine-labradorite to bytownite. (Fig. 18)

The intrusive rocks which bear each of these plasioclases increase their basicity in their enumerated order.

Fig. 18.

Kinds of plagioclases in the intrusive rocks.



○ *An %, gained from the direct measurement of 2V angles.*

● *2V angles, gained from the direct measurement of An %.*

Chemical Properties of the Rocks.

The chemical analysis of the rocks above mentioned is shown in Table 3. As we see in the table, the percentage of the weight of SiO_2 contained in each of the rocks, varies from 44.06% to 59.71%, and does not exceed 60%. And that of Al_2O_3, Na_2O and K_2O in the hornblende-trachyandesite is higher than in any other five kinds of rocks. TiO_2, Fe_2O_3 and FeO are higher in the olivine-basalt, and that of MgO in the pyroxene-andesite is higher as compared with the iron-oxides.

The normative minerals, the quantities of which are calculated from the chemical analysis

Table 3.

Chemical analysis of the intrusive rocks in the Chikuhō region.

Rocks / Chem. Components	Hornblende-trachy-andesite	Pyroxene-andesite				Olivine-basalt
		Bronzite-bearing	Hornblende-bearing	Mica-bearing	Olivine-bearing	
SiO_2	57.06	59.71	51.48	53.64	50.54	44.06
TiO_2	0.70	0.22	0.79	0.56	0.50	2.69
Al_2O_3	18.50	14.47	14.73	13.62	13.14	15.17
Fe_2O_3	3.48	2.97	1.83	1.32	1.73	3.64
FeO	2.33	7.31	5.52	4.73	4.55	10.98
MgO	3.29	3.51	8.76	9.52	8.39	7.76
CaO	3.70	6.64	7.90	6.82	5.52	9.62
Na_2O	4.40	2.46	0.77	1.30	2.57	2.25
K_2O	1.74	1.06	0.79	0.91	1.08	0.82
MnO	0.11	0.35	0.14	0.18	0.12	0.22
H_2O	4.56	1.37	2.32	3.15	3.40	1.82
CO_2	—	—	4.82	3.67	8.28	—
P_2O_5	0.15	0.15	0.33	0.34	0.09	0.75
Total	100.02	100.22	100.18	99.76	99.91	99.78
Analyst	U. Ushijima	T. Kumasaki	K. Horii	K. Horii	U. Ushijima	U. U.

by the methods of C. L. P. W. systems[1) 2) 3)] are shown in Table 4. The quantity of the normative quartz can be calculated out in any of the intrusive rocks with the exception only of the olivine-basalt. The normative orthoclase and albite are in much abundance in the hornblende-trachyandesite; the anorthite is least in the rock. The normative corundum is calculated only in the hornblende-trachyandesite, olivine is only in the last two rocks. The normative diopside, hypersthene and the magnesium-iron silicates predominate in the pyroxene-andesite.

Table 4.

Normative minerals in the intrusive rocks in the Chikuhō region.

Rocks / Wt. % / Minerals	Hornblende-trachy-andesite	Pyroxene-andesite				Olivine-basalt
		Bronzite-bearing	Hornblende-bearing	Mica-bearing	Olivine-bearing	
Quartz	12.10	18.75	13.31	14.84	7.92	—
Orthoclase	10.00	6.28	4.64	5.06	6.67	5.01
Albite	37.20	20.85	6.50	6.81	22.01	18.87
Anorthite	17.50	25.24	34.47	31.85	20.57	28.91
Corundum	2.90	—	—	—	—	—
Diopside	—	5.76	2.44	—	5.03	11.60
Hypersthene	8.60	16.74	27.29	30.78	16.20	7.24
Olivine	—	—	—	—	6.45	14.37
Magnetite	5.10	4.32	1.50	1.93	2.56	5.34
Ilmenite	1.30	0.43	1.50	1.64	0.92	5.17
Apatite	0.30	0.34	0.77	0.81	0.34	1.68
* Water	4.56	1.37	2.32	3.15	3.40	1.82
* CO_2	—	—	4.82	3.67	8.28	—
Total	99.86	100.09	98.59	100.54	100.39	100.01

* Do not join with the normative minerals.

According to the normative classification of the igneous rocks, the hornblende-trachyandesite can be included in the rock, II. 4. 3. 4, that is "Tonalose", the pyroxene-andesite also can be included in the rock, II. 4. 4. 4–5, that is "Bandose" and the olivine-basalt, III. 9. 4. 4–5, that is "Auvergnose".

The normative minerals and the modal ones do not coincide with each other exactly in the same rocks, because the common minerals such as micas and hornblonde etc. of complicated chemical compositions do not join with the norm. The modal quartz and the orthoclase will be observed when the rock is holocrystalline, but they will turn into volcanic glass in the groundmass when the rock is vitreous, although they are calculated out as the normative minerals. If we compare the modal minerals in Table 1 with the normative minerals in Table 4, it will be seen that there is no inconsistency between them.

The calculated values, according to Osann's[4) 5)] method from the chemical analysis of the intrusive

Table 5.

Formulae obtained by Osann's method.

Rocks / Formulae	Hornblende-trachy-andesite	Pyroxene-andesite				Olivine-basalt
		Bronzite-bearing	Hornblende-bearing	Mica-bearing	Olivine-bearing	
S	65.89	64.85	59.20	59.92	59.42	50.19
K	1.13	1.38	1.26	1.26	1.07	0.81
N	8.0	7.5	6.0	6.8	7.8	8.0
A	8.47	3.37	1.32	2.02	3.53	2.18
C	8.74	7.27	8.06	6.61	4.93	5.05
F	12.79	19.39	20.58	21.36	21.46	22.77

1) Cross, W., Iddings, T., Pirsson, L. and Washington, H. S., A Quantitative Chemico-mineralogical Classification and Nomenclature of Igneous Rocks. Jour. Goel. X, 1902, pp. 555–690.

2) Cross, W., Modifications of the Quantitative System of Classification of Igneous Rocks. Jour. Geol. XX, 1912, pp. 550–561.

3) Washington, H. S., Chemical Analysis of Igneous Rocks. U. S. G. S. Prof. Pap., No. 99., 1917, pp. 1157–1164.

4) Osann, A., Versuch einer chemischen Klassification der Eruptivgesteine. Tschermaks Min. u. Petr. Mitt., 1899, XIX, S. 351–469, 1900, XX, S. 399–558, 1902, XXI, S. 365–448, 1903, XXII, S. 322–356, 403–436.

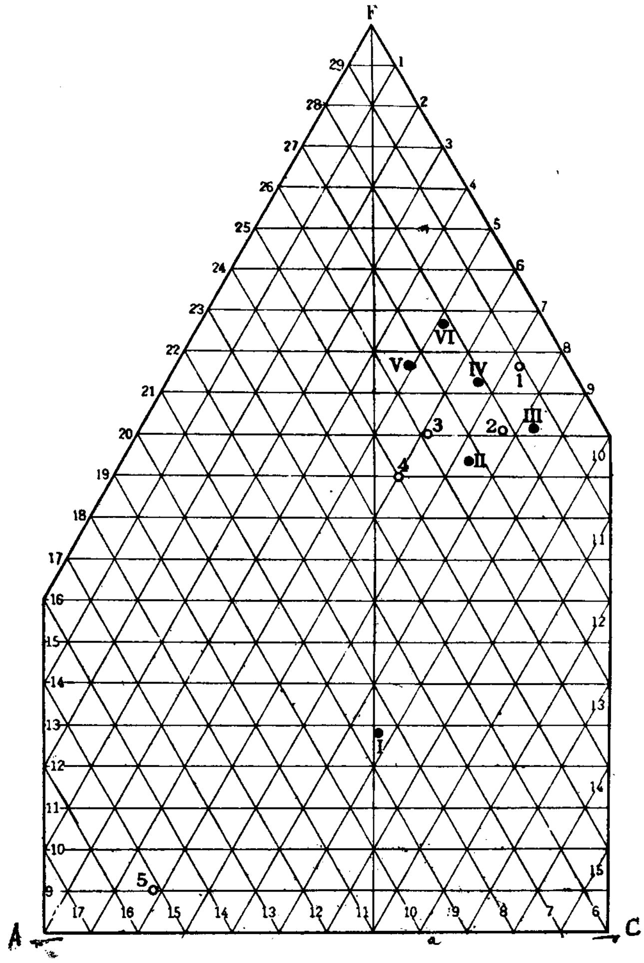
5) Rosenbusch, A. u. Osann, A., Elemente der Gesteinslehre. 4. Aufl. 1923, S. 96–103.

rocks in the region, are shown in Table 5, where S, means the contents of silica, K, means the ratio of the total silica to that of the feldspars and the metasilicates, usually the amount of quartz in the rocks. N, means the alkaline ratio; A, alkali-feldspars, C, anorthite molecules in the plagioclase, and F, means the ferromagnesian constituents. As we see in the table, the amount of silica contained is the largest in the hornblende-trachyandesite, and the lowest in the olivine-basalt.

A, C and F in the trachyandesite are different from those in the other rocks. N, in the hornblende-trachyandesite and the olivine-basalt are somewhat higher than any other pyroxene-andesite. Most of the igneous rocks in the region show a high crystallinity and K, is higher than 1, except the olivine-basalt which is somewhat lower in its crystallinity. The author found that, the above chemical properties of the rocks coincide exactly with the microscopical characteristics of them already described in the earlier pages of this chapter.

Fig. 19.

Triangular diagram of the chemical properties of intrusive and effusive rocks.



I–VI. Intrusive rocks in the Chikuhō region.
I. Hornblende-trachyandesite,
II–V. Pyroxene-andisite,
VI. Olivine-basalt.
1–5. Effusive rocks in the Inland Sea region.
1. Pyroxene-andesite,
2. Hornblende-andesite,
3, 4. Pyroxene-andesite,
5. Hornblende-andesite. (Chūgoku type.)

Petrogenesis.

Hornblende-trachyandesite contains somewhat higher amount of silica and it is alkaline, and different from the other pyroxene-andesites and the olivine-basalt. These relations can be seen clearly in the diagram proposed by Osann[1] (Fig. 19) The pyroxene-andesites have an intimate relation with the volcanic rock in Inland Sea region,[2) 3)] and also the hornblende-trachyandesite with the volcanic rock in Chyūgoku[4) 5)] region.

The exact date of the intrusion of the intrusive rocks in the Chikuhō region is unknown to us, but it is probably in the latest Pliocene or in the early Pleistocene in age, according to the studies of K. Kimitsuka,[6] H. Yoshizawa[7] and Dr. M. Yehara[8] in the other parts of the Inland Sea region.

Physical Properties of Metamorphosed Coal.

Types of the Coal.

There are several grades in the contact-metamorphosis of coal in relation to the intrusive rocks. The author classified it into two classes and four subclasses, according to its physical and chemical properties.

1. Decrepitating coal. This class of coal includes all the contact-metamorphosed coal which decrepitates on being heated. It shows no cakings, burns without flame and smoke, its fuel ratio is commonly above 5 up to 10 and rarely above 10. It contains above 3% to 12%, average 7%, of volatile matter.

2. Non-decrepitating coal. This class of coal includes all the contact-metamorphosed coal which

1) Rosenbusch, A. u. Osann, A., loc. op. cit., 1923, S. 96–103.
2) Kotō, B., On the Volcanoes of Japan. V. Jour. Geol. Soc. Tōkyō, Vol. XXIII, No. 273, 1916, p. 107.
3) Weinschenk, E., Beiträge zur Petrographie Japans. Neu. Jahrb. f. Min. Beil. Bd., VII, 1891, S. 145–151.
4) Kotō, B., loc. op. cit., 1916, p. 116.
5) Kōzu, S. and Watanabe, M., Distribution of the Volcanic Rocks in Japan. (in Japanese), Petr. Min. and Oredep. Vol. 1, No. 2, 1929, p. 27.
6) Kimitsuka, K., On the Eruptive Area of Volcano Murō. Bull. Volc. Soc. Japan, (in Japanese), Vol. 1, No. 2, 1932, p. 34.
7) Yoshizawa, H., Summary Report on the Volcano Nijo-san. (in Japanese), Globe, Vol. XIV, No. 5, 1930, pp. 344–362.
8) Yehara, M., Geologic and Tectonic Study of Shikoku. Jap. Jour. Geol. and Geogr. Vol. VII, No. 1, 1929, p. 15.

is non-decrepitating on being heated. It shows no cakings, burns with or without short flames and smoke, its fuel ratio is commonly 2 to 6, nearly always lower than 10. It contains above 10% up to 20% of volatile matter, and grades by degrees into normal bituminous coal.

The author again classified the decrepitating coal into two subclasses, the stone-coal and the hard-coal, and the non-decrepitating coal also into two subclasses, the soft-coal and the brittle-coal.

Physical Properties of the Coal.

The main physical properties are shown in Table 6, the mean specific gravity and the hardness of the decrepitating coal are higher than that of the non-decrepitating coal, but the porosity of them is the reverse. These physical properties are different from the bituminous coal and cokes.[1]

Especially, the properties of the decrepitation on heating is the peculiar characteristic of the contact-metamorphosed coal. These decrepitations are shown in Figure 20. Most of the decrepitating coal decrepitates at a lower temperature than 500°C, and most actively at the temperature 300°C ± 50°C. The fragments, larger than 10 mesh in their sizes, amount to 84% of the whole, after the perfect decrepitation, and those of 27% only are lower than 35 mesh, by Tyler's screen.

Table 6.

Physical properties of the metamorphosed coal.

No. of Samples	Kinds of Coal	Localities	To face Coal-Seams	Weight of Samples (gram)	Specific Gravities	Porosities (%)	Relative Hardness
1(a)	Decrepitating coal	Namazuta	20	1.5762	2.364	11.34	3.50–3.50
2	”	”	20	0.6275	1.458	10.98	3.00
3	”	Yoshikuma	14	1.2853	1.584	10.83	2.75–3.00
4	”	”	14	1.2535	1.606	14.93	2.75–3.00
5(a)	”	Genwō	9	1.4280	1.812	4.00	2.75–3.00
6	”	Inatsuki	10	0.9055	1.602	14.88	2.75–3.25
7	”	”	10	1.8752	1.495	12.05	2.75–3.25
1–7	mean	—	—	—	1.703	11.29	2.75–3.50
8	Non-decrepitating coal	Namazuta	20	0.8605	1.386	22.09	2.25
9	”	Gōtōji	9	1.7641	1.466	25.01	2.25–2.75
× 10	”	Yoshikuma	14	1.3060	1.480	21.86	2.25–2.50
× 11	”	Genwō	16	1.1690	1.641	26.42	2.25
× 12(b)	”	Katsuno	14	1.2733	1.413	9.77	2.25
8–12	mean	—	—	—	1.477	21.03	2.25–2.75

(a) Direct contact with the intrusive sheet.
(b) 3 meters distant from the intrusive sheet.
Measured at 22°C except × at 4°C.

Microscopical Characteristics of the Coal.

Certain studies of the microscopical characteristics of the metamorphosed coal was published by the present author in 1930–1932.[2) 3) 4)]

Characteristics in Reflected Light.

The author has studied the polished surface of the coal, etching it with tetralline solution.[5)] But some structures could be clearly observed on the surfaces of the carefully polished section without any etching.

The yielding structure (Fig. 21, 22) the crushed structure (Fig. 23) and corroded structure (Fig. 24) are commonly observed on the polished surface of the decrepitating stone-coal. Sometimes the irregular tongues of the intrusive rocks (Fig. 25) are observed in the coal and also the calcite (Fig. 26) and light bluish opal are found in such coal. The banded structure (Fig. 27) the woody

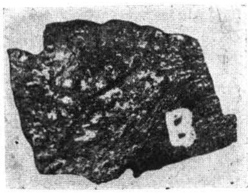
1) Ueji, T., Relation between Coal-beds and Intrusive Rocks, Chikuhō Coal-Field, Japan. (in Japanese), 1934, pp. 13–27.
2) Ueji, T., Microscopical Observation on "Senseki" the Contact-Metamorphosed Coal. (in Japanese), Suiyokwaishi (Transact. of the Min. and Met.), Kyōto Imp. Univ., Vol. VI, No. 3, 1930, pp. 284–290.
3) Ueji, T., General Properties of the Coal, Metamorphosed by Intrusive Rocks. (in Japanese), Comm. Ess. Celeb. 61th birth. Prof. Dr. T. Ogawa, Geol. Part, 1930, pp. 679–697.
4) Ueji, T., On the Microscopical Study of the Thin Section of Coal, Metamorphosed by Intrusives. (in Japanese), Suiyokwaishi (Transact. of the Min. and Met.), Kyōto Imp. Univ., Vol. VII, (Ann. Vol. Prof. Dr. D. Saitō, Celeb. 61th Birth.) 1932, pp. 632–637.
5) Iwasaki, C., Coalification and the Origin of the Fushun Coal. (in Japanese), Jour. Eng. Ass. Manchuria, Vol. V. No. 26, 1928, pp. 235–250.

Fig. 20.

Decrepitations of the metamorphosed coal.

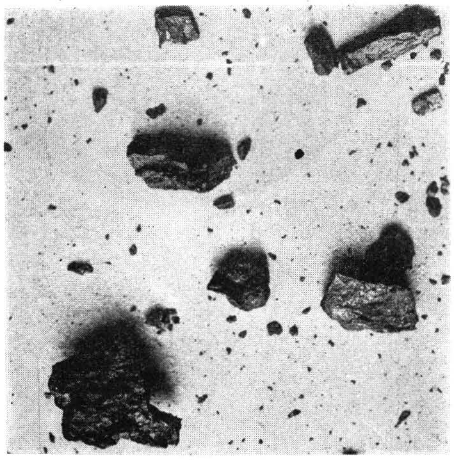
a. Original smaples. (Natural sizes, nearly)

A.

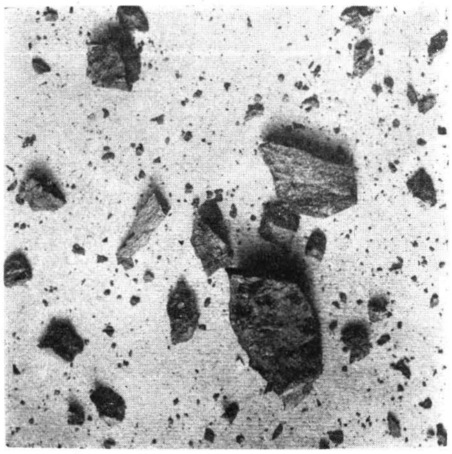


B.

b. Heated to 300°C.

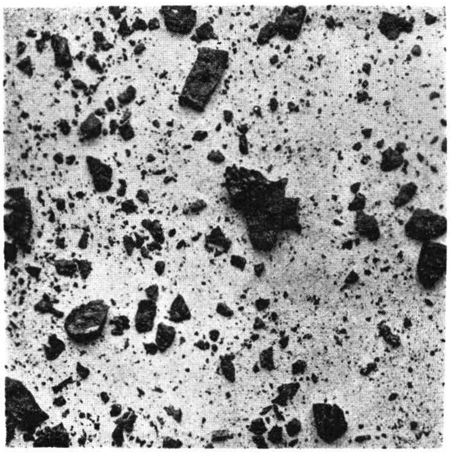


A.

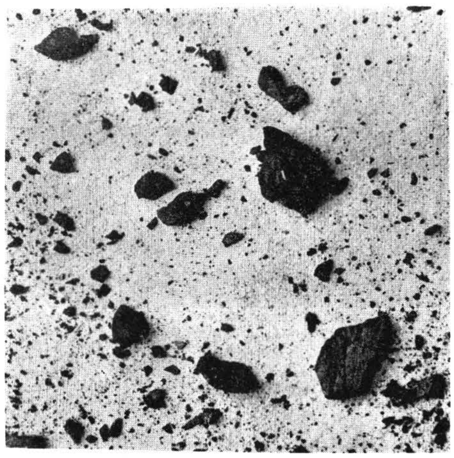


B.

c. Heated to 500°C.



A.



B.

Sample A...Metamorphosed coal from Yoshikuma colliery,
Yamano-Yoshikuma district.
B...From Genwō colliery, Yamada district.

Structures and minerals in the metamorphosed coal under reflected light. I.

Fig. 21.

From Namazuta. ×18.

Fig. 22.

From Namazuta. ×18.

Fig. 23.

From Namazuta. ×18.

Fig. 24.

From Yoshikuma. ×10.

V...Vitrain. D...Durain.

Structures and minerals in the metamorphosed coal under reflected light. II.

Fig. 25.

From Namazuta. ×18.

Fig. 26.

From Namazuta ×18.

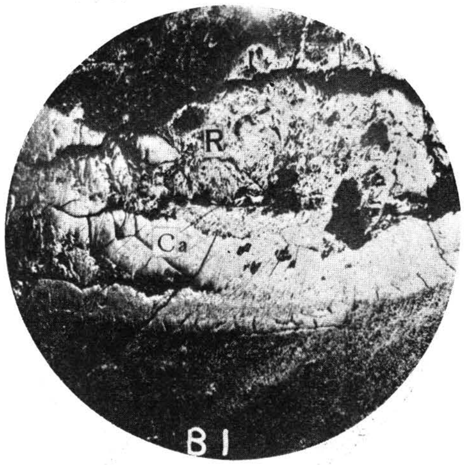
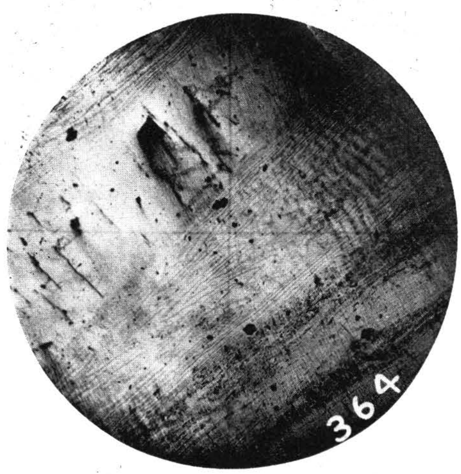


Fig. 27.

From Namazuta. ×18.

Fig. 28.

From Namazuta. ×18.



V...Vitrain. D...Durain. R...Intrusive rocks. Ca...Calcite.

Structures and minerals in the metamorphosed coal under reflected light. III.

Graphite crystals.

Fig. 29.

From Inatsuki +N ×130.

Fig. 30.

From Inatsuki ×470.

Fig. 31.

From Namazuta ×235.

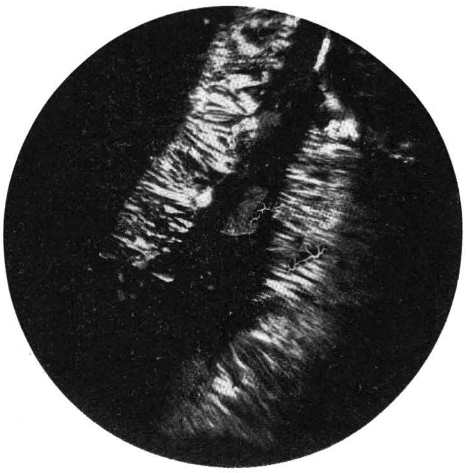


Fig. 32.

From Inatsuki ×235.

structure (Fig. 28) and the earthy structure are commonly observed on the surfaces of the non-decrepitating coal.

We can observe micro-crystalline graphite in the decrepitating coal which came into the part of the direct contact with the intrusives. The crystals of graphite are granular, scaly, (Fig. 29) Spherulitic, (Fig. 30 and 32) prismatic (Fig. 31) or radiated (Fig. 32) in forms, very brittle and of lower hardness in physical properties and grey in colour. The diameter or the length of the single crystal of graphite is smaller than 0.1 mm. The properties of strong absorption under the polarized light and the anisotropism under the crossed nicol-prism are the characteristics of the crystals of graphite in the coal.

Structures and minerals in the metamorphosed coal under transmitted light. I.

Fig. 33.

From Iitsuka. ×30.

Fig. 34.

From Shimo-Yamada. ×50.

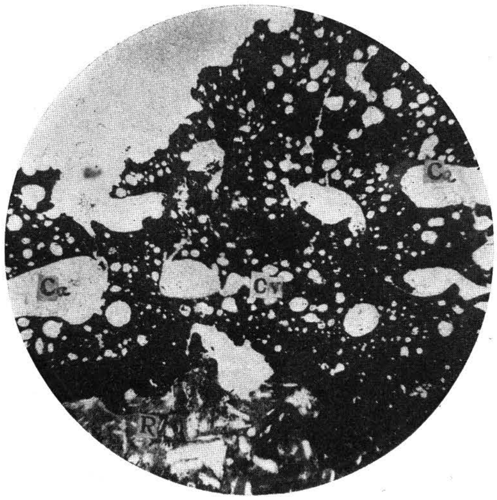


Fig. 35.

From Kawasaki. ×170.
(Photo. 1/2)

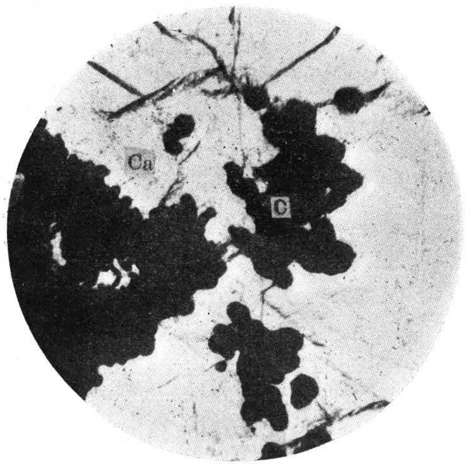
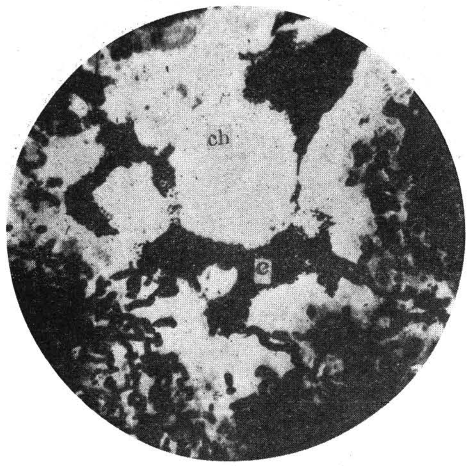


Fig. 36.

From Kawasaki. ×170.
(Photo. 1/2)



R ...Intrusive rocks.
Ca...Calcite.
C...Coal.
Cv...Amygdaloidal cavities.
Ch...Chalcedony.

Structures and minerals in the metamorphosed coal under transmitted light. II.

Fig. 37.

From Kami-Yamada. ×170.
(Photo. 1/2)

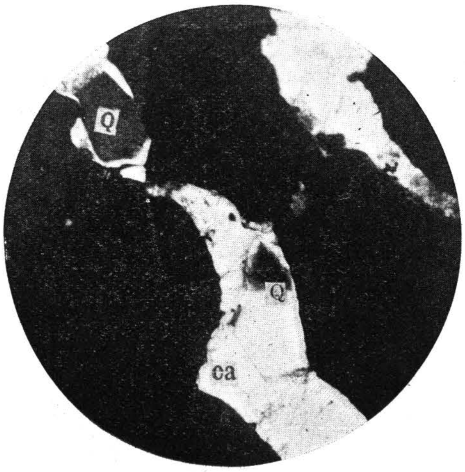


Fig. 38.

From Tagawa. ×25.

Fig. 39.

From Tagawa. ×30.

Fig. 40.

From Kami-Yamada. ×350.

Q...Quartz. Ca...Calcite. Ch...Chalcedony.
O...Opal. Z ...Zeolite.

Characteristics through Transmitted Light.

The minute amygdaloidal structure (Fig. 33–34) is sometimes observed in the thin section of the decrepitating metamorphosed coal, these minute cavites are sometimes filled up with calcite, quartz, chalcedony, opal and zeolites. Sometimes rounded or wormlike minute fragments of coal are included in the above minerals.

These peculiar structures and minerals are shown in Fig. 33–40. We can not observe such structures and minerals as above mentioned, in the bituminous coal in the coal-field.[1] It is certain that these structures and minerals have occurred by through the action of the heat, water-vapor and the hydrothermal solutions from the liquidal intrusives which invaded in the coal-beds. The minerals, such as quartz and calcite which are found in the metamorphosed coal, are low-temperatured ones. Probably they crystalized out at a temperature lower than 1200°C.[2]

We have not yet found a means of determining the actual temperature of the invading intrusives, but some basic andesites in this region melted completely at temperatures between 1155°C–1335°C in an experiment by the dry fusion method in our laboratory; and, if dissolved gases in the basic magma were relatively small than the presence of acidic intrusives would premise a temperature considerably higher than 1000°C.

Chemical Properties of Metamorphosed Coal.

Proximate Analysis.

The proximate analysis of the metamorphosed

Table 7.

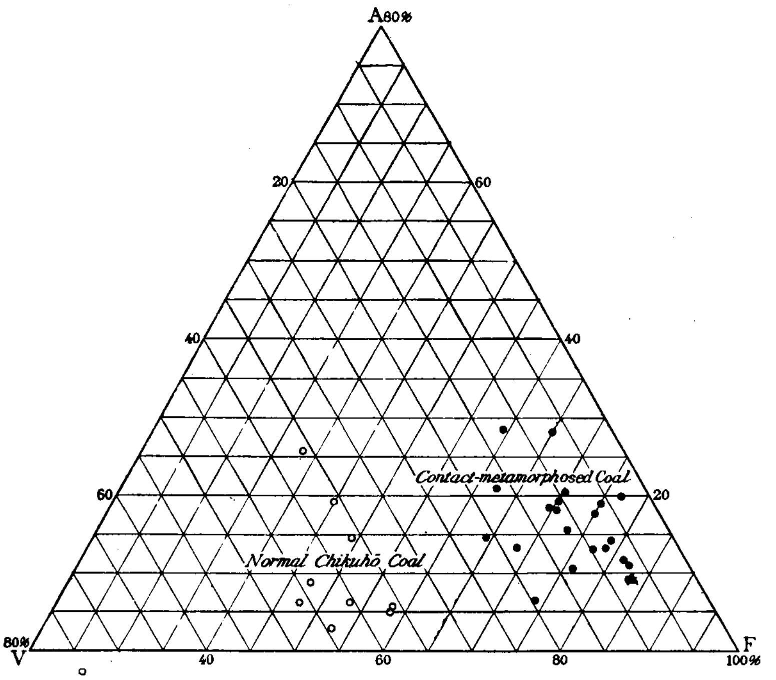
Proximate analysis of the metamorphosed coal.

No. of Samples	Localities	To face Coal-Seams	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Caking Power	Fuel Ratio
				Decrepitating Stone-coal.				
1	Namazuta	20	2.16	25.88	12.23	59.74	None	4.884
2	,,	20	1.65	18.52	9.40	70.49	,,	7.502
3	Ōmine	9	2.63	25.47	6.80	65.10	,,	9.574
4	Namazuta	20	2.13	15.63	7.31	74.94	,,	10.251
5	Ōmine	24	1.92	17.41	11.75	68.92	,,	5.865
1–5	mean		2.10	20.58	9.49	67.84	,,	7.615
				Decrepitating Hard-coal.				
6	Inatsuki	10	3.95	15.75	3.06	77.24	None	25.240
7	Yoshikuma	10	4.20	7.54	7.41	81.12	,,	11.361
8	,,	10	3.14	8.51	6.46	81.89	,,	12.676
9	Genwō	16	2.27	15.68	6.18	74.87	,,	12.115
10	Ōmine	9	3.86	9.55	8.15	78.44	,,	9.627
6–10	mean		3.68	11.41	6.25	78.71	,,	14.204
				Non-decrepitating Soft-coal.				
11	Genwō	16	2.50	11.48	7.54	78.48	None	10.408
12	Yoshikuma	10	3.06	16.33	10.28	70.33	,,	6.841
13	,,	10	1.80	13.87	10.93	73.40	,,	6.737
14	Inatsuki	10	1.93	9.02	13.30	75.72	,,	5.693
15	Kawasaki	6	1.70	16.23	10.17	71.90	,,	7.113
11–15	mean		2.20	13.39	10.44	72.97	,,	7.356
				Non-decrepitating Brittle-coal.				
16	Kawsaki	6	1.28	19.81	16.51	62.40	None	3.779
17	,,	6	1.40	13.10	21.30	64.20	,,	3.014
18	Yoshikuma	10	1.86	12.37	16.94	68.83	,,	4.063
19	Kami-Yamada	10	1.34	4.37	19.89	74.40	,,	3.741
20	Genwō	16	3.17	10.98	9.93	75.92	,,	7.645
16–20	mean		1.81	12.13	16.91	69.15	,,	4.448

1) Ueji, T., loc. op. cit., 1934, pp. 34–45.
2) Ueji, T., loc. op. cit., Suiyokwaishi, 1932, pp. 634–631.

Fig. 41.

Triangular diagram of the chemical properties of coal.



A...Ash, V...Volatile matter, F...Fixed carbon.

coal is shown in Table 7. The superiority in moisture, ash, fixed carbon and the fuel ratio, and the inferiority in volatile matters are the conspicuous differences between this and the bituminous coal in the field, (Fig. 41). On other words, the bituminous coal of low grade in the field has been raised to coal of higher grade, viz. semi-bituminous or anthracitic coal, through metamorphosis by contact with the intrusives and has been raised to graphite in the extreme case, as in some foreign countries.[1)2)]

Ultimate Analysis.

The ultimate analysis of the coal is shown on table 8. In general the quantity of carbon contained in it increases as it nears the intrusive rocks, but it is actually most plentiful at some distance from the intrusive rocks, not in the part in immediate contact with them. Oxygen and hydrogen decrease in inverse proportion to the proximity of the intrusives. But when the coal

Table 8.

Ultimate analysis of the metamorphosed coal and the bitumious coal.
(No. 21 seam, Namazuta. No. 14 seam, Yoshikuma. No. 23 seam, Ōmine.)

No. of Samples	Distance from Intrusives (meter)	Moisture (%)	Ash (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Sulphur (%)	Nitrogen (%)	H/O Ratio	H+O
Namazuta (Coal of the western-side of the igneous dyke, 4 meters in width.)										
1	0.15	1.60	18.51	72.50	3.43	2.83	0.20	0.93	1.21	6.26
2	0.30	0.94	11.19	81.19	3.97	2.15	0.38	0.18	1.84	6.12
3	0.60	0.99	20.82	71.95	2.83	2.02	0.31	1.08	1.40	4.85
4	1.00	0.83	8.76	84.35	2.97	1.82	0.34	1.23	1.47	4.49
5	3.00	1.07	16.58	74.01	3.08	3.87	0.31	1.08	0.80	6.95
6	6.40	1.32	5.10	80.83	4.42	6.67	0.26	1.40	0.66	11.04
7	12.00	1.63	10.91	67.45	4.98	13.70	0.28	1.05	0.36	18.68
8	21.00	1.18	7.89	66.44	5.13	15.87	0.35	1.22	0.32	21.00
9	39.00	1.12	4.95	66.41	5.17	20.89	0.38	1.08	0.25	26.09
* 10	85.00	0.77	7.57	65 00	5.52	18.86	0.27	1.20	0.29	24.38
Yoshikuma (Coal under the intrusive sheet, 0.9 meters in thickness.)										
11	0.15	4.20	7.54	80.77	4.04	2.45	0.30	0.70	1.48	6.49
12	0.73	3.13	8.51	82.60	3.39	1.91	0.42	1.03	1.77	5 30
13	0.75	2.06	17.33	74.55	3.08	1.80	0.73	1.00	1.43	4.38
14	0.88	1.80	13.87	74.56	3.37	4.13	1.01	1.26	0.82	7.50
15	1.00	1.86	12.37	75.33	3.61	4.40	0.95	1.48	0.82	8.01
* 16	1.50	1.29	13.52	67.74	4.61	11.32	0.37	1.15	0.41	15.93
Ōmine (Coal of the eastern-side of the igneous dyke, 0.3 meters in width.)										
17	0.09	1.92	17.41	71.01	4.04	3.19	1.26	1.17	1.27	7.23
18	0.39	0.52	6.74	79.62	3.52	7.38	0.88	1.34	0.47	10.90
19	0.69	1.39	8.30	67.88	4.69	15 92	0.63	1.19	0.29	20.61
20	1.00	2.41	4.61	67.57	4.98	18.34	0.87	1.22	0.27	23.32
21	4.30	1.27	8.92	67.15	4.68	16.11	0.87	1.00	0.29	20.79
* 22	8.87	1.32	5.33	70.99	5.17	15.35	0.75	1.09	0.33	20.52

* Bituminous coal.

1) Fuchs, W., Die Chemie der Kohle. 1931, S. 385.
2) Petrascheck, W., Entstehung, Veredelung und Verwertung der Kohle. 1930, S. 12.

is in direct contact with the rocks, these elements do not attain the minimum but rather increase a little in amount, especially in the case of the hydrogen. J. A. Taff[1] already has noticed this phenomenon and explained it by saying that these volatile substances came from other bituminous coal on cooling. But his theory does not seem to explain the phenomenon for these volatile substances become higher at the point in direct contact and a little lower at some distances from it. H. Washington[2] discussed the Eby's study and he said that the contact-metamorphism of coal is not only a caustic phenomenon but that the effects of moisture and other gases emanated from the intrusives must be taken into consideration, although he did not study them. Recently H. Briggs proposed the water-gas hypothesis on the contact-metamorphism of coal-seams.[3]

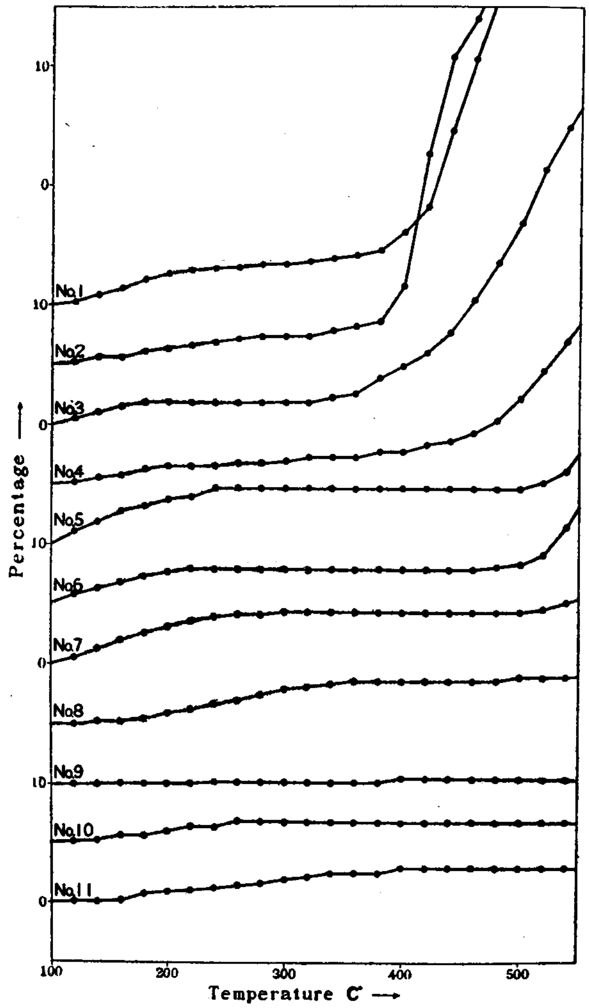
The hydrogen and the oxygen in the contact-metamorphosed coal, in direct contact with the intrusives, may probably have been supplied in some degree, in the form of water-vapor etc., from the intrusive molten materials.

Measurement of the Change of Weight.

The author chose eleven samples, viz. 6 of metamorphosed coal, 2 of bituminous coal and 3 of cokes, and dried them in an oven at 105°C, then measured the change of weight on heating in a thermobalance.[4] The weight of the samples did not necessarily decrease in proportion to the increase of temperature, but some weight was lost at the low temperatures such as 200°C. then the weight was nearly constant till the phenomenon of combustion began. The decrease of the weight at the low temperature is due mainly to the evaporation of the moisture[5] and its decrease is

Fig. 42.

Heating and change of weight.



No. 3–No. 8. Metamorphosed coal.
No. 1–No. 2. Bituminous coal.
No. 9–No. 11. Coke.

Table 9.

Analysis of ash.

No. of Samples	Coal-Seams	Kinds of Coal	Dist. from Intrusives	Ash %	Molecular Percentage								
					SiO_2	Al_2O_3	FeO Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	Total
1	20	Decrepitating	5 cm	22.85	66.14	15.82	3.61	1.01	6.71	5.62	0.84	0.25	99.99
2	9	"	5	16.62	51.11	19.07	3.21	1.91	21·16	1.76	0.92	0.87	100.01
3	9	"	13–19	8.78	55.82	14.13	3.33	2.60	15.02	4.26	1.39	0.29	99.84
4	20	"	20–30	12.92	61.36	21.98	4.90	1.42	7.63	0.92	0.70	1.10	100.01
5	20	Non-decrepitating	80–90	9.10	59.96	21.51	7.07	1.62	6.22	1.95	0.58	1.01	99.92
6	20	Bituminous	—	8.47	63.09	21.91	2.35	0.90	8.53	2.08	0.46	0.62	99.94
7	14	"	—	6.01	57.92	22.47	5.59	1.63	6.75	4.66	0.66	0.35	100.03

1) Taff, J. A., loc. op. cit., 1906, p. 696.
2) Washington, H. S., "in a discussion of Eby's paper." Trans. Amer. Inst. Min. and Met. Eng., Vol. 71, 1925.
3) Briggs, H., loc. op. cit., 1935, p. 196.
4) Honda, K., On a Thermobalance. Sci. Rep., Tōhoku Imp. Univ., Vol. IV, 1915, pp. 97–103.
5) Ueji, T., loc. op. cit., 1934, pp. 72–79.

generally more abundant in the metamorphosed coal than in any other kinds of coal, as shown in Fig. 42.

Properties of Ash.

The chemical properties of ash are shown in Table 9 in molecular percentages. The molecules of silica, ferromagnesia, lime and alkali are somewhat more abundunt in the ash of the contact metamorphosed coal than in that of the normal bituminous coal.

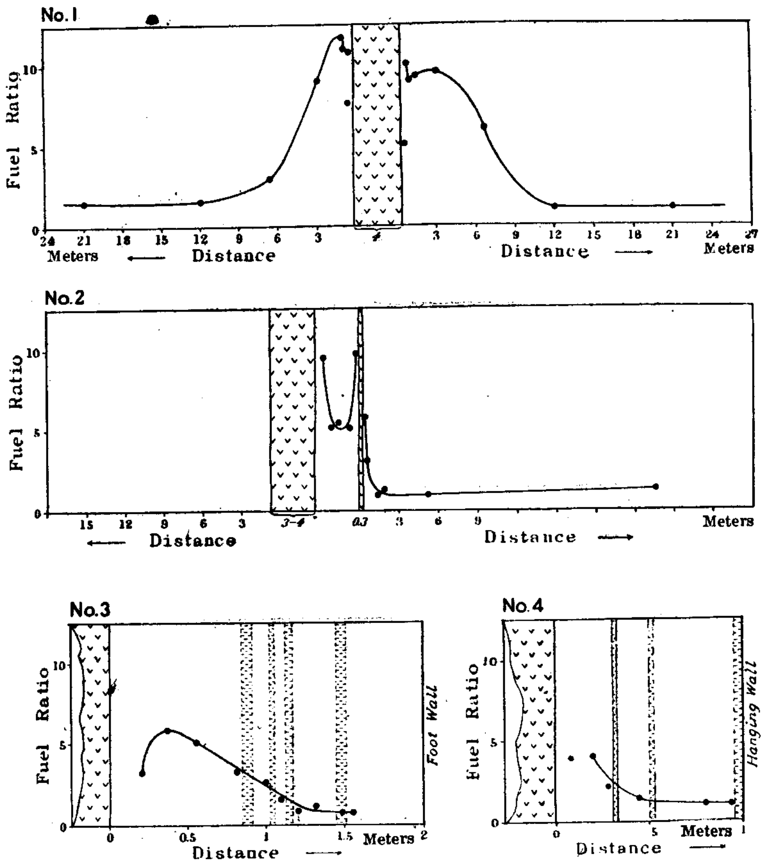
Areas of the Metamorphism.

The writer has determined the distances of the metamorphic effects on coal-beds from the margin of intrusives according to the fuel ratio. (Fig. 43). These limits are nearly the same as those of determined by the ratio of the hydrogen to oxygen. (Fig. 44)

From these figures it may be deduced that the contact-metamorphic effects upon the coal-beds are stronger around the dykes and weaker around the sheets. The effects of the intrusive sheets on the hanging wall of coal-beds are somewhat stronger than those on the foot wall, but the accurate measurement of the effects of the sheets upon the coal-beds are difficult because several partings alternate in the coal-seams in this field.

Fig. 43.

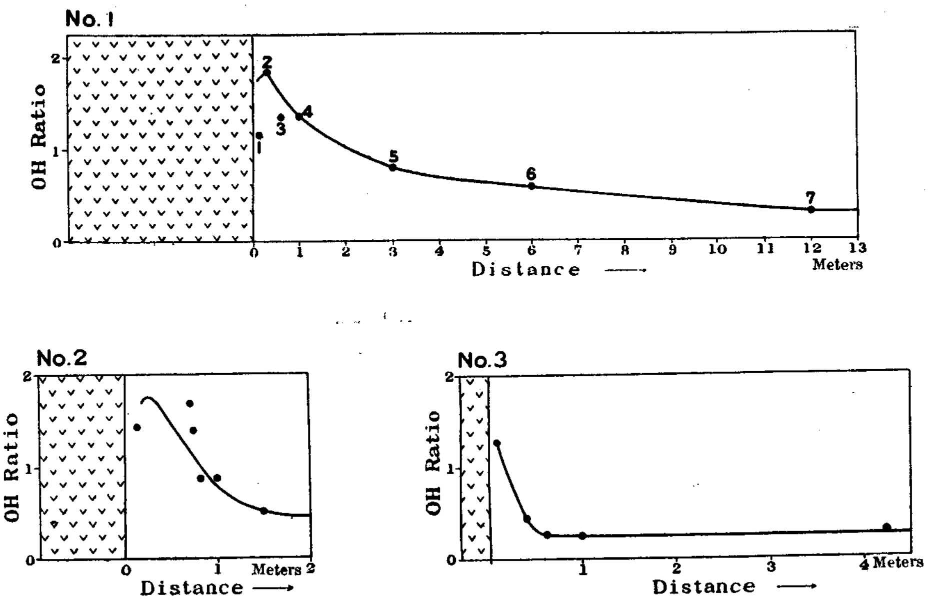
Changes of the fuel ratio of coal near the intrusives.



No. 1, Namazuta, No. 2, Ōmine, igneous dykes cutting through the coal-seams. No. 3, Kawasaki, No. 4, Kami-Yamada intrusive sheets extending under the foot wall or on the hanging wall of the coal-seams.

Fig. 44.

Changes of OH ratio.



No. 1, Namazuta, No. 3, Omine, igneous dykes cutting through the coal-seams. No. 2, Yoshikuma, a intrusive sheet extending on the hanging wall of a coal-seam.

Nature of the Contact-Metamorphism of Coal by Intrusives and Hints on the Utilization of the Coal.

Nature of the Contact-Metamorphism of Coal-Seams.

The phenomenon of the contact-metamorphism of rocks by intrusives was first studied by H. Rosenbusch on Steiger Schiefer.[1] Several other students[2] have made farther researches on the subject. But almost all these studies have been devoted to the common rocks, they rarely refer to the metamorphism of coal-beds.

Coal is mainly composed of carbonaceous matter, bearing several volatile substances in it, then the baking phenomenon appears strongly upon the contact-metamorphism. But we can observe several characteristic minerals such as quartz, calcite, zeolites, volcanic glass etc. in addition to the micro-pieces of the intrusive rocks in the metamorphosed coal. The coal has a characteristic property of decrepitation on heating; the chemical properties of ash are somewhat different from those of the bituminous coal or coke and the softening points of the ash in the metamorphosed coal are mostly lower than those of the other coal. (Table 10)

As we have seen in the above paragraphs, the metamorphism of coal can not be explained completely by the simple caustic phenomenon only, but some substances, such as water-vapor, gases and hydrathermal solutions from the intrusive rocks, have been supplied to the metamorphosed coal in the high pressured conditions underground. Though he proposes a hydrothermal hypothesis on the metamorphism of coal by intrusives, but these effects are not so intense, because the scale of the intrusives were not so large and the rocks in the Chikuhō region were mostly basic types.

Some Points to be observed in the Utilization of the Coal.

Certain bituminous coal of low grade in the Chikuhō region has been raised to a higher ranked coal, such as semi-bituminous or anthracitic coal, by the contact of the intrusives. But on the other hand some coal has become valueless for in the

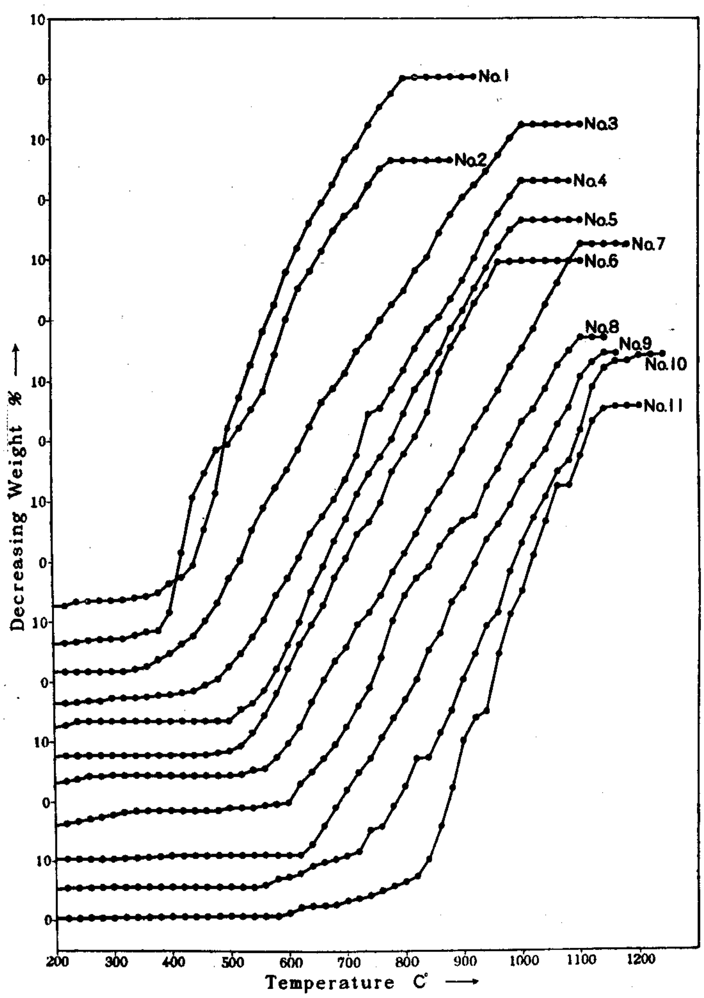
Table 10.

Measurement of softning temperature of ash. (To 1500°C)

No. of Samples	Coal-Seams	Kinds of Coal	Softning Temperature °C Begin-ning	Finish	Dif-ference
1	9	Decrepitating	1168	1239	71
2	6	,,	1202	1250	48
3	14	,,	1191	1261	70
4	19	,,	1137	1310	173
5	20	,,	1291	1355	94
6	9	,,	1250	1405	155
7	20	,,	1390	—	—
8	19	non-decrepitating	1220	1305	85
9	20	,,	1315	1340	25
10	20	,,	1415	—	—
11	12	,,	—	—	—
12	9	,,	—	—	—
13	20	Bituminous	—	—	—
14	6	,,	1395	1415	20
15	14	,,	1170	1395	225
16	16	,,	1312	1370	58
17	14	,,	1245	1320	75
18	—	Coke	1240	1307	67
19	—	,,	1265	1313	48
20	—	,,	1365	1465	100

Fig. 45.

Combustion phenomena of some Chikuhō coal.



No. 1– 2. Bituminous coal.
No. 3– 8. Metamorphosed coal.
No. 9–11. Coke.

1) Rosenbusch, H., Die Steiger Schiefer und ihre Kontaktzone usw. 1877.
2) Grubenmann, V. und Niggli, P., Die Gesteinsmetamorphose. 1924, S. 8.

amount of ash it contains and through having the properties of decrepitation on heating.

The main points in the utilization of the coal are as follows:

Combustion phenomena. The combustion of the metamorphosed coal, measured by the thermobalance, begins at 500°C–600°C, that is at a higher temperature than is required for the bituminous coal and lower than for the coke, and the continuation of the combustion is longer than in the two other kinds of coal. (Fig. 45)

Calorific powers. Most of the metamorphosed coal is higher in its calorific power than is the bituminous coal, as shown in Table 11. The metamorphosed coal which has banding structures is the highest in calorific values. These bandings can be observed even with naked eyes.

Volatile matters. Most of the metamorphosed coal has 6% to 10% of volatile matter, this is higher than that of coke and much lower than that in the bituminous coal. Some such coal can be used as domestic fuel.

Decrepitation. Most of the decrepitating coal has been used in the lime-kiln heretofore. The properties of decrepitation became weaker in the fragments, and did not decrepitate in the fragments lower than 35 mesh (Tyler's Screen Scale.) by the author's experiments. This is probably a little amount of occluded materials might be easily escaped in the crushed fragments.

Softening temperature of ash. The softening temperatures of ash of the stone-coal is usually lower than those of other kinds of coal, but those of several samples, such as hard-coal, did not soften at a lower temperature than 1500°C. (Table 10 and Fig. 46)

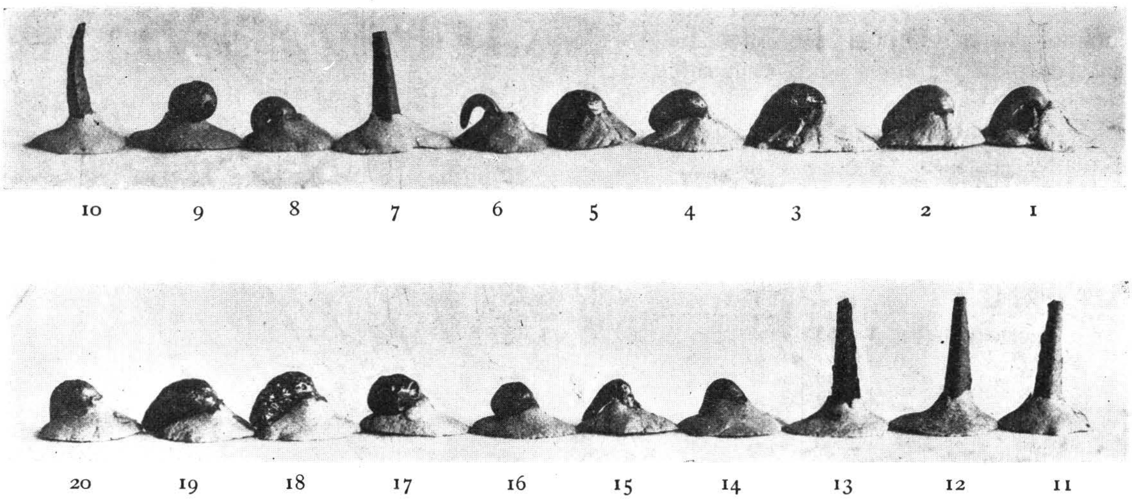
Table 11.

Calorific powers of some Chikuhō coal.

Metamorphosed Coal by Intrusives. (cal.)	Bituminous Coal. (Cal.)	To face Coal-Seams. (No.)
7.366	6.994	24
7.135	7.055	20
7.308	7.012	20
7.417	—	9
8.004	7.405	10
7.159	6.437	14
7.318	—	9
7.497	5.254	2

Fig. 46.

Softening of some ash.



No. 1– 7. Decrepitating coal,
No. 8–12. Non-decrepitating coal,
No. 13–17. Bituminous coal,
No. 18–20. Coke.

Summary and Conclusion.

1. Chikuhō coal-field lies in the northern part of Kyūshū Island, Japan. The coal-bearing strata are known as the Palaeogene Tertiary, containing about 40 workable coal-seams. Coals of the field belong to the bituminous type of low grade.

2. The intrusive rocks occur widely in the southern half of the field, forming intrusive sheets and dykes. The sheets are mostly distributed irregularly in the thicker coal-seams, and sometimes the dykes merge into the sheets when they cross the coal-seams. These intrusives not only inconvenience to the coal mining in the field, but also have caused a marked metamorphic change in the bituminous coal around them.

3. The intrusive rocks can be classified into three kinds, pyroxene-andesite, hornblende-trachy-

andesite and olivine-basalt. The pyroxeneandesite is distributed most widely and belongs to the petrographical province of the middle eruptive zone in southwestern Japan. Probably, the rock intruded in the late Pliocene or in the early Pleistocene in age. The hornblende-trachyandesite and the olivine-basalt both belong to the northern eruptive zone in southwestern Japan. It might have intruded later than the other two intrusive rocks.

4. The metamorphosed coal around the intrusives assumes a columnar or massive structure, and differs in physical and chemical properties from the bituminous coal in the field.

5. The property of decrepitation on heating is one of the characteristics of the metamorphosed coal. The behavior becomes weaker in relation to the distance from the intrusives.

6. Minerals such as quartz, calcite, zeolite and volcanic glass in the metamorphosed coal have been crystallized from the substances that had been supplied from the molten rocks.

7. A higher percentage of carbon and ash, another a lower percentage of volatile matter are characteristics of the metamorphosed coal. The bituminous coal of low grade in the field has been raised to semi-bituminous coal or anthracite by the process of contact-metamorphism.

8. The molecules of silica, ferro-magnesia, lime and alkali are somewhat abundant in the ash of the metamorphosed coal, especially in coal nearest to the intrusives, when compared to the normal bituminous coal in this field.

9. The nature of the contact-metamorphism of coal can not be explained as a thermal effect only, but some substances such as water-vapor, gases and hydrothermal solutions have been added from the molten intrusives to the decrepitating coal.

10. Main points to be considered in the utilization on the metamorphosed coal are as follows :—

(a) The kindling temperature of the coal is at 500°C–600°C, and the continuation of the combustion is longer than that of the bituminous coal.
(b) The calorific powers of the metamorphic banding coal are 7000–8000 calories.
(c) The volatile matter contained in the coal is inconspicuous, being generally 6–10%.
(d) The decrepitation of the coal on heating becomes weaker in the fragments of the coal.
(e) Most of the softening temperatures of the ash of the decrepitating coal are mostly lower than those of the non-decrepitating coal.

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