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Stratigraphic Coalification Pattern and its Implication to the Geologic Development of the Ishikari Coalfield, Japan*

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Abstract

It is one of the major problems for the Japanese coal geologists to elucidate the geologic conditions of formation and coalification of the Japanese Tertiary coal that has characteristic nature of high volatile matter and high hydrogen contents than the foreign Paleozoic coal. The Paleogene Ishikari coalfield in the Hokkaido island is selected as an objective area to investigate coalification problem of this characteristic domestic coal. Vitrinite reflectance was measured to indicate degree of coalification both on samples from numerous horizons of different districts in the coalfield and on cutting samples from oil exploring deep drill holes that penetrate the same geologic horizons at the northern extension of the coalfield for comparison.

Regional and stratigraphic coalification pattern in the coalfield are delineated and examined by referring to the sedimentational and structural data of the coalfield and the present depth-reflectance gradient of the drill hole samples, which reach to a conclusion that the coalification pattern had been drawn during the later stage of the Hidaka orogenic movement implicating a synorogenic coalification process though the initial pattern was partly deformed by the successive tectonic movement of the latest stage.

The characteristic nature of the coal and the coalification pattern would be endowed by the successive geologic events of thick sedimentation that occurred in the continually subsiding basin with intermittent and progressive migration and also by simultaneous and successive tectonic movement that took place within a limited geologic time interval and a paleogeothermal condition of low geothermal gradient.

I. Introduction

The Japanese Tertiary coals with rank ranging from lignite to anthracite are characterized by high volatile matter content in proximate analysis and also by high hydrogen content in ultimate analysis especially for sub-bituminous to bituminous rank. It had been granted that this characteristic nature was partly caused and emphasized by the exceptional coal petrographic composition of the Japanese Tertiary coal, however recent detailed chemical and physical studies on concentrated vitrinite fraction of various rank of the Japanese coal showed that the fraction had also higher volatile matter and hydrogen contents than foreign vitrinite (SUGIMURA *et al.*, 1966). This chemical peculiarity of the Japanese vitrinite had to be endowed during an appropriate process of coal formation

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and coalification under a distinctive geologic condition of the country taking account of difference in chemical composition of woody original materials.

It is one of the themes for Japanese coal geologist to incorporate the geologic condition of coal formation and coalification of this characteristic domestic coal. In connection with this fundamental investigation, the Paleogene Ishikari coalfield, the largest coalfield in Japan, was selected for an objective area and have been studied (AIHARA, 1968; 1976; 1977; AIHARA and TASHIRO, 1977; AIHARA, NAKAMURA and TASHIRO 1978), and the coalification pattern and paleo-geothermal condition could be revealed through these studies as summarized in this paper.

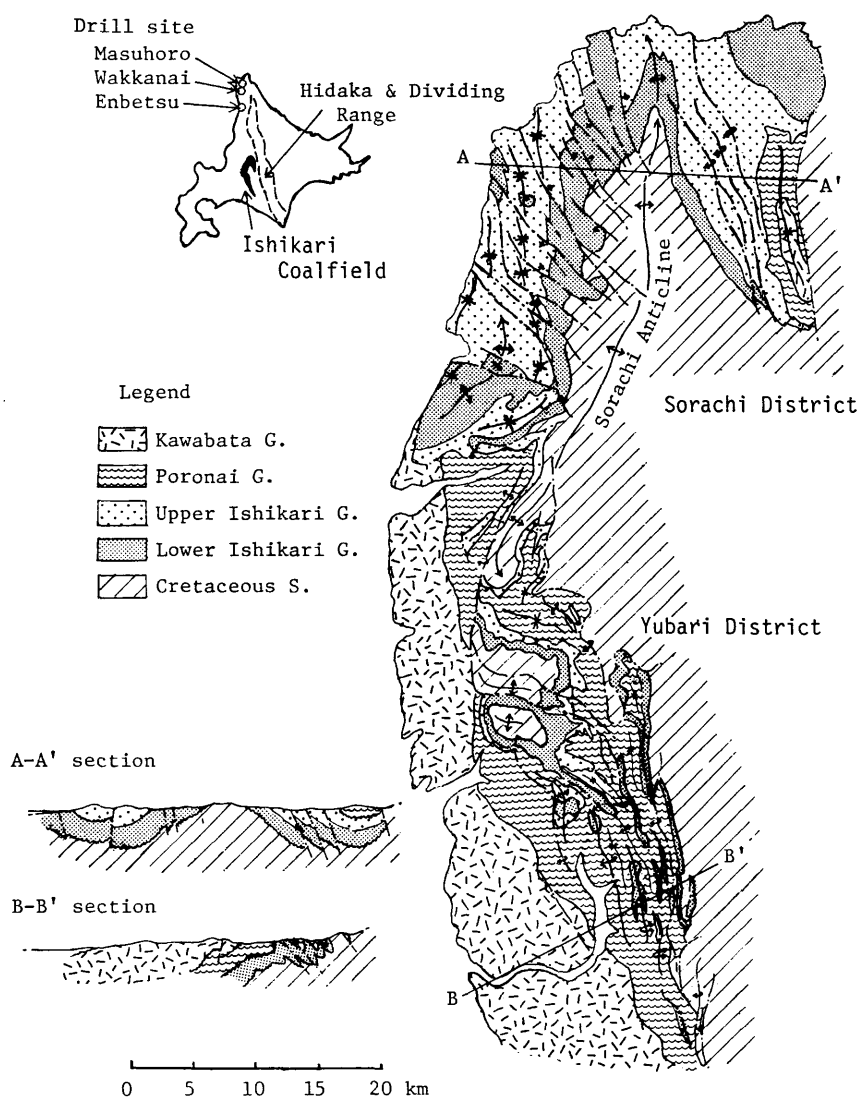


Fig. 1. The Ishikari coalfield, location and generalized geologic map.

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II. Geologic outline of the Ishikari coalfield

A. Geologic setting

The Ishikari coalfield covers an area of 1200 km² of Eocene to Oligocene fresh-water and marine sediments of the Ishikari group in the central western part of the Hokkaido island as shown in the Fig. 1.

The coalfield is subdivided both from geographic and geologic view points into northern half, the Sorachi district, and southern half, the Yubari district. The Sorachi district that occupies an inverted V-shape around the Sorachi anticline is characterized by its thicker development of the Ishikari group composed of nine formations with rather gentle structure, while the Yubari district is characterized by the more thinner Ishikari group composed of five formations that are covered unconformably by thick monotonous marine mudstone of the Poronai group and also by complicated overfolded and thrustured structure. Their stratigraphic succession and thickness variation are summarized as in the Table 1 and the Fig. 2 referring to the previous works (MATSUI, 1962; SHIMOKAWARA, 1963; TAKAO, 1952; TASHIRO, 1951; TESHIMA, 1967a). Deposition of these sediments was commenced and successively continued in the westerly adjoining depression that developed in north-south direction along the Hidaka orogenic belt after filling up of the Cretaceous Yezo geosyncline (MATSUMOTO, 1940) which was differentiated from the older Hidaka geosyncline.

B. Coal geology and coal rank parameter

There are numerous coal-bearing horizons in the Ishikari group with considerable regional variation in their distribution; three major and two minor coal-bearing formations in the Sorachi district and two major and one minor ones in the Yubari district. Minute studies on the variation of coal seams, in thickness, distribution and coal petrographic character, have proved that the variation have intimate relationship with variation of sedimentational condition reflecting the development of the Ishikari sedimentary basin (AIHARA, 1967; MATSUI, 1962; SHIBAOKA, 1957).

Coal rank of the coalfield ranges from sub-bituminous (C, D) to bituminous (B₁, B₂, C), of which regional variation in major coal-bearing formations have been studied mainly based on their proximate and ultimate analytical data (AIHARA 1968; SHIBAOKA 1962, 1964). But the recent minute chemical and physical studies on concentrated vitrinite fraction from selected Japanese coalfields clarified considerable difference in H/C versus O/C diagram (VAN KREVELEN,

Table 1. Generalized stratigraphic succession of the Ishikari coalfield.

Geologic Age		Succession	Sorachi District		Yubari District		
			Thick (m)	Facies	Thick (m)	Facies	
Tertiary	Eocene-Oligocene	Ishikari Group	Kawabata G.	0-1000	M-B	2000-4000	M-B Δ
			Poronai G.	0-700	M	1000-2500	M
			Ashibetsu F.	50-400	T-B $\circ$		
			Hiragishi F.	300-800	B-M Δ		
			Ikushunbetsu F.	50-700	T-B $\circ$	100-300	T-B $\circ$
			Akabira F.	50-700	B-M Δ		
			Bibai F.	50-250	T-B $\bullet$		
			Wakanabe F.	100-250	M-B(T) Δ	50-80	M-B(T) Δ
			Yubari F.	50-500	T-B $\bullet$	50-160	T-B $\bullet$
			Horokabetsu F.	80-200	B	60-110	B
			Noborikawa F.	100-600	T-B $\bullet$	20-90	T-B $\bullet$
			Cr.	Maast. Camp. Sant.	Hakobuchi G.	0-300	M-B(T)
Upper Yezo G.	500+	M			500+	M	

Abbreviation

T : terrestrial, B : brackish, M : marine

$\bullet$: major coal-bearing formation, $\circ$: minor coal-bearing formation, Δ : local coal development,

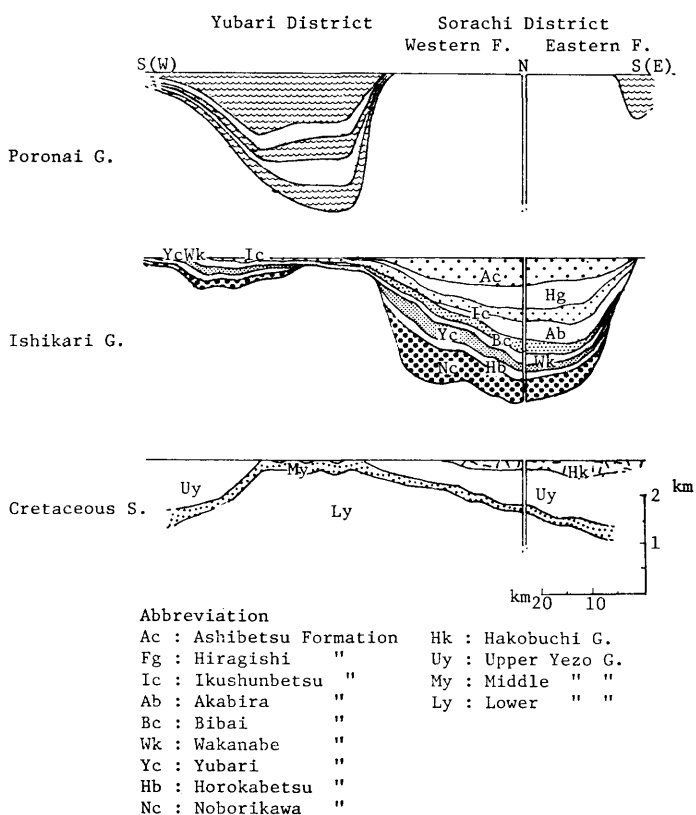


Fig. 2. Total thickness variation of the Cretaceous and the Paleogene sediments in the Ishikari coalfield.

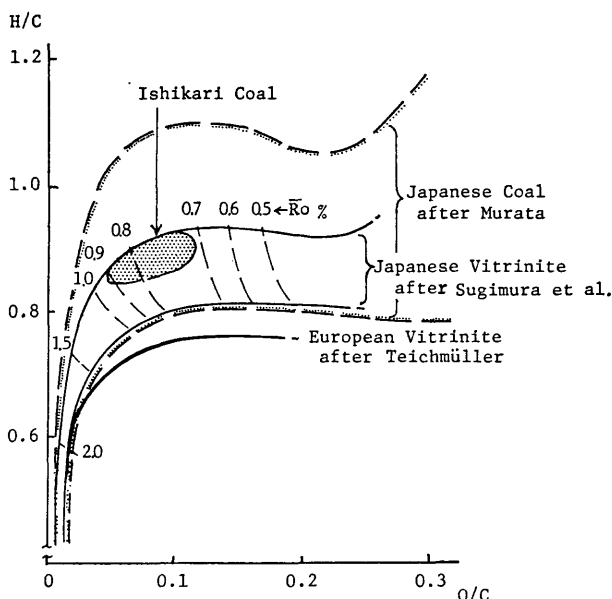


Fig. 3. H/C vs. O/C diagram of the Japanese coal.

1950) between this Japanese vitrinite coal-band and the former Japanese coal-band (MURATA, 1964) as shown in the Fig. 3, thus the more strict discussion on the coalification problem of the Japanese coal and coalfield should be based on analytical data of vitrinite. In this study, the vitrinite reflectance is adopted as the coal rank parameter since the mutual relationship between coal rank and vitrinite reflectance of the Japanese coal was precisely studied (SUGIMURA *et al.*, 1967). The reflectance values (SUGIMURA *et al.*, 1967) are summarized and graphically shown on the Fig. 3. The vitrinite reflectance measurement of this study was executed by Leitz MPE with Leitz Ortholux conforming the International Standard (I.C.C.P., 1963, 1971) and the American Standard (A.S.T.M., 1972) and the measured data are expressed by $\bar{R}_o$ value.

III. Coal rank variation pattern

A. Vitrinite reflectance gradient along the western flank of the Hidaka orogenic belt

There are north to south linear distributions of Tertiary coalfields and oilfields along the western slope of the dividing range of Hidaka mountains and its extension. Several oil exploring deep drills in this area penetrate coal-bearing formations that are correlated stratigraphically and paleontologically to the Ishikari group. In order to obtain a vertical coalification pattern (depth-reflectance gradient), vitrinite reflectance was measured on the coal cuttings of Neogene to Cretaceous sediments from the deep drill holes. The results are illustrated in the Fig. 4, in which abscissa is logarithmic scale to represent the "vitrinite reflectance gradient" in a straight line. The linear and almost the same gradient

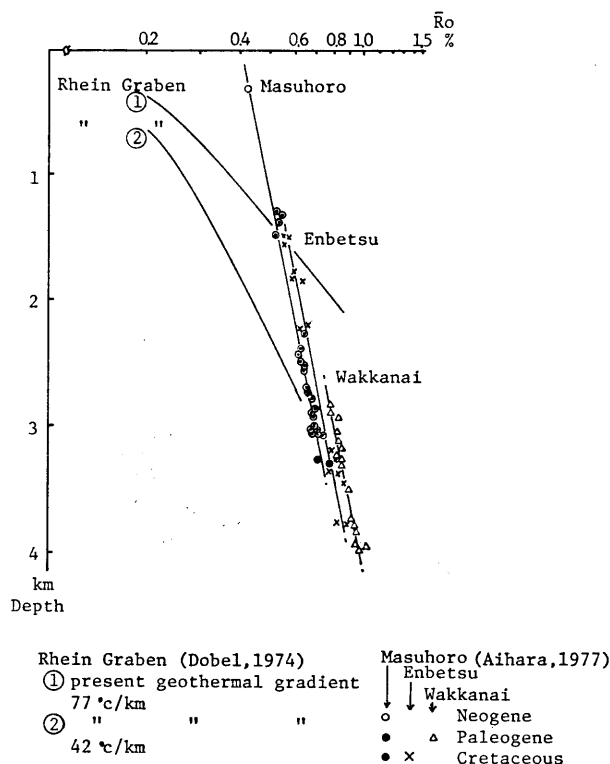


Fig. 4. Depth-vitrinite reflectance relationship of the oil exploring deep drill holes (position of drill hole refers to the Figs. 1 & 8).

in the vertical coalification pattern of the deep drill holes together with their present geothermy and comparison with the data of the Rhein Graben (DOBEL *et al.*, 1974) suggest an accelerated coalification condition with subsided burial depth within a paleogeothermal condition of rather uniform and low heat flow.

B. Stratigraphic variation of vitrinite reflectance in the coalfield

The reflectance measurement on coal or phytoclast samples that are collected from numerous stratigraphic horizons on a horizontal sampling line at right angle to general strike on surface or underground provides fundamental data to examine coalification pattern along a geologic cross section of the sampling line in connecting geologic coalification process with sedimentational and tectonic movements as illustrated by M. & R. TEICHMÜLLER (1966). From this point of view, sampling lines were laid on many selected parts in the coalfield, and variation of reflectance value in accordance with stratigraphic succession is investigated, of which particular patterns along the typical geologic cross sections (A-A', B-B' of the Fig. 1) are illustrated in the Fig. 5.

A general tendency of increasing reflectance value in accordance with descending stratigraphic sequence is recognized in all instances with some exceptions. Minute investigation on the figure shows slight difference in the

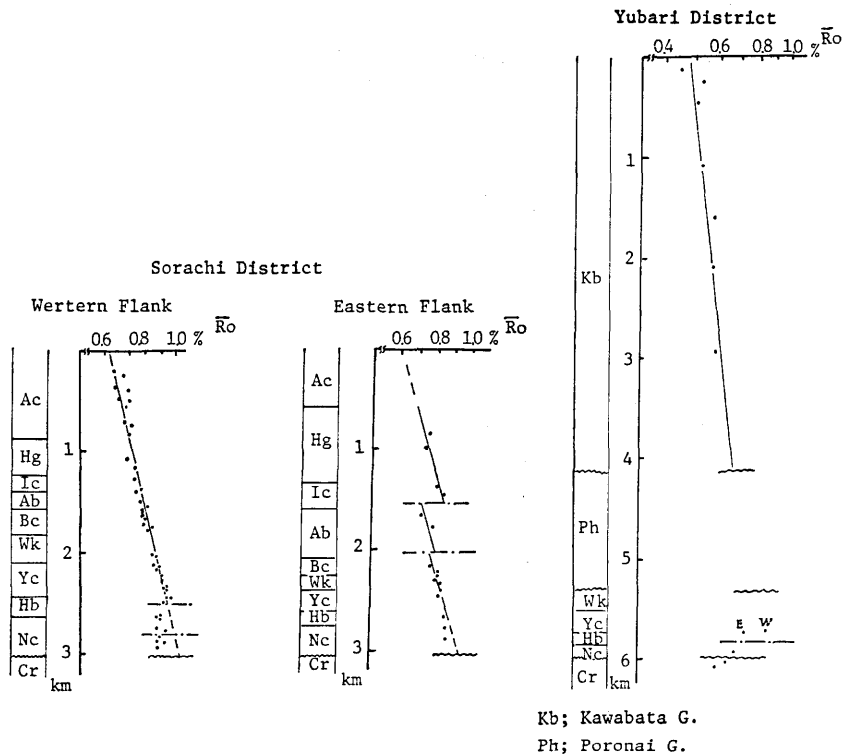


Fig. 5. Stratigraphic vitrinite reflectance variation of the typical geologic cross sections.

stratigraphic reflectance gradients and deformed general tendency. Geologic consideration on cause and process of this extraordinary stratigraphic coalification pattern or difference in the gradients will be discussed in the next chapter.

IV. Geologic condition of coalification in the Ishikari coalfield

A. Stratigraphic coalification pattern

The depth-reflectance gradient obtained from the oil exploring deep drill hole samples and the general increasing tendency in accordance with descending stratigraphic succession represent an accelerated condition in such coalification factors as temperature, pressure and their duration in accordance with increasing burial depth. In the case of surface geologic survey, horizontal observation and sampling on vertical strata are identical with those of successive sedimentary change vertically above a point within a basin, and the stratigraphic thickness coincides with a part of burial depth, but this will not always be applicable to gently inclined strata of variable thickness as diagrammatically illustrated in the Fig. 6 (case B). There are several cases in variation of the stratigraphic reflectance gradient as in this figure, and this example will be favourable to explain the characteristic stratigraphic coalification pattern of the coalfield.

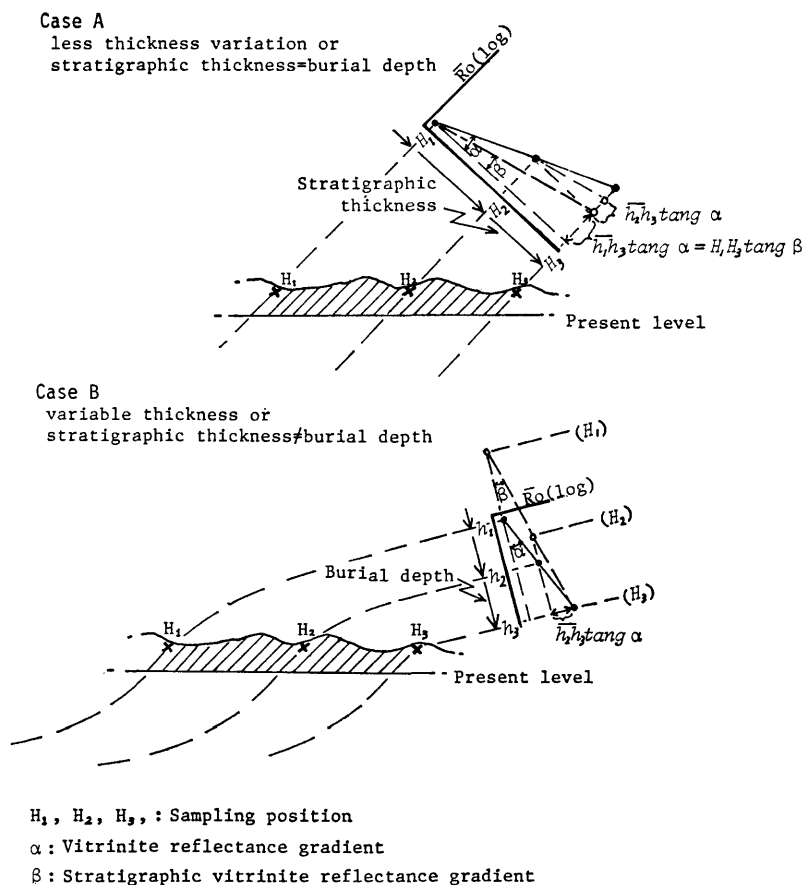


Fig. 6. Explanatory scheme of relationship between thickness variation and burial depth with vitrinite reflectance gradients.

The fact that the reflectance value of the lowest horizon at the western flank of the Sorachi anticline is nearly equal to that of the middle horizon of the group as shown in the Fig. 5 will be explained by combining the case A and B of the Fig. 6. The steeply inclined upper and middle parts of the western flank correspond to H_1 – H_2 of the case A, while the gently inclined lowest part corresponds to h_2 – h_3 of the case B. This presumption is testified by the thinning and facies change of each formation of the group toward the anticlinal axis (AIHARA, 1968; MATSUI, 1962), which were resulted from differential subsidence of the basin and progressive migration of the depositional centre toward the northwest or west in this area. Similar situation is presumably applied to the Noborikawa and the Cretaceous Hakobuchi coal seams in the Yubari district though the structural deformation of this district made the pattern more complicated.

The comparatively lower reflectance gradient of the Neogene Kawabata group in the Yubari district is explained by the same way mentioned above. Concerning with the thickness variation of the group of this area, it has been

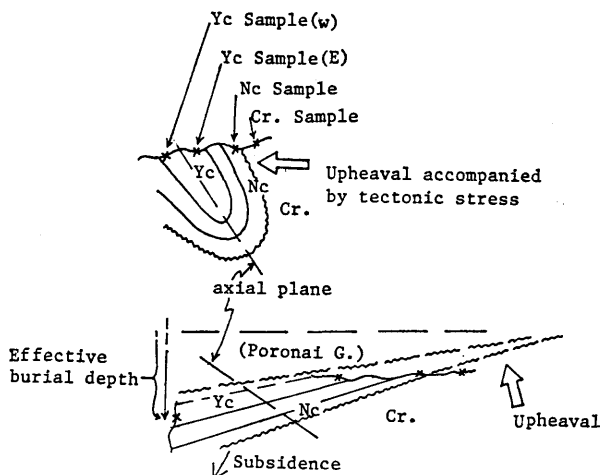


Fig. 7. Generalized restoration of overfolded structure with regard to burial depth in the Yubari district.

already pointed out that the graphically accumulated or simply measured stratigraphic thickness at the surface is apt to overestimate the true depositional thickness (TESHIMA, 1976b) since the group is consisted of molasse type sediments that were deposited during progradational movement at the later stage of the Hidaka orogeny.

Tectonic deformation of the initial stratigraphic coalification pattern is observed at the eastern flank of the Sorachi anticline and the eastern margin of the Yubari district. In the eastern flank of the Sorachi anticline, the total thickness of the Ishikari group increases toward the east and northeast (MATSUI, 1962) and the group is finally covered unconformably by the Poronai and the Kawabata groups on the Ashibetsu anticline at the northeastern margin of the coalfield. The relatively high reflectance value of the upper horizon in the eastern part as shown in the Fig. 5 is also explained by the same way mentioned above after restoring the hanging blocks of the reverse faults to the east.

Tectonic deformation of the Yubari district is so complicated that the only one simplified schema of single overfolding is quoted as in the Fig. 7. Even in this simplified figure, it is evident that the present sampling points on the surface remarkably differ from the deposited points of samples, and that the coalification process in the lower coal-bearing horizons of the Noborikawa and the Cretaceous Hakobuchi would be affected by relatively stagnant subsidence and relatively advancing upheaval and by the later structural stress from the east generated by latest stage of the Hidaka orogenic movement. This situation may be explained by applying an extreme variation of tilting of the case B of the Fig. 6 after restoring the overfolded structure.

B. Geologic background for coalification

The effect of temperature for coalification reaction has been recognized not only by geologic observation in field evidences but also in laboratory experiments.

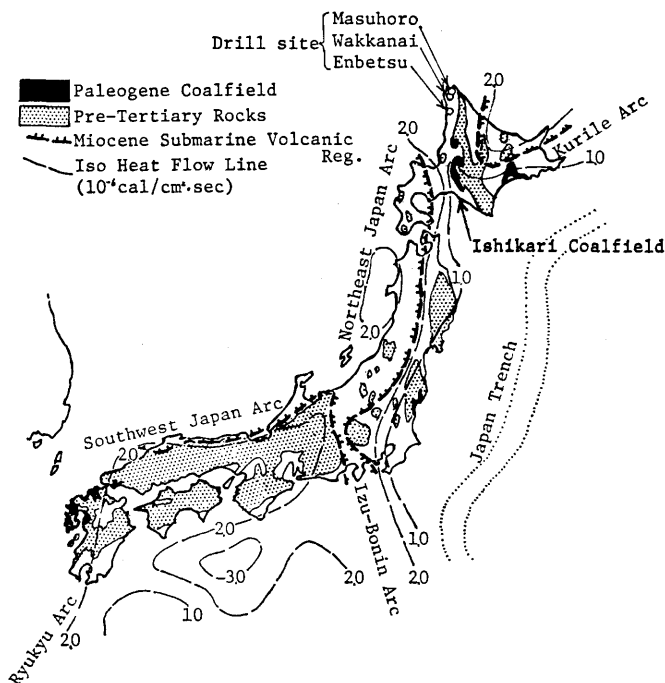


Fig. 8. Terrestrial heat flow distribution around the Japanese islands with special reference to the Ishikari coalfield.

Concerning with the thermal background of the Ishikari coalfield, the increase in temperature in accordance with the burial depth by the geothermal gradient would be the most prominent factor for accelerating coalification process since there is no particular plutonic batholith or intensive igneous activity that penetrate both the Tertiary sediments and Cretaceous miogeosynclinal thick sediments in and around the coalfield. Present terrestrial heat flow researches in the Hokkaido island (EHARA *et al.*, 1970, 1971) and around the Japanese islands (UYEDA *et al.*, 1964, UYEDA 1972, WATANABE, 1972; YASUI *et al.*, 1965) prove a concurrence of extraordinary low heat flow region with the Japan trench and existence of its bending branch through the southwestern Hidaka mountains where the Ishikari coalfield is situated as shown in the summarized figure of the Fig. 8. The depth-reflectance gradient obtained from the oil exploring deep drill hole samples and the stratigraphic reflectance gradient in the coalfield imply a predominance of lower geothermal gradient of the districts in the geologic past that have continued to the present terrestrial heat flow condition.

The coalification process in the Ishikari coalfield commenced successively, and proceeded under increasing temperature and static pressure conditions in accordance with respective burial depth that was controlled by depositional movement of the subsiding basin, and continued within the duration time through the Hidaka orogenic movement. The restored coalification pattern in the typical geologic cross sections at the end of the Kawabata sedimentation, the later stage of the orogeny, are tentatively exemplified in generalized schema as in the Fig. 9

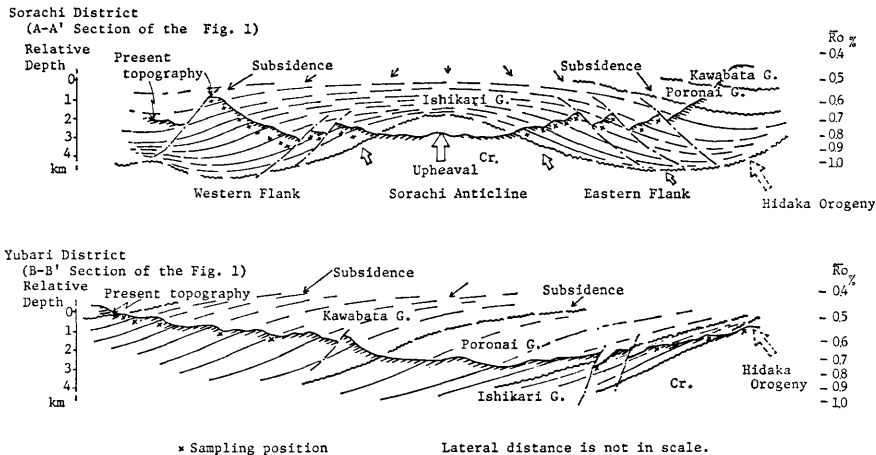


Fig. 9. Restoration of generalized burial condition at Miocene epoch in the typical geologic cross sections.

with an assumption that thermal condition was concordant with depth. The effect of the Hidaka orogeny which gradually developed since late Cretaceous period had been already reflected in the depositional and structural developments that occurred before the stage of this figure. But the later effect of upheaving movement that occurred near the present major anticlines and the eastern margin gradually developed to decrease in burial depth and corresponding temperature and to release coalification process. The accelerated upheaving movement in the latest stage was accompanied by the structural deformation with additional stress from the east which played the important role of rearrangement of the initial coalification pattern in shallowing depth and lowering temperature at the marginal and upheaving areas while the coalification process would be accelerated simultaneously at the subsiding area.

V. Conclusion

The following summary may be drawn as a conclusion from the above-mentioned data and discussion.

The deposition of the coal-bearing Paleogene Ishikari group commenced unconformably covering the miogeosynclinal Cretaceous Yezo group at the west-erly migrated depression from the geosyncline. Thus the movement of the depression, the Ishikari basin, was inherently affected by the development of the Hidaka orogenic movement from late Cretaceous to middle Tertiary period and was reflected both on the thickness variation together with facies change and on the diagenetic alteration of the organic sediments.

The degree of diagenetic alteration is determined by rank of coalification by measuring vitrinite reflectance of which samples were systematically collected from various coal-bearing horizons to represent a stratigraphic variation of coalification. Comparing this stratigraphic coalification pattern of the coalfield with the present depth-reflectance gradient of the oil exploring deep drill holes

at the northern extension of the coalfield, it is clearly indicated that the accelerated coalification condition in accordance with the deeper burial depth of the lower stratigraphic horizon was situated within rather cool paleogeothermal environment which could be inherited to the present geothermal condition as revealed by the present terrestrial heat flow studies, and also that the nominal stratigraphic sequences at the present surface do not always correspond to successive burial depth. The discrepancy between stratigraphic order at present surface and past burial depth may be explained, in combining depositional and structural histories of the coalfield, that it was attributed to the progradational migration of the basin caused by the relatively slower subsidence at the present axial part of the major anticlines and eastern margin of the coalfield which effected thinner overburdening sediments to retard coalification process in the coal seam of the lower stratigraphic horizons of these parts.

The coalification reaction in the Ishikari coalfield commenced and proceeded through the deposition and structural development during the Hidaka orogeny, but sequential upheaval accompanied by tectonic deformation resulted in lowering temperature for coalification and in interrupting the reaction. Thus the present stratigraphic reflectance gradient and total coalification pattern on the surface of the coalfield implicate synorogenic to partial preorogenic coalification processes which were generated on the Pacific side of the Northeast Japanese Island arc corresponding with extremely low heat flow region that is closely related to the subducting zone between the two global tectonic units of the Pacific ocean and the continental margin. The coalification reaction had almost progressed within the limited geologic time interval, from Eocene to Miocene, of duration under thick cover of sediments in the low heat flow region, which would be remarkably effective to arrest the split off and removal of edge group rich in hydrogen and oxygen, main component of volatile matter, in chemical structure of vitrinite and to characterize the distinctive chemical property of the Japanese Tertiary coal.

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