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Accumulation and diagenesis of Tertiary coals in some marginal areas of the Asian continent

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Abstract: Tertiary coals and coal-bearing formations are sporadically distributed in marginal areas of the Asian continent. Their economical qualities and quantities are inferior to continental Paleozoic coals, but their geological significance should be emphasized for studies of accumulation and transformation mechanisms of coal-bearing formations in continental margins.

This paper attempts to discuss the geological processes that occurred during accumulation and diagenesis of the Tertiary coal-bearing formations in Kyushu, Japan and other Asian regions.

GEOLOGICAL SETTING OF THE AREAS

In northern Kyushu, Japan, Eocene-Miocene (?) successions are exposed in separate small basins (Fig. 1). At the base there are non-marine red beds which grade stratigraphically upward into marine sandstone and shale through coal-bearing parts. The thickness and lithology are variable among the basins. The sequences are severely faulted and folded, and these structures are regarded to have been originally formed by tectonic movement at the end of the Cretaceous or the beginning of the Tertiary. The faults were reactivated repeatedly during Tertiary sedimentation, resulting in the thickness and lithologic variations described above. All of these features are ascribed to the geologic situation of the sequences at the tectonically active continental margin.

Late Oligocene to Miocene formations consisting of sandstone, shale and lignite show sporadical distribution in northern Thailand and the surrounding Indochina regions (Fig. 1). The basins in Thailand are geo-tectonic grabens formed by post-Cretaceous crustal movements (Polachan and Sattayarak, 1989).

Miocene formations in south Korea and northern Taiwan include thin coal seams, although their surface distribution is very limited. The coals are lignitic to sub-bituminous, and sub-bituminous to bituminous in rank, respectively (Fujii and Park, 1985; Wu, 1976).

ACCUMULATION PROCESSES

Based on published data (Miki, 1975, 1988) it seems likely that the Tertiary basins in northern Kyushu, Japan were formed as fault grabens at the tectonically active continental margin. The tectonic elements were reactivated repeatedly during and after sedimentation, and sequences of variable thickness and lithology over a short distance were deposited in narrow basins. Similar processes are considered also to have occurred in the Tertiary coal basins in northern Thailand. They are originally geo-tectonic grabens (Polachan and Sattayarak, 1989) formed in intermontane, lacustrine and littoral environments (Ratanasthien and Honda, 1992). Other Tertiary fault grabens are known in Vietnam. The Miocene sequences consist of sandstone, siltstone, claystone and coal of lagoonal, deltaic, swampy and fluvial origins. The coals are lignite to sub-bituminous in rank (ESCAP, 1990). Neogene coal-bearing formations in south Korea are non-marine (Kim, 1987), and those in Taiwan laterally change to marine facies (Wu, 1976).

It is well known that the Tertiary coals from Kyushu are rich in vitrinite and poor in liptinite and inertinite in maceral composition and are similar to coals from Thailand (Miki and Aizawa, 1995), Korea (Park and Yamazaki, 1987), Taiwan (Wu, 1976) and Vietnam (ESCAP, 1990). Those maceral compositions suggest the accumulation of plant debris under a wet environment as in high water-table basins at the continental margin. Analytical data of these coals (Figs. 2 and 3) also indicate a rapid submergence of the transported materials and covering with clastics due to tectonic subsidence of the basin floor during sedimentation.

DIAGENESIS OF COALS AND COAL-BEARING FORMATIONS, AND PALEO-GEOTHERMAL BACKGROUND

Some Tertiary rocks in northern Kyushu, Japan are tuffaceous, and are composed of various kinds of authigenic clays and zeolites. Stratigraphical arrangements of the mineral zones are clearly observed in respective basins, indicating that the successions were basically influenced by burial diagenesis (Miki *et al.*, 1993). Degree of diagenesis increases regionally to the northwest, which suggests an additional heat supply from the sea region between northern Kyushu and Korea (Miki *et al.*, 1993). The degree of diagenesis observed today was, consequently, attained by a combination of burial diagenesis and syngenetic additional heat supply. A delay in zeolite transformation after coalification, particularly in the northwestern extremity of the area (Tsuyazaki-Oshima in Fig. 4), may suggest that the region was under high paleo-geothermal environment, and that the heat source was northwest of the region. This explanation is derived from an idea that the mineral

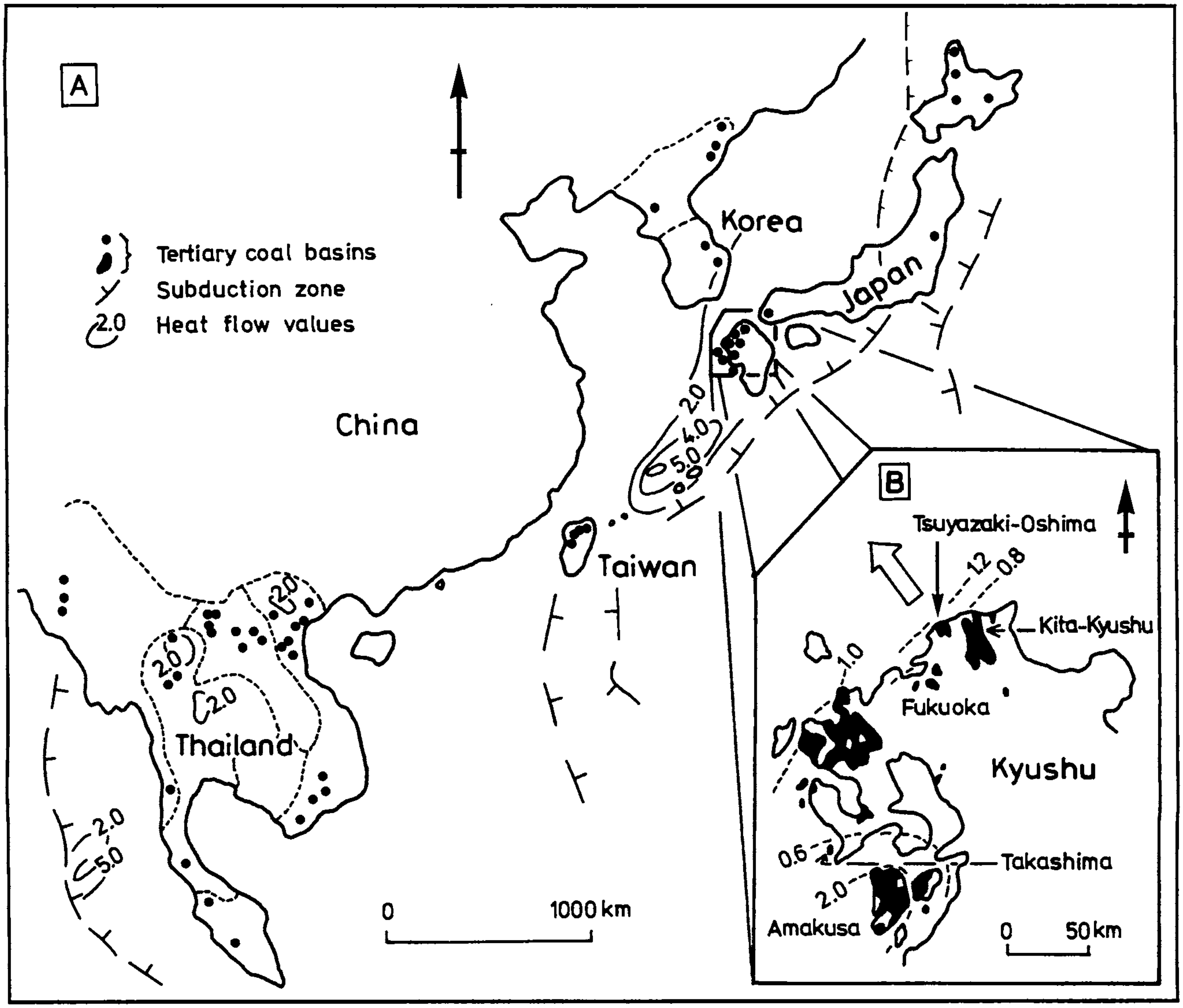

Figure 1. Location maps with geophysical data. Heat flow values are after Watanabe *et al.* (1970), Thienprasert and Raksaskulwong (1984), Rodolfo (1969), and Yem *et al.* (1991). Numerals in B indicate the vitrinite reflectance values, and the arrow shows the increasing direction of the degree of diagenesis (summarized after Miki *et al.*, 1993).

Table 1. Analyzed data of coals from Kyushu and Malaysia.

Basin	Formation	Moisture	Ash	Volatile matter	Fixed carbon	Volatile* matter	Fixed* carbon	C*	H*	H/C**	Rmax
Chikuho	Sakamizu	8.42	29.76	30.36	31.46	49.11	50.89	69.36	5.49	0.95	0.53
Chikuho	Yamaga	7.02	16.99	37.57	38.42	49.44	50.56	72.54	5.52	0.91	0.43
Chikuho	Onga	6.87	39.88	30.37	22.88	57.03	42.97	71.17	7.27	1.23	0.58
Chikuho	Onga	4.93	48.29	30.38	16.40	64.94	35.06	68.02	6.56	1.16	0.53
Chikuho	Onga	5.06	7.06	37.71	50.17	42.91	57.09	79.44	6.12	0.92	0.66
Chikuho	Takeya	4.51	26.83	30.88	37.78	44.98	55.02	76.39	6.00	0.94	0.71
Chikuho	Sanjaku-Goshaku	2.67	47.21	27.35	22.77	54.57	45.43	70.91	6.54	1.11	0.61
Munakata	Ikeda	3.76	7.13	35.91	53.20	40.30	59.70	79.20	5.45	0.73	0.68
Munakata	Kamizaki	3.64	52.61	12.18	31.57	27.84	72.16	82.65	5.06	0.83	1.40
Takashima	Hashima	1.30	3.00	40.80	54.90	42.60	57.40	83.00	6.04	0.87	0.81
Takashima	Hashima	1.30	3.00	40.80	54.90	42.60	57.40	83.00	6.04	0.87	0.81
Karatsu	Yoshinotani	2.71	12.61	41.89	42.79	49.46	50.54	79.30	6.30	0.95	0.66
Amakusa	Toishi	1.70	3.40	11.70	83.20	12.30	87.70	90.43	4.09	0.54	2.36
Amakusa	Toishi	3.11	5.53	17.15	74.16	18.78	81.22	87.66	4.18	0.57	2.02
Amakusa	Toishi	2.89	5.79	15.89	75.43	17.40	82.60	88.21	4.40	0.60	1.81
Malaysia		16.50	9.71	45.98	27.81	62.31	37.69	65.50	5.76	1.06	–

* d.a.f.%
** atomic ratio

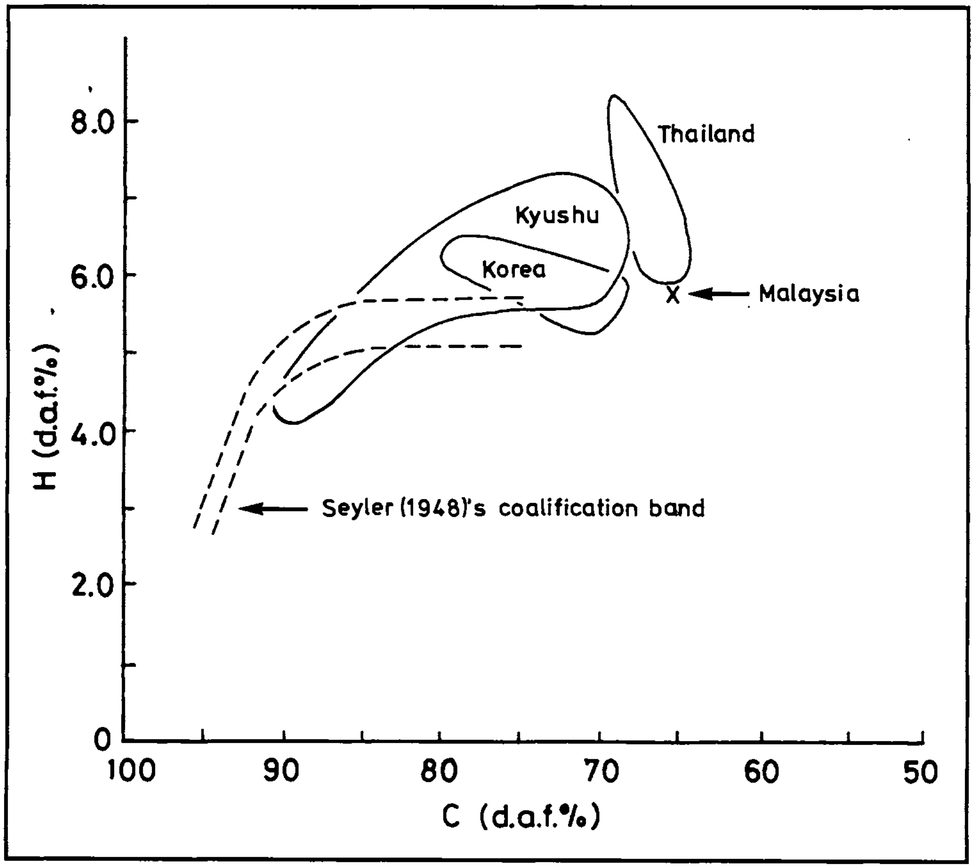

Figure 2. Relationship between hydrogen (H) and carbon (C) contents in Asian coals. Data sources. Thailand: Miki and Aizawa (1995), Korea: Park and Yamazaki (1987).

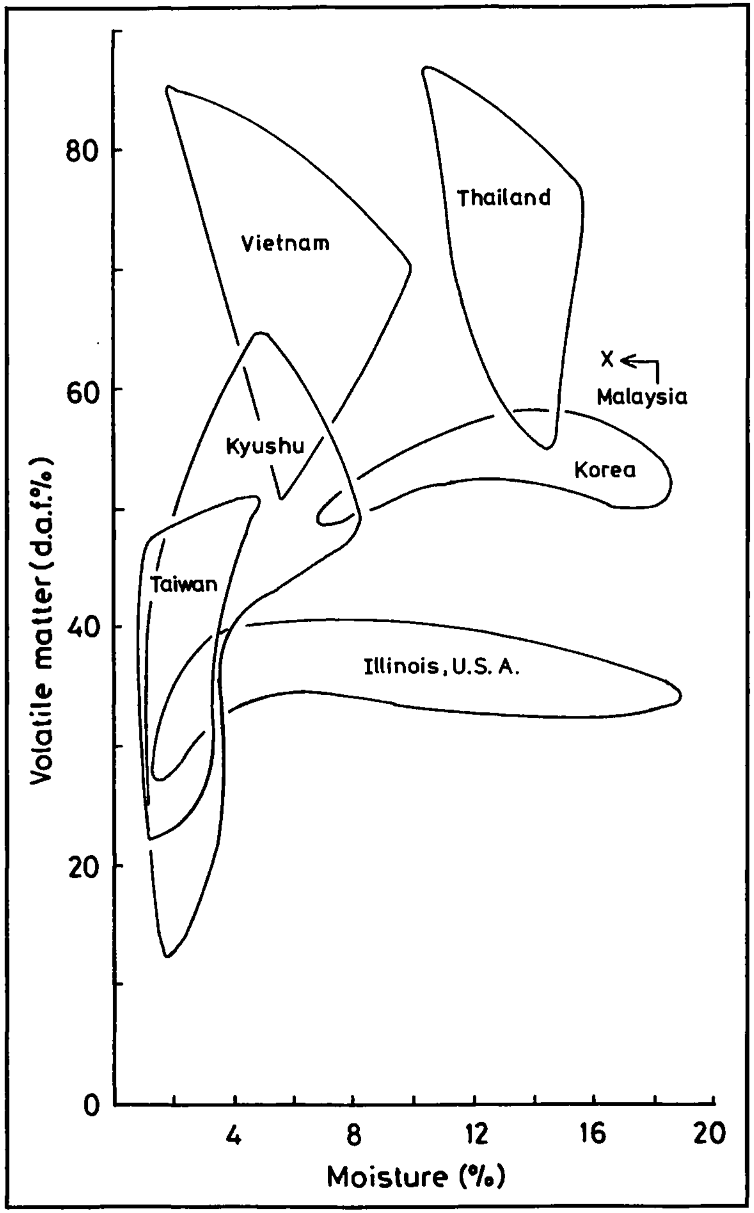

Figure 3. Relationship between volatile matter and moisture contents in Asian coals. Data sources. Thailand: Miki and Aizawa (1995), Korea: Park and Yamazaki (1987), Vietnam: ESCAP (1990), Taiwan: Wu (1976), Illinois, U.S.A.: Thomas and Damberger (1976).

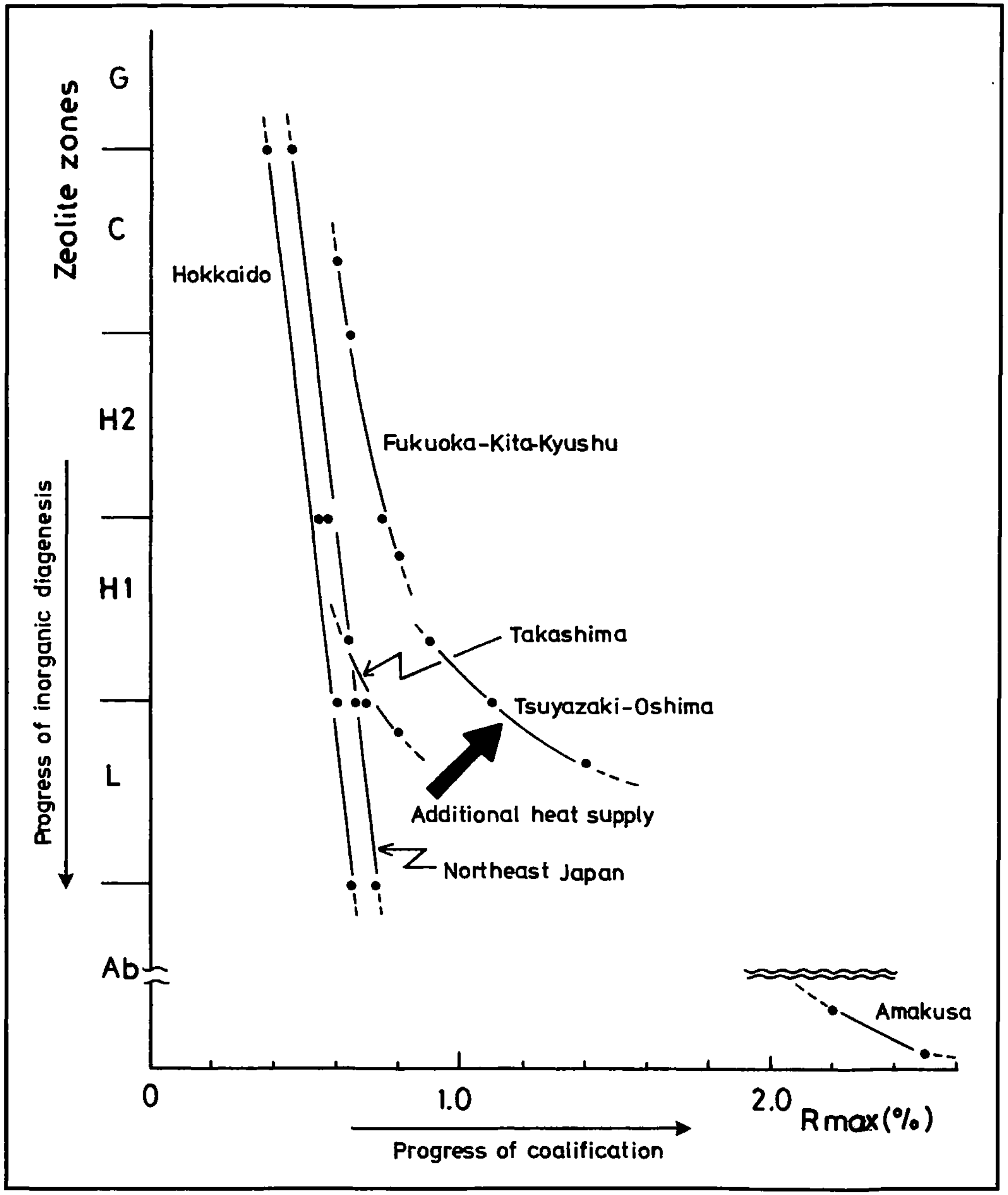

Figure 4. Relationship between zeolite zones and vitrinite reflectance values (Ro). Original data for Kyushu are from Miki *et al.* (1993). Data for Hokkaido and northeast Japan are from Sasaki *et al.* (1982). G: volcanic glass, C: clinoptilolite, H2: heulandite type 2, H1: heulandite type 1, L: laumontite, Ab: albite.

transformation needs a longer period of time of thermal events on a regional scale. Northern Kyushu-Korea sea region is characterized by the present-day high heat flow conditions (Uyeda and Horai, 1964; Watanabe *et al.*, 1970), which may be inherited from the opening of the Sea of Japan during the Tertiary.

Within the Tertiary formations of northern Thailand, the stratigraphical and regional diagenetic patterns are variable (Miki and Aizawa, 1995). Northern Thailand is a thermally active region characterized by present-day high geothermal gradients (around 70°-90°C/km) and high heat flow values (higher than 2.5 HFU in maximum) (Thienprasert and Raksaskulwong, 1984; Barr *et al.*, 1979). These high geothermal environments may be the result of sea-floor spreading in the Andaman Sea and subsequent basaltic intrusions during late Cenozoic time (Barr *et al.*, 1979).

The occurrence of bituminous coals to semi-anthracites in Kyushu, Japan suggests that coalification depends basically on deep burial as estimated by thick overburden more than several thousand meters under the influence of an additional heat supply. The rank of Thai coals, on the other hand, is lignite notwithstanding the high geothermal properties of the area today. The occurrence of this low rank coal may be ascribed to shallow burial with thin overlying successions and short duration of burial. Loose consolidation of sandstones in lignite-bearing formations supports the shallow burial of sediments. The high geothermal conditions in the late Cenozoic did not contribute remarkably to a progress of coalification, although they modified the stratigraphical variation patterns of the rank.

The Miocene drilled offshore near Miyakojima, which is located in the western margin of the present-day remarkably high geothermal area of the Okinawa Trough, shows vitrinite reflectance values of 0.5–0.6% in the lowest part of the successions (Tsuburaya and Sato, 1985). The increasing rate of the values (0.17%/km) is not great. The same aged coals from the adjacent islet (Iriomote-jima) have values as high as 1.0% in maximum and rate as 1.5%/km (Chijiwa, 1991). The rank of Miocene coal from Taiwan, which is geographically adjacent to the above islets, is also low. These data conform the local variations of geothermal conditions and burial history of sediments over a short distance. It should be noted that the present-day high geothermal conditions are generally inherited from the Tertiary but not directly linked to a progress of Tertiary diagenesis.

CONCLUSIONS

Tertiary coal-bearing formations in some marginal areas of the Asian continent provide similar characteristics: locally dispersed small-scale distribution, marked variation in lithology and thickness among the basins, geo-tectonic origin of the basins, and highly advanced coalification at some localities. All of these features are genetically related to the geological situation of the areas at tectonically active continental margin mobile belts. The basin floor had repeated subsidence and the transported sediments were maintained under the water table, which brought the vitrinite-rich maceral composition of coal indicating the wet environment.

High geothermal environment of the area is essentially related to plate motions since the Tertiary. In some regions, however, present-day geothermal data do not harmonize well with the degree of diagenesis of sediments. This indicates that the ancient geothermal conditions do not coincide completely with the modern ones, and that a long period of time is necessary for a progress of diagenesis.

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