STRUCTURAL CONTROL ON SEDIMENTATION OF COAL-BEARING FORMATIONS IN JAPAN

Keizo FUJII

Geological Survey of Japan, 1-1-3 Higashi, Tsukuba, Ibaraki, 305, Japan

Abstract. Major coal-bearing formations in Japan are Tertiary, mostly Paleogene, in age. The distribution, sedimentological facies and formation of coal fields are closely associated with the plate tectonics of active plate margins. Coal basin development seems to have been primarily controlled by grabens or half-grabens closely associated with active fault movement. Three kinds of basins are recognized: strike-slip fault or pull-apart basins in the Ishikari, Rumoi and Joban coal fields, a tensional forearc basin in the Kushiro coal field, and a basin related to flexural-slip folding in the northwestern Kyushu coal field. Subsidence of the basins might have been directly synchronous with uplift of the source areas on the upthrown side of the faults. Therefore, sedimentary facies in these coal fields have limited lateral extents. Similarly, the lateral extent of coals seams is controlled by tectonic movement, not by changing topographic surfaces as in stable continental regions.

1. Introduction

As most of the economically workable coal seams have been found in stable continental regions from the upper Carboniferous to Permian, upper Triassic to Jurassic and upper Cretaceous to middle Tertiary ages, a number of depositional models have been presented for coal-bearing formations in such stable continental regions. Many papers attempting to interpret the sedimentology of coal-bearing formations have often cited the Mississippi delta and the Everglades swamps in the United States as recent models.

In the Mississippi delta, peat accumulates in large-scale interlobe basins, which switch according to the migration of channels (KOSTER et al., 1987). In the Everglades swamps, the peat distribution reflects underlying topography connected with rising areas, which is modified by the impact of overland flow of water and by inland flow of tidal water (SPACKMAN et al., 1966). As a result, there is no systematic change in the lateral distribution of peat deposits.

In petrological studies, coal from continental regions is characterized by a comparatively high content of inertinite, which formed under dry conditions or low water tables (STACH et al., 1982; STRAUSS et al., 1976; FUJII, 1983). In the Everglades swamps, peat exhibits the highest percentage of inertinite (COHEN and SPACKMAN, 1977).

As yet, however, few depositional models have been published for coal-bearing formations in the active plate margins of east Asia (SAKAKURA, 1961; SASA, 1966; KOESOEMADINATA, 1978).

This paper summarizes the results of structural, sedimentological and coal petrological studies in Japanese coal fields. Most of the important Japanese coal seams were formed
during the Eocene to Oligocene ages, and active fault movement was a major factor controlling development of the seams. The formation, distribution and sedimentological facies of coal fields are closely associated with the plate tectonics of active plate margins.

2. **Tectonic Framework in the Paleogene Age**

Detailed reconstruction of the possible tectonic history of Japan has been proposed in relation to plate tectonics in east Asia and the Pacific Ocean (UYEDA and MIYASHIRO, 1974; MARUYAMA and SENO, 1986). The development of Paleogene basins in Japan is closely associated with the interaction between the Japanese islands and the Kula and Pacific plates.

The north–northwestward subduction of the Izanagi plate was initiated about 140 Ma (MARUYAMA and SENO, 1986), and the Okhotsk megablock collided with northeast Asia at about 90 Ma (NATALIN and PARFENOV, 1983); the block probably migrated with the Izanagi plate. The Kula plate started to subduct westward from about 85 Ma. The transition from the Kula plate subduction to the Pacific plate subduction in east Asia is estimated to be about 70 Ma by ENGBRETSON et al. (1985).

The Kula–Pacific ridges subducted at about 70 Ma in southwest Japan and about 60 Ma in Hokkaido. The Philippine ridge was part of the Kula-Pacific ridge, connected by a large transform fault, and was migrating northward (UYEDA and BEN-AVRAHAM, 1972). While the Kula–Pacific ridge descended beneath east Asia, the Philippine ridge was left behind, and is estimated to have become an extinct ridge at about 50 to 60 Ma (UYEDA and MIYASHIRO, 1974). The subduction boundary in northeast Asia shifted to the Okhotsk megablock, after collision of the megablock with northeast Asia. Between the Okhotsk block and western Hokkaido–Sakhalin, a small ocean basin was trapped at about 60 Ma (MARUYAMA, 1984; KIMURA, 1985). Paleogeographic reconstruction at about 60 Ma is shown in Fig. 1 (UYEDA and BEN-ABRAHAM, 1972; MARUYAMA and SENO, 1986).

During about 40–50 Ma, the triple junction (a) was moving toward point (b) in Fig. 1, as the subduction zone between the trapped plate and the east Hokkaido–Okhotsk block was moving westward. Therefore, convergence of the trapped plate under west Hokkaido–Sakhalin had a dextral strike-slip vector. As a result, oblique convergence and a dextral strike-slip fault occurred contemporaneously along the subduction zone between the trapped plate and west Hokkaido–Sakhalin. The trapped Kula plate closed at about 40 Ma.

3. **Geologic Structure, Sedimentation and Basin Formation**

The major coal-bearing formations in Japan are Tertiary in age; most of them date from the Paleogene, but a few others are of Mesozoic age.

Most of the important and productive coal fields are distributed on Hokkaido and northwestern Kyushu, but a few are also found on Honshu island. On Hokkaido, the Ishikari and Rumoi coal fields are distributed in the central part, and the Kushiro coal field is distributed in the eastern part. On Kyushu, the Chikuho, Sakito–Matsushima, Takashima, Miike and Amakusa coal fields are distributed in its northwestern part. The Joban coal field is distributed in the northeastern part of Honshu.

3.1 **Hokkaido island**

A. The Ishikari coal field

The Ishikari coal field can be divided into two districts by the Pombetsu fault, Sorachi in the north and Yubari in the south (Fig. 2). Eocene to Oligocene strata with many
coal-bearing formations unconformably overlie Cretaceous rocks. These strata accumulat-
ed under environments of fresh-water flat lowlands and estuaries, and brackish lagoons
near the seashore. The strata in the Sorachi district are 3000 m thick and are mainly
composed of sandstone (70%), while those in the Yubari district are less than 500 m thick
and mainly composed of shale (90%) (Sakakura, 1954).

Tectonic features are characterized by a southward tilting uplift and erosion of the
mountains of the Yubari district block, and sedimentation in rapidly subsiding basins of the
Sorachi district block. Basins and uplifted blocks resulting from the splaying, offsetting and
anastomosing of faults and folds are essential features.

Sedimentation was controlled by the active movement of the Pombetsu fault at the
time of deposition of the coal-bearing formations. Since the depositional basin was
continually subsiding, particular facies tended to remain in the same zones for long periods
of time, and lateral migration of facies was limited. Three depositional facies of coal can be
observed: a marginal (inner) facies, an intermediate facies and a submargin (outer) facies

These structural and sedimentary features are characteristic of those caused by dextral
strike-slip fault systems (Reading, 1980). These strike-slip systems are interpreted to be
closely associated with an oblique convergence between the trapped Kula plate and west
Hokkaido-Sakhalin in the Eocene (Fig. 1b).

B. The Rumoi coal field

Coal-bearing formations are Eocene in age, corresponding to the upper half of the
sequences of the Ishikari coal field, and unconformably overlie the Cretaceous rocks. The
coal basin has a quadrangular shape extending in a north-south direction. Subsidence at the
border of this basin became more rapid due to a northwestward tilting fault movement (Fig.
3).

Detailed investigation of the depositional environments in this basin has been made by
Sogabe (1966). The strata have a maximum thickness of 355 m and thin rapidly eastward
and gradually southward; the strata thin out at the northwest margin of this basin. In the
Showa area, 5 cyclothem are observed, while in the Asano area, only 2 upper cyclothem
are recognized. The thickness ratio of both sandstone and conglomerate against the total
thickness of the coal-bearing formations is 50% in the west and 30% in the east of the Showa
area, while the ratio ranges from 30% to 50% in the west and from 0 to 10% in the east of the
Asano area. The coal seams tend to coalesce southeastward in the upper part of each
cyclothem. These thickness changes and facies variations are thought to be caused by
northwestward tilting block movement under a tensile stress field.

Deformation took place initially under a tensional stress field, changing to compres-
sional as the cyclothem was completed. Axial traces at folds, and secondary thrust and
reverse faults trend in a NW direction and are arranged in an en echelon pattern (Fig. 3)
(Sugai, 1968). This indicates that the displacement along the large fault at the eastern
boundary of this coal basin has a dextral strike-slip component. This basin is interpreted to
have formed as a pull-apart basin associated with subduction of the trapped Kula plate
under west Hokkaido-Sakhalin, similar to the tectonic movement of the Ishikari coal field.

C. The Kushiro coal field

The Kushiro coal field is divided into western and eastern districts (Fig. 4). The coal-
bearing formations are Eocene in age, unconformably overlying Cretaceous rocks, and
include two megacycles of sedimentation. The first megacycle proceeds from non-marine,
through brackish water to marine sediments, and the second one from brackish water to
non-marine sediments.

In the western district, the thickness of coal-bearing formations increases gradually
from 450 m in the west to 950 m in the east. The formations are characterized by marked lateral facies variations. In the western margin, where a large NS trending fault limits the western end of the coal-forming basin, each formation rapidly thins (Fig. 4), and the grain size of the sandstone rapidly becomes coarser towards this fault (MABUCHI, 1962; SOGABE, 1967).

In the eastern district, the thickness of coal-bearing formations increases from 400 m in the north to 800 m in the south. The grain size of the sandstone in the coal-forming formations becomes coarser southward. The coal-bearing basin is composed of rectangular blocks with ESE–WNW and NNE–SSW trending faults, and is tilted southward (SATO, 1967; HYAKKOKU, 1967).

As the subduction zone between the trapped Kula plate and the east Hokkaido–Okhotsk block was moving westward, and the zone between the Pacific plate and east Hokkaido–Okhotsk Block was moving southward (Fig. 1b), the strength of the mechanical
couplings between the trapped plate, the east Hokkaido–Okhotsk block and the Pacific plate became weak, and the stress field became tensional.

Therefore, the coal basin in the western district is interpreted to have formed as a tensional forearc basin in the collision between the trapped Kula plate and the east Hokkaido–Okhotsk block; the basin in the eastern district was formed as a tensional forearc basin in the collision between the east Hokkaido–Okhotsk block and the Pacific plate.

3.2 Honshu island

A. The Joban coal field

The coal-bearing formations in the Joban coal field are late Eocene to early Oligocene in age (YANAGISAWA and SUZUKI, 1987), unconformably overlying pre-Tertiary rocks. The Joban coal field is divided by three major faults into four blocks, the Futatsuya, Akai, Yunotake and Yamada blocks from north to south. (Fig. 5) (YOSHIDA and SUYAMA, 1952).
In general, each block tilts eastward and forms a basin structure by a dextral strike-slip fault accompanying normal slip throw. This indicates that the three major faults have great influence on the structure of this coal basin, that the faulting began at the time of deposition of the coal-bearing formations, and that movement along the fault continued during their
deposition. Therefore, changes of thickness and facies variation were small within each block, but are large between blocks (Yoshida and Suyama, 1952; Eguchi and Shoji, 1955; Sugai et al., 1957).

The Pacific plate motion changed from a NNW to a NW direction at 43 Ma. Its motion had a southward strike-slip vector, which caused the dextral side-stepping faults in this coal field. Therefore, these dextral side-stepping faults are closely associated with subduction of the Pacific plate under northeast Honshu.

3.3 Kyushu island

In the northwestern part of Kyushu, there are four important coal fields, the Chikuho, Sakito–Matsushima, Takashima and Miike (Fig. 6). The main coal formations are Eocene in age, and are unconformably overlying pre-Tertiary rocks. Depositional basins are NNE–SSW extending trough-type graben or half-graben type basins. Generally, the eastern end of each coal basin is bounded by a normal fault, the dip angle of which gradually
Fig. 4. Cross section coal-bearing formations in Kushiro coal field taken from MARUCHI (1962), SOGARE (1967) and HYAKKOKU (1967). A: Reppo formation; B: Harutori formation; C: Tenneru formation; D: Yubetsu formation; E: Soun formation, F: Shitakara formation; G: Shakubetsu formation.

decreases away from the fault. The western side of the fault is subsided and tilted eastward, while its eastern side is uplifted (NAGAHAMA, 1962; KAMURA, 1982). The younger formations show a small displacement along the fault plane, while older formations show a large displacement, which means that this normal fault was formed at the time of sedimentation of the coal-bearing formations.

These coal basins were formed under a tensional stress field in the Eocene. However, NNW-SSE trending thrust faults and folds coexist at the Amakusa coal field in the southern end of the northwestern Kyushu coal field, where deformation was initially tensional at the time of coal seam deposition. The coexistence of a thrust fault and folds suggest that the Amakusa coal field was under a compressional stress field when deposition of the coal-bearing formations was completed (MATSUSHITA, 1951, 1971; TAKAHASHI et al., 1971; TAKAI and BOJO, 1963).

These structural patterns in the northwestern part of Kyushu can be explained by the bending of the southwest Japan and Ryukyu arcs (HASHIMOTO, 1962; MATSUMOTO, 1976; TERAOKA et al., 1981; AIHARA, 1983; FAURE and LALEVEE, 1987). The Philippine ridge is
considered to be extinct at about 50 to 60 Ma, but the Pacific ridge was still actively moving against the eastern part of Kyushu. As a result, differential movement along the transform fault caused the bending of Kyushu island in the Eocene, as shown in Fig. 6.

This bending caused a tensional stress field with an EW direction, and NS~NNE~SSW trending grabens or half-grabens in the outer arc, a compressional stress field in an EW direction in the inner arc, and NNW~SSE trending faults and folds in the Amakusa coal field.

4. Development of Cyclothsems and Coal Seams

Japanese coal-bearing formations are composed of many cyclothsms. This kind of cyclic sedimentation typically takes place in an unstable shelf or interior basin where intermittent submergence occurs. The following sequence of rock units is commonly represented from top to bottom in Japanese coal field cyclothsms;
  - upper shale (non-marine)
  - coal (swamp)
  - lower shale (non-marine)
  - fine-grained sandstone (non-marine)
  - coarse- to medium-grained sandstone with pebbles (non-marine).

Disconformity or scour contact is widely present. The basal part of the cyclothem often shows "wash-out" or abrupt transition from upper shale or coal to coarse- to medium-
grained sandstone (TASHIRO, 1952; SHIBAOKA, 1962, 1964). However, some cyclothsms are actually incomplete in comparison with common rock units. In some regions, it is necessary to set up a different succession of rock units; for example, in the Joban and Sasebo coal fields, acidic tuff and tuff breccia are frequently seen at the lowest and upper parts of cyclothsms (SHOJI, 1960; TAKEHARA, 1955).

Facies variations in the formations show large differences between coal seams, cyclothsms and fault movement. Many cases illustrate coal seam splitting and thinning from the upthrown to downthrown block, as follows.

Situations range from: (1) those where subsidence was too slow for peat to accumulate, or where the supply of coarse sediment overpowered peat growth in the margin of the uplifted block; the cyclothem is incomplete and thin, and the coal seam thins out; through (2) those where subsidence and sedimentation were balanced, allowing formation and preservation of peat in the middle part of the subsided block; the cyclothsms have intermediate thickness and are complete, and the coal seam is thick enough; to (3) those where subsidence was rapid enough to preclude the formation of substantial peat toward the margin of the subsidence block, the cyclothem is thick and incomplete, and the coal
seams intercalate many partings and split up into more beds of coal (SHIBAOKA, 1962, 1964).

Cyclothsms are irregular in many ways, particularly with regard to the distribution, thickness and lithologic characters of individual units. These irregularities appear to be related to local influences of fault movements. Movement in the depositional area might have been directly synchronous with uplifting of the source area of the upthrown side of the fault block. As a result, the sedimentary facies units are of restricted lateral extent.

From the facies described above, the depositional environment and an active fault-bounded basin are concluded to be the most important factors in controlling the cyclothem rock units and the development of coal seams.

First, the rock unit is characterized by coal being covered by non-marine shale. Most of the coals in Japan were formed in a fresh-water swamp environment, distinctly different from the environment in stable continental regions, where most of the coals overlaid shoreline or deltaic deposits and were covered by marine limestone or fossiliferous shale, perhaps affected by eustatic rises in sea level (WELLER, 1930, 1956; RAMSBOTTOM, 1979).

Secondly, for seams of thick peat to be preserved in the rock record, a continually slow subsidence of the peat-forming basin and the accumulation of peat must be balanced, to allow the formation and preservation of thick peat for long periods of time. Thus, an active fault-bounded coal-forming basin is the most suitable environment for the accumulation and preservation of thick peat.

5. Coal Petrology

Maceral composition in the main Japanese coal seams is characterized by a higher content of vitrinite group maceral (Fig. 7) (FUJII, 1983, 1985). The vitrinite group maceral includes degradinite, to which special attention should be paid. It is not classified internationally as an independent maceral, but is considered to be a variety of the vitrinite

Fig. 7. Maceral composition of coals in island arc region including Japan, the Philippines and Indonesia, and continental region. 1: Tertiary coals of island arc; 2: Pennsylvanian coals of USA and Canada; 3: Permian coals of Australia.
group (Stach et al., 1982). The degradinite is composed of finely dispersed, almost structureless, fluorescing groundmass, with a high content of strongly corroded resin and sporinite, and is characterized by low reflectivity, colorful fluorescence, higher H/C atomic ratio, and an alkane content compared with other vitrinite group maceral.

Although degradinite is included in the vitrinite group, it would be logical to classify it instead as an exinite group maceral, such as liptodetrinite. Degradinite is thought to deposit under wetter conditions or higher water tables, and to be subject to intensive anaerobic decomposition such as that in swamps (Hagemann and Wolf, 1987; Takahashi, 1977). A high content of 30% to 50% degradinite is characteristic of Japanese coal maceral, as is the very rare existence of inertinite, which is deposited under dry conditions or a low water table. As a result, Japanese coals were formed under wetter and more anaerobic conditions with higher water tables compared to the conditions of continental region coals.

6. Conclusion

In Japanese coal fields, active fault movements exert a dominant control upon peat-forming basins and their depositional environments, while in stable continental regions, the topographic surface on which peat swamps developed is a major factor in controlling peat-forming basins and their depositional environments.

Primary structural control on the development of coal basins in Japan seems to have been influenced by interaction between the Pacific plate and the east Asian plate. There are three kinds of coal-forming basins: the strike-slip fault or pull-apart basin in the Ishikari, Rumoi and Joban coal fields, the tensional forearc basin in the Kushiro coal field, and the basin related to flexural-slip folding in the northwestern Kyushu coal field.

Characteristics of sedimentation and its environment are summarized as follows.

1. Uplifting and erosion in a block, and sedimentation in the other rapidly subsiding block might have been synchronous with tectonic movement during the time of deposition of coal-bearing formations.

2. Sedimentary facies tend to remain in the same zones because sedimentation is controlled by active fault movement. The lateral extent of coal seams is also controlled by tectonic movement, not by changes of the topographic surface.

3. The coal-forming environment is interpreted to be under anaerobic conditions with high water tables, such as swamps, as opposed to continental coal-forming environments under oxidizing conditions with low water tables.

Acknowledgements

The author wishes to thank Mr. Yuichi Suzuki and Dr. Shuichi Tokuhashi, the Geological Survey of Japan, for their constructive comments, discussions and some data provided. Various versions of the manuscript have benefited from discussion with and critical comments by Dr. Masatsugu Ogasawara, the Geological Survey of Japan.

REFERENCES


FUJI, K., Some examples of application of coal petrology, UNESCO Region Workshop on Coal Geol. Southeast Asia, Fin. Rept., 41–70, 1983.


SHIBAOKA, M., Development and the cyclothem and the coal seams in the Ishikari coal field, J. Fuel Soc. Japan,
WELLER, J. M., Cyclical sedimentation of the Pennsylvanian period and its significance, J. Geol., 38, 97-135, 1930.