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Variability in coal facies as reflected by organic petrological and geochemical data in Cenozoic coal beds offshore Shimokita (Japan) - IODP Exp. 337

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ABSTRACT

This study reports on Cenozoic coal seams recovered at Integrated Ocean Drilling Program (IODP) Site C0020 during Expedition 337. IODP Site C0020 is located in a forearc basin formed by the subduction of the Pacific plate off Shimokita Peninsula (Japan). Hole C0020A penetrated 14 coal layers between 1825 and 2466 mbsf. Eleven of them were investigated within the frame of this paper. Investigated seams show a slight maturity increase with depth from lignite to sub-bituminous coal. In order to detect temporal changes in maceral and molecular composition and to relate them to changes in vegetation and depositional environment, macro- and micropetrographic data, bulk geochemical parameters, biomarker analysis, stable isotope geochemistry, and vitrinite reflectance measurements were performed. Results were also compared with palynological data obtained from 9 coal samples.

Elevated sulfur contents and high ash yields occur in the upper seams (cores 14R to 18R) whereas low sulfur contents and varying ash yields were determined for the lower coal seams (24R to 30R). The maceral composition and biomarker ratios of the uppermost seams argue for coal formation in a paralic environment and brackish, alkaline water conditions. In contrast, lignite samples from the lower part of unit III point to a limnic-fluviatile deposition. Conifers contributed significantly to peat formation in the uppermost seams (from cores 15R to 22R) and in the lowermost lignite seam. In all other samples, angiosperms are considered as the major peat-forming plants. The pollen and spore floras indicate rich angiosperm vegetation, however significant contributions from Pinaceae and Taxodiaceae are evident for all coals. Sporophytes have no dominant influence on the coal flora. Microbial activity in the peat is suggested for instance by higher concentrations of hop-17(21)-ene with increasing contents of hopanes or by low $\delta^{13}C$ values of hop-17(21)-ene. The revealed changes in the environment during coal deposition highlight the importance of combined organic petrography, organic geochemistry and palynology to reconstruct palaeoenvironmental conditions.

1. Introduction

Maceral-based facies indicators in combination with biomarker and carbon isotope data have become important tools in the past years for the reconstruction of depositional environments and floral changes (e.g. Bechtel et al., 2001, 2007; Otto and Wilde, 2001; Stefanova et al., 2011; Stojanović and Životić, 2013). In addition, Jasper et al. (2010) additionally demonstrated that the combination of coal petrography, organic geochemistry and palynology is a good tool to investigate the evolution and formation of swamps. Taxonomic differentiation of source plants and maturity assessment can be performed by the investigation of biomarker molecules. In addition, effects of humification, microbial activity and environmental changes during coal formation can be evaluated by organic geochemical studies.

Cenozoic coal seams occur in Hokkaido and in the coastal areas of Honshu (Saito et al., 1960) and continue southwards and eastwards into the offshore region. Coals in this area are typically rich in hydrogen and are therefore potential targets for hydrocarbon exploration (Oda, 2004). To our knowledge, past research work did not address factors controlling depositional environment and coal facies applying combined petrographic, organic geochemical and palynological techniques on coals onshore and offshore Japan.

The offshore extension of Cenozoic coal beds was drilled during IODP Expedition 337. Hole C0020A penetrated a 2466 m thick sedimentary sequence, including 14 coal layers between 1825 and 2450 m below seafloor (mbsf). A major target of IODP Expedition 337 was to

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study the hydrocarbon system associated to the deeply buried coalbeds (Inagaki et al., 2010). To evaluate the relationship between the deep microbial biosphere and the subseafloor coalbeds was one primary objective of the presented work. The exploration of the limits of life in such deeply buried horizons was another one (Inagaki et al., 2012). Inagaki et al. (2015) now provide evidence for existing microbial communities within coal beds at 1.8 to 2.5 km below seafloor in the Pacific Ocean off Japan.

The borehole MITI Sanriku-Oki, located approximately 50 km south of Hole C0020A, was drilled in 1999 and penetrated Cenozoic and Upper Cretaceous sediments (Oda, 2004; Osawa et al., 2003). The Eocene (e.g. Takano et al., 2013) or Oligocene (Oda, 2004) age of the Cenozoic coal-bearing sediments is poorly constrained. In addition, information regarding coal petrography or organic geochemistry is rare.

The aim of this contribution is to characterize the coal facies and to reconstruct the related environmental and floral changes with time. To do so, maceral, biomarker, bulk geochemical and palynological data were obtained. The combination of petrographic, organic geochemical and palynological techniques will lead to improved understanding of coal deposits in Japan and marks a starting point for further investigations on Cenozoic coals onshore and offshore Japan.

2. Geological setting

The IODP site C0020 is located at 41°10.5983′N, 142°12.0328′E in the Hidaka Trough situated between Hokkaido, Honshu and the Japan Trench (Fig. 1). The Hidaka Trough is dominated by the S–N trending Ishikari–Sanriku-oki forearc zone, extending northwards to onshore Hokkaido.

The Ishikari–Sanriku-oki forearc zone formed during Cenozoic time by the subduction of the Pacific plate beneath the NE Japan Arc (e.g. Maruyama et al., 1997), contemporaneously with the backarc opening of the Japan Sea (Kano et al., 2007). The Ishikari–Sanriku-oki forearc zone was bordered to the west by a volcanic arc and to the east by an uplifted trench slope break. Basin subsidence along the Ishikari–Sanriku-oki forearc zone commenced after a period without forearc basin development ("K/T gap unconformity") in Paleocene/Eocene time (Takano et al., 2013). Different subsidence patterns, probably due to strike-slip tectonics, resulted in basin segmentation (Fig. 1; Takano et al., 2013). Coal bearing (Upper Cretaceous and) Eocene rocks have been drilled in the MITI Sanriku-oki borehole (Osawa et al., 2003) (see Fig. 1 for position of wells in the "Sanriku-oki subbasin"). According to Takano et al. (2013), Paleogene sediments along the Ishikari–Sanriku-oki forearc zone have been deposited in fluvial, brackish and shallow marine (<200 m water depth) environments. The age of the coal-bearing sediments is poorly constrained and may be Eocene (e.g. Takano et al., 2013) or early Oligocene (Oda, 2004).

After late Miocene time the collision of the Kuril and NE Japan arcs resulted in the development of a foreland basin onshore Hokkaido (Ishikari lowland) (Noda et al., 2013).

Site C0020 is located about 50 km north of the MITI Sanriku-oki borehole near the northern margin of the "Sanriku-oki subbasin" (Fig. 1), where Cenozoic deposits overlie Triassic to Early Cretaceous sedimentary rocks or Cretaceous granites (Inagaki et al., 2012). Site C0020, was initiated during the *Chikyu* shakedown cruise (Expedition CK06-06), which drilled Pleistocene diatomaceous silty clays intercalated with tephra and sand layers to a depth of 647 m below sea floor (mbsf; Inagaki et al., 2010). In addition, layers with gas hydrates were found. Hole C0020A continued at this depth and reached a total drilling depth of 2466 mbsf.

A stratigraphic column of the borehole is provided in Fig. 2. From top to base, the following units were described (Fig. 2; Inagaki et al., 2012):

- Unit I (647–1256.5 m) is about 610 m thick and consists primarily of diatom-bearing silty clay representing a distal, offshore marine environment. Diatom floras are consistent with a Pliocene cool-water continental shelf succession. Dinoflagellate cysts indicate a high-

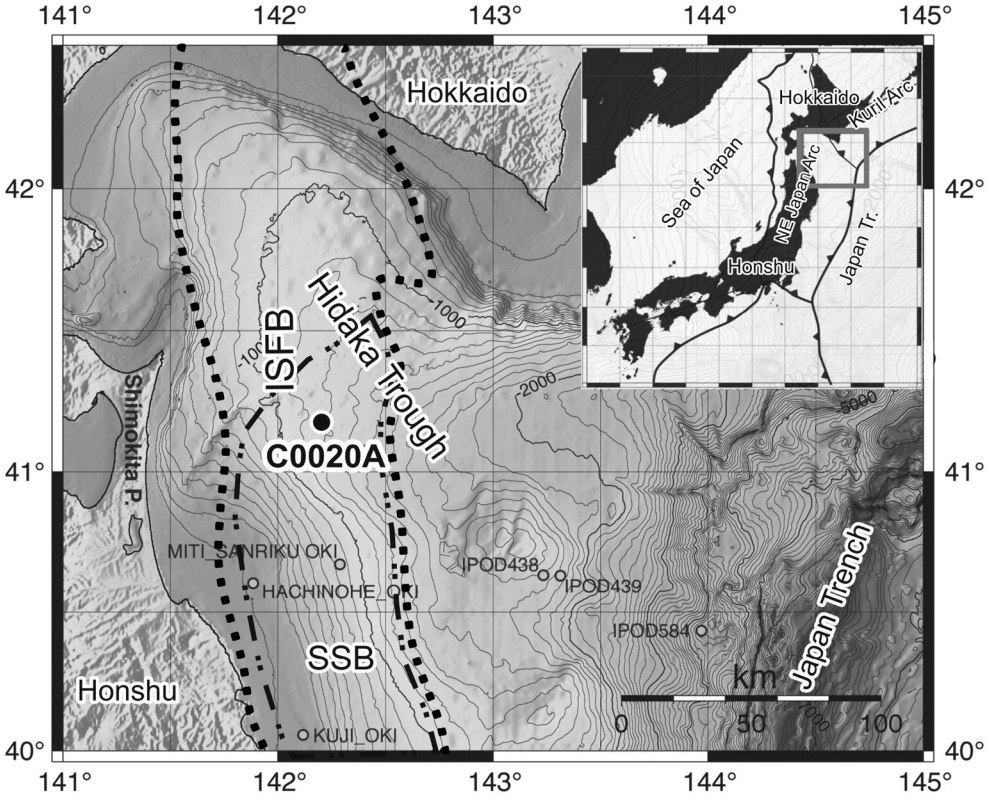

Fig. 1. Bathymetric map of the IODP Expedition 337 Site C0020 Hole A (C0020A) and existing drill holes off the Shimokita Peninsula. Inset map shows plate configuration around Japanese Islands and the location of the index map (gray square). (ISFB: Ishikari–Sanriku-oki forearc basins; SSB: Sanriku-oki subbasin).