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Cyclostratigraphy - Recognition of Climate Forcing Stratigraphic Cycles from Well Logs of the MITI Sanriku-Oki borehole, offshore northeast Japan

Introduction

Coals are considered as good source rocks for petroleum and natural gas resources all over the world. For example, there are a lot of giant oil and gas fields in Mahakam area, East Kalimantan Indonesia. Source rocks for them are Miocene coals and coaly shells deposited there.

In Japan there were once numerous coalfields. And most of them are closed now. However the coal resources are still calculated as more than 20 billion tons. So we are hopeful to find the petroleum and natural gas resources generated from these coals. But it is necessary to develop the unique evaluation method of Japanese coals. Because Japanese coals are richer in hydrogen than other coals and they contain “degradinite”. So the authors have investigated the characteristics of Japanese coals which generate petroleum and natural gas.

The MITI Sanriku-Oki borehole was drilled in 1999 to a depth of 4,500 m to explore offshore gas resources derived from the Cretaceous and the Oligocene coals and coaly shales. The borehole site is located 857 m deep below the sea level and about 60 km offshore Hachinohe City, Aomori Prefecture, north Japan. And the coal bearing beds correlated with formations of the MITI Sanriku-Oki are exposed inland along the coast. The authors have been conducting a sequence stratigraphic, sedimentological, and geochemical study for the reconstruction of sedimentary facies and organic features of the natural gas reservoirs derived from coal and coaly shale in this area. The data of vitrinite reflectance of these coals indicate around 0.5 %, showing that these coals are still immature However Rock-Eval data show between 100 and 180, showing these coals are classified as organic type II / III. Coals from Kuji area, north Japan, are still immature but high potential for petroleum and natural gas resources. There are numerous coalfields in Japan. So they can be new targets for petroleum and natural gas explorations. Institute for Geo-Resources and Environment of AIST (former Geological Survey of Japan) and Japan Energy Development Co., Ltd. have been conducting a collaboration on sequence stratigraphic, sedimentological, and geochemical reconstruction of coals in this area. As a part of the collaboration, a time series frequency analysis of wireline log data was applied to evaluate a sequence stratigraphic framework in the reservoirs of the MITI Sanriku-Oki borehole by using CycloLog, a trademark of ENRES International.

Electric wireline logs record continuous variations in bulk rock physical properties in perforated intervals of the earths crust. These bulk rock properties are recorded using nuclear, resistivity, and acoustic techniques that respond primarily to variations in lithology type, fluid type and bulk fluid volumes. Electric wireline log variations in depth may be, although not necessarily, correlated to sedimentation rates. They are not correlatable to relative or absolute time between events in the geological past. Nor are wireline log records directly correlatable to two-way time surface seismic records, which respond to reflection coefficients at interval boundaries and interval impedences.

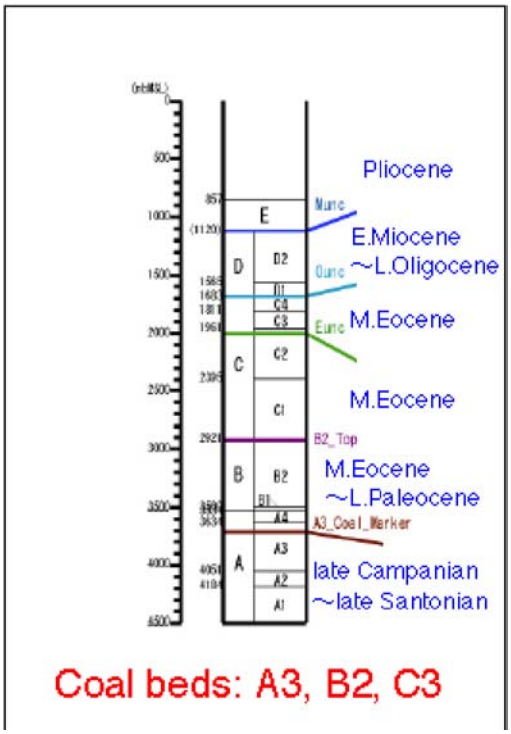
Climatic change accompanies substantial variations in *insolation* (the solar energy received at the surface of the Earth) that result from well-understood variations in the Earth's orbit. These insolation

changes were first quantified by Milutin Milankovitch. The third order Exxon depositional sequences (Vail et al 1977) are attributed to eustatic sea level variations. In their work, such observed rhymic changes were not attributed to orbit forced climate changes. Recent developments in the spectral processing of electric wireline logs and the analysis of the spectra obtained reveals the presence of these orbital climate forcing cycles recorded in electric wireline log records.

Geologic Settings and Coal Samples

Upper Cretaceous Kuji and lower Oligocene Noda Groups are distributed along Iwate Sanriku coast, north Japan. Kuji Group is dated as Early Campanian from molluscan biostratigraphy including *Inoceramus*. And the Noda Group is correlated with the Lower Oligocene. Both groups were not tectonically modified, but show slightly inclination eastward. In 1999 the MITI Sanriku-Oki was drilled offshore Hachinohe City and natural gas derived from coals and/or coaly shales were explored.

Stratigraphy of MITI Sanriku-Oki borahole



Kuji Group is overlain by Cretaceous Miyako Group and granite, and it inclines northeastward. Kuji Group is divided into three formations: Tamagawa, Kunitan, and Sawayama Formations. Lithological change of Kuji Group is interpreted as transgressive sequence including peat, medium-to-coarse sandstone, trough cross-stratified sandstone, hummocky cross stratified sandstone, and bioturbated sandstone. Kunitan Formation contains various coal beds. But this thickness is very thin, around 50 to 60 cm and coal ranks are low. Peat layers were deposited in river mouth and natural levee of swamp. Coal beds of Kuji Group are characteristic with bearing a lot of amber.

Noda Group overlays Kuji Group with unconformity. And it is divided into two formations: Minato and Kuki Formations. Noda Group is correlated with the lower Oligocene by fossil flora, which are similar to those of Ishikari coalfield in Hokkaido, north Japan. Minato Formation is characterized by abundant round pebble layers deposited in river channels. And it also has various coal beds which are about 60 cm in thickness and continuous. Lithlogical cycles are observed in Minato Formation

including conglomerate, sandy tuff, siltstone and mudstone, showing deltaic formation.

Frequency Analysis of Wireline Log Data

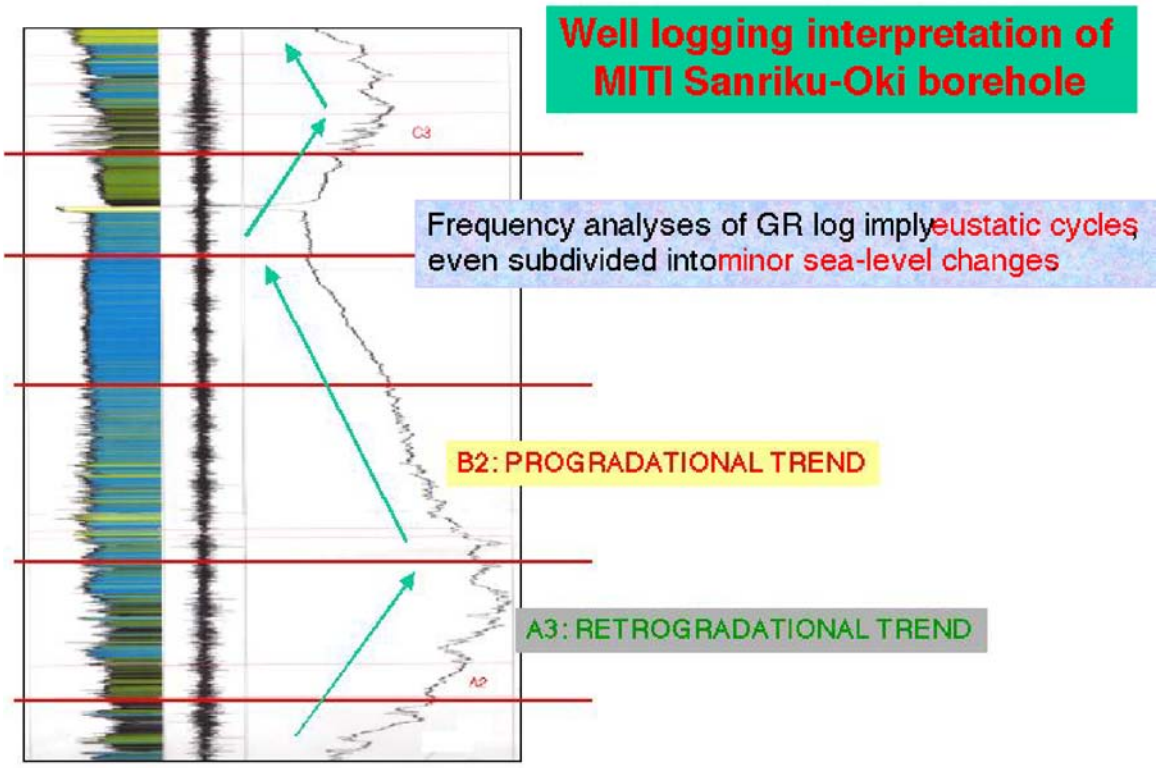
Some recent developments in the use of well logs to recognise the earth's orbital cycles within the Milankovitch band are described. Milankovitch orbital cycles are revealed by time series analysis of conventional well logs. Time series analysis reveals cyclic events whilst episodic events are not revealed. Cyclostratigraphy, therefore represents a method to recognise the results in the sedimentary record of orbital climate forcing sedimentary processes which may be further used as a near synchronous correlation tool across sedimentary basins. By contrast, Exxon's third order depositional sequences are not necessarily periodic and although they are considered to represent the results of rhythmicity in sea levels in the range of the half a million to upwards of 5 million years,
their use could make correlations problematic and non-synchronous.

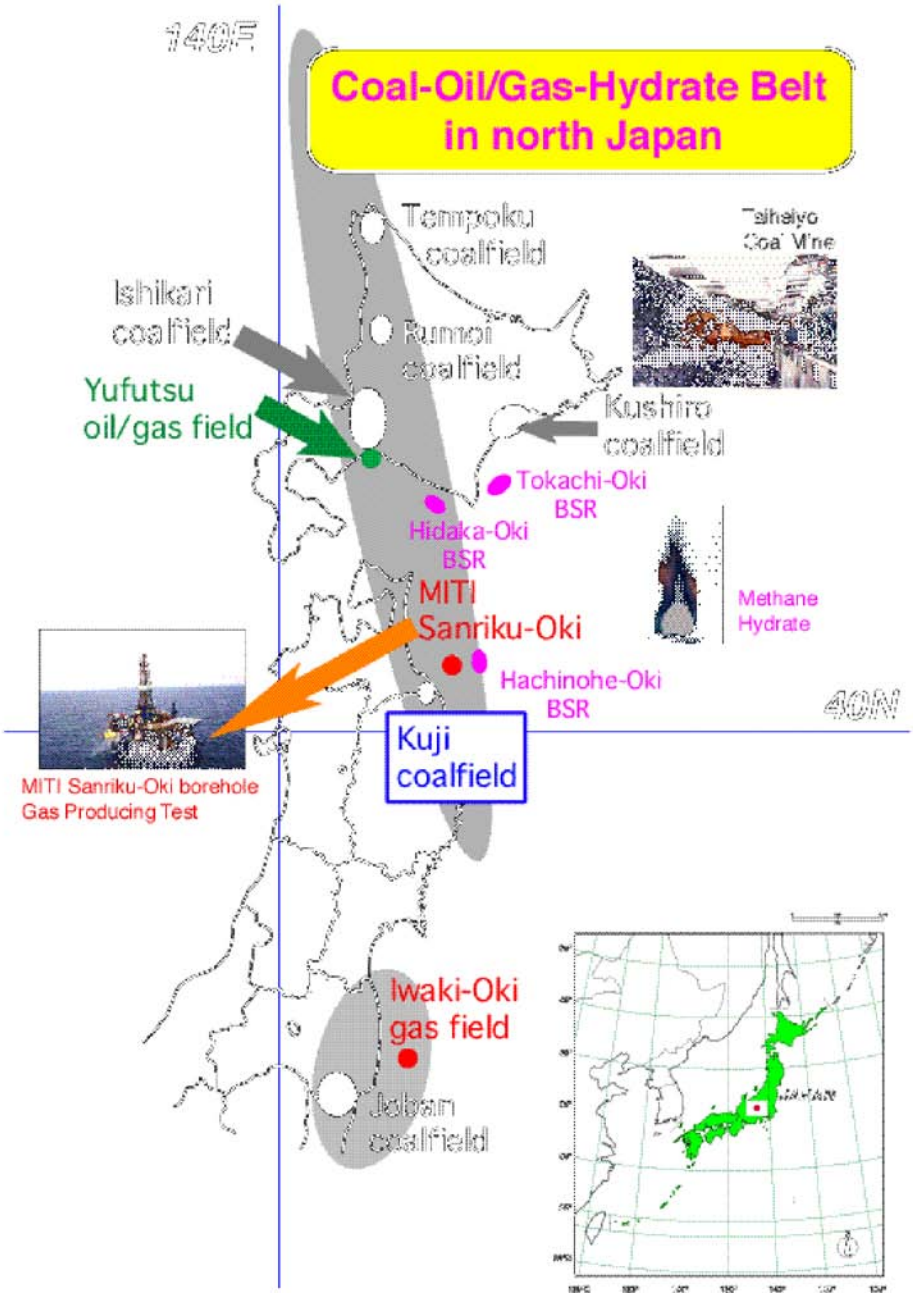
Spectral processing of the gamma ray, which is a facies sensitive wireline log response, has been used to analyse cyclic frequency content of Cretaceous and Tertiary section of the MITI Sanriku-Oki. Spectral trend attributes have been used to correlate onland outcrops in Kuji coalfeld. The spectral analysis of the gamma ray log over the Cretaceous and the Tertiary section of reveals well defined Milankovitch cycles in the log response of the sedimentary succession. All Milankovitc cycles have been identified from both gamma and density logs.

The INPEFA curve from the Gamma ray reveals both positive and negative trends. The inflection points represent important geological events. A trend to the right indicates a water depth increase caused by increased sea level related to climate warming. This trend also repsreents decreasing sand prone sedimentation. A trend to the left (negative) represents a shallowing of sea levels and is related to climate cooling. More erosion and sediment input arises and the sand-shale ratio will increase.

In the frequency analysis, GR log data was processed using Maximum Entropy Spectral Analysis (MESA). Firstly, part of a series of data points is analyzed to predict the next points in the series. In MESA, the prediction error calculation is conducted to evaluate the degree of deviation or best fit within the next point in the series. The prediction is based on an assumed pattern of cycles within the data series. Secondly, based on the prediction error calculation, Prediction Error Filter Analysis (PEFA) calculates the position and amplitude of breaks in the frequency successions or breaks in the phase of each cycle present within the total frequency. Finally, the integration of one set of PEFA values is carried out to produce an Integrated Prediction Error Filter Analysis (INPEFA) curve.

Based on foraminiferal and other biostratigraphic data, the MITI Sanriku-Oki borehole is interpreted to have deposited in the late Santonian to the late Early Miocene, which can be related with third order eustatic cycles. By analyzing all available data, these cycles are further subdivided into smaller cycles related with forth sea-level changes.





Conclusions

Well defined cyclic sedimentation of Milankovitch band periodicity, which may correspond to periods of non-deposition and submarine hardground formation, has been identifed in the MITI Sanriku-Oki borehole.

Based on biostratigraphy the MITI Sanriku-Oki borehole is interpreted to have deposited in the late Santonian to the late Early Miocene, which can be related with third order eustatic cycles. By analyzing all available data, these cycles are further subdivided into smaller cycles related with forth sea-level changes.

Spectral attribute analysis allows the recognition of the major sedimentary events in the basin associated to climate change. In addition to this, correlatable higher frequency climate induced cycles demonstrate major erosional and onlap surfaces. These activities combined with conventional seismic interpretation represents a powerful tool in prospect generation.

Activities of petroleum explorations have been focused on backarc (Sea of Japan) side in Japan. Because the back-arc basins of Japan have good reservoirs, the Neogene “Green Tuff”. And partly because coals have not been considered as good source rocks in Japan without enough source rock evaluation. However, in the forearc (Pacific Ocean) side of Japan there are a lot of sedimentary basins bearing coalbeds, deposited in Cretaceous and Paleogene. Source rock potentials of Cretaceous and Paleogene coals from forearc basins, especially in Ishikari, Kushiro, Kuji, and Joban coalfields, north Japan, can be good enough to generate oils and natural gases. So it is necessary to develop the unique evaluation method of Japanese coals to explore potential petroleum and natural gas resources in Japan. And this method will be applied to coalfields including in Brazil, Colombia, Indonesia, and so on.
gas explorations.