Drilling in the Bay of Bengal for reconstruction of the Indian summer monsoon variability

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The Indian summer monsoon brings rainfall in the Indian Subcontinent, and the precipitated water flows mainly into the Bay of Bengal. We can, thus, understand past changes in the Indian summer monsoon variability by estimating paleosalinity and riverine sediment load in the Bay of Bengal. During IODP Exp. 353 (iMonsoon; November 2014 to January 2015), we drilled six sites in the Bay of Bengal and the Andaman Sea. Cretaceous to Quaternary pelagic sediments were retrieved at Site U1443 (Ninetyeast Ridge). Miocene to Quaternary turbidites and hemipelagites were retrieved at Site U1444 (central Bay of Bengal). Miocene to Quaternary and Middle Pleistocene hemipelagic sediments were retrieved at Sites U1445 and U1446 (Mahanadi basin off India), respectively. Miocene to Quaternary hemipelagic sediments were retrieved at Sites U1447 and U1448 (the Andaman Sea).

Keywords: Bay of Bengal, IODP Exp. 353, Indian monsoon

Sedimentary records and heavy minerals assemblages of the Bengal Fan deposits recovered during IODP Exp. 354

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The deep-sea Bengal Fan is the largest submarine fan in the world. The formation of this fan is a direct result of the erosion of the Himalayan orogen (Curray and Moore, 1971). Thus the change of the mineral and geochemical characteristics of this fan sediments records uplift, erosion, weathering history of the Himalayan orogenic system during Paleogene-Neogene period.
IODP Exp. 354 drilled seven sites in an E-W transect, with three deep and four shallow holes, at 8° N , in the mid fan region of Bengal Fan. The deepest site, U1451, ~1500 meters below seafloor recovered a complete sequence of the fan deposits which overlie on lower Oligocene pre-fan deposits (France-Lanord et al., 2015). The fan sediments drilled in the mid fan region mainly consist of mica- and quartz-rich sand, silt, and clay with several hemipelagic deposits. The hemipelagic deposits, which associated distinct seismic reflectors, consists of calcareous clay and nannofossil ooze. At the bottom of the hole, Eocene and Paleocene limestones were recovered. Above mentioned results are evidential for the record of early fan deposition by 10 My into the late Oligocene.
These sediments were documented mineralogical signatures relevant for reconstructing time series of development of Himalaya. Previously, several researches on heavy minerals of Bengal Fan sediments were carried out using the fan sediments on DSDP Leg 22, Site 218 (Thompson, 1974) and ODP Leg 116, Sites 717-719 (Yokoyama et al., 1990; Amano and Taira, 1992). In this study, we show the result of the modal proportions of heavy mineral in the sediments recovered from site U1451, by smear slides and thin sections, and discuss the historical change of the mineral assemblages.
The heavy mineral assemblage of the Late Oligocene sands, which is oldest sediments from the Bengal Fan, mainly consists of ultra-durable ZTR component (zircon-tourmaline-rutile) with rare garnet, amphibole and pyroxene. The heavy mineral assemblage, in the Early Miocene sediments, mainly includes ZTR component with small amount of garnet, apatite and rare aluminosilicates (kyanite). - At the early part of Middle Miocene sequence, amphibole and garnets rapidly increase with frequent occurrence of aluminosilicate. In the Middle Miocene sediments, the assemblage of heavy minerals become diverse and metamorphic minerals such as staurolite, chloritoid, aluminosilicate, amphibole and garnet, are frequently included in the sediments.
These results of preliminary measurement of heavy minerals show rapid uplift and sediment production from metamorphic terrane in the Himalayas during early part of the Middle Miocene period, though the erosional history in Early Miocene and Oligocene periods is still obscure.
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Keywords: Bengal Fan, Himalaya, Heavy Minerals

Initial results of IODP Expediton 355, Cenozoic Arabian Sea Monsoon

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During International Ocean Discovery Program (IODP) Expedition 355, two sites (U1456 and U1457) were drilled in Laxmi Basin in the eastern Arabian Sea. Scientific objectives are (1) to document the coevolution of mountain building, weathering, erosion, and climate over a range of timescales, and (2) to recover basement from the eastern Arabian Sea for constrainting on the early rifting history of the western continental margin of India.
Penetration depth at Sites U1456 and U 1457 were 1109.4 and 1108.6 m below seafloor (mbsf), respectively. Drilling reached sediments at Site U1456 were dated to 13.5–17.7 Ma, although with a large hiatus between the lowermost sediment and overlying deposits dated to <10.9 Ma as a result of a large mass wasting deposit, the Nataraja Slide emplaced before 10.9 Ma. At Site U1457, igneous basement, comprising massive basalt was cored. The calcareous sediment on top of the volcanics were biostratigraphically dated to ~62 Ma[DP1] .
In spite of hiatuses spanning ~8.2–8.7 and ~4.1–5.6 Ma, continuous sedimentary sections spanning the 8 Ma climatic transition were recovered. Sediments from a large mass transport deposit were also recovered, with measuring ~330 and ~190 m thick at Sites U1456 and U1457, respectively. Siliceous microfossils are found only in the mudline and the uppermost cores from both sites, whereas calcareous microfossils occur in varying numbers throughout the succession. Diatoms in the mudline samples are well preserved and consist mainly of coastal species, whereas these taxa are absent in the cored sediments. Diatoms are restricted in the uppermost 10 and ~0.5 mbsf at Sites U1456 and U1457, respectively. The assemblage includes benthic and freshwater taxa that indicate the lateral transport to those sites.

[DP1]We have not yet dated. Therefore I feel we should put late Cretaceous, instead of 62 Ma.

Keywords: Arabian Sea, monsoon, IODP

Preliminary report of International Ocean Discovery Program Expedition 356 -What can we learn from the (sub) tropical carbonates off northwest Australia? -

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International Ocean Discovery Program (IODP) Expedition 356 cored the upper 400 to 1000 m of Cenozoic strata off northwestern Australia from 1st August to 30th September 2015. The main goals were: 1) to reveal a detailed history of variation in the Indonesian Throughflow (ITF), determine timing of onset of the Leeuwin Current, and explore their relationships to regional and global climates; 2) to obtain a 5 Myr orbital-scale record of tropical to subtropical paleoceanographic and paleoclimatic changes in the Australian monsoon area; and 3) to describe the spatio-temporal patterns of subsidence along the Northwest Shelf of Australia. Expedition 356 recovered cores from seven sites (U1458, U1459, U1460, U1461, U1462, U1463, and U1464) along a latitudinal transect from 28° 40' S to 18° 31' S. Biostratigraphic ages were determined to be early Eocene to Pleistocene at Site U1459, Pliocene to Pleistocene at Site U1460, and Miocene to Pleistocene at Sites U1461, U1462, U1463, and U1464. The lithology at all sites is composed mainly of unlithified to lithified carbonates (mudstone to packstone), intercalated with dolomitized layers at two sites. Thick evaporite (anhydrite and gypsum) in the Miocene strata at Site U1464 implies a sabkha environment (drier conditions). The very good preservation of calcareous microfossils in the latest Miocene to Pleistocene at Site U1463 will allow us to investigate orbital-scale secular changes in paleoceanographic and palaeoclimatic environments during the last 5 Myr.

Keywords: IDOP Expedition 356, Australia

Cyclo-stratigraphy of the Middle Miocene interval at Site U1430 and its paleoceanographic reconstruction using XRF core scanner

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The Middle Miocene is characterized by the east Antarctic ice sheet expansion and orbitally driven ice volume changes that affected the climatic changes during this interval [Zachos et al., 2001, Holbourn et al., 2005]. Recently, high-resolution Middle Miocene paleoclimatic and paleoceanographic changes are reconstructed based on orbitally-tuned oxygen isotope records and XRF core scanner data obtained from marine sediment cores. The results revealed close linkage between the paleoclimatic and paleoceanographic changes and changes in orbital parameters [e.g., Holbourn et al., 2013; Westerhold et al., 2005]. However, an orbitally-tuned high-resolution age model has not yet been established in the North Pacific because calcareous microfossils are nearly absent in its sediments
The Japan Sea was a semi-closed marginal sea during the Middle Miocene [Iijima et al., 1988]. Consequently, paleoceanographic condition in the sea changed in association with orbitally-paced sea-level changes and the fluctuations in the position of oxygen minimum zone. These variabilities were reflected in lithological changes in the Japan Sea sediments [Tada, 1994]. Therefore, establishment of the precise age model and reconstruction of lithological change pattern using the sediment cores recovered from the sea is essential to better understand sea-level and ocean circulation changes in the Pacific associated with waxing and waning of east Antarctic ice sheet. In this study, we utilize Integrated Ocean Drilling Program (IODP) cores recovered from Site 1430 in the Ulleung Basin to establish high-resolution cyclo-stratigraphy covering the Middle Miocene. We reconstructed a perfectly continuous sedimentary column using shipboard data and core photos. Based on this revised composite column (revised splices), physical property data such as GRA and NGR were re-edited. We constructed a tentative age model based on biostratigraphy, and extracted the 400, 100, 40-kyr cyclicities from the time-series data to correlate with orbital parameters. Based on this orbitally-tuned age model, we examined temporal changes in elemental composition of the sediments analyzed by XRF core scanner to explore its paleoceanographic implications.
In the presentation, we will discuss the establishment of orbitally-tuned age model, the variability of elemental composition in the Japan Sea sediment and its possible causes.

Keywords: Middle Miocene, Cyclo-stratigraphy, XRF core scanner, IODP Exp.346

Glacial-interglacial biotic changes on the Great Barrier Reef from onshore and offshore boreholes

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Understand how ecosystems respond to global environmental changes is important to predict their fate and decide on adequate measures of protection. The fossil record offers a unique opportunity to study the influence of natural perturbations on ecosystems. Here we examine the response of the Great Barrier Reef (GBR) coral communities to glacial-interglacial cycles based on a combination of offshore and onshore boreholes drilled by IODP Exp. 325 in 2010 and by the International Consortium for the GBR Drilling in 1995, respectively. Thirty four offshore boreholes were drilled during IODP Exp. 325 along four transects at three localities along the shelf edge of the GBR (Hydrographers Passage, Noggin Pass, and Ribbon Reef). These boreholes record the evolution of the GBR during glacial-deglacial conditions when the continental shelf was exposed and reef growth was restricted to the shelf edge. The onshore core material consists of two deep boreholes drilled in Ribbon Reef 5 (RR5) and Boulder Reef (BR) in the northern GBR. The RR5 and BR boreholes record a succession of highstand reef sequences formed during late deglacial-interglacial conditions when the shelf was submerged. These two data sets combined provide the first record of biotic changes in the GBR during a complete cycle of glacio-eustatic sea level change, from the glacial maximum to full interglacial conditions. Our statistical analysis reveals a marked difference in coral composition between glacial-early deglacial fringing reefs and late deglacial-interglacial barrier reefs, and enables us to clarify the relationships between reef architecture, shelf morphology and coral composition.

Keywords: Corals, Glacial-interglacial cycles, Great Barrier Reef, Quaternary, Boreholes

Ages of sequence boundaries based on the core analysys of IODP Expedition 317 and their correlation between shelf and slope on the basis of reinterpretation of the seismic profiles, offshore New Zealand

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The Canterbury Basin is located on the eastern margin of South Island of New Zealand, and underlies present-day onshore Canterbury Plain and offshore continental shelf. The seismic surveys and industrial and scientific drillings have been carried out in this area. Lu and Fulthorpe (2004) recognized 19 sequence boundaries since middle Miocene and determined those ages in the seismic profiles. IODP Expedition 317 drilled three sites on the shelf (U1351, U1353 and U1354) and one site on the upper slope (U1352) in 2009 and 2010. Hoyanagi et al. (2014) showed the Pleistocene age model based on the correlation between benthic foraminiferal oxygen isotope records from the U1352 and LR04 stack (Lisiecki and Raymo, 2005). Formation ages of sequence boundaries on the basis of this age model did not coincide with those of Lu and Fulthorpe (2004). This study reinterpreted seismic sequence boundaries in the seismic profiles and tried to correlate them with discontinuities in the cores from the IODP sites. As a result, we recognize seven discontinuities in the cores, which placed the same depth of the seismic sequence boundaries in the profiles. We recognized them as the sequence boundaries and named them SB1 to SB7 in descending order. Based on the revised age model of the U1352, the sequence boundaries SB 1 to 6 were formed during the lowstand stage of MIS 6, 8, 16, 22 and 54 respectively. While, the discontinuity represented hiatus between 2.7 and 1.8 Ma on shelf and slope sites coincide with the sequence boundary SB7. The sequence boundary SB3 cut below two sequence boundaries in the seismic profiles, and it might indicate that the lowering of sea level at the MIS 16 has been greater than the other glacial stages.

Keywords: IODP Expedition 317, Seismic profiles, Pleistocene, Sea-level change, New Zealand

Evidence for low temperature smectite to illite transformation in the Bering Sea slope sediments (IODP Expedition 323)

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The smectite to illite (S-I) transformation is a kinetically or thermodynamically controlled diagenetic process with dehydration in sediments at a relatively high temperature range of 60℃ to 150℃. The S-I transformation also significantly impacts on *in-situ* physical and geochemical characteristics, such as pore water pressure, faulting, and migration of hydrocarbon gasses. Recent experimental studies showed that anaerobic iron-reducing microbial activity of possibly promoted the S-I transformation at low temperatures (Kim et al., 2004). However, the low temperature S-I transformation has not been observed in natural sedimentary environments. In this study, we demonstrate here the transformation of S-I at <40C in the Bering Sea Slope sediments based on the pore water chemistry, clay mineral composition, and microstructures. The sediment samples were obtained by drilling down to ~800 m below seafloor (mbsf) at Sites U1341 (Bowers Ridge), U1343 (Bering Sea Slope) and U1344 (Bering Sea Slope) during the Integrated Ocean Drilling Program (IODP) Expedition 323.
Geochemical analyses of pore water samples from Bering Sea Slope sediments showed that chloride concentrations slightly decreased from ~550 mM near the seafloor to ~500 mM at the core bottom. Dissolved potassium concentrations decreased from ~13 mM at 150 mbsf to 6 mM at the core bottom. Below 150 mbsf, oxygen and hydrogen isotopic compositions of pore water (H_2O) increased from 0‰ to 1.5‰ and decreased from -2‰ to -10‰ with increasing depth, respectively. These trends would be attributed to the release of dehydrated water into the pore water and the potassium uptake by the authigenic S-I transformation. However, those trends were not observed in sediments from the Bowers Ridge. The Illite/smectite mixed layered clay minerals, which are the intermediate products of the S-I transformation, were identified only from the Bering Sea Slope sediments based on XRD analyses of the clay-sized fractions. Illite content of the Illite/smectite mixed layered clay minerals increased from 2% near the seafloor to ~8% at 200 mbsf. TEM lattice fringe image of the clay minerals in 210 m-deep sample at Site U1343 showed that the layers of 1.0-nm spacing, which were illite, partially distributed at the tip of hairy shaped authigenic smectite particles, clearly indicating the occurrence of S-I transformation *in situ*. Because the thermal gradients at Sites U1343 and U1344 were 49.0℃/km and 53.3℃/km, respectively, indicating that the temperature ranged in the cored sediments was generally lower than 40C. Consequently, our geochemical, geophysical and mineralogical data indicate that the low temperate S-I transformation occurs below 150 mbsf in the Bering Sea slope sediments. A possible explanation for this phenomenon is the contribution of microbial activity such as iron reduction. Interestingly, the occurrence of authigenic siderite ($FeCO_3$) concretion was observed only below 150 mbsf at the Bering Sea Slope sediment (Pierre et al. 2014), supporting the increase of alkalinity by microbial decomposition of organic matters and reduction of Fe (III) to siderite that leads to the low temperature S-I transformation.

Keywords: smectite-illlite transformation, Bering Sea, Clay mineral

Physical properties of Fore-arc-basalt and Boninite inthe drilled cores during the IODP Expedition 352

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The Izu-Bonin-Mariana (IBM) arc, which is located to the southeast from Japan, is a typical intra-oceanic arc system and is the type locality for subduction initiation. IBM project, which is a part of International Ocean Discovery Program (IODP) expeditions, is aimed to understand subduction initiation, arc evolution, and continental crust formation. Expedition 352 is one of the IBM projects and that has drilled four sites at the IBM fore-arc in the period from 30th of July to 29th of September, 2014. Expedition 352 has successfully recovered fore-arc basalts and boninites related to seafloor spreading during the subduction initiation as well as the earliest arc development. The fore-arc basalts were recovered from two sites (U1440 and U1441) at the deeper trench slope to the east, whereas the boninites were recovered from two sites (U1439 and U1442) at the shallower slope to the west.
In this study, we studied textures and physical properties of both the fore-arc basalt and the boninite samples recovered by IODP Expedition 352. The fore-arc basalt samples showed aphyric texture, whereas the boninites showed hyaloclastic, aphyric and porphyritic textures. For the physical properties, we measured density, porosity, P-wave velocity and anisotropy of magnetic susceptibility. P-wave velocities were measured under ordinary and confining pressure.
As a result, the densities are in a range between 2 g/cm^3 and 3 g/cm^3. The porosities are in a range between 5 % and 40 %. The P-wave velocities are in a wide range from ~3 km/s to ~5.5 km/s and have a positive correlation to the densities. The magnetic susceptibilities showed bimodal distributions so that the physical properties were classified into two groups: a high magnetic susceptibility group (>5×10^{-3}) and a low magnetic susceptibility group (<5×10^{-3}). The high magnetic susceptibility group is almost identical with the fore-arc basalt and boninite samples with the higher correlation trend between the P-wave velocities and the densities, whereas the low magnetic susceptibility group is only the boninite samples with the lower correlation trend between the P-wave velocities and the densities. It suggests that the densities could be related to the occurrence of magnetite in the samples, since the magnetic susceptibilities were remarkably correlated with the relationships between P-wave velocities and densities. In addition, these trends have also been found in the physical properties measured on board during Expedition 352.

Keywords: IODP Exp.352, Izu-Bonin forearc, volcanic rocks, density, P-wave velocity, Magnetic Susceptibility

An impact of water activity on microbial activity - A case study of IODP Expedition 337

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Water activity is one of the important factors that can limit and preserve the microbial growth in soils and foods as well as in deep sediments biosphere. However, water activity for the subseafloor sediments had not been measured so far, the correlation between water activity and microbial activity was not clear. In this study, water activity in relation to microbial activity for the deep sub-seafloor environments was studied by using core samples obtained from Integrated Ocean Drilling Program Expedition 337, the deep-water coal bed basin off Shimokita. The water activities of core samples were measured by using two commercial water activity sensors, Lab Touch-aw (Novasina, Switzerland) and WP4-T (Decagon Devices, Inc., USA) at 25 ºC of temperature.
Water activity at the depth from 0 to 2466 mbsf ranges from 0.96 to 0.98, which represents much greater habitable environment for most micro-organisms, though the correlation between water activity and microbial biomass is not clear. The water activity of sedimentary rocks is not affected by lithology, porosity, or relative change of water contents. Instead, water activity depends more on NaCl concentration. Moreover, the measured water activity is in good agreement with the prediction made from the Rault’s law in corporation with interstitial water chemistry measured on board. Apparent reduction of cell abundance associated with increase in water activity at four sites could be explained by the assumption that amount of nourishment for microorganism solved in pore water is proportional to solutes concentration. Strong correlation between cell abundance and porosity and free fluid content, which was evaluated from NMR logging, suggests that amount of energy sources and mobility of energy in the pores will account for the reduction in cell population with depth at basin off Shimokita.

Keywords: water activity, IODP expedition 337, microbial activity, porosity

Chemical composition distribution of the drilled core across the fault zone of the Nobeoka thrust

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Megasplay fault branching from a plate boundary at subduction zone is thought to be the source of earthquakes and tsunamis. Nobeoka thrust is the low-angle thrust which subdivides the Shimanto belt in Kyushu into the northern (Cretaceous and Tertiary) and the southern (Tertiary) subbelts, and is an exhumed analogue of an ancient megasplay fault. The hanging wall and the footwall of Nobeoka thrust show difference in lithology and metamorphic grade and their maximum burial temperature is estimated from vitrinite reflectance analysis to be 320~330°C and 250~270°C, respectively. Assuming these temperature gap is made by fault displacement, the total displacement is approximately 10 km (Kondo et al., 2005). As a unique analogue of modern megasplay fault, the Nobeoka thrust is the key for understanding current plate boundary process.
Fluid-rock interaction is one of a very important processes for faulting. We focus on the element composition distribution across the Nobeoka thrust, and thus analyzed chemical composition of the drilled core obtained by Nobeoka thrust drilling project (NOBELL). Major elements and trace elements are analyzed by XRF and ICP-MS, respectively
Results of XRF analysis showed no significant difference between the hanging wall and the footwall despite the difference in lithology and metamorphic grade. Na_2O, Al_2O_3, SiO_2, K_2O and CaO increase just above the fault core (Depth 41.3~41.8 m). This increase would be caused by the decrease in SiO_2, because SiO_2 is the dominant component in the analyzed rocks (60~80 wt.%).
Results of ICP-MS analysis also did not show significant difference between the hanging wall and the footwall, except for Li and Cs which are relatively abundant in the footwall. High concentration of Li just above the fault core may suggest Li-rich fluid from external source. The provenance of Li can be attributed to the basalts where significant quantity of the oceanic crust is subducting. Some elements showed increase just above the fault core as observed in the major elements.
Summarizing the results, the divergence in chemical composition is limitedly observed in the vicinity of the upper interface of the fault core. The depletion in Si just above the fault core might be caused by the development of pressure solution resulting Si dissolution and flowing-out in this horizon. Chemical anomalies observed within and just above the fault core suggest high-temperature fluid-rock interaction associated with the faulting. Further characterization of stable isotope analysis (such as Sr, Nb) will provide insights into the provenance of the fluids.

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Keywords: fluid-rock interaction, NOBELL, thrust

Thermal structure of the Nankai accretionary prism estimated by vitirinite reflectance of carbonaceous material

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Paleothermal structure of an accretionary prism is one of the basic information to understand the nature of plate subduction seismogenic zones. To evaluate the entire thermal structure of the Site C0002 located in the Kumano Basin off Kii Peninsula, we performed vitrinite reflectance analysis for cuttings samples collected every 100 m from 870.5 to 3058.5 m below sea floor (mbsf) during the Integrated Ocean Drilling Program (IODP) Expedition 348: Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), which drilled down to 3058.5 mbsf.
Ro values of vitrinite reflectance are ~0.15 to ~0.20 in Unit III (forearc basin), 0.21 to 0.27 in Unit IV (accretionary prism), and ~0.26 to ~0.38 in Unit V (hemipelagic sediment), respectively. In general, Ro values tend to increase with depth, but several reversals of Ro suggest the existence of faults which have large displacements enough to offset paleothermal structure.
We estimated paleotemperature based on reaction rate equation of EASY%Ro (Sweeney and Burnham, 1990). Two heating duration time was assumed in the calculation: 1) depositional age of several formations by shipboard nannofossil ages, which is the maximum heating duration time, and 2) depositional age of lower forearc basin (1.67 Ma), which is minimum heating duration time.
Estimated maximum paleotemperatures are 1) ~58℃ in Unit IV and ~74℃ in Unit V, 2) ~67℃ in Unit IV and ~88℃ in Unit V, respectively. These temperatures are lower than estimated modern temperatures based on borehole temperature measurements and their downward extrapolations (Sugihara et al., 2014).

Keywords: accretionary prism, Nankai Trough, vitrinite reflectance

Estimation of cuttings lag depth error in deep water riser drilling hole: A case study of NanTroSEIZE Site C0002.

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Drilling cutting is a unique tool to directly evaluate geological information in drilling hole, and precision and accuracy of cuttings lag depth are important for the geological evaluation to . During an actual operation, it is considered that mud water lag depth is the same as cuttings lag depth. However, since the cuttings lag depth obviously depends on size of cuttings, error of the cuttings lag depth should be independently evaluated as compared with the mud water lag depth. In this presentation, basic concept of the cuttings lag calculation is reviewed, and error of the cuttings lag depth is conceptually defined. As the result, potential of the cuttings evaluation is discussed showing quantitative result of the cuttings lag depth error.

Keywords: Deep water drilling, Cuttings, Mud logging, Lag depth

Borehole informatics: scientific drilling as an information science

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Borehole drilling is a method to explore deep subsurface and the only way to confirm the material and measure the in-situ environment directly and precisely. We have been using materials and datasets from deep targets by drilling, but datasets we can get are many more and of various kinds, most of which have not been even acquired. Expansion of data we get through drilling and extraction of information from the data, sophistication and integration of the information for drastic improvements of our scientific understanding of the subsurface; this is the borehole informatics.

The presentation introduces our challenges to acquire more data from drilling operations and subsurface materials, and what we see next.

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