

Quaternary radiolarians biostratigraphy in the Alaska margin (IODP Exp.341 Site U1417)

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The Gulf of Alaska is marked by the St. Elias orogen largely influenced by the ice-sheet expansion over the past 10 Myr. In this context, the Integrated Ocean Drilling Program (IODP) Expedition 341 drilled several sites in southern Gulf of Alaska in order to determine the linkage between the tectonic uplift, erosion by ice sheet and climate changes since Miocene. Concerning the paleontological aspect of the collected cores, siliceous microfossils were not abundant. Cores collected from Site U1417 present the highest abundance in siliceous microfossils. Indeed, in Site U1417, siliceous microfossils present moderate abundance for the upper 200 meters CCSF-B, which correspond to the Pleistocene. This interval is composed of dark gray mud with several interbeds of diatomaceous oozes. For deeper intervals, siliceous microfossils abundances were low, with numerous barren intervals.

Therefore, in this study, samples from the upper 200 m CCSF-B of Site U1417 were analyzed in order to establish the depth-age model based on shipboard diatom/radiolarian biostratigraphy and paleomagnetic polarity stratigraphy for enables further paleoceanographic studies. Indeed, several radiolarian datum events such as the last occurrences (LOs) of *Stylatractus universus*, *Lychnocanoma sakaii* and *Amphimelissa setosa* appear to be important for chronostratigraphic use. Particularly, temporal distribution of *Amphimelissa setosa* is highly interesting because the LO records at the MIS 4/5 boundary (77 ka) in the North Pacific, while this species is still extant in the Arctic Ocean, Norwegian Sea, or in the Labrador Sea. In this study, we could establish the LOs of *Sphaeropyle robusta* (1,500 ka, 161.9 m CCSFB at the median depth), *Eucyrtidium matuyamii* (1,250 ka, 143.3 m), *Stylatractus universus* (450 ka, 74.9 m), *Axoprunum acqilonium* (350 ka, 61.5 m) and *Amphimelissa setosa* (77 ka, 25.0 m), and acme of *Lychnocanoma sakaii* (61 ka, 18.81 m). On the other hand, the FO of *Amphimelissa setosa* could be established for the first time in the northeastern Pacific between the LO of *Eucyrtidium matuyamii* and the base of Jaramillo magnetic normal polarity epoch (1,072 ka).

Keywords: Quaternary, Radiolarians, Biostratigraphy

Last glacial to deglacial biotic changes on the Great Barrier Reef from offshore boreholes

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IODP Expedition 325 drilled 34 boreholes into submerged reef structures along the shelf edge of the Great Barrier Reef (GBR). The boreholes were drilled between 42 and 167 mbsl at 17 sites along four transects at three geographic locations (Hydrographers Passage, Noggin Pass, and Ribbon Reef). The last glacial to deglacial reef sequence (~8 ka to ~27 ka) varies in thickness from ~5.5 m to ~34 m and consists primarily of coralgall boundstone with various proportions of microbialite. We use a detailed chronostratigraphic scheme based on numerous C14 and U-Th ages to discuss the evolution of the coralgall communities since the last glaciation. Exp. 325 cores show that different phases of sea level change promoted different shallow reef-building coral species at the study sites. The onset of the deglacial (16-19 ka) is characterized by a peak abundance of *Seriatopora* and *Tubipora* whereas the following rapid sea level rise (<16 ka) is marked by the dominance of massive *Isopora* and *Acropora* with medium- to robust-size branches. The shift in composition of coral communities around 16 ka coincides with the flooding of a pre-LGM MIS2 reef terrace, an event which had a major influence on reef growth and reef composition. We discuss the impact of this event on coralgall communities in the GBR and its significance for Quaternary reef evolution in general.

Keywords: IODP Expedition 325, Great Barrier Reef, Coralgall assemblages, Sea level changes, Glacial, Deglacial

Geochemical variation of Izu rear-arc volcanic rocks at drill Site U1437: Preliminary results from IODP Expedition 350

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The Izu-Bonin-Mariana (IBM) arc is a good place to understand oceanic arc evolution. Crustal composition of the Izu segment of the arc differs beneath the arc-front and rear-arc (e.g. in terms of K, LREEs) (e.g. Hochstaedter et al., 2001; Ishizuka et al., 2003; Tamura et al., 2007). However, the magmatic history of the Izu rear-arc has not been well studied because Oligocene and Eocene Izu rear-arc lavas and volcanoclastics produced before the opening of the Shikoku basin have not been recovered by dredging or ROV sampling. Site U1437, drilled during IODP Expedition 350, is the first drill site in the Izu rear-arc and aimed to recover a record of volcanism in the rear arc from the present day to the Paleogene. This study will present preliminary major element (measured by X-ray fluorescence, XRF), trace element (measured by XRF and inductively coupled plasma-mass spectrometry, ICP-MS) and isotope ratios such as Sr, Nd, Pb and Hf (measured by ICP-MS and thermal ionization mass spectrometry, TIMS) to examine the geochemical signature of the recovered material and whether it can be related to the present day rear-arc or arc-front.

Site U1437 is located in a basin between the Manji and Enpo rear-arc seamount chains, about 90 km west of Myojinsho volcano on the Izu arc-front. Drilling reached 1806.5 meters below seafloor (mbsf), and the recovered rocks were divided into seven lithostratigraphic units and one igneous unit (a rhyolite intrusion). Lithostratigraphic Units I to V (0-9 Ma) dominantly consist of tuffaceous mud/mudstone. Below 1320 mbsf, Units VI and VII (older than 9 Ma) are composed chiefly of volcanoclastic layers, including coarser (>2 cm) volcanic clasts that are possibly derived from more proximal sources (Tamura et al., 2015).

Initially we have analyzed the major and trace element compositions of the volcanic clasts from Units VI and VII. Those show a wide range of compositions, from basalt to rhyolite, but are mainly intermediate (average SiO₂ = 54.1 wt%). The K₂O contents of the basalt to andesite clasts within the volcanoclastics are <0.9 wt%, with the exception of one clast, and their Zr/Y are <3.2 (average = 2.4), with the exception of two clasts. These characteristics are within the range of both the present day Izu arc-front and rear-arc. The present rear-arc type lavas are strongly enriched in LREEs, whereas the arc-front type are depleted. However, the chondrite normalized REE patterns of the clasts are flat (La/Yb ~ 1.0) or show slight depletions in LREEs relative to HREEs, so it is not clear if these proximal clasts are similar to the current arc-front or rear-arc. The deepest clasts that have been analyzed (from 1797.26 and 1798.57 mbsf) are basaltic andesites and have relatively high Zr/Y (3.5 and 4.1, respectively), similar to the present day rear-arc. However, their K₂O contents (0.89 and 0.35 wt%, respectively) and flat REE patterns are not.

The wide range of clast compositions make it difficult to distinguish whether the clasts from the deeper part of Site U1437 are derived from the present day Izu arc-front or rear-arc and whether or not this geochemical distinction existed when this material was erupted on the basis of major and trace elements alone. Analyses from additional samples and the isotope compositions of the clasts may be more diagnostic.

High temperature metamorphism recorded on chromitite samples in drilling cores from ocean floor

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Metagabbro and some serpentinites are not only extremely altered, but also metamorphosed at high temperature up to mid-amphibolite facies. Chromian spinel included in those samples, which is normally well preserved under the condition of ocean floor metamorphism, also metamorphosed into chrome-bearing magnetite and/or magnetite. The crystal orientation varies inside a grain with chemical modification of the metamorphism. We discuss the possibility of such high temperature metamorphism in the deep oceanic plate.

Keywords: chromitite, IODP Exp. 345, high temperature metamorphism, Moho transition zone, oceanic crust, ODP Leg 209

Mud logging in hard rock drilling

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Mud logging in a riser drilling operation has been powerful tool in the scientific drilling. Since fast and safe drilling are minimum requirements in the deep drilling operation, it is generally difficult that continuous coring is carried out to obtain geological sample (rocks and fluid). Therefore, cuttings survey and mud gas monitoring in mud logging are essentially important in the riser drilling for scientific research. Some hard rock drilling operations by using the Chikyu have been planned (e.g., IBM, MoHole). Since continuous coring in the hard rock drilling is technically more difficult as compared with the drilling for sedimentary rocks and slow rate of penetration results in consuming much of operation time, the cuttings survey is a unique approach for lithological characterization in the hard rock drilling. In addition, fluid sampling from hard rock core is also difficult, even if core sample is obtained. Thus, the mud logging is especially important for the hard rock drilling, not only minimizing operation time but also maximizing scientific result. In this presentation, we will introduce current technology of advanced mud logging and discuss on potential of the mud logging for the hard rock drilling.

Keywords: Mud logging, Deep drilling, Hard rock drilling, Riser drilling, Mud gas monitoring, Cuttings

Distribution of physical properties and pore pressure of sediments off Costa Rica: IODP Expedition 344

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Evolution of physical properties in subduction zone is a key to understand lithification processes, location of decollement, and stress distribution. In this study, we examined the physical properties of sediments using on-board data and laboratory experimental data on sediments obtained off Costa Rica margin to understand the distribution of acoustic properties.

Target sites are in the Integrate Ocean Drilling Program (IODP) Expedition 344 off Costa Rica, including reference sites (U1381 and U1414), frontal prism site (U1412), mid-slope site (U1380) and upper-slope site (U1413). In this study 4 samples from reference sites are from Unit I in shallower Unit. Only one sample in U1381 is located in Unit II below the Unit I. Another samples is from UnitII.

Laboratory experiments for velocity and porosity measurements were conducted with variation of effective pressure.

In U1381, porosity, P-wave velocity, and S-wave velocity were represented about 50-72%, 1.4-1.7m/s and 0.75-0.85 m/s, respectively, during the experiments. From the value, V_p/V_s , bulk modulus and shear modulus were calculated to be 1.85-2.02, 1.8-2.6GPa and 0.8-1.0GPa, respectively. A sample in U1381 was from Unit II, which has relatively low bulk density, indicates 80-66% of porosity, 1.5-1.6 m/s of V_p , 0.85-0.9 m/s of V_s , were obtained, and 1.74-1.78 of V_p/V_s , 1.7-2.0GPa of bulk modulus, and 1.0-1.1GPa of shear modulus correspond to obtained V_p and V_s .

In Unit 1414, similarly described above, porosity, P-wave velocity, and S-wave velocity ranges, 55-73%, 1.5-1.7km/s, and 0.85-0.95 km/s, respectively. V_p/V_s , bulk modulus and shear modulus were computed to be 1.85-2.02, 1.8-2.6GPa and 0.8-1.0GPa, respectively.

Finally, Unit 1412, porosity, P-wave velocity, and S-wave velocity covers, 73-76%, 1.51 -1.56km/s, and 0.75-0.77 km/s, respectively. V_p/V_s , bulk modulus and shear modulus were obtained as 2.0, 0.91-0.95GPa, and 2.4-2.7GPa, respectively.

V_p -porosity relationships from on-board data and from laboratory experiments are comparable nicely and also represents a good agreement with global empirical model, although Site U1381 Unit II has relatively high velocity. This comparable trend in V_p -porosity relationship suggests that the physical properties of sediments except for U1381 Unit II can be similar.

In V_s -porosity relationship, V_s increases with depth increment in each site although the difference in porosity is very small around 0.7 in the obtained state. The sample from U1412 has relatively high both in V_p and V_s even the sample depth is shallow around 14 mbsf.

In terms of bulk and shear moduli, samples from reference sites represent a constant bulk modulus with wider variation of shear modulus. U1381 Unit II shows relatively low bulk modulus in middle value in the variation of shear modulus due to low bulk density and relatively high V_s . A sample from U1412 shows relatively high bulk modulus and low shear modulus.

For sediments in Unit I of reference sites, the trend of constant bulk modulus with variation in shear modulus is similar to that reported from off Osa Peninsula, Costa Rica (ODP Leg 170) (Gettemy and Tobin, 2003). It might be a common evolution in reference site with depth. The samples from U1412 is located at frontal prism even in shallow portion. The sediments should be affected by shear deformation, which may make V_p and V_s increased. Therefore, the bulk modulus is relatively high among the samples. The sample in U1381 Unit II has low bulk modulus due to higher porosity in deeper portion. The higher porosity is kept by skeletons of nanofossils which act as a cement in the sediment. The change in physical properties from Unit I to Unit II is large at the boundary. The effect of the change in physical properties on fluid pressure at the unit boundary should be examined in the near future.

Keywords: Drilling, IODP, Costa Rica, Expedition 344, Physical properties

Structures characterizing the megasplay fault across shallow slope sediments of the Nankai accretionary prism

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LWD measurements at Hole C0022A and coring at Hole C0022B during IODP Expedition 338 confirm the early suggestion from seismic reflection imaging that a branch of the mega-splay fault crosses shallow slope sediments and may thus get close to the sea bottom. At C0022A, the evidence include (1) the presence of moderately to steeply dipping fractures between 86.6 and 105.5 mbsf and (2) the presence of a low-resistivity zone at the same interval, with a particularly low resistivity interval at 100-101 mbsf. At C0022B, the evidence include (1) three age reversals recognized between 76.48 and 84.48 mbsf, between 132.38 and 142.70 mbsf, and between 142.70 and 148.46 mbsf, (2) a bedding disturbed interval from 73.49 to 143.82 mbsf, (3) poor core recovery in the interval of 94.5-99.5 mbsf, suggesting highly fractured or disturbed material, and (4) the presence of three intervals of clay characterized by a composite planar fabric (338-C0022B-10T-5, 49-51 cm, 10T-CC, 19-20 cm, and 11H-1, 18-19 cm). By comparison with the nearby 3D seismic reflection image, the C0022A low-resistivity image at 100-101 mbsf could correspond to the megasplay fault core zone where displacement is supposed to be the largest. The sudden drop in core recovery at this interval indicates that coring at Site C0022 likely missed the megasplay fault core zone. Conversely, coring likely sampled secondary fault zones characterizing the damage zone of the megasplay fault branch at Site C0022. Post-cruise investigations aim at examining all structures and microstructures associated with this supposed damage zone.

Based on CT scan images, seven intervals were selected from Core 10T (three from section 5, one from core catcher) and from Core 11T (three intervals). For each interval, a slab was cut, dried, epoxied and polished before being analysed by XRF scanner for compositional mapping. Polished thin sections were made from the most deformed-looking parts of the slabs.

XRF scanning analysis brings two main results: At least three gently dipping planar surfaces outlined by iron sulphide (most likely pyrite) cross the cores. It is not clear whether these surfaces are faults or not but, in one case (11T-1, 72-83 cm), the surface separates clays with different Ca contents, suggesting some offset. The presence of iron sulphide along the surfaces may be related to fluid flow having allowed recrystallization of this mineral species. Shipboard observation revealed three intervals characterized by weakly marked planar fabrics. Two of these intervals (338-C0022B-10T-5, 49-51 cm and 11H-1, 18-19 cm) are characterized by a depletion in Ca and Sr and an enrichment in K with respect to the surrounding sediments.

Lastly, preliminary optical microscope observation indicates that some incipient non-coaxial shear deformation (asymmetrical sand lenses and composite planar fabric) affected the intervals with planar fabrics. Put together, these results indicate that deformation so far recognized in C0022B cores is weak to moderate. This is not an unexpected result given (1) the young age of the sediments and (2) the fact that samples likely come from the damage zone a few meters and not from the core zone.

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Distribution and evolution of organic matters in deep seafloor sediments collected during IODP Exp.338 and 348

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Seafloor sediments are important as a significant reservoir of organic matter, especially organic carbon and nitrogen. Sedimentary organic matters are mainly supplied through a photosynthetic process of phytoplankton biomass and other metabolisms of zooplankton and matured during diagenesis (Lee *et al.*, 1988). Proteins, peptides, and amino acid monomers are the main components and account for 30 – 40% of the total nitrogen and 10 – 15% of the total organic carbon content of seafloor sediments (Burdige and Martens, 1988). Some studies revealed the distribution and concentration of organic matters including hydrolyzable amino acids in shallow seafloor area (e.g., Cowie and Hedges, 1992; Kawahata and Ishizuka, 1993). The recent Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTro SEIZE) Expedition 338 and 348 at Site C0002 drilled and cored successfully up to 3059 mbsf. In this study, concentrations of hydrolyzable amino acids and maturation stage of organic matters in the sediments collected during the expeditions were determined in order to evaluate the distribution and evolution of sedimentary organic matters during diagenesis in deep seafloor.

Sediment core samples collected at Site C0002 (202.1 – 2216.9 mbsf), C0021 (3.7 – 186.4 mbsf), and C0022 (1.2 – 411.4 mbsf) were dried and powdered manually with an agate mortar on shore. The type and maturity of sedimentary organic matters were determined using Rock – Eval pyrolysis method at Japan Petroleum Exploration CO., LTD.

A part of the sediments were hydrolyzed to extract the amino acids from the hydrolyzable peptides and proteins. 1.0 g of the dried sediment was reacted with 6 N HCl at 110 °C for 22 h. The amount of total hydrolyzable amino acids (THAA) in the treated sample solutions were measured by high performance liquid chromatograph using postcolumn ortho-phthalaldehyde derivation.

The concentrations of THAA in the core collected at Site C0002 vary between 819.9 – 177.1 nmol/g, and Gly was the most abundant amino acid followed by Asp, Ser, Ala, Val, and Phe. At Site C0021 and C0022, the concentrations of THAA were 4679.2 and 6729.7 nmol/g at surface, respectively, and decreased drastically with depth. The THAA carbons account for <1% of total organic carbon and nitrogen, indicating that most of the biogenic organic matters would be changed into kerogens.

The amounts of hydrocarbons generated through thermal cracking of non-volatile sedimentary organic matter (S_2) were 1.2 – 0.15 mg/g. The low S_2 values and TOC (1.2 – 0.3 %) indicate that most of kerogen in the cores is categorized as type III. The temperatures at which the maximum release of hydrocarbons from thermal cracking of kerogen occurs during pyrolysis (T_{max}) were 379 – 416 °C at the shallow area (1.2 – 91.7 mbsf), increased gradually with depth, and reached to 439 °C at 2216.9 mbsf. Rock – Eval data indicate that the maturation of kerogens could be progressed with depth in seafloor sediment.

Keywords: Rock Eval, Kerogen, Amino Acids

Vitrinite reflectance of carbonaceous materials in cuttings retrieved during the IODP Expedition 348

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Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) Expedition 348 took place from 13 September 2013 to 29 January 2014. During the Exp. 348, cuttings, core samples, mud gas, and logging data were collected from Holes C0002N and C0002P down to 3058.5 mbsf. Four lithologic units were identified at Site C0002 based on geological and geochemical characteristics of core and cuttings samples: Unit II (475-512.5 mbsf in Hole C0002M), Unit III (875.5-975.5 mbsf in Hole C0002N), Unit IV (975.5-1665.5 mbsf in Hole C0002N), and Unit V (1665.5-2325.5 mbsf in Hole C0002N, and 1965.5-3058.5 mbsf in Hole C0002P)(Tobin et al., 2015).

To evaluate whole thermal structure of the Site C0002, we performed vitrinite reflectance analysis for cuttings samples collected every 100 m of Holes C0002N and C0002P. Vitrinite reflectance (R_o) is an indicator to estimate maximum paleotemperature, which has been widely applied to reveal tectonic evolution of on-land accretionary complex (e.g. Underwood et al., 1992; Sakaguchi, 1996; Ohomori et al., 1997) and thermal anomalies along fault slip zones reflecting frictional heating due to seismic slip (e.g. Sakaguchi et al., 2007; Sakaguchi et al., 2011). This is the first study that applied vitrinite analyses systematically to the entire modern accretionary prisms.

In this presentation, we report preliminary results of vitrinite reflectance analysis. R_o values are 0.15 to 0.20 in Unit III (forearc basin strata), 0.20 to 0.27 in Unit IV (accretionary prism strata), and 0.20 to 0.45 in Unit V (hemipelagic sediment). In general, R_o values tend to be gradually and continuously increasing with depth. Estimated paleotemperatures of Unit IV and V are approximately 40 °C and 90 °C, respectively, which are consistent with estimated modern temperatures (Sugihara et al., 2014).

Keywords: vitrinite reflectance, carbonaceous matter, paleotemperature, accretionary prism

Preliminary results of anelastic strain recovery (ASR) measurements during IODP Expedition 337

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During IODP (Integrated Ocean Drilling Program) Expedition 337 "Deep Coalbed Biosphere off Shimokita", a deep riser-drilling borehole was penetrated to 2,466 meters below seafloor (mbsf) by D/V CHIKYU at Site C0020 in off Shimokita, Japan. To determine three-dimensional stress, we measured anelastic strain recovery of core samples caused by stress release. The measurements are time sensitive, so were conducted onboard the ship.

We collected seven whole round core samples from a depth range between 1,370 - 2,448 mbsf, and successfully obtained high-quality anelastic strain recovery data from six core samples. The successful ASR measurement of the core sample from 2,448 mbsf was the deepest application of ASR in ocean drilling programs. From the strain data, three-dimensional stress orientations were preliminarily determined. The shallower five core samples' strain data showed normal faulting stress regimes, whereas the deepest core sample from 2,448 mbsf reveals a nearly reverse faulting stress regime. In addition, the maximum horizontal stress orientations of all the six core samples were dominantly in west-east direction, and distributed between west-northwest and south-southwest.

We gratefully acknowledge the IODP for providing core samples used in this study and the supports of the IODP Expedition 337 scientists, D/V Chikyu drilling crew, and laboratory technicians.

Keywords: Stress, ASR, IODP, Exp 337

Stress State in the Tip of Ilan Plain and Its Applications for Taiwan Geothermal Plan

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Understanding the relationship between in-situ stress and fluid-conduits is one of the most important keys for developing the enhanced geothermal system. At the same time, understanding this relationship also provide insights into evaluating the well locations and drilling direction.

The Ilan Plain of northeastern Taiwan is located between the Hsuehshan Range and Backbone Range and is influenced by the compression of mountain building between the Eurasian and Philippine Sea Plates and the back-arc extension of Okinawa Trough simultaneously. As a result, the 3D stress field is complicated and the attitude and spatial distribution of fluid conduits is not clear. To develop the technology of the enhanced geothermal system, this study focused on the evaluation of in-situ stress state on multiple scales.

Stress inversion of regional focal mechanism suggests that the stress state varies dramatically in the region and it is strike-slip faulting stress regime with NNE-SSW compression in the tip of Ilan Plain. The paleostress inversion results from the southern foothills show that the stress pattern of strike-slip faulting and normal faulting regime took place repeatedly and horizontal minimum stress orientation switched between N-S and W-E orientation. Analysis of anelastic strain recovery experiments on the retrieved cores of 720-920m indicates that a strike-slip faulting stress regime with NNW compression and NEE tension. Several hydraulic fracturing tests were conducted in the interval of 750-765m. The shut-in pressure is determined as 13.57MPa and reopening pressure is estimated as 12.66MPa. Diameter Core Deformation Analysis and rock mechanics experiments are also conducted. Integration of different stress assessments and rock strength data will provide insights to understanding the reasonable 3D in-situ stress in the tip of Ilan plain and further help the development of enhanced geothermal system.

Keywords: in-situ stress, enhanced geothermal system, Taiwan, Ilan Plain, hydraulic fracturing, ASR

Introduction of a new XRF core scanner and application of marine core science

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A new XRF core scanner (ITRAX) by COX was introduced to Center for Advanced Marine Core Research, Kochi University last year. ITRAX is an automated core scanning instrument that records optical, radiographic and elemental variations in sediment cores at a high resolution (200 microns) using photography,x-radiography and XRF analysis. Here, we will introduce some examples of application of marine core analysis.

Keywords: XRF core scanner, ITRAX, marine core science