Rock magnetic analyses for understanding of depositional processes of turbidites induced by large earthquakes in Japan Trench

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Ikehara et al., 2016 revealed that the thick turbidite depositions corresponding to 2011 and the other two historical large earthquakes were archived in Japan Trench (JPT) basins. It is then crucially important to determine the distributions of those event deposits in space and time for the JPT paleoseismology. In order to understand the details of their depositions as robust evidences for the large earthquake occurrences, rock magnetic analysis was applied to measure variation of the turbidite intervals. Magnetic granulometry provides the information of sediment depositional processes. Particularly monotone fining upward of magnetic grain size in a few meter scales is found as the most unique feature in the studied sediments. Magnetic grain analysis in detail indicates grain fining occur in various modes. Those variations seem to be linked to respective seismo-events. Additionally anisotropy of magnetic susceptibility (AMS) were measured to detect settling process of particle grains form turbidity flows in the intervals of thick turbidites. Generally dominant lineation of AMS is recognized as not single direction in each event interval while grain size decrease upward monotonously. Some lineations reoriented by paleomagnetic declinations are oblique to the strike of JPT trench. This observation may suggest the complex flow in the confined and elongated basins in JPT. It is considered that the variations of magnetic grain size and fabric data are useful to understand the depositional processes of thick turbidites.

Keywords: Turbidite, Japan Trench, Rockmagnetic property

Origin of deep-sea turbidite by stratigraphic variations of terrigenous organic carbon ratio, examples from the off Kii and Boso peninsulas

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Origin of turbidite are important for paleoseismic studies by using deep-sea turbidite, because turbidity currents are caused not only by slope failure during submarine earthquakes, but also by flood and storms. In this study, we try to recognize origin of each turbidite with stratigraphic patters of terrigenous organic carbon (TerOC) ratio by stable organic carbon isotope analyses of deep-sea sediments. Several stratigraphic patterns of TerOC ratio were recognized in turbidite mud deposited by the modern natural disasters, such as the 1596 Keicho-Bungo earthquake, the 1889 Totsukawa Flood, the 1959 Isewan Typhoon, the 2003 flood by Typhoon no.10, the 2004 off-Kii Peninsula earthquakes, and the 2011 Kumano flood by Typhoon no.12 (Omura et al., 2014). Flood-induced turbidite mud have two stratigraphic patterns of TerOC ratio as follows, 1) high and stable TerOC ratio, and 2) low TerOC ratio in lower part and high TerOC ratio in upper part. Slope failure sediments have two stratigraphic patterns of TerOC ratio as follows, 3) low and stable TerOC ratio, and 4) upward decrease of TerOC ratio (Omura et al. 2014). In this study, origin of past deep-sea turbidite are examined by correlation with modern stratigraphic variations of TerOC ratio.

Sediment cores were acquired from the off Kii Peninsula (KT-12-34-PC01, 5.2 m long) at about 2,000 m water depth and the off Boso Peninsula (KS-13-T5-PC02, 9.2 m long) at about 2,500 m water depth by using piston corer. The coring sites of KT-12-34-PC01 and KS-13-T5-PC02 were not directly affected by the submarine canyon. These sediments are composed mainly of olive black clayey silt layers, but includes numerous turbidite layers. Nine intervals of turbidite mud and hemipelagic mud were examined by stable organic carbon analyses. Turbidite mud layers were distinguished from hemipelagic mud by visual examination of soft X-radiographs, on which they show weaker X-ray transmission. Continuous sub-samples were collected at one centimeter intervals from turbidite mud and hemipelagic mud. Total organic carbon contents and stable organic carbon isotope ratio were measured by using an elemental analyzer (Flash EA and Flash 2000) and a mass spectrometer (MAT 253) at the National Museum of Nature and Science, Tokyo. The terrigenous and marine fractions of the organic carbon in the sediment were calculated from the measured stable organic carbon isotope ratio.

In sediment core KT-12-34-PC01, the stable organic carbon isotope ratio was between −19.1‰ and −22.6‰, and the estimated terrigenous fraction was between 0% and 40%. Stratigraphic variations of both flood-induced and slope failure sediments are recognized in TerOC ratio. These results indicate that deep-sea turbidite off the Kii Peninsula were deposited by flood or slope failure. In sediment core KS-13-T5-PC02, the stable organic carbon isotope ratio was between −20.4‰ and −21.7‰ and the estimated terrigenous fraction was between 11% and 28%. Stratigraphic variations of slope failure sediments are recognized in TerOC ratio. These results indicate that deep-sea turbidite off the Boso Peninsula were mainly deposited by slope failure.

The stratigraphic variations of TerOC ratio might be important information for paleoseismic studies by using deep-sea turbidites.

Omura, A., Ikehara, K., Katayama, H., Usami, K., Irino, T., Kuwae, M., Shirai, M. and Ashi, J. (2014) Stratigraphic variations of terrigenous organic carbon ratios in flood and slope failure sediments of marine area, examples from the modern natural disasters of Japan. 19th International Sedimentological Congress,

Geneva, T2S3-P14.

Keywords: turbidite, terrigenous organic carbon, stratigraphic variation

Identification of muddy seismogenic turbidite from sedimentary structure and chemical composition

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Paleoseismology using marine seismogenic turbidites has been conducted on many seismically active continental margins. In recent years, “muddy turbidites” which do not contain clear signs of sand grain sedimentation is drawing attention. However, few studies have illustrated muddy turbidite characteristics. The purpose of this study is to identify the muddy turbidites mainly from sedimentary structures and chemical compositions.
The samples are multiple and piston cores collected from the sedimentary basin off Kii peninsula and Hyuga-nada, SW Japan. Visual observation, X-ray CT scans and other measurements such as anisotropy of magnetic susceptibility (AMS), paleomagnetism, electrical resistivity and X-ray fluorescence core scanning (XRF core scanner) were conducted.
X-CT scans clearly reveals sedimentary structure of homogeneous clay sequence above the silty lamination as reported by Okutsu et al. (2016, JpGU abstract) even on structureless mud interval by visual observation. Ca and Fe analyses by XRF core scanner show peaks at around the basement of turbidite layers identified by X-CT scanner. Mn peak also shows similar tendency, but does not always exhibit the same trend. Those variations of Ca and Fe contents are consistent with the previous work of Iwai et al. (2014, Geol. Soc. Japan abstract). More specifically, Ca peaks were always observed at the slightly upper level than the Fe peaks position. Because correlation of Ca and Fe show different trends between the turbidite layers and other layers, the difference could be available for discrimination between turbidite and hemipelagic mud. Ca and Fe peaks can be recognized even in the heavily bioturbated turbidite which have no original sedimentary structure in X-CT image. Therefore, XRF core scanner can be a useful tool to identify the muddy turbidite layer in addition to X-ray CT scanner.

Keywords: turbidity current, event deposit, paleoseismic records, Nankai trough

Stratigraphic changes and sedimentary facies of lacustrine sediment gravity flow deposits in the Middle Pleistocene Miyajima Formation, Tochigi Prefecture, northeast Japan

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Sediment gravity-flow deposits, induced by flood and slope failure events, are widely observed in varied environments from deep sea to lake environments. In marine environments, many sedimentological studies have been carried out; however, it is hard to distinguish event origins from the deposits. In recent years, modern lacustrine sediment gravity-flow deposits have been studied using sedimentary cores. Studies of lacustrine sediment gravity-flow deposits can provide a high-resolution event stratigraphy and the basis for identification event types because of their confined sedimentary environments. In this study, we analyzed sedimentary facies of lacustrine sediment gravity flow deposits in outcrops and studied their stratigraphic changes.

The Middle Pleistocene Miyajima Formation, consisting of lacustrine deposits, is located in Nasushiobara City, Tochigi Prefecture, northeast Japan. The main portion of the formation includes varved sediments intercalating many sediment gravity flow deposits. A varve in the formation is composed of light lamina dominated by *Stephanodiscus niagarae* and dark lamina dominated by inflow particles. The studied outcrop is located in Nakashiobara, Nasushiobara City and is exposed continuously along the Hahaki River. We obtained a continuous photograph series and columnar samples of the outcrop. Sedimentary facies of sediment gravity-flow deposits, their recurrence intervals, stratigraphic variations of facies types and their thicknesses were analyzed using the photographs and samples.

The 1,177 varves with 634 sediment gravity-flow deposits were obtained from the analyzed section. The average of thickness of a varve is ca. 1.2 mm and the average thickness of sediment gravity-flow deposits is ca. 9.3 mm. The sediment gravity-flow deposits can be classified into 310 beds of grading types, 315 beds of structureless types, and 9 beds of inverse grading types. The sediment gravity flow deposits have a silty matrix except for several layers in the uppermost part. Each type is subdivided by conditions of basal erosion, including rip-up clasts and sand-sized particles.

Because most parts of the varved sediments in the formation comprise of lacustrine planktonic diatoms, the sediment gravity flow deposits consisting mainly of clastics are suggested to have been formed by a flood inflow. Flood-induced slope failure deposits, including rip-up clasts and blocks of slump-folded beds and diatomaceous beds, are also included. Sediment gravity-flow deposits with an erosional base are suggested to have been deposited by a hyperpycnal flow along the bottom of the lake, whereas sediment gravity-flow deposits without an erosional base are thought to have been deposited by hypopycnal or homopycnal flows that spread along a lake surface or a thermocline of the lake. Graded bedding is a typical characteristic of a base cut hyperpycnite or is suggested to have been deposited by a suspended cloud, whereas an inverse grading is considered a relict of acceleration-phase deposits uneroded by following phases. Structureless beds are suggested to be deposited from floc of suspended particles.

Sedimentary facies of varved sediments and sediment gravity-flow deposits differ between the lower 720-year and upper 450-year intervals. In the upper part, “double laminae” and sediment gravity-flow deposits without an erosional base are dominant, whereas “single lamina”, including sediment gravity-flow deposits with the erosional base, are dominant in the lower part. Different lake water conditions are suggested between the parts. Double laminae were formed by two diatom blooms induced

by lake water circulations after lake water stratifications in summer and during a “cool” winter. Because low-density sediment gravity flows are relatively difficult to submerge into stratified lake waters as a hyperpycnal flow, it is suggested that sediment gravity flow deposits without an erosional base are dominant in the upper part.

Keywords: sediment gravity flow deposit, hyperpycnal flow, varve, lacustrine sediment, Miyajima Formation, Shiobara Group

Sedimentary structures within sedimentary gravity flow deposits formed under upper flow regime conditions and their association with sedimentary topography

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Sedimentary structures formed under upper flow regime conditions (Fr > 1), such as massive structureless units, spaced planar laminations (SPLs), and occasionally hummocky cross-stratification mimics (HCS mimics), are observed within the lower portions of sediment gravity flow deposits. These structures are overlain by planar laminations and ripple cross-laminations formed under lower flow regime conditions. The resulting successions of structures, formed under both flow regime conditions, constitute Bouma and Lowe sequences. The lower unit of sediment gravity flow deposits is typically dominated by massive structureless units, and SPLs and HCS mimics are not frequently observed. Additionally, it has been suggested that the structures in the lower unit often change with respect to one another along the lateral or paleocurrent directions, as well as vertical directions. However, the depositional processes responsible for the formation of these sedimentary structures are unclear and detailed descriptions of the transitions are rare, particularly for the lateral and paleocurrent directions. Well-exposed, laterally continuous sediment gravity flow deposits in outcrop can provide insights into the depositional processes that formed the structures in the lower unit. In this study, we carried out detailed mapping of these sedimentary structures and the basal topographies within sediment gravity flow deposits, and determined their transitional patterns.

We investigated the turbidite succession of the Neogene Aoshima Formation, Miyazaki Group, which is well-exposed in the paleocurrent direction along the Nichinan Coast of Miyazaki and Nichinan cities. The studied outcrop, located at Shirahama, shows sediment waves with wavelengths of 300–400 m. The sedimentary structures in the sediment gravity flow deposits, which can be traced for approximately 700 m, were mapped using a series of sequential photographs taken at the outcrop. The sediment gravity flow deposits were selected for mapping based on their basal topographies, which are characterized by moderately undulating, slightly undulating, and relatively flat intervals.

The sediment gravity flow deposit facies of the Aoshima Formation have been subdivided into graded, massive, and inverse graded bed types. These bed types show SPLs and HCS mimics in the basal interval. Paleocurrent directional mapping of the sedimentary structures showed that SPLs are dominant in the relatively flat beds; whereas, in the undulating intervals, HCS mimics and SPLs are observed on the upstream and downstream flanks, respectively. When sediment waves are formed as cyclic steps, it is suggested that massive structureless units can be deposited on the upstream flank due to a hydraulic jump; whereas, SPLs are dominant on the downstream flank due to high shear stress flow. In the Aoshima Formation, HCS mimics on the upstream flanks may have been deposited by relatively erosive flows associated with breaking waves, not only hydraulic jumps, because the basal undulations in the study interval are not large enough to have developed clear sediment wave topographies. In contrast, in the intervals characterized by relatively flat topography, it is suggested that laterally continuous SPLs, which extend for tens of meters, may have been deposited under conditions without the effects of basal topography.

Keywords: sedimentary gravity flow deposits, upper flow regime condition, sediment wave, sedimentary structure, Aoshima Formation

Effect of surge-duration on the velocity distribution of turbidity current and resultant cyclic step morphology: PIV measurements of the surge-type turbidity currents in flume experiments

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Cyclic steps are often found in channels on the prodelta surfaces or submarine canyons, which is attributed to turbidity currents. Field observations of turbidity currents and seabed topography on the Squamish delta in British Columbia, Canada revealed that cyclic steps formed by the surge-type turbidity currents. The high-density portion of the flow, which affects the sea floor morphology, lasted only 30-60 seconds (e.g., Hughes Clarke, 2016). We are doing flume experiments aiming to investigate the relationship between the condition of surges and resultant morphology.
Experiments had been performed at Osaka Institute of Technology. A flume, which is 7.0 m long, 0.3 m deep and 2 cm wide, was suspended in a larger tank, which is 7.6 m long, 1.2 m deep and 0.3 m wide, filled with water. The inner flume tilted at 7 degrees. As a source of turbidity currents, mixture of salt water (1.17 g/cm^3) and plastic particles (1.3 g/cm^3, 0.1-0.18 mm in diameter) was prepared. The concentration of the sediments was 6.1 weight % (5.5 volume %) in the head tank. This mixture of salt water and plastic particles poured into the upstream end of the inner flume from head tank for 3-, 5-, and 7-seconds and continuous flow. For 3-, 5-, and 7-seconds-surges, 130 or 140 surges were made respectively. Discharge for unit time ranges 102 to 290 mL.
As a result, surge-type turbidity currents, regardless the surge duration, formed cyclic steps, but the continuous currents did not form cyclic steps. Moreover, the locations where the steps moved upstream vigorously differ from each other, the shorter the duration, the closer to the upstream end.
The velocity distribution of the profile of the turbidity currents were measured using PIV. Comparing the median velocity of 3s-, 5s-, 7s-surges and continuous turbidity currents, it is revealed that the longer the surge duration, the faster the median velocity for the same unit discharge.

Keywords: Surge turbidity current, cyclic step, flume experiment, surge duration, PIV measurement

Three types of submarine canyons offshore southwest Taiwan

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The sea floor off SW Taiwan is represented by an active margin. Morphologically, the margin is occupied by the narrow Kaoping shelf (<10 km) and the broad Kaoping slope which extends to a depth of about 3000m. Several submarine canyons are located on the active margin off SW Taiwan. Looking from NW to SE, these canyons are the Penghu, Shoushan, Kaohsiung, Kaoping, Fangliao, and Hongtsai canyons. Although these canyons are under the same regional controls (i.e., tectonics, sea level change), they have evolved with time and resulted in distinct morphologies.

Canyons off southwestern Taiwan are classified into three different types: 1. river-connected; 2. shelf-indented; 3. blind (confined to the slope). Type 1 canyon, the Kaoping Canyon, is directly connected to the Kaoping River, and is supplied with much sediment. The canyon head segment thus has relatively high tendency to generate hyperpycnal flows during flood seasons. The Penghu, Shoushan, Kaohsiung, and Fangliao canyon belong to type 2. The Fangliao Canyon is intensely incised into the shelf. The other three canyons are characterized by relatively weak headward erosion into the shelf. The Hongtsai Canyon is a type 3 canyon and is mainly resulted from activity of mud diapir and thrust faulting.

Keywords: submarine canyon, Taiwan

Development Processes of Turbidity Currents Toward the Equilibrium State: Examination by Numerical Simulation

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In this study, development processes of turbidity currents toward the equilibrium state was investigated by the numerical simulation using the renormalized group k-epsilon turbulence model. Turbidity currents are particle-laden currents driven by gravity, which occur in deep seas and lakes. It has been indicated that turbidity currents run out over tens to hundreds of kilometers and deposit vast amounts of sediments on submarine fans of deep sea floors. Existing layer-averaged numerical models of turbidity currents, however, cannot reproduce such long-traveled turbidity currents because the flows entrain the ambient water and get diluted as they run down. Recently, Luchi et al. (2015) developed the vertically resolved k-epsilon model of turbidity currents in the steady condition, and implied that turbidity currents become bipartite at the horizon showing the maximum flow velocity. Their model indicated that the upper parts of turbidity currents get rarified as they run down, whereas the lower parts which carry most of the suspended sediment have the equilibrium state, which can be sustained over long distances without any dilution and deceleration. Although this model might explain the reason why turbidity currents can run out for long distances, their model assumed the steady state, so that it was not explained whether the flows can reach the equilibrium state within realistic spatio-temporal scale in the actual sedimentary environments.

Therefore, this study focuses on the processes of both temporal and spatial developments of turbidity currents to become the equilibrium state. This study conducted the two-dimensional numerical simulations using computational fluid dynamics software FLOW-3D in order to obtain spatio-temporal change of flow properties of turbidity currents in both vertical and flow-parallel directions. The simulation was conducted under the condition at which the turbidity current continued flowing from the upstream end of the computational domain at constant rates of velocity and sediment concentration for a given time. The computational domain was 200 m long and 30 m deep, and the computational grid size was 5 cm for both vertical and horizontal directions. The flow velocity and height at the upstream boundary were respectively fixed to the values 1 m/s and 0.5 m, and the experimental duration was set to 1800 seconds. As a result of simulation, we obtained the following findings: (1) the turbidity current reached the steady state about several minutes after the beginning of simulation, (2) the height of the horizon showing the maximum velocity was constant in the region about 4 m from the inlet to the downstream end, (3) the maximum velocity converged to the constant value at about 150 m from the inlet, and (4) the flow height defined by the inflection point of the flow velocity profile continuously increased downstream. These results suggest that the lower part of the turbidity current reached the equilibrium state within about 150 meters at the given experimental condition, whereas the upper part of the flow remained non-uniform because of entrainment of the ambient water. Although further numerical simulations at various experimental conditions are required to conclude, we tentatively infer that the lower part of turbidity currents at natural scale can easily reach the equilibrium state and the upper part continues being rarified. In the future, this study will lead to the development of a new layer-averaged model of two-layered turbidity currents which can solve the large-scale morphodynamic problems.

Reference

Luchi, R., Parker, G., Balachandar, S., and Naito, K. (2015). Mechanism governing continuous long-runout

turbidity currents (in Japanese with English abstract). *Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering)*, 71.

Keywords: turbidity current, numerical simulation, development processes

Inverse analysis to reconstruct hydraulic conditions of non-steady turbidity currents considering multiple grain-size classes

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Turbidity currents emplace turbidite sandstones that are characterized by graded bedding. In spite of their significance in the paleoenvironmental researches and the resource geology, the flow properties of turbidity currents in deep-sea environments remain unclear because in-situ measurements have been disturbed by their highly destructive nature and infrequent occurrences. Therefore, in order to understand the behavior of actual turbidity currents, this study aims to develop a new method of the inverse analysis to reconstruct the paleo-hydraulic conditions of turbidity currents from ancient turbidites. There have been a few studies of inverse modeling of turbidity currents; however, several problems in their studies have been pointed out. For instance, the previous study employed the oversimplified forward model that assumes temporally steady flows, which cannot produce graded bedding. Normal grading and other successive transition of sedimentary structures (i.e. the Bouma sequence) is typical features of ancient turbidites, so that their steady-flow assumption is not suitable for analysis of natural turbidity currents. In contrast, the author inverse model employed two-dimensional Navier-Stokes equations for the forward model, but the calculation cost of their method is too high to apply it to the field-scale data. To this end, this study proposes a new forward model of non-steady turbidity currents with consideration of mixed grain-size sediment, which can describe the behavior of a turbidity current that deposits a typical turbidite showing graded bedding. Our model employs the one-dimensional shallow water equation, which is applicable to the field-scale problems. The “lock-exchange” type condition is assumed as the initial setting in this model. For inverse analysis, the objective function is defined as sum of squares of deviations between the results of the observation and the numerical calculation. In our inverse calculation, the initial hydraulic conditions that minimize the objective function are explored by the genetic algorithm. Tests of our inversion method using the artificial data provided reasonable results, suggesting adequacy of the optimization methodology. We then applied our method to a turbidite in the Kiyosumi Formation, Boso Peninsula, Japan. The Kiyosumi Formation is composed of sand-dominated alternations of turbidite sandstone and hemipelagic mudstone, which are considered to be deposits of the submarine fan lobe. In this study, the individual turbidite bed intercalated between the two key-tuff layers was correlated over 20 km, and thickness and grain-size distribution of the bed were measured at the seven sampling localities. As the result of the inverse analysis, the hydraulic conditions of the turbidity current that had emplaced the turbidite bed was estimated. When the flow reached at the downstream end of the study area, the flow thickness, velocity, and total sediment concentration were reconstructed to be 334.55 m, 0.98 m/s, and 0.0058% respectively at the downstream end of the sampling area. Although the verification of this result will be discussed as a future issue, these reconstructed values are in agreement with the hydraulic conditions of turbidity currents monitored by the previous studies.

Keywords: inverse analysis, turbidity current , turbidite, the Kiyosumi Formation

