Discriminant functions for formative conditions of bedforms in open-channel flows

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Fluvial bedforms such as ripples and plane bed are formed by interactions between flows and processes of sediment transport. Sedimentary structures formed by bedforms, hence, are clues to reconstruct paleo-flow conditions. For analysis of sedimentary structures, bedform existence diagrams have been proposed on the basis of laboratory and field observations, and have been widely used. To utilize the bedform existence diagrams for analysis of sedimentary structures, boundary lines of bedform stability regions are significant.
This study provides boundary surfaces of bedform stability regions defined as discriminant functions of dimensionless parameters. In previous studies, the lines were described manually without quantitative examination. Thus, previous studies that apply these diagrams to sedimentary structures lack sufficient statistic basis. To this end, this study obtained boundary lines as polynomial equations of dimensionless parameters.
First of all, we defined a new bedform existence diagram based on 3272 existing laboratory and field data. We used three parameters in dimensionless form. Some of diagrams in previous studies were not sufficient in the number or kinds of parameters. This study produces a new bedform stability diagram, which defines bedform stability regions by three dimensionless parameters: dimensionless grain size D_*, Shields mobility parameter τ_* and Froude number Fr.
On the basis of the diagram described above, discriminant functions are derived by following procedures. At first, a polynomial function with arbitrary coefficients which divides parametric space is supposed as a candidate of a discriminant function. Then, the ratio of data points of bedform experiments that was judged incorrectly by the polynomial function is calculated. At last, in order to minimize the ratio, coefficients of polynomial function is optimized.
The discriminant functions of bedforms obtained in this study can serve quantitative paleo-flow analysis of sedimentary structures. Their form is $Fr = f(D_*, \tau_*)$. This function can be recast in the form $U = f(D, h)$, where U = flow velocity; D = sediment particle size; h = flow depth. Thus, when we obtain the data of sediment particle size and flow depth from sedimentary structures, we can estimate paleo-flow velocity. The discriminant functions are useful and objective for estimation of paleo-flow conditions.

Keywords: Bedform, Discriminant analysis

Quantitative analysis of erosional marks at the bases of sediment gravity flow deposits

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Erosional marks, such as flute and groove marks, are frequently observed at the base of sediment gravity flow deposits, especially for turbidites. It is suggested that the flow velocity and the duration of the erosional flow affect the distributions and sizes of the marks. Additionally, the substrate materials and the characteristics of the erosional flow have an impact on the marks. A large olistolith in the Nichinan Group is distributed at the Izaki Cape, Nichinan City, Kyushu Island, Japan. The olistolith is a block of a turbidite succession deposited in a deep sea environment. Many turbidites deposited on the channel levee and the frontal splay in the block have various types of erosional marks. The distributions and sizes of the erosional marks on the turbidites in many parts of the block suggest differences in the erosional flow duration in different areas, even if it is over an individual turbidite bed (Yumi and Ishihara, 2012). The results suggest that the flow velocity and the duration of the erosional flow deduced from the erosional marks provide additional information about the depositional settings and the paleotopographies of deep sea environments. Yumi and Ishihara (2012) analyzed the distribution and sizes of the erosional marks on a two-dimensional horizontal surface; i.e., they analyzed the planar projections of the erosional marks. However, because most of the erosional marks are observed as a cross section on an outcrop surface, three-dimensional topographical analyses should be carried out. In the present study, we show results of a three-dimensional analysis of outcrop examples of the erosional marks in the Izaki Cape and those formed by flume experiments.

Yumi and Ishihara, 2012, Jour. Sedim. Soc. Japan, 71, 173-190

Keywords: turbidite, flute mark, geomorphic analysis

Investigation of numerical forward model toward inverse analysis of ancient turbidities: Comparison between results of numerical simulation and grain-size analysis of the ancient turbidite bed in the Pliocene Kiyosumi Formation, Boso Peninsula, Japan

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Turbidity currents are considered as a main mechanism of sediment-transport toward deep-seas, and deposits of turbidity currents, i.e. turbidite sandstones, can be reservoir rocks of petroleum. Therefore it is important to understand the behavior of turbidity currents not only from the perspective of earth sciences, such as sedimentology and stratigraphy, but also resource geology. However, it is quite difficult to observe turbidity currents directly because of their high-velocity and intermittency of occurrences, so that the detailed mode of sediment transport and depositional processes remain unclear. To this end, the methods for inverse analysis to reconstruct flow conditions of turbidity currents from thickness and grain-size distribution of ancient deposits have been developed. However, previous studies have difficulty in feasibility of application to natural examples because of calculating costs of their forward model (2D DNS model). Here we examine that applicability of the forward model of turbidity currents based on the non-steady 1D shallow-water equation for inverse analysis of ancient turbidites. The 1D shallow-water equation model of turbidity currents is superior to the DNS model from the viewpoint of calculation costs, but it is not fully tested for flows that contain sediments of multiple grain-size classes.
First, this study investigated thickness and grain-size distribution of the ancient turbidite bed in the Mio-Pliocene Kiyosumi Formation, Boso Peninsula, Japan. The Formation is composed of sand-rich alternating beds of sandstone and mudstone, which have been interpreted as deposits of the submarine fan. This study focused on the turbidite sandstone G1, which is sandwiched between two characteristic tephra and therefore it can be traced over 40 km. We measured thickness of the sandstone bed and collected samples for grain size analysis by using the settling-tube method. As a result, it was revealed that (1) bed thickness decrease downcurrent non-linearly. There are points where volume per unit area of each grain-size class decrease remarkably. (2) Locations of the points where sediment volume per unit area decrease vary depending on grain size classes. Then, we conducted numerical experiments to reproduce geometrical features of the turbidite bed described above. We employed 1D shallow water equation model with sediment conservation equations of each grain-size class and active-layer approximation of grain-size distribution of the basal surface. In this study, grain-size distribution is approximated to the two grain-size classes: medium sand (2 phi) and silt (8 phi). As a result, distribution pattern of sediment volume per unit width was well reproduced by our model. Sand-sized sediments pinched out downcurrent, whereas silt-sized sediments show continuous thickness distribution downcurrent. This result imply that the inversion model using the forward model based on shallow-water equation could be applicable for ancient turbidites that have 10s km in spatial scale.

Keywords: Kiyosumi Formation, numerical simulation, turbidity currents

Changes in shapes and microtextures on quartz grains of fluvial sediments at Hime Kawa.

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[Introduction]
Quartz is a highly resistant and ubiquitous mineral in nearly every environment. Microtextures such as small pits and conchoidal fractures can be observed on quartz grain surface. Many researchers have observed quartz surface by scanning electron microscope (SEM) and studied to link microtextures to the sedimental environments and transport mechanisms (Krinsley and Doornkamp, 1973; Mahaney 2002). Quartz microtextures have been mainly examined in continental regions such as Europe. It is supposed that geological and geomorphological features relate to the frequency distribution of microtextures. However, little is known on the microtextures of quartz deposited in orogenic belt and monsoon region like Japan.
In this study, we focused on the fluvial sediments in Japan. The changes in the surface textures of quartz grains were determined from upstream to downstream areas of a steep river, Hime Kawa. The shapes of the quartz grains were also examined.
[Methods]
The studied area was situated in Hime Kawa in Nagano and Niigata Prefectures. Seven fluvial sediment samples from the bed of Hime Kawa and one nearshore sample near the mouth of Hime Kawa were collected. Carbonates, iron oxides and organic matters were removed from samples by chemicals. The quartz grains in the size range of 0.1mm up to 1mm were sputter coated for 60s with a current of 40 mA in a palladium coating. Fifteen grains per sample were observed by SEM (JEOL, JSM-6610LV) in high vacuum mode and the voltage was 25kV.
[Result and Discussion]
Most of the quartz grains in fluvial samples show angular outline and there are no clear changes along Hime Kawa. The nearshore sample also contains angular grains which resemble the fluvial samples. Most of the grains in upstream area have high relief, and the relief gets slightly lower along Hime Kawa. These changes may be caused by the collision of the grains in subaqueous environment. Some grains show characteristics shapes, namely twinned quartz. Both penetration twin and contact twin are found in fluvial samples.
On the quartz surface, conchoidal fractures, V-shaped percussion cracks and straight steps are found in both fluvial and nearshore samples. It has been proposed that they are produced by a powerful impact or pressure on the grain surface in high-energetic subaqueous environment (Vos, 2014). In our study, frequency distribution of each microtexture has not drastically changed except small pits.
Small pits (< 5μm), which derives from small inclusions in quartz, can be abundantly observed in the samples along upstream area of Hime Kawa. They are observed sparsely along downstream area. It means the amount of inclusions in quartz is quite different between upstream and downstream areas at Hime Kawa. The tributaries such as Tsuchitani Gawa and Nakatani Gawa flow into the middle reaches of Hime Kawa. Quartz particles we observed in this study may have different derivations due to the sediment supply from tributaries in the middle reaches.

Keywords: quartz, surface texture, SEM, twins, provenance study

Use of statistical information to characterize sedimentary facies of alternating successions: an example using gamma rays and graphic logs

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Alternating successions consisting of monotonously rhythmic alternating beds occur in various depositional environments. Because quantitative data can be obtained from these alternating successions, they sometimes have been quantitatively analyzed sedimentary facies, in addition to traditional qualitative sedimentary facies analysis work conducted by geologists. Especially, well-log data of turbidite successions are frequently and quantitatively analyzed because turbidite successions can be important reservoirs for oil and gas (Rider and Kennedy, 2011). However, integration of well-log analysis data and traditional sedimentary facies analysis data from graphic logs is often not achieved because quantitative studies of sedimentary facies are rare. In this study, we examined common statistical indices that can be used to characterize sedimentary facies from well-log data and graphic logs collected on the same turbidite succession.

In regard to the well-log analyses, spectroscopy gamma ray (SGR) data were mainly used because they are the most sensitive parameter for lithofacies. The SGR data commonly have a poor resolution for individual beds because the vertical resolution is only 15 cm. Thus, graphic logs were interpreted for equal interval data corresponding to the SGR data. The lithology, ratio of sandstone to mudstone, and vertical grain size variation were used in the sedimentary facies indices to identify the lithofacies of turbidite successions. These parameters were grouped into clusters indicative of the different sedimentary facies through a cluster analysis technique.

Lithologies from SGR data were identified by the lamina identifying method proposed by Sasaki et al. (2015). Ratios of mudstone to sandstone in analysis windows were then estimated by using the identified lithology. Stratigraphic grain size variations were estimated by using differences in the SGR data of upper and lower parts in the analysis windows. In the case of graphic logs, ratios of mudstone to sandstone and stratigraphic grain size variations were estimated from the equal interval lithological data.

As a result of the cluster analysis, 12 clusters were derived. These clusters contained information about the lithology, ratio of mudstone to sandstone, and stratigraphic grain size variation. For example, the cluster information of sedimentary facies was useful for distinguishing between weathered sandstone or mudstone, sandy or muddy horizons, and upward fining or coarsening in the facies. We show the results for the identified sedimentary facies by considering the vertical transitions in these types of information.

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Rider, M. and Kennedy, M., 2011, The Geological Interpretation of Well Logs. 432p.
Sasaki et al., 2015, *Journal of the Sedimentological Society of Japan*, 74, 31-43.

Keywords: sedimentary facies analysis, turbidite succession, gamma-ray log, cluster analysis

Record of thickness and fluorescence intensity of annual layers in a stalagmite of Shiraho Saonetabaru Cave, Ishigaki Island

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Various paleoenvironmental proxies, such as fluctuations in oxygen isotope ratio and Mg/Ca, have been extracted from stalagmites using geochemical analyses. In these studies, fluorescent annual layers observed in stalagmites are often used as a proxy for time. Although the thickness of these layers has been interpreted as a proxy for precipitation in some paleoenvironmental studies (e.g. Burns et al., 2002), some items, particularly concerning the formation process of the annual layers, remain unclarified. Furthermore, implications regarding the fluorescence intensity of annual layers have not yet been examined. In this study, a lamina analyzing method, developed by Sasaki et al. (2015), was applied to a stalagmite obtained from the Shiraho Saonetabaru Cave, Ishigaki Island. Accumulative changes in thickness and fluorescence intensity of annual layers are examined and these time series are then used to clarify the paleoenvironment.

The study cave is located near New Ishigaki Airport on the east coast of Ishigaki Island. In this area, some caves, including the Shiraho Saonetabaru Cave, developed in the Ryukyu Limestone Formation, which extends from west to east. Numerous fossils, including human and animal bones, were discovered from cave deposits of the Shiraho Saonetabaru Cave (e.g. Nakagawa et al., 2010).

Using the lamina analyzing method, annual layers representing approximately 600 years (2015 - 1415) have been identified. The average thickness of annual layers in the stalagmite is about 0.35 mm, slightly thicker than those of caves on Honshu Island. In time series of annual layer thickness, remarkable thin layers are observed during 1540-1580 and 1790-1810. Commonly, stalagmite growth rate is influenced by dripping water intervals, cave air temperature, and supersaturation degrees with respect to calcite in dripping waters depending on the partial pressure of CO_2 in the cave air. The partial pressure of CO_2 is predominantly affected by the degree of cave air circulation, because cave temperature is almost constant throughout the year. Therefore, significant decreases in layer thickness can be related to periods of decreasing intervals of rain water precipitation or cave air circulation. Relative fluorescence intensity decreases noticeably during 1480-1500, 1530-1540, 1880-1890, and 1960-1990. The fluorescence intensity is thought to be mainly influenced by the growth rate of annual layers and the flux of fulvic acid in dripping waters. Namely, fluorescence intensity is weaker when the growth rate of annual layers is higher and/or the flux of fulvic acid in dripping water is lower. However, both annual layer thickness and fluorescence intensity decreased during the period 1480-1500, suggesting that the flux of fulvic acid in that period was significantly low. We discuss the potential for paleoenvironmental proxies suggested by these results.

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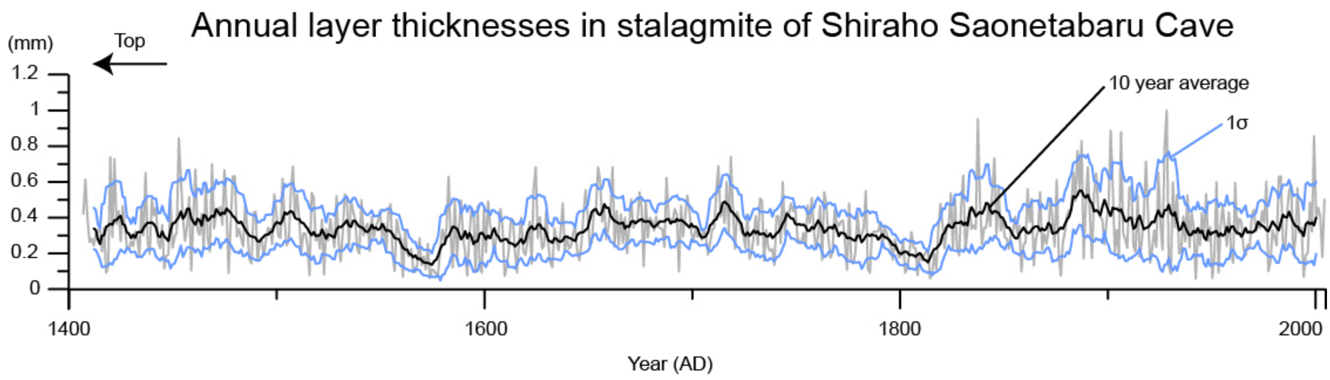
Keywords: annual layer, stalagmite, time series analysis


Annual layer thicknesses in stalagmite of Shiraho Saonetabaru Cave
(mm)
Top
1.2
1
0.8
0.6
0.4
0.2
0
10 year average
1σ
1400
1600
1800
2000
Year (AD)

Variation in depositional conditions across the Toarcian (Early Jurassic) OAE: Mudstone lithofacies analysis of the Nishinakayama Formation

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The early Toarcian (Early Jurassic) oceanic anoxic event (T-OAE) was a significant palaeoenvironmental perturbation that led to marked changes in ocean and atmospheric chemistry. This event is characterized by the widespread occurrence of a ~3–7‰ negative excursion in the carbon-isotope ($\delta^{13}C$) composition of marine organic and inorganic matter and terrestrial plant material. In addition, one of the distinct phenomena during the early Toarcian is the abrupt rise of pCO_2 and consequent global warming, which led to tropical to subtropical storm intensification. Although such storms are predicted to have been intensified globally at low to mid latitudes during the Early Jurassic, tropical storm intensification outside the Tethys realm has not been demonstrated. To address this issue, we investigated the Nishinakayama Formation of the Toyora area, southwest Japan, which represents an organic-rich silty mudstone-dominated succession deposited at the shallow margin of the northwestern Panthalassa Ocean. First, we established a high-resolution carbon-isotope chemostratigraphy. As a result, the characteristic T-OAE negative $\delta^{13}C$ excursion was recognized around the middle part of the Nishinakayama Formation, making accurate international correlation possible. Then, we carried out a mudstone microfabric analysis to reconstruct hydrological and sedimentological changes. Our results indicate that the Nishinakayama black silty mudstones exhibit a variety of microfabrics, sedimentary structures, and textures. These features indicate a dynamic range of depositional conditions. In particular, we note evidence for mudstone deposition by bottom currents, and silty mudstones exhibiting evidence of energetic conditions are concentrated during the carbon-isotope negative excursion interval. Mudstones from the pre- and post-excursion intervals generally show parallel-laminated features that suggest settling from suspension. These sedimentological changes, in combination with carbon isotope stratigraphy, provide the first evidence for storm intensification during the T-OAE interval from the mid latitude Panthalassic margin. Our results are consistent with previously published papers documenting sedimentological changes in Tethyan T-OAE successions.

Keywords: Toarcian oceanic anoxic event, Panthalassa, Nishinakayama Formation

A rationale of shoreline autoretreat provided by the grade index model

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The dynamics of delta distributary channels can be intensely affected by basin water depth in front of the delta, particularly in terms of a long time scale. The previous experiments conducted in use of tank facilities suggest that with deeper basin water, delta distributary channels have lower rates of alluvial aggradation and lateral migration. If the delta faces very deep water, the channels attain alluvial grade and are stabilized in a particular position in the delta plain. This effect of basin water depth can be numerically expressed with grade index (G_{index}), which ranges between 0 (perfect alluvial aggradation) and 1 (alluvial grade). Given basin water depth (h), delta plain radius (x) and alluvial slope (S_a), we define dimensionless basin water depth as $h^*=h/S_a x$. Assuming a set of particular geometrical conditions that (1) the basin floor is flat and horizontal, (2) the delta is always attached with a vertical wall on the back, and (3) base level is stationary, grade index is given as $G_{index}=(1+2h_*+S_{a*}h_*^2)^{-1}$, where S_{a*} is alluvial slope normalized with the delta's foreset slope S_f (i.e. $S_{a*}=S_a/S_f$).
In a hypothetical setting where (1) base level rises at a constant rate (i.e. h also increases in proportion to time), (2) the entre sediment supplied from the outside of the system is constant (rate Q_s) and accumulates as part of the delta, and (3) the delta's angle parameters are always retained constant, time derivative of the delta's volume $V(x,h)$ is equal to Q_s. Based on this relation, easy calculation leads to a dimensionless progradation rate (R_{pro*}) of the delta: $R_{pro*}=(1-A_{B*})G_{index}$, where A_{B*} is the delta's bottom surface area that is made dimensionless with autostratigraphic 3D length scale L_{3D}. It follows that shoreline autoretreat starts when A_{B*} exceeds unity. By a similar procedure, we find that the dimensionless rate of alluvial aggradation (R_{agg*}) is given by: $R_{agg*}=A_*+(1-A_{B*})G_{index}$, where A_{B*} is the delta plain's horizontal cross section area that is made dimensionless with autostratigraphic 3D length scale (L_{3D}). When the retreating shoreline arrives at the back wall, alluvial plain disappears and the entire depositional system is drowned (autodrowning). At this critical moment, $G_{index}=0$ and $A_*=0$, thus $R_{agg*}=0$.
The argument above brings a proposition that the shoreline autoretreat-autodrowning sequence, as a non-equilibrium response of the delta to steady sea level rise, is closely related to grade index. This sequence is due to the delta's progressive expansion and increasing basin water depth (i.e. sea level rise), and thus clearly related to grade index. The grade index model provides a novel rationale for the occurrence of the autoretreat-autodrowning sequence.

Keywords: deltas, shoreline autoretreat, grade index, sea level rise, nonequilibrium response

Verification of the method to reconstruct histories of crustal uplift rate from river longitudinal profiles: Application to the central part of Boso Peninsula, Japan

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A method for estimating spatial and temporal histories of crustal uplift rate from longitudinal river profiles was proposed by Roberts and White (2010). When bedrock is uplifted, an abrupt change in gradient (i.e., knickpoint) occurs along the river bed, and then subsequent erosional processes cause upstream-migration of knickpoints. Therefore, river longitudinal gradient change reflects the history of uplift rate of bedrock, where older history is recorded in the upstream region. For analyzing river longitudinal profiles, a forward model that calculates incisional processes of river profiles from uplift rate histories with four erosional parameters was developed. Then, the inverse algorithm that minimizes the misfit between calculated and observed river profiles by optimizing uplift rates and erosional parameters was produced to obtain spatial and temporal patterns of regional uplift rate histories. This method is superior to other existing methods for estimating spatial variation of bedrock uplifting rate, and has been applied on profiles of rivers in stable continental regions (e.g., Africa and Australia). However, it has not been tested to tectonically active regions such as the Japan Islands.
Here, we aim to verify the method for analyzing river profiles in tectonically active regions where the uplifting rates of bedrock varies in smaller spatial and temporal scales. We investigated uplift rate histories of the central part of the Boso Peninsula in Japan, and examined the effectiveness of the method, comparing results of multiple rivers that locate in same region. As a result, we found that the uplift rate histories estimated from multiple rivers were inconsistent each other although they locate on the same tectonic terrain. We infer that cause of this inconsistency in estimated uplifting histories can be attributed to the heterogeneity in erodibility of the bedrock in the study area. The forward model employed in this study assumes that the erodibility of bedrock is constant in space; however, several knickpoints actually locate at the lithological boundaries, suggesting the possibility that variation in erodibility should be taken account in the model. Thus, we suggest that parameterization of physical controls such as lithologic variation is significant in order to improve the method to estimate uplift rate histories from longitudinal river profiles in tectonically active regions.

Keywords: river longitudinal profile, inverse analysis, erosion

Deep-seated Rockslide Avalanches of The Eastern Sekita Mountains, Niigata Prefecture, Central Japan; Pleistocene tectonic events

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1. Introduction
Sekita Mountains, which locate near the border on Niigata and Nagano Prefecture, is mainly composed of Quaternary system. It is known that there are a number of huge collapses of the terrain in this area. This report is intended to describe the huge collapse of the Pleistocene that develops in the north side of Sekita Mountains.
2. Topographic Setting
East of Sekita Mountains continues from Mt. Hishigadake (1,129.2m) Mt. Sanpousan to Mt. Amamizuyama (1,088m), forms to continue flat-top peak and is reducing the gradually advanced to the east. The Nonomi pond is distributed widest small undulating flat surface in Sekita Mountains. Northern side of Sekita Mountains develops continuous with the steep cliff from 150 meters to 400 meters in relative elevation. Following on the north side of the steep cliff, small undulating flat spreads widely.
3. Geologic Setting
Volcanic rocks of Uonuma Group that is from the late Pliocene to the late Pleistocene in age are distributed widely in the southern slopes of ridgeline of Sekita Mountains. However, in the north side of this ridgeline sedimentary rocks of Uonuma Group are distributed widely, the lower strata are distributed more as go to the north.
4. Topography and geology of the huge collapse slopes
Nonomi Collapse has scarp of about 150 meters in relative elevation and sliding width of about 2,000m is ascertained. Sediment deposition surface formed by collapse is ascertained Syoubu plateau. The horizontal travel distance from the scarp reaches about 2,700 meters. The thickness of the deposit will be less than 50 meters. Tensui Collapse has the sliding height to reach from 200 meters to about 400 meters in relative elevation and the sliding width of about 2,600 meters. Sediment deposition surface can be ascertained as a small relief flat surface with sliding block in astringent the Shibumi River. The horizontal travel distance reaches about 4,500 meters. The thickness of the deposit will be less than 50 meters and it is estimated to be from 15 meters to 30 meters on average.
Most of the sediment is andesitic one, rarely there is deposit which is mainly composed of siltstone. Features of andesitic deposits have no sedimentary structure with or in water, composed of gravel, such as andesite, siltstone, sandstone, tuff and “kusare” gravel, matrix be composed of sandy silt, tuffaceous silt. The collapse big event is estimated as follows; collapse consisting mainly of siltstone as the initial event occurred, after which the collapsed mainly composed of volcanic rocks occurred at many times. Equal coefficient of friction (H/L) are Nonomi Collapse 0.18, Tensui Collapse 0.14.
Hinterland of huge collapse, namely the south side of the mountain slopes from the ridgeline is where Kubota et.al (2015) has claimed the Sagging slope. It can be seen the depression terrain of large and small like valley and many cliffs in the hinterland around the huge collapse. It is a characteristic that many small cliffs show the displacement of the southern inclination.
5. Conclusions
It is estimated that huge collapse, which has occurred in Uonuma Group distribution areas around the north of Sekita Mountains, had not intervening water as debris flow. Both large-scale collapse

and edifice deformation developed in the eastern mountains of this area and the Sagging terrain formation in the south of the ridgeline are important big event related to the edifice formation.

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Keywords: rockslide avalanche, giant collapse, Sekita Mountains, Uonuma Group

