Japan Geoscience Union Meeting 2015
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Tectonic features around the Abukuma ridge and their relationship with tectonic framework of the Northeastern Japan Arc

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The Abukuma rigde is a significant buried uplift zone bordering the east of southernmost part of the forearc basin extending from the central axial Hokkaido through offshore Shimokita and Kitakami to offshore Joban area in the Pacific side of northeast Japan.

Its tectonic characteristics and formation mechanisms might be decisive information to elucidate not only geotectonic framework of the Northeastern Japan Arc but spreading processes of the northern portion of Japan Sea.

In order to do so, following items must be clarified by the seismic dataset and well geological information at the Abukuma ridge and its adjacent area: i) structural geological characteristics of fault groups and folds, ii) their extending trend and direction, and iii) sedimentological and stratigraphic relationship of erosional or starved discontinuous surfaces.

Accordingly the authors are conducting re-interpretation of the following seismic surveys: i) approximately 2,000 square kilometers "Southern Abukuma ridge" three-dimensional seismic data acquired by METI in 2009, and ii) approximately 2,500 kilometers "Offshore Southern Sanriku and Kashima" two-dimensional seismic data acquired by MITI in 1986.

Three MITI wells, moreover, "Kesennuma-oki," "Soma-oki" and "Joban-oki," and several commercial exploratory wells had been drilled in the above mentioned waters. The "Kesennuma-oki" well, spudded in 1984, had drilled thick upper Cretaceous section and reached early Cretaceous granite basement at the total depth of 2,027.00 meter. The "Soma-oki" well, spudded in 1990, had drilled Neogene and Paleogene successions and reached upper Cretaceous at the total depth of 3,500.00 meter. The "Joban-oki" well, spudded in 1991, had drilled thick lower Miocene and upper Cretaceous overlain by relatively thin middle to late Miocene and Quaternary sediments, and confirmed Turonian at the total depth of 3,170.00 meter. Geological information from those wells are utilized as chronostratigraphic and lithostratigraphic controls for the seismic interpretation.

It became gradually clear as tentative results of the interpretation that:

i) the above mentioned forearc basin in the studied area may be subdivided into a few portions by several structural lineations characterized by strike-slip components, ii) the basin therefore may not have simple north-south elongated geometry, iii) such lineations are possibly continuous with some geologic tectonic lines or geotectonic discontinuities specified by subaerial geological descriptions in the northeast Japan, on the basis of their location and direction, and iv) several groups of a number of faults, identified at the southern part of Abukuma ridge in the 3D seismic dataset, may possibly be interpreted as a record for stress field directions of each geologic age.

Keywords: Abukuma ridge, offshore Miyagi Prefecture, offshore Fukushima Prefecture, Northeastern Japan Arc

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Tephrochronology in the Cretaceous forearc basin, northern Japan

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1. Introduction

Tephrochronology is useful method for basin analysis because tephra provide isochronous horizons across the different facies. Although numerous studies of tephra correlations have long been conducted on the Quaternary strata, there are much fewer attempts to correlate pre-Quaternary tephra because most of the pre-Quaternary tephra are not appropriate for applying conventional tephrochronological methods on account of alteration of glass. On the other hand, several studies based on the heavy mineral chemistry of tephra have been successful in identifying and correlating highly altered tephra (e.g., Sell and Samson, 2011a, b). Detailed tephra correlations by these studies solved various controversies on the Euro-American Ordovician biostratigraphy, biogeography and sequence stratigraphy. Consequently, prevailing tephrochronologic study of the pre-Quaternary strata appears to bring significant progress in the various field of earth sciences because it can provide a much higher precision of chronostratigraphic correlation than that of the radiometric dating in both local and regional scale.

The Yezo Group, exposed in Hokkaido, Japan, is represented by the mid-Cretaceous — Paleocene marine sequences which were deposited in a fore-arc basin along east of the active Asian continental margin. This group contains abundant macro- and microfossils as well as felsic tuffs. However, it has been very difficult to correlate between shallow and deep sea facies in detail because of difference in fossil fauna and sedimentary facies. In order to establish detailed depositional model in such old basin, we establish the Cretaceous tephrochronology in the Yezo Group based on the heavy mineral chemistry of phenocrysts within the tuffs.

2. Method

We collected 30 tuff samples from the whole horizons of the Yezo Group in Tomamae, Oyubari and Urakawa areas. The samples were separated into light and heavy fractions using sodium polytungstate. The separated heavy fraction was collected and handpicked under a binocular microscope to collect the apatite and biotite grains. 20 biotite phenocrysts per sample were analyzed major elements at the Department of Earth Science, Tohoku University using a JEOL 7330. 20 apatite phenocrysts per sample were analyzed major and minor elements at the Institute for Material Research, Tohoku University using a JEOL 8530F. Apatite analyses followed the method described in Gross et al. (2013).

3. Result and discussion

Apatite is one of the most common accessory mineral in the volcanic rocks, and is highly resistant to weathering, diagenetic alteration and diffusion processes. Furthermore, apatite shows a wide variety of trace-element compositions because the structure of apatite is highly tolerant of structural distortion and chemical substitutions. Therefore, chemical fingerprinting of apatite is ideal method to discriminate the altered tephra. Each tuff exhibits unique trend in Cl, Mg, Fe, and Mn concentrations in apatite, which demonstrates that apatite chemistry is useful for discriminating tuffs in the Yezo Group. Although biotite is one of major phenocrysts in the tuffs of the Yezo Group, it is less useful than apatite because of its weakness against diagenesis and weathering. However, Mg number and TiO_2 content of biotite are most effective discriminator of the tuffs in the Yezo Group, and each tuffs are distinguishable on the bivariate plot of the Mg number and TiO_2 contents.

Based on the above result, we correlated tuffs of the Yezo Group among the Tomamae area and the other areas in Hokkaido. As a result, we confirmed that at least 3 tuffs (tuffs at Lower Cenomanian, Turonian/Coniacian boundary and Santonian/Campanian boundary) can be traced widely (more than 100 km distance) throughout Hokkaido and across the different sedimentary facies.

Keywords: Cretaceous, Tephrochronology, Apatite, Yezo Group

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Formation of forearc basins and its relationship to subduction zone dynamics

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Forearc basins along subduction zones are important for studying sediment routing systems, submarine resources, and natural hazards. However, there are still many unresolved problems about them, for example, how do they evolve? or how do they interact with growth of accretionary prisms or intensity of tectonic erosion of the same age? Forearc basins were proposed as basins developed at landward side of accretionary prisms, whose depocenters migrated seaward as growth of the accretionary prisms [1] or landward as uplift of the outer arc highs [2]. However, there are some forearc basins without accretionary prisms along tectonic erosion-dominated subduction zones, which are controlled mainly by normal faults [3]. In addition, it was realized that sediment flux at the trench is important to control volume of outer wedge [4], suggesting it could also influence formation or style of evolution of forearc basins. In fact, subsidence curves of modern and ancient forearc basins are more variable than those of foreland, rift, or strike-slip basins [5].

In this study, I tried to understand formation of forearc basins by means of geological and geomorphological characters of 37 forearc basins with the outer wedges (frontal and middle prisms) in the world. I also measured width (W_{basin}) and sediment thickness (T_{basin}) of forearc basin, width (W_{wedge}) and slope angle (α) of outer wedge, slab dip angle under the wedge (β), orthogonal convergent rate of subducting plate (V_{orth}), thickness of trench fill sediments (T_{trench}).

As a result, forearc basins can be divided into 5 types (compressional/extensional accretionary, compressional/extensional strike-slip, and non-accretionary). A character of the compressional accretionary type is landward tilt of the basin due to uplift of outer arc high associated with backthrust or splay fault. Basin formation of this type may be related to self-similar growth or thickening of the outer wedge. In the extensional accretionary type, seaward migration of outer arc high by gravitational force, generating listric normal faults in the basins, can subside the basin. Internal or basal friction may be too weak to keep the taper angle of the wedge. The non-accretionary basins do not have conspicuous outer arc highs, resulting from tectonic erosion-induced subsidence. Strike-slip type shows intermediate characters between accretionary and non-accretionary types, but whose depocenters occasionally migrate parallel to the trench. Some basins show changes from non-accretionary type to accretionary one, and vice versa.

Width of wedge (W_{wedge}) has a positive correlation with T_{trench}/V_{orth} as a proxy of sediment flux at the trench. T_{basin} has a positive correlation to W_{basin} for the accretionary type, but is basically constant for the non-accretionary type. W_{basin}/T_{basin} of the accretionary type is almost constant regardless of W_{wedge}, but shows a negative correlation to W_{wedge} for the non-accretionary type. For all types of forearc basins, T_{basin} has a positive correlation to W_{wedge} or T_{trench}.

Variations of sediment flux at subduction zones can influence degree of growth/decay of outer wedges, and then, may switch the type of forearc basins. Changes from accretionary to non-accretionary type may cause subsidence of outer arc high because of tectonic erosion, which leads to remove accommodation space and erode the basin strata, and then produces a new basin with large W_{basin}/T_{basin}. On the other hand, changes from non-accretionary to accretionary type may uplift a part of the basin as an outer arc high, and generate a new basin at the landward side.

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Keywords: forearc basin, subduction zone, sediment flux, accretionary prism, sedimentary basin

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Relationship between trends in Miocene basin development and outcrop-based depositional cycles and geological structures

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During the Late Oligocene-Middle Miocene, the Japanese archipelago was formed under control of extensional tectonics. At that time, a series of extensional basins developed in the back arc side of Honshu Island. The development of the Niigata basin, which is the largest basin in the coast of the Japan sea, has been argued in various ways. The Tsugawa-Aizu province (Shimadu, 1973) is important for the good understanding of the early stages of development of the Niigata basin. According to Toyoshima (2014), Miocene and later geological structures of Northeast Japan were formed by combination of multiple trends such as NNE-SSW (Niigata trend), NW-SE to WNW-ESE (transverse trend) and NNW-SSE to N-S (Tanagura trend). Relationship of the structural trends and basin development, especially such as field-scale sedimentary and structural processes, has not been considered in detail in the Niigata basin which includes the Tsugawa-Aizu province.

This outcrop-based study discusses basin development in Northeast Japan by sedimentary facies and structural analysis, considering cyclicity and basin geometry of the Mikawa and Tsugawa basins in the Tsugawa-Aizu province. The study area, the Tsugawa area in Aga, Niigata, has various scale basins which include the Mikawa basin in the west and the Tsugawa basin in the east. We estimate vertical changes of depositional environments by field work on Miocene deposits from the Tsugawa Formation to the Nomura Formation in the Yagiyama area, eastern part of the Tsugawa basin.

Comparison between the Mikawa basin and the Tsugawa basin show that the cyclicity of these basins is similar to each other. This study considers basin development also from fault trends by fault analysis. In general, geological structures in the Mikawa area show NNW-SSE to N-S trends, while those in the Yagiyama area have an obvious NW-SE trend.

Keywords: Miocene, back arc, Northeast Japan, sedimentary facies, fault

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Crustal structure off western Noto Peninsula to the Yamato Basin observed by seismic reflection survey

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Since recent years, the source fault of the Japan Sea has been reviewed through several projects (e.g., Ministry of Land, Infrastructure, Transport and Tourism, 2014). As a part of these efforts, we conducted research in collaboration with the "Multidisciplinary research project for construction of fault model in the high strain rate zone" consisting of marine seismic surveys using a multichannel seismic system (MCS) and the ocean-bottom seismographs (OBSs) in the eastern part of the Japan Sea. As a result, these studies revealed the relationship between the distribution of crustal structure and seismic activity or shortening structure in the eastern part of the Japan Sea (e.g., No et al., 2014; Sato et al., 2014). However, observations to evaluate the potential damage of earthquakes and tsunamis had not been carried out fully west of Noto Peninsula and off western Hokkaido in the Japan Sea. Therefore, crustal structure data other than those of the eastern part of the Japan Sea are required.

In July and August 2014, we conducted a marine seismic survey to study the crustal structure from the region off western Noto Peninsula to the Yamato Basin. Some studies of crustal structure had been carried out in this survey area (Ludwig et al., 1975; Katao, 1988; Hirata et al., 1989). However, these studies were not able to obtain the spatial variations of the crustal structure and the relationship with active structure. Recently, seismic acquisition technology for deep and detailed seismic imaging has improved. By using this recent technology, we were able to obtain important data to study the relationship between the active structure and crustal structure in the vicinity of the survey area. Based on the results of these studies, although it is important to identify where the source faults have developed in the Japan Sea, structural factors are an important key for determining the development and size of the source faults. In addition, because there is ODP Leg 127 site 797 (Tamaki et al., 1990) directly beneath our seismic survey line, we contributed to the study on the formation of the Yamato Basin by examining the relation between the ODP results and our results.

We present an outline of the data acquisition and preliminary results of the data processing and interpretations from this study. Asymmetrical anticlines with reverse faults are well developed off the northern to western Noto Peninsula. The basement around the continental shelf and continental slope shows larger deformation. In the Yamato Basin, a clear reflector estimated to be the Moho can be identified in the vicinity of about 9 s (two-way time). The characteristics of the sedimentary layer are common within the survey area. For example, a strong coherent reflector that is estimated to be an opal-A/opal-CT BSR (bottom simulating reflector) (Kuramoto et al., 1992) was confirmed in all survey lines in the Yamato Basin. Furthermore, a coherent reflector across the entire crust was confirmed in some of the survey lines in the Yamato Basin.

Keywords: Japan Sea, Seismic survey, Yamato Basin, off Noto Peninsula, Yamato Rise, source fault

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Structural analyses of sedimentary basins using gravity anomaly and gravity gradient tensor data

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Seismic exploration and gravity surveys have often been employed to estimate subsurface structures, and gravity surveys have been used most often as rough surveys because they can cover a wide area in a short period with low cost. In addition, gravity surveys have other advantages regarding data interpretation; it is possible to interpret their map data intuitively and easily. For example, we could interpret low-gravity areas as thick sedimentary layers or low-density layers/materials with much accuracy. We can obtain detailed information on subsurface structures, such as density distribution and shape, by quantitative analyses. However, these analyses require a lot of time and prior information on subsurface structures (e.g., basic subsurface structure and density contrast) for solving problems.

In such a situation, semi-automatic interpretation methods, which are considered as intermediate methods between quantitative analyses and qualitative interpretations, can be used. In this method, structural boundaries are identified from gravity anomalies without constraint conditions on geology and geophysics. Types of high-pass filtering such as horizontal first derivative and vertical first derivative are well-known techniques.

In recent years, gravity-difference surveys have been carried out worldwide, and filtering and semi-automatic interpretation techniques using gravity gradient tensor have been developed and suggested. For example, Shape Index defined by xy components of gravity gradient tensor expressing curvature of gravity field (e.g., Cevallos, 2013), Dimensionality Index defined by combination of eigenvalues of the tensor (e.g., Perdersen and Rasmussen, 1990; Beiki and Pedersen, 2010), and a technique that estimates locations of causative source using eigenvectors of the tensor (e.g., Beiki and Pedersen, 2010; Beiki, 2013).

In general, it is necessary to obtain gravity gradient data with a gradiometer for performing analyses using gravity gradient tensor. However, these data can be derived by combining integration and differential of surface gravity anomalies in the Fourier domain (e.g., Mickus and Hinojosa, 2001).

In this presentation, the author will show derivations of all components of gravity gradient tensor from surface gravity-anomaly data using the Fourier method and will report results obtained by applying techniques using the tensor to structural analyses of structural basins.

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Burial process of segmented backarc basins: Hokuriku-oki, San'in-oki and Kitakyushu-oki shelves of southwest Japan

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Backarc sedimentary basins of southwest Japan have developed since the Miocene rifting and opening of the western part of Japan Sea. They are bordered by the eastern Noto Plateau and western Korean Peninsula, and segmented by the Oki Plateau in between. From east to west, Hokuriku-oki, San'in-oki and Kitakyushu-oki shelves have undergone different burial histories reflecting spatiotemporal variation of tectonic events. Hokuriku-oki subbasin is characterized by large topographic reliefs of Oki Trough and Oki Ridge, which were originated from divergent rift system of the western part of Japan Sea. It has a complicated deformation history reflecting successive collision episodes in front of the Izu-Bonin arc and Fossa Magna region. Miocene sedimentation pattern implies development of gentle warping of the backarc shelf having nearly perpendicular trend to the elongate direction of the arc. Thermally subsided margin of the San'in-oki subbasin is buried by a thick pile of Miocene sediments accumulated after post-opening stagnant sedimentation in middle Miocene. Distribution and stacking pattern of the Miocene clastics suggest emergence of highs and lows aligned across the arc, just the same as those in the Hokuriku-oki shelf. Apart from the northern domains, northwestern shelf of the Kyushu Island was a site of Miocene short-lived pull-apart basin formation upon a regional right-lateral fault system bounding the Japan Sea backarc basin. The most remarkable transversal tectonic event on these segments is a strong N-S compression and deformation around the end of Miocene, which is probably related with a change of convergence mode of the Philippine Sea Plate. Seismic profiles delineate intensive folding along the backarc margin and clear angular unconformity at that age for both of the Hokuriku-oki and San'in-oki subbasins. Rifting-induced horst/graben blocks on the Oki Plateau were also strongly inverted and their landward extension is known as the Shinji Folded Zone generated at ca. 5 Ma. The regional fold zone was converging on the Tsushima Islands at the western end of the San'in-oki subbasin, and some of numerous transcurrent faults in the Kitakyushu-oki subbasin were reactivated in an opposite (left-lateral) sense. The latest tectonic episode was brought about by the Quaternary fluctuation of convergence mode of the Philippine Sea Plate. As a result of enhanced highly oblique subduction on the Philippine Sea/Eurasian margin, recent southwest Japan has suffered wrench deformation under simple shear stress, and the backarc shelf is eventually bisected by a right-lateral fault running parallel to the Median Tectonic Line. Although the westward indentation of the forearc sliver of southwest Japan inevitably causes active extrusion of the Kyushu Island, the deformation front has not reached backarc domain since the Kitakyushu-oki subbasin is immune from notable neotectonic deformation.

Keywords: sedimentary basin, tectonics, Japan Sea, southwest Japan, backarc, Cenozoic

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Cenozoic interaction processes of forearc, strike-slip and foreland basins along the NE Japan and Kuril arc junction

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The N-S trending zone from the forearc side of the northern NE Japan arc to central Hokkaido, which corresponds to the Sorachi-Yezo belt or Ishikari-Teshio belt, demonstrates a complex tectonic history during the Cenozoic, since forearc, strike-slip and foreland settings had been interacted as the junction zone between the NE Japan and Kuril arcs. This study investigated the Paleogene to early Neogene sedimentary basin history along this zone to reveal the temporal and spatial interaction processes between the three tectonic settings, mainly based on 2D and 3D seismic survey, exploration well and outcrop survey data sets.

During the Paleogene, the northern part of this zone was situated in a territory of a strike-slip setting between the Okhotsk block and Eurasia Plate, whereas the southern part was situated in a forearc setting along the Pacific Plate subduction zone. Sedimentary basins created along the northern strike-slip part were characterized by en echelon-arranged small basins, whereas those along the southern forearc part were characterized by uplifted trench slope break (TSB) on the subduction zone side of the forearc basins and by a bay to fluvial depositional system in the basin infilling sediments. The transition point between the strike-slip and forearc settings was originally located in central Hokkaido in early Paleogene, but it gradually shifted toward the south through the Paleogene. In addition, even in the southern forearc zone, strike-slip tectonics affected the forearc basins to be segmented into subbasins. When the strike-slip motion was the maximum at around mid Oligocene, transpressional uplift occurred along the trench slope break, and regional unconformity was created (Ounc: Oligocene Unconformity). After the formation of Ounc, the southern forearc part started to subside, forming a slope type deep marine forearc basins. During the Early Miocene, the Miocene unconformity (Munc) was created again due to Japan Sea opening-related NE Japan arc uplift, which was induced by eastward migration of the NE Japan arc. After this event, westward migration of the forearc sliver of the Kuril arc induced the collision of the Hidaka block, resulting in the formation of foreland basins along this zone in central Hokkaido, in which strike-slip faults were converted to a thrust belt. The thrust block on the Hidaka side provided a large amount of clastics into the basin to form a thick pile of turbidite successions in the foreland basins. Geohistory diagrams showing basin subsidence history after this collision event demonstrate a completely different pattern between the forearc and foreland territories.

Keywords: Sanriku-oki, central Hokkaido, Early Cenozoic, forearc basin, strike-slip basin, foreland basin

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Fault geometry and its characteristics in the southern part of Abukuma ridge, offshore Fukushima Prefecture, Japan

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The Abukuma ridge extends for more than 100 km from off the Soma to off the Kashima city along Japan Trench where the Pacific Plate is being subducted beneath the North American Plate. 3D seismic survey and its observations were carried out in this area off the Iwaki city, Fukushima prefecture, northeastern Japan by METI (JOGMEC, 2011). We referred to boreholes MITI Jhoban Oki (JAPT. 1993) in order to connect our seismic interpretation and stratigraphic data. As a result, nine seismic horizon (reflectors) were assigned upper limit of Santonian, upper limit of Campanian, upper limit of Maastrichitian, upper limit of Paleocene, upper limit of Oligocene, upper limit of Lower Miocene, upper limit of Middle Miocene, upper limit of Upper Miocene, and upper limit of Pliocene respectively. Abukuma ridge are distributed in north-northeast (NNE) to south-southwest (SSW) trending anticline recognized within pre-Middle Miocene strata. A number of lineaments, normal faults, bunch perpendicular within Abukuma ridge, most of which were initiated in the Cretaceous and had been active through the Paleogene, Miocene, and Pliocene. Fault morphology is classified into west-dipping north-south trending faults and north dipping east-west trending faults. They displaced by several hundreds to tens of meters. The most remarkable feature is the Abukuma ridge structure divided by large faults across the seismic section. It is apparent that there are dividing four areas where large faults and these faults are concentrated. Some of the large faults have significant strike-slip component. Subsurface structures delineated by reflection 3D seismic data suggest a different phase of activities of Abukuma ridge. Fault geometry is reflecting a complicated slip history in this area.

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Subsurface structure of northern Osaka basin based on borehole database

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Several large cities and metropolitan areas, such as Osaka and Kobe are located in the Osaka basin, which has been filled by the Pleistocene Osaka group and the later sediments. The basin is surrounded by E-W trending strike slip faults and N-S trending reverse faults. The basin consists of granitic basement and overlaying thick unconsolidated sediment called as the "Osaka Group". Several marine clay layers (Ma-1 to Ma13) of the Osaka Group are key layer for stratigraphy and are assigned to the oxygen isotope events. An interval accumulation rate between two marine clay layers represents a cycle of eustatic sea level changes, and thus indicates a tectonic subsidence rate.

Kansai Geo-informatics Network has compiled a large number of borehole data and has constructed borehole database. The many borehole data have been interpreted by compared with several geological investigated borehole and extend the lithological and geological information in lateral direction. The distribution of interpreted marine clay layers (Ma9 to Ma13) was investigated in the northern part of Osaka. The tectonic subsidence rates represent differential subsidence around the Uemachi fault and branched flexure in detail.

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Keywords: Osaka basin, Uemachi fault, borehole database