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Geologic Structures and Boundary Faults along the Western Margin of the Odate Basin, Northeast Japan

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Abstract Under conditions of horizontal shortening tectonics, active reverse faults and flexures often occur between a basin and its surrounding mountains. The purpose of this paper is to evaluate the existence of active faults between those two landforms on the western margin of the Odate Basin, the inner zone of the Northeast Japan Arc, on the basis of the Upper Cenozoic geologic structures and the succession of the sedimentary basin. The Miocene rocks covering the investigated area are the Fujikuragawa Formation consisting of hydrothermally altered andesitic to dacitic lava, the upper member of the Hayaguchigawa Formation composed of interfingering pyroclastic rocks and andesitic lava, and the Ittori Formation comprising dark gray to black mudstone deposited in the middle bathyal zone, in ascending order. Fluvial higher terrace surfaces, that is, O-H Surfaces of Middle Pleistocene age, are slightly recognized on the hilltop along the margin. Inside the basin, the Alluvial deposits and Latest Pleistocene and Holocene pyroclastic flow deposits are widely distributed.

The boundary faults on the western margin of the Odate Basin, such as the Niida Fault, are certain to have been inverted to reverse faults after the deposition of the Ittori Formation, namely, in the earliest Pliocene. The basin is inferred to have been a sedimentary basin accompanied by reverse faults probably during Pliocene to Early Pleistocene time, because Middle to Upper Miocene formations in front of the faults underwent horizontal shortening deformation. On the other hand, no distinct reverse fault is currently confirmed to exist along the western fringe of the basin, especially close to the frontal margin of the surrounding mountainous and hilly areas, from the Upper Cenozoic structures. It is concluded that the Odate Basin and its surrounding areas are dominated by gentle uplift-subsidence at present with no relation to faulting.

Key words: Late Cenozoic, active fault, boundary fault, sedimentary basin, horizontal shortening, Odate Basin, Northeast Japan Arc

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1 Introduction

In the case of a sedimentary basin which notably subsides and then grows due to horizontal shortening tectonics, active reverse faults and flexures are often recognized between the basin and its surrounding mountains. The Yokote (*e.g.* Nakata, 1976 ; Ikeda, 1983), Hanawa (Naito, 1970 ; Otsuki *et al.*, 1998), and Shonai Sedimentary Basins (Komatsubara, 1997) are examples of this in the Northeast Japan Arc (Fig. 1). In the Odate Basin, which is situated in the Yoneshirogawa River Basin, Akita Prefecture, no distinct active fault has been recognizable geomorphologically along both its western and eastern fringes, except for a few lineaments (Certainty III : The Research Group for Active Faults of Japan, 1980, 1991).

The purpose of this paper is to evaluate the existence of active faults on the boundary between the Odate Basin and the neighboring mountainous and hilly areas to the west of the basin, on the basis of the Upper Cenozoic geologic structures and the succession of the sedimentary basin.

2 Geologic and Geomorphic Setting around the Odate Basin

The Odate Basin, about 50 kilometers from the Japan Sea coast, has an approximate width of 8 kilometers from east to west and of 16 kilometers from north to south. The surrounding mountainous area ranges in altitude from 300 to 600 meters, and both the northern and western parts of this area mainly consist of the Lower and Middle Miocene, the so-called "Green Tuff," whereas Middle Miocene pyroclastic rocks, hard mudstone, intrusive rocks, and Pliocene pyroclastic rocks constitute the eastern parts (Hirayama and Sumi, 1963 ; Inoue *et al.*, 1973 ; Nakajima, 1989).

On the basin floor 40 to 100 meters in altitude, the Alluvial deposits are widely distributed, as are Latest Pleistocene and Holocene pyroclastic flow deposits which originated from the Towada Caldera east of the basin (Fig. 2). It is difficult to identify geomorphologically whether active faults exist or not, where these younger pyroclastic deposits occur close to the margins of the basin. Quaternary basin-fills are about 100 meters in maximum thickness, overlying the Middle and Upper Miocene basement (Metallic Minerals Exploration Agency of Japan, 1965, 1966, 1968). Fluvial terrace surfaces are slightly recognizable on the hilltop along the western and eastern margins.

3 Geology of the Area on the Western Margin of the Odate Basin

The investigated area is composed of Miocene rocks and Middle to Upper Quaternary deposits, and there are no Pliocene and Lower Quaternary. Figures 3 and 4 show the geology and geologic structures of the area. Each formation is described

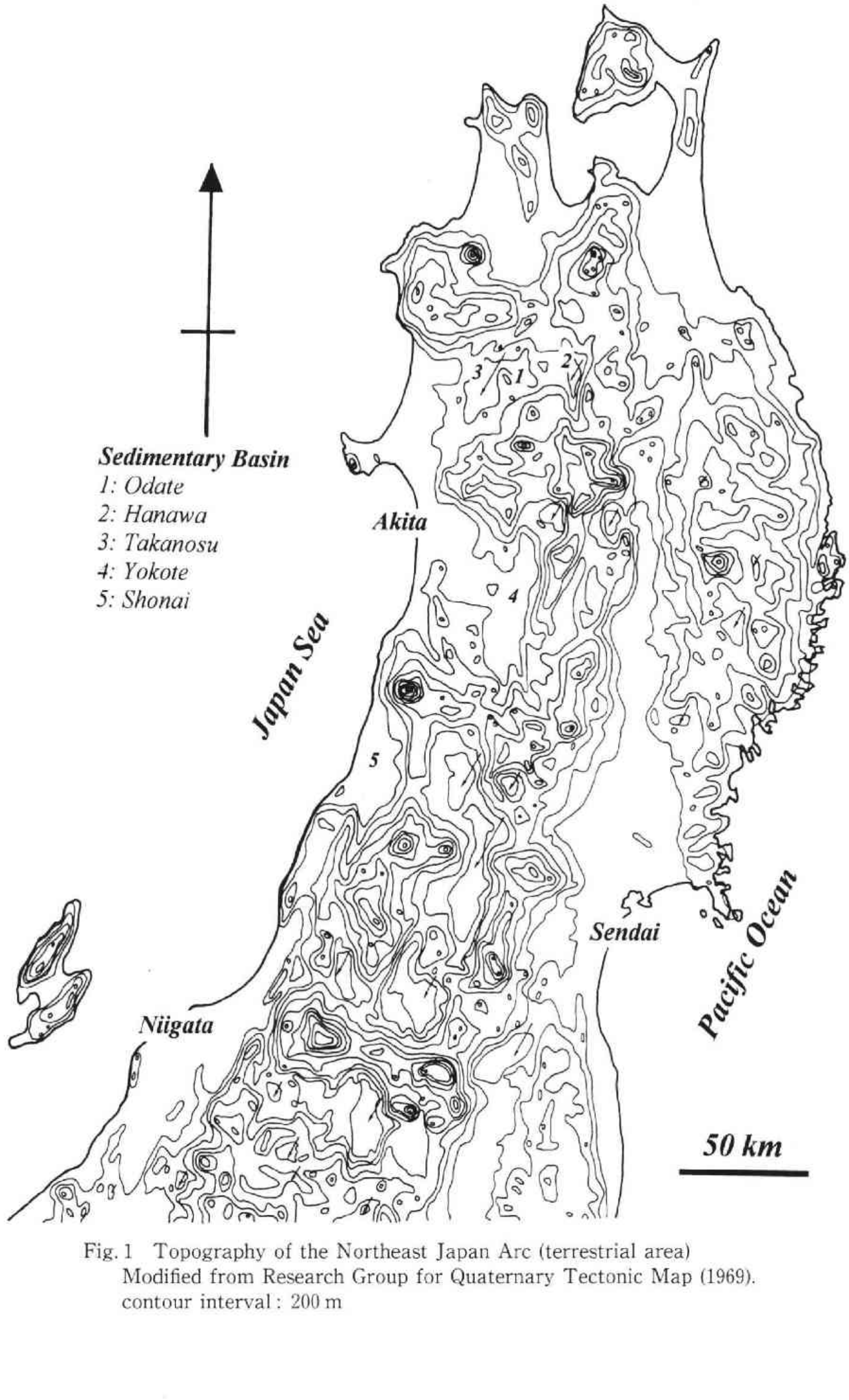

Fig. 1 Topography of the Northeast Japan Arc (terrestrial area)
Modified from Research Group for Quaternary Tectonic Map (1969).
contour interval : 200 m

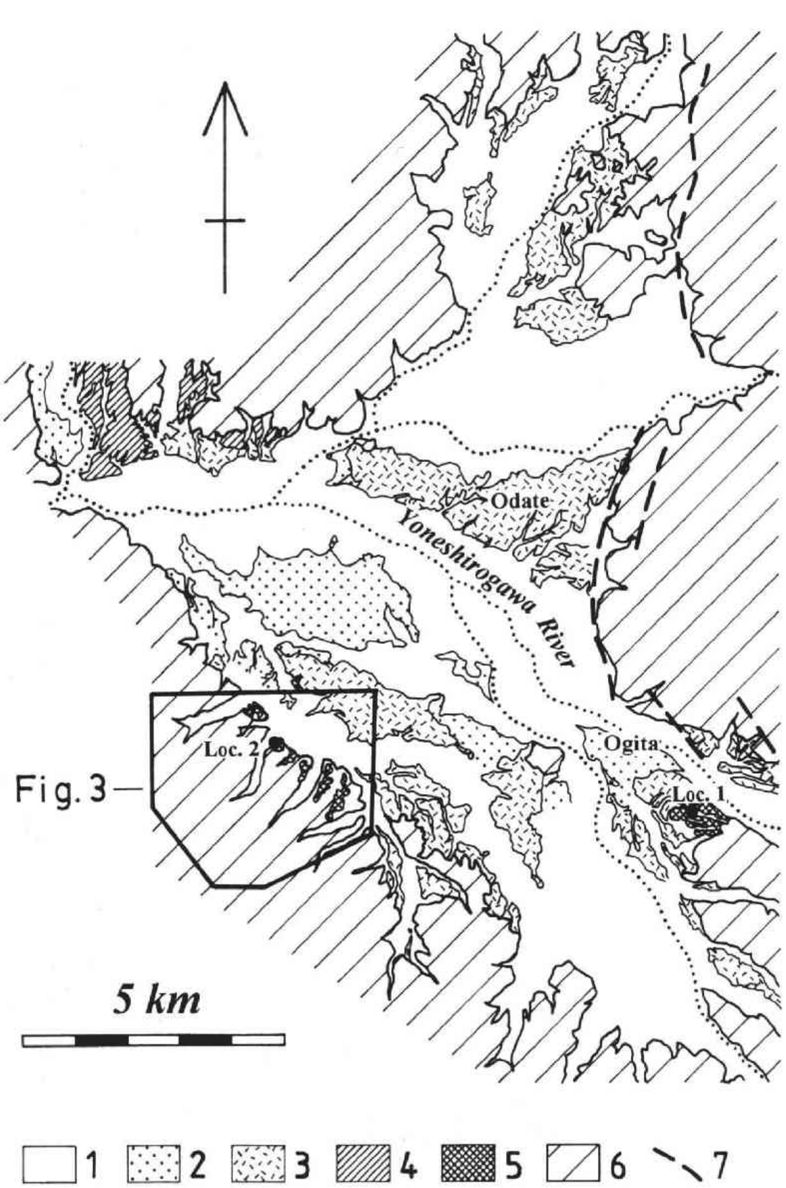

Fig. 2 Geomorphological map of the Odate Basin
1 : Alluvial surfaces 2 : depositional surface of Kemanai Pyroclastic Flow and its secondary surface 3 : depositional surface of Hachinohe Pyroclastic Flow and its secondary surface 4 : depositional surface of Ofudo Pyroclastic Flow and its secondary surface 5 : higher terrace surfaces 6 : mountainous and hilly areas 7 : lineament after The Research Group for Active Faults of Japan (1991)

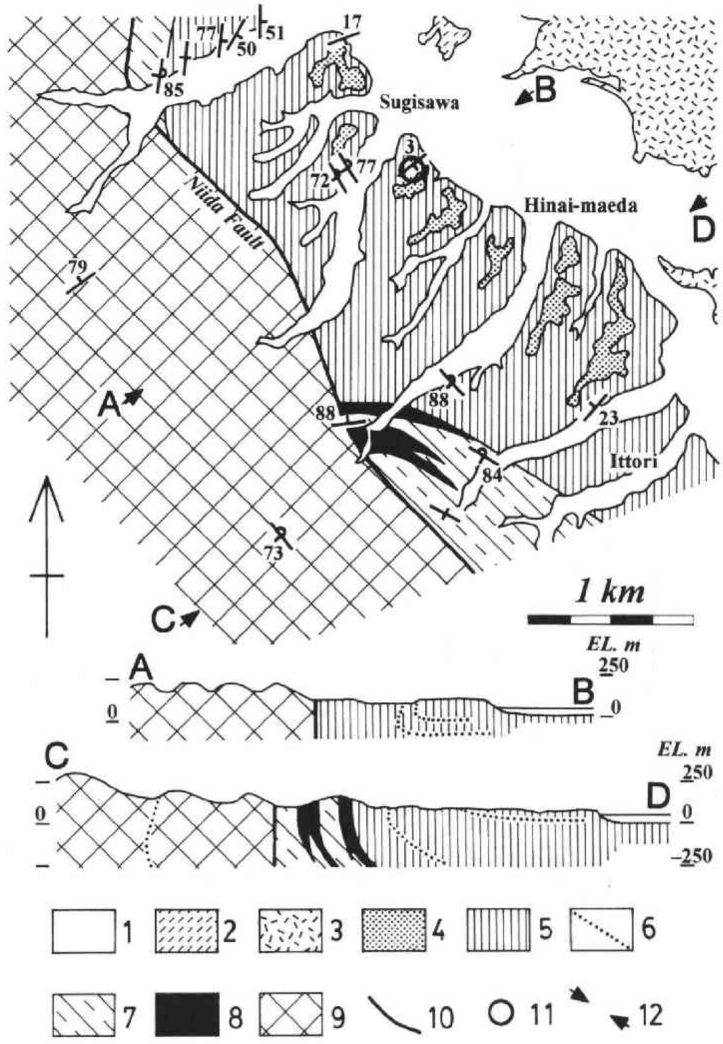

Fig. 3 Geological map and geological section of the investigated area on the west of the Odate Basin
1: Alluvial deposits (partly omitted in cross section) 2: Kemanai Pyroclastic Flow Deposit (omitted in cross section) 3: Hachinohe Pyroclastic Flow deposit (omitted in cross section) 4: higher terrace deposits (omitted in cross section) 5: Ittori Formation 6: thin beds of pyroclastic rocks in Ittori Formation or Fujikuragawa Formation (omitted in geological map) 7: upper member of Hayaguchigawa Formation (pyroclastic rocks) 8: upper member of Hayaguchigawa Formation (andesitic lava) 9: Fujikuragawa Formation 10: fault 11: Loc. 2 at Sugisawa 12: position of cross section

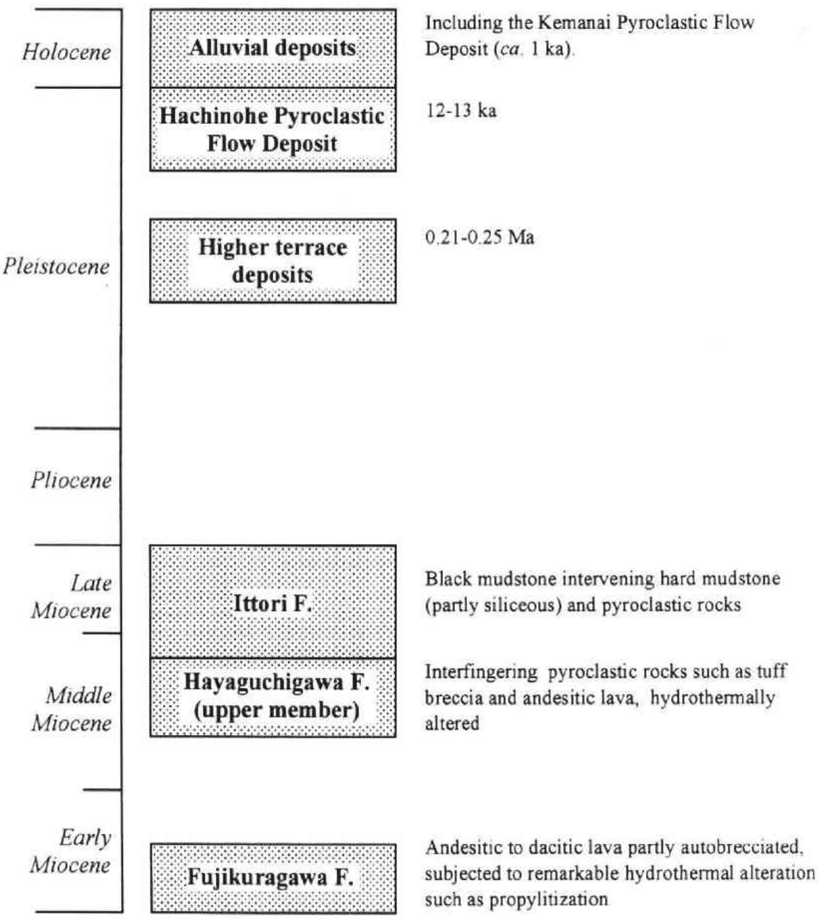

Fig. 4 Stratigraphy of the Upper Cenozoic on the west of the Odate Basin
F.: Formation

as follows, though description of Alluvial deposits, except for the Kemanai Pyroclastic Flow Deposit of about 1 ka, is omitted.

3.1 Fujikuragawa Formation

The formation was named by Sumi *et al.* (1962). Its type locality is situated in the upstream of the Okawamegawa River, Tashiro Town, northwest of the basin. The formation is exposed around the boundary between Odate City and Takanosu Town in the western part of the study area. It reaches 1,400 meters in minimum thickness (Hirayama and Sumi, 1963).

The formation chiefly consists of andesitic to dacitic lava and autobrecciated lava, with occasional thin beds of pyroclastic rock. Because these rocks are subjected to remarkable hydrothermal alteration such as propylitization, they have turned greenish and widely include much pyrite. The strikes and dips of the lava are discernible at only a few localities, because the lava is massive and has undergone the alteration.

It has been confirmed that the formation unconformably overlies pre-Tertiary rocks and has a conformable relationship with the overlying Lower to Middle Miocene series outside the study area. The formation, therefore, is considered to be Earliest Miocene in age (Sumi *et al.*, 1962).

3.2 Upper Member of the Hayaguchigawa Formation

The Hayaguchigawa Formation was described in detail by Sumi *et al.* (1962), and by Hirayama and Sumi (1963), who divided it into three members, *i.e.*, lower, middle, and upper. The type locality of the upper member of the formation is located in the middle of the Tazawagawa River, Takanosu Town, west of the Odate Basin. In the investigated area, the upper member crops out along the Niida Fault and is estimated to be approximately 700 meters in total thickness.

The upper member principally comprises pyroclastic rocks such as tuff breccia, lapilli tuff, and acid tuff containing sparse pumice grains. Hydrothermally altered andesitic lava in which pyrite is observable is intercalated in the pyroclastic rocks, and those rocks are inferred to have an interfingering relationship with each other.

Ôzawa *et al.* (1983) mentioned that this formation is correlated with the Nishikurosawa Formation in the Oga Peninsula, the site of one of the most standard sections of Neogene sediments in the Northeast Japan Arc, and that it is of Middle Miocene age. Around the basin, the lower limit of the upper member cannot be confirmed by the existence of the Niida Fault. It is obvious, however, that the member rests unconformably upon the Fujikuragawa Formation.

3.3 Ittori Formation

The Ittori Formation was named by Inoue *et al.* (1959), and its type locality is at Ittori, Hinai Town, in the south of the study area. The formation occurs in the hilly area on the west of the Odate Basin. Its thickness is estimated to attain a maximum of more than 600 meters.

The formation is characterized by dark gray to black mudstone in its facies. Generally, hard mudstone and siliceous mudstone are abundant in the lower part of the formation, and fine sandstone which locally contains glauconite occurs in the upper part. Some pyroclastic layers such as acidic fine tuff, pumice tuff, and lapilli tuff layers, intervene in the formation. The main part of the formation is inferred to have been deposited in the middle bathyal zone, based on analysis of fossil benthonic foraminiferal assemblages (Ogasawara *et al.*, 1986 ; Hasegawa, *et al.* 1989). However, as Nakajima (1989) also pointed out, an upward increase in grain size shows that its sedimentary environment became shallower gradually during the deposition.

The formation is considered to have a conformable relationship with the upper member of the Hayaguchigawa Formation beneath, since no apparent unconformity between them can be observed. Because the Ittori Formation corresponds to the Onnagawa and Funakawa Formations in the Akita Oil Fields, it ranges in age from Middle to Late Miocene (*e.g.* Hirayama and Sumi, 1963 ; Ogasawara *et al.*, 1986).

3.4 Higher Terrace Deposits[1] (O-H Surfaces)

The higher terrace deposits, whose depositional surfaces are O-H Terrace Surfaces (Otsuki, 1992), are distributed along the western and eastern margins of the basin. Terrace surfaces range in altitude from 85 to 100 meters in the west of the basin, and from 100 to 130 meters in the east. As mentioned below, it is inferred that O-H Surfaces include terrace surfaces of different ages. It is difficult, however, to distinguish them because the surfaces are highly dissected and their distribution is fragmentary. The total thickness of the terrace deposits is several meters, in places reaching about 15 meters.

The deposits are made up mainly of cobble- to pebble-sized and sorted gravel. A 2- to 3-meter thick silty sand layer containing thin pebbly layers overlies the gravel layer. These terrace deposits are overlain by brown to reddish brown tephric fine-grained soils, so-called "loam," and so forth. The tephric fine-grained soils inter-

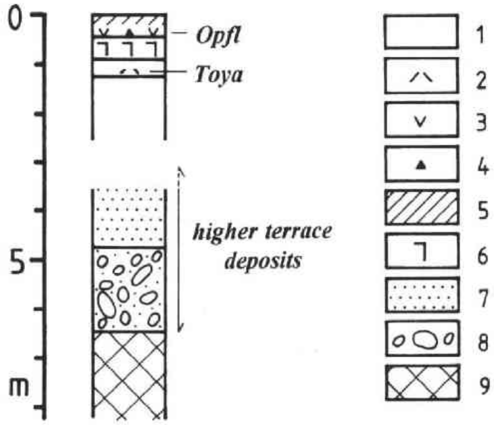

Fig. 5 Columnar section of tephric fine-grained soil covering higher terrace deposits (Loc. 1 at Shukunai, Hinai Town)
Opfl : Ofudo Pyroclastic Flow Deposit (*ca.* 30 ka) *Toya* : Toya Ash (90-100 ka)
1 : tephric fine-grained soils 2 : volcanic ash 3 : pumice 4 : lithic fragment 5 : kuroboku soils (black humic soils) 6 : crack 7 : sand 8 : gravel 9 : Tertiary rocks

Table 1 Chemical composition of volcanic glass shards

	SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	K_2O	Na_2O	Total
Shukunai, Hinai Town	78.20	0.08	13.47	0.87	0.28	0.36	3.09	3.65	100.00
(Loc. 1)	0.42	0.02	0.11	0.03	0.11	0.02	0.11	0.52	
Nakayashiki, Takanosu Town	78.70	0.04	13.64	0.87	0.32	0.34	2.80	3.29	100.00
(Loc. c)*	0.14	0.02	0.09	0.04	0.02	0.03	0.04	0.14	
Osawa, Moriyoshi Town	77.90	0.06	13.60	0.85	0.27	0.34	2.94	4.05	100.00
(Loc. d)*	0.29	0.02	0.08	0.05	0.07	0.02	0.05	0.34	
Misaka, Aikawa Town	77.73	0.06	13.65	0.85	0.29	0.33	2.91	4.17	100.00
(Loc. e)*	0.51	0.02	0.07	0.04	0.05	0.03	0.08	0.62	
Umesaka, Aikawa Town	77.52	0.07	13.35	0.85	0.28	0.37	2.91	4.64	99.99
(Loc. g)*	0.29	0.03	0.11	0.03	0.06	0.03	0.10	0.35	

Upper line in each measurement indicates weight percentage, and lower line shows the standard deviation. Oxide percentages are renormalized to 100%.
*Toya Ash in the Takanosu Basin, west of the Odate Basin (Otsuki, 1991)

calates patched light brown tephra as shown in Fig. 5. From the chemical composition of volcanic glass[2)] in the tephra (Table 1), it is correlative with the Toya Ash which derived from the Toya Caldera, in the western part of Hokkaido (Machida *et al.*, 1987).

The surfaces are inferred to have emerged in 0.21 to 0.25 Ma (Otsuki, 1992), the Middle Pleistocene time, on the basis of the stratigraphic position of the Toya Ash and the accumulation rate of the tephric fine-grained soils, that is, approximately 1.2×10^{-2} mm/yr during the Late Pleistocene in the Yoneshirogawa River Basin (Otsuki, 1998). Obviously the deposits unconformably overlie the Ittori Formation.

3.5 Hachinohe Pyroclastic Flow Deposit

Naitô (1966) reported in detail on the stratigraphy and distribution of the Late Quaternary pyroclastic deposits in the drainage basin of the Yoneshirogawa River including the Odate Basin. The pyroclastic deposits around the Towada Caldera were later renamed by Nakagawa *et al.* (1972). The type locality of the Hachinohe Pyroclastic Flow Deposit in the Yoneshirogawa River Basin is at Torigoe, Kosaka Town in the Hanawa Basin, east of Odate. The deposit occurs widely in the whole area of the basin. Around the study area, the depositional surface of the pyroclastic flow and its secondary surface are approximately 65 meters in altitude, and the deposit has a maximum thickness of more than 15 meters.

The lithofacies of the deposit is grayish white pumice flow deposit, namely, a non-stratified turbulent mixture of ash and random-sized pumice grains with occasional blocks of charcoal. Essential materials such as pumice and ash, mainly including orthopyroxene, clinopyroxene, and hornblende, are contained. The radiocarbon ages of the Hachinohe Pyroclastic Flow Deposit were compiled by Toyoshima (1987), and it dates from 12 to 14 ka of Latest Pleistocene age in his results.

3.6 Kemanai Pyroclastic Flow Deposit

The Kemanai Pyroclastic Flow Deposit, which flowed westward from the Towada Caldera, was named by Naitô (1966) and Nakagawa *et al.* (1972). Its type locality near the Yoneshirogawa River is situated at Kemanai, Kazuno City in the Hanawa Basin. The deposit is distributed in the south of the Odate Basin, along the Yoneshirogawa River. The depositional surface of the pyroclastic flow and its secondary surface have an altitude of 47 meters around the area, and the maximum thickness of the deposit is estimated to be about 5 meters.

The deposit is similar to the Hachinohe Pyroclastic Flow Deposit in lithofacies; the Kemanai Pyroclastic Flow Deposit, however, is distinguished from the Hachinohe Deposit by the absence of hornblende in the essential materials. The age of the deposit is inferred to be about 1 ka by ^{14}C dating and archeological data (*e.g.* Machida *et al.*, 1981).

4 Geologic Structures and Presence of Boundary Faults

4.1 General Structures

In the west of the investigated area where the Fujikuragawa Formation is distributed, as already stated, the structures are indefinite because of hydrothermal alteration, but the formation is considered to have an almost vertical dip. The Niida Fault, named by Hirayama and Sumi (1963), restricts the distribution of the Fujikuragawa Formation (Fig. 3). The fault strikes northwest in most parts of the area, and is inferred to dip with a steep angle of nearly 90 degrees.

The upper member of the Hayaguchigawa Formation and the Ittori Formation dip northeast in general. Especially, the steeply dipping zone, in which the dips of these formations are approximately vertical, in places overturned, is recognizable for a distance of several hundred meters on the east of the fault (Fig. 3). Its presence is regarded as an indicator of horizontal shortening due to deformed morphologies, and it implies that the fault slipped remarkably as a reverse fault in the past. Basinward, the dip of the Ittori Formation change rapidly, and those near the basin become gentle, in cases almost horizontal, though slump structures of mudstone locally occur in the Ittori Formation and particular attention should be paid to determining the true dips of the mudstone in detail. An example of the slump structures from an exposure at the western fringe of the basin will be described in the next chapter as related to the existence of the present boundary faults of the sedimentary basin.

4.2 Exposure at the Western Fringe of the Odate Basin : Relation to the Existence of Active Boundary Faults

As shown in Fig. 6, the higher terrace deposits and grayish black mudstone of the Ittori Formation are exposed in the quarry at Sugisawa (Loc. 2 : Fig. 3), Odate City, at the western margin of the Odate Basin. The uppermost of the exposure corresponds to O-H Surfaces which are divided into two surfaces in altitude here, and the difference of the height between them is about 6 meters, above F in Fig. 6. The higher terrace deposits, which have a maximum thickness of more than 10 meters, are underlain by the mudstone of the Ittori Formation at this site.

Some faults dipping southwestward, such as F in the weathered zone of the mudstone, can be recognized. Given the form of the faults and the fact that numerous minor normal faults including conjugate ones are observable in the lateral side (Fig. 7), they are thought to be normal faults accompanied by the occurrence of syn-depositional or meta-depositional slumping under water. It seems that these faults converge at the very low-angled slip-surfaces in the lower part of the outcrop. The true dip of the mudstone under the slump structures is nearly horizontal, and this trend is considered to be continuous as far as the inside of the basin. At the other sites of the western fringe, no deformation except for slump structures can currently be found.

In the higher terrace deposits, it is recognizable that silty sand with occasional pebbly beds erodes the underlying terrace gravel and abuts gently on it around the point where the upper limit of the gravel changes in altitude (Fig. 8). Based on this, the altitudinal difference of the terrace surfaces in this locality is inferred to have resulted from the existence of the terrace scarp subdued between the different aged surfaces, not from association with the fault displacement. The undulating bottom surface of the terrace gravel above F is also considered to have no relation to faulting.

If active boundary faults promoting the present growth of the sedimentary basin exist, then the most active reverse-faults run along the frontal (toward basin) margin of mountains or hills including area of higher terraces distributed in many cases, for instance in Northeast Japan, such as the Yokote Basin (*e.g.* Ikeda, 1983), Shonai Sedimentary Basin (Komatsubara, 1997), Hanawa Basin (Otsuki *et al.*, 1998), and Sendai Sedimentary Basin (*e.g.* Nakata *et al.*, 1976). On the western fringe of the Odate Basin, however, no distinct deformation suggesting the existence of the present boundary faults can be recognized from the Upper Cenozoic structures.

5 Tectonic Processes of the Odate Basin

Fujii *et al.* (1969) clarified the Neogene structures around the Odate and Hanawa Basins as shown in Fig. 9. The figure is indicative of the following three points : The first is that the Odate Basin came into existence in Middle Miocene time, though the

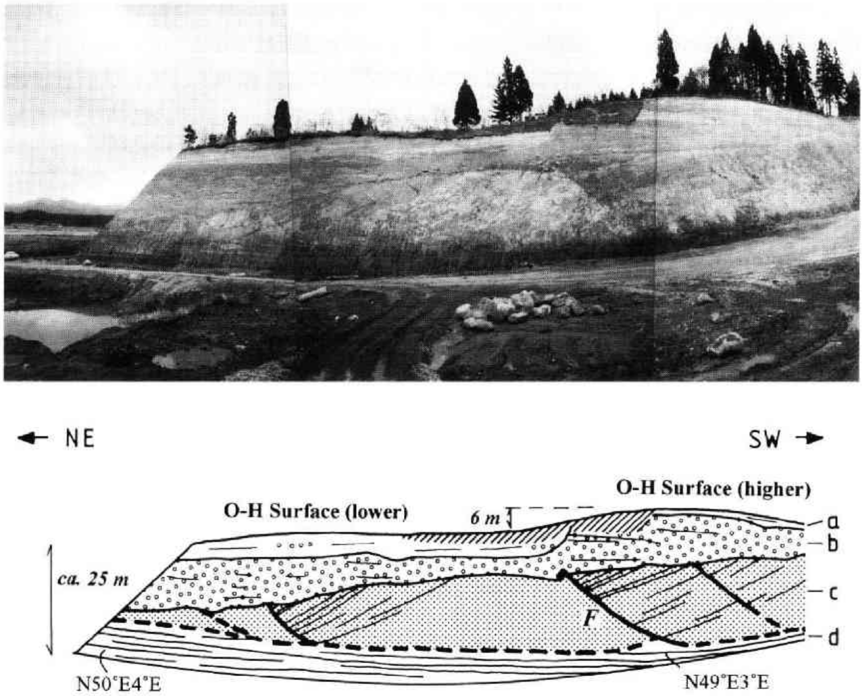

Fig. 6 Photograph and sketch of the exposure (Loc. 2) at Sugisawa, Odate City, in the western fringe of the Odate Basin
a : sandy silt with thin pebble layers (higher terrace deposits), and tephric fine-grained soils b : gravel (higher terrace deposits) c : weathered mudstone (Ittori Formation) d : parallel-laminated black mudstone (Ittori Formation)

Fig. 7 Photograph of the exposure (Loc. 2) at Sugisawa, Odate City, in the western fringe of the Odate Basin
On the lateral side of the exposure, conjugated minor normal faults are discernible.

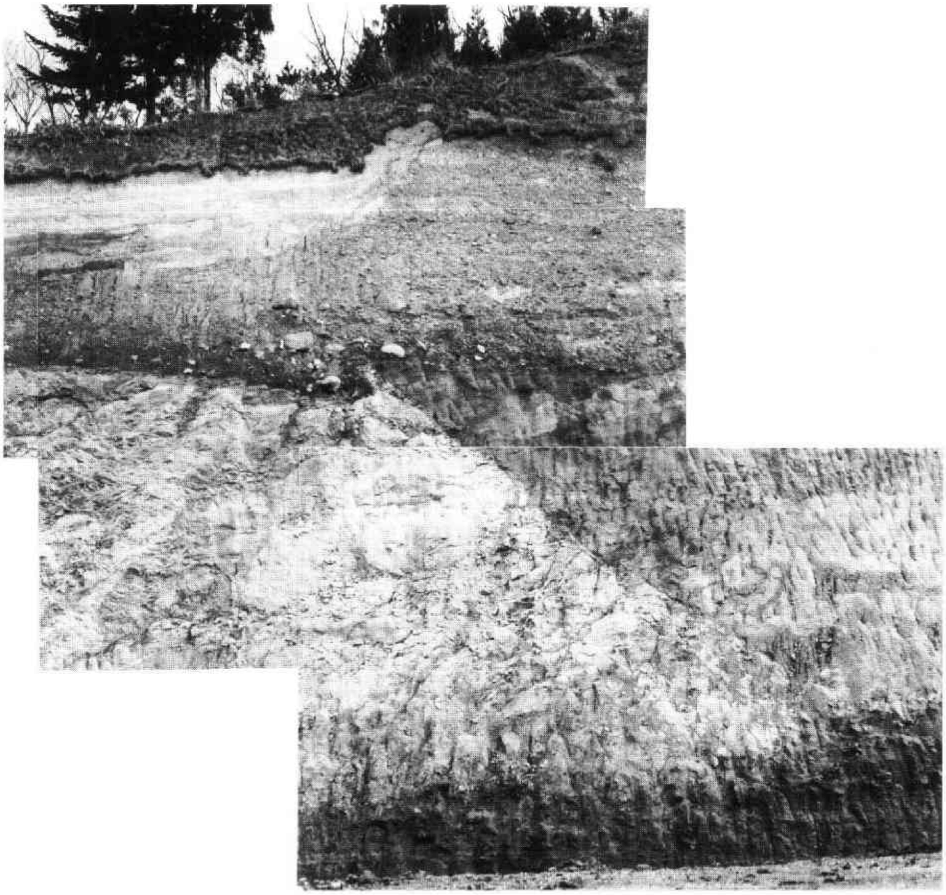

Fig. 8 Higher terrace deposits and mudstone (Ittori Formation) around the point where the terrace surfaces change in altitude, at Loc. 2
It is recognizable that silty sand with occasional pebbly beds erodes the underlying terrace gravel and abuts gently on it. Fault in the mudstone is correspond to F (see Fig. 6).

area of the sedimentary basin at that time was different from the present one; the second is that the top of the pre-Tertiary basement is deeper in the Odate Basin than in any other area, whereas the Quaternary basin-fills in the Odate Basin are thinner than those in the Hanawa Basin; and the third is that the lowest gravity anomaly appears in the Hanawa Basin. These features suggest that the Odate Basin obviously appeared much earlier than the Hanawa Basin, and that the present locality of the Hanawa Basin was situated on the western flank of the Ou Backbone Range before the emergence of the Hanawa Basin. It is inferred that the Hanawa Basin started to subside at an age slightly earlier than 1 Ma of Early Pleistocene age (Otsuki, 1995), on

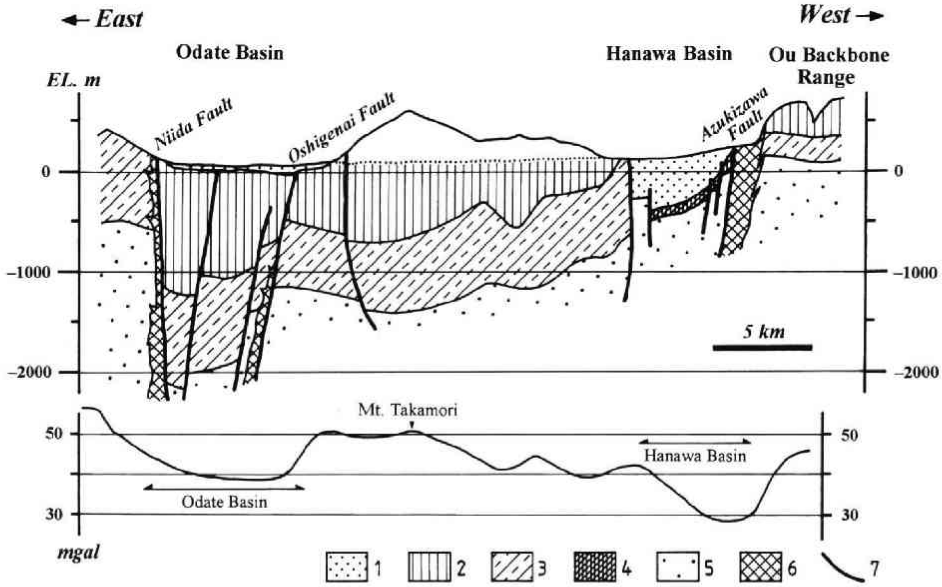

Fig. 9 Geological section along the JR Hanawa Line (almost along the Yoneshirogawa River), and cross section of gravity anomaly in the E-W direction passing across Mt. Takamori (east of the Odate Basin), after Fujii *et al.* (1969) (slightly simplified)
1 : Quaternary 2 : Middle Miocene 3 : Lower Miocene 4 : Middle to Lower Miocene 5 : pre-Tertiary rocks 6 : intrusive rocks 7 : fault

the basis of K-Ar dating of the Kashinai Formation (Tamanyu and Lanphere, 1983) intercalated in the lower part of the basin-fill sediments.

It is certain that the boundary faults on the western margin of the Odate Basin, such as the Niida Fault, inverted to reverse faults (Fig. 10) after the deposition of the Ittori Formation, that is, in the earliest Pliocene, from the presence of the steeply dipping zone in front of the faults, though the basin initially appeared as a graben bordered by the normal faults on both sides as described in Fig. 9. Almost the same argument is probably applicable to the eastern faults of the basin, because the steeply dipping zone of the Middle Miocene rocks along the eastern margin was also shown by Inoue *et al.* (1973) and Nakajima (1989). After the Latest Miocene, the Odate Basin was a sedimentary basin accompanied by reverse boundary faults, as is also the case with several sedimentary basins in the Northeast Japan Arc.

At present, Quaternary basin-fills in the Odate Basin are estimated to be less than 100 meters thick, about a quarter of the thickness of those in the Hanawa Basin (Metallic Minerals Exploration Agency of Japan, 1965, 1966, 1968 ; Fujii *et al.*, 1969), in accordance with a trend of gravity anomaly. The Alluvial surfaces are widely distributed in the Odate Basin, except the surfaces created by the pyroclastic flow.

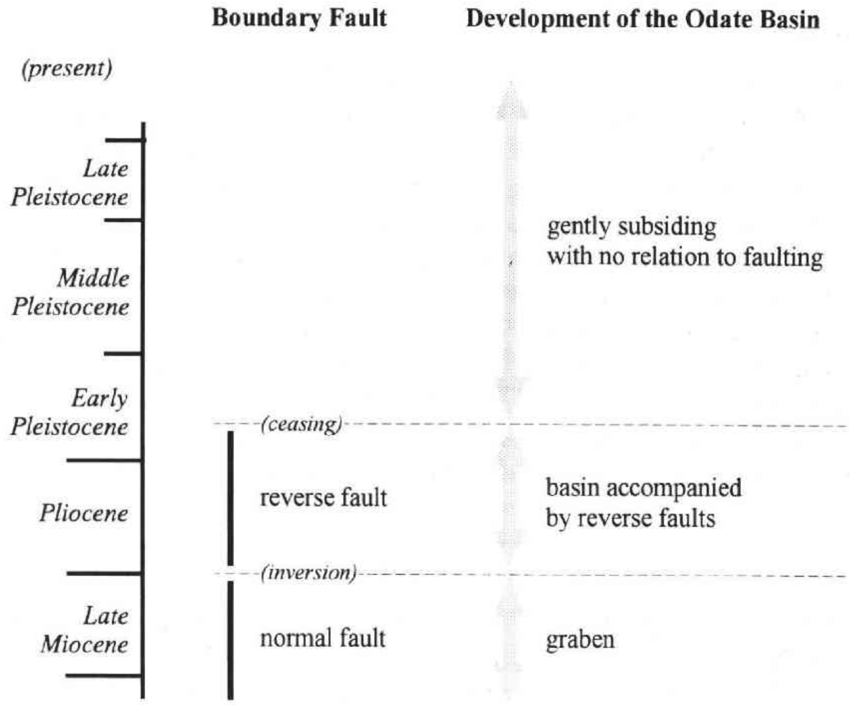

Fig. 10 Late Cenozoic succession of the Odate Basin

From these, it is considered that the present subsidence of the Odate Basin continues ; its degree, however, is relatively weaker. There is no evidence of currently faulting around the boundary faults, such as the Niida Fault on the western margin, based on the geomorphologic and geologic features. In consideration of the presence of the higher terrace as an indication of uplift from the terrace-emerging age up to present (Otsuki, 1991), even the foot-wall side of the boundary faults, where hilly area including O-H Terraces is distributed, is inferred to uplift. Present boundary faults are not also traceable in the frontal area of the hills, as described above. It is thus concluded that the Odate Basin and its surrounding areas are presently dominated by gentle uplift-subsidence independent of faulting, like warping. Although the age when the reverse faults ceased is presently unknown, it is presumed to correspond with the appearance of the Hanawa Basin, where a notable subsidence of about 0.3 mm/yr in rate has occurred accompanying the movement of the reverse boundary faults (*e.g.* Azukizawa Fault) on the east side since the Early Pleistocene (Otsuki *et al.*, 1998).

6 Conclusion

The boundary faults on the western margin of the Odate Basin moved as reverse faults probably during Pliocene to Early Pleistocene time, because the Middle to Upper Miocene in front of the faults underwent horizontal shortening deformation. The Odate Basin is inferred to have been a sedimentary basin accompanied by reverse faults at that time. On the other hand, no distinct reverse fault is currently confirmed to exist along the western fringe of the basin, especially close to the frontal margin of the surrounding mountainous and hilly areas, from the Upper Cenozoic structures.

In the Yoneshirogawa River Basin, several Latest Cenozoic sedimentary basins are present, and the topographic basinform of the Odate Basin is apparent, as is also the case with the Hanawa Basin, in which the Alluvial surfaces are widely distributed. It is, however, concluded that the Odate Basin and its surrounding areas are dominated by gentle uplift-subsidence at present with no relation to faulting.

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Notes

1) In this paper, "higher terrace" and "higher surface" are defined respectively by the terrace and terrace surface which formed in the former age than Last Interglacial Maximum time (older than 0.13 Ma), mainly in the Middle Pleistocene, according to Otsuki (1991).
2) The glass shards in marker tephra were analyzed with EPMA (HITACHI-X560S, Kevex-Quantex 7000) in the Institute of Mineralogy, Petrology and Economic Geology, Tohoku University. Measurement condition was as follows: Accelerating Voltage, 20 kV; Beam Current, 2×10^{-10} A; Beam Size, about 2 μm in diameter.

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