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A note on tectonic evolution within a Neogene basin: new evidence from the Early to Middle Miocene Ichinohe Basin, northeast Japan

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Abstract The Ichinohe Basin, defined by the exposed extent of the Early and Middle Miocene Yotsuyaku and Keiseitoge formations, is tectonically characterized by N-S trending normal-faults at the eastern margin of the basin and by E-W trending normal-faults at the northern part of the basin. Such contradicting tectonic structures reflected a change in the stress regime during the Neogene time. The N-S oriented normal-faults with the longitudinal basin-filling of the Yotsuyaku Formation indicate the crustal extensional tectonism during the Early and Middle Miocene time. Talus sheets with steeply inclined basin walls also suggest that the basin was formed as a rifting basin within the Kitakami Massif. However, the E-W extensional regime must have changed into the E-W compressional stress regime after forming the Middle and Late Miocene Kadonosawa Basin, located farther north to the Ichinohe Basin. The newly exposed E-W trending normal-fault proves the change of stress regime during the Late Neogene time.

Key words: N-S and E-W trending normal-faults, rifting basin, longitudinal basin-filling, change of stress-regime, Neogene Ichinohe Basin

Introduction

The Early and Middle Miocene Ichinohe Basin is a northward-opening, U-shaped basin, having dimensions of 8 km in E-W and 16 km of N-S directions (Fig.1). Chinzei (1966) once detailed the sequential development of Neogene basin-fillings farther northward areas, particularly the Kadonosawa and San-nohe basins of Middle ~ Late Miocene and Pliocene ages. Owing to the new roadcuts and outcrops, however, Yagishita & Komori (2000) have dealt with the oldest Neogene sediments just above the Mesozoic basement rocks and discussed the sedimentological aspects (*i.e.* facies and paleocurrent analyses) of the deposits. In this report we will describe and discuss the evolution of the Ichinohe Basin in terms of tectonics. New information achieved from the fresh outcrops again enables us to argue about the incipient and late stages of the Neogene tectonics. Tectonic structures recognized within the Ichinohe Basin show a contradiction of tectonism during the Neogene time.

Geological setting and paleocurrent pattern

The Ichinohe Basin, of which eastern, western and southern margins are bounded by the Mesozoic basement rocks of the Kitakami Massif (Yagishita & Komori, 2000), consists of the lower formations of the Shiratorigawa Group, the Yotsuyaku and Keiseitoge formations (Fig. 2). The depocenter of the basin shifted northwards later into a broader basin, the Kadonosawa Basin, which chiefly consists of the younger formations of the group, *i.e.* the Kadonosawa and Sueno-matsuyama formations (Chinzei, 1966). Deposits of lower part of the Yotsuyaku Formation (the Koiwai Member) suggest an infilling from the basin margin. However, sediments of the upper part of it (the Sugohata Member) show that most coarse-grained deposits were transported from southern elevated sources towards the north (Fig. 3, Yagishita & Komori, 2000). The longitudinal basin-filling by southerly sourced Mesozoic basement rocks reflected an incipient Neogene tectonism, as described below. In contrast, volcanoclastic sedi-

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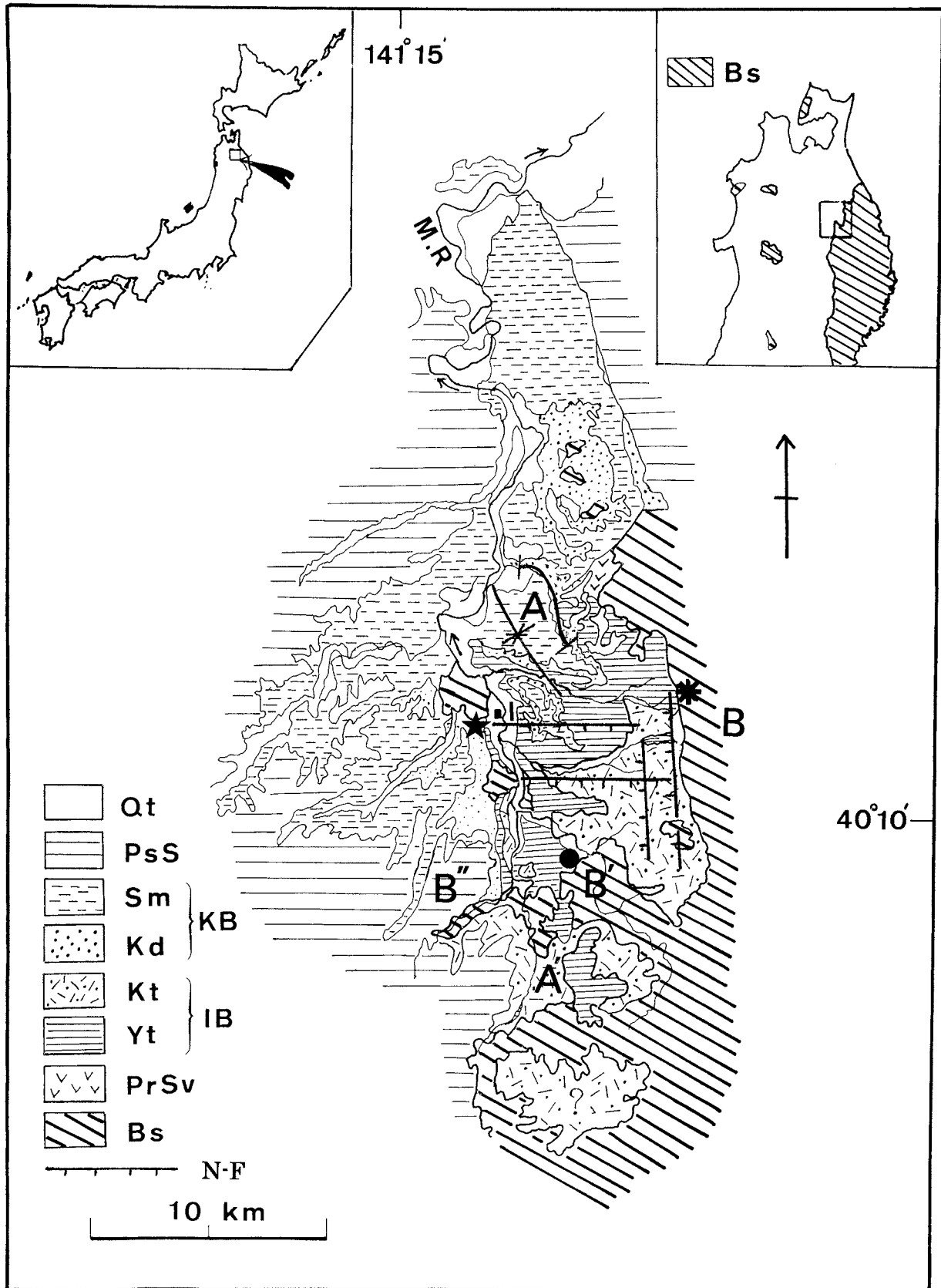


Fig. 1 Geologic map of the Ichinohe Basin (IB) and the Kadonosawa Basin (KB). Note that the Ichinohe Basin is surrounded by the Mesozoic basement rocks (Kitakami Massif). Yt: Yotsuyaku Formation. Kt: Keiseitoge Formation. Kd: Kadonosawa Formation. Sm: Sueno-matsuyama Formation. psS: post-sedimentation of the Shiratorigawa Group except Quaternary deposits (Qt). N-F: normal fault. I: Ichinohe Town. M.R.: Mabechi River. Bs (inset): Kitakami basement rocks. Asterisk mark denotes N-S normal-fault (Fig. 4A), star mark, E-W normal-fault (Fig. 5A, B), and closed circle, steeply inclined basin-wall with talus sheet (Fig. 4C). Curved thick line denotes the Shiratori River section of Fig. 7. A-A' and B-B'-B'' show cross-section directions in Fig. 7 (modified after Yagishita & Komori, 2000).

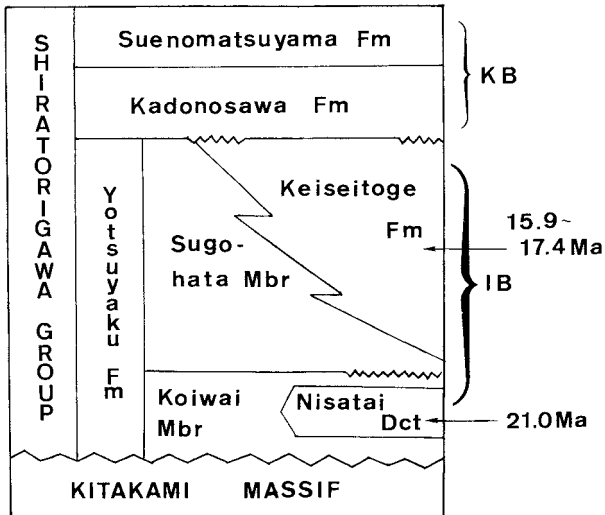


Fig. 2 Stratigraphic column of the Shratorigawa Group. Abbreviation of IB is the deposits constituting Ichinohe Basin, and KB, Kadonosawa Basin. Other abbreviations, such as Kt and Sm are the same as in Figs. 1 and 6. Radiometric dating of the Nisatai Dacite (21.0 Ma) and that of andesite of the Keiseitoge Formation (15.9-17.4 Ma) were carried out by Tagami *et al.* (1995) and Ishizuka & Uto (1995), respectively (after Yagishita & Komori, 2000).

ments of the Keiseitoge Formation, which are assemblages of ignimbrites, tuffs, tuffaceous silty sandstones and minor amount of lava flows, are sourced from the eastern volcanic range (Fig. 3). Because of the volcanoclastic materials of the formation, however, the transversal paleocurrent direction does not seem to be related to the tectonism during basin-filling.

Tectonics

Most outcrops of the Yotsuyaku Formation show a monoclinic structure, gently dipping to the north or northwest. The angle of dipping of the strata is mostly within 15° . It should be noted, however, the relatively thin sediments of the formation (total thickness < 160 m) can be recognized throughout the Ichinohe Basin, from the southern margin of the basin to the northernmost part of it (Fig. 1). This subject will be detailed later. Some normal-faults, particularly the N-S trending faults, exist along the eastern margin of the basin (Fig. 1). The occurrence of littoral molluscan fauna, such as *Nipponomarcia* and other molluscs in the Koiwai Member provides a marker horizon on each side of the normal faults and demonstrates a remarkable throw (more than 200 m) across the faults (Figs. 1 and 4A). An E-W trending high-angle normal-fault with dragging strata of the Shikonai Member, middle part of the Kadonosawa Formation, was newly confirmed at the northern part of the basin (east of Ichinohe Town, at Kitadate, Figs. 5A and

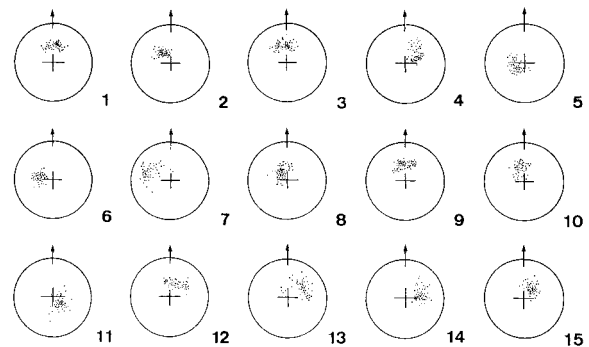
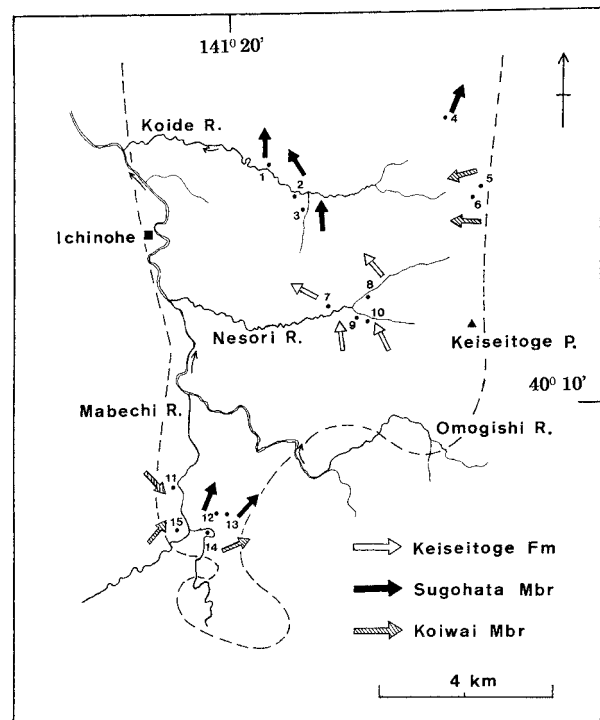


Fig. 3 Paleocurrent directions deduced from pole plots of imbrication plane of conglomerates of the Yotsuyaku and Keiseitoge formations. The imbrications of 50 gravel clasts in each outcrop were chosen along the bedding plane. All data obtained in the field were corrected for structural dip, and all plots are shown by lower-hemisphere projection. Broken line indicates the Ichinohe Basin outline (modified after Yagishita & Komori, 2000).

5B). Strike and dip of the fault plane is E-W, 70° S. Although the magnitude of the throw is not known, the presence of *Crassostrea gravitesta*, which is one of the typical autochthonous molluscs in basal beds of the Kadonosawa Formation, the Tate Member (Chinzei, 1966), suggests that the throw may reach a few tens of meters, at least. The fault may also laterally extend a few kilometers.

Uplifted horsts or steeply inclined basin walls with a talus sheet are present (Figs. 4B and 4C). The talus sheet comprises basal beds of the Yotsuyaku Formation, including an *Ostrea* bed (*Crassostrea gigas*) of the Koiwai Member. The talus sheet with

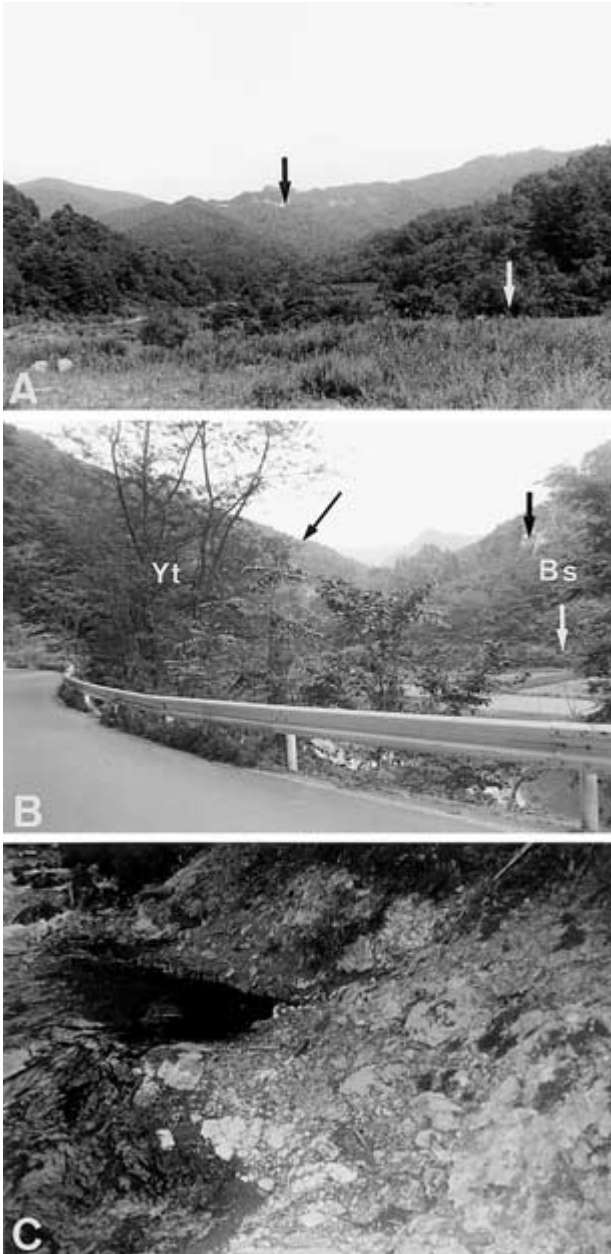


Fig. 4 A. View of N-S trending normal fault at eastern margin of the Ichinohe Basin. Black arrow shows the eastern side of the fault and roadcut producing littoral molluscan fossils of the Koiwai Member, the Yotsuyaku Formation. White arrow shows the western side of the fault where the same fossil assemblage is observed in a creek. The throw of the fault is more than 200 m. B. View of the steeply inclined basin wall. Thick black arrow is the Mesozoic basement rocks (Bs, chert and green rock) and white arrow shows a creek of talus sheet of C. Left (north) side of the valley (Omogishi River) is sand- and silt-stone beds of the Koiwai Member of the lowermost Yotsuyaku Formation (Yt, inclined thin arrow). C. Talus sheet derived from the basin wall of B. Breccias are mostly green rock. The hammer is 0.3 m long.

steep walls is recognized not only at the southern basin margin but also at the northernmost margin. The fact shows the incipient tectonism within the Ichinohe Basin, suggesting that the basin was formed as a rift basin.

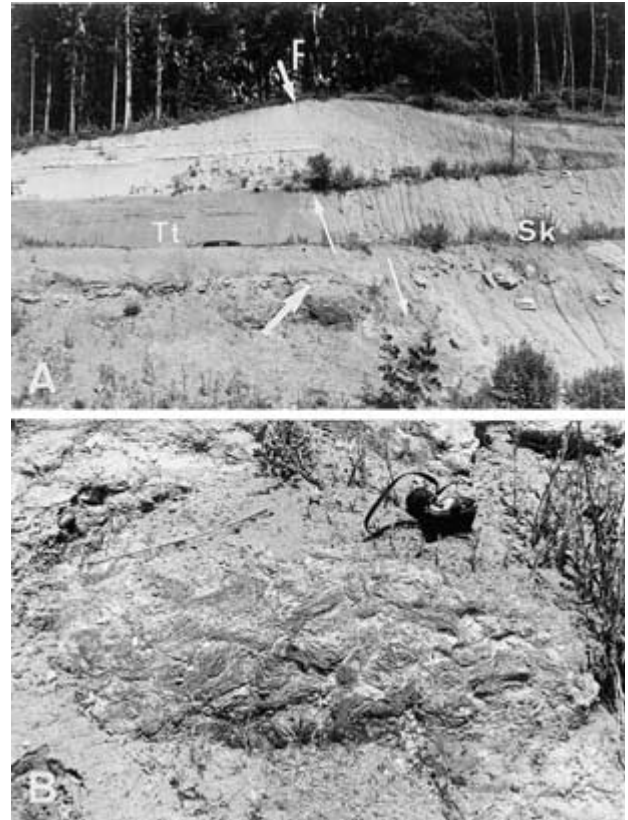


Fig. 5 View of newly exposed E-W oriented normal-fault, east of Ichinohe Town. A. Right (south) side of the fault is the the Shikonai Member (Sk) of siltstone beds, the middle part of the Kadonosawa Formation. The beds show a dragging structure. Left (north) side is basal beds of the Kadonosawa Formation, the Tate Member (Tt). Strike and dip of the fault plane is E-W, 70°S. 'F' with inclined white arrow displays fault plane, and thick white arrow shows the fossil bed of B. B. Close view of the fossil bed of A, *Crassostrea gravitesta*. The camera provides the scale.

Discussion and conclusion

According to the strain ellipse model of pure shear (Fig. 6A), the structural pattern of the N-S trending normal-fault (Fig. 4A) suggests that the fault-controlled tectonics in the Ichinohe Basin was a consequence of E-W trending extensional regime. The N-S trending longitudinal basin-filling of the upper part of the Yotsuyaku Formation (Fig. 3) also indicates the extensional tectonism. The existence of the talus sheet in the Koiwai Member (Fig. 4C) suggests that the initial movement of crustal extension was likely achieved in the Early Miocene time before main deposition of the Ichinohe Basin infilling. The talus sheet with the steeply inclined walls (Fig. 4B) proves that the basin was formed as a rifting basin within the Kitakami Massif.

However, the E-W trending extensional tectonic regime must have changed into the E-W compressional stress regime long after forming the

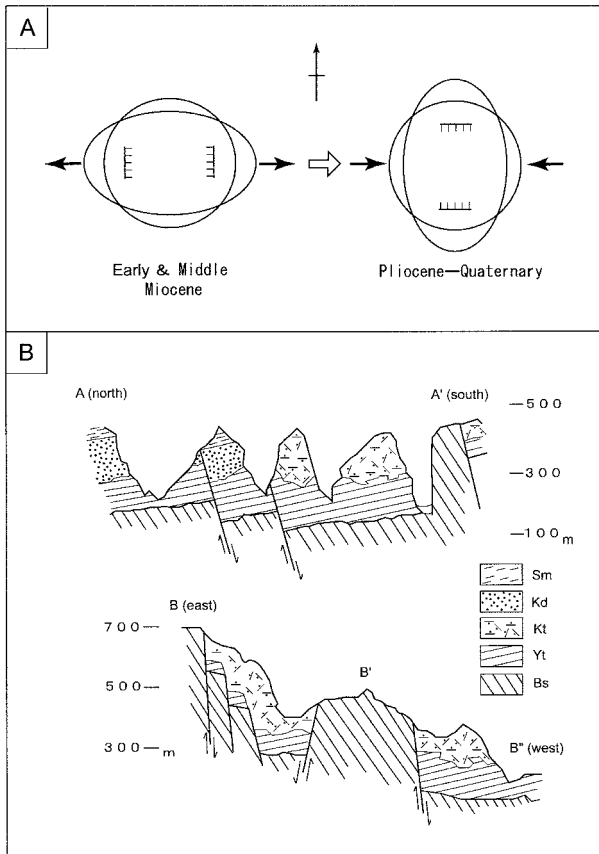


Fig. 6 A. Strain ellipse model of pure shear showing east-west extensional stress regime during the Early and Middle Miocene, and the compressional regime from the Pliocene to Quaternary time. B. Schematic cross sections of north-south and east-west directions of the Ichinohe Basin. Compared with horizontal scale, vertical scale is extremely exaggerated. Cross section directions are shown in Fig. 1, and abbreviation of each formation is the same as shown in Fig. 1.

Kadonosawa Basin, resulting in E-W oriented normal-faulting (Figs. 5A, 5B and 6A). The outcrop clearly shows that the faulting was not formed as syn-sedimentary deformation. The reason for the existence of well-exposed outcrops of the Yotsuyaku Formation in the northern part of the Ichinohe Basin can be explained by the E-W oriented and south-dipping normal-faulting. Otherwise the strata are underlain by thick sediments of the Kadonosawa and Sueno-matsuyama formations (Fig. 6B). Without such normal-faulting, even gently dipping strata of the Yotsuyaku Formation (say, 10° to the north) would have subsided more than 1,000 m at about 6 km from southern margin of the basin. However, this is not the case. We also consider that, instead of a single fault, step-faulting must be more plausible for catching up the large-scale downthrow. The step-faulting (no star mark of E-W oriented line in Fig. 1), however, is tentatively assumed and not exposed in the investigated area.

Chinzei (1958, 1966) disclosed a large-scale fold-

ing structure, in which NNW-SSE synclines and anticlines develop in the Kadonosawa Basin (Fig. 1), and he suggested the basin evolution might have related to the folding structure. However, we interpret that the structure was formed long after the Kadonosawa basin evolution and made under the E-W trending compressional stress regime. This is because that the E-W oriented normal faulting described above cut through the thick Kadonosawa Formation (Fig. 5A). Moreover, the total thickness of the Kadonosawa Formation along the Shiratori River is found to be more than 500 m (Fig. 7), about three-times thicker than the individual outcrop thickness measured by Chinzei (1958). The total thickness was measured from the basal conglomerate bed near Tate to the uppermost part of the formation near Anaushi. The thickness is also much thicker than that of the same interval estimated by Irizuki & Matsubara (1994). Their estimated thickness is only about 100 m. However the outcrops are well-exposed and rather continuous, but there is no major fault running across the section. And even minor faults are quite rare. The conglomerate bed near Tate is overlain by autochthonous molluscs, such as *Dosinia nomurai*, *Tapes shiratoriensis* and *Crassostrea gravitesta*, and the uppermost part of the formation is characterized by ravinement surface with the overlying coarse-grained Sueno-matsuyama Formation at Anaushi. Our measured thickness seems to be much thicker than the sediments generally produced by a sagging basin formed by gently folding of the basement rocks. We believe that the thick sediments were formed while the Kadonosawa basin was still under the E-W extensional regime. It is also interesting to note that the subsidence rate due to rifting might have been high enough to keep a relatively deep depth of the Kadonosawa basin. This is because of a ubiquitous occurrence of *Mizuhopecten* sp. with other molluscs from fine-grained sediments of the entire section (Fig. 7).

The numerous N-S trending Miocene basins were formed in areas farther to the west of the Kitakami Massif, *i.e.* in the Green Tuff Region. Evolution of such Miocene basins was produced under extensional stress regime related to the opening of the Sea of Japan (Yamaji, 1989; Sato & Amano, 1991). The sporadically distributed N-S trending basins in the Green Tuff Region characterize the early stage of the rifting (Yamaji, 1989), where Lower Miocene coarse-clastic basin-fills (mostly fluvial and volcanoclastics) are bounded by granitic basement rocks with normal faults. And the rapid subsidence took place in such basins from 16 Ma, resulting in deep marine sedimentation over the coarse fluvial clastics (Yamaji, 1990). Likewise, from faunal evidence the sediments of the

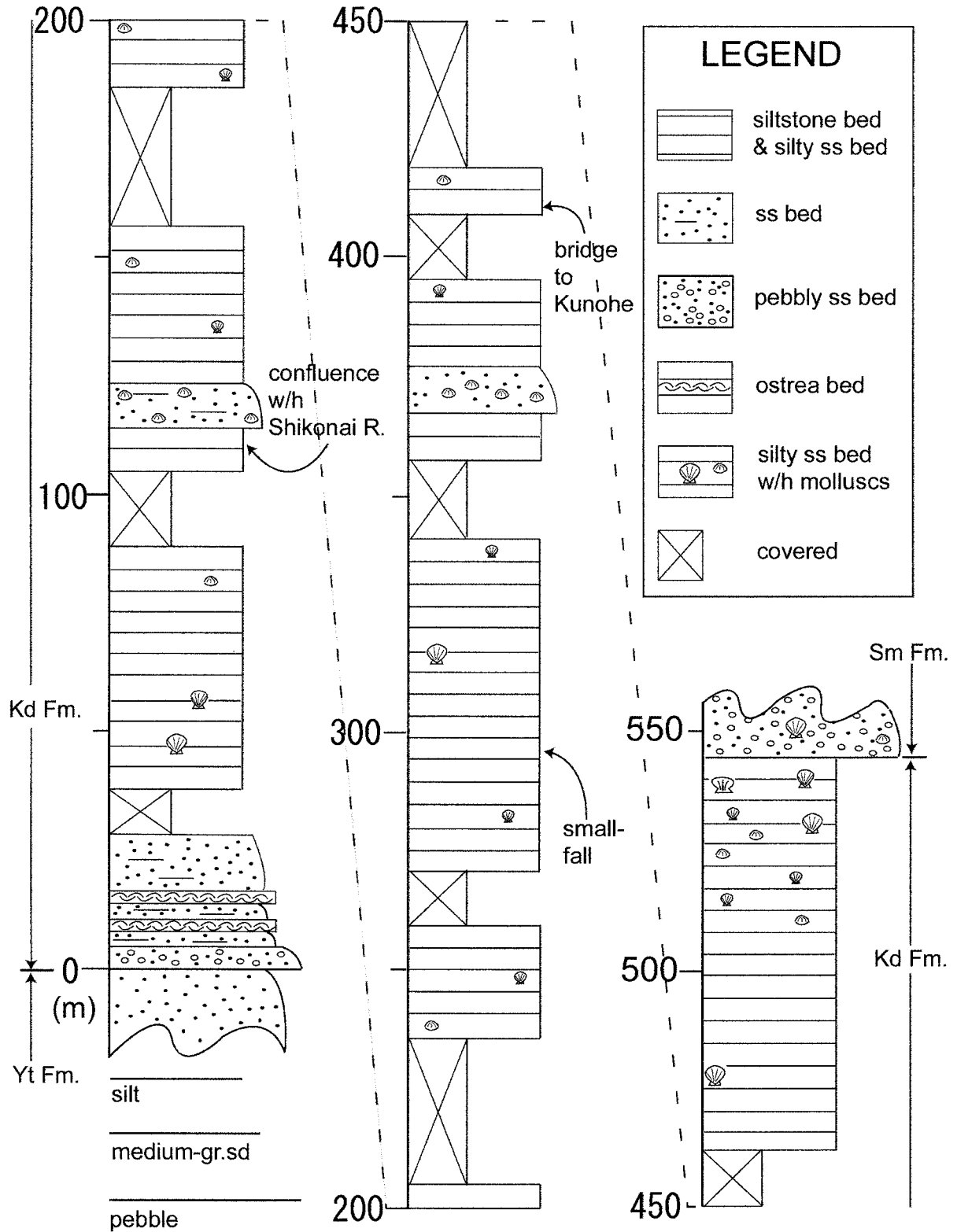


Fig. 7 Entire section of the Kadonosawa Formation along the Shiratori River from basal conglomerate beds near Tate to the uppermost part of the formation at Anaushi. The thick sediments are interpreted as the product of rifting basin-filling but not as the sagging basin-filling deposits due to basement rocks (Kitakami Massif) folding. Yt Fm.: Yotsuyaku Formation. Kd Fm.: Kadonosawa Formation. Sm Fm.: Sueno-matsuyama Formation.

Shiratorigawa section of the Kadonosawa Formation (Fig. 7) was dated to be N.8 of Blow, sometime between 16~15 Ma, and a relatively deep marine (> 200 m) depositional environment was kept at the middle stage of entire sedimentation (Irizuki & Matsubara, 1994).

Directional analyses of dyke swarms formed during the Early to Middle Miocene time also indicate the E-W extensional stress regime (Uyeda, 1982). The longitudinal basin-fill of the Ichinohe Basin, which is supported by the paleocurrent patterns of the Sugohata Member, shows another line of evidence for the rifting (Fig. 3). However, the change in the stress regime occurred during the Late Pliocene and Quaternary time; from the E-W crustal extension to the E-W compression (Uyeda, 1982). Recent reports dealing with the 'inversion tectonics' in the Sea of Japan also claimed the stress change during the time (e.g. Okamura *et al.*, 1995). They confirmed that many normal-faults produced during the Early and Middle Miocene time reactivated as reverse-faulting during the Pliocene to Quaternary time.

To our knowledge, terrestrial Neogene basins, in which the contradicting tectonic structures can be observed, are rather rare. The Ichinohe Basin is one of such basins displaying the tectonic history of the stress change within the basin.

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