

Chapter 2

Geomorphology and Tectonic Setting of the Sanriku Coast, Northeastern Japan, and Introduction of Recent Studies on the Formation of Alluvial Plains and Holocene Crustal Movements Along the Coast

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Abstract The 2011 Tohoku-Oki earthquake dramatically changed the coastal environment along the Pacific coast of northeastern Japan. In particular, coseismic subsidence of up to 1.3 m was recorded along the Sanriku Coast. However, well-preserved Middle to Late Pleistocene marine terraces along the northern Sanriku Coast have been interpreted to indicate uplift since the Late Quaternary. This discrepancy between long-term uplift and short-term subsidence has been attributed to coseismic uplift during an unidentified megathrust earthquake. To clarify the interplay of uplift and subsidence, we introduce the tectonic setting of the Sanriku Coast and recent studies on the geomorphology and geology along the coast, which focus on crustal movements during the Holocene along the southern Sanriku Coast. The results of recent studies indicate that, contrary to the previous view that the northern Sanriku Coast has experienced long-term uplift, the southern Sanriku Coast has been subsiding since the 10 ka (since the latest Pleistocene).

Keywords Alluvial plain • Coastal geomorphology • Holocene crustal movement • Pacific coast of northeastern Japan • Tectonic setting

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2.1 Introduction

Well-preserved Middle to Late Pleistocene marine terraces along the Sanriku Coast of northeastern Japan have generally been interpreted to indicate long-term uplift in the region, especially along the northern coast (Koike and Machida 2001). However, geodetic and tide gauge data show rapid subsidence in this area over the last several decades, including considerable subsidence during the 2011 Tohoku-Oki earthquake (M_w 9.0) (Kato and Tsumura 1979; Ozawa et al. 2011). This discrepancy between long-term uplift and short-term subsidence has been recognized by several researchers but has not yet been fully explained (e.g., Ikeda et al. 2012; Niwa et al. 2015). In this chapter, we summarize the tectonic setting and geomorphology of the Sanriku Coast, introduce recent studies on the processes that formed the alluvial plains along the coast, which consider the relationship of those processes to Holocene crustal movement on the southern Sanriku Coast.

2.2 Plate Tectonic Setting and Overview of Large-Scale Landforms in the Tohoku Region

There are four major tectonic plates in the region of the Japanese Islands: the Pacific, North America, Eurasia, and Philippine Sea plates (Fig. 2.1). The northeastern Japan arc lies on the southwestern extremity of the North America plate where it is separated from the Pacific plate to its east by the Japan Trench. The Pacific plate is currently subducting under the North America plate at about 10 cm/year (Koike 2005).

Basement in the Tohoku region consists mainly of Jurassic accretionary complex rocks (Taira 2001). North–south-trending reverse fault systems in the region indicate an east–west compressional stress regime. Three ranges of north–south-trending mountains are developed in the Tohoku region (Fig. 2.2). The O-u and Dewa mountains of the inner arc region have been uplifted by faulting and are separated by basins and lowlands (Koike 2005). The Kitakami and Abukuma mountain ranges of the outer arc region consist of Cretaceous granitic rocks intruded into older basement and are the result of upwarping (Okada and Ikeda 2012). North–south-trending lowlands separate the mountain ranges of the inner and outer arc regions.

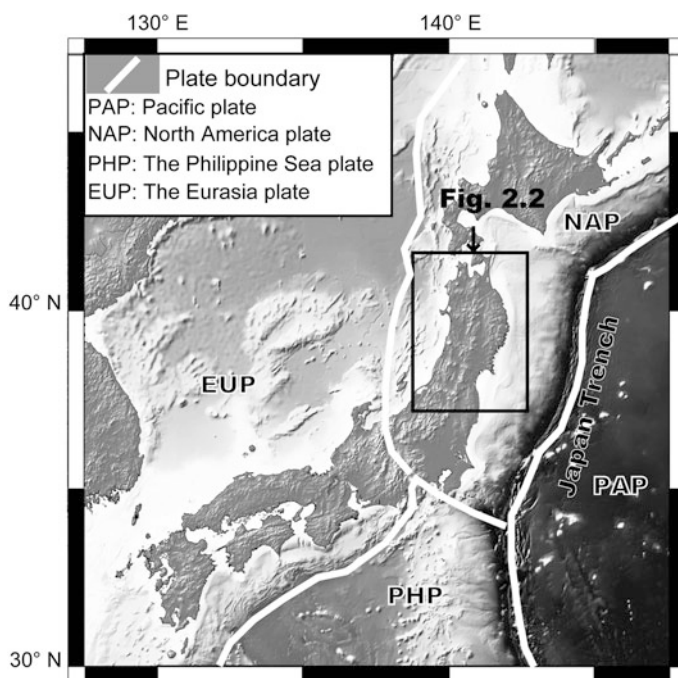
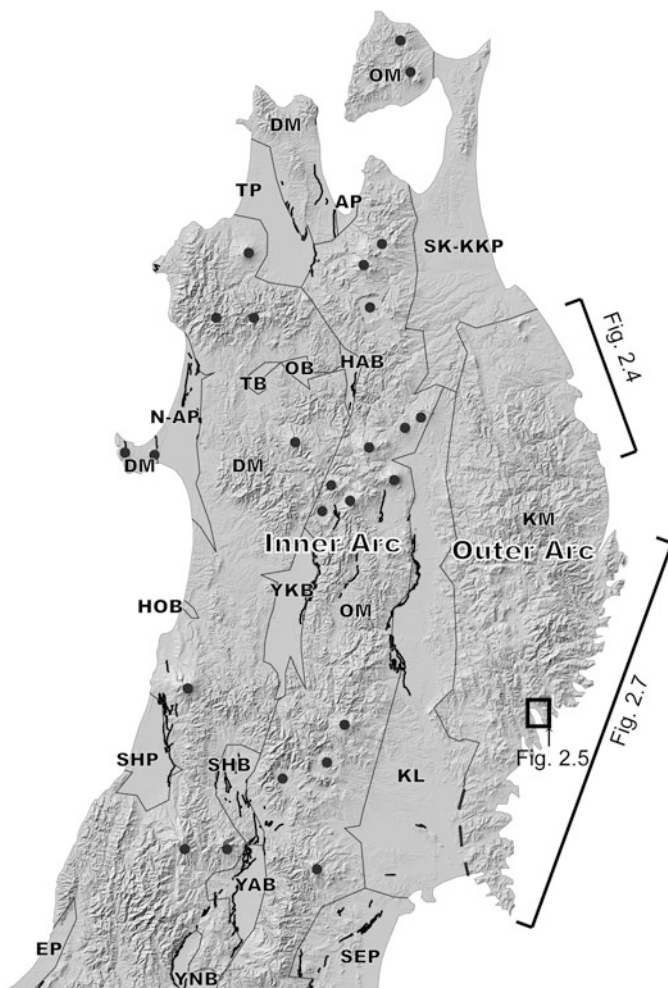


Fig. 2.1 Regional map showing distribution of major tectonic plates in the region of the Japanese Islands

2.3 Landforms of the Sanriku Coast and Distribution of Quaternary Marine Terraces

The Sanriku Coast lies east of the Kitakami Mountains and extends over a distance of about 600 km. Basement consists mainly of Mesozoic and Paleozoic sedimentary rocks (Fig. 2.3; Koike 2005). Sheer, rocky coastal cliffs are common along the northern Sanriku Coast, and indentation of the coastline there is uncommon. A marine terrace formed during the last interglacial (MIS 5e; 125 ka) stretches continuously from Hachinohe to Kuji, decreasing in elevation from 40 m at Hachinohe to 20 m at Kuji. There are six or seven levels of Middle Pleistocene marine terraces at elevations above the MIS 5e terrace; the oldest of these has been correlated with MIS 19 (ca. 800 ka) (Koike and Machida 2001). The elevation of this uppermost terrace is 280 m east of Kuji, and decreases to 140 m at Miyako, some 70 km to the south. The elevations of the younger of these terraces also decrease southward (Figs. 2.3c and 2.4; Yonekura 1966; Miyauchi 1985).



Legends

Mountains

KM: Kitakami mountains OM: O-u mountains DM: Dewa mountains

Plain/Lowlands

SK-KKP: Kamikita-Shimokita plains KL: Kitakami lowlands

SEP: Sendai plain AP: Aomori plain TP: Tsugaru plain

HAB: Hanawa basin OB: Odate basin TB: Takasu basin

N-AP: Noshiro-Akita plains YKB: Yokote basin

HOB: Honjo basin SHB: Shinjo basin YAB: Yamagata basin

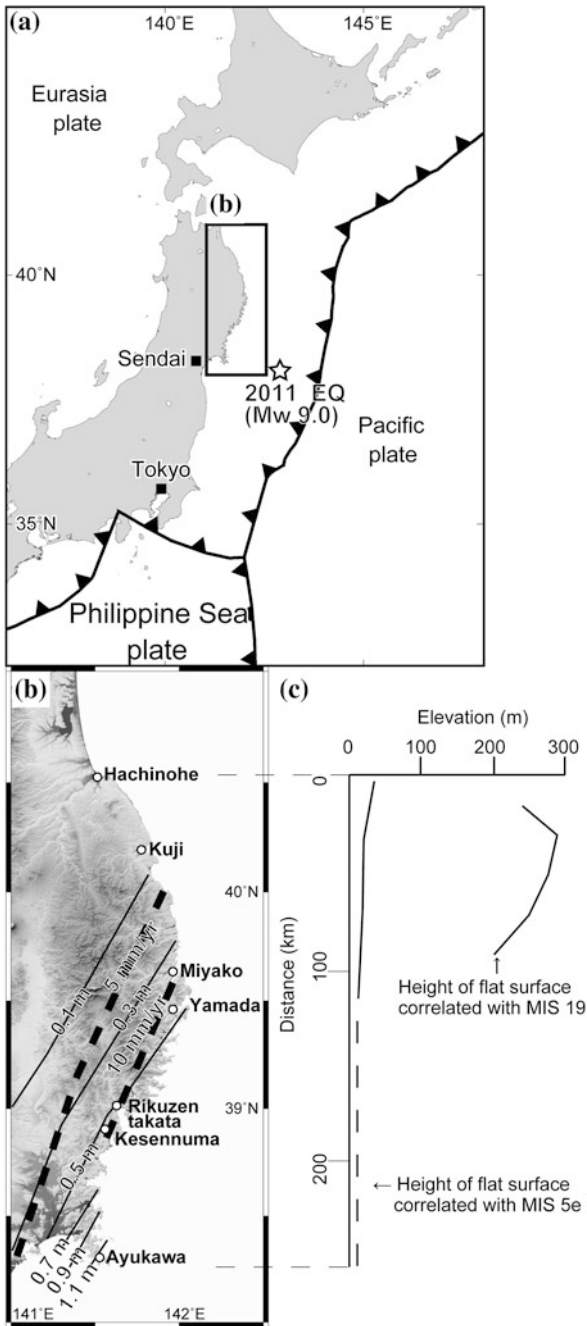
SHP: Shonai plain YNB: Yonezawa basin EP: Echigo plain

— Active fault

● Volcano

Fig. 2.2 Large-scale landform classification map of the Tohoku region. Landform classification is from Koike (2005). Distributions of active faults and volcanoes are from Nakata and Imaizumi (2001) and Imaizumi (1999), respectively

Fig. 2.3 **a** Epicenter of the 2011 Tohoku-Oki earthquake in relation to the Japanese Islands and major tectonic plates. **b** Amount of subsidence during the 2011 Tohoku-Oki earthquake (thin contours) and rate of subsidence (thick broken contours) over the last several decades. **c** Elevation profile of flat surfaces interpreted as Pleistocene marine terraces. **a** and **b** are modified from Niwa et al. (2015). **c** is modified from Miyauchi (2012)



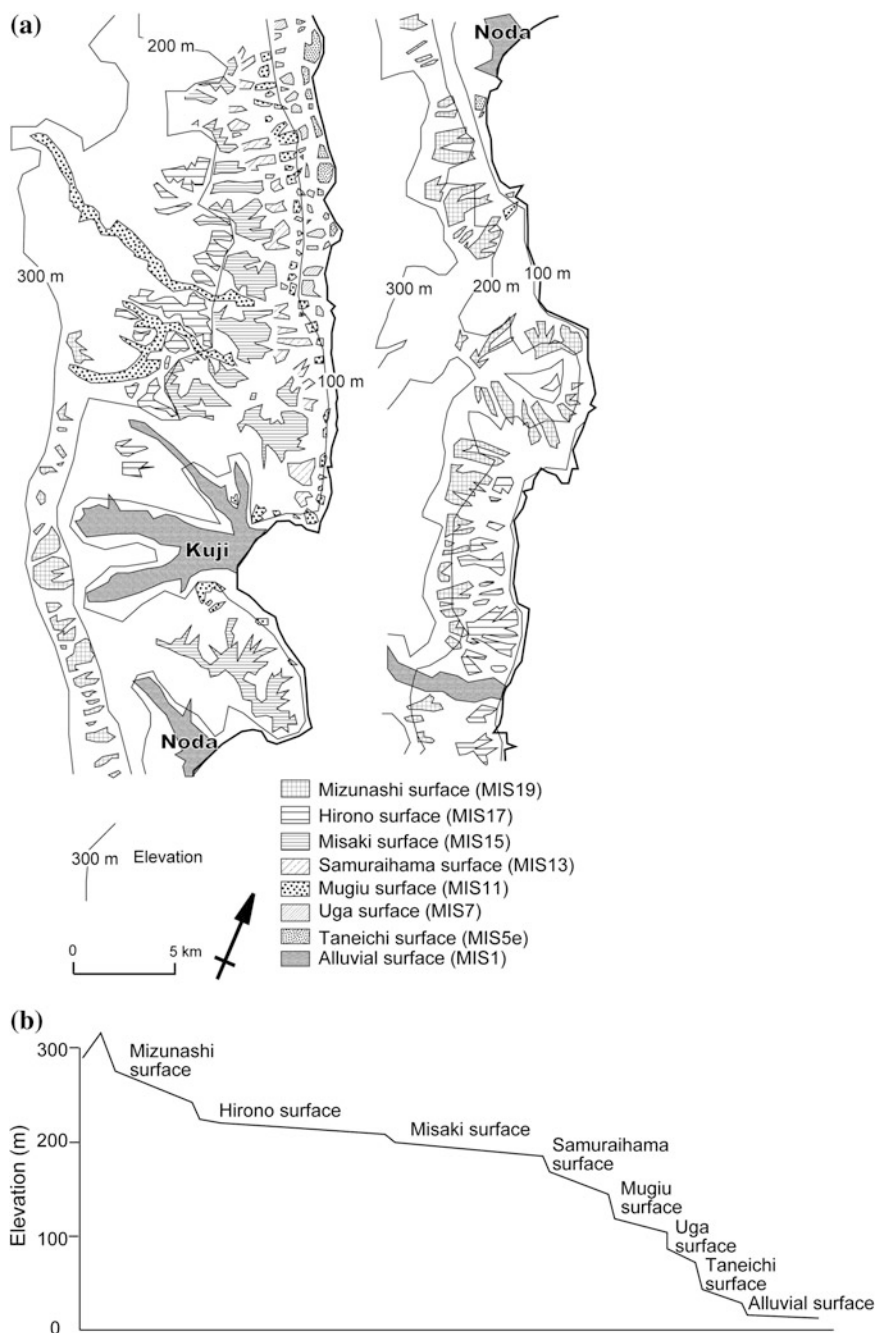
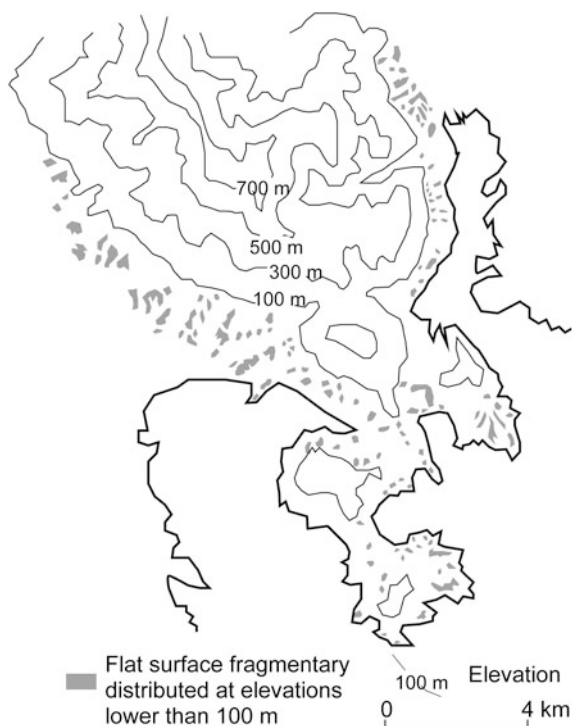


Fig. 2.4 **a** Distribution of marine terraces along the northern Sanriku Coast and **b** schematic geomorphic cross section (after Yonekura 1966). Correlation of ages of marine terraces with Marine Isotope Stage (MIS) is from Koike and Machida (2001). Location of map is shown in Fig. 2.2

Fig. 2.5 Example of fragmentary distribution of flat surfaces along the southern Sanriku Coast (after Miura, 1968) that has been interpreted as Pleistocene marine terraces. Their distribution and lack of clear evidence of marine origin (e.g., shells, burrows) preclude confirmation that they represent marine terraces. Location of map is shown in Fig. 2.2



In contrast, the southern Sanriku Coast (south of Miyako; Fig. 2.3b) is a typical ria coast with many deep embayments and capes. Along this part of the coast, there are fragmentary flat surfaces at elevations from several tens of meters to 70 m (Fig. 2.5; Miura 1966, 1968; Yagi and Suzuki 2001). Gravel layers have been identified in outcrop on these surfaces (Miura 1966, 1968; Yagi and Suzuki 2001), but whether they are of marine or nonmarine origin is unclear, and a lack of tephra layers has precluded determination of the timing of terrace formation (Miura 1966, 1968; Yagi and Suzuki 2001). Thus, the processes of formation and the ages of these surfaces are unclear.

2.4 Crustal Movement on the Sanriku Coast During the 2011 Tohoku-Oki Earthquake

On 11 March 2011, the Tohoku-Oki earthquake (Mw 9.0) caused subsidence of up to 1.3 m along the entire Sanriku Coast (Fig. 2.3b; Ozawa et al. 2011). The source of the earthquake was in the Pacific Ocean off the Sanriku Coast (Fig. 2.3a) at a focal depth of about 24 km (Japan Meteorological Agency 2011), and the resultant tsunami flooded most of the coastal plain (Haraguchi and Iwamatsu, 2011). The

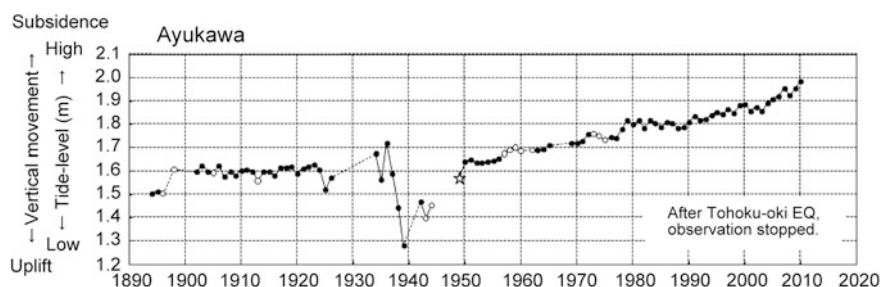


Fig. 2.6 Example of tide-gauge data suggesting continuous subsidence during the past several decades at Ayukawa on the southern Sanriku Coast (Coastal Movements Data Center 2015). Location of Ayukawa is shown in Fig. 2.3b

coseismic subsidence during the 2011 earthquake is consistent with the century-long subsidence trend of several to ten millimeters per year determined from geodetic and tide gauge data (Figs. 2.3b and 2.6; Kato and Tsumura 1979; Nishimura 2012). However, this subsidence is in conflict with the longer term (10^5 years) uplift suggested by the marine terraces along the northern Sanriku Coast.

2.5 Late Quaternary Crustal Movement Along the Sanriku Coast Before and After the 2011 Tohoku-Oki Earthquake

The well-preserved Middle to Late Pleistocene marine terraces along the northern Sanriku Coast have been interpreted to indicate uplift since the Late Quaternary. Interpretation of fragmentary flat surfaces along the southern Sanriku Coast as marine terraces also suggests Late Quaternary uplift (Yagi and Suzuki 2001). Thus, the trend of crustal movement since the Late Quaternary appears to be uplift along the entire Sanriku Coast. However, geodetic records show rapid subsidence at several to 10 mm per year over the past 100 years (Fig. 2.3b; Kato and Tsumura 1979; Nishimura 2012).

Ikeda (1996) explained the discrepancy between long-term uplift and short-term subsidence by inferring coseismic uplift caused by an unidentified past megathrust earthquake. Other hypotheses to explain the long-term uplift include uplift of the coastal area by a large earthquake with a different mechanism to that of the 2011 earthquake, or uplift due to afterslip of the 2011-type earthquake (Ikeda et al. 2012; Miyauchi 2012; Nishimura 2012). However, long-term crustal movements along the Sanriku Coast are not fully understood because of the fragmentary distribution of terrace surfaces and a lack of data to allow determination of their ages, especially along the southern Sanriku Coast. To clarify the uplift and subsidence history of the Sanriku Coast, estimates of long-term crustal movement based on geomorphologic and geologic data must become more accurate than those made to date.

2.6 Recent Studies Indicating Holocene Subsidence on the Southern Sanriku Coast

Because of the fragmentary distribution of flat surfaces (previously interpreted to be possible marine terraces) and lack of chronological data along the southern Sanriku Coast, an understanding of long-term crustal movements there must rely on analyses of other geomorphic and geologic features.

The small alluvial plains adjacent to the shores of embayments along the southern Sanriku Coast (Fig. 2.7; Chida et al. 1984) are composed of incised-valley-fill sequences that are typical of ria coastlines. Facies analyses and high-density radiocarbon dating of cores from those sequences can reveal changes of relative sea level (RSL), including the effect of tectonic crustal movements. The contribution of tectonic crustal movements can be determined from the difference of RSL curves estimated using core data from RSL curves modeled excluding tectonic movements (Fig. 2.8).

Here, we use paleo-geodetic data from recent studies on the southern Sanriku Coast to examine long-term crustal movements by considering the processes that formed two alluvial plains: the Rikuzentakata (Niwa et al. 2014) and Kesennuma Okawa (Niwa et al. 2015) plains.

2.6.1 *Rikuzentakata Plain*

2.6.1.1 Regional Setting and Sediment Core

The Rikuzentakata Plain is in a restricted-bay setting on the shore of Hirota Bay (Fig. 2.7); it extends about 2 km from north to south and about 2.5 km from east to west. Most of the plain is less than 5 m above sea level. The Kesen River, which flows through the plain, is about 50 km long with a catchment of about 540 km². The basement around the plain consists of Paleozoic sedimentary rocks in the upper reaches and Mesozoic granite in the middle and lower reaches (Chida et al. 1984). Paleo-channels are widely distributed on the plain (Fig. 2.9).

Before the 2011 Tohoku-Oki earthquake, there was a beach ridge along the shoreline with a lagoonal area (Furukawa Lake) landward of it. Most of this beach ridge was destroyed by the tsunami associated with the 2011 Tohoku-Oki earthquake, resulting in a marine incursion into Furukawa Lake. Sediment core RT1 was drilled on the back marsh about 500 m inland from the shoreline before the 2011 earthquake and tsunami. Niwa et al. (2014) conducted facies analyses and radiocarbon dating of 25 sediment samples from core RT1.

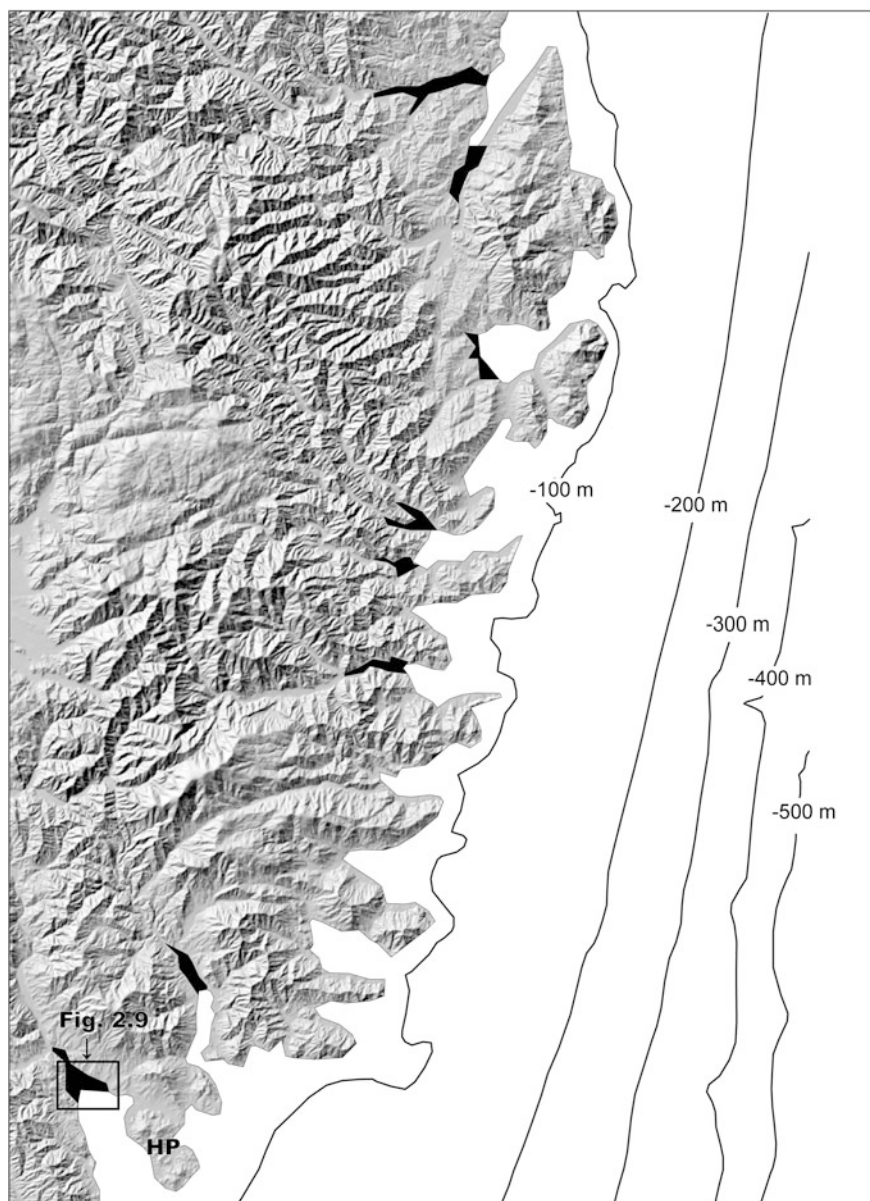


Fig. 2.7 Distribution of alluvial plains (*shaded black*) on the shores of embayments along the southern Sanriku Coast. Bathymetry from Cabinet Office, Government of Japan (2006)

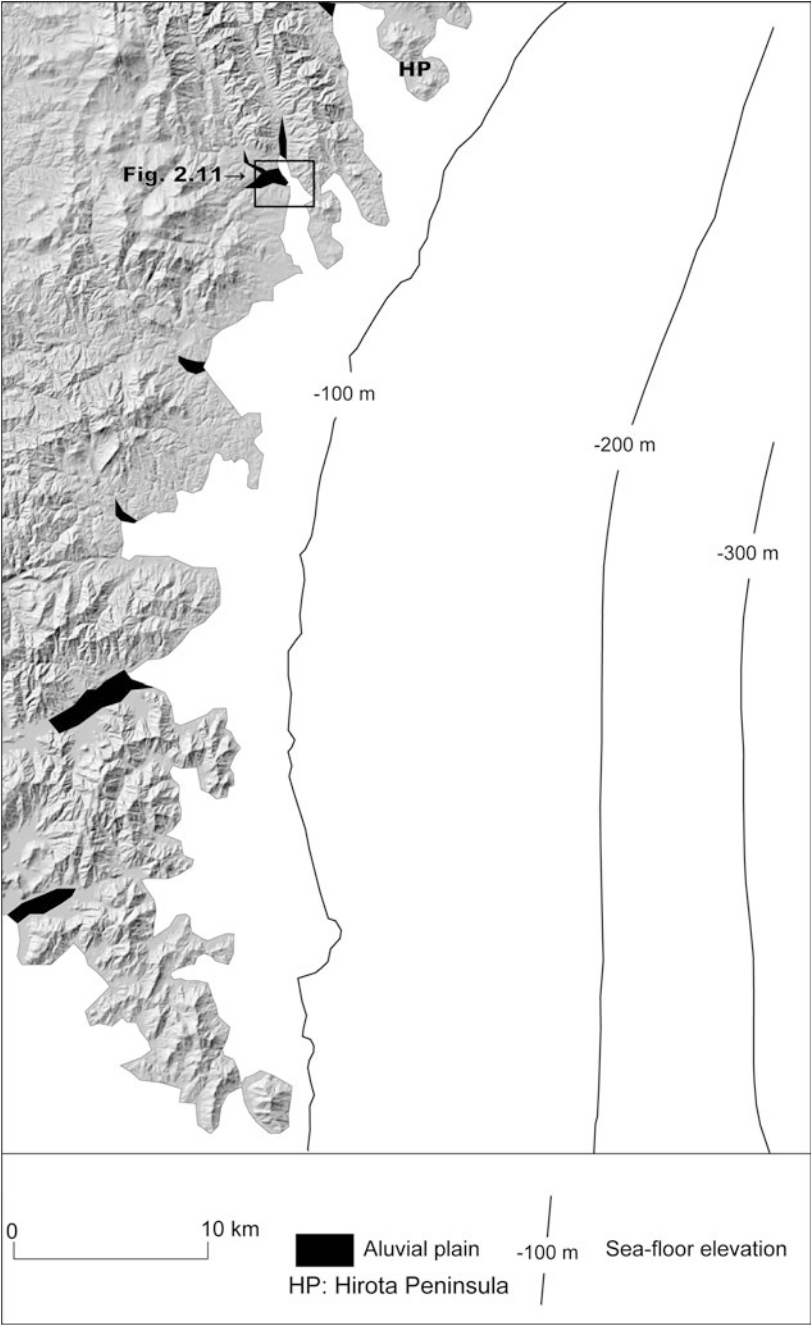


Fig. 2.7 (continued)

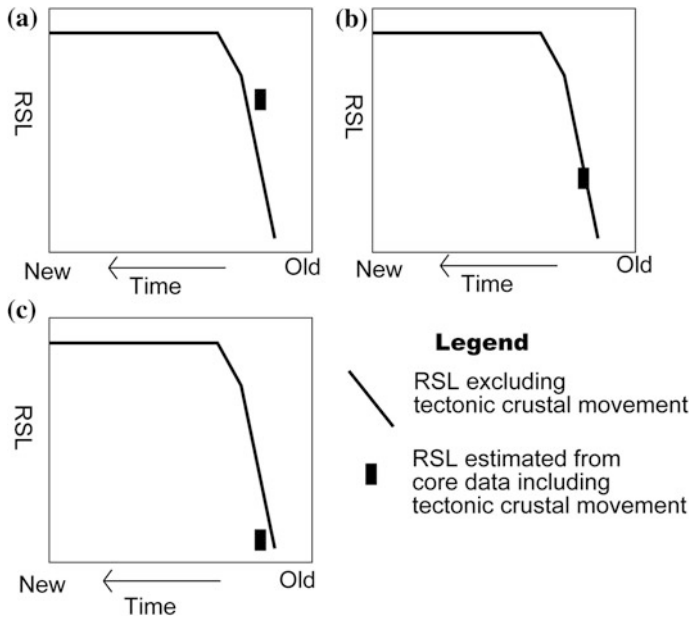


Fig. 2.8 Schematic diagrams showing the relationship between relative sea level (RSL) estimated from core data and a modeled RSL curve. **a** RSL estimated from core data higher than a modeled RSL curve excluding tectonic crustal movements, indicating an uplifting trend. **b** RSL estimated from core data similar to a modeled RSL curve, indicating tectonic stability. **c** Estimated RSL lower than a modeled RSL curve, indicating a subsiding trend

2.6.1.2 Holocene Sequence

Sediments in core RT1 were divided on the basis of lithofacies into depositional units 1–6, in ascending order (Fig. 2.10). Molluscan shells, and diatoms were identified in the core sediments (Niwa et al. 2014).

Unit 1 consists of sand and well-rounded gravel containing no shell fragments and was interpreted by Chida et al. (1984) to represent the basal gravel of the incised-valley-fill sequence, thus indicating deposition in a fluvial environment during the lowstand of the Last Glacial Maximum (Iseki 1975).

Unit 2 consists of alternating, thin laminated layers of silt and very fine sand, indicating deposition in a tidally influenced environment (Reineck and Singh 1980). The upper sequence of unit 2 fines upward, indicating an upward decrease of current velocity in a tidally influenced channel (Dalrymple 1992). Niwa et al. (2014) interpreted this unit to represent tidal river deposits.

Unit 3 consists of sandy silt to silty sand and includes thin laminated alternations of very fine sand and silt similar to those identified in unit 2. The presence of molluscan shells (e.g., *Macoma contabulata*, *Batillaria cumingii*) in the lower part of unit 3 indicates deposition in an intertidal environment. Thus, Niwa et al. (2014)

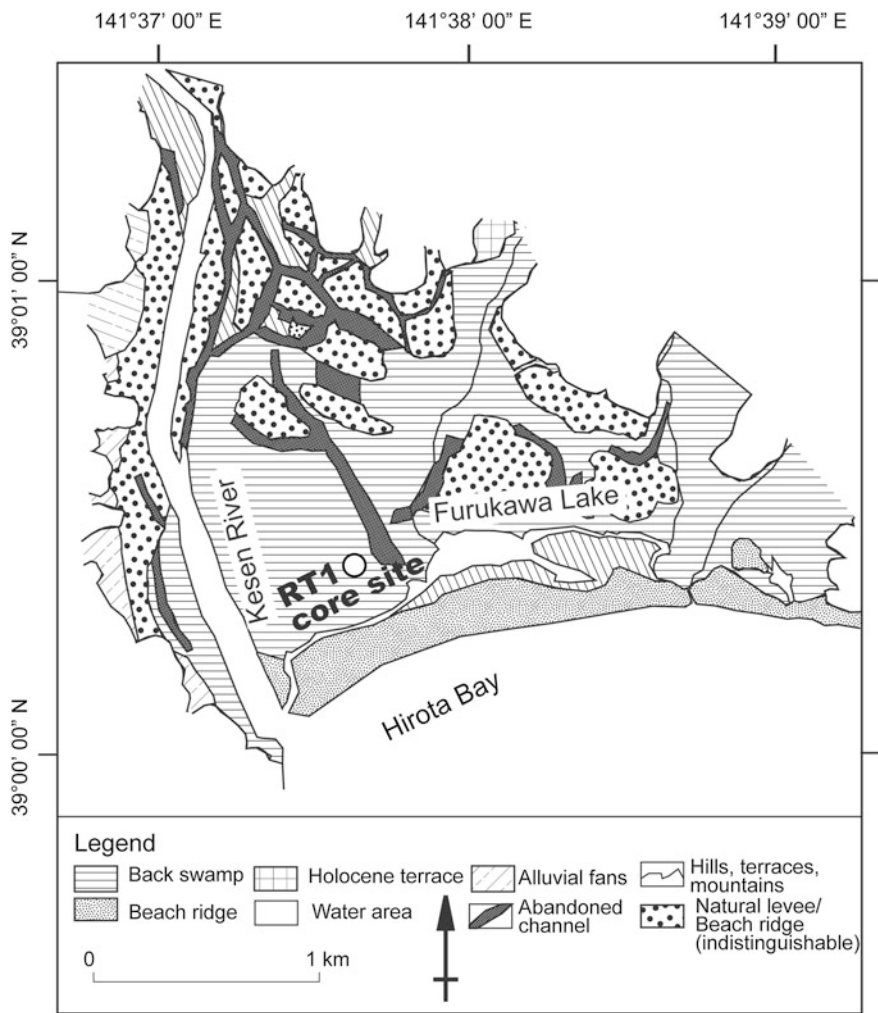


Fig. 2.9 Landform classification map of the Rikuzentakata Plain showing location of core RT1 (after Niwa et al. 2014)

interpreted this unit to be tidally influenced shallow-marine deposits (including tidal flat deposits).

Unit 4 is an upward coarsening sequence of sandy silt to fine sand. The lower part of the unit contains molluscan shells (e.g., *Dosinella penicillata*), indicating deposition in an inner bay subtidal environment. Plant fragments are more prevalent in the upper part of the unit. Thus, unit 4 represents prodelta to delta-front deposits, indicating the approach of the river mouth to the core site (Bhattacharya and Walker 1992).

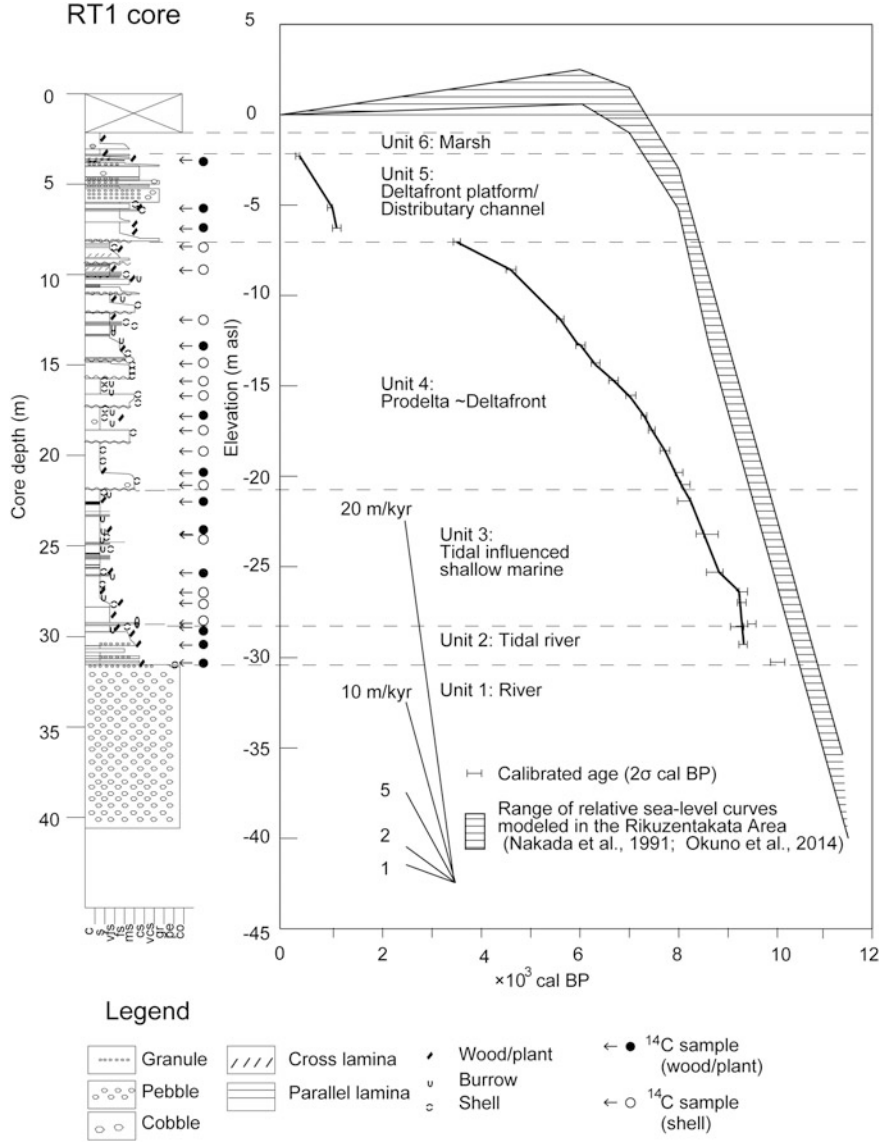


Fig. 2.10 Sedimentary column, sediment-accumulation curve from core RT1, and previously modeled RSL curves excluding tectonic crustal movements (after Niwa et al. 2014). The theoretical RSL calculated at Rikuzentakata is shown as in Niwa et al. (2014). Thus, the theoretical RSL is referred from Nakada et al. (1991) for 11,500 cal BP and Okuno et al. (2014) for the period after 8500 cal BP at the Rikuzentakata. Between 11,500 and 8500 cal BP, the RSL is interpolated from those at 11,500 and 8500 cal BP. The vertical range of the RSL at 11,500 cal BP is shown as difference between the RSL from ARC3 + ANT3B and viscosity model B and that from ARC3 + ANT3B and viscosity model C of Nakada et al. (1991). After 8500 cal BP, the vertical range represents the difference in RSLs based on ANUr model and ANU model of Okuno et al. (2014)

Unit 5 consists of sediment of fine sand to granule size. Some sand layers show cross-lamination. The boundary between units 5 and 4 is sharp. Unit 5 contains molluscan shells (e.g., *Dosinorbis japonicus*) indicative of deposition in an intertidal to subtidal environment. The unit 5 sequence is coarser than unit 4 and contains shallow-marine molluscan shells that indicate deposition in a delta-front platform environment (Yamaguchi et al. 2005) or in a distributary channel on a lower delta plain (Davis 1992).

Unit 6 consists mainly of silt and contains plant fragments and abundant freshwater diatom species, indicating that this unit represents terrestrial marsh deposits.

The sediment-accumulation curve we constructed based on 25 radiocarbon ages from core RT1 samples (Fig. 2.10) shows that accumulation rates were high (>20 mm/year) from 9500 to 9300 cal BP, low (2–7 mm/year) from 9300 to 3300 cal BP, and again high (5–10 mm/year) after 1200 cal BP. Niwa et al. (2014) interpreted the high accumulation rate from 9500 to 9300 cal BP to reflect large volumes of sediment supply due to increased accommodation space in response to sea-level rise during deglaciation. The decreased rate after 9300 cal BP probably reflects decreasing sediment supply due to expansion of the area of marine deposition and retreat of the river mouth as sea level rose. The high rate after 1200 cal BP reflects the close proximity of the river mouth to the RT1 core site at this time (Niwa et al. 2014).

2.6.1.3 Holocene Subsidence Inferred from Elevations and Ages of Intertidal Deposits

Niwa et al. (2014) estimated the trend of Holocene crustal movement by comparing the RSL curve we determined from core data with RSL curves derived from geophysical modeling in the Japan region by Nakada et al. (1991) and Okuno et al. (2014).

Because unit 2 (9500–9300 cal BP) represents tidal river deposits, RSL at the time of deposition was at or slightly higher than the elevation of the unit 2 depositional surface indicated by the sediment-accumulation curve (Fig. 2.10). The presence of molluscan shells in the lower part of unit 3 (9300–8600 cal BP) indicates an intertidal environment, so RSL at that time was at about the same elevation as the depositional surface indicated by the sediment-accumulation curve. Thus, core data indicate that RSL rose from about 30 m below present sea level at 9500 cal BP to about 23 m below present sea level at 8600 cal BP. However, the modeled RSL curves show a rise of RSL from about 20 m to about 15 m below present sea level (Fig. 2.10; Nakada et al. 1991; Okuno et al. 2014). Thus, the RSL determined from core data is lower than the modeled RSL, indicating that subsidence was predominant on the Rikuzentakata Plain during the Holocene, as has been the case over the last 100 years (Niwa et al. 2014).

2.6.2 Kesennuma Okawa Plain

2.6.2.1 Regional Setting and Sediment Core

The Kesennuma Okawa Plain on the western shore of Kesennuma Bay (Fig. 2.7) is a Holocene fluvial–coastal lowland on which a delta plain has been formed by sediments of the Kesennuma Okawa and Kamiyama rivers (Fig. 2.11). The Kesennuma Okawa and Kamiyama rivers are 23.9 and 6.9 km long, respectively, and drain a total catchment area of 168 km². The maximum spring tidal range in Kesennuma Bay is 1.3 m. The fluvial–coastal lowland extends 1.0 km from north to south and 3.0 km from east to west. Most of the plain is less than 5 m above sea level. Basement rocks under the catchment are Permian sedimentary rocks and Cretaceous granite, plutonic, volcanic, and sedimentary rocks (Geological Survey of Japan 2014).

Sediment core KO1 was drilled on reclaimed land in the lower reaches of the Kesennuma Okawa Plain. Niwa et al. (2015) conducted facies analyses and radiocarbon dating on 13 samples from this core.

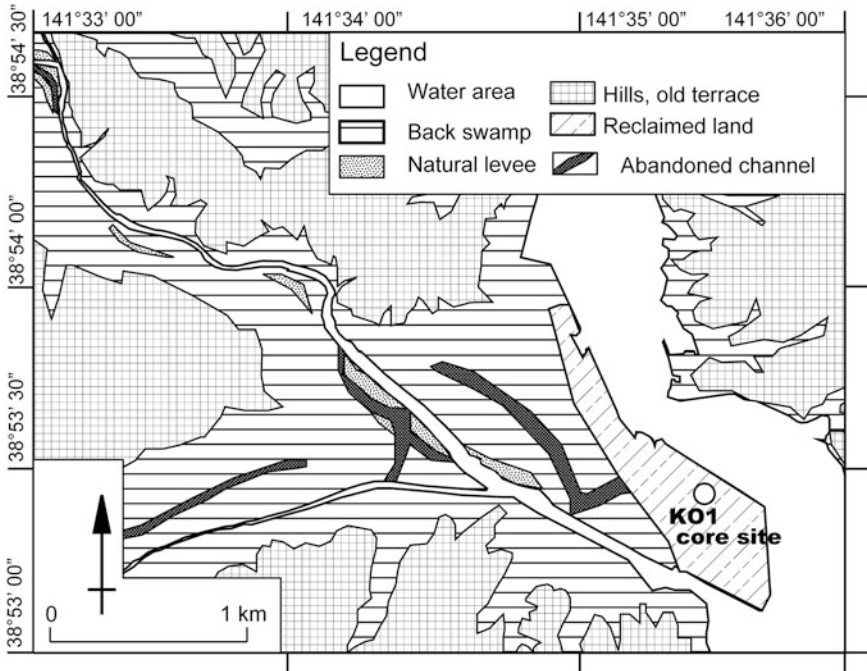


Fig. 2.11 Landform classification map of the Kesennuma Okawa Plain showing location of core KO1 (after Niwa et al. 2015)

2.6.2.2 Holocene Sequence

Sediments in core KO1 were divided into depositional units 1–5, in ascending order, on the basis of lithofacies and the molluscan shell species present (Fig. 2.12; Niwa et al. 2015).

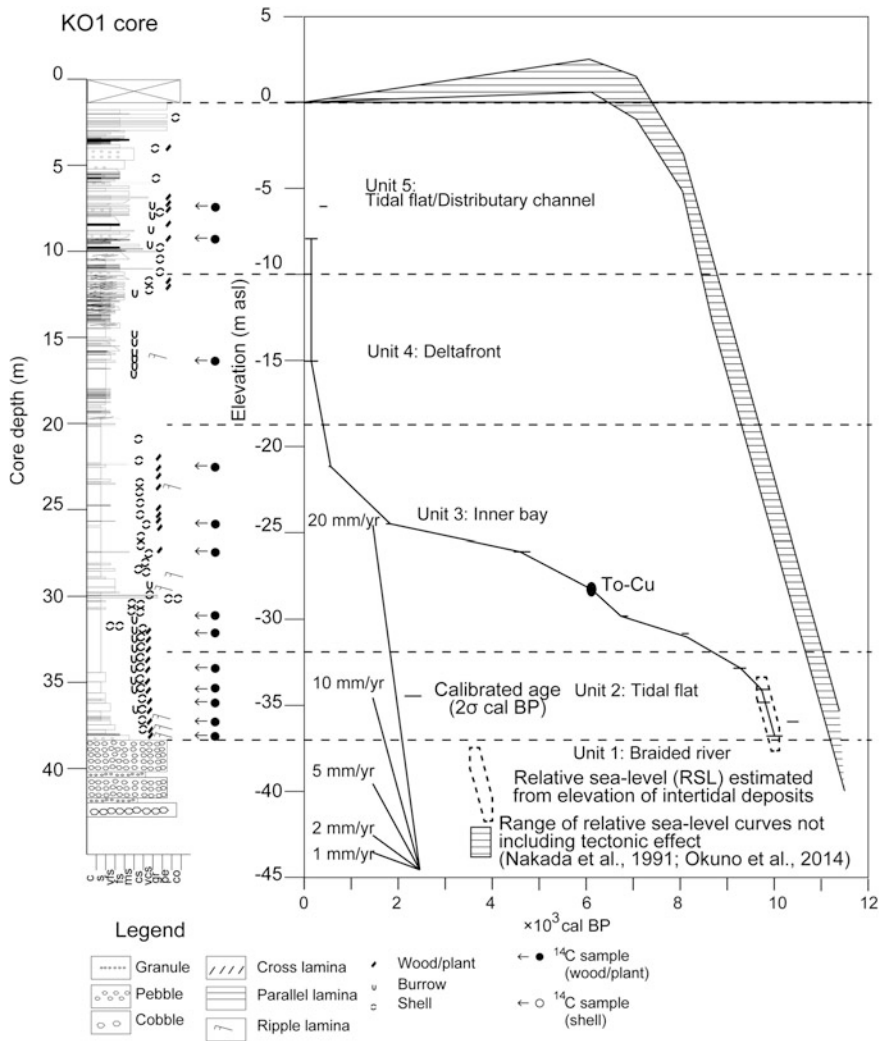


Fig. 2.12 Sedimentary column, sediment-accumulation curve of core KO1, and previously modeled RSL curves excluding tectonic crustal movements (after Niwa et al. 2015). The theoretical RSL calculated at Rikuzentakata, 15 km north of the study area, is shown as in Niwa et al. (2015). Thus, the theoretical RSL is referred from Nakada et al. (1991) for 11,500 cal BP and Okuno et al. (2014) for the period after 8500 cal BP at the Rikuzentakata. Between 11,500 and 8500 cal BP, the RSL is interpolated from those at 11,500 and 8500 cal BP. The vertical range of the RSL at 11,500 cal BP is shown as difference between the RSL from ARC3 + ANT3B and viscosity model B and that from ARC3 + ANT3B and viscosity model C of Nakada et al. (1991). After 8500 cal BP, the vertical range represents the difference in RSLs based on ANUr model and ANU model of Okuno et al. (2014)

Unit 1 consists of sand and well-rounded gravel and contains no shell fragments and is correlated with the basal gravel of the incised-valley-fill sequence of Chida et al. (1984), thus indicating deposition in a fluvial environment during the low-stand of the Last Glacial Maximum (Iseki 1975).

Unit 2 consists of silt and sand with thin laminated alternations of very fine sand and silt, suggesting deposition in a tidally influenced environment (Reineck and Singh 1980). The unit contains molluscan shells (e.g., *B. cumingii*) indicating an intertidal environment of deposition. Thus, Niwa et al. (2015) interpreted unit 2 to represent tidal flat deposits.

Unit 3 consists of massive silt to clay and contains molluscan shells (e.g., *Scapharca brouhtonii*, *Fulvia mutica*) indicative of a subtidal inner bay-floor environment of deposition. Thus, Niwa et al. (2015) interpreted unit 3 to represent inner bay deposits.

Unit 4 consists of sandy silt to fine sand in an upward coarsening succession, indicating deposition in a delta-front environment.

Unit 5 consists of sediments of silt to granule size and contains molluscan shells (e.g., *Batillaria multiformis*, *Nuttallia ezonis*) indicative of deposition in an intertidal or sandy-floored shallow-marine environment. Unit 5 is interpreted to represent tidal flat and/or distributary channel deposits (Niwa et al. 2015).

The sediment-accumulation curve we constructed based on 13 radiocarbon ages from core KO1 (Fig. 2.12) shows that accumulation rates were high (>10 mm/year) from 10,000 to 9700 cal BP, low (1–2 mm/year) from 9700 to 500 cal BP, and again high after 500 cal BP. Niwa et al. (2015) interpreted the high sediment-accumulation rate from 10,000 to 9700 cal BP to reflect large volumes of sediment supply in response to increased accommodation space as a result of sea-level rise during deglaciation. The decrease after 9700 cal BP probably reflects decreasing sediment supply in response to expansion of the area of marine deposition and river mouth retreat during sea-level rise. The high rate after 500 cal BP reflects the close proximity of the river mouth to the site of core KO1 at this time. These changes of sediment-accumulation rate are consistent with the sequence penetrated at the site of core KO1 representing a typical deltaic sequence (Niwa et al. 2015).

2.6.2.3 Holocene Subsidence Inferred from Elevations and Ages of Intertidal Deposits

The RSL rise from about 37 to 34 m below sea level determined from core data from 10,100 to 9600 cal BP (mainly unit 2) is almost equal to the elevation of the depositional surface because unit 2 is rich in intertidal molluscan shells (e.g., *B. multiformis*, *B. cumingii*) and therefore represents tidal flat deposits. However, the modeled RSL curves show a rise of sea level from about 17 to 11 m below present sea level (Fig. 2.12; Nakada et al. 1991; Okuno et al. 2014). Thus, the RSL curve derived from core data is lower than those of the two models and indicates that

Table 2.1 Summary of key geomorphic features and crustal movements on the Sanriku Coast

	Northern Sanriku Coast	Southern Sanriku Coast
Geomorphic features	Well-developed Pleistocene marine terraces	Fragmented flat surfaces; no definitive marine terraces Typical ria coastline
Long-term crustal movement	Marine terraces suggesting uplift since the Middle to Late Pleistocene	Lack of definitive marine terraces suggesting no uplift since the Late Pleistocene Sedimentary succession indicating possibility of long-term Holocene subsidence

subsidence was predominant in the Kesennuma Okawa Plain during the Holocene (Niwa et al. 2015).

2.6.3 Comparison of Subsidence Rate Through the Holocene with that During the Last Several Decades

The predominance of subsidence during the Holocene on the two alluvial plains described above (Table 2.1) suggests long-term subsidence of the southern Sanriku Coast (Niwa et al. 2015), contrary to the previous views that there has been long-term uplift in the region since the Late Quaternary. On the basis of radiocarbon ages and the differences between RSL derived from core data and modeled RSL curves, Holocene subsidence rates were 0.6–1.3 mm/year on the Rikuzentakata Plain (Niwa et al. 2014), and 0.9–1.8 mm/year on the Kesennuma Okawa Plain (Niwa et al. 2015). These rates are considerably lower than the rate of subsidence over the last several decades (5–10 mm/year; Kato and Tsumura 1979). Because the Early Holocene tidal deposits, used in calculation of subsidence rate, lies directory on the basement or gravel layer, the influence of compaction on the Holocene subsidence rate is likely to be negligible. Thus, one possibility is that we attribute this difference to the contribution of compaction to the subsidence rate over the last several decades. And, another possibility is that the Holocene subsidence rate includes contributions from undiscovered crustal movements (Niwa et al. 2015).

2.7 Summary and Conclusions

In this chapter, we described the geomorphology of the Sanriku Coast, introduce recent studies on the development of alluvial plains and reconstruction of Holocene crustal movement along the southern Sanriku Coast. The main points are summarized below.

1. The Sanriku Coast subsided dramatically by up to 1.3 m during the 2011 Tohoku-Oki earthquake. Geodetic and tide gauge data from the coastal region show rapid subsidence at several to ten millimeters per year over the last several decades.
2. The northern Sanriku Coast is characterized by well-developed Middle to Late Pleistocene marine terraces, which indicate a long-term trend of uplift since the Late Quaternary. On the southern Sanriku Coast, there are no definitive marine terraces, and the lack of information about terrace geomorphology precludes a clear understanding of long-term crustal movements there.
3. The southern Sanriku Coast has a typical ria coast line with many capes and deep embayments. Since the 2011 Tohoku-Oki earthquake, there have been several studies of small alluvial plains on the shores of embayments, which have focused on their development on the basis of facies analyses and high-density radiocarbon dating.
4. Recent studies of the alluvial plains along the southern Sanriku Coast have recognized sedimentary successions influenced by Holocene sea-level changes and identified a long-term trend of subsidence during the Holocene on the basis of the elevations and ages of intertidal deposits. The results of these studies suggest that, unlike the previous view that the southern Sanriku Coast has experienced long-term uplift since the Late Quaternary, subsidence has probably been predominant during Holocene.

More research is needed to further clarify the interplay of uplift and subsidence in the Late Quaternary history of the Sanriku Coast. Construction of RSL curves, including tectonic crustal movements, on the basis of the burial histories of incised-valley-fill sequences should be the first step, followed by reconstruction of Holocene crustal movements based on those RSL curves. Finally, there is a need to better understand the relationship of deformation during the 2011 Tohoku-Oki earthquake to long-term crustal movements and plate tectonics in the region.

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