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Variation in Forearc Basin Configuration and Basin-filling Depositional Systems as a Function of Trench Slope Break Development and Strike-Slip Movement: Examples from the Cenozoic Ishikari–Sanriku-Oki and Tokai-Oki–Kumano-Nada Forearc Basins, Japan

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Additional information is available at the end of the chapter

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1. Introduction

This chapter aims to elucidate variation of forearc basins in terms of basin configurations and basin-filling depositional systems with some examinations of their controlling factors, using actual examples from the Cenozoic forearc basins along the Northeast and Southwest Japan Arcs. Forearc basin is a sedimentary basin formed in the arc-trench gap between a volcanic arc and plate subduction zone (Figure 1) [1]. Although there are some notable past forearc basin studies (e.g., [1, 2]), the detailed characteristics of forearc basins have not been fully understood, since they show wide-range variation in styles, possibly reflecting various plate tectonic conditions at the plate subduction zone. As well-documented textbooks, Dickinson and Seely [2] and Dickinson [1] compiled and summarized the general outline of the forearc basin architecture and basin-filling sediments with explanations about some actual ancient and modern example forearc basins. The major contributions of these comprehensive textbooks include not only the presentation of various forearc basin styles, but also the explanation of related elements characterizing the forearc basin styles, such as dimension, subsidence, basin filling patterns, accretionary sill conditions and trench slope break development. Among these forearc basin elements, Dickinson [1] especially picked up two major elements: basin filling conditions and sectional basin configuration controlled by the relative height of trench slope break, to determine the morphological classification of forearc basins.

This chapter attempts to examine these two major factors: basin filling condition and basin configuration, by diagnosing two contrasting actual forearc basin packages around Japan: the Eocene Ishikari–Sanriku-oki forearc basins along the NE Japan Arc and the Pleistocene Tokai-oki–Kumano-nada forearc basins along the SW Japan Arc (Figure 2). To delineate the basin filling condition, we examine sedimentological characteristics including depositional systems, sequence stratigraphic contexts and related controlling factors. Regional seismic survey sections are used to manifest the basin configuration and to discuss controlling factors on forearc sedimentation for the two example forearc basins. In addition to these major factors, we discuss the role of strike-slip tectonics on the forearc basins, as it is reported in a former literature that strike-slip movement related to oblique plate subduction may affect the forearc basin tectonics and sedimentation.

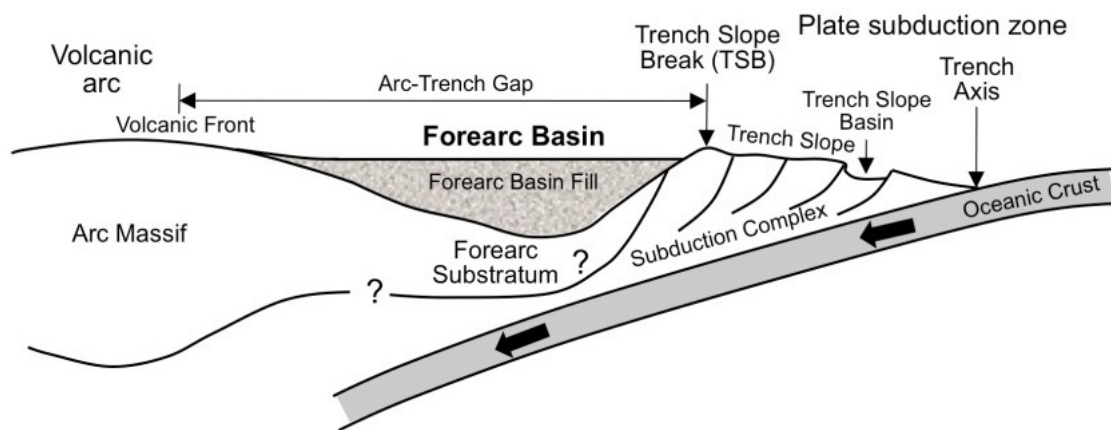


Figure 1. Schematic cross section of a forearc zone including a forearc basin, showing the basic terms used in this chapter. Modified after [1].

2. Eocene Ishikari–Sanriku-oki forearc basins

2.1. Geologic setting

The Eocene Ishikari–Sanriku-oki forearc basins were developed in the forearc zone along the NE Japan Arc (Figure 2A), which corresponds to the N-S trending narrow zone extending from the “Sorachi–Yezo Belt [3]” in central Hokkaido to the Pacific side offshore of northeast Honshu Island (Figure 2B). Although paleogeography around the NE Japan Arc was quite different from the present because the backarc basins of the NE Japan and Kuril Arcs had not opened [e.g., 4, 5], the tectonic history along the forearc zone during the Cretaceous to Paleogene can be summarized using the geologic evidences as follows. During the Cretaceous time, the eastern plates, which were regarded as the Izanagi and Kula Plates [4, 6], subducted underneath the western volcanic arc, and the forearc basin fully developed along this zone (Yezo Forearc Basin; Figure 2B [6, 7, 8]). During the Early Paleocene time, it is believed that a ridge between the Kula and Pacific Plates passed by along this forearc zone [5], causing total extinction of the forearc basins once. This tectonic event was widely recorded as “KT gap

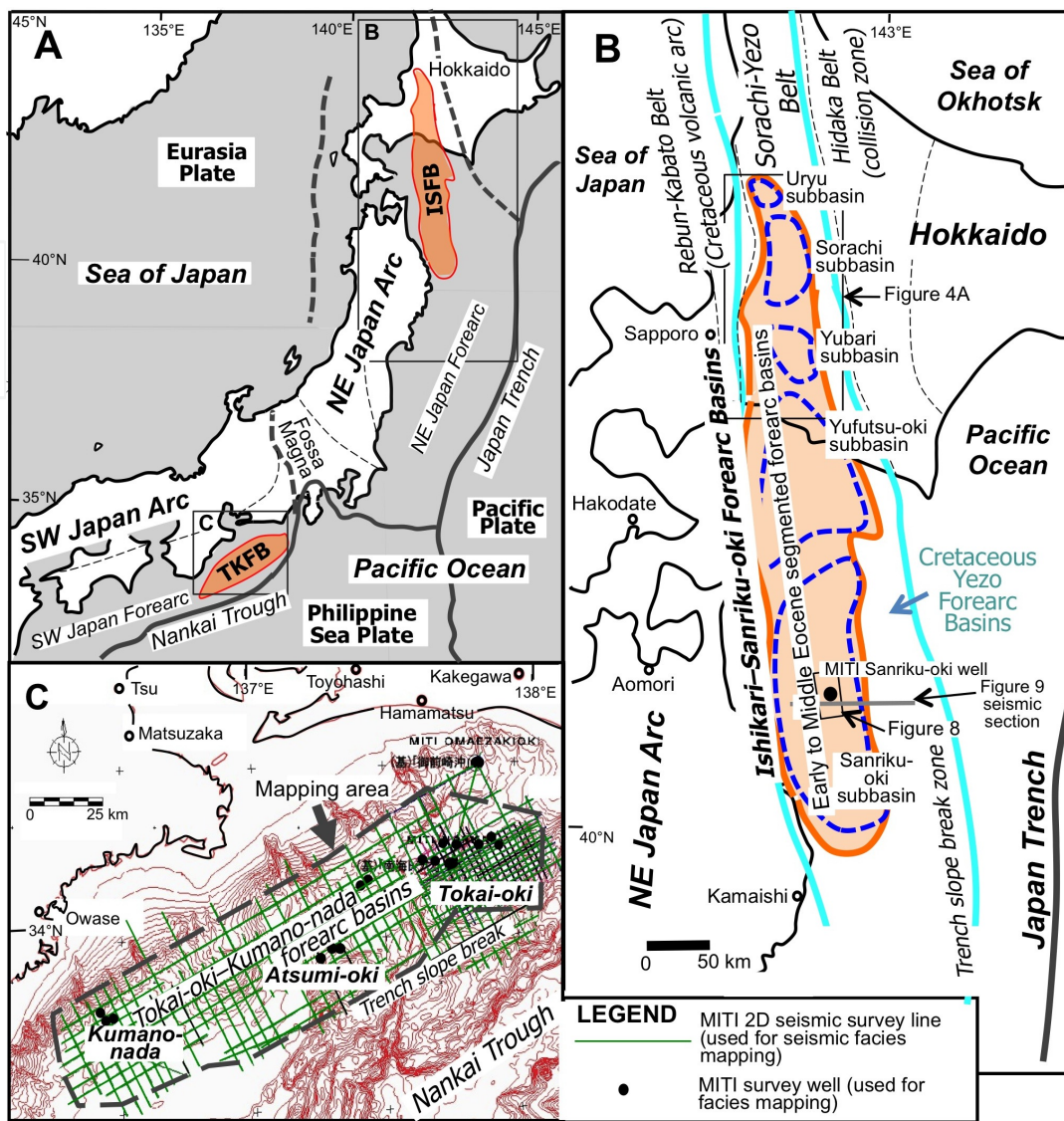


Figure 2. A) Index map showing the locations of two example forearc basins: Early to Middle Eocene Ishikari–Sanriku-oki forearc basins (ISFB) and Pleistocene Tokai-oki–kumano-nada forearc basins (TKFB). B) Close-up map showing the distribution of the Early to Middle Eocene Ishikari–Sanriku-oki forearc basins (orange lines) and the Cretaceous Yezo forearc basins (sky blue lines). The Eocene Ishikari–Sanriku-oki forearc basins are segmented into several subbasins (blue dashed lines). Compiled after [6, 8, 10, 11]. C) Close-up map of the Pleistocene Tokai-oki–Kumano-nada forearc basins, showing the mapping area and 2D seismic survey line positions used for seismic facies analysis. Modified after [23, 24].

unconformity [6, 8] (Figure 3)'' seen in sedimentary successions along the Sorachi-Yezo Belt and the Ishikari–Sanriku-oki forearc zone with a minor time transgressive trend of the unconformity development possibly related to the ridge passage [8, 9]. After this tectonic event, fragmented small basins sporadically developed along the Ishikari–Sanriku-oki forearc zone. The Eocene was a relatively widespread phase of forearc basins, extending from Sanriku-oki to central Hokkaido (Figures 2B, 3). These Eocene forearc basins were segmented into several subbasins: Sanriku-oki, Yufutsu-oki, Yubari, Sorachi and Uryu subbasins [10, 11] (Figure 2B).

This section picks up the Sorachi, Yubari and Sanriku-oki subbasins for examining the basin filling condition and basin configuration.

2.2. Sorachi and Yubari subbasins (Ishikari Group)

2.2.1. Stratigraphic framework

The Sorachi and Yubari subbasins are located in central Hokkaido (Figures 4), and situated near the northern end of the Eocene Ishikari–Sanriku-oki forearc basins (Figure 2B). The Sorachi and Yubari subbasins developed and started sedimentation at the early Middle Eocene time, and continued until the Early Oligocene time with some short breaks by unconformities [12] (Figure 3). This section focuses on the Middle Eocene Ishikari Group (Figure 3), which constitutes the major part of the Sorachi and Yubari subbasin fill.

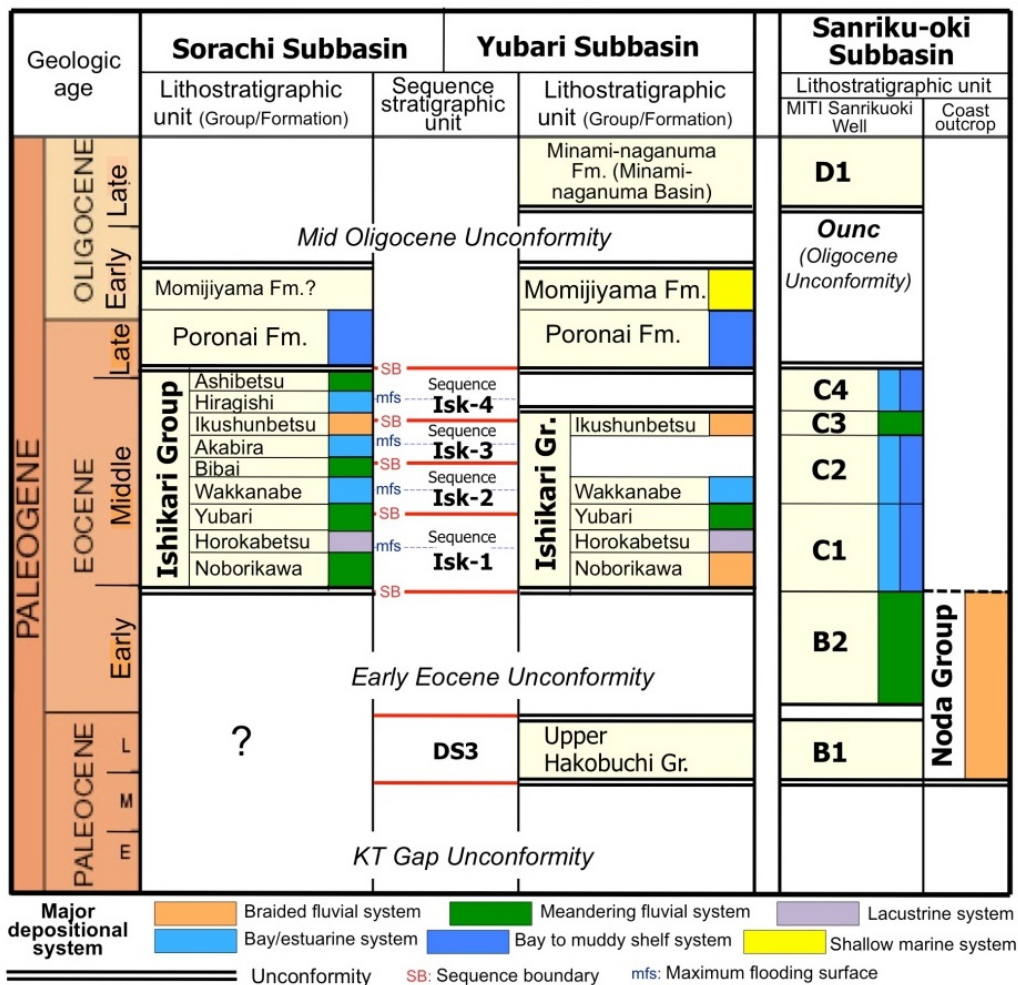


Figure 3. Generalized stratigraphic framework of the Paleocene, Eocene and Lower Oligocene in the Sorachi, Yubari and Sanriku-oki subbasins of the Ishikari–Sanriku-oki forearc zone. Colored columns beside the stratigraphic unit names denote the major depositional systems. This chapter mainly targets the Early to Middle Eocene basin fills. Compiled after [10–13, 15].

The Ishikari Group is divided into nine lithostratigraphic units: the Noborikawa, Horokabetsu, Yubari, Wakkanabe, Bibai, Akabira, Ikushunbetsu, Hiragishi and Ashibetsu Formations. From the standpoint of sequence stratigraphy, the Ishikari Group can be divided into four 3rd-order depositional sequences: Sequence Isk-1 to -4 in ascending order, and each depositional sequence is further divided into TST (transgressive systems tract) and HST (highstand systems tract), based on transgressive/regressive trends and marine incursion beds (Figures 3, 5) [11, 13]. In the Sorachi subbasin, the nine lithostratigraphic units are all developed, whereas in the Yubari basin, the Bibai, Akabira, Hiragishi and Ashibetsu Formations are absent, suggesting that the basin filling sedimentation was not continuous but episodic in the Yubari subbasin.

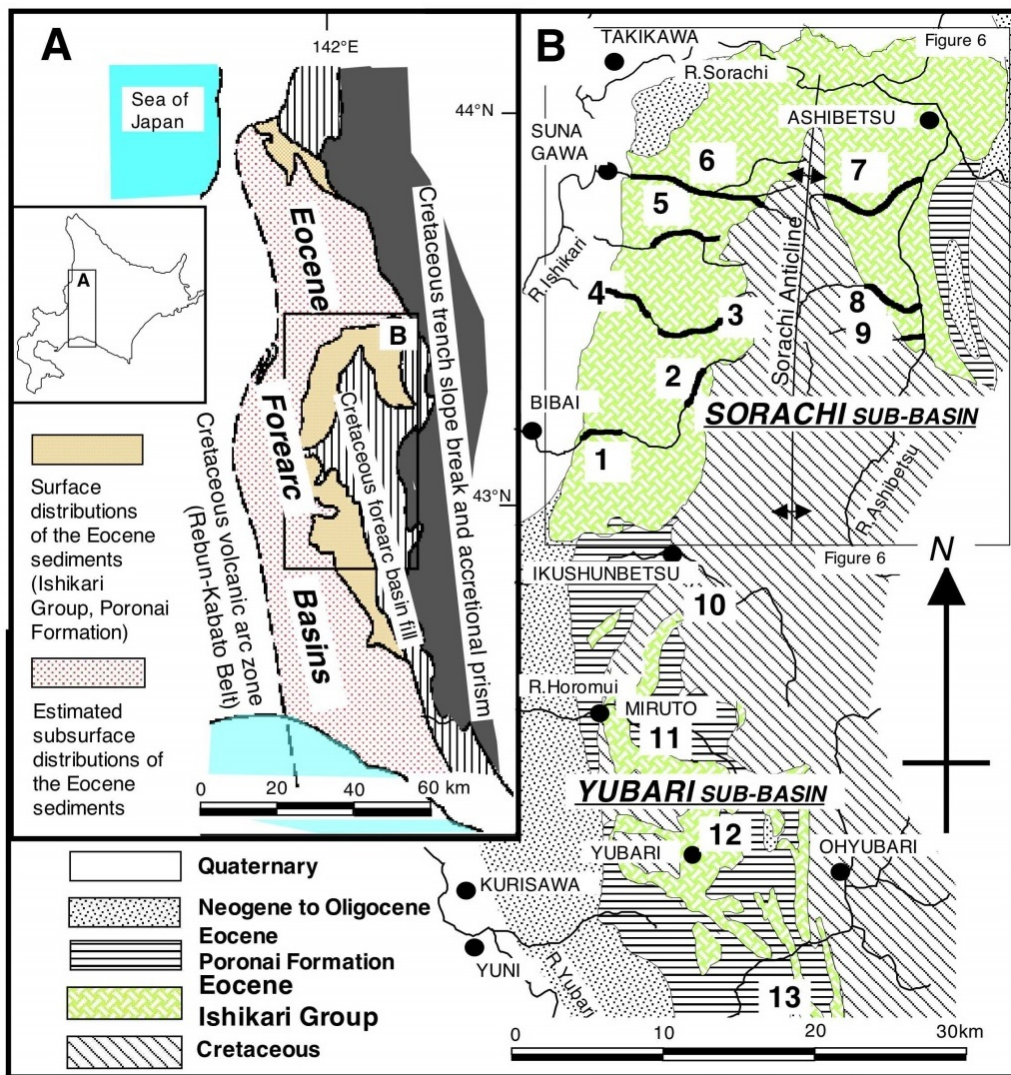


Figure 4. A) Geologic map showing the distributions of the Eocene forearc basin sediments in central Hokkaido, near the northern end of the Ishikari–Sanriku-oki forearc basins. B) Close-up geologic map showing the surface distributions of the Middle Eocene Ishikari Group in central Hokkaido. The Middle Eocene forearc basin in this area was segmented into the Sorachi subbasin on the north and the Yubari subbasin on the south. Numbers shown along rivers denote transect numbers of geologic survey, which correspond to numbers on the geologic cross section in Figures 5 and 7B. Modified after [11].

2.2.2. Depositional systems

Sedimentary facies analysis reveals that the Ishikari Group in the Sorachi and Yubari subbasins is composed of 24 sedimentary facies. These sedimentary facies are further assembled into five facies associations: braided fluvial facies association (BF), meandering fluvial facies association (MF), lacustrine facies association (LA), bay margin–estuarine facies association (ES) and bay center facies association (BA), as groups of sedimentary facies based on genetically related sedimentary environments and succession patterns [11, 13] (Figure 5). These five facies associations indicate that the Ishikari Group consists of five depositional systems: braided fluvial system, meandering fluvial system, lacustrine system, bay margin–estuarine system and bay system. Figure 5 depicts the schematic cross section showing the temporal and spatial distributions of depositional systems within the sequence stratigraphic framework in the Sorachi subbasin. As Figure 5 shows, the Ishikari Group mainly consists of a meandering fluvial system with some developments of a braided fluvial system. Lacustrine, bay margin / estuarine and bay center systems cyclically occur as marine incursion beds at around the maximum flooding surface of each 3rd-order depositional sequence.

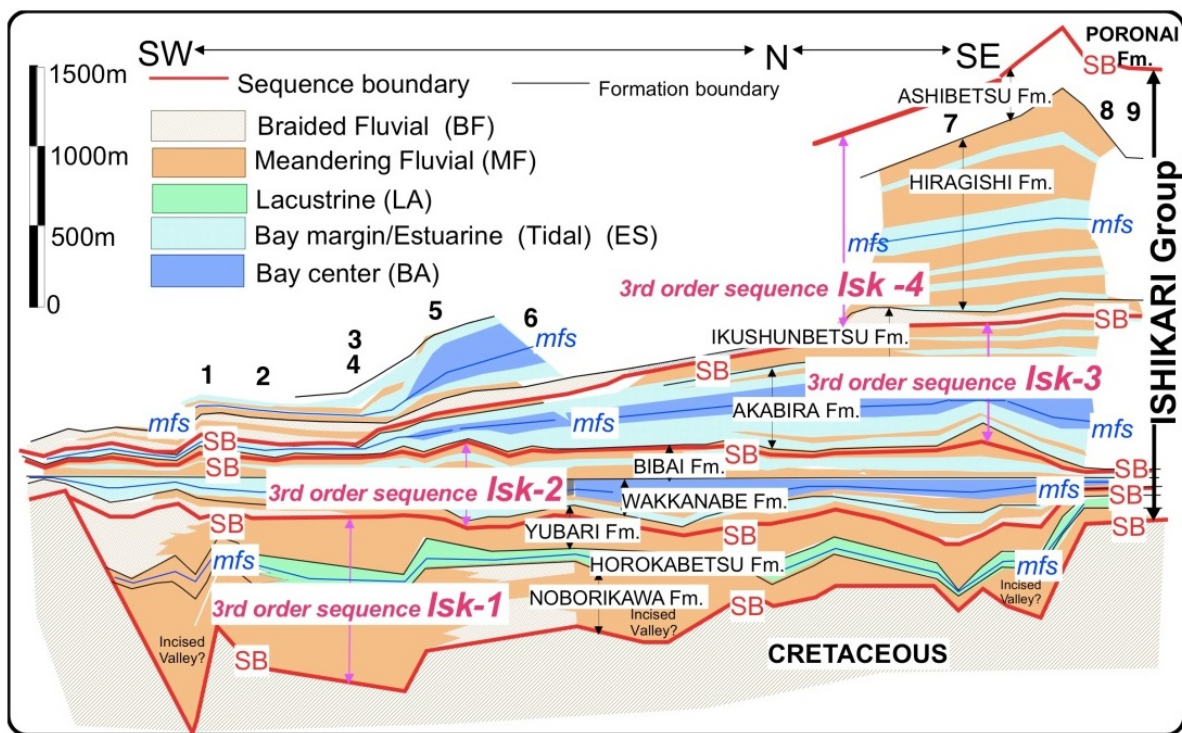


Figure 5. Schematic cross section of the Middle Eocene Ishikari Group in the Sorachi subbasin, showing sequence stratigraphic division and temporal and spatial distributions of depositional systems. Numbers above the cross section denote transect numbers of geologic survey shown in Figure 4B. Modified after [11, 13].

Figure 6 depicts facies maps showing spatial distributions of depositional systems for each systems tract of Sequences Isk-1 to -3. It is estimated that in response to relative sea level changes, the sedimentary environments in the Sorachi subbasin changed by cyclic transgression and regression. At the early phase of transgression and the late phase of regression,

braided and meandering fluvial environments were dominant, whereas at the maximum flooding phase, bay center and bay margin environments were dominant. These facies maps indicate that marine influence became strong northeastward, whereas terrestrial environments such as braided / meandering river environments were dominant in the southern or southwestern area of the Sorachi subbasin.

One of the notable characteristics of the depositional systems in the Ishikari Group in the Sorachi subbasin can be predominance of tidal deposits in a bay margin–estuarine system. Even though shallow marine condition periodically occurred during deposition, there are no wave-influenced sandy shallow marine facies such as foreshore and shoreface sandstone facies in the Ishikari Group. These facts indicate that the basin setting of the Sorachi subbasin was protected by wave action, and was not directly facing an open sea.

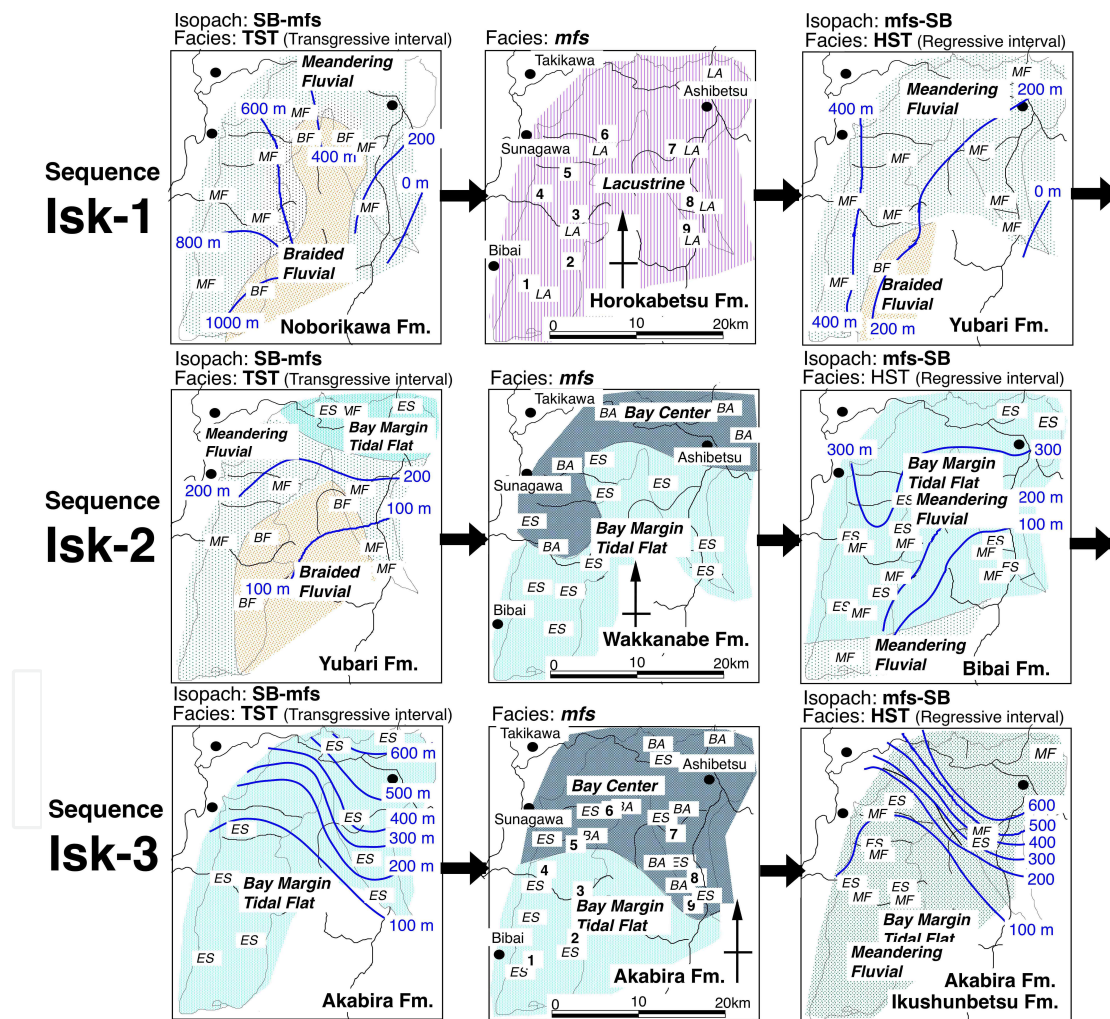


Figure 6. Spatial distribution maps of depositional systems in the Sorachi subbasin, showing paleogeographical changes for systems tracts (TST: transgressive interval; mfs: maximum transgression; HST: regressive interval) of 3rd-order Sequences Isk-1 to -3. Maps were created on the basis of facies association plots at the survey transect position. MF: meandering fluvial, BF: braided fluvial, LA: lacustrine, ES: bay margin–estuarine, BA: bay center. Blue contours denote isopach (iso-thickness) lines. Modified after [11].

2.2.3. Subsidence history

Figure 6 also depicts isopach contours for each systems tract of depositional sequences in the Sorachi subbasin. These isopach maps suggest that the thickness trend, indicating the depocenter, changed intermittently during deposition of the Ishikari Group. Since the depositional environments (altitude of deposition) in the Sorachi subbasin were more or less equivalent to a relative sea level or base level, it is regarded that the thickness trend indicates a spatial trend of total basin subsidence. Figure 7A demonstrates total subsidence curves of three different positions of the Sorachi subbasin, which were created on the basis of the thickness information. These isopach maps and total subsidence curves indicate that the western part of the subbasin rapidly subsided first. Subsequently during deposition of Sequence Isk-3 and -4, the northeastern part selectively subsided at a drastically rapid rate, and finally accumulated 3000 m-thick tidal-dominant deposits. Thus the Sorachi subbasin is characterized by a differential subsidence especially in the later half of the Ishikari Group deposition [11].

In addition to a differential subsidence within a subbasin, the subsidence patterns between subbasins show a notable difference. Figure 7B depicts the schematic cross section across the Sorachi and Yubari subbasins, showing a large thickness difference [14], possibly related to the difference in subsidence pattern as shown in Figure 7A. Accordingly, it is suggested that the segmented forearc basins in the Ishikari–Sanriku-oki forearc zone show highly variable subsidence patterns within and between subbasins.

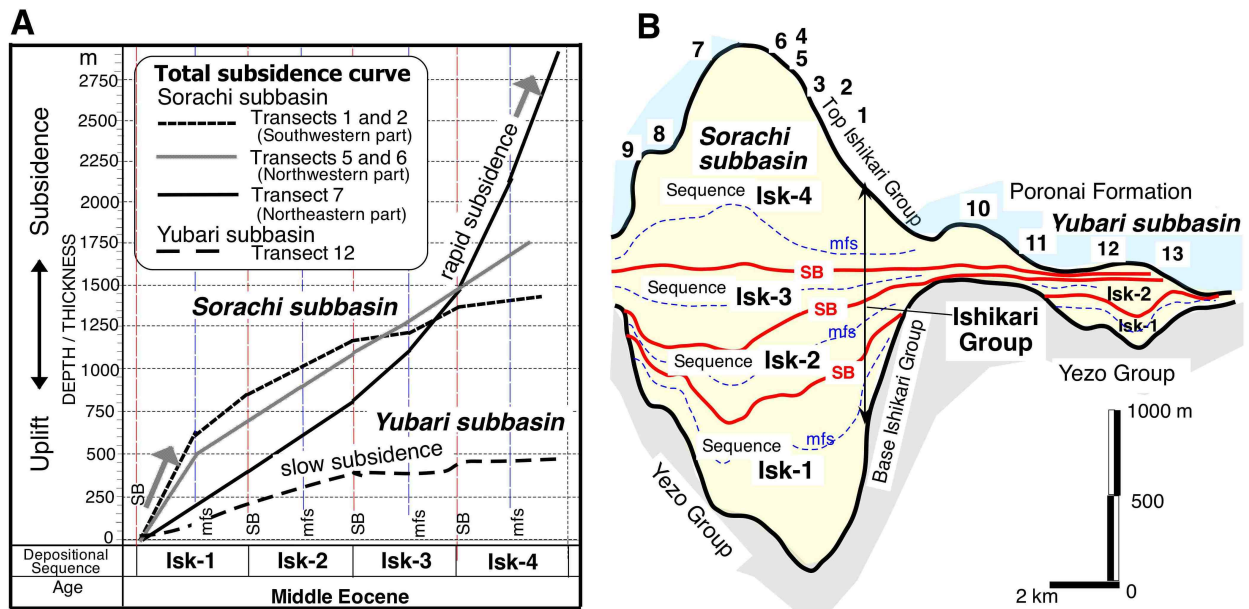


Figure 7. A) Diagram showing total subsidence histories along the selected transects during deposition of the Ishikari Group in the Sorachi and Yubari subbasins. Modified after [11]. B) Schematic sectional diagram showing thickness change of the Ishikari Group between the Sorachi and Yubari subbasins. Numbers above the Ishikari Group on the section denote transect numbers of surveys shown in Figure 4B. SB: sequence boundary, mfs: maximum flooding surface. Modified after [14].

2.3. Sanriku-oki subbasin

2.3.1. Stratigraphic framework

The Sanriku-oki subbasin is located in northeastern offshore of the Honshu Island, and situated near the southern end of the Eocene Ishikari–Sanriku-oki forearc basins (Figure 2B). After the K/T gap unconformity, the Sanriku-oki subbasin started basin-filling sedimentation in Late Paleocene time, and continued until the large-scale Oligocene unconformity (Ounc [10]) was formed (Figure 3). This section focuses on the Lower to Middle Eocene forearc basin-filling sediments, which are divided into the B2, C1, C2, C3 and C4 units [15] (Figure 3), for examining the depositional condition and basin configuration.

2.3.2. Depositional systems and basin setting

According to the MITI Sanriku-oki well report [15], the Lower to Middle Eocene successions in the Sanriku-oki subbasin are mainly composed of mudstone, sandstone and coal-bearing alternating beds of sandstone and mudstone, which were deposited in terrestrial, brackish and neritic marine environments. Figure 8 demonstrates interpreted seismic facies maps of the lower and upper intervals of the Lower Eocene B2 unit in the 3D seismic surveyed area, including the MITI Sanriku-oki well location, in the central part of the Sanriku-oki subbasin (Figure 2B). These seismic facies maps, which were displayed by different colors assigned for each “seismic trace shape” class, show intricate meandering, braided or partly networked fluvial channel zones and floodplain–back marsh zones.

Based on the sedimentary environment information from the MITI Sanriku-oki well and the seismic facies maps, it is interpreted that the B2 and C3 units consist mainly of a coal-bearing meandering fluvial system with minor bay center to bay margin systems as marine incursion beds, and the C1, C2 and C4 units consist mainly of bay to muddy shelf systems (Figure 3). Since all these component depositional systems resemble those of the Sorachi/Yubari subbasins, it is regarded that the Eocene Sanriku-oki subbasin was in a confined forearc setting, which was not directly facing an open sea and was protected by wave action. This basin setting during the Eocene time is supported by the basin configuration shown on a long 2D seismic section transecting the Sanriku-oki subbasin (Figure 9), in which the trench slope break prominently uplifted and eroded by Ounc (Oligocene Unconformity [10]), and the Cretaceous to Eocene basin-filling succession seems to be confined within the arcward side of the uplifted trench slope break. This confined forearc setting was terminated by the Ounc event, accompanied with seaward migration and large subsidence of the trench slope break, which finally caused transformation of the forearc basin setting from a fluvial to deep-marine slope condition as shown in the cross section in Figure 9. Consequently, it is regarded that the Sanriku-oki forearc basin setting was strongly controlled by the trench slope development.

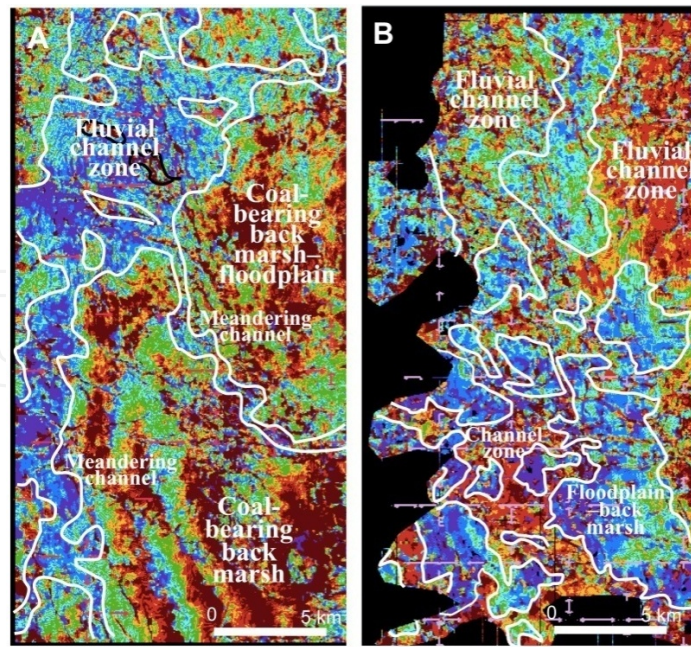


Figure 8. Seismic facies maps showing the distributions of a fluvial channel zone and a floodplain-back marsh zone in a meandering fluvial system in the central part of the Sanriku-oki subbasin. Map colors were assigned for each different seismic trace shape, which can indicate difference in sedimentary environment. A) Case of a lower horizon of the B2 unit. Bluish colors are interpreted as a channel zone on the basis of the seismic trace shape and distribution pattern. B) Case of an upper horizon of the B2 unit. Reddish colors are interpreted as a channel zone. The map location is shown in Figure 2B.

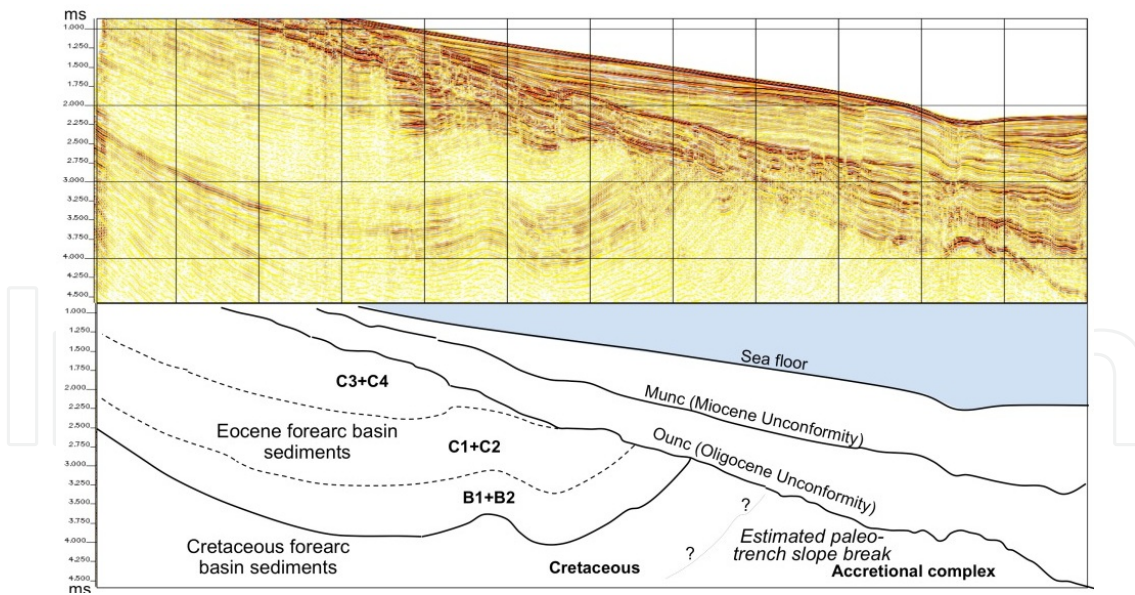


Figure 9. An E-W long 2D seismic section transecting the Sanriku-oki subbasin, showing trench slope break uplift and subbasin confinement. Although the present status of the Cretaceous to Eocene forearc basin fill and trench slope break seems to be inclined seaward, it is estimated that the trench slope break was more or less uplifted and emerged as a barrier because of the leaping-up morphology and fluvial-dominated environments in the Cretaceous to Eocene forearc basin-fill successions. The 2D seismic data were acquired in a MITI survey [16]. The seismic survey line location is shown in Figure 2B.

2.4. Forearc setting model

Based on the characteristics of depositional systems and basin configurations of the Sorachi, Yubari and Sanriku-oki subbasins, a forearc setting model of the Eocene Ishikari–Sanriku-oki forearc basins can be proposed as shown in Figure 10. The trench slope break ridge is estimated to have emerged above the sea along the eastern margin (subduction zone side) of the forearc basins, and formed a barrier to the open sea condition in the trench side of the trench slope break. This uplifted trench slope break condition is supported by previous petrography studies [17–19], which reveal that sandstones of the forearc basin fill (Ishikari Group) contain chrom-spinels derived from an emerged ridge of the Kamuikotan Belt. The N-S trending Kamuikotan Belt is distributed along the eastern margin of the forearc zone in Hokkaido (Sorachi–Yezo Belt), and mainly consists of serpentinite and various kinds of high pressure-type metamorphic rocks with tectonic mélanges, formed in an accretional prism [3, 20].

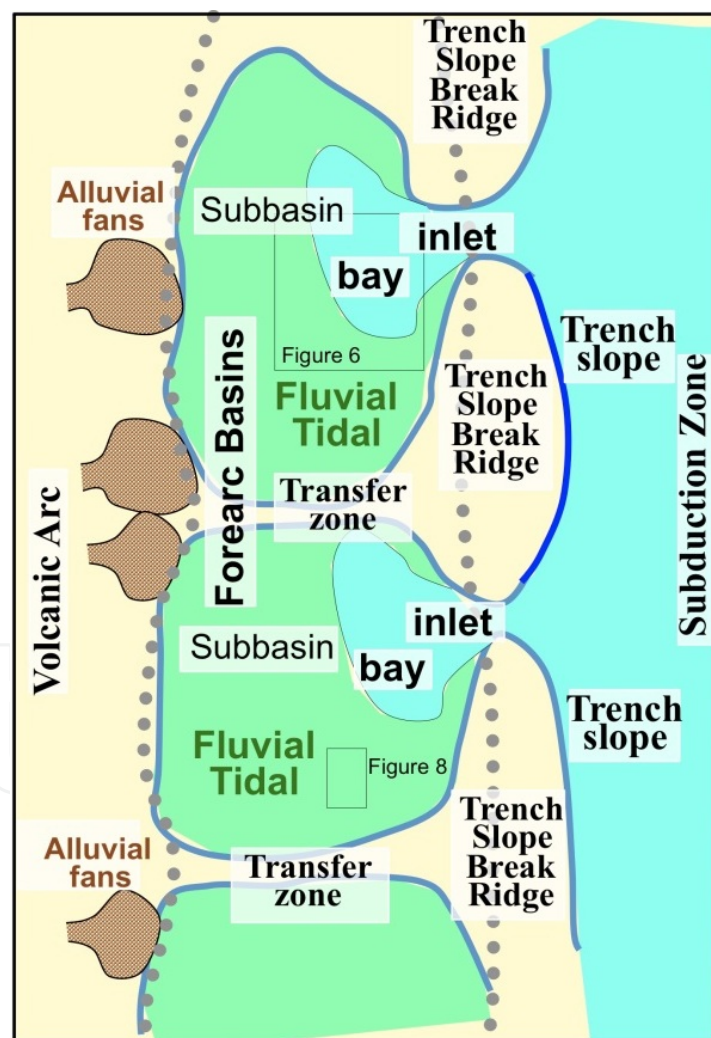


Figure 10. Schematic and conceptual forearc setting model for the Eocene Ishikari–Sanriku-oki forearc basins, including the Sorachi, Yubari and Sanriku-oki subbasins. Small rectangles inside the basin denote approximate positions of the mapped areas for the Sorachi subbasin (Figure 6) and the Sanriku-oki subbasin (Figure 8).

Inside the forearc basin, major depositional systems were bay to fluvial systems without any wave-influenced facies. In response to relative sea level changes, transgression and regression repeated, and the major depositional system alternated between a fluvial system-dominated condition and a bay system-dominated condition. Because of the existence of marine sediments, it is estimated that there were an inlet interconnecting between the open sea and the inside of the forearc basin, through which the seawater came into the inside of the forearc basin.

Our forearc setting model also demonstrates forearc basin segmentation, reflecting the fact that the Eocene Ishikari–Sanriku-oki forearc basins were segmented into 50 to 150 km long subbasins aligned along the forearc extension (Figure 2B). As described above, the segmented subbasins show a different subsidence pattern and different sediment thickness for each subbasin.

3. Pleistocene Tokai-oki–Kumano-nada forearc basins

3.1. Geologic setting and stratigraphic framework

The Pleistocene Tokai-oki–Kumano-nada forearc basins were developed in the forearc zone between the SW Japan Arc and the Nankai Trough subduction zone (Figures 2A, 2C). On the contrary to the sporadic developments of forearc basins during the late Paleogene and early Neogene time, thick sedimentary packages of the Late Pliocene to Pleistocene Tokai-oki–Kumano-nada forearc basins widely developed in this forearc zone. This section picks up the major basin-filling sediments equivalent to the Late Pliocene to Early Pleistocene Kakegawa Group (Atsumi-oki Group [21]) and Middle Pleistocene Ogasa Group (Hamamatsu-oki Group [21]; Figure 11) to examine the basin filling conditions and basin configurations. The Kakegawa Group unconformably overlies the underlying units with a certain time gap, indicating the different phase of forearc basin tectonics, and the Ogasa Group unconformably overlies the Kakegawa Group, indicating a tectonic event between depositions of the two groups. The study area is set between the Present continental slope toe and the trench slope break zone, which covers the Tokai-oki, Atsumi-oki and Kumano-nada areas (Figure 2C). From the standpoints of sequence stratigraphy and sedimentology, the targeted forearc sediments are divided into seventeen depositional sequences: Sequence Kg-a to -h and Og-a to -i, based on reflection termination patterns on the seismic sections and facies succession patterns on the well successions [22, 23](Figure 11). The major depositional system of the whole interval is a submarine fan turbidite system [22, 23].

3.2. Transformation of depositional styles

Takano et al. [22] demonstrated a series of facies maps in the Tokai-oki–Kumano-nada forearc basins for each depositional sequence unit for the interval equivalent to the Kakegawa and Ogasa Groups (Figure 12). These facies maps were created on the basis of seismic facies information plotted on the seismic survey line maps as well as some exploration well data (Figure 2C) [22–25]. These facies maps clearly show the depositional patterns of submarine fans, indicating that quite a few numbers of submarine canyons from the main land of Japanese

Geologic age		Lithostratigraphic unit	Sequence stratigraphic unit	(Sequence Boundary)	Depositional system	
Pleistocene	Late	Ogasa Gr.-equivalent Hamamatsu-oki Gr.	Sequence Og-i	SB Og-i	Submarine fan system	
			Sequence Og-h	SB Og-h		
			Sequence Og-g	SB Og-g		
			Sequence Og-f	SB Og-f		
			Sequence Og-e	SB Og-e		
			Sequence Og-d	SB Og-d		
			Sequence Og-c	SB Og-c		
			Sequence Og-b	SB Og-b		
	Middle	0.9 Ma	Ogasa Gr.-equivalent Hamamatsu-oki Gr.	Sequence Og-a		SB Base Ogasa
				Sequence Kg-h		SB Kg-h
	Early	?	Kakegawa Gr.-equivalent Atsumi-oki Gr.	Sequence Kg-g		SB Kg-g
				Sequence Kg-f		SB Kg-f
				Sequence Kg-e		SB Kg-e
				Sequence Kg-d		SB Kg-d
Sequence Kg-c				SB Kg-c		
Sequence Kg-b				SB Kg-b		
Late	?	Kakegawa Gr.-equivalent Atsumi-oki Gr.	Sequence Kg-a	SB Kg-a		
			Sagara Gr.			

Figure 11. Litho- and sequence stratigraphic framework of the latest Pliocene to Pleistocene successions in the Tokai-oki–Kumano-nada forearc basins. Modified after [22, 23].

Islands functioned as fixed feeder systems, along which submarine fans were formed in the forearc basins (Figure 12). These facies maps also suggest that submarine-fan architecture was intermittently transformed through time (Figure 12)[22, 26]; from a braided channel-dominated condition (Stage 1 represented by the map of Sequence Kg-a), through a small fan-dominated condition with shrinking separated small basins (Stage 2 represented by the map of Sequence Kg-e), and a trough-fill turbidite-dominated condition (Stage 3 represented by the map of Sequence Og-e), to a channel-levee system-dominated condition (Stage 4 represented by the map of Sequence Og-h). Although the submarine-fan architecture was transformed temporary, some spatial differences in depositional patterns between the Tokai-oki, Atsumi-oki and Kumano-nada areas can also be recognized (Figure 12), possibly resulting from forearc basin segmentation and sediment supply variation.

3.3. Transformation of basin configuration and background tectonics

To examine the relationships between the changes in the submarine-fan depositional styles and basin configuration, which may be indicating the background tectonics, we investigated seismic sections transecting the Tokai-oki–Kumano-nada forearc basins. Figure 13 depicts the interpreted cross sections with depositional stage division characterized by the different submarine-fan depositional styles as mentioned above. The interrelationships between the geologic structures and sediment thickness change shown on these cross sections reveal that the depositional stage division can be connected with tectonic phases that created specific

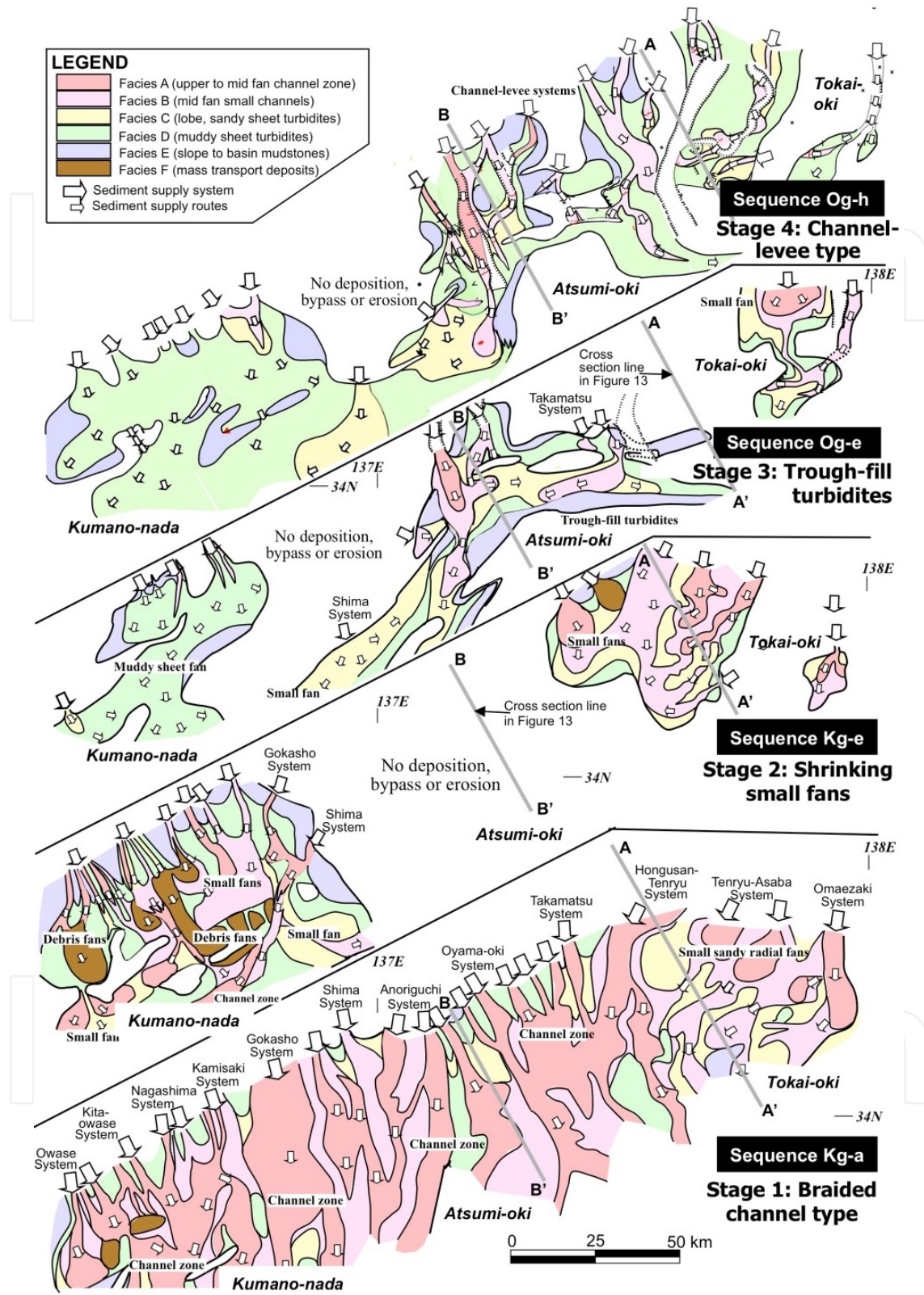


Figure 12. Facies maps of Sequence Kg-a, -e, Og-e and -h in the Tokai-oki-Kumano-nada forearc basins, showing the transformation of submarine-fan morphology and distributions. Modified after [22]. The mapping area is shown in Figure 2C.

geologic structures related to basin configuration (Figures 13, 14). Since the Stage 1 sediments show a mostly uniform thickness and a braided channel-dominated condition, the forearc basin during Stage 1 (Late Pliocene to earliest Pleistocene) is interpreted to have been a gently inclined, sloped basin without major topographic undulation, which is characteristic of an incipient phase of forearc basin development [27]. Stage 2 (Early Pleistocene) is interpreted as a compressional stress stage with trench slope break uplift, since only limited synclinal areas contain thick sediments, and the depositional areas shrunk continuously. Stage 3 (Middle Pleistocene) can be a relaxing phase, which induced subsidence of folded forearc basins, since the sedimentation is characterized by trough-fill (syncline-fill) turbidite systems and the depositional territory became wider gradually. Stage 4 (Middle to Late Pleistocene) can be a compressional stress stage again, as trench slope break prominently uplifted as shown on the section B–B' in Figure 13.

Consequently, it is suggested that during the Pleistocene time, two compressional phases occurred in response to trench slope break uplift and arcward suppression, and the forearc depositional styles were strongly controlled by these tectonic events.

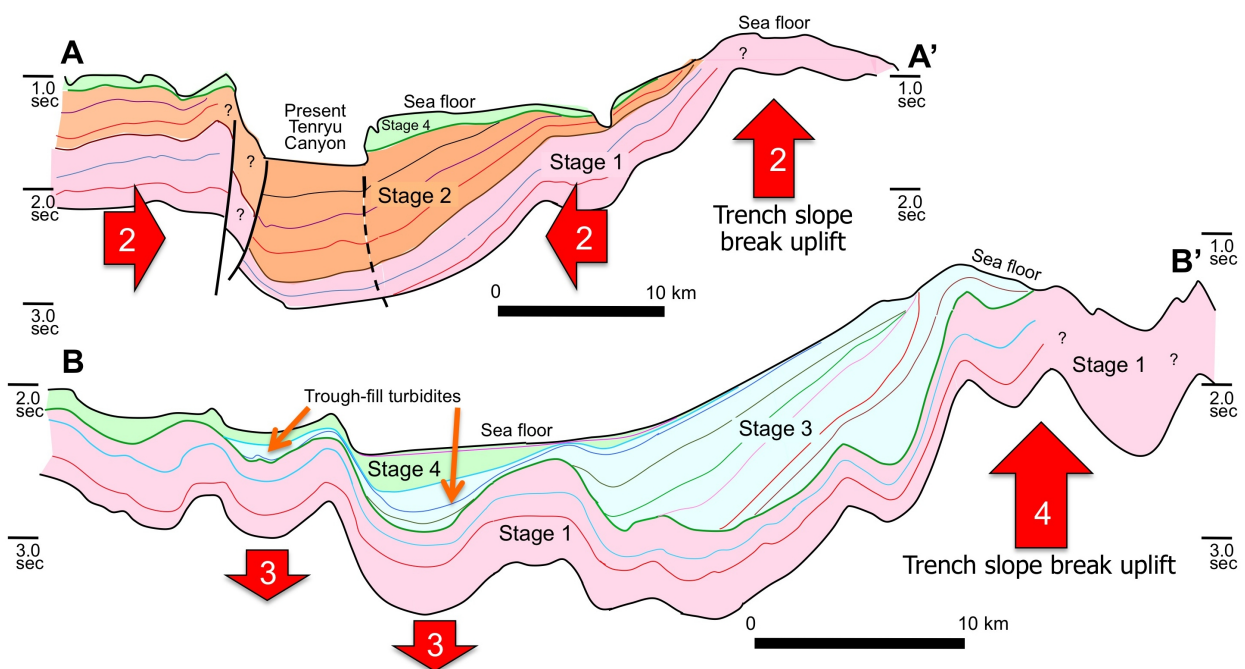


Figure 13. Cross sections based on the interpreted seismic sections transecting the Tokai-oki-Kumano-nada forearc basins, showing the basin deformation and background tectonics during Stages 2, 3 and 4. Traced lines on the cross sections denote sequence boundary (SB) horizons corresponding to those of Figure 14 in line colors. The section locations (seismic survey lines) are shown on the maps in Figure 12. Seismic sections were acquired in a MITI (Ministry of International Trade and Industry of Japan) survey [24]. Large red arrows denote compression and uplift during Stage 2, subsidence during Stage 3 and uplift during Stage 4.

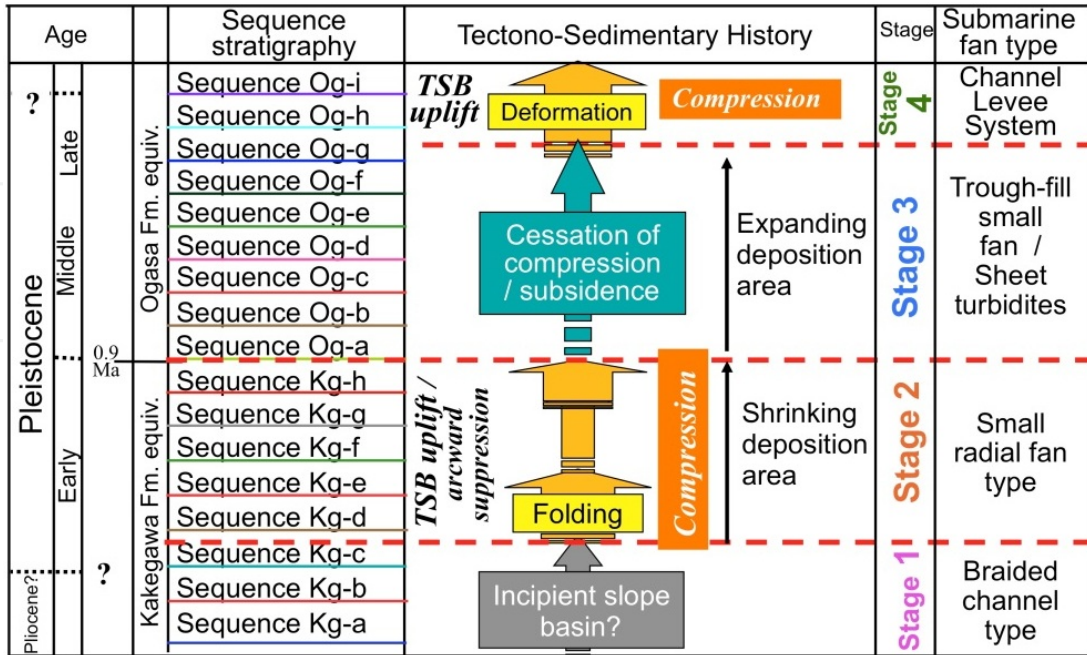


Figure 14. Generalized summary chart showing the transformation of the tectono-sedimentary conditions and submarine-fan types of the Pleistocene Tokai-oki-Kumano-nada forearc basin fill. Compiled and modified after [23, 26].

4. Discussion

4.1. Comparison with Dickinson’s forearc basin classification scheme

Dickinson’s simple classification scheme for forearc basin morphology [1] is based on the basin filling conditions and sectional basin configurations basically controlled by trench slope break height (Figure 15). Since the basin filling condition comprises two classes: underfilled and overfilled, and the sectional basin configuration comprises four classes: sloped, ridged/terraced, ridged/shelved and ridged/benched, depending on the trench slope break height, forearc basins can be classified into eight different types in the Dickinson’s classification scheme [1] (Figure 15). According to our analysis results, the Eocene Ishikari-Sanriku-oki forearc basins can be categorized into the “emergent ridged”, “overfilled shelved” to “benched” types (Figure 15), as it is interpreted that the trench slope break was uplifted and emerged, and the major sedimentary environments were mostly near the sea level except partly developed braided rivers in an elevated setting. On the contrary, the Pleistocene Tokai-oki-Kumano-nada forearc basins can be categorized into the “overfilled sloped”, “underfilled submerged ridged” to “overfilled deep marine terraced” types (Figure 15), as the estimated trench slope break was submerged and low, and the major sedimentary environments were submarine fans and muddy slope to basin floor.

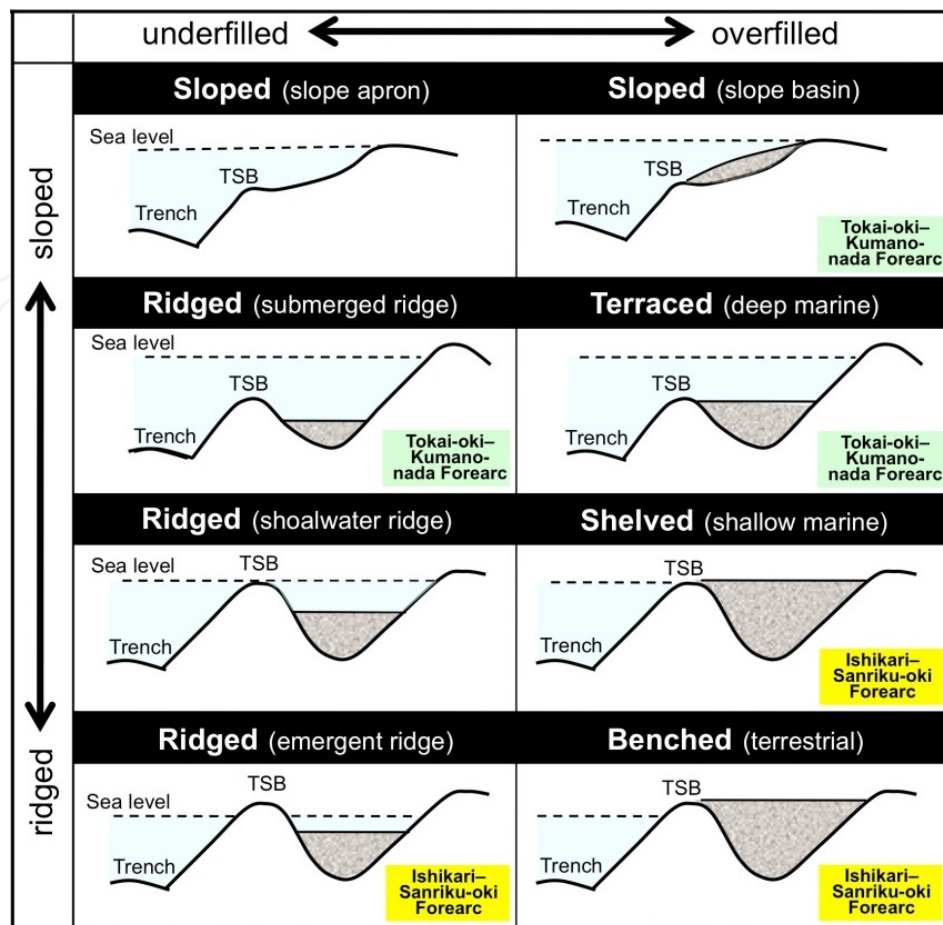


Figure 15. Dickinson's forearc basin classification chart on the basis of basin filling conditions and sectional basin configuration. Modified after [1]. TSB: trench slope break.

4.2. Controlling factors on the variation in forearc basin styles

This section attempts to discuss major controlling factors on the variation in forearc basin configurations and depositional systems on the basis of the results of the examinations above (Figures 16, 17).

4.2.1. Trench slope break development

Trench slope break is a topographic high bounding the forearc basin to a trench slope steeply dipping to the subduction zone (Figure 1). As the Dickinson's forearc basin classification places great importance [1] (Figure 15), the results of our examination also indicate that the development condition of a trench slope break is the most principal factor to control the forearc basin configurations and basin filling depositional systems. In case the trench slope break development is minor or moderate as seen in the Tokai-oki-Kumano-nada forearc basins, the trench slope break ridge is submerged, and the basin filling sediments tend to be deeper marine shales or turbidites. On the other hand, in case the trench slope break prominently develops as seen in the Ishikari-Sanriku-oki forearc basins, the trench slope break ridge is emerged, and

the basin filling depositional systems tend to be fluvial to bay systems if sediment supply is enough. Dickinson [1] suggests that the trench slope break development is strongly related to differences in plate subduction conditions such as accretional prism formation and tectonic erosion.

In addition to the height of a trench slope break, related arcward suppression accompanied with the trench slope break uplift is also regarded as an important factor to control basin deformation as seen in the Tokai-oki–Kumano-nada forearc basin (Figure 13).

4.2.2. Balance between basin accommodation and sediment supply

Even in a fully uplifted trench slope break setting, a condition under minor sediment supply or relatively rapid subsidence causes a deeper marine forearc basin. The Ishikari–Sanriku-oki forearc basins maintained a balanced condition between the amount of sediment supply and the basin accommodation space, causing a thick accumulation of fluvial to bay sediments. Accordingly, it is suggested that the balance between sediment supply and forearc basin accommodation created by a trench slope break barrier and basin subsidence [28] (total subsidence) can be a crucial controlling factor not only on the forearc basin filling conditions such as underfilled and overfilled conditions but also on the variation of depositional systems. Dickinson [1] suggests that the underfilled types mostly occur along an island arc with a small amount of sediment supply, whereas the overfilled types mostly occur along a continental arc with a large amount of sediment supply.

4.2.3. Strike-slip movement related to basin segmentation

Our examination results suggest that a forearc zone is commonly segmented into subbasins. The Ishikari–Sanriku-oki forearc basins were segmented into 50 to 150 km long subbasins aligned along the forearc extension (Figure 2B). The Tokai-oki–Kumano-nada forearc basins are also possible to have been segmented as suggested by Sasaki et al. [29] and as seen in the facies maps (Figure 12), in which the sedimentary packages tend to be segmented into the Tokai-oki, Atsumi-oki and Kumano-nada possible subbasins. As described above, the segmented subbasins show a different subsidence pattern and sediment thickness for each subbasin (Figures 7, 13), and differential subsidence within a subbasin is characteristically observed (Figures 6, 7).

As a possible formation mechanism of forearc segmentation, Dickinson [1] suggests strike slip tectonics along a forearc zone, induced by oblique plate subduction underneath a forearc zone. As many of plate subduction direction at the convergent margin tend to be not complete normal direction to the subduction trench, oblique plate subduction is quite common. The oblique subduction may induce a strike-slip motion of forearc sliver and basin segmentation as seen in the Sumatra forearc and Aleutian forearc [1].

To examine the effect of strike-slip motion on the forearc basin segmentation, Kusumoto et al. [30] conducted dislocation modeling for basin segmentation, using the Sorachi and Yubari subbasins as examples. Dislocation modeling is to simulate basin dislocation by fault movement with the assumption of a homogeneous elastic body. Kusumoto et al. [30] picked up fault

arrays around the subbasins, which indicate a strike-slip fault system consisting of main faults and splay faults, and set them in the model. When right-lateral motion occurred along the main faults, then the subbasins corresponding to the Sorachi and Yubari subbasins were properly simulated in the modeling [30]. This result suggests that the forearc basin segmentation was caused by strike-slip tectonics along the forearc zone.

Consequently, strike-slip tectonics is also one of the crucial factors to determine basin configuration and depositional system distributions in a forearc zone (Figures 16, 17). Figure 17 demonstrates schematic diagram showing type variations of forearc basins as functions of trench slope break development, arcward compression and strike-slip movement. In addition to the Dickinson's forearc basin classification scheme (Figure 15), this study delineates that both arcward compression and strike-slip movement are crucial factors in forearc basin classification. In case arcward compression is intense due to trench slope break evolution, a confined shrinking or trough-fill type forearc basin can be formed, as seen in Stages 2 and 3 in the Tokai-oki-Kumano-nada forearc basins (Figures 12, 13, 14). In case strike-slip movement is dominant, a segmented marine or non-marine forearc basins can be formed, as seen in the Sorachi and Yubari subbasins (Figures 5, 10). When strike-slip movement is intense, the forearc basin can be transformed into a fragmented strike-slip basin.

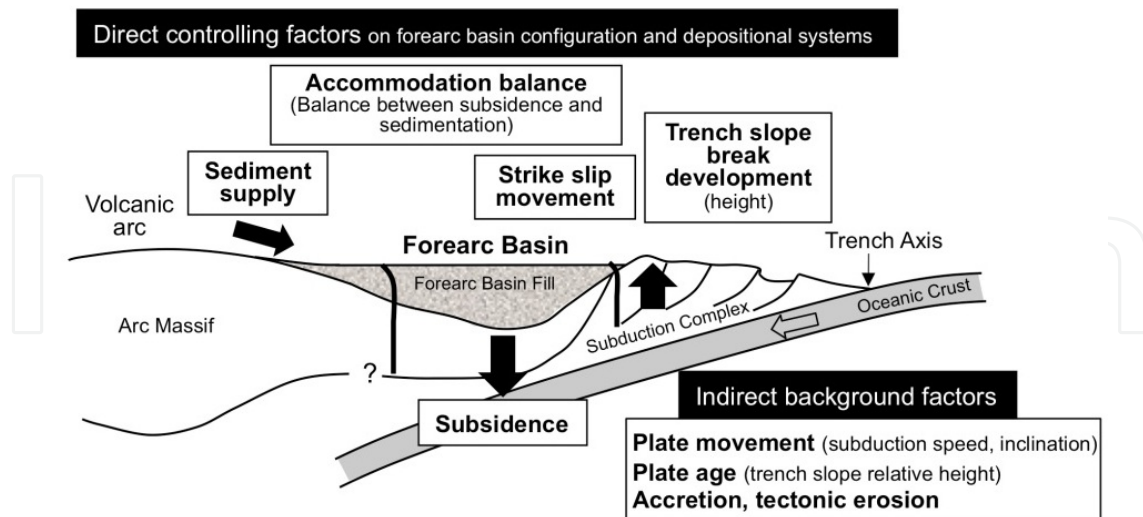


Figure 16. Controlling factors on variation in forearc basin configuration and depositional systems.

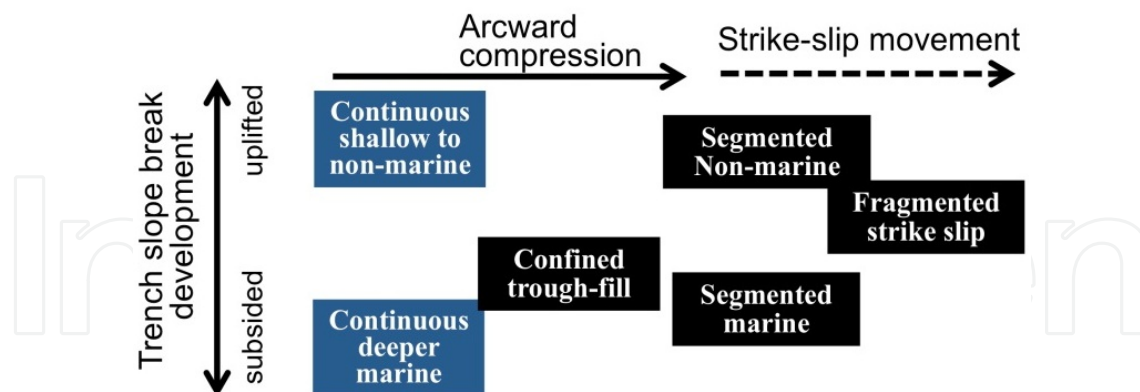


Figure 17. Schematic diagram showing type variations of forearc basins as functions of trench slope break development, arcward compression and strike-slip movement. Arrow direction denotes intensity of each factor.

5. Conclusions

To elucidate forearc basin variation and its controlling factors, the basin configurations and basin-filling depositional systems were examined for actual examples from the Eocene Ishikari–Sanriku-oki forearc basins and the Pleistocene Tokai-oki–Kumano-nada forearc basins. As the results, the following points were revealed.

1. The Ishikari–Sanriku-oki forearc basins are filled with aggradational sediments consisting of bay to fluvial systems. Since the trench slope break is estimated to have uplifted and emerged to form a barrier to an open sea condition, the Ishikari–Sanriku-oki forearc basins can be categorized into the “emergent ridged”, “overfilled shelved” to “benched” types of Dickinson’s forearc basin classification [1]. Basin segmentation is commonly observed, and the subsidence pattern is different between subbasins.
2. The Tokai-oki–Kumano-nada forearc basins are filled with continuously changing submarine-fan systems. Since the trench slope break is estimated to have submerged, the Tokai-oki–Kumano-nada forearc basins can be categorized into the “overfilled sloped”, “underfilled submerged ridged” to “overfilled deep marine terraced” types [1].
3. Our examination results suggest that the major controlling factors on the forearc basin configurations and depositional systems include a) the trench slope break condition such as development height and arcward suppression, b) the balance between basin accommodation and sediment supply, c) and the strike-slip movement of forearc sliver, inducing forearc basin segmentation. Although the Dickinson’s forearc basin classification [1] is effective, two factors of arcward compression and lateral-slip movement should be added for useful classification (Figure 17).

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