Forearc Tectonics and Tentative Plate-tectonic Synthesis for Jurassic – Cretaceous Hokkaido, Japan

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ABSTRACT

Plate-tectonic synthesis for Middle Jurassic - Late Cretaceous Hokkaido, Japan is tentatively but first presented. Middle Jurassic eastward subduction beneath the margin of Asian Continent produced accretionary body of characteristic continental clastic supply. Jump of trench to the east in the earliest Cretaceous age caused a wide forearc basin and volcanic-arc activity. During early Late Cretaceous, uplift and emergence of high-pressure type metamorphosed part of accretionary body occurred inside of the forearc, and formed local unconformity in the forearc sequence. This process shows growth and evolution of the eastern margin of Asian Continent before the Neogene opening of the Japan Sea. Geologic information given from forearc units is important for understanding the tectonics of arc-trench system.

Keywords: Forearc, Plate-tectonics, Cretaceous Hokkaido, Clastic supply, Unconformity

GEOLOGIC FRAMEWORK OF HOKKAIDO

The tectonic history of Jurassic-Cretaceous Hokkaido can be summarized in a plate-tectonic framework of westward subduction. Pre-Eocene geologic division of Hokkaido is represented as; Oshima, Rebun-Kabato, Sorachi-Yezo, Hidaka, Tokoro and Nemuro Belts, from west to east (Fig. 1). The Oshima, Sorachi-Yezo and Hidaka Belts are accretionary complexes showing eastward-younging polarity formed by westward subduction. The age of accretion, indicated by the age of clastic rocks or matrix of chaotic facies, ranges from Middle Jurassic to Early Paleogene, from west to east (Fig. 2). The Rebun-Kabato Belt is recognized as an Early Cretaceous volcanic arc. The Sorachi-Yezo Belt includes a widely distributed forearc sequence, the Yezo Supergroup.

The Tokoro and Nemuro Belts in eastern Hokkaido, and the eastern half of the Hidaka Belt are excluded from this article because they are considered to be related to an eastward subduction system of less known tectonic framework. West of the Oshima Belt, Cretaceous on-land volcanics and felsic plutons are distributed in Okushiri Island, but their geologic setting and significance are little known.

OVERVIEW

Jurassic to Cretaceous tectonics of Hokkaido can be expressed by these four topics;

1) Jurassic Oshima accretionary belt with characteristic Precambrian continental clastic supply.
2) Jump of subduction zone led to the formation of a wide Yezo Forearc Basin, which is floored by trapped oceanic plate.
3) Appearance of Early Cretaceous Rebun-Kabato Volcanic Arc influenced clastic sedimentation of the forearc.
4) Uplift of high-pressure type metamorphics inside the forearc resulted in the Middle Yezo

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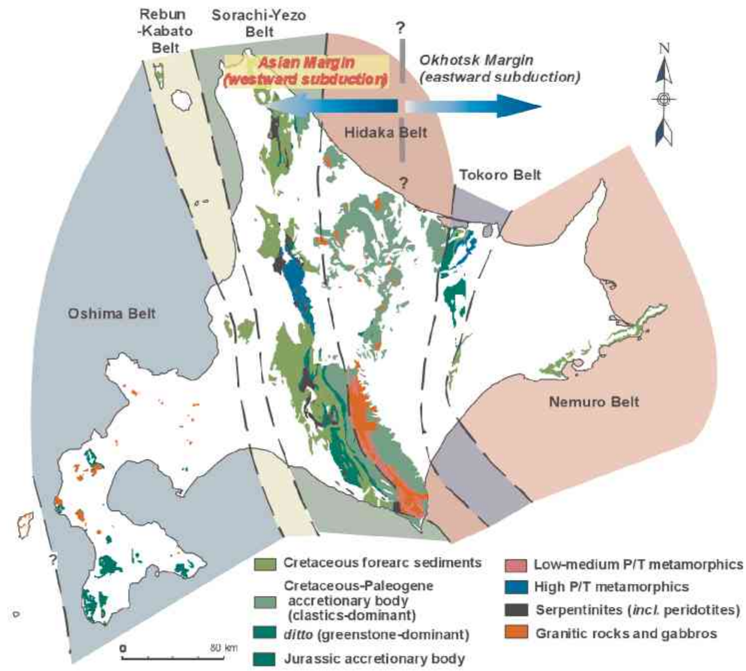

Fig. 1 Pre-Eocene geologic division of Hokkaido

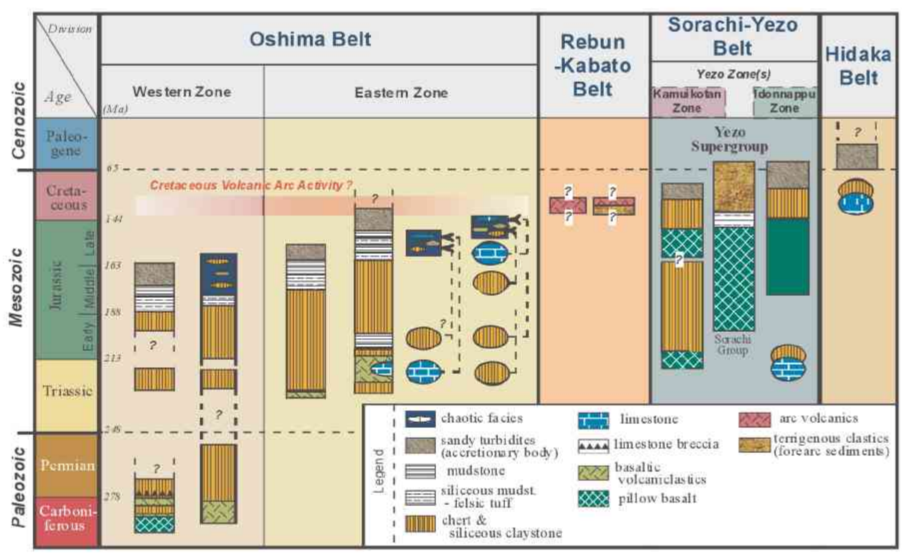

Fig. 2 Tectonostratigraphy of pre-Eocene Hokkaido

Unconformity.

Significance of Forearc Tectonics

Forearc is an interface domain between oceanic plate and continental to island-arc region. Hence, the descriptive knowledge of forearc geological process is very important for understanding the arc-trench tectonism and also the long-term tectonic change in time scale of 10–100 Ma order.

PLATE-TECTONIC SCHEME OF JURASSIC - CRETACEOUS HOKKAIDO

Plate-tectonic scheme of Jurassic-Cretaceous Hokkaido can be tentatively summarized as follows (Fig. 3).

Pre-Late Jurassic (> 150 Ma): An accretionary belt (Oshima Belt) was formed by westward subduction of oceanic plate beneath the Asian Continent. It

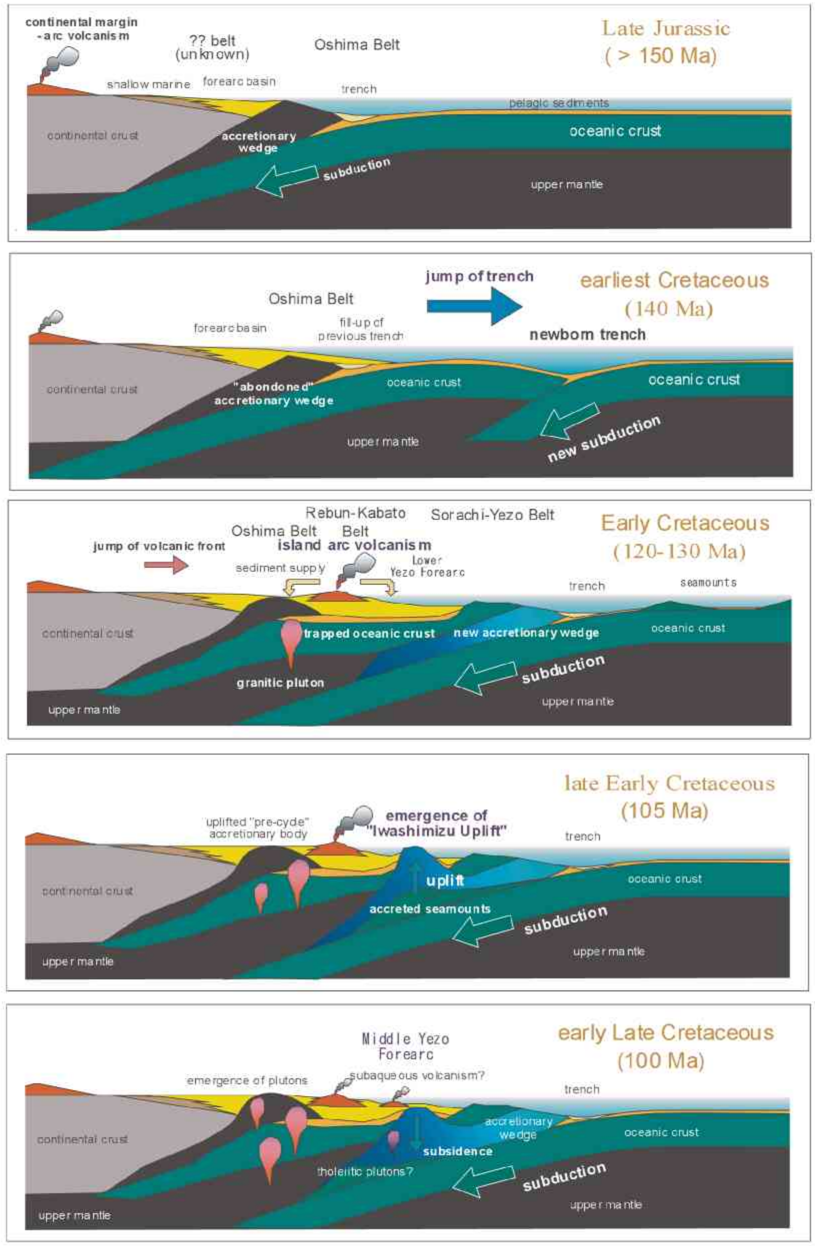

Fig. 3 Plate-tectonic scheme of Jurassic - Cretaceous Hokkaido

is a starting steady state for this tectonic scheme. Forearc region neighboring the accretionary belt was missing, owing to later Neogene opening of the Japan Sea.

Earliest Cretaceous (140 Ma): An eastward jumping of trench occurred [1]. Between the newborn trench and the former trench, wide forearc area floored by trapped oceanic plate was formed.

Early Cretaceous (120–130 Ma): The new subduction caused an island-arc volcanism (Rebun-Kabato Belt) in the forearc region. The island arc supplied volcanic detritus to the easternmost part of the Oshima Belt, as well as the Yezo Forearc Basin to the east.

Late Early Cretaceous (105 Ma): Rapid uplifting of a part of high-P/T metamorphic body occurred. As a result, the Iwashimizu Uplift emerged in the middle of the Yezo Forearc.

Early Late Cretaceous (< 100 Ma): The uplifted region subsided after a relatively short duration and the Middle Yezo Group covered it. The Middle Yezo Unconformity was thus formed.

CONTINENTAL CLASTIC SUPPLY DURING JURASSIC

Terrigenous clastic rocks of the Oshima Belt represent trench-fill turbidite sequence. They indicate the age of accretion, mainly of Middle to Late Jurassic. The turbidite sandstone of the sequence shows characteristic high-silica nature resulted from continental clastic supply.

Trench-fill Quartz-rich Turbidite

The trench-fill turbidites are composed of the alternation of sandstone and mudstone. Under microscope, the Oshima sandstone shows very felsic nature, rich in quartz as well as plagioclase grains, potassium feldspar and polycrystalline quartz grains (Fig. 4). Grains of meta-quartz sandstone, namely orthoquartzite, are also found in the Oshima sandstone. Such clastic grains suggest the reworking of the sedimentary rocks in the interior of craton.

High-SiO_2 Nature of the Oshima Sandstone

In the QFL mode diagram (Fig. 5), the Oshima sandstone shows distinct felsic nature. It is very poor in lithic fragments, and plots clearly in the continental source field of the discriminant diagram after Ref. 2.

The bulk-rock chemical composition of the Oshima sandstone also indicates characteristic high-silica nature. In the frequency diagram for silica contents, Oshima sandstone shows a clear peak in high-silica area with around 80 wt% (Fig. 6). Histogram in the background indicates frequency of the sandstones of various geologic setting of the Japanese Islands based on Ref. 3. Here, bimodal nature is very distinct, and a peak in high-silica area is characteristic of the sandstones of the Japanese Islands. The peak of Oshima sandstone is in agreement with the high-silica peak of this bimodal distribution. For reference, low-silica peak around 60 to 65 wt% is made of ordinary sandstone.

Such high-silica nature of the Oshima sandstone is also represented in the diagram of alumina/silica ratio versus mafic/felsic ratio, called the Kiminami Diagram [3]. According to the composition, the Oshima sandstone occupies a "Continental Domain" discriminant field in silica-rich region clearly separated from other three volcanic-arc fields (Fig. 7).

Jurassic Clastic Supply from the Asian Continent

What is the origin of high-silica nature of the Oshima sandstone? Fig. 8 represents a ternary diagram, calcium + manganese, ferric iron and magne-

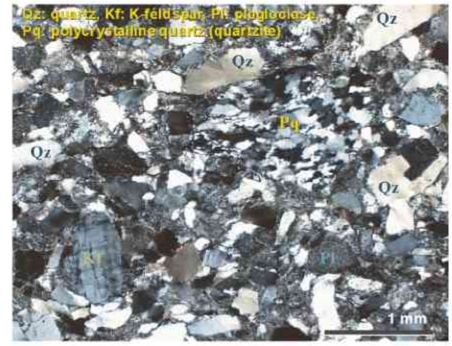

Fig. 4 Photomicrograph of Oshima sandstone

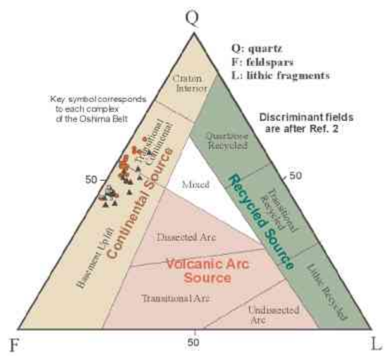

Fig. 5 QFL mode diagram of Oshima sandstone

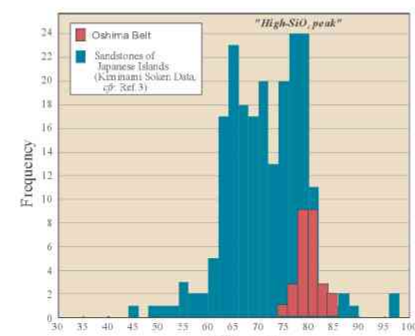

Fig. 6 SiO_2 frequency of Oshima sandstone

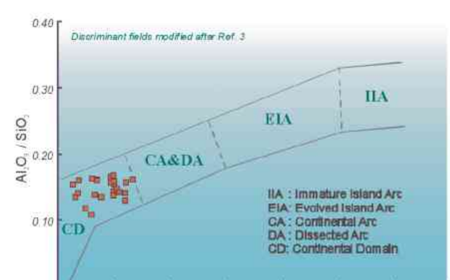

Fig. 7 Oshima sandstone in Kiminami Diagram

sium molecule, for the mineral composition of detrital garnet grains of the Oshima sandstone. Magnesium values in garnets are over 40% at maximum, which indicates that they have been derived from high-grade metamorphics as those of granulite facies. Figure 9 shows Uranium-Lead SHRIMP age of the detrital zircon in Oshima sandstone [4]. Along the concordia line, Early Proterozoic ages of about 1800 Ma and 2450 Ma are clearly shown. They represent the first reported Precambrian mineral ages from Hokkaido, and indicate that the Oshima sandstone has clastic source from Precambrian metamorphic terrane as Asian Continent, far west of recent Hokkaido. The meta-quartz sandstone grains in Oshima sandstone described before, are considered to have been derived from Late Proterozoic to Early Paleozoic sedimentary rocks of the Sino-Korean Block of the Asian Continent.

Figure 10 shows a reconstruction of tectonic arrangement of geologic belts of the Japanese Islands and Sikhote-Alin before Neogene opening of the Japan Sea, modified from Ref. 5. It shows that the Oshima Belt was once located in and/or along Sikhote-Alin in the eastern margin of Asian Continent before the Neogene. In the southern extension of the Oshima Belt, Jurassic accretionary belts are distributed in Northeast Japan, and generally correlated to the Taukha Terrane of Sikhote-Alin. Those terranes were dislocated by the formation of NNE-trending strike-slip faults and also by the opening of the Japan Sea.

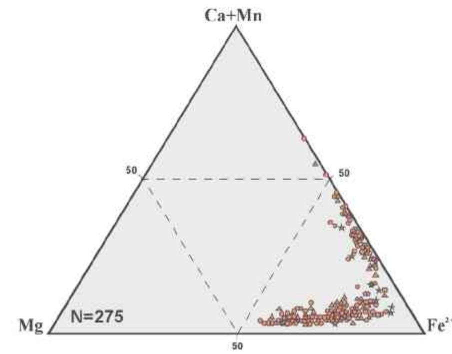

Fig. 8 Composition of detrital garnets of Oshima sandstone

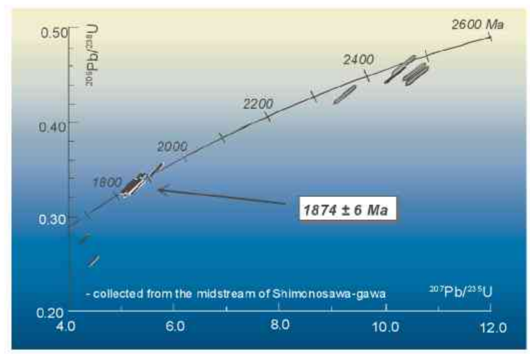

Fig. 9 SHRIMP age of the detrital zircon of Oshima sandstone

BEGINNING OF FOREARC SEDIMENTATION AND APPEARANCE OF VOLCANIC ARC

Due to the jump of trench during earliest Cretaceous age, forearc sedimentation occurred on the trapped oceanic plate. After a short duration, of probably 10–15 million years, Early Cretaceous volcanic activity started in the forearc region owing to the advance of subducting slab edge. This volcanic arc supplied volcanic detritus into the forearc region, and produced mixed clastic supply.

Cretaceous Yezo Forearc Basin

Yezo Supergroup is a Cretaceous forearc sequence of the Sorachi-Yezo Belt, deposited on trapped oceanic plate and pelagic to hemipelagic cover. It is divided into Lower Yezo, Middle Yezo, Upper Yezo and Hakobuchi Groups from stratigraphically lower to upper levels (Fig. 11). Total thickness of the Yezo Supergroup reaches over several thousand meters. Generally, the facies of Yezo

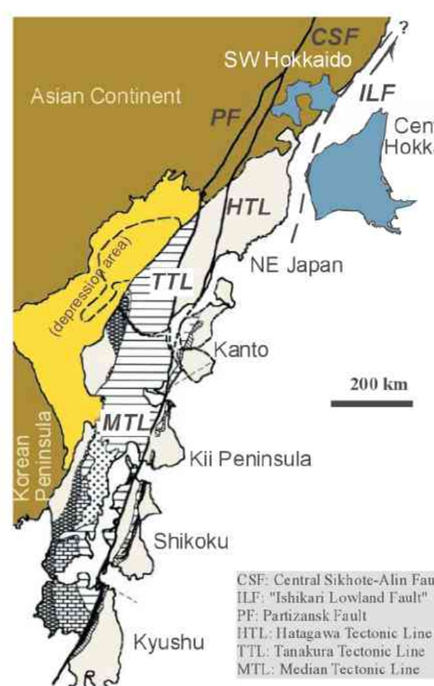

Fig. 10 Pre-Neogene reconstruction of Japanese Islands. Modified after Ref.5.

Supergroup changes from forearc - offshore turbidites to shallow-marine and even fluvial deposits, showing mega-order shallowing-upward sequence (Fig. 11).

Volcanic-arc Influence in Clastic Supply of the Yezo Forearc

Lower Yezo Group, which is the lowest member of the Yezo Supergroup, is composed mainly of turbiditic sequence, sometimes thick-bedded and coarse-grained. It directly overlies hemipelagic to pelagic sediments of the upper Sorachi Group. That is, the Lower Yezo Group represents the initial stage of Yezo Forearc Basin.

Turbiditic Lower Yezo sandstone shows a mixed nature of quartz-feldspathic and volcanic-lithic clastic supplies. The mixed nature is clearly indicated by the bulk-rock chemical composition of the sandstone. In the Kiminami Diagram, Lower Yezo sandstone shows a diverse distribution from Continental Domain field to Evolved Island Arc field (Fig. 12).

A simple mixing simulation (Fig. 12) for possible sources of the Lower Yezo sandstone shows that the clasts were supplied from both continental source as well as the Oshima sandstone, and volcanic-arc source such as the Rebun-Kabato Arc. The diversity in chemical composition of the Lower Yezo sandstone is a result of such mixing in clastic supply, and in addition, removal of plagioclase due to the weathering and sorting in the source area.

Volcanic-arc Detritus in the Eastern Margin of the Oshima Belt

As stated, the Oshima Belt is generally considered to be a Jurassic accretionary body formed prior to the appearance of Rebun-Kabato Arc.

The "Toi Complex" is distributed in the eastern part of the Oshima Belt. It consists of a tectonically lower chaotic Shirikishinai Unit and the upper clastic Karakawa Unit. The Karakawa Unit has been generally considered as a trench-fill quartz-feldspathic turbiditic sequence of the accretionary body, as well as those of the other part of the Oshima Belt.

The Karakawa Unit yields several beds of greenish volcanic sandstone. This sandstone contains abundant fragments of andesitic volcanic rocks and clinopyroxene grains. Electron microprobe analysis (EPMA) of the clinopyroxene [7] shows clear island-arc tholeiite signature (Fig. 13), namely a volcanic-arc origin. These facts suggest that the younger eastern part of the Oshima Belt received volcanic-arc clastics. The sedimentation age of the Karakawa

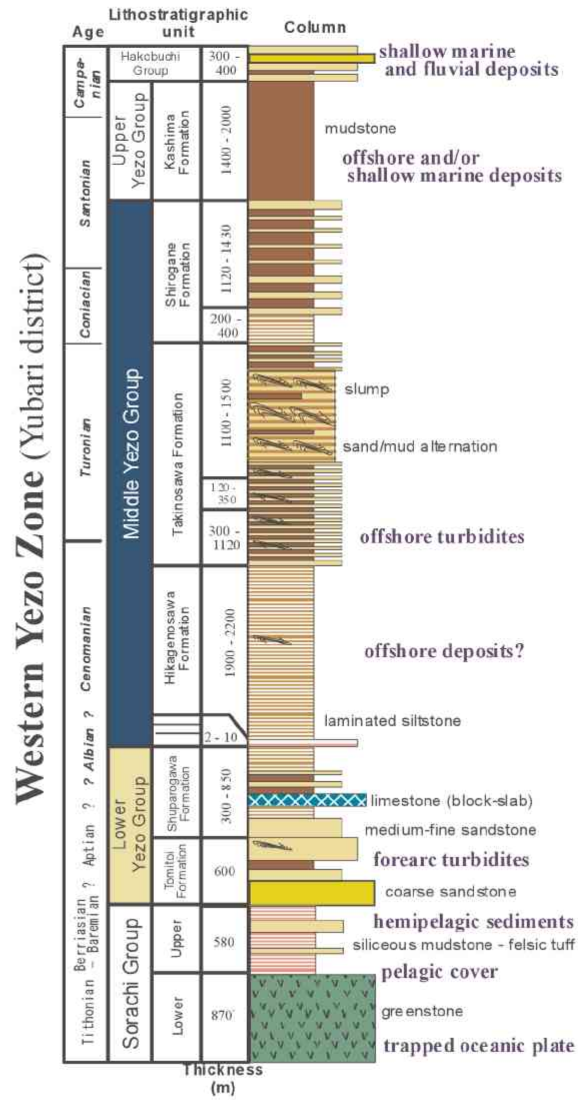

Fig. 11 General stratigraphic column of Yezo Supergroup. Modified after Ref. 6.

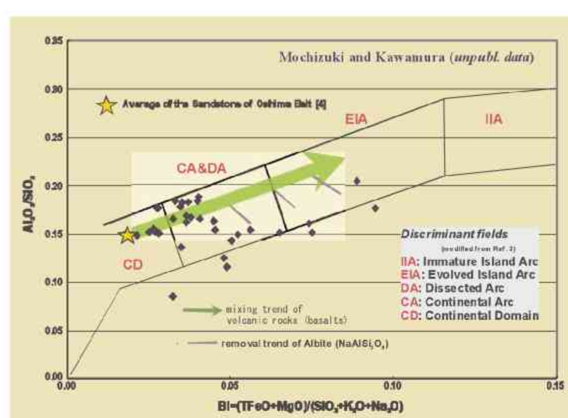

Fig. 12 Chemical composition of the Lower Yezo sandstone and mixing simulation

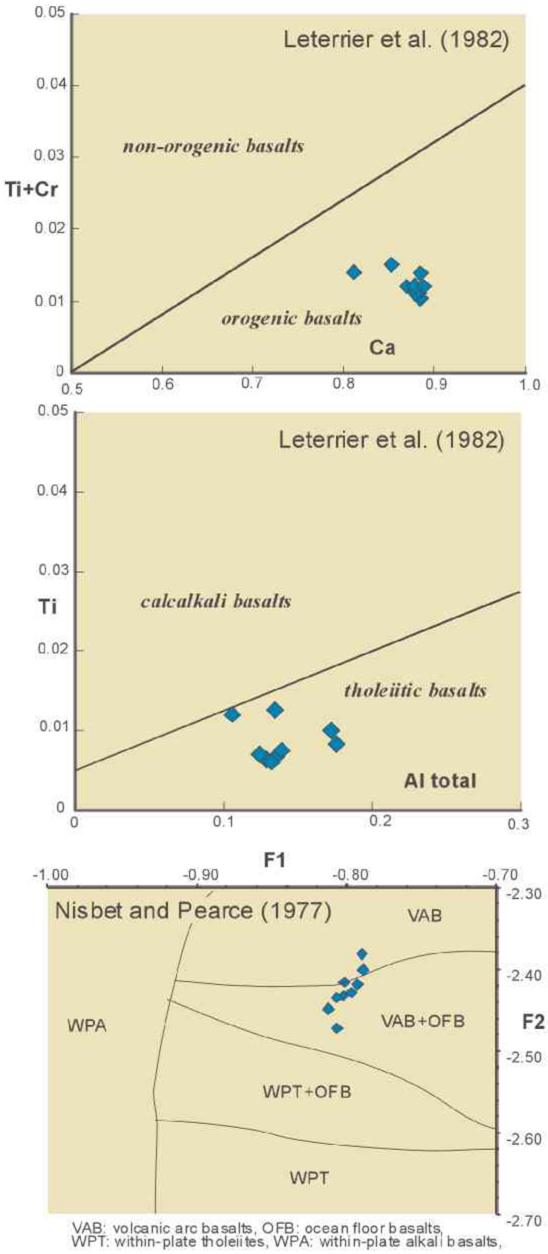

Fig. 13 Composition of detrital clinopyroxene of the sandstone of Karakawa Unit

Unit reaches to Early Cretaceous. Hence, the volcanic-arc detritus in the Karakawa Unit is considered to have been derived from the Rebun-Kabato Arc, situated east of the Oshima Belt. During Early Cretaceous, the Oshima Belt was no more an accretionary belt. Due to the jump of trench, it was transformed to a sedimentary basin covering the former accretionary body (Fig. 3). After the appearance of Rebun-Kabato Arc, the newly formed basin became a back-arc basin in a sense, and received volcanic-arc clastic supply from the volcanic arc in the east.

Estimation of Depth of the Subducted Plate

Timing of the jump event of trench is generally considered to be earliest Cretaceous (about 140 Ma). The Rebun-Kabato Arc activity started in the Early Cretaceous (130–120 Ma). If the arc activity was caused by a new subduction event, is the duration of 10–15 Ma long enough to generate a new arc?

A simple and rough method for estimation of the depth of edge of the subducted plate has been shown in Fig. 14. Parameters used are: rate of subduction, duration of subduction, and subduction angle. Other factors, such as sphericity of the Earth surface, deformation and strain in the plate-slab, are ignored. The estimates indicate that subducted plate-edge can reach a depth of "arc-magma generation", generally considered to be 120–160 km, within a duration of 10–15 million years provided that the convergent rate is 6–8 cm/yr and the subduction angle is 8–10 degrees. These subduction parameters are reasonable and feasible.

UPLIFT EVENT INSIDE THE FOREARC REGION

Cretaceous Yezo Supergroup is a sedimentary sequence deposited in a widespread forearc basin in the Sorachi-Yezo Belt of central Hokkaido. The existence of an unconformity in the middle of the Yezo Supergroup has been pointed out by several authors (see Ref. 8), since the early days of study for Mesozoic strata of Hokkaido. Its tectonic significance is, however, not yet clear.

Some recent studies reveal such unconformity which indicates uplift event of high-pressure type metamorphosed accretionary body emerged inside the forearc basin [8]. The unconformity is observed at several localities in the Eastern Yezo Zone. A description of the stratigraphic situation in the Shizunai district is given below.

Middle Yezo Unconformity

Sorachi-Yezo Belt in south central Hokkaido is divided into four sub-zones, as the Western Yezo, Kamuikotan, Eastern Yezo and Idonnappu Zones from west to east [6]. The Yezo Supergroup is distributed in the Western Yezo and Eastern Yezo Zones. A rock specimen that includes an unconformity plane was sampled from the base of the Middle Yezo Group of the Eastern Yezo Zone (Fig. 15). It shows that a basal conglomerate covers weakly metamorphosed greenstone of the Iwashimizu Complex with

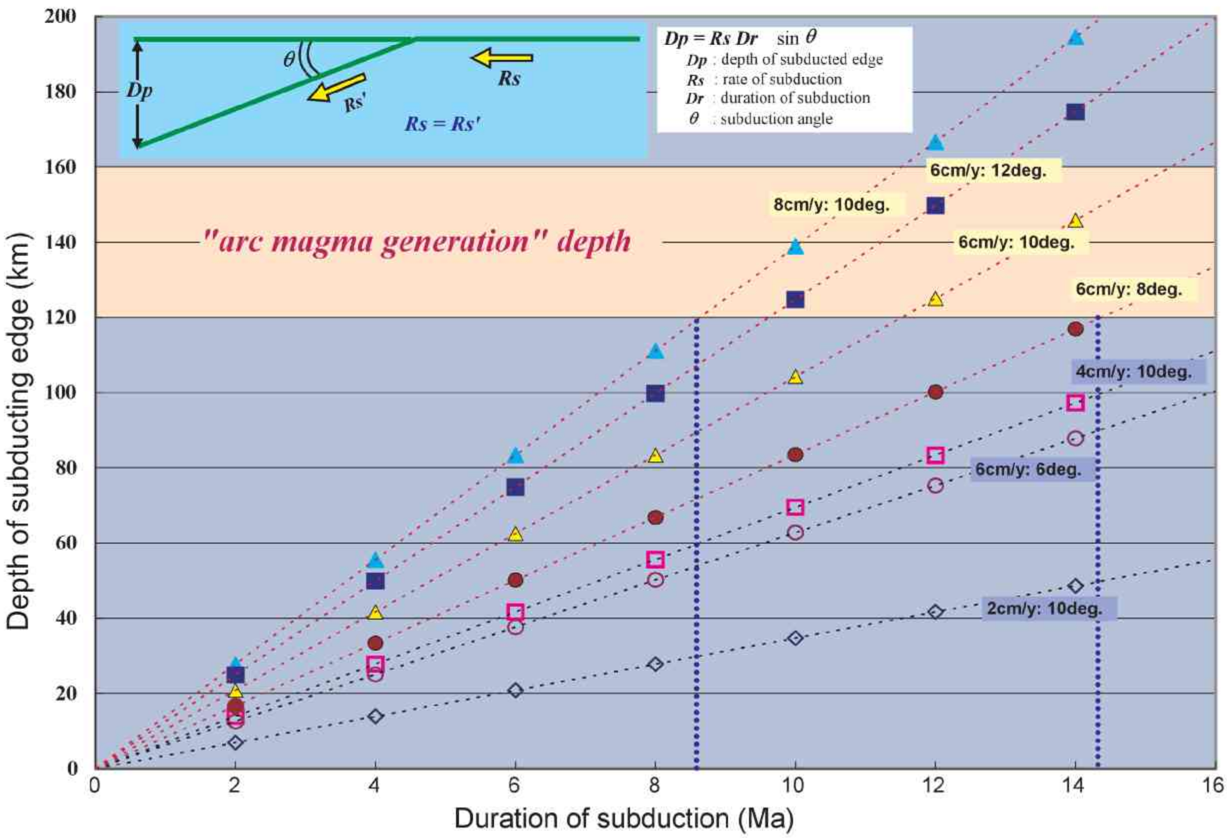

Fig. 14 Depth of the subducted plate

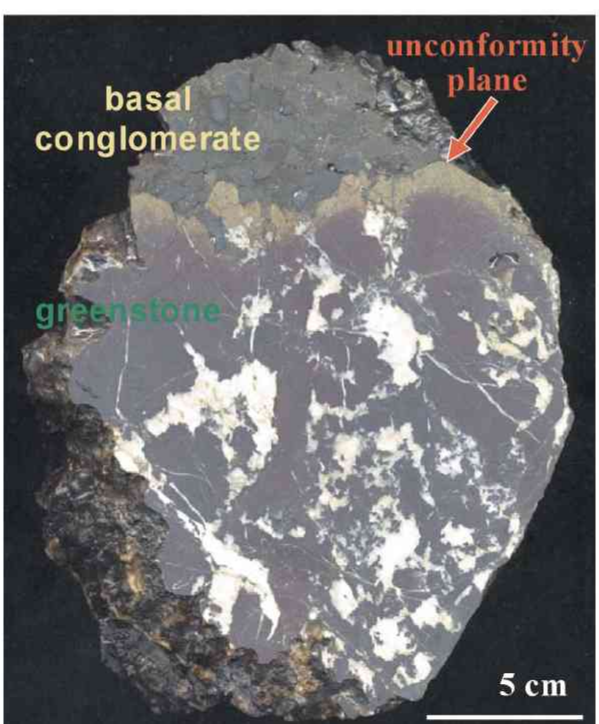

Fig. 15 Specimen of Middle Yezo Unconformity

rough and irregular erosive boundary. The basal conglomerate contains abundant rounded pebbles of greenstone. Above the basal facies, a marine sequence of mudstone, felsic tuff and sandstone is developed. This sequence represents lithologies common to the Middle Yezo Group all over the Sorachi-Yezo Belt.

Emergence of High-P/T Metamorphics in the Yezo Forearc

As a characteristic feature, the basal facies of the Middle Yezo Group in Eastern Yezo Zone often contains clasts of high-pressure type metamorphics, which contain blue sodic amphiboles (Fig. 16). These sodic amphiboles are identified as riebeckite and magnesio-riebeckite by EPMA. Compositional range of the sodic amphiboles corresponds to that of the Iwashimizu Complex distributed in the southern part of the Kamuikotan Zone.

Stratigraphic Summary of the Eastern Yezo Zone

In the Shizunai district, as already described, the Middle Yezo Group unconformably overlies metabasalt of the Iwashimizu Complex (Fig. 17). In the

Mitsuishi district, south of the Shizunai district, fluvial basal facies of the Middle Yezo Group unconformably overlies not only mélange facies of the Iwashimizu Complex, but also the Lower Yezo deformed turbidites (Fig. 17). In the northern part of the Eastern Yezo Zone (Hidaka-Soshubetsu distict), the base of the Middle Yezo Group conformably overlies the Lower Yezo Group (Fig. 17). Large-scale slump body is sometimes intercalated at the boundary between the two groups. This conformable relationship is also observed in the Western Yezo Zone.

Fig. 16 Metamorphic clast with blue amphibole in Middle Yezo sandstone

These stratigraphic data indicate that the unconformity is somewhat local. However, this unconformity marks significant hiatus. And the eroded high-pressure type metamorphic rocks are directly covered by the Middle Yezo Group

Lithostratigraphic Transition in the Eastern Yezo Zone

A lithostratigraphic scheme for the Middle Yezo Group, Lower Yezo Group, Sorachi Group and Iwashimizu Complex in and around the Eastern Yezo Zone, from south to north, is presented in Fig. 18. For reference, a column of the Western Yezo Zone is also shown. Clasts of high-pressure type metamorphic rocks are widely distributed even in the area where an unconformity has not been recognized. A regional stratigraphic correlation of

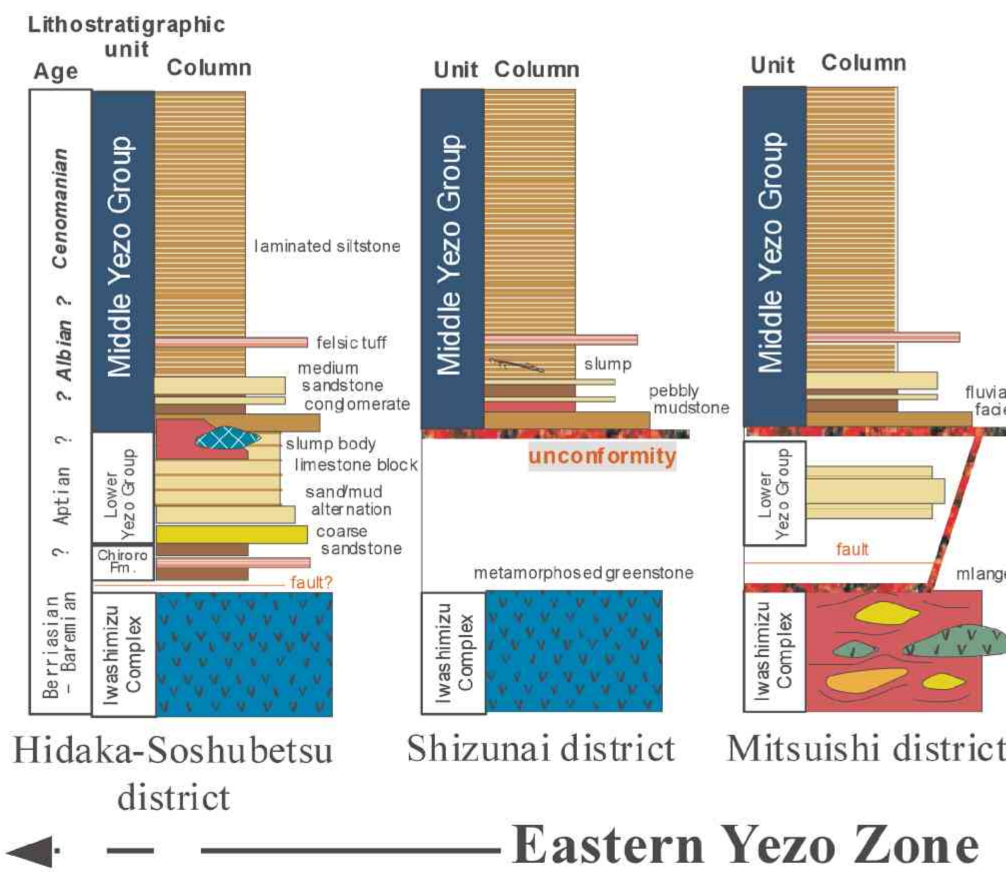

Fig. 17 Stratigraphic scheme of Eastern Yezo Zone

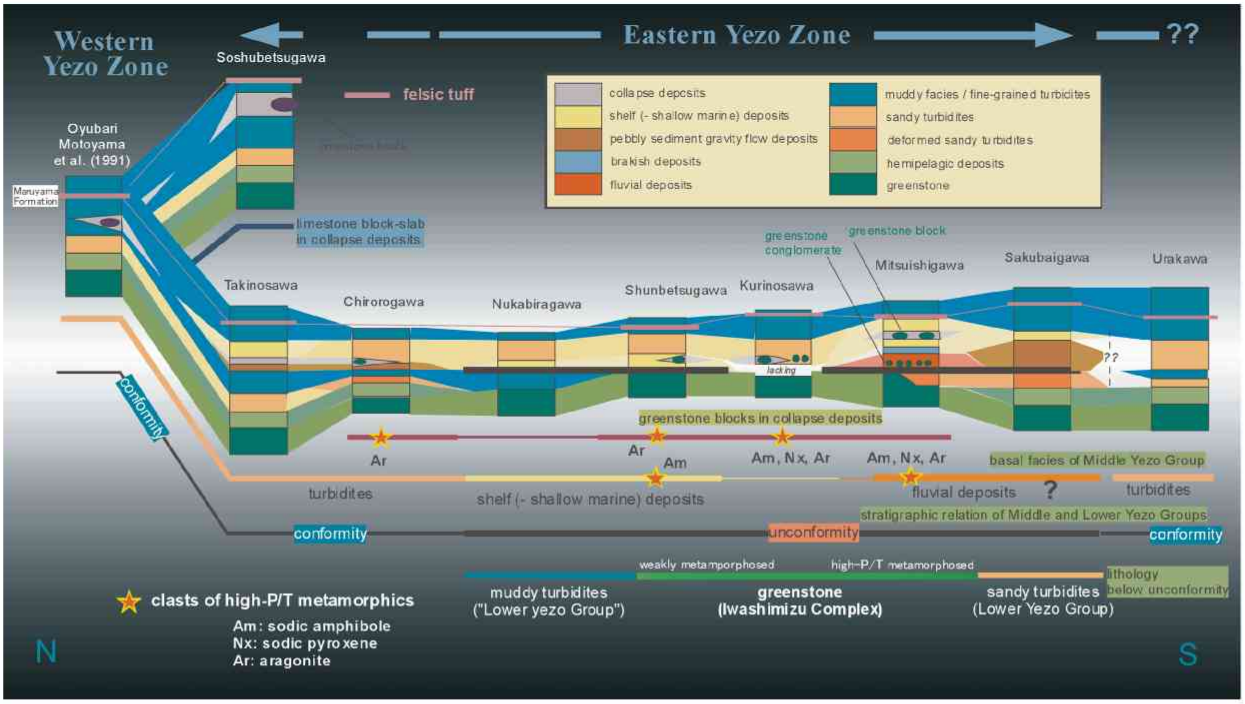

Fig. 18 Lithostratigraphic summary in the Eastern Yezo Zone

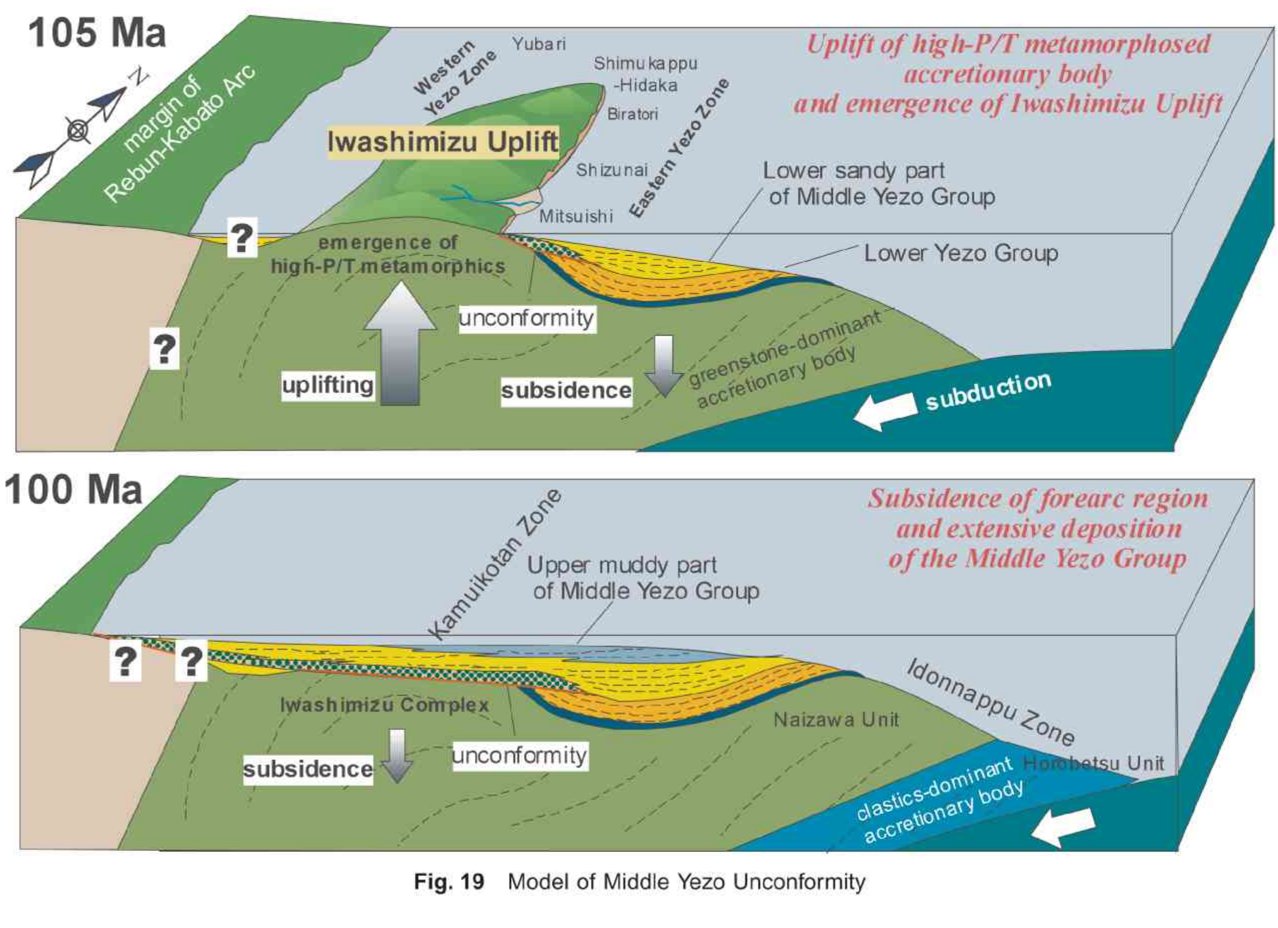

Fig. 19 Model of Middle Yezo Unconformity

the Eastern Yezo Zone has not been complete till now, mainly because of the lack or scarcity of biostratigraphic data.

Model for Yezo Forearc Basin and Iwashimizu Uplift

Tectonic model of the Middle Yezo Unconformity is summarized as follows (Fig. 19). At about 105 Ma, high-pressure type metamorphic body beneath the Yezo Forearc Basin uplifted locally and emerged to form a land area (Iwashimizu Uplift). About 5 million years later, the uplifted area was subsided, and the Middle Yezo Group was deposited above it. Thus the Middle Yezo Unconformity was formed.

Rate of the uplift movement is roughly estimated by Ref. 9 as about 20 km per 20 million years at minimum, namely 0.1 cm/yr. This rate is not extremely high, but it is somewhat conspicuous that a deeper part of the accretionary body uplifted and eventually emerged into a forearc with fast recycling of subducted material. Cause and process underlying this uplift event are still unknown. However, a mechanical "jack-up effect" induced by repeated subduction and underplating of seamount edifices, for example, is one of the possible explanations (Fig. 3), as pointed by Ref. 9.

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