Jurassic Accretionary Complex as a key to Understand the Mesozoic Tectonic Evolution along the Eastern Margin of Asia

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Abstract
The Jurassic accretionary complex in Japan and Far East Russia records the deformation structures formed through several deformation events. Moreover the Jurassic accretionary complex, exposing in at least two geologic belts along the eastern margin of Asia, serves as a marker of displacement and deformation related to (1) the Cretaceous sinistral shearing and (2) the formation of the Sea of Japan (East Sea). This paper briefly discusses the Mesozoic and Cenozoic tectonic evolution along the eastern margin of Asia revealed from structural analyses of the Jurassic accretionary complex.

Keywords: accretionary complex, off-scraping, underplating, Jurassic, Cretaceous, sinistral shearing, Sea of Japan (East Sea), tectonics

1. INTRODUCTION
The Jurassic accretionary complex occupies a significant part of the Japanese Islands. It mainly comprises disrupted oceanic-plate stratigraphy, beginning from ocean-floor basalt that is conformably covered, in ascending order, by radiolarian chert (partly reef-forming limestone), siliceous shale, black shale and coarser clastic rocks. The oceanic-plate stratigraphy documents the travel history of a segment of an oceanic plate that was born along a mid-ocean ridge and was subducted beneath the oceanic trench along the east Asian continental margin (Matsuda and Isozaki, 1991). Along the Permian–Triassic (P–T)
boundary, there is a siliceous to carbonaceous shale layer that may reflect drastic decrease of radiolarians and is mechanically weaker than the lower and upper chert layers. This weak shale layer likely worked as the most effective detachment layer during the subduction of the oceanic-plate stratigraphy, and two lithologic units are discriminated in the Jurassic accretionary complex of Japan. One (the type-I unit) comprises disrupted chert–clastics sequences, which represent the upper part of the oceanic-plate stratigraphy on top of the P–T boundary and were most likely accumulated by off-scraping in a shallower part of a subduction zone. The other (the type-II unit) comprises disrupted basalt–chert sequences, which represent the oceanic-plate stratigraphy lower than the P–T boundary and were most likely accumulated by underplating in a deeper part of the subduction zone.

Although deformation structures in an accretionary complex, at least in Japan, are attributed to the shearing during accretion (e.g. Wakita, 2000), any accretionary complex can undergo deformation in various stages of its evolution. We have already discriminated deformation structures in the Jurassic accretionary complex of Japan formed at two or more stages of deformation (e.g. Sasaki et al., 2001). This short paper aims (1) to introduce the lithology and distribution of the Jurassic accretionary complex in Japan and Far East Russia, and (2) to present a model of restoration of displacement and deformation recorded in the accretionary complex or detected from the offset of similar accretionary complexes.

2. JURASSIC ACCRETIONARY COMPLEX IN JAPAN AND FAR EAST RUSSIA

Jurassic accretionary complex in Japan and Far East Russia occurs in several belts subparallel to the length of the Japanese Islands and to the coastline of Far East Russia. Here we make brief descriptions of the accretionary complex in each belt.

2.1. Samarka Belt (Russia)

The Samarka Belt lies between the Khanka belt and Partizansk–Central Sikhote-Alin fault in the southern part of Primorye, Far East Russia (Fig. 1). The accretionary complex of the belt likely extends to the Nadanhada range of Northeast China on the north of the Khanka belt (Kojima, 1989). The Samarka Belt mainly comprises Middle to Late Jurassic accretionary complex comprising Middle to Late Jurassic...
terrigenous clastic rocks and oceanic materials such as Carboniferous to Permain basaltic rocks, Carboniferous to Permian limestone and Permain to Early Jurassic radiolarian chert. The Paleozoic Kalinovka Ophiolite and Udeka Formation tectonically cover the accretionary complex of the Samarka Belt (Kojima et al., 2000).

2.2. Tamba–Mino–Ashio Belt (Japan)

The Tamba–Mino–Ashio (TMA) Belt occurs between the Maizuru Belt and the Median Tectonic Line (MTL) in Southwest Japan and on the west of the Tanakura Tectonic Line (TTL) in Northeast Japan (Fig. 1). The accretionary complex of the TMA Belt mainly comprises two units: the type-I and type-II units, in ascending order. The type-I unit consists mainly of disrupted Triassic to Late Jurassic chert–clastics sequence, whereas the type-II unit consists mainly of disrupted Permain seamount-basalt–limestone and basalt–chert sequences and Late Triassic to Middle Jurassic clastic rocks (Ishiga, 1983).

The Paleozoic Yakuno Ophiolite and Hikami Formation of the Maizuru Belt tectonically cover the accretionary complex of the TMA Belt, and resemble the Kalinovka Ophiolite and the Udeka Formation, respectively, mentioned before. Hence the tectonic position of the accretionary complex of the TMA Belt, as well as the lithological assemblage and age, is identical to that of the Samarka Belt (Kojima et al., 2000).

2.3. Northern Chichibu Belt (Japan)

The Northern Chichibu Belt occurs between the Sambagawa Metamorphic Belt and the Kurosegawa Tectonic Belt (KTB) in Southwest Japan (Fig. 1). The accretionary complex of the Northern Chichibu Belt mainly comprises three units: the Kashiwagi, Kamiyoshida and Sumaizuku units, in ascending order (Matsuoka et al., 1998). The Kashiwagi Unit consists of red chert, intercalating layers of mafic tuff and dolostone, felsic tuff, Late Triassic megalodont limestone, and Berriasian–Valanginian siliceous mudstone. The Kamiyoshida Unit consists mainly of disrupted Triassic to Middle Jurassic chert–clastics sequence, with small amounts of mafic lapilli tuff. The Kamiyoshida Unit is lithologically and tectonostratigraphically correlative to the type-I unit of the TMA Belt. The Sumaizuku Unit, which is
lithologically and tectonostratigraphically correlative to the type-II unit of the TMA Belt, consists mainly of disrupted Permian basalt–chert sequences and Late Triassic to Early Jurassic clastic rocks.

2.4. Taukha Belt (Russia)

The Taukha Belt lies in the southeastern part of Primorye (Fig. 1). The accretionary complex of the belt mainly comprises three units: the Silinska, Gorbusha and Ustinov units, in ascending order (Khanchuk et al., 1996). The Silinska Unit consists of Middle to Late Jurassic basalt, Late Jurassic to earliest Cretaceous chert, and overlying Berriasian–Valanginian turbidite. The Gorbusha Unit is characterized by fault-bounded repetition of chert–clastics sequences, consisting of Triassic to Middle Jurassic chert, Late Jurassic siliceous shale, Tithonian to Berriasian turbidite and overlying mélange. The Ustinov Unit consists mainly of Valanginian to Barremian mélange, with the clasts of Devonian to Permian limestone, Permian basalt and chert, and Halobia- and Monotis-bearing Triassic clastic rocks. Moreover, the mélange of the Gorbusha and Ustinov units characteristically include clasts of Late Triassic megalodont limestone.

2.5. North Kitakami Belt (Japan)

The North Kitakami Belt lies between the South Kitakami and Sorachi–Yezo belts in Northeast Japan (Fig. 1). The accretionary complex of the North Kitakami Belt is roughly divided into three units (Otoh and Sasaki, 2003). The lower unit consists of Late Triassic basalt and megalodont limestone, lying between mudstone-matrix mélanges. The middle unit consists of fault-bounded repetition of Triassic to
Middle Jurassic chert-clastics sequences. The upper unit, closest to the South Kitakami Belt, consists mainly of strongly sheared, mudstone-matrix mélange, with subordinate Permian red chert and red shale.

2.6. Southern Chichibu Belt (Japan)

The Southern Chichibu Belt lies between the KTB and the Shimanto Belt (occupied by Cretaceous accretionary complex) in Southwest Japan (Fig. 1). The accretionary complex of the Southern Chichibu Belt is divided into three units: the Sambosan, Togano, and O’hirayama units in ascending order (Matsuoka et al., 1998). The Sambosan Unit consists of Late Triassic basalt and megalodont limestone, same with the Takuha and North Kitakami belts, accompanied by latest Jurassic to Early Cretaceous mudstone-matrix mélange. The Togano Unit consists of fault-bounded repetition of Triassic to Late Jurassic chert-clastics sequences. The O’hirayama Unit, closest to the KTB, consists mainly of Early Jurassic sheared mudstone-matrix mélange, including clasts of Permian and Triassic limestone and chert.

3. OPENING OF THE SEA OF JAPAN (EAST SEA)

From this section, we present our model for restoration of the Mesozoic–Cenozoic displacement and deformation of Japan.

We have presented a synthetic restoration model for the Sea-of-Japan (East-Sea) opening based mainly on (1) estimation of the amounts of intra-arc deformations, (2) review of paleomagnetic data, and (3) present submarine topography (Yamakita and Otoh, 1999). Our model successfully restored the Northeast and Southwest Japan arcs in the area of the present-day Sea of Japan. The model revealed that there was an NNE-trending huge sinistral fault system along the eastern margin of Asia in Cretaceous time. The fault system comprises the MTL, KTB, Hatakawa Tectonic Line, and Central Sikhote-Alin Fault with a by-pass of the Tanakura Tectonic Line and Partizansk Fault in Northeast Japan.
and the southern part of Primorye (Fig. 2). Two rows of Jurassic accretionary complexes in Primorye and Japan, i.e. the Tamba–Mino–Ashio–Samarka belt and the Southern Chichibu–North Kitakami–Takuiha belt, also connect smoothly in our restoration model (Fig. 2).

4. CRETAEOUS SINSIRAL SHEARING

Cretaceous sinistral shearing was concentrated along the MTL (Late Cretaceous) and KTB (Early Cretaceous) in Southwest Japan and was rather dispersed in TMA Belt and Northeast Japan. Late Cretaceous left-lateral strike-slip displacement along the MTL is estimated to have been about 500 km using the length of the strike-slip Izumi basin as an offset marker (Yamakita and Otoh, 2000a). After restoring the displacement, the Northern Chichibu Belt comes on SSW of the TMA Belt (Fig. 3).

The amount of Early Cretaceous sinistral displacement along the KTB is estimated to have been more than 800 km from bivalve paleobiogeography. Tashiro (1985) discriminated two distinct groups of Early Cretaceous strata, with contrasting lithofacies and fossil contents, in the Outer Zone of Southwest Japan: (1) the Monobegawa Group and its equivalents and (2) the Nankai Group and its equivalents. Tashiro (1985) further suggested the presence of a huge sinistral displacement between the two groups of strata. Yamakita (1998) revealed, from the study of pre–Early Cretaceous geology, that the two groups of strata occur in different geologic belts: i.e. the Monobegawa and Nankai groups cover the pre–Early Cretaceous rocks of the Northern Chichibu and Kurosegawa Tectonic belts, respectively. We recently found sinistral fault rocks in and along the northern boundary of the KTB in Shikoku and its equivalent in Kyushu, suggesting the presence of the Kurosegawa Fault System (KTB and its northern extension; Yamakita and Otoh, 2000a). According to the paleobiogeographical study of Tashiro (1985), the fault system has the displacement of more than 800 km and must have been one of the largest Early

Figure 3 The Japanese Islands and Far East Russia before the sinistral motion of MTL (90 Ma; Yamakita and Otoh, 2000a).
Cretaceous fault systems in East Asia. Restoring the displacement along the Kurosegawa Fault System, all the Jurassic accretionary complex in present-day Japan and Far East Russia make a single belt on the oceanward side of all the pre-Jurassic geologic units (Maizuru, Akiyoshi and Hida Marginal belts and their equivalents in Fig. 3).

Large-scale conical folds associated with sinistral shear zones also represent the Early Cretaceous sinistral shear deformation of the Jurassic accretionary complex of Japan. The folding and shearing are not restricted to the accretionary complex but extend to the pre-Jurassic geologic units. In fact, the association of conical folds and sinistral shear zones were first noticed in the South Kitakami Belt of Northeast Japan, which is occupied by Paleo–Mesozoic shallow-marine carbonate, volcanic and clastic rocks (Sasaki, 2001). Sasaki (2001) delineated Early Cretaceous sinistral shear zones in the South Kitakami Belt and discussed its mechanical relation with the major conical folds in the belt. Similar major folds with the half-wavelength of 5 to 10 km are also known in the accretionary complex of Northeast Japan and Southwest Japan, although the axes of the major folds in Northeast Japan and Southwest Japan plunge in different directions (southward and westward, respectively) because of the Miocene bending of the Japan Arc. These folds have been considered to be cylindrical open folds. To clarify the configuration and origin of the major folds, lithologic and structural mapping of the Jurassic accretionary complex was carried out in three areas of the TMA Belt, the largest exposure of the Jurassic accretionary complex of Japan. The three areas are, the Ashio (A), Nyukawa (N; Sasaki et al., 2001) and Inuyama (I) areas from east to west. We revealed that the configuration of the major synclines, which opens to SW (A) or W (N & I) is in fact conical, from the stereographic projection of the bedding plane in the synclines. We also revealed that sinistral shear zones, comprising foliated cataclasite and closely associated with tectonic mélangé, run along the northwestern (A) or northern (N & I) limb of the synclines and cut lithologic boundaries. We interpret, from the configuration of the deformation structures described above, that (1) the accretionary complex of the TMA Belt had originally strike subparallel to the length of the Japanese Islands and dipped NW (A) or N (N & I); (2) the major conical synclines were formed by the southwestward (A) or westward (N & I) dragging of the accretionary complex along the sinistral shear zones mentioned above; and (3) the mélangé that is closely associated with the shear zones was formed during the sinistral shearing. Considering that the youngest rock of the studied accretionary complex is of early Late Jurassic (ca. 155 Ma) time and the granitoid of 116 Ma has cut the deformation structures, the
sinistral shearing most likely took place in Early Cretaceous time. Our preliminary restoration of the
deformation by the shearing and folding reveals that the TMA Belt, which has the length of about 1000
km along the Japanese Islands, was three times longer before the shearing and folding. The accretionary
complex of the TMA Belt was hence most likely formed along some 3000-km-long coastline of East Asia.

5. EXHUMATION OF THE ACCRETIONARY COMPLEX AND SUBSEQUENT DEPRESSION

The Jurassic accretionary complex of Japan exhumed subhorizontally soon after the accretion, but was
again buried under thick pile of volcanic rocks at least in the North Kitakami Belt, Northeast Japan. In the
North Kitakami Belt, the Berriasian–Valanginian Omoto Formation, which contains abundant plant fossils,
covers the Jurassic accretionary complex with slightly angular unconformity, suggesting the subhorizontal
uplift of the accretionary complex. The Hauterivian–Barremian Harachiyama Formation with bimodal
volcanic rocks in SiO$_2$ content conformably covers the Omoto Formation. The Harachiyama Formation
contains Kuroko-type ore deposits, suggesting a deep-sea (> 1000 m) hydrothermal activity, and has
undergone burial metamorphism under the prehnite–pumpellyite to greenschist facies condition (Moriya,
1972), i.e. the confining pressure of 0.2–0.3 GPa (6–10 km depth). Moreover the pre-Aptian strata were
intruded by 120 Ma granitoid bodies under the confining pressure of 0.2–0.3 Ga, according to
geobarometric data using amphiboles. These lines of evidence strongly suggest that a kind of rifting in
Hauterivian–Barremian time formed a deep sea, which was filled up with volcanic rocks with bimodal
SiO$_2$ content. All these rocks had exhumed again and were unconformably overlain by the Late Aptian to
Albian Miyako Group, marking the second stage uplift.

6. FORMATION OF THE JURASSIC ACCRETIONARY COMPLEX

As we wrote before, there is a siliceous to carbonaceous shale layer along the Permian–Triassic (P–T)
boundary that likely worked as the most effective detachment layer during the subduction of the oceanic-
plate stratigraphy. Two tectonostratigraphic units are hence discriminated in the Jurassic accretionary
complex of Japan: the type-I unit comprising disrupted chert–clastics sequences and the type-II unit
comprising disrupted basalt–chert sequences. The type-II unit contains older (Late Triassic–Middle
Jurassic) clastic rocks than the type-I unit (containing Middle Jurassic–earliest Cretaceous clastic rocks), and lies on the type-I unit in many areas of Japan (Ishiga, 1983; Matsuoka et al., 1998; Yamakita and Otoh, 2000b). Although the process of putting the underplated (type-II) unit on top of the off-scraped (type-I) unit is still unknown, the relationship between the two units will provide a key to understand the formation process of the Jurassic accretionary complex of Japan. Here we present a variation of the critical taper model that necessarily, but not sufficiently, explains the configuration of the TMA Belt.

Latest Permian to Early Jurassic continental margin that later accumulated the accretionary complex of the TMA Belt must have been in an extensional or transtensional tectonic setting. The tectonic setting is evidenced by (1) the exhumation of HP/LT Suo metamorphic rocks of the Sangun Metamorphic Belt (s.l.), and (2) the formation of Triassic to Early Jurassic transtensional strike-slip basins in the Miné, Nariwa, Kuruma, Toyora, and other areas. The horizontal extension or transtension must have thinned the crust of the continental margin and decreased the taper angle of the accretionary wedge. The Late Triassic to Middle Jurassic underplating of the disrupted basalt–chert sequences likely compensated for the crustal thinning and later thickened the crust, resulting in an increase in the taper angle above the critical value. This crustal thickening, in turn, may have promoted the off-scraping of chert–clastics sequences at the tip of the accretionary wedge.

7. DISCUSSION

The above structural events may or may not be related to the coeval structural events of Korea. Here I would like to emphasize that the Hueriverian–Barremian rifting in Northeast Japan may be closely related to the formation of the Gyeongsang basin, although the age of volcanism differs between the two areas. Our restoration of sinistral displacement and deformation indicates that Northeast Japan was located close to Korea in Hueriverian–Barremian time. Although these Early Cretaceous tectonic events are attributed to the result of ridge subduction, the Permian–Triassic oceanic rocks of Japan cast negative evidence to this hypothesis. The East Asian continental margin must have been far from an oceanic ridge until earliest Cretaceous; the Permian–Triassic oceanic rocks had traveled more than 100 my from a remote ocean to the subduction zone along east Asia. To complete the ridge hypothesis we have to find out evidence for (1) the passage of a large-scale transform fault followed by an oceanic ridge or (2) the formation of a new
ridge in an old oceanic crust. The chert pebbles in the Gyeongsang Supergroup also show geologic connection between Korea and Japan. Considering the age of the Gyeongsang Supergroup that contains chert pebbles, they may have supplied from the east during or after the second stage uplift (Barremian–Aptian) recorded in the geology of Northeast Japan.

Latest Permian to Early Jurassic extension or transtension in the landward side of the future (Jurassic) accretionary wedge, triggering Late Triassic to Middle Jurassic underplating of the disrupted basalt–chert sequence, may be related to the movement of the South Korean Tectonic Line and/or Kyonggi Shear Zone (Chough et al., 2000; Kim et al., 2000). Further international cooperative studies are needed to solve these and other problems on Paleo–Mesozoic tectonics of Northeast Asia.

REFERENCES


Khanchuk, A.I., Ratkin, V.V., Ryazantseva, M.D., Golozubov, V.V. and Gonokhova, N.G., 1996, Geology and mineral deposits of Primorskiy Krai (Territory). Far East Geological Institute, Russian Academy of Science, Vladivostok, 61 p.


