Research progress on migration and accretion of Nadanhada terrane

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Abstract. The Nadanhada terrane is the most developed area of Mesozoic marine strata in eastern China. The migration process of the Nadanhada terrane is restored from two aspects of Palaeomagnetism and biopalaeogeography. It is concluded that the subduction of the oceanic plate to the continental margin of East Asia is accompanied by the strong deformation of the sedimentary cover during the growth of the Nadanhada terrane. Under the continuous compressive force generated by the subduction of the oceanic plate to the continental margin of East Asia, accretionary wedges continue to form in the direction of oceanic basin. At the same time, large detachment planes gradually form between accretionary complex and the basement of the Jiamusi massif. The evolution history of the Nadanhada terrane can be divided into five stages: the drift stage, the accretion stage of the continental margin, the bending stage of the terrane structural line, the compression stage of the terrane and the anticlockwise rotation stage of the terrane. Bijin terrane can be seen as the extension of Nadanhada terrane in NNE direction.

1. Regional situation

The Nadanhada terrane is the most developed area of Mesozoic marine strata in eastern China. It is located at the border of different tectonic units. It is a key area and an important window to study the Late Mesozoic tectonic characteristics and growth process of the continental margin of Northeast Asia. Therefore, it has attracted much attention from scholars at home and abroad. Geological survey in Nadanhada began in 1957. The Heilongjiang Bureau of Geology and Mineral Resources and Changchun Institute of Geology successively carried out mineral survey and geological investigation in this area, followed by a large number of geologists carried out detailed research on terrain, which accumulated valuable geological data for further research work in this area.

For a long time, many scholars have studied the Nadanhada terrane in different ways. Some scholars have used the methods of paleomagnetism and stratigraphic paleontology to restore the ancient position and collage age of the terrane. They believe that the Nadanhada terrane has many similarities with the Meinong terrane of the Japanese archipelagos and the Sikhot-Alin terrane of Russia. It is presumed that the three were unified superterranea before the formation of the Sea of Japan. The terrain originated near the equator and drifted long distances to middle and high latitudes since the Mesozoic. It was collaged
with the Jiamusi massif from the Late Jurassic to the Early Cretaceous. Some scholars have studied the
collage age of the Nadanhada terrane by using isotope chronology. By measuring the isotope age of the
melange and granite, the emplacement age of the Nadanhada accretionary complex is limited to 150-
131 Ma [3]. Some scholars have studied the effect of the Raohe Triassic stratified chert on the orogenic
fluids. The time of gravity and magnetization indirectly infers that the accretion age of the Nadanhada
terrane is from Late Jurassic to Early Cretaceous. In recent years, according to the geochemical
characteristics of rocks, some scholars have classified the basalts in the terrane into two types, one is the
oceanic island basalts distributed in the eastern part of the terrane, the other is the mid-oceanic ridge
basalts exposed near the Yuejinshan fault zone [5].

2. Migration process
Paleomagnetism is the only discipline that can quantitatively determine the paleolatitude of the
lithospheric plate. It has unique advantages in solving the problem of terrane migration, especially the
displacement in the near north-south direction. According to the paleomagnetic data of different
geological times, the movement track of terrane in latitude can be roughly restored. Biopalaeogeography
can determine the palaeogeographic environment of terranes in different geological periods. According
to the ecological differentiation of palaeobiotic communities in different latitudes and land and sea
environments, the migration process of terranes in different biota can be revealed.

Based on paleomagnetic data of the Nadanhada, Jiamusi, North China and Yangtze plates, Wankuo
screened and synthetically analyzed paleomagnetic data. As shown in Table 1, the migration process of
the Nadanhada terrane was restricted.

Table 1. Paleomagnetic Correlation table of Nadanhada Platform, Jiamusi Platform, North China plate
and Yangtze Plate

| Age            | P | T2 | T3   | T3-J1 | J3  | K1  |
|----------------|---|----|------|-------|-----|-----|
| Latitude of Nadanhada | 10.3°S | 8°S | 5.4°N | 19.8°N | 43.5°N | 61.4°N |
| Latitude of Jiamusi      | —  | —  | —    | 34.6°N | 48.2°N | 52.6°N |
| Latitude of North China     | 20.1°N | 23.1N | 30.2°N | 30.2°N | 30.7°N | 38°N  |
| Latitude of Yangtze        | 2.1°N  | —  | 28.9°N | 24.8°N | 21.5°N | 23.9°N |

Paleomagnetic data in the Nadanhada area indicate that the terrane was located near the equator
(10.3°S~5.4°N) during the Permian-Middle Triassic (Fig. 1a, b), south of the North China plate and the
Yangtze plate; during the Late Triassic-Early Jurassic, the terrane moved northward and the
paleolatitude changed to 19.8°N, which is still in the middle and low latitudes (Fig. 1c). Located in the
south of the Jiamusi, North China and Yangtze plates, it is the southernmost of the four blocks. In the
Late Jurassic, the paleolatitude of the terrane changed to 43.5°N, indicating that the Early-Middle
Jurassic terrane continued to migrate northward rapidly, crossing the North China plate (30.2°N) and
the Yangtze plate (21.5°N), reaching the paleolatitude of the Jiamusi block (48.52°N). At this time,
the Nadanhada terrane was located in the eastern margin of the Jiamusi massif (Fig. 1d); during the
Early Cretaceous, four blocks continued to migrate northward at the same time, and the Nadanhada
terrane moved with the Jiamusi massif to the middle and high latitudes (Fig. 1e).
The palaeogeographic environment reflected by the palaeontological assemblage and sedimentary facies of the Nadanhada terrane basically coincides with the palaeogeographic environment obtained by palaeomagnetic measurements. In the Nadanhada terrane, limestone produces Carboniferous-Permian cockroaches and coral fossils [7]. They belong to the warm water biota near the equator, indicating that the terrane might be in the low latitude shallow sea island environment at that time. In the Triassic-Middle Jurassic, the palaeontological assemblage was represented by pelagic radiolarians, during which the radiolarian population completed Pseudoheliod. The transition from iscus cluster to Parahsuum cluster to Stichocapsa cluster [8], the suitable water temperature of the three groups decreased in turn, indicating that the terrane continued to drift northward in the oceanic basin environment and reached the middle and high latitudes cold water environment in the middle Jurassic; in the late Jurassic, typical offshore trench mixed accumulation was widely developed in the terrane, and the Donganzhen Formation (Jurassic). At the turn of Cretaceous, fossils of the northern shallow-sea fauna represented by Buchia were produced, indicating that the terrane had entered the subduction zone and began to proliferate towards the continental margin. In the early Cretaceous, the neutral-intermediate acid continental volcanic rocks of the Pikeshan Formation unconformly covered various exotic rocks, indicating that the proliferative activity of the terrane had ended.
3. Proliferative process
The Nadanhada terrane is a complex assemblage formed by repeated superimposition of a series of tectonic slices, which are mainly composed of siliceous rocks, semi-deep-sea siliceous mudstones, terrestrial rocks and mixed accumulation [10]. The strata in terrane can be divided into three layers from bottom to top, and each layer represents different stages of tectonic evolution: the lowest layer is stratified siliceous rocks from Middle Triassic to Early Jurassic, which formed in the oceanic basin environment, indicating the oceanic sedimentary environment and history; the middle layer is yellow-green phyllite, slate and black in the mid-Jurassic semi-deep sea environment. Silicate slate and tuffaceous sandstone, formed in the transitional zone between continents and oceanic basins, indicate that the oceanic plate is approaching the continental margin; the upper layer is trench turbidite with mixed accumulation characteristics, which includes Carboniferous-Permian limestone, Middle Triassic-Middle Jurassic siliceous mudstone, basic lava, snake. Greenstone and clastic rock blocks, formed in the late Jurassic, are the products of collapse and accumulation on the continental margin, reflecting that the oceanic crust has entered the subduction zone and began to accrete to the continental margin. The sedimentary sequence of oceanic siliceous rocks and terrigenous rocks in the Nadanhada terrane conforms to the modern accretion wedge structure [11]. It was formed at the bottom of the trench slope converged on the continental margin. The accretion wedge structure is basically the same as that of Bijin, Taukha, Samarka, Khabarovsk and Badzhal terranes in the Sikhote-Alin area [12]. They are different ages of the oceanic plate. The results of partial subduction and local accretion of different lithologies [13].

During the growth of the Nadanhada terrane, the subduction of the oceanic plate to the continental margin of East Asia was accompanied by strong deformation of the sedimentary caprock. Firstly, at the bottom of the gully slope, turbidite in the upper layer of sedimentary caprock repeatedly “overlaps” under “shoveling” and forms a series of tectonic slices composed of terrigenous rocks. Subsequently, under the imbricated zone, the semi-deep-sea and deep-sea sediments in the middle and lower layers of the sedimentary caprock enter the subduction zone, forming inconsistent inversion folds with different amplitudes under the action of simple shear, and their axes incline to the continental direction. The sediments continue to deform until they reach the limit of rock strength and fracture occurs. Then, along these faults, the underpinning of the floor and the superimposition of rock slices took place, and finally the imbricated thrust structure composed of accretive complex was formed.

Under the continuous compressive force generated by the subduction of the oceanic plate to the continental margin of East Asia, accretionary wedges continue to form in the direction of oceanic basin. At the same time, large detachment planes gradually form between accretionary complex and the basement of the Jiamusi massif. During the movement of tectonic slices along the detachment facing the Jiamusi massif, a large number of fault planes and fold axis planes tend to reverse, from pointing to the continents to pointing to the oceanic basins, resulting in the development of thrust nappé faults with SE tendency in terranes.

4. Conclusion
The evolution history of the Nadanhada terrane can be divided into five stages: the drift stage, the accretion stage of the continental margin, the bending stage of the terrane structural line, the compression stage of the terrane and the anticlockwise rotation stage of the terrane. Bijin terrane can be seen as the extension of Nadanhada terrane in NNE direction.

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