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Tectonic constraints to Cretaceous magmatic arc deduced from detrital heavy minerals in northeastern Japan – evidence from detrital garnets, tourmalines and chromian spinels

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ABSTRACT

Tectonic histories of sedimentary basins in the Cretaceous Japan arc have been assessed to understand the response of the Asian continental margin to the oblique subduction of the Paleo-Pacific (i.e. Kula or Izanagi) Plate beneath the Asian continent during the Early Cretaceous and that which subducted orthogonally in the Late Cretaceous. In the Lower Cretaceous Kuji Group (Santonian–Campanian) of the Kitakami Massif in northern Japan, sandstone petrography and chemistry of detrital heavy mineral grains were performed on sandstones to assess the tectonic environment on the basis of provenance analysis.

Sandstone petrography results suggest that the material of the Kuji Group was derived mainly from areas of a Cretaceous volcanic belt (Rebun-Kabato Belt) and from a Jurassic accretionary complex (North Kitakami Terrane), which was intruded by Cretaceous granite, adjacent to the depositional basin. The chemical composition of detrital garnets suggests a North Kitakami Terrane origin, and detrital tourmalines are considered to have been derived mainly from meta-sedimentary rocks. The composition of detrital chromian spinels are compositionally diverse and mainly derived from tholeiitic and intra-plate basalts showing high TiO_2 (>about 1.0 wt%) and island arc basalts with moderately low TiO_2 ($1.0 > TiO_2 > 0.5$ wt%) and high Cr#. Latter chromian spinels can be considered as a record of island arc activity including high Mg-andesite in Early Cretaceous time. Because adequate source rocks of the spinels are elusive near the basin compared with those of detrital garnets and tourmalines, these rocks are believed to have been disturbed by Cenozoic tectonics and eroded and covered by newly formed volcanic and sedimentary rocks.

Comparison of chemical composition of the chromian spinels between Lower and Upper Cretaceous deposits in northern Japan indicates that chromian spinels with very low TiO_2 (<0.5 wt%) prevail in the Lower Cretaceous (Aptian–Albian). In contrast, chromian spinels showing moderately low TiO_2 predominated in the Upper Cretaceous (Santonian–Campanian). This clear difference suggests the change of oceanic plate motion around Japan arc promoted the change of source rock assemblage and the arc volcanic activity in mid-Cretaceous time. Thus the characteristics of detrital heavy mineral composition of the Kuji Group give the key to clarify the interaction between the swaying of young and hot plate and development of the Cretaceous island arc in eastern Asian margin.

1. Introduction

The success of sandstone petrology in determining the provenance and tectonic settings of modern and ancient sandstones has been widely documented (Dickinson and Suczek, 1979; Ingersoll, 1978; Dickinson and Valloni, 1980; Dickinson et al., 1983; Critelli and Ingersoll, 1994, 1995; Critelli and Le Pera, 1994). In recent years, additional effort has been made to relate the composition of detrital heavy minerals to potential source areas for reconstruction of the source lithology and paleogeography (Morton, 1985; Hisada et al., 2008). The combination of sandstone petrography and chemistry of detrital heavy minerals offers the necessary information for determining the relation between provenance and major tectonic events.

The orthogonal subduction of the Paleo-Pacific (i.e. Kura or Izanagi) Plate during the Triassic to Late Jurassic transformed to oblique subduction during the Late Jurassic to Early Cretaceous (Chang, 1995; Lithgow-Bertelloni and Richards, 1998). This

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northward oblique subduction led to major tectonic events such as arc magmatism, orogeny, and sinistral shearing in the overriding continental plate in the Early Cretaceous period. As a result, many strike-slip basins trending northeast–southwest were formed in the East Asian continental margin (Maruyama and Seno, 1986; Maruyama et al., 1997; Okada and Sakai, 2000). Furthermore, from 90 Ma to the end of the Cretaceous, the oceanic plate was moving to the west and an oceanic ridge that existed between the Izanagi–Kula Plate and the Pacific Plate subducted beneath the Asian continent near southwestern Japan (Maruyama et al., 1997). The change of plate motion with high speed subduction of the young and buoyant oceanic plate generated remarkable igneous activity (Takahashi, 1983; Maruyama and Seno, 1986; Tsuchiya et al., 2005, 2007). Thus, tectonics in the eastern marginal area of the Asian continent, which includes the Japanese islands, eastern China, the Korean peninsula, and Far East Russia, is characterized by magmatism and metamorphism caused by swaying plate motion of the young and buoyant oceanic plate with high speed convergence.

The Kuji Basin is a small Cretaceous basin in the northern Japanese islands. The Cretaceous sedimentary rocks deposited in this basin could contain a record of specific tectonics related to the subduction of hot and young oceanic plates during Cretaceous, because the depositional duration of the Kuji Group show considerable overlap with change of oceanic plate motion shown by Maruyama and Seno (1986) and Maruyama et al. (1997). This paper reports the petrography and chemistry of heavy mineral grains in the sandstones of the Lower Cretaceous Kuji Group (Shimazu and Teraoka, 1962) distributed in the Kitakami Massif in northern Japan (Fig. 1). In this study, in order to clarify the tectonic influence of the transition of Cretaceous plate motion, we discuss the chemistry of garnet, tourmaline, and chromian spinel detrital grains; these heavy minerals are important accessory minerals in metamorphic and mafic-ultramafic rocks (Dick and Bullen, 1984; Arai and Okada, 1991; Morton and Hallsworth, 1999; Barnes and Roeder, 2001; von Eynatten, 2003; Yoshida et al., 2010).

2. Geological setting

The Kuji Group is located in the northern part of the Kitakami Massif which primarily consists of a Jurassic accretionary complex known as North Kitakami Terrane and Lower Cretaceous granites. The Kuji Group unconformably overlies these pre-Upper Cretaceous units (Shimazu and Teraoka, 1962) and is disconformably overlain by the Paleogene Noda Group (Figs. 2 and 3).

The Kuji Group is approximately 400 m thick and consists of the Tamagawa, Kunitan, and Sawayama formations in ascending order. The Tamagawa Formation is probably Santonian in age (Miki, 1977). The stratigraphy is constrained by *Inoceramus*, mainly from the Kunitan Formation, and is assigned to the Santonian (Terui and Nagahama, 1995). A zircon fission track age of 71.2 ± 14.4 Ma reported from a felsic tuff in the Sawayama Formation suggests a Campanian age (Kato et al., 1986). Clay mineral assemblages and vitrinite reflectance of carbonaceous matter indicate diagenetic palaeotemperatures below 50 °C (Kimura et al., 2005). The age of the Noda Group was determined as early Oligocene from plant fossil data (Shimazu and Teraoka, 1962).

2.1. Tamagawa Formation

The Tamagawa Formation reaches a maximum thickness of 80 m and gradually thins toward the northwest. The lithofacies consists of a basal breccia conglomerate followed by cross-bedded sandstone with coal seams and *Ostera* beds. In the middle part, alternating beds of cross-bedded granule–pebble conglomerate and

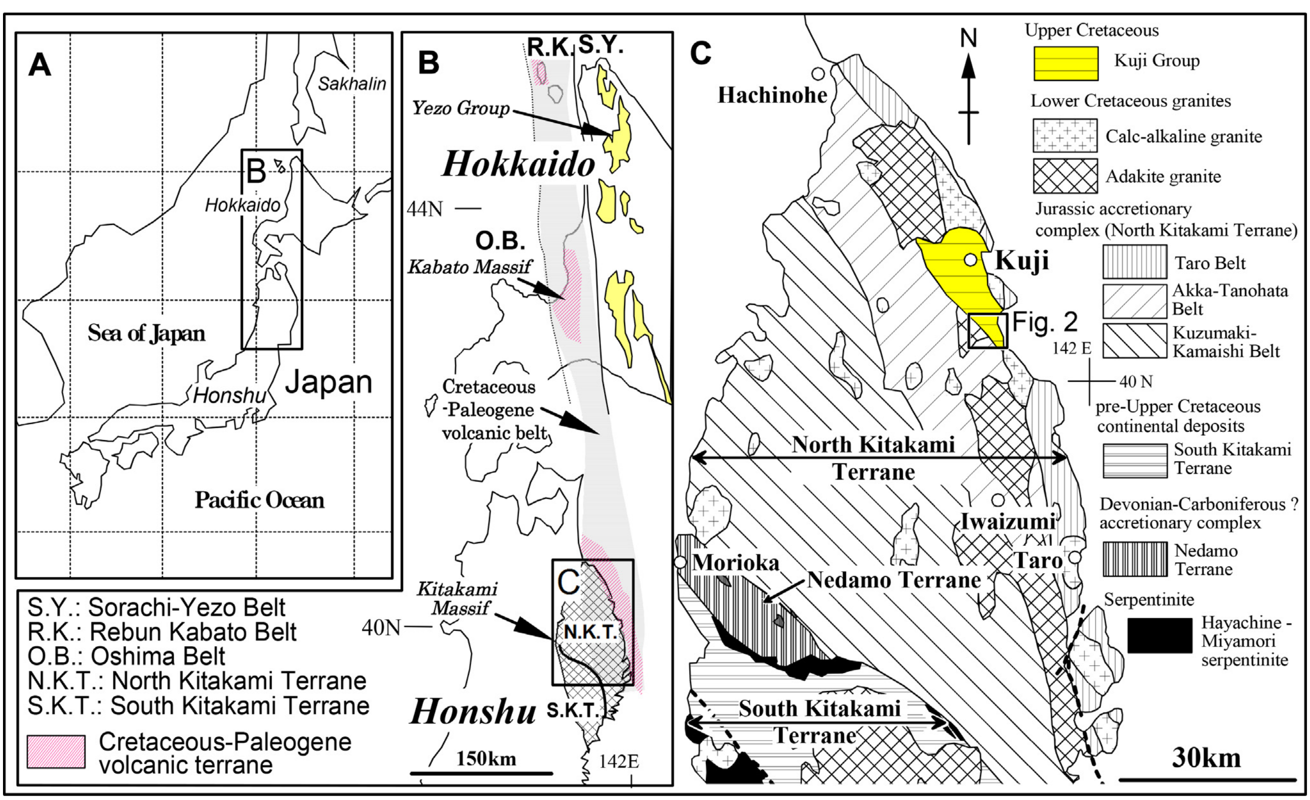

Fig. 1. A: Index map of study area. B: Distribution of Cretaceous volcanic rocks and division of geological belt compiled from Segawa and Furuta (1978) and Kiminami et al. (1986). C: Division of the geological belts in the Kitakami Massif. The simplified geology is compiled from Kawamura et al. (1990), Tsuchiya et al. (2005), and Uchino et al. (2005).