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Sr, Nd, and Pb isotope compositions of hemipelagic sediment in the Shikoku Basin: Implications for sediment transport by the Kuroshio and Philippine Sea plate motion in the late Cenozoic

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ABSTRACT

The provenance of hemipelagic sediments in the Shikoku Basin during late Cenozoic time was studied through the temporal variations in the Sr–Nd–Pb isotopic compositions of detrital sediments from Integrated Ocean Drilling Program Site C0011 from the late Miocene (7 Ma) to the present. Detrital sediments at Site C0011 are interpreted as a mixture of sediments originating from the southwest Japan arc and lands around the East China Sea. Sediments from the East China Sea were transported by the Kuroshio, while Japanese sediments were transported by turbidity currents, bottom currents, and ocean surface currents. The isotopic evidence suggests that the main source of hemipelagic sediments gradually changed from the East China Sea to Japan from 4.4 to 2.9 Ma, in accordance with the northward movement of Site C0011 with the Philippine Sea plate in this period. A contemporaneous increase in grain size also supports this interpretation. The beginning period of these changes, 4.4 Ma, conforms closely to the postulated advent or acceleration of trench-normal subduction of the Shikoku Basin lithosphere.

1. Introduction

The Nankai Trough, part of the convergent margin where the Philippine Sea plate subducts beneath the Eurasia plate along the southwest Japan arc, has been the site of repeated destructive earthquakes in historical times (Ando, 1975). Large tsunamis are generated by the rupture of mega-splay faults that branch from the plate boundary fault into the accretionary prism (Moore et al., 2007). Because the accretionary prism is largely composed of sediments deposited in the Shikoku Basin, and because fault behavior is strongly influenced by the composition of the surrounding material (e.g., Saffer and Marone, 2003), knowledge about the origin of the Shikoku Basin sediment is important for resolving mechanisms of plate boundary earthquakes and the evolution of continental crust.

The sediment supply to the Shikoku Basin is sensitive to the bathymetry, oceanography, and tectonics of the region surrounding the basin. In particular, the migration of the Philippine Sea plate is capable of causing large changes in the sedimentary environment by altering the spatial relations between the sources and the sink. Subduction of the Philippine Sea plate is considered to have been trench-normal since a notable change in its direction or velocity at around 5 Ma (Hall et al., 1995; Kimura et al., 2005). This latest Miocene tectonic event may have left its traces in the sedimentary succession of the Shikoku Basin.

The paleomagnetic orientation of rocks and sediments on a plate is a useful indicator for reconstructing the paleolatitude of a site (e.g., Yamazaki et al., 2010). However, the uncertainty of paleomagnetic data is too large to detect the migration of the few hundred kilometers that is estimated to be the extent of the Philippine Sea plate that has been subducted since ∼5 Ma (Kimura et al., 2005). On the other hand, the provenance of seafloor sediments can be a sensitive indicator of previous plate configurations. Feeding paths and mechanisms inferred from the sources that provided sediment to a site can confine the possible settings of the site.

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For example, the presence of sand derived from the Yangtze River drainage in a Miocene turbidite suggests that the Shikoku Basin was topographically connected to the mouth of the Yangtze at ∼15 Ma (Clift et al., 2013) and supports the idea that the Philippine Sea plate has rotated clockwise rapidly since 15 Ma (Hall et al., 1995; Sdrolias et al., 2004). Similar data from more time points will allow us to reconstruct the plate motion more completely.

The hemipelagic sediment cored at the northern end of the Shikoku Basin during Integrated Ocean Drilling Program (IODP) Expedition 333 is suitable for such study. Expedition 333 was designed to document the sedimentary strata and igneous basement of the incoming plate before its arrival at the subduction front as a part of the Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) program of expeditions. NanTroSEIZE aims to investigate fault mechanics and seismogenesis along the subduction megathrusts of the Nankai Trough through direct sampling, in situ measurements, and long-term monitoring (Tobin and Kinoshita, 2006). Expedition 333 obtained cores from a late Miocene to Holocene succession of hemipelagic muddy sediments at Site C0011, located north of the Shikoku Basin on the northeastern part of the Philippine Sea plate (Expedition 333 Scientists, 2012).

In this paper, we report the radiogenic isotope compositions of strontium ($^{87}Sr/^{86}Sr$), neodymium ($^{143}Nd/^{144}Nd$), and lead ($^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$) in hemipelagic detrital sediments deposited from 7 Ma to the present at Site C0011. Radiogenic isotopes of Sr, Nd, and Pb can be reliable tracers of the source of fine sediments in marine environments (e.g., Revel et al., 1996; Bentahila et al., 2008). It then identifies the major sources of the Site C0011 sediments by comparing the isotope compositions with the possible sources. This paper then discusses how the changes in these sources are related to the oceanographic and tectonic setting around Site C0011.

2. Geologic background of the Shikoku Basin

2.1. Tectonics

The Shikoku Basin is a back-arc basin that formed by rifting and spreading of the eastern part of the Philippine Sea plate between 27 and 15 Ma (e.g., Okino et al., 1994). Constituting the northeastern part of the Philippine Sea plate, the basin is bounded by the Izu–Bonin–Mariana arc on the east, the Kyushu–Palau Ridge on the west, and the Nankai Trough on the north (Fig. 1A). The Kyushu–Palau Ridge is a remnant Eocene–Oligocene arc that split from the Izu–Bonin–Mariana arc during rifting of the Shikoku Basin. The Kinan Seamount chain, between the two arcs, represents a fossil spreading center in the Shikoku Basin. The Shikoku Basin merges to the south with the Parece Vela Basin.

The Shikoku Basin lithosphere is subducting northwestward under the Eurasia plate at the Nankai Trough at 4.5–5.5 cm/yr around the Kii Peninsula as part of the Philippine Sea plate (e.g., Seno et al., 1993). The present rotation pole of the Philippine Sea plate is near or just north of its northern edge (e.g., Ranken et al., 1984; Seno et al., 1993). As rotation about this pole cannot account for the shifts in paleomagnetic inclination before ∼5 Ma, it is thought that the kinematics of the Philippine Sea plate changed significantly around 5 Ma (Hall et al., 1995). The plate is suggested to have rotated clockwise by 40° around a pole at 15°N, 160°E between 25 and ∼5 Ma (Hall et al., 1995). Sdrolias et al. (2004) suggested that the majority of this rotation (34°) must have been confined to the period between 15 and 5 Ma.

However, rapid rotation after 15 Ma conflicts with evidence that the collision of the Izu–Bonin–Mariana arc against the southwest Japan arc started about 15 Ma, and the location of the collision zone has not moved significantly since then (e.g., Amano, 1991; Taira, 2001). Taira (2001) argued that Philippine Sea plate subduction and the collision of the Izu–Bonin–Mariana arc against Honshu initiated at 15 Ma, and that a main phase of this subduction began at 8 Ma. Yamazaki et al. (2010) presented a model in which the Philippine Sea plate rotated 90° clockwise between 50 and 15 Ma around a pole near 23°N, 162°E so as not to contradict the initiation of collision at 15 Ma.

Provenance study of sandy sediments in the Shikoku Basin seems to favor a period of rapid rotation after 15 Ma. The U–Pb zircon ages of sandy sediment from 15.4 Ma from ODP Site 1177 have a much wider range than the ages of zircon grains contained in sediments of several rivers in Japan (Clift et al., 2013). This difference can be explained by input of sediment from the Yangtze River, which encompasses a large variety of source rocks. Clift et al. (2013) inferred that this was possible because the Kyushu–Palau Ridge intersected the Eurasia plate farther southwest at 15.4 Ma, and the Yangtze River mouth remained linked to the Shikoku Basin until the opening of the northern Okinawa Trough at ∼10 Ma (e.g., Letouzey and Kimura, 1985). However, accreted sedimentary and meta-sedimentary rocks in southwest Japan could contain zircon grains of various ages.

Kimura et al. (2005) compiled reports of igneous activity in the Shikoku and Chugoku areas of southwest Japan and estimated the subduction rate of the Philippine Sea plate under the assumption that the Izu–Honshu collision point has been fixed since 15 Ma. They calculated the following subduction rates based on the position of the leading edge, as inferred from the locations of volcanic activity and rock compositions: >10 cm/yr during 17–12 Ma, 0.9 cm/yr during 12–4 Ma, and 4 cm/yr after ∼4 Ma. On the other hand, Mahony et al. (2011) explained the volcano-tectonic evolution in Kyushu since 15 Ma under the assumption of significant clockwise rotation of the Philippine Sea plate since 15 Ma (Hall et al., 1995; Sdrolias et al., 2004; Gaina and Muller, 2007). They argued that at ∼5 Ma, the change in relative motion between the Philippine Sea and Eurasia plates from sinistral strike-slip to convergence led to subduction of the older western part of the Philippine Sea plate beneath Kyushu, resulting in an increasingly arc-like signature of volcanism in Kyushu after 6.5 Ma. The absence of subduction-related volcanism in Kyushu from 10 to 6 Ma (e.g., Kamata, 1992) was explained by especially slow subduction due to the dominance of sinistral strike-slip motion. Although their two scenarios conflict, it is important that Kimura et al. (2005) and Mahony et al. (2011) agreed that the trench-normal component of subduction was small between 10 and ∼5 Ma and increased after ∼5 Ma.

2.2. Oceanographic setting

The Shikoku Basin is strongly affected by the Kuroshio (Fig. 1A). The modern Pacific Ocean circulation, including the northward deflection of warm equatorial currents that forms the Kuroshio, was established at 13.9 Ma when eustatic sea level fall caused by major expansion of the East Antarctic ice sheet restricted the Indonesian throughflow (Kuhnt et al., 2004). Since then, the Kuroshio has flowed northward along the margin of the Eurasian continent as a western boundary current, then eastward along the southern margin of the Japanese islands. The Kuroshio along southwest Japan may have strengthened at 3 Ma coincidentally with the final closure of the Central American seaway (Tsuchi, 1997; Underwood and Fergusson, 2005), although expansion of the western Pacific warm pool at 4.4–3.6 Ma following the closure of the Indonesian and Central American seaways (Sato et al., 2008) could have strengthened the Kuroshio earlier, by 3.6 Ma.