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Tectonic, climatic, and diagenetic control of magnetic properties of sediments from Kumano Basin, Nankai margin, southwestern Japan

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ABSTRACT

Integrated Ocean Drilling Program (IODP) Site C0002 was cored in the Kumano Basin, which is a forearc basin in the Nankai margin of southwest Japan. The uppermost 1052.5 m of sediment in the accretionary prism, slope, and overlying forearc basin was recovered discontinuously during Expedition 315. Magnetic minerals from Site C0002 were studied to understand sedimentary, tectonic, and diagenetic processes in this forearc environment. Four rock magnetic units (A, B, C, and D) are identified. In the forearc basin sediments of Unit A, high concentrations of detrital magnetic iron oxides in surface sediments give way to progressive diagenetic dissolution with depth. Nevertheless, large titanomagnetite particles survived diagenetic dissolution along with magnetic nanoinclusions within host silicates that preserve a relict magnetic signal that records climatic modulation of sediment delivery to the Kumano Basin. The authigenic iron sulphides, ferrimagnetic greigite and paramagnetic pyrite, formed in association with gas hydrates and anaerobic oxidation of methane in the forearc basin sediments of Unit B. Methane venting from deeper within the slope sediments of Unit C and accretionary prism sediments of Unit D has given rise to formation of pyrite aggregates along sediment fractures and has contributed to further diagenetic depletion of magnetic signals in these units. Structural evolution of the Kumano Basin has caused migration of the gas hydrate stability zone (GHSZ) through time so that the Site C0002 sediments record both the present and fossil GHSZ positions. Magnetic properties of Kumano Basin sediments provide insights into the interplay between diagenetic, climatic, and tectonic processes that controlled the sedimentary evolution of this forearc basin.

1. Introduction

Forearc basins form between oceanic trenches and associated magmatic arcs along convergent tectonic margins. Stratigraphic sequences in such basins record the history of convergence, including collision of continental lithospheric plates, and oceanic plates with continents. They also reflect interactions between sedimentation, tectonics, climate, and sea-level fluctuations (Moore et al., 2015). However, it is difficult to study these basins systematically because they have dynamic geological environments and the sedimentary record in ancient forearc basins tends not to be well preserved (Ramirez et al., 2015). The Kumano forearc basin is located in the Nankai margin of southwest Japan, where the Philippine Sea Plate (PSP) is subducting beneath the Eurasian Plate (Fig. 1a; Seno et al., 1993; Miyazaki and Heki, 2001). It has been the subject of recent attention as a source of great thrust earthquakes and for commercial utilization of gas hydrates (Tobin and Kinoshita, 2006; Miyakawa et al., 2014; Wiersberg et al., 2015). As part of the Integrated Ocean Drilling Program (IODP) Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE), Sites C0009 and C0002 were drilled in the Kumano forearc basin (Expedition 315 Scientists, 2009; Expedition 319 Scientists, 2010; Strasser et al., 2014). The tectonic and sedimentary history of the Kumano Basin can now be assessed in detail by combining 3D and 2D seismic reflection data with drill hole lithological, geochemical, and geophysical data (Park et al.,

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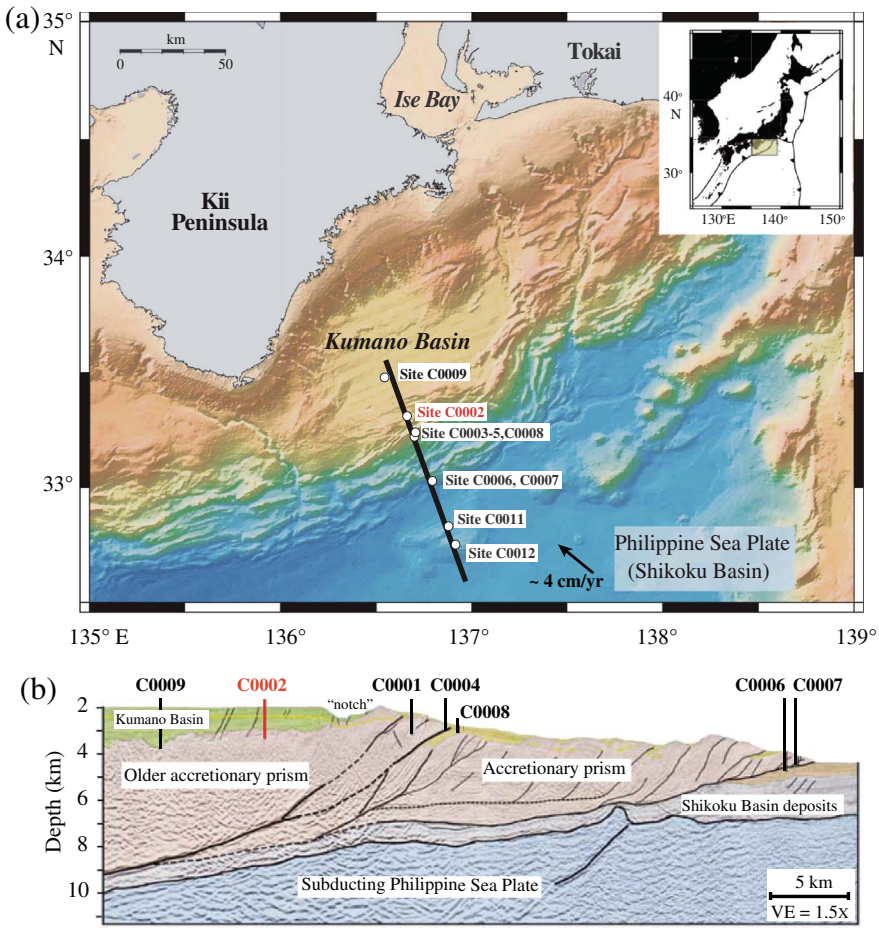

Fig. 1. (a) Location of IODP Expedition 315 Site C0002 and other drill sites from the Nankai margin, offshore of SW Japan. (b) Spliced composite profile of a representative 3D seismic reflection depth section with positions of IODP drill Site C0002 and several other drill sites (after Underwood et al., 2009).

2002; Moore et al., 2007, 2015; Strasser et al., 2009; Kimura et al., 2011; Underwood and Moore, 2012; Usman et al., 2014; Buchs et al., 2015; Ramirez et al., 2015).

Magnetic minerals in marine sediments originate mainly from detrital input, biomineralization, or post-depositional alteration. The composition and grain size of magnetic minerals are sensitive to environmental changes. Therefore, magnetic properties can help to track sediment sources and transportation pathways and to characterize depositional regimes and geochemical environments (e.g., Thompson and Oldfield, 1986; Hilgenfeldt, 2000; Rowan et al., 2009; Just et al., 2012; Liu et al., 2012; Roberts et al., 2013). For example, dissolution of primary magnetic minerals and authigenic growth of secondary magnetic iron sulphides are usually used to detect sulphidic diagenetic conditions or the presence of gas hydrates (Housen and Musgrave, 1996; Musgrave et al., 2006; Enkin et al., 2007; Larrasoaña et al., 2007; Rowan et al., 2009; Kars and Kodama, 2015a, 2015b; Roberts, 2015). Recently, Kars and Kodama (2015a, 2015b) studied the magnetic characteristics of gas hydrate-bearing sediments at IODP Site C0008 from the megasplay fault zone of Nankai Trough and revealed the importance of diagenetic processes. However, knowledge of the magnetic properties of marine sediments in forearc basins and their relationship to tectonic evolution remains poor. Previous magnetic studies of sites C0002 and C0009 reveal the presence of magnetite and iron sulphides (Expedition 315 Scientists, 2009; Expedition 319 Scientists, 2010; Kanamatsu et al., 2012). The sampling resolution of these preliminary studies, however, was low, and they did not focus on diagenetic processes or their environmental implications.

We present detailed magnetic results and electron microscope observations for 374 discrete samples from Site C0002. Our objectives are to: 1) obtain a detailed magnetic parameter sequence for a vertical section through the Kumano Basin, and to 2) reveal relationships between magnetic mineral assemblages, sedimentation, tectonic evolution, climatic modulation, and diagenesis.

2. Geological setting and sampled material

Nankai Trough is a convergent margin, where the Philippine Sea Plate is subducting to the northwest beneath the Eurasian Plate at a rate of ~4 cm/yr (Fig. 1a; Seno et al., 1993; Miyazaki and Heki, 2001). The convergence direction is approximately normal to the trench and the Kii Peninsula, and sediments of Shikoku Basin are actively accreting at the deformation front (Park et al., 2002). Kumano Basin sits between the upper trench slope and a megasplay fault associated with a forearc high that marks the transition in the Nankai margin from a downslope to an imbricate thrust zone. The basin basement is a Miocene–Pliocene accretionary prism that is overlain by lower Pliocene trench-slope deposits (Expedition 315 Scientists, 2009).

Uplift along a regional out-of-sequence thrust (megasplay) fault began at around 1.95 Ma (Strasser et al., 2009) and is thought to have created accommodation space for thick forearc-basin deposits near the distal edge of the basin on the Kumano transect (Fig. 1b; Underwood and Moore, 2012). Motion along a new, landward splay fault branch caused tilting of the lower forearc basin between ~1.2 and 0.9 Ma (Gulick et al., 2010); continued splay fault slip caused further landward tilting of the sediment sequences (Gulick et al., 2010; Moore et al., 2015). A gas hydrate-bearing zone was identified indirectly in the interval from 218 to 401 m below seafloor (mbsf) above a bottom-simulating reflector (BSR) identified from electrical resistivity and seismic P-wave velocity measurements (Expedition 314 Scientists, 2009). Massive methane release is considered to have occurred along the seaward edge of the Kumano forearc basin at 0.05 Ma (Bangs et al., 2010).

Site C0002 (Fig. 1a, b) is located on the southern margin of Kumano