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Environmental conditions for the presence of magnetofossils in the Last Glacial Maximum inferred from magnetic parameters of sediments from the Ulleung Basin, East Sea

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ABSTRACT

Magnetic characterization of sediments from the Ulleung basin in the East Sea (Japan Sea) was carried out to decipher changes in environmental conditions over the last ~39,000 years. Magnetic susceptibility (χ), intensities of natural remanent magnetization (NRM), anhysteretic remanent magnetization (ARM), partial ARM (pARM), and saturation isothermal remanent magnetization (SIRM) were measured. For selected samples, IRM acquisition, hysteresis and first-order reversal curve (FORC) measurements were made. The ratios of rock-magnetic parameters, such as χ_{ARM}/χ, SIRM/ARM and S-ratio, were determined to identify magnetic grain size and mineralogical variations along with electron microscope observations of magnetic mineral extracts. Down-core variations in rock-magnetic parameters for the 5.21-m-long sediment core reveal distinct intervals with different grain size, concentration and composition of magnetic minerals. The uppermost portion and the high magnetic intensity zone (HIZ) in marine isotope stage (MIS) 2 are characterized by higher concentrations of fine-grained magnetite, whereas the MIS 1 and 3 intervals contain lower concentrations of coarser-grained magnetic minerals with increasing influence of hematite and/or iron sulphide minerals. The HIZ interval is inferred to contain high occurrences of fine-grained bacterial magnetosomes. Based on geochemical proxies, East Sea conditions for the HIZ interval, coincident with the last glacial maximum (LGM), can be summarized as having low total organic carbon (TOC), enhanced eolian contributions from terrestrial organic particles and iron-bearing minerals under the influence of an intensified East Asian winter monsoon, along with iron-reducing, but not sulphidic, conditions that favoured growth and preservation of magnetotactic bacteria. The delicate balance between reductive dissolution of magnetofossils under sulphidic conditions and production and preservation of magnetotactic bacteria in overlying iron-reducing sediments for the HIZ interval is responsible for the resultant abundance variations of magnetosomes in the studied sediments.

1. Introduction

Environmental magnetism is used to explore the relationship between grain size, concentration and compositional variations of naturally occurring magnetic materials and processes regarding their formation, transportation, deposition and post-depositional changes. Since early studies in the mid 1970s, environmental magnetism (Thompson et al., 1980; Liu et al., 2012) has contributed considerably to understanding paleoenvironmental and paleoclimatic changes. Climatic changes in the past, ranging from winter and summer monsoons with annual cycles to orbital-scale glacial–interglacial cycles, result in sea surface temperature, salinity, nutrient concentration and primary productivity changes as well as of wind and ocean current patterns, in addition to changing weathering processes and supply of detrital minerals to nearby ocean basins. These changes collectively bring about varying geochemical conditions in the water column and sediments. Diagenetic alteration and authigenic formation of magnetic minerals in response to different conditions, for instance, should leave a magnetic signature that can be detected using sediment magnetic properties. Magnetic minerals are sensitive to environmental processes and conditions, therefore, rock-magnetic studies can provide powerful insights into paleoenvironmental and paleoclimatic processes. In early studies, the East Sea (Japan Sea) was interpreted to have been stagnant during glacial periods based on observations of ferrimagnetic iron sulphides in sediments (Kobayashi and Nomura, 1972). More recently, magnetic properties of glacial–interglacial sediments from the Yamato and Japan Basins have been shown to be controlled by diagenetic and climate-related processes as evident in variations in concentration, mineralogy and grain size of magnetic minerals (Vigliotti, 1997). Magnetic mineral alteration through reductive dissolution and authigenic formation of new minerals is widely used to infer changes in past climatic and geochemical conditions (Larrasoaña et al., 2003; Yamazaki et al., 2003; Hayashida et al., 2007; Blanchet et al., 2009; Nowaczyk et al., 2012).

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It has been generally considered until recently that terrigenous and abiotic authigenic minerals are the major constituents of sedimentary magnetic mineral assemblages. Increasingly, the importance of biogenic magnetite has been recognized as a carrier of ancient magnetizations in sediments and sedimentary rocks (Blakemore, 1975; Kirschvink, 1983; Stolz et al., 1989). Magnetotactic bacteria, intracellular magnetosome producing microbes, are commonly known to live around the oxic-anoxic transition zone (OATZ) in aquatic environments (e.g., Bazylinski and Frankel, 2004; Kopp and Kirschvink, 2008; Roberts et al., 2013). For magnetosomes to be preserved geologically, the magnetite particles must survive diagenetic oxidation and reductive dissolution. Early diagenesis is inseparably linked to degradation of organic carbon, where organic carbon particles are degraded by microbial respiration processes using different electron acceptors (e.g., Froelich et al., 1979; Thamdrup and Canfield, 2000; Roberts, 2015). Magnetosomes can form in iron-reducing conditions, but will be readily destroyed in the underlying sulphate-reducing environments. Thus, the balance between production and the degree of preservation of magnetosomes under given geochemical conditions determines the resultant abundance of magnetosomes and their contribution to the magnetic properties of sediments. In this study, the presence of fossil magnetosomes (known as magnetofossils), identified by various magnetic properties and electron microscope observations, in the Last Glacial Maximum (LGM) interval of the Ulleung Basin, East Sea, is elucidated in relation to environmental conditions associated with their increased occurrence.

2. Study area and methods

The East Sea is a marginal sea with the deepest portion exceeding 2000 m in depth. The East Sea consists of three well developed deep basins: the Ulleung Basin, Yamato Basin, and Japan Basin. The Ulleung Basin, located in the southwestern part of the East Sea, is bowl-shaped and is bounded by the Oki-Bank to the east, the Korea Plateau to the north, a steep Korean continental slope to the west and a gentle continental slope toward Japan to the south (Fig. 1). The Ulleung Basin is affected by the cold Liman Current and North Korean Cold Current and by the warm Tsushima Current that moves northward through the Korea Strait (Tsushima Strait). Primary productivity and export flux of organic matter in the Ulleung Basin are especially high compared with other areas of the East Sea (Hyun et al., 2009; Kim et al., 2009; Yamada et al., 2005). The average sedimentation rate in the Ulleung Basin is about 20 cm/ka based on ^{14}C ages measured from several ash layers (Park et al., 2005). Interbedded tephra layers and dark laminated mud horizons in Ulleung Basin sediment cores have been used to determine sediment ages and for chronostratigraphic correlation (Park et al., 2002, 2006; Chun et al., 2004, 2007).

Two piston cores were collected from sites 8 (36°53′31.80″N, 130°29′35.40″E) and 10 (36°30′0.00″N, 131° 0′0.00″E) at water depths of 2127 m and 2024 m, respectively, in the Ulleung Basin, with core lengths of 5.21 m for site 8 and 4.66 m for site 10 (Fig. 1). Discrete samples were collected in non-magnetic plastic cubes and descriptions of sedimentary facies and X-radiographs were made. Rock-magnetic parameters, such as the magnetic susceptibility (χ), intensities of the natural remanent magnetization (NRM), anhysteretic remanent magnetization (ARM), isothermal remanent magnetization (IRM) up to saturation (SIRM), and partial ARM (pARM) were measured. A pARM, which is an ARM imparted for a specific interval of a decaying alternating field (AF), was obtained using an AF control attachment to the Molspin AF demagnetizer. Ratios of rock-magnetic parameters, such as χ_{ARM}/χ, where χ_{ARM} is the susceptibility of ARM

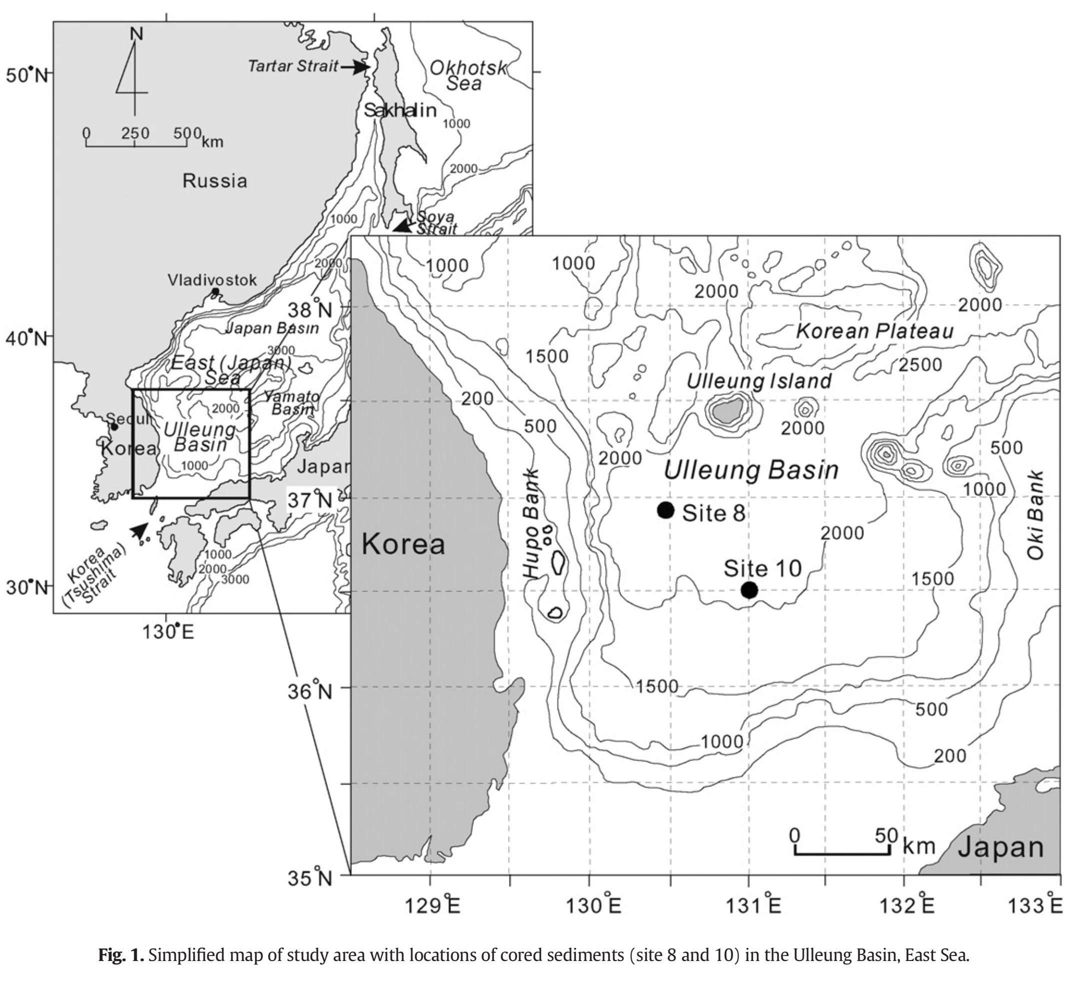

Fig. 1. Simplified map of study area with locations of cored sediments (site 8 and 10) in the Ulleung Basin, East Sea.