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The onset of fabric development in deep marine sediments

Marco Maffione [a,b,*], Antony Morris [c]

[a] School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK
[b] Department of Earth Sciences, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, Netherlands
[c] School of Geography, Earth and Environmental Sciences, Plymouth University, Drake Circus, Plymouth, PL4 8AA, UK

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ABSTRACT

Post-depositional compaction is a key stage in the formation of sedimentary rocks that results in porosity reduction, grain realignment and the production of sedimentary fabrics. The progressive time-depth evolution of the onset of fabric development in deep marine sediments is poorly constrained due to the limited quantity and resolution of existing data. Here we present high-resolution anisotropy of magnetic susceptibility (AMS) results from clay-rich deep marine sediments recovered at International Ocean Discovery Program Site U1438 (Philippine Sea). AMS is a petrofabric tool sensitive to the preferred orientation of grains in rocks. Down-section variations of AMS parameters, density, porosity and the inclination of magnetic remanences demonstrate that fabrics develop in response to compaction and dewatering but also that they do not develop progressively with depth below the mudline. Instead, a horizontal foliation first forms at 83 mbsf once the sediment load reaches an effective stress threshold for the onset of compaction and is then continuously enhanced down to 113 mbsf, defining a 30 m-thick 'initial compaction window'. The magnetostratigraphic age model for IODP Site U1438 indicates a delay of 5.7 Ma in initial fabric formation following sediment deposition, with strongly defined fabrics then taking an additional 6.5 Ma to develop.

1. Introduction

During deposition of (hemi)pelagic sediments in deep-sea environments, platy minerals (mainly phyllosilicates) tend to align with their long axes parallel to the water–sediment interface. Bottom-current disturbance and bioturbation, together with the natural predisposition of clay flakes to form edge-to-edge and edge-to-face contacts due to surface electric charge distribution (Bennett et al., 1991), eventually result in an uppermost sedimentary interval characterized by a chaotic internal structure (i.e., isotropic fabric) and high porosity and water content (Bennett et al., 1991; Reynolds and Gorsline, 1992). With increasing vertical burial load at depth, clays particles rotate to form horizontal face-to-face contacts, accompanied by simultaneous dewatering and porosity reduction (Bennett et al., 1981; Bennett and Hulbert, 1986). The effect of this process on the microstructure of the sediment is the formation of a fabric characterized by a well-defined horizontal foliation plane.

The majority of dewatering and compaction in pelagic sedimentary sequences is thought to occur progressively within the uppermost stratigraphic intervals (e.g., Arason and Levi, 1990). However, only a few previous studies have investigated microstructure changes during compaction and initial fabric development in deep marine environments (Kopf and Behrmann, 1997; Hirano et al., 2001; Kawamura and Ogawa, 2002, 2004), and none have a sufficiently high spatial and temporal resolution to describe in detail the evolution of this process.

Here we present results of a high-resolution anisotropy of magnetic susceptibility (AMS) analysis of a sequence of unconsolidated deep marine sediments recovered in the Philippine Sea by International Ocean Discovery Program (IODP) Expedition 351 (Arculus et al., 2015a), where magnetostratigraphy provides an accurate age model. We use AMS as a sensitive measure of fabric development in these sediments (e.g., Rochette et al., 1992; Tarling and Hrouda, 1993; Borradaile and Jackson, 2004), and compare magnetic fabric parameters with other physical properties to tightly constrain the depth and timing of the onset and evolution of fabric development in a deep marine environment.

2. Geological background and sampling

2.1. Tectonic framework of the Philippine Sea Plate and IODP Site U1438

The Philippine Sea Plate (PSP) is an oceanic plate located between the Eurasia and Pacific plates and bordered by active sub-

* Corresponding author.
E-mail address: m.maffione@bham.ac.uk (M. Maffione).

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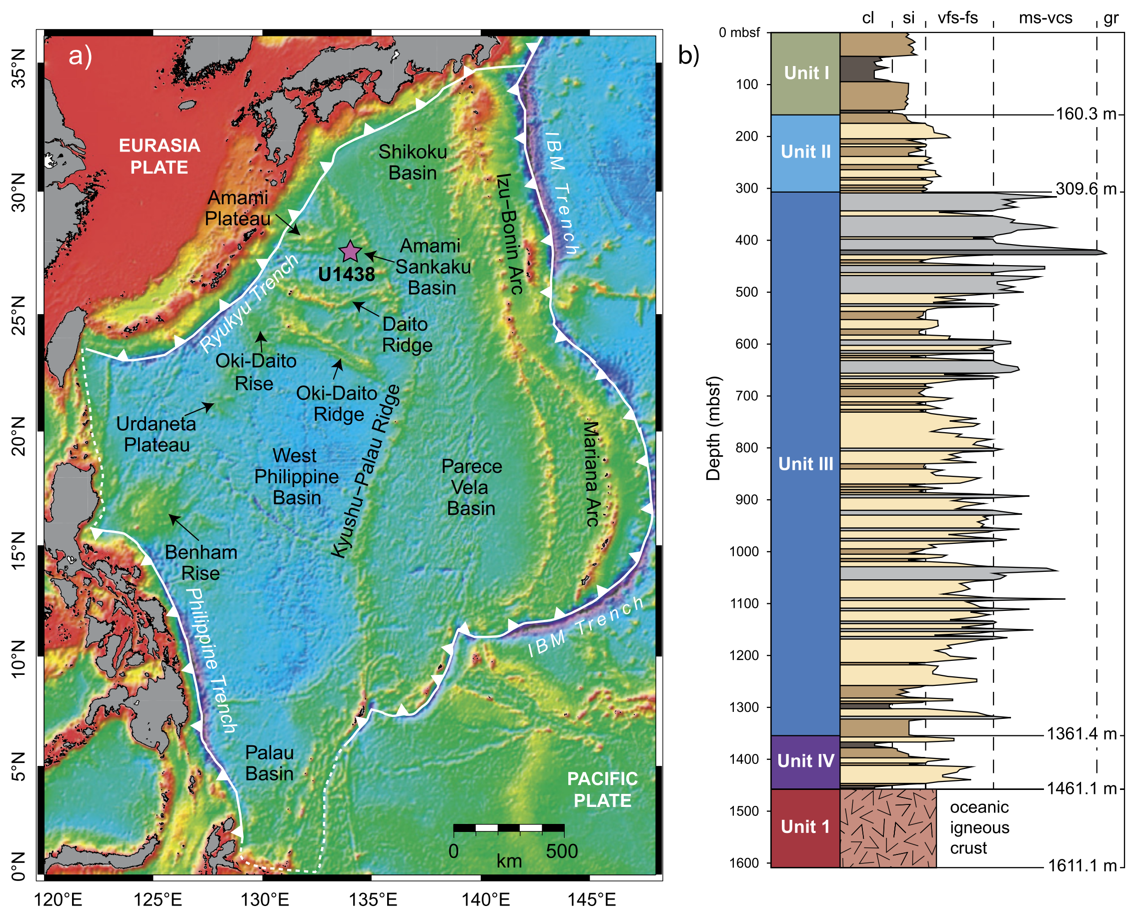

Fig. 1. (a) Location map of the Philippine Sea Plate (PSP) showing the main geological structures and domains inferred from bathymetry, and the location of IODP Site U1438. (b) Lithostratigraphic log from Site U1438 (after Arculus et al., 2015a). The grain size is averaged over 5 m thick intervals. (cl) clay; (si) silt; (vfs-fs) very fine to fine sand; (ms-vcs) medium to very coarse sand; (gr), granules. Unit subdivision is indicated.

duction zones (Fig. 1). The PSP can be subdivided into three tectono-stratigraphic domains: (i) a western domain floored by a complex array of oceanic plateaux, ridges, and basins of Cretaceous to Oligocene age and bordered to the east by the Eo-Oligocene (∼55–25 Ma) Kyushu-Palau Ridge (e.g., Deschamps and Lallemand, 2003; Okino and Fujioka, 2003; Ishizuka et al., 2011a, 2013); (ii) a central domain dominated by the Miocene (∼25–12 Ma) Parece Vela-Shikoku back-arc basin (Okino et al., 1994) occurring between the Kyushu-Palau Ridge and the modern Izu-Bonin-Mariana (IBM) arc; and (iii) an eastern domain forming the forearc region between the modern IBM arc and the IBM trench, developed upon initiation of subduction of the Pacific plate below the PSP at ∼52 Ma (Ishizuka et al., 2011b; Reagan et al., 2010; Arculus et al., 2015b).

During June and July 2014, IODP Expedition 351 (Arculus et al., 2015a) recovered a suite of sedimentary and volcanic rocks at Site U1438 (4700 m water depth) in the western domain of the PSP (Amami Sankaku Basin; 27.38°N, 134.32°E; Fig. 1a). Four progressively deeper holes were drilled at this site, down to 26.5, 257.3, 897.8, and 1611 meters below seafloor (mbsf), at Holes U1438A, B, D and E respectively. Recovered rocks (Fig. 1b) consist of a thick sedimentary sequence (Units I–IV) deposited since the Early Eocene (∼55 Ma) and recording the birth, evolution and death of the Kyushu-Palau Ridge, overlying igneous basement rocks (Unit 1).

2.2. Deep marine sedimentation in the west PSP (Unit I)

Unit I (0–160.3 mbsf; Hole U1438B) is an unconsolidated fine-grained pelagic and hemipelagic sedimentary sequence composed of mud, tuffaceous mud, mud with ash, and clay with discrete ash beds. Paleomagnetic and biostratigraphic constraints place the base of Unit I at the Miocene–Oligocene transition (Arculus et al., 2015a). Deposition of Unit I therefore started soon after the demise of Kyushu-Palau Ridge volcanism and initial opening of the Parece Vela-Shikoku back-arc basin to the east (thought to occur at ∼25 Ma; Okino et al., 1994). Since no significant tectonic events occurred since that time at the location of Site U1438, Unit I represents the product of deep marine sedimentation, with sedimentation rates ranging from ∼2 to ∼0.5 cm/kyr (Arculus et al., 2015a).

The average grain size of Unit I changes slightly down-core, with the uppermost interval (0–45 mbsf) mainly represented by silt with a significant (up to 60%) biogenic, mainly siliceous component, a central interval (45–93 mbsf) dominated by clay with a lower biogenic content, and a bottom interval (93–160.3 mbsf) represented again predominantly by silt. Bioturbation is rare in the upper interval of Unit I (<93 mbsf) and increases at depth, with more bioturbated intervals occurring below 121 mbsf. X-Ray diffraction analyses revealed a predominant assemblage of quartz, plagioclase, chlorite, muscovite, illite and other clay minerals (Arculus et al., 2015a). Below ∼93 mbsf (in the lower silt) quartz content decreases, while the content of zeolite and clay minerals increases.

3. Methods

Anisotropy of magnetic susceptibility (AMS) is a petrofabric tool used to determine the preferred orientation of minerals (e.g.,