ARTICLE IN PRESS
EPSL:14530

Earth and Planetary Science Letters ••• (••••) •••–•••

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Grain size dependent magnetic discrimination of Iceland and South Greenland terrestrial sediments in the northern North Atlantic sediment record

Robert G. Hatfield [a,*], Joseph S. Stoner [a], Brendan T. Reilly [a], Frank J. Tepley III [a], Benjamin H. Wheeler [a], Bernard A. Housen [b]

[a] *College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR, 97331, USA*
[b] *Geology Department, Western Washington University, Bellingham, WA, 98225, USA*

ARTICLE INFO

Article history:
Received 12 October 2016
Received in revised form 23 June 2017
Accepted 25 June 2017
Available online xxxx
Editor: M. Frank

Keywords:
source unmixing
environmental magnetism
North Atlantic
Iceland
Greenland
provenance

ABSTRACT

We use isothermal and temperature dependent in-field and magnetic remanence methods together with electron microscopy to characterize different sieved size fractions from terrestrial sediments collected in Iceland and southern Greenland. The magnetic fraction of Greenland silts (3–63 μm) and sands (>63 μm) is primarily composed of near-stoichiometric magnetite that may be oxidized in the finer clay (<3 μm) fractions. In contrast, all Icelandic fractions dominantly contain titanomagnetite of a range of compositions. Ferrimagnetic minerals preferentially reside in the silt-size fraction and exist as fine single-domain (SD) and pseudo-single-domain (PSD) size inclusions in Iceland samples, in contrast to coarser PSD and multi-domain (MD) discrete magnetites from southern Greenland. We demonstrate the potential of using magnetic properties of the silt fraction for source unmixing by creating known endmember mixtures and by using naturally mixed marine sediments from the Eirik Ridge south of Greenland. We develop a novel approach to ferrimagnetic source unmixing by using low temperature magnetic susceptibility curves that are sensitive to the different crystallinity and cation substitution characteristics of the different source regions. Covariation of these properties with hysteresis parameters suggests sediment source changes have driven the magnetic mineral variations observed in Eirik Ridge sediments since the last glacial maximum. These observations assist the development of a routine method and interpretative framework to quantitatively determine provenance in a geologically realistic and meaningful way and assess how different processes combine to drive magnetic variation in the North Atlantic sediment record.

1. Introduction

Marine sediments from the Northern North Atlantic (NNA) consistently provide high quality paleomagnetic and environmental magnetic records (Stoner et al., 1996; Channell and Lehman, 1997; Kissel et al., 1999; Watkins and Maher, 2003; Kissel, 2005; Hatfield et al., 2016). This quality is often attributed to an abundance of ferrimagnetic minerals that originate from mid ocean ridge volcanism and subglacial erosion of crystalline basement that surrounds the NNA (e.g. Watkins and Maher, 2003). These grains are efficiently transported from their source regions to the ocean in subglacial outwash or icebergs and are (re)distributed by down slope mass transport and by surface and deep-ocean currents (e.g. Robinson, 1986; Stoner et al., 1996; Kissel et al., 1999; Watkins and Maher, 2003; Kissel, 2005). Due to minimal magnetic mineral diagenesis (e.g. Robinson et al., 2000; Kawamura et al., 2012), these minerals retain a primary signature reflecting their source (e.g. Watkins and Maher, 2003; Hatfield et al., 2013) and their transport/depositional history (e.g. Robinson, 1986; Stoner et al., 1996; Kissel et al., 1999; Kissel, 2005).

Downcore variations in bulk magnetic properties can be grouped into distinct spatial patterns across the NNA (e.g. Kissel, 2005). Peaks in magnetic susceptibility and coarsening of magnetic grain size are often interpreted as increased delivery of larger lithic grains from glacial marine processes, either IRD (i.e., Robinson, 1986) or overflows associated with down slope transport (i.e., Stoner et al., 1996), and/or as stronger bottom currents resulting in enhanced sediment transport (e.g. Kissel et al., 1999; Snowball and Moros, 2003). Correlation of bulk magnetic properties to independent datasets sensitive to transportation/depositional pro-

---

* Corresponding author.
E-mail address: rhatfield@ceoas.oregonstate.edu (R.G. Hatfield).

http://dx.doi.org/10.1016/j.epsl.2017.06.042
0012-821X/© 2017 Elsevier B.V. All rights reserved.

Please cite this article in press as: Hatfield, R.G., et al. Grain size dependent magnetic discrimination of Iceland and South Greenland terrestrial sediments in the northern North Atlantic sediment record. Earth Planet. Sci. Lett. (2017), http://dx.doi.org/10.1016/j.epsl.2017.06.042

cesses (e.g. Robinson, 1986; Stoner et al., 1996; Channell et al., 2016) or to climatic variations observed in Greenland ice cores (that are generally thought to reflect Atlantic Meridional Overturning Circulation; e.g. Rasmussen et al., 1997; Kissel et al., 1999; Snowball and Moros, 2003), have reinforced transport driven explanations for magnetic mineral variations. In contrast, changes in source are often overlooked as fundamental drivers of downcore magnetic variability, despite their role in controlling the abundance, mineralogy, and grain size of the magnetic materials available for transport. This has resulted from difficulties in the subtle discrimination of ferrimagnetic minerals using bulk environmental magnetic techniques (e.g. Thompson and Oldfield, 1986). In practice, unless non-ferrimagnetic contributions are routinely identified, sediment sources to NNA sediment records are frequently considered relatively uniform, despite being a convolution of source and transport processes. Accordingly, methods capable of robustly discriminating ferrimagnetic source variability from transport driven changes are required.

Magnetic properties of terrestrial and marine sediments from the NNA exhibit strong physical grain size dependence (Hatfield et al., 2013, 2016). For example, non-cohesive silts (10–63 μm) from Greenland and Iceland, two large NNA terrestrial sediment sources, possess 2–5 times the mass-specific magnetic susceptibility (χ) values of fine silt/clay (<10 μm) or sand (>63 μm) fractions (Hatfield et al., 2013). While M_{rs}/M_s values (the ratio of saturation remanence [M_{rs}] to saturation magnetization [M_s] as a proxy for ferrimagnetic grain size) of Iceland clays (<3 μm; M_{rs}/M_s range = 0.26–0.46), silts (3–63 μm; 0.20–0.32), sands (>63 μm; 0.19–0.31) and Greenland clays (0.10–0.33) are all similar, Greenland silts (0.03–0.15) and sands (0.02–0.14) are magnetically coarser and distinct from all Icelandic fractions (Hatfield et al., 2013). By restricting analysis to the silt-size fraction, Hatfield et al. (2013, 2016) demonstrated that the relative contribution of terrestrial sources could be determined and isolated relative to sediment transport/depositional processes that dictate sediment texture. However, while this methodology implied source variability may be an important driver of bulk NNA ferrimagnetic records (Hatfield et al., 2013, 2016), the origins of the observed variance in terrestrial samples (Hatfield et al., 2013) or marine sediments (Hatfield et al., 2016) are still unclear and have not sufficiently been explored.

To better understand the discrimination afforded between Iceland and Greenland terrestrial sources and the implications they have for driving bulk NNA variability, we build upon the research of Hatfield et al. (2013) in four ways. First we expand the terrestrial χ and M_{rs}/M_s dataset through the measurement of 84 new sediment fractions from Iceland and Greenland. Second, using the same sediment samples as Hatfield et al. (2013) we make detailed temperature, frequency, and field dependent magnetic measurements and electron microscopy and energy dispersive spectroscopy (EDS) observations. This array of measurements allows an understanding of 1) why and how (sub)micron size ferrimagnetic grains exist in Icelandic silt and sand fractions, 2) what (if any) magnetic mineral variation exists between the distinct geological terranes, and 3) further the discrimination of the particle-size specific magnetic character of these sources. Next, we investigate unmixing of magnetic concentration, magnetic grain size, and magnetic mineralogy in the silt-size fraction through the measurement of known mixtures in order to investigate how these sources might behave in mixed sedimentary systems (e.g. marine sediment cores). Finally, we compare marine sediments to terrestrial endmembers and mixtures and discuss implications for source-sink process interpretations in a geologically realistic and meaningful context.

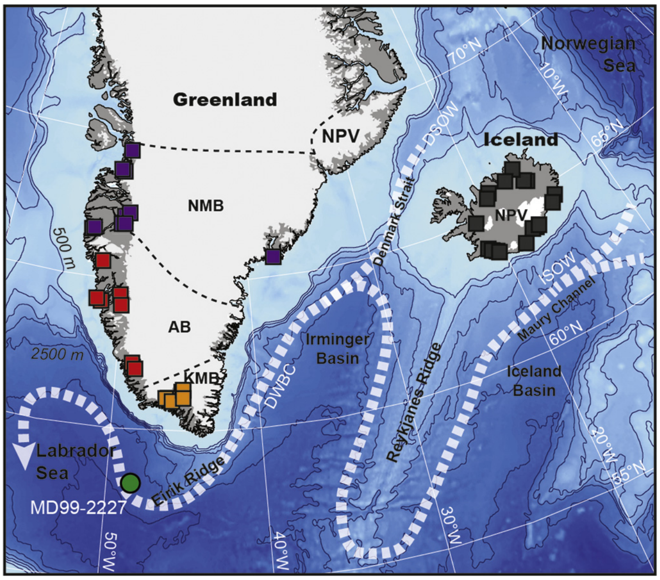

Fig. 1. Location of terrestrial sediment samples from the Neogene and Paleogene volcanics (NPV) of Iceland (black squares), and the three terranes of southern Greenland; the Nagssustoqidian Mobile Belt (NMB; purple squares), Archean Block (AB; red squares), and Ketilidian Mobile Belt (KMB; orange squares). The location of core MD99-2227 (green circle) on the Eirik Ridge is shown alongside the path of the Deep Western Boundary Current (DWBC) and its two major precursors, Denmark Strait Overflow Water (DSOW) and Iceland Scotland Overflow Water (ISOW). Bathymetry contours are at 500 m intervals. (For interpretation of the colors in this figure, the reader is referred to the web version of this article.)

2. Samples and methods

2.1. Sample locations and sample preparation

The collection of Greenland and Iceland glacio-fluvial sediment samples is previously detailed in Hatfield et al. (2013); sampling locations and geological terrane boundaries are summarized in Fig. 1. Iceland and east-central Greenland are mainly composed of tholeiitic basalts, transitional alkali basalts, and alkali olivine basalts of Neogene and Paleogene age with regional variations encompassing ultramafic to rhyolitic compositions (e.g. Jakobsson, 1972; Pedersen et al., 1997). The Precambrian rocks of southern Greenland can be sub-divided into three geological terranes that extend roughly west-east and outcrop from under the ice sheet along the coastal margins (Fig. 1). The Ketilidian Mobile Belt (KMB) is composed of juvenile Proterozoic crust consisting of voluminous granitic intrusions, while the Archean Block (AB) and Nagssugtoqidian Mobile Belt (NMB) are dominated by Archean age gneisses and granites that remained undeformed (AB) or were later metamorphosed during the Proterozoic (NMB) (Fig. 1; Korstgard et al., 1987; Escher and Pulvertaft, 1995). Although most sampling sites are located in the south and west of Greenland (Fig. 1) previous studies have shown it is reasonable to consider these as geological analogues for outcrops within the same terrane in east Greenland (Colville et al., 2011; Reyes et al., 2014; Hatfield et al., 2016). Hatfield et al. (2013) reported χ data on five fine silt/clay and silt fractions and hysteresis data on clay, silt, and sand fractions from 67 locations in Greenland and 11 from Iceland. We augment this dataset with χ measurements of clay, silt, and/or sand from 79 new and existing locations (61 in Greenland, 18 in Iceland) and hysteresis measurements from 41 new locations (28 in Greenland, 13 in Iceland). All samples were collected during the same field programs as those presented in Hatfield et al. (2013). The sand fraction was isolated by wet sieving at 63 μm and the clay (<3 μm) and silt (3–63 μm) fractions were separated according to Stokes law following Hatfield et al. (2013). To assess

Please cite this article in press as: Hatfield, R.G., et al. Grain size dependent magnetic discrimination of Iceland and South Greenland terrestrial sediments in the northern North Atlantic sediment record. Earth Planet. Sci. Lett. (2017), http://dx.doi.org/10.1016/j.epsl.2017.06.042