Geophysical Research Abstracts
Vol. 19, EGU2017-11018, 2017
EGU General Assembly 2017

Widespread occurrence of magnetic nanoparticle inclusions in marine sediments and their importance in paleomagnetism and environmental magnetism

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Magnetic mineral inclusions occur commonly within other larger mineral phases in igneous rocks and have been demonstrated to preserve important paleomagnetic signals. While the usefulness of magnetic inclusions in igneous rocks have been explored extensively, their presence in sediments has only been speculated upon. The contribution of magnetic inclusions to the magnetization of sediments, therefore, has been elusive. In this study, we use transmission electron microscope (TEM) and magnetic methods to demonstrate the widespread preservation of silicate-hosted magnetic inclusions in marine sedimentary settings. TEM analysis reveals detailed information about the microstructure, chemical composition, grain size, and spatial arrangement of nanoscale magnetic mineral inclusions within larger silicate particles. Our results confirm the expectation that silicate minerals can protect magnetic mineral inclusions from sulfate-reducing diagenesis, and increase significantly the preservation potential of iron oxides in inclusions. Magnetic inclusions should, therefore, be considered as a potentially important source of fine-grained magnetic mineral assemblages, and represent a missing link in a wide range of sedimentary paleomagnetic and environmental magnetic studies. In addition, we present depositional remanent magnetization (DRM) modeling results to assess the paleomagnetic recording capability of magnetic inclusions. Our simulation demonstrates that deposition of larger silicate particles with magnetic inclusions will be controlled by gravitational and hydrodynamic forces rather than by geomagnetic torques. Thus, even though these large silicates may contain ideal single domain particles, they can not contribute meaningfully to paleomagnetic recording. However, smaller silicate grains (e.g., silt- and clay-sized) silicates with unidirectionally magnetized magnetic inclusions can potentially record a reliable DRM.