New insights on sediment magnetic remanence acquisition point out complexity of magnetic mineral diagenesis

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Paleomagnetic records from sedimentary sequences have a fundamental importance both for tectonic and stratigraphic studies (Kodama, 2012). However, despite many decades of research on sedimentary paleomagnetism (the first study was published 80 years ago; McNish and Johnson, 1938), details concerning the mechanism(s) by which sediments become magnetized are still poorly understood.

To maximize the usefulness of paleomagnetic data from sediments, the modes and the age of acquisition of the magnetic remanence should be known at the highest possible resolution. In fact, the reliability of sedimentary paleomagnetic data depends on the validity of the assumption that the magnetic polarity recorded by a sedimentary sequence was acquired at the time of deposition or shortly thereafter. This requirement is of utmost importance especially when the fine details of past transient geomagnetic field behavior are sought at high resolution, such as for reconstructions of geomagnetic paleosecular variation (Lund, 2007), relative paleointensity (Tauxe, 1993; Brachfeld, 2007), geomagnetic excursions (Laj and Channel, 2007; Roberts, 2008) and polarity reversals (Sagnotti et al., 2014; 2016; Kirscher et al., 2018). In integrated stratigraphic studies the recognition of past geomagnetic field variations then provide original and valuable tools that have been extensively used to develop original stratigraphic dating (Verosub, 2000) as well as high-resolution age models calibrated to cycles of astronomical parameters (e.g., Hilgen, 1991; Heslop et al., 2000). To achieve these results, the age and timing of the remanence acquisition should be known with a precision that imply no significant asinchronicity.

Nonetheless, the assumed synchronicity between ChRM acquisition and sediment age does not always hold, and it must be tested by carefully investigating the nature, origin and age of the magnetic minerals carrying the observed remanence component(s).

It is known that a paleomagnetic record in a continuous sedimentary sequence is the result of a variety of depositional and post-depositional processes that affect the alignment of particle magnetic moments to the ambient magnetic field and their immobilization (lock-in) due to dewatering and compaction (Verosub, 1977). Therefore, it is recognized that the lock-in process introduces uncertainties on the precise timing between the true age of the sediment and the age of magnetic remanence acquisition (Verosub 1977, Tauxe et al., 2006). Progressive acquisition of a post-depositional detrital remanent magnetization (PDRM) has been modeled as an exponential or cubic function of progressive remanence lock-in with depth (Hyodo, 1984; Roberts and Winklhofer, 2004), defined as the depth at which the remanent magnetization is ultimately fixed (Bleil and von Dobeneck, 1999). At the fine scale, it has been pointed out that this lock-in depth may vary even between adjacent sections of the same stratigraphic sequence (Sagnotti et al., 2005a).

Furthermore, sediments may undergo geochemical change during early burial as they transform into a sedimentary rock. The eventual alteration of detrital magnetic grains during diagenesis and growth of new authigenic ferrimagnetic minerals add further timing unknowns and uncertainties that may prevent the use of paleomagnetic data for a variety of geological applications (Roberts, 2015).

In fact, during diagenesis detrital magnetic minerals may undergo extensive dissolution (Leslie et al., 1990a; 1990b) and new magnetic phases may nucleate and grow (Jackson et al., 1988; Jackson, 1990). In particular, diagenetic iron sulfides can provide a significant source of sedimentary magnetism (Sagnotti, 2007). The role of sulfate reduction and the growth of iron sulfides – such as ferrimagnetic greigite in particular - has been recognized as a potential critical aspect, which may compromise the use of paleomagnetic data in fine-grained sedimentary units that were deposited in reducing environments (Roberts and Turner, 1993). Magnetic iron sulfides can be produced through a number of different processes both during syndepositional, early diagenetic or late diagenetic phases (Roberts, 2015). The timing of iron sulfides formation depends also on the stability of the geochemical and redox conditions following sediment deposition. Steady state diagenesis with stable ambient conditions sets a delay between sediment deposition and remanence acquisition. Conversely, in non-steady state physical-chemical environments diagenetic changes may occur at any stage after sediment deposition (Tarduno and Wilkison, 1996), due for instance to fluid migration and changes in pore-water chemistry, introducing an additional important source of uncertainties on the exact age of remanence acquisition. This kind of processes may affect sedimentary sequences and remagnetize them partially (Sagnotti et al., 2005b) or even totally (Sagnotti et al., 2010), thus preventing the retrieval of paleomagnetic information useful for stratigraphic purposes.

Hence, the assessment of diagenetic effects has become a necessary component of any paleomagnetic study in sediments (Roberts, 2015). In particular, for the interpretation of paleomagnetic records when ferrimagnetic iron sulfides are a main magnetic carrier it is critical to understand mechanisms and timing of sulfate reduction processes.

The new study by Ebert et al. (2018, Geology, this issue) addresses fundamental aspects of remanence acquisition in sediments from the Dead Sea that underwent diverse sedimentary and diagenetic processes under different climatic conditions (glacial and interglacial climates) by using up-to-date techniques of rock magnetic analyses and magnetic force microscopy. In their study, Ebert et al. provide new insights on the mechanisms that may result in the erasure of any primary depositional magnetization and the overwriting of the magnetic signal recorded by detrital grains. The data indicate that bacterial mediated diagenetic effects may result in alteration of the primary detrital remanent magnetization that are more complex and varied than formerly thought. In fact, the effects are not only limited to dissolution of ferrimagnetic grains, which implies erasing the primary paleomagnetic signal, but they also result in a widespread remagnetization due to nucleation of single-domain (SD) ferrimagnetic grains in new authigenic phases and domain rearrangement in large multi-domain (MD) detrital titanomagnetite grains.

This new evidence points out two critical aspects that are firstly recognized: (1) SD ferrimagnetic greigite may occur within paramagnetic pyrite grains, solving a long-standing paleomagnetic conundrum of the abundance of pyrite grains in magnetic extracts (Nowaczyk, 2011), (2) the alteration of large MD detrital grains may also result in an effective demagnetization mechanism.

Paleomagnetic research will continue to advance toward the reconstruction of subtle details and/or rapid episodes of geomagnetic field changes during the geological past at increasingly high-resolution, with results that are fundamental for addressing many geophysical and geological questions. The new study of Ebert et al. (2018) fosters the development of new analytical tools to unravel the complex processes that underlay the acquisition of a remanent magnetization during diagenesis and will contribute to more accurate interpretation of the paleomagnetic data.

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