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Remagnetization mechanisms in Triassic red beds from South China

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ABSTRACT

Paleogeographic reconstructions based on paleomagnetic data rely on the reliability of the natural remanent magnetization (NRM) as a primary geomagnetic signal. Remagnetizations, however, can be common in many rock types, including late Paleozoic and Mesozoic red beds, and they complicate paleogeographic interpretations. Extracting the primary NRM from partially remagnetized rocks, and understanding the remagnetization mechanism are important in these contexts. We carried out a systematic paleomagnetic study of red bed samples from the Triassic Huangmaqing Formation, Nanjing (32.0°N, 118.9°E), South China. Two NRM components carried by secondary and primary hematite are isolated in 47 of the 94 samples studied, where the latter component has a direction in stratigraphic coordinates of $D = 29.2°$, $I = 34.6°$ ($\alpha_{95} = 10.9°$, 47 samples from 6 sites) that yields a paleopole of $\lambda = 60.8°$N, $\phi = 228.1°$E, $dp/dm = 12.5/7.2$, which is consistent with Triassic pole positions for the South China Block. A secondary chemical remanent magnetization (CRM) ($D = 227.1°$, $I = 80.8°$, $\alpha_{95} = 7.3°$) is documented in all 94 samples from 10 sites and is carried by pigmentary hematite that is inferred to have been generated by magnetite oxidation during orogenic activity. This secondary component has steep inclinations and is interpreted to have been influenced by a combination of the remanence carried by original parent magnetite, the orogenic stress field, and the prevailing geomagnetic field direction during deformation. This CRM direction is recorded commonly by red beds from the South China Block, and is significant for regional tectonic studies in the area.

1. Introduction

Remagnetization, a phenomenon by which a natural remanent magnetization (NRM) is acquired in an ambient magnetic field of a much younger age than that of the rock or sediment itself, complicates interpretation of paleomagnetic data from rocks, soils, and sediments (McCabe and Elmore, 1989; Suk et al., 1993; Lu et al., 1994; Piper et al., 1999; Roberts and Weaver, 2005; Rowan and Roberts, 2006; Deng et al., 2007; Jin and Liu, 2011; Liu et al., 2011; Van der Voo and Torsvik, 2012; Roberts, 2015). Generally, remagnetization mechanisms involve several pathways, 1) mineral transformations associated with redox process, i.e. magnetite, greigite, or pyrrhotite formation (Katz et al., 2000; Weaver et al., 2002; Roberts and Weaver, 2005), 2) deformation-associated fluid migration and/or pressure solution (McCabe and Elmore, 1989; Elmore and McCabe, 1991; Housen et al., 1993), 3) chemical weathering in moist, tropical weathering, and soil-forming environments (Creer, 1961, 1968; Jin and Liu, 2011; Liu et al., 2011), or 4) thermoviscous remanent magnetization acquisition (Scotese et al., 1982; Kent, 1985; Hashimoto et al., 2008; Globokar, 2014). Acquisition of secondary magnetizations through any such mechanism will obscure the primary paleomagnetic record (McCabe and Elmore, 1989; Van der Voo and Torsvik, 2012), and may lead to inaccurate paleomagnetic interpretations if not recognized (McCabe and Elmore, 1989; Van der Voo and Torsvik, 2012; Dekkers, 2012).

In the South China Block (SCB), widely distributed late Paleozoic and Mesozoic red beds have been subjected to extensive paleomagnetic investigations, aimed at reconstructing regional pa-

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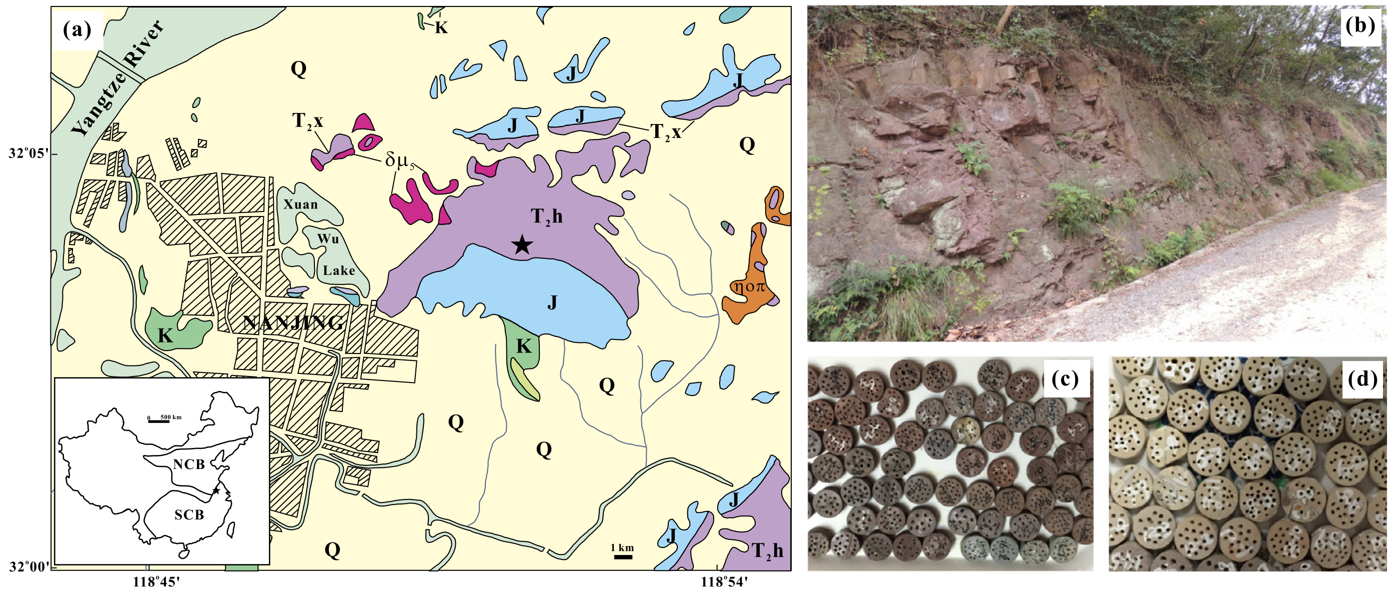

Fig. 1. (a) Geological map of the study area in Nanjing, where the inset is a tectonic sketch map of South China (NCB and SCB represent North China Block and South China Block, respectively). The star denotes the locality sampled in this study. Abbreviations: Q = Quaternary; K = Cretaceous; J = Jurassic; T = Tertiary; T_2h = Huangmaqing formation; T_2x = Xujiashan formation; $\delta\mu_5$ = diorite porphyrite; $\eta o \pi$ = Quartz monzonitic porphyry. (b) Representative photograph of the sampled section with strike/dip orientation of strata of 200°/21°. (c) Oriented samples prior to chemical demagnetization with 0.5-mm drill holes in their surfaces. (d) Oriented samples after chemical demagnetization.

leogeography (e.g. Achache et al., 1984; Zaman and Torii, 1999; Steiner and Lucas, 2000; Sun et al., 2006). However, the reliability of the NRM recorded by red sediments is often questioned because widespread and largely pervasive remagnetizations have been documented (Dobson and Heller, 1992; Wang and Van der Voo, 1993; Huang and Opdyke, 1996; Liu et al., 2011). The prevalent remagnetization scenario is considered to be some form of chemical remanent magnetization (CRM) acquired long after deposition (McCabe and Elmore, 1989; Elmore et al., 2012; Van der Voo and Torsvik, 2012). The most frequently occurring CRM carrier in red beds is hematite pigment, which can overprint a detrital remanent magnetization (DRM) carried by primary hematite. Therefore, discrimination of a CRM from a DRM is central to paleomagnetic studies of red beds. Hematites from different environments have distinct morphologies, crystallinity ranges, and magnetic properties (Collinson, 1965; Walker et al., 1981; Sugimoto et al., 1993, 1998; Jiang et al., 2012, 2014), which can be used to distinguish the origin of the hematite under investigation.

Thermal demagnetization (TD) is the most popular method for identifying a DRM or CRM in red beds due to their different unblocking temperature spectra (McClelland-Brown, 1982; Iosifidi et al., 2010; Jiang et al., 2015). Detrital hematite has a narrow unblocking temperature spectrum at the highest temperatures (∼660–680 °C) because it usually occurs as stable single domain (SD) particles with often close to ideal stoichiometry. Pigmentary hematite is typically finer-grained with size closer to the superparamagnetic (SP) to SD threshold size, so that it has a much broader unblocking temperature spectrum at lower temperatures (300–650 °C) (Stokking and Tauxe, 1990a; Jiang et al., 2015). Alternating field demagnetization (AFD) is also important in paleomagnetic studies, but it is not particularly effective for treating red beds because hematite has high coercivities (Butler, 1992; Dunlop and Özdemir, 1997). Chemical demagnetization (CD) has been used only occasionally for analyzing red sediments with multiple NRM components within a single sample (Burek, 1969; Collinson, 1975; Kent and Opdyke, 1978; Henry, 1979; Tauxe et al., 1980; Tan et al., 2007). Most rocks contain a relatively large number of remanence-carrying grains that have variable chemical and physical properties. Ideally, the remanence in certain grains will be effectively removed by chemical dissolution during CD, whereas in others it will remain unchanged. As the level of demagnetization (i.e. hematite dissolution) increases, the number of grains affected also increases (Larson, 1981). Grains that are more likely to acquire secondary magnetic components are more susceptible to lower levels of demagnetization. The fine-grained hematite pigment will dissolve first, leaving behind partially dissolved coarser specularite grains (Henry, 1979; Tauxe et al., 1980; Tan et al., 2007). This would allow identification of the NRM component carried by detrital specularite.

For remagnetized red beds, it is difficult to isolate the characteristic remanent magnetization (ChRM) and to establish it as the primary NRM component, especially in pervasively remagnetized red beds. The relative effectiveness of the various demagnetization techniques for identifying the advantages and disadvantages of each method has yet to be tested widely for remagnetized red beds. Therefore, in this study, we carried out systematic TD, CD, and combined CD–TD, with associated rock magnetic analysis, on 94 remagnetized red bed samples to assess their efficacy for paleomagnetic analysis of remagnetized red bed samples and to investigate the mechanisms by which remagnetization occurred.

2. Sampling and measurements

2.1. Sampling

The Middle Triassic Huangmaqing Formation is investigated here. A total of 94 standard paleomagnetic cores (10 sites) with 25-mm diameter, were collected in a transect from the village of Xiawuqi to Zijinshan Hill to the northeast of Nanjing, South China (32.0°N, 118.9°E) (Fig. 1a). The Huangmaqing Formation consists of clastic rocks, including purplish-red siltstones and fine sandstones (Fig. 1b). The beds dip shallowly to the south (7–22°). Paleomagnetic samples were cored with a portable drill and were oriented magnetically. Core samples were cut into three cylindrical sister-specimens 1-cm in length in the laboratory for TD, combined CD–TD treatment on NRM, and combined CD–TD treatment on three-orthogonal isothermal remanent magnetization (IRM) com-