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Palaeoclimatology

Weathering geochemistry and palaeoclimate implication of the Early Permian mudstones from eastern Henan Province, North China

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Abstract Terrigenous clastic sediments are generated by the integration of the Earth surface processes and their deep-time counterparts provide a valuable archive for regional/global climatic, geographic and landscape evolution. It is thus important to read and interpret these deep-time sedimentary records, especially for reconstructing continent climate. Previous studies on the Early Permian sequences from the North China document a dominant control of source chemical weathering on mudstone compositions and its linkage with continent climate conditions. Based on the weathering geochemical data of these mudstones, element mobility during weathering can be ordered as Ca > Na ≥ Mg > Sr > K ≥ Ba > Rb. The weathering regime in the source area is inferred to be supply-limited according to the estimated continent physical erosion rate and regional tectonic evolution, sedimentation in North China. Further exploration of palaeoclimate implication is presented in terms of variation of high-to-low latitudinal temperature gradient across the Early Permian glacial to post-glacial climate transition.

Keywords Chemical weathering, Weathering geochemistry, Mudstones, Early Permian, North China

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1. Introduction

Sediment generation is largely controlled by continental weathering (*e.g.*, McLennan, 1993), a process involving primary mineral decomposition and mobile element release (Wilson, 2004), and is sensitive to climate and tectonic processes (Nesbitt and Young, 1982; Nesbitt *et al.*, 1997; Rasmussen *et al.*, 2011; Riebe *et al.*, 2004). Numerous studies have attempted to quantify the intensity of rock chemical weathering based on geochemical compositions of resultant soils and sediments/sedimentary rocks and have resulted in the development of various chemical

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weathering indices (Fedo *et al.*, 1995; Gaillardet *et al.*, 1999; Goldberg and Humayun, 2010; Nesbitt and Young, 1982; Parker, 1970). Calculation of these indices involves evaluations of variations in the proportion of mobile elements, such as sodium, calcium and potassium, and contrast with provenance analysis which is based on immobile elements (McLennan *et al.*, 1993; Meinhold *et al.*, 2007; Scheffler *et al.*, 2003; Yang *et al.*, 2012). Chemical weathering indices have been used to measure source weathering intensity of fine-grained sedimentary rocks and thus constrain deep-time climatic conditions (temperature and precipitation) (Goldberg and Humayun, 2010; Rieu *et al.*, 2007; Scheffler *et al.*, 2003, 2006; Yan *et al.*, 2010; Young *et al.*, 2004). In general, hot and humid climate enhances chemical weathering, whereas cold and arid climate suppresses weathering (Nesbitt and Young, 1982, but see Wan *et al.*, 2017).

We here further explore the source weathering conditions of the Early Permian sedimentary rocks in North China by combining preciously reported weathering geochemical data of these sequences and modern landscape weathering mechanics. Compiled data of low- and high-latitudinal sediments were then used to reveal the variation of low-to-high latitude temperature gradient across the Early Permian glacial to postglacial transition.

2. Chemical weathering indices

Chemical composition of weathered materials has long been employed to trace weathering history (Reiche, 1943; Ruxton, 1968) with a purpose to provide a quantitative measure of compositional alteration during weathering in reference to the parent rock (Price and Velbel, 2003). This has led to a variety of chemical indices as reviewed by Yang *et al.* (2016). Here we focus on chemical index of alteration (CIA) and elemental weathering indices (α_E and $\alpha^{Al}{}_E$).

The chemical index of alteration (CIA) is based on the removal of alkalis (Na, Ca and K) from feldspar by dissolution and the accumulation of alumina in the weathered product (Nesbitt and Young, 1982). CIA is expressed as molar ratio of 100 × $A1_2O_3$/(Al_2O_3—CaO* + Na_2O—K_2O) and describes the amount of feldspars altered into clay minerals and thus provides a qualified measure of the degree of weathering of the upper continental crust, related to climatic conditions (Nesbitt and Young, 1982). The index is usually used in conjunction with graphic representation on the derivative A—CN—K (Al_2O_3—CaO* + Na_2O—K_2O) triangular diagram (Fedo *et al.*, 1995; Nesbitt and Young, 1984; Yang *et al.*, 2004). Weathering intensities can also be calculated using a series of weathering indices (Gaillardet *et al.*, 1999) defined for each individual soluble element by comparing their concentrations to that of an immobile element (α_E). Concentrations are normalized to those of the parent source rock (upper continental crust for sediments on a global scale). Paired mobile and immobile elements should have close magmatic compatibility (see Hofmann, 1988) to minimize the uncertainty that exists in the protolith composition (*e.g.*, UCC, upper continental crust). A value $\alpha_E > 1$ means a depletion and $\alpha_E = 1$ implies no net depletion of soluble element *i* with respect to parent rock (*e.g.*, UCC). However, the paired mobile and immobile elements could be respectively hosted in minerals of different densities and denser minerals can be concentrated locally by hydrodynamic processes (Garzanti *et al.*, 2013), resulting in a hydraulic-sorting bias of results. To avoid this, Garzanti *et al.* (2013) recommended using Al as the immobile element for all elemental weathering indices calculations, expressed as $\alpha^{Al}{}_E$.

3. Sampled Early Permian sedimentary sequences

Samples for analysis were collected from a drill core Zk1401 through the upper Shanxi Formation and the conformably overlying Xiashihezi Formation in Yongcheng Coalfield, eastern Henan Province, North China (Fig. 1). The sampled sequence was deposited in the Sakmarian—Artinskian (Yang *et al.*, 2014) and consists of black-gray mudstones, siltstones and fine sandstones with several coal seams (Fig. 2). This core succession was selected to test the sensitivity of weathering indices because: (1) a tuff bed from the top of Shanxi Formation has been dated at 293 ± 2.5 Ma and the sampled sequence covers the Early Permian glacial—postglacial transition period and thus provides a sedimentary archive across an interval of significant global climate changes (Yang *et al.*, 2014, 2016); (2) North China occupied a near equatorial region during the Early Permian time (Embleton *et al.*, 1996; Huang *et al.*, 2001; Zhu *et al.*, 1996) providing a contrast with data from time-equivalent high latitude glacial-deglacial sedimentary records from Gondwana; (3) sampling drill core provides samples for chemical analyses without any influence from present-day weathering (Goldberg and Humayun, 2010); and (4) the Late Paleozoic coal-bearing sequences overly disconformably on Ordovician carbonate-dominated strata in cratonic basins of North China precluding significant input of recycled siliclastic sediments from the underlying units.