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Research paper

Geochemistry of a paleosol horizon at the base of the Sausar Group, central India: Implications on atmospheric conditions at the Archean–Paleoproterozoic boundary

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ABSTRACT

A paleosol horizon is described from the contact of the Sausar Group (~2400 Ma) and its basement (Tirodi Gneiss; >2500 Ma) in Central India. Physical evidence of pedogenesis is marked by the development of stress corrosion cracks, soil peds, corestone weathering and nodular rocks. XRD and SEM-EDX data indicate the presence of siderite, ankerite, uraninite, chlorite, alumino-silicate minerals, ilmenite, rutile and magnetite, in addition to quartz, feldspar and mica. The chemical index of alteration, the plagioclase index of alteration, and the chemical index of weathering show an increasing trend from parent rock to the paleosol and indicate a moderate trend of weathering. The A-CN-K plot indicates loss of feldspars, enrichment in Al_2O_3 and formation of illite. Different major element ratios indicate baseloss through hydrolysis, clay formation, leaching of some elements, and more precipitation with good surface drainage. The paleosol is depleted in HREE in comparison to the parent rock indicating high fluid-rock interaction during weathering. The paleosol samples show flat Ce and Eu anomalies, low ΣREE, and high $(La/Yb)_N$, indicative of a reducing environment of formation. Reducing condition can also be inferred from the concentration of elements such as V, Co, Cu, Pb, and Zn in the paleosol profile. Although enriched in Fe and Mg, the overall geochemical patterns of the paleosol indicate oxygen deficient conditions in the atmosphere and development by weathering and leaching processes associated with high precipitation and good surface drainage at the time of development of this paleosol during the Archean–Paleoproterozoic transition.

1. Introduction

The Archean–Proterozoic transition is marked by many tectonic and geochemical changes such as orogenic events that formed megacratons, mafic dyke swarms associated with continental break-up, worldwide glaciation, significant rise in atmospheric oxygen and appearance of life (Barley et al., 2005). Atmospheric conditions were anoxic at ~2.5–2.4 Ga, but were followed by a rise of oxygen levels in the atmosphere (the Great Oxidation Event, GOE). Most researchers consider the oxygen increase in the atmosphere to have been drastic (e.g., Goldblatt et al., 2006; Bekker and Holland, 2012). However, the pattern of oxygen rise in the GOE is still in dispute (e.g., Murakami et al., 2011; Lyons et al., 2014). Rising atmospheric oxygen was accompanied by CO_2 draw down and the widespread Huronian Glaciation, which may have produced a "snow ball" Earth (Barley et al., 2005). The atmospheric and hydrospheric conditions during this transition period are inferred from the rocks formed at ~2500 Ma ago. Precambrian paleosols have long been used to predict ancient atmospheric compositions on the basis of geochemical variations, mineralogical changes, weathering regimes and paleoenvironmental reconstructions (Gay and Grandstaff, 1980; Schau and Henderson, 1983; Holland, 1984, 1994; Grandstaff et al., 1986; Kimberley and Grandstaff, 1986; Reimer, 1986; Retallack, 1986a, b; Zbinden et al., 1988; Holland et al., 1989; Maynard, 1992; MacFarlane et al., 1994; Rye and Holland, 1998, 2000; Gall, 1999; Panahi et al., 2000; Yang and Holland, 2003; Sheldon, 2006a; Driese et al., 2007; Mitchell and Sheldon, 2009, 2010).

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We have analysed the geochemical changes associated with a paleosol horizon developed by in-situ weathering of Archean granite in Central India (Fig. 1a, b). This paleosol is found at the contact of the Sausar Group (~2400 Ma) with the basement Tirodi Gneiss (>2500 Ma) (Mohanty, 1993). Re-Os molybdenite ages for calc-silicate rocks confirm a Paleoproterozoic age for the Sausar Group of between 2410 and 2450 Ma (Stein et al., 2014). Hence the age of formation of the paleosol can be attributed to the Archean–Proterozoic transition period. Paleoproterozoic glaciation has also been reported from the Sausar Group (Mohanty, 2006; Mohanty et al., 2015). Therefore, the Sausar paleosol profile is considered to be important for understanding atmospheric evolution during the Archean–Proterozoic transition period.

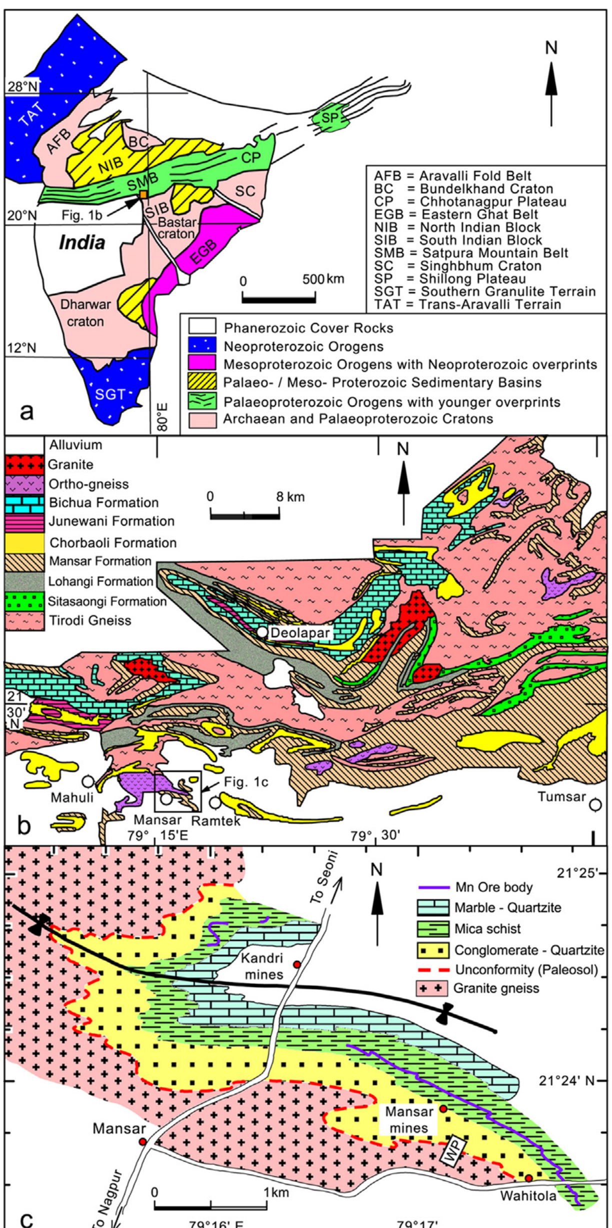

Figure 1. (a) Generalised geological map of peninsular India. (b) Regional geological map of the western part of the Sausar belt (after Narayanaswami et al., 1963). (c) Geological map of the Mansar area (modified after Mohanty et al., 2000) showing the paleosol profile analysed (WP).

2. Geological setting

2.1. Regional geology

The Sausar Belt of the Central Indian Shield is located at the southern margin of the Satpura Mountain Belt (Fig. 1a), which was developed by the collision of the North Indian Block (NIB) and the South Indian Block (SIB) during the Proterozoic (Radhakrishnan and Ramakrishnan, 1988). The belt comprises two major lithostratigraphic units: the Tirodi Gneiss (TG) and the Sausar Group (SG), and has a curvilinear geometry with a WNW–ESE trend in the west, an east-west trend in the centre and an ENE–WSW trend to the east (Fig. 1b; Straczek et al., 1956; Narayanaswami et al., 1963). The Tirodi Gneiss is an Archean complex of dominantly felsic gneisses with enclaves of metabasic rocks and lenses of high-grade (granulite facies) rocks. The Sausar Group is represented by quartzite, calc-silicate rocks, calcitic and dolomitic marbles, pelitic schist, and Mn-ore horizons of Paleoproterozoic age (Straczek et al., 1956; Narayanaswami et al., 1963; Roy, 1981; Mohanty, 1993, 2010, 2012). The contact of the Tirodi Gneiss and the Sausar Group is marked by the presence of a paleosol horizon and a conglomerate containing pebbles and boulders of the Tirodi Gneiss, indicating an unconformity between the Tirodi Gneiss and the Sausar Group (Mohanty, 1993).

Detailed mapping in the Sausar Group indicates that the rocks have undergone four phases of superposed deformations (Mohanty, 1988, 2002, 2003a, b, 2009, 2010, 2012; Bandyopadhyay et al., 1995; Mohanty and Mohanty, 1996; Mohanty et al., 2000; Chattopadhyay et al., 2003a, b). The first deformation in the Sausar Group (SD_1) is represented by isoclinal folds (SF_1) with an axial planar cleavage (S_1), whereas the second deformation (SD_2) produced upright to steeply inclined isoclinals folds (SF_2) with broadly east-west fold axes and an axial planar crenulation cleavage (S_2). Open folds with subhorizontal axial planes (SF_3) were developed during the third deformation (SD_3). The fourth deformation (SD_4) gave rise to the development of upright open folds (SF_4) with broadly north-south axial traces (Mohanty, 1988, 2002, 2003a, b, 2010; Mohanty and Mohanty, 1996; Mohanty et al., 2000). The Sausar Belt shows Barrovian-type regional metamorphism with increasing grade from south to north and from east to west (Narayanaswami et al., 1963; Bhowmik et al., 1999). Peak metamorphism in this area is constrained at $P = \sim 7$ kbar and $T = \sim 675$ °C (Brown and Phadke, 1987; Phadke, 1990; Bhowmik et al., 1999). Low-grade greenschist to greenschist-amphibolite facies transition zone metamorphism has been recognised all along the southern periphery of the Sausar belt.

2.2. Age constraints

Geochronologic data from the Sausar Belt are scanty. Sarkar et al. (1986) reported a Rb-Sr whole rock isochron age of 1525 ± 70 Ma and a combined four mineral fraction (biotite, muscovite, plagioclase and K-feldspar) isochron age of 860 ± 25 Ma from the Tirodi Gneiss. They interpreted the 1525 Ma event as the main Sausar metamorphism, leading to partial melting of the basal psammo-pelitic unit, and the younger 860 Ma event as the terminal thermal overprint on the Sausar rocks. The Tirodi Gneiss has yielded a depleted mantle model (Sm/Nd) age between 2325 and 2494 Ma (Mishra et al., 2009). Similar ages are also reported for the equivalent rock units of the basement gneisses, locally known as the Amgaon Gneiss (U-Pb zircon age of 2378 ± 17 and 2432 ± 5 Ma; Ahmad et al., 2009) and the Malanjkhand Granite (2480 ± 3 Ma U-Pb zircon age by Panigrahy et al., 2002; 2478 ± 9 Ma Re-Os age by Stein et al., 2004). Molybdenite grains in quartz veins intruding the calc-silicate rocks of the Sausar Group have Re-Os ages between