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Geochemistry of black shales from the Mesoproterozoic Srisailam Formation, Cuddapah basin, India: Implications for provenance, palaeoweathering, tectonics, and timing of Columbia breakup

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ABSTRACT

The Mesoproterozoic Srisailam Formation, exposed along the northern part of the Cuddapah basin, India, comprises mainly medium- to fine-grained siliciclastics, and is devoid of any carbonate sediment. Preliminary sedimentological studies helped in recognizing fifteen distinct facies (five facies associations) in Chitrial outlier of the Srisailam Formation deposited in continental half-graben basin(s). Black shales (*sensu lato*) are minor components of the Srisailam Formation, and inferred to have deposited in deep lacustrine and prodelta facies of the half-graben(s). The black shales show restricted thickness (up to 29.0 m), and are characterized by overall high 'black shale' to 'total shale' ratio (> 0.51). Their geochemical characteristics were studied to constrain provenance, palaeoclimate, and tectonic setting of deposition of the Srisailam Formation. Further, an attempt has been made to use the Srisailam black shales as proxy for constraining the timing of breakup of the supercontinent Columbia.

The Srisailam black shales are geochemically quite distinct. At similar SiO_2 contents they are considerably different from PAAS. They are characterized by considerably lower ΣREE (Av. 136.0 ± 50.4 ppm) but a more conspicuous negative Eu-anomaly (Av. 0.34 ± 0.09) than PAAS. Al_2O_3/TiO_2 and TiO_2/Zr ratios coupled with Eu/Eu*, Gd_{CN}/Yb_{CN}, La/Sc, Th/Sc, and Th/Cr ratios suggest their derivation from granite and granodiorite. The CIA values (65–90, Av. 72 ± 9) as a whole indicate moderate chemical weathering under semiarid climate. Discriminating geochemical parameters indicate passive margin depositional setting. The combined sedimentological and geochemical characteristics reveal deposition of the Srisailam sediments in continental rift basin(s).

Thick succession of black shales (with high CIA values) that deposited with shelf carbonates proxy for mantle superplume and supercontinent breakup events. The sedimentological characteristics and geochemical data of the Srisailam black shales plausibly exclude any large-scale breakup of Columbia during the interval (1400–1327 Ma) of deposition of the Srisailam Formation.

1. Introduction

The geochemistry of mudrocks is commonly used as sensitive indicator of provenance character (Cullers, 2000), palaeoclimate and palaeoweathering conditions (Nesbitt and Young, 1982; Fedo et al., 1995), and tectonic settings of sedimentary basins (Roser and Korsch, 1986; McLennan et al., 1990). It is also used to evaluate the composition, and understand the evolution of the continental crust (Taylor and McLennan, 1985; Condie, 1993). Being fine grained and impermeable, mudrocks preserve the near-original geochemical signature of the provenance composition (Paikaray et al., 2008 and references therein). Mudrocks provide more information about the regional tectonic settings than the associated sandstones (Cullers and Podkovyrov, 2000). Though, most mudrocks are formed in restricted basin environments in specific tectonic settings (Cox and Lowe 1995), black shale, a dark-coloured mudrock (Swanson, 1961), is found in a wide spectrum of geological settings over the entire span of the geological time (Tourtelot, 1979). Nevertheless, the deposition of the Precambrian black shales has been considered by several researchers to be more important in some tectonic settings (Condie et al., 2001). Such 'tectonic bias' often puts constraints in understanding the evolution of especially the Precambrian black shales in a specific geological setting. Under

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such circumstances geochemical characteristics of black shales may be of immense use in understanding their provenance, weathering conditions, and depositional settings. Further, a global correlation between the deposition of especially the Proterozoic black shales and mantle superplume as well as supercontinent formation/breakup events has been observed (Condie et al., 2001; Condie, 2004). The thickness and CIA (Chemical Index of Alteration; Nesbitt and Young, 1982) of black shales, deposited in passive margin, intracratonic, or platformal basins, could be used as proxies for mantle superplume and supercontinent formation/breakup events (Condie et al., 2001; Condie, 2004).

Black shales have been reported from the Neoarchaean Sandur greenstone belt (Manikyamba and Kerrich, 2006), and a number of Proterozoic intracratonic basins in Peninsular India (Murty et al., 1962; Pandalai et al., 1983; Banerjee et al., 2006; Manikyamba et al., 2008) as well as from the extra-peninsular Himalayan belt (Rawat et al., 2010; Williams et al., 2012). In spite of availability of huge volume of black shales in the Proterozoic Cuddapah basin, there is a dearth of studies on their geochemical aspects for understanding the provenance and its compositional variation with time, tectonic evolution of different subbasins of the Cuddapah basin, and the realm of palaeoclimatic conditions under which weathering and erosion of provenance took place. Only Manikyamba et al. (2008) studied the geochemical characteristics of the black shales of the Cumbum Formation for tracing provenance and tectonic setting of the basin, and evaluating weathering intensity of the provenance. In order to bridge this gap, the present study is focused on understanding the provenance of the Mesoproterozoic Srisailam Formation, its palaeoweathering, and tectonic evolution of the Srisailam subbasin in the northern part of the Cuddapah basin (Fig. 1a) from mainly the geochemical characteristics of the Srisailam black shales. Preliminary sedimentological studies have also been carried out for better understanding of the geochemical signatures and making the geochemical interpretations especially on tectonic evolution more meaningful. The Srisailam black shales have also been used as potential proxy to constrain the timing of breakup of the supercontinent Columbia that has long been debated.

2. Geological setting

The Proterozoic Cuddapah basin is located in the central part of the Eastern Dharwar Craton, India (Fig. 1a). It is a polyphase basin, and sedimentation in this basin took place in a series of successively evolved, spatially distributed but interconnected subbasins viz. Papaghni, Nallamalai, Srisailam, and Kurnool-Palnad (Fig. 1a; Basu et al., 2014 and references therein). The sediments of the Cuddapah basin range in age from Palaeoproterozoic to Neoproterozoic (Fig. 1b), and the Mesoproterozoic Srisailam Formation was deposited in the Srisailam subbasin located in the northern part of the Cuddapah basin (Fig. 1a). The Neoarchaean gneisses (Pb–Pb age of 2638 ± 94 Ma; Vimal et al., 2012), thin slivers of greenstone belt (Peddavoora schist belt), Palaeoproterozoic granitoids (Pb–Pb age of 2442 ± 13 Ma; Pandey et al., 2009), and mainly WNW-ESE/NW-SE, N-S/NNE-SSW to minor NE-SW trending Palaeoproterozoic (Sm-Nd age of 2173 ± 64 Ma; Pandey et al., 1997) gabbro/dolerite dykes, N-S/NNE-SSW to NE-SW trending quartz reefs form the basement for the Srisailam sediments to the north (Fig. 1a and c). In contrast, the sediments of the late Palaeoproterozoic to early Mesoproterozoic (1659 ± 22 Ma to ~1590 Ma) Nallamalai Group (Saha, 2002; Collins et al., 2015) form the basement to the south (Fig. 1a and c). The Srisailam Formation comprises mainly quartzite (sandstone), siltstone, shale (Nagaraja Rao et al., 1987; Lakshminarayana et al., 2001), and is characteristically devoid of any carbonate sediment. The Srisailam Formation is approximately 620 m thick at Srisailam type area (Murthy, 1979). However, recent borehole data revealed a maximum thickness of 419 m at Kottapullareddipuram (Fig. 1c; Banerjee et al., 2012). The sedimentary succession of the Srisailam Formation has variously been interpreted to be the deposits of shallow marine/tidal flat (Nagaraja Rao et al., 1987), shoreline to intertidal sand flat environments with fluvial influence (Lakshminarayana et al., 2001). However, a detailed analysis of facies and sedimentological study is not available till date. The sediments of the Srisailam Formation have been affected by mainly E–W to NW-SE trending faults and N-S/NNE-SSW trending lineaments/fractures. The sediments are generally unmetamorphosed. A horse-shoe shaped outlier (~60 sq km) of the Srisailam Formation, occurring near Chitrial village, Nalgonda district, India (hereafter Chitrial outlier; Fig. 1c), along the northern periphery of the Srisailam subbasin (Fig. 1a and c) represents the geological domain for this study.

In Chitrial outlier, the Srisailam Formation occurs as flat-lying to gently (5–8°) SE-dipping strata. It comprises variably sorted arenaceous siliciclastics, subordinate argillaceous and minor rudaceous sediments. The sediments have been affected by post-sedimentary faults. Locally, mild warping has also been observed in the sediments. Dominantly coarse-grained to often porphyritic, grey biotite-granite to locally leucogranite form the basement for the Srisailam sediments in Chitrial outlier. Neoarchaean tonalite-granodiorite-adamellite (TGA) suite of rocks has been reported (Vimal et al., 2012) from the vast terrane occurring farther east and northeast of the study area, especially east and northeast of NW-SE trending Peddavoora schist belt (Fig. 1a and c).

3. Age constraints and palaeolatitude

3.1. Stratigraphic correlation

The stratigraphic correlation of the Srisailam Formation has long been debated. The lithostratigraphic correlation established by King (1872) was exclusively followed for almost a century. King (1872) considered the Srisailam sediments (Sreeshalum Quartzites) to be the youngest member of the 'Kistnah Group' (now non-existent nomenclature; Table S1) that comprises successively older Kolamnala (Kolumnullah) Slates and Irlakonda (Irlaconda) Quartzites, and overlies the Cumbum Slates and Bairenkonda (Byrenconda) Quartzites of the Nallamalai (Nullamullay) Group with a doubtful unconformity. However, Rajurkar and Ramalingaswami (1975) were first to differ, and consider the Srisailam Quartzite (Formation) as the youngest member of the Cumbum Slate (Formation). They omitted the Kistnah Group (Table S1), and opined that all its constituent members are parts of the Cumbum Slate. The Irlakonda Quartzite was shown to be lateral lithofacies variation of the Cumbum Slate (Nagaraja Rao et al., 1987). In contrast, Meijerink et al. (1984) considered the Srisailam sediments to be the youngest formation of the Bairenkonda (Quartzite) Subgroup (Fig. 1b; Table S1). Subsequently Nagaraja Rao et al. (1987), on the basis of identification of unconformable relationship with the Kolamnala Shale (equivalent to the Cumbum Shale) at a number of places, established the Srisailam Formation to be younger than the Nallamalai Group (Fig. 1b), and accepted the nomenclature 'Kistnah Group' as redundant. Their stratigraphic positioning of the Srisailam Quartzite was similar to that proposed by Dutt (1975). Saha (2002) also reported the Srisailam Formation to unconformably overlie the Cumbum Formation of the Nallamalai Group. In the light of this latest well-accepted lithostratigraphic correlation, the regional litho-structural relationship and igneous intrusive events have been considered here to bracket the age of the Srisailam Formation.

3.2. Age constraints

The sediments of the late Palaeoproterozoic to early Mesoproterozoic (1659 ± 22 Ma to ~1590 Ma) Nallamalai Group (Saha, 2002; Collins et al., 2015), underlying the Srisailam Formation, have been intruded by the Vellaturu Granite (Fig. 1a) at ~1575 Ma (Crawford and Compston, 1973). Further, Racherla syenite and Chelima lamproite ($^{40}Ar/^{39}Ar$ age of 1417.8 ± 8.2 Ma; Chalapathi Rao et al., 1999) intrude the sediments of the Nallamalai Group (Fig. 1a). A number of coeval lamproites have been reported also from the