Available online at www.sciencedirect.com

SciVerse ScienceDirect

Geochimica et Cosmochimica Acta 104 (2013) 63–83

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

Mineralogy and geochemistry of the Mahi River sediments in tectonically active western India: Implications for Deccan large igneous province source, weathering and mobility of elements in a semi-arid climate

Anupam Sharma [a,*], Sarajit Sensarma [b], Kamlesh Kumar [c], P.P. Khanna [d], N.K. Saini [d]

[a] *Central University of Himachal Pradesh, P.O. Box 21, Dharamshala 176 215, India*
[b] *Centre of Advanced Study in Geology, University of Lucknow, Lucknow 226 007, India*
[c] *Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow 226 007, India*
[d] *Wadia Institute of Himalayan Geology, 33 General Mahadeo Singh Marg, Dehradun 248 001, India*

Received 28 March 2012; accepted in revised form 2 November 2012; available online 3 December 2012

Abstract

Large igneous provinces (LIPs) hosting mafic rocks over million km^2 are likely to influence global sediment production and distribution and help in resolving discrepancies in upper continental crust (UCC) compositions. This work focuses on the texture, mineralogy, and compositions including REE of fine sand/silt deposited by a small to medium-sized river, the Mahi River (about 600 km) in a tectonically active, semi-arid region draining the Deccan Traps in western India, one of the largest LIPs in the world. The results are also applied to a sedimentary rock of fluvial origin (Siwalik mudstone/siltstone) to ascertain the source characteristics of this alluvium and evaluate comparative element (K, Ba, Sr, Na, Ca and Mg) mobility.

The Mahi sediments are lithiarenite, mostly composed of quartz and basalt fragments with lesser pyroxene, biotite, feldspar, calcite and clay minerals (smectite ± illite). The Mahi sediments have higher FeO^t ($\leqslant$10.9 wt.%), TiO_2 ($\leqslant$2.41 wt.%), Al_2O_3 ($\leqslant$15.2 wt.%), Cr ($\leqslant$737 ppm), Co ($\leqslant$36 ppm), Cu ($\leqslant$107 ppm) than the UCC and PAAS; Ni ($\leqslant$54 ppm) higher than the UCC (33.5 ppm), but similar to PAAS (60 ppm). The low CIA (37–59) values and presence of basalt fragments and smectite in the samples suggest incipient weathering in the semi-arid Mahi catchment. In agreement with the mineralogy, the UCC-normalized LREE depleted patterns (LREE/HREE < 1) in the Mahi sediments confirm Deccan basalt contributions from the provenance with about 70–75% basalts and 25–30% Archean biotite-rich granitoids. The mafic contribution, in addition to the UCC, is important for the Siwalik rocks too.

Similarly limited depletion of Ba, K and Ca (Ba $\geqslant$ K > Ca) in weathering-limited Mahi (aver CIA 47.5) and transport-limited Siwalik (aver CIA 69) systems indicate their climate insensitivity. At the same time, more Ba depletion than Ca is new for the Deccan Traps River. Decoupling of Ca and Sr, however, could be mineralogy controlled.

1. INTRODUCTION

Rock weathering and erosion are two fundamental earth surface processes intrinsic to sediment formation and element distribution (e.g., Suttner, 1974; Stallard and Edmond, 1983; Basu, 1985; Sharma and Rajamani, 2001; Singh and Rajamani, 2001). The composition of the upper

* Corresponding author. Address: School of Earth and Environmental Sciences, Central University of Himachal Pradesh, P.O. Box 21, Dharamshala, Himachal Pradesh 176 215, India. Tel.: +91 01892 229330; fax: +91 01892 237286.
E-mail address: anupam110367@yahoo.com (A. Sharma).

0016-7037/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.gca.2012.11.004

continental crust (UCC) is approximately granodioritic (SiO_2 55–66 wt.%), typically forming at the present-day convergent margins (Taylor and McLennan, 1985). During fluvial reworking, sediments get homogenized and effectively represent average 'granodioritic' continental crustal compositions (Taylor and McLennan, 1985; Rudnick and Gao, 2003). However, there are discrepancies regarding the concentrations of certain trace elements. For example, discrepancies in Cr and Co concentrations by nearly a factor of 2–3 seem common (McLennan, 2001). Weathering accounts for ~20% Mg loss from the continents, aiding in the formation and sustenance of a Si-rich and Mg-poor continental crust (Lee et al., 2008), in addition to granodiorite production through magmatic processes. The La/Nb ratio in the continental crust is better modeled by mixing between intraplate basalt and convergent margin magmas (Rudnick, 1995). Thus the global continental provenance may not necessarily be of granodiorite compositions only, but it could have a more mafic component.

Mafic to ultramafic igneous rocks have higher contents of Cr, Co, Cu than silicic and intermediate igneous rocks (Brügmann et al., 1987). The large igneous provinces (LIPs) (e.g., continental flood basalt provinces) host significant amounts of mafic rocks on the Earth's surface, covering about 50–100 × 10^3 km^2 (e.g., Sensarma, 2007; Sheth, 2007; Bryan and Ernst, 2007). Altogether somewhat more than 150 LIPs are known (see Bryan and Ernst, 2007) and the number of LIPs is expanding with better identification and recognition throughout the geologic record. This makes LIPs to stand out as an important provenance worth considering in the models of continental crustal composition and its evolution. The origin of LIPs is a major area of research in understanding global mantle and crust/mantle systems (http://www.largeigneousprovince.org; http://www.mantleplume.org). The possible role of LIPs, with the abundant presence of more weatherable mafic rocks, in sediment production and global sediment supply is not adequately known. This is important because LIPs may have significant contributions in influencing the upper crustal compositions and help to address discrepancies of the elemental abundances mentioned above.

The Himalayas and the Deccan LIP are the two most important geologic entities of global significance in India. The contributions of the Himalayan lithology, tectonics, and climate in sediment production and distributions are well recognized (e.g., Sarin et al., 1989; Krishnaswami et al., 1992; France-Lanord and Derry, 1997; Gaillardet et al., 1999; Galy and France-Lanord, 2001; Singh et al., 2006, 2008). Limited research, however, has been done on the role of the Deccan LIP on this aspect, though it covers ~0.5% of the global drainage area (Das and Krishnaswami, 2006).

The mainland Gujarat region in western India has several rivers including the Tapti and Narmada that flow from the Peninsular India into the Arabian Sea (Fig. 1a and b) passing through the Deccan Province and they must have been carrying sediments from multiple sources, including the Deccan basalts. Except for some geochemical study of dissolved load of the rivers draining the Deccan province (e.g., Dessert et al., 2001, 2003; Gupta and Chakrapani, 2005, 2007; Das et al., 2005; Das and Krishnaswami, 2007; Sharma and Subramanian, 2008; Gupta et al., 2011), limited mineralogical and geochemical study of these sediments have been done. Moreover, these rivers are relatively small (<~600 km), carry higher ionic load (Sharma et al., 2012), and are thus good candidates for unraveling weathering processes, sediment production and distribution, and their source rock characteristics.

As part of our ongoing research on western Indian fluvial sediments, comparison between the Mahi River sediments and the surrounding rocks from which they were derived allows us to better explore the link between the sedimentary record and the large Deccan basaltic provenance. In this paper, we discuss the mineralogy and geochemistry of a ~8.5 m thick deposit exposed near Mujpur village (22°09′07″N: 72°35′28″E) in the lower Mahi River Basin. Textural and mineralogical data of sediments, bulk major element, and trace element compositions are combined to develop an integrated model to understand the relative control of tectonic–climate–lithology and source area characteristics for the Mahi sediments. Finally, the results are applied to the alluvium in the sedimentary rock of the Siwalik mudstone/siltstone to test its source characteristics and evaluate mobility of certain elements. This study has an important bearing on the general understanding of the role of LIPs in the petrogenesis of clastic sediment production and composition.

2. STUDY AREA AND PREVIOUS WORK

The Mahi River, approximately 600 km long, emerges near the Sardarpur District (Madhya Pradesh) and starts flowing North-Westerly to enter into the southern Rajasthan where it takes a southwesterly turn. The river then flows along the intercontinental Cambay Graben (Biswas, 1987) to meet the Cambay Bay (Fig. 2). The intersection of Precambrian orogenic trends, the NE–SW Aravalli trend, and the ENE–WSW Satpura trend/Narmada-Son lineament (NSGF) led to formation of several rift basins (e.g., Narmada, Cambay and Kutch rift basins) (Biswas, 1987) (Fig. 1c). The Bhuj Earthquake (intensity 6.9 on Richter scale) in 2001 suggests tectonic activity in the terrain continues to the present-day. The Mahi River largely flows in the upper reaches over the Deccan Traps (basalts, picritic basalts, minor rhyolite), sedimentary-metasedimentary rocks of the middle Proterozoic Vindhyan Supergroup, the 2.5 Ga Aravalli Supergroup rocks (leucogranite intrusions, metasediments, granites, minor komatiites, amphibolites) and the still older 3.5 Ga banded gneissic complex (BGC) rocks (Fig. 2). The BGC is predominantly composed of biotite granite gneiss with enclaves and inclusions of amphibolites (komatiitic), quartzite and calcareous rocks, and minor pegmatite.

A complex interplay of tectonism, climate and base level changes during the Holocene were responsible for sedimentation in the area by marine, fluvio–marine, fluvial and possibly some aeolian processes (e.g., Chamyal et al., 2003 and references therein; Tandon et al., 1999; Rachna et al., 1999; Maurya et al., 2000; Juyal et al., 2006; this work). The Middle Holocene Mujpur succession represents tidal estuarine