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Geochemistry of sediments of the Peninsular rivers of the Ganga basin and its implication to weathering, sedimentary processes and provenance

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ABSTRACT

Geochemistry of the Himalayan rivers has been a major point of contention in sedimentary geochemistry because of its global impact on ocean chemistry and climate. Among the Himalayan rivers, the Ganga and its Himalayan catchment have been studied extensively. However, the Peninsular rivers constituting a significant part of the Ganga basin have not received much attention, heretofore. In the present geochemical study of the Peninsular river's sediments, we have found that the initial chemical weathering of rocks in the catchment produces texturally, mineralogically and geochemically diverse sediments and fluvial processes further segregate them into the geochemically contrasting coarse channel and fine-grained suspended sediments. The overbank sediments possess an intermediate texture and geochemistry, but more towards the suspended sediments. The sediment geochemistry data indicates that the Peninsular river's sediments show an increase in the weathering intensity from the west (Banas river) to the east (Son river) along the climate gradient, i.e., from the arid-semiarid to the sub-tropical condition. The higher chemical index of alteration (CIA) values of the Peninsular river's sediments than the Yamuna and Ganga river sediments reflect the control of weatherable lithology in the tectonically stable, low relief and subtropical climate condition. The Yamuna and Ganga river sediments with lower CIA values show more physical weathering in the tectonically active Himalaya. The suspended and overbank sediments of the Yamuna and Ganga rivers show an increase in their CIA values after the confluence of the Peninsular rivers, indicating the contribution of more weathered materials by the Peninsular rivers. It has been found that there is a geochemical split between the channel and suspended sediments of the Peninsular rivers for sharing different sources, i.e., the dominant contribution of felsic sources to the channel and mafic sources to the suspended sediments. The weathering geochemistry, trace element systematics, and REE patterns suggest that the dominant sources of the channel sediments of the Peninsular rivers are the felsic crystallines and sedimentary lithologies of the Aravalli range, Bundelkhand and Chhotanagpur granite and gneisses, and Vindhyan sandstones. Whereas, the mafic lithologies such as the Deccan traps and mafic components of the felsic lithologies appear to be the major sources of the suspended sediments. Within the range of intermediate composition, the overbank sediment chemistry reflects more contribution of the mafic sources except for the Ken which shows a higher contribution of the felsic sources. The geochemical split between the channel and suspended sediments of the Peninsular river's sediments for the different provenances indicates differential weathering of the Deccan basalts, Bundelkhand crystalline, and Vindhyan sedimentary rocks; and also the hydrodynamic control of the Peninsular rivers during erosion, transport, and deposition. However, the Himalayan rivers do not show such contrast between the channel and suspended sediments because of the higher physical weathering and sediment mixing in the high gradient topography of the Himalayan catchment.

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1. Introduction

Geochemical study of clastic sediments has been carried out extensively to understand the aspects of provenance, weathering and erosion, tectonic setting, fluvial processes, paleoclimate, the evolution of the continental crust, exogenic processes, biogeochemical cycles and anthropogenic impact on the environment (Nesbitt and Young, 1982; Bhatia, 1983; Taylor and McLennan, 1985; Cullers, 1988; Tripathi and Rajamani, 1999; Gaillardet et al., 1999; Roy et al., 1999; Singh and France-Lanord, 2002; Rahaman et al., 2009; Garzanti et al., 2010, 2011;

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Lupker et al., 2012; Sharma et al., 2013). The chemical composition of clastic sediments is controlled by several factors such as source rock composition, nature and extent of weathering of the source rocks, sedimentary sorting and recycling, and post-depositional changes during diagenesis and metamorphism (Taylor and McLennan, 1985; Sawyer, 1986; Feng and Kerrich, 1990; Nesbitt et al., 1996; Singh and Rajamani, 2001b; Tripathi et al., 2007). However, the behavior of these factors and their relative control on sediment chemistry in diverse tectonic, lithological, climatic and geomorphic set up is equivocal and discriminating the effects of each factor becomes one of the major scientific challenges in sedimentology.

Rivers are the major natural systems transporting most of the eroded materials from continents to oceans. Fluvial sediments have been used to find integrated information on continental surface processes, as rivers cover a large part of the land and preserve the geological and environmental records depending on the tectonic and climatic setting of the river basin. Provenance and weathering studies of river basins help to evaluate the contribution from different sources, their erosion rates and sedimentary budgets, and tectonic-climate-weathering relationship (Jian et al., 2013). However, studies have shown contrasting results for the control of tectonics, lithology, weathering (climate vs tectonic control) and fluvial processes on clastic sediment composition (Yang et al., 2004; Roddaz et al., 2006; Liu et al., 2007, 2012; Borges et al., 2008; Garzanti et al., 2011; Shao et al., 2012; Chetelat et al., 2013). The textural and mineralogical modification by weathering and subsequent fractionation by sedimentary processes resulting in geochemical heterogeneity of fluvial sediments during their generation, transportation and deposition pose a major difficulty in utilizing sediment chemistry data for the provenance, weathering, paleoclimate and crustal evolution studies. Unraveling the mechanisms and magnitude of textural, mineralogical and geochemical modification of fluvial sediments by various factors require more geochemical information from diverse geological environments for a better understanding of the earth surface processes. It becomes important to study the sediments from the modern and dynamic fluvial systems to have a more robust understanding of the controls on sediment composition, which will further help in inferring the geological and environmental information stored in ancient sedimentary deposits.

The Ganga river system, one of the largest and most dynamic river system in the world, forms one of the vast and most productive alluvial plains, by depositing the eroded sediments in the foreland basin of the Himalaya during the Quaternary (Rowley, 1996). The Ganga river receives sediments from the Himalayan catchment in the north as well as from the Peninsular catchment in the south, encompassing diverse lithologies of different compositions and ages, climate, tectonics, topography, relief and vegetation. The nature and proportions of the sediments from the Himalaya and Peninsula varied with time in response to the prevailing tectonic and climatic conditions during the evolution of the foreland basin (Agrawal et al., 2013; Tripathi et al., 2013). It is vital to understand how the geological and geographical diversity of these catchments influences the sediment budget and composition of the Ganga plain, and overall geochemical evolution of the Ganga Basin and Bay of Bengal. Previous studies on the Ganga river system were mostly confined to its Himalayan catchment, the Ganga plain and delta region in the Bay of Bengal. The Peninsular sub-basin constituting a major portion (~35%) of the Ganga basin (Rao, 1979), is scarcely investigated except for a few studies mainly focussing on chemical weathering, weathering rates, and associated CO_2 consumption, denudation and flux, which were mostly based on the solute and little on sediment chemistry of the selected Peninsular rivers (Abbas and Subramanian, 1984; Sarin et al., 1989; Jha et al., 1993; Rengarajan and Sarin, 2004; Rengarajan et al., 2009; Rai et al., 2010; Maharana et al., 2015). The previous workers have suggested a dominant contribution of the Himalayan rivers to the Ganga plain and the Bay of Bengal (Galy and France-Lanord, 2001). Some of the recent studies have suggested a significant Peninsular contribution to the Ganga basin (Singh et al., 2008; Sinha et al., 2009; Tripathy et al., 2011; Lupker et al., 2012; Tripathi et al., 2013; Garçon and Chauvel, 2014). However, the sources and processes controlling the sediment geochemistry of these rivers in the Peninsular catchment have not been well constrained and therefore requires a detailed study for a better understanding of the catchment specific control on the geological and geochemical evolution of the Ganga river system and the Bay of Bengal.

The work presented here is a comprehensive and coordinated study of integrated textural, mineralogical and geochemical data of the sediments from all the major Peninsular rivers of the Ganga basin (the Chambal, Sindh, Betwa, Ken, Ton and Son rivers) including the Yamuna and Ganga rivers to understand (i) the nature and extent of weathering in the catchment of the Peninsular rivers, (ii) influence of sedimentary processes on sediment geochemistry, (iii) the provenance of sediments carried by the Peninsular rivers, and (iv) the control of various factors on sediment composition and their variability in diverse catchment of the Ganga basin by comparing the geochemical data of the Peninsular and Himalayan rivers.

2. Study area

The Ganga basin spanning a huge and diverse catchment comprises three major components, i.e., the Himalaya in the north, the Ganga plain in the middle and Indian Peninsula in the south with distinct geological, geographic and climatic setup. The drainage basin of the Ganga river covers an area of around 1.06 million square kilometers of which 17% belongs to the Himalaya, 35% to the Peninsular India and 48% to the Ganga plain (Rao, 1979). The Peninsular sub-basin covers an area of $\sim 350 \times 10^3\,km^2$ of the Ganga basin, which is almost double the area covered by the Himalayan sub-basin (Galy and France-Lanord, 1999; Rao, 1979). The characteristics of the Ganga river including its Himalayan catchment and the Ganga plain has been discussed extensively by several workers in the earlier studies (Singh, 2010 and reference therein). The important characteristics of the Peninsular sub-basin are discussed below.

2.1. Geological setting

The major lithologies exposed in the Peninsular drainage of the Ganga basin are the Cretaceous Deccan traps, the Proterozoic Vindhyan Supergroup, the Archean Bundelkhand Granitic Complex and the Aravalli Supergroup, the Gondwana, the Mahakoshal Group, the Chottanagpur granites and gneisses (CGC) and the Quaternary alluvium forming a complex mosaic of rock types (Fig. 1). The headwaters of the Chambal, Sindh, Betwa and Ken rivers lie in the Deccan traps region which is mainly composed of tholeiitic basalts, porphyric basalts with phenocryst of olivine, augite and plagioclase (Srivastava et al., 1988). All the Peninsular rivers in their lower stretch drain Proterozoic Vindhyan Supergroup, which includes four major groups, i) the Semri Group consisting basal conglomerate, glauconitic sandstone and stromatolitic carbonates followed by felsic volcanics and tuffs (porcellanite), shale, limestone and sandstone, ii) the Kaimur Group includes sandstone and shale (pyritiferous and carbonaceous) iii) the Rewa Group consists of shale, sandstone and conglomerate and iv) the Bhander group is made up of shale, conglomerates, limestones and sandstones (Soni et al., 1987). The Bundelkhand craton covering an area of $\sim 26{,}000\,km^2$ (Mondal and Zainuddin, 1996), primarily drained by the Sindh, Betwa and Ken rivers. The Bundelkhand craton is a coarse-grained granite of batholithic body with patches of older gneisses and NE-SW trending quartz reefs (Valdiya, 2010). It contains phases of granites (hornblende granite, biotite granite, and leucogranite) with phenocrysts of alkali and plagioclase feldspars as the dominant lithology and subordinate gneisses with a Tonalite-Trondhjemite-Granodiorite composition, banded iron formations, mafic-ultramafic suites and mafic dikes (Ramakrishnan and Vaidyanadhan, 2008). The Banas river, one of the major tributary of the Chambal river