Strontium and neodymium isotopic compositions in sediments from Godavari, Krishna and Pennar rivers

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We report here strontium (Sr) and neodymium (Nd) isotopic compositions in bed sediments from the Godavari, Krishna and Pennar rivers, draining into the Bay of Bengal. The isotopic compositions of these sediments range from 0.7190 to 0.7610 for $^{87}Sr/^{86}Sr$ and –12.04 to –23.68 for ε_{Nd}. This wide range in Sr and Nd isotopes is derived from variable proportions of sediments from different rock types in their drainage basins. All the three rivers have their characteristic isotopic signatures. The results display highest $^{87}Sr/^{86}Sr$ (0.7610) and most negative ε_{Nd} values (–23.68) for the sediments of Pennar river. This is attributed to the chemical weathering of gneisses and granites in its drainage basin. The $^{87}Sr/^{86}Sr$ and ε_{Nd} values for the Godavari river sediments range from 0.7196 to 0.7210 and –15.31 to –18.22 respectively. $^{87}Sr/^{86}Sr$ and ε_{Nd} values in Krishna river sediments lie from 0.7217 to 0.7301 and –12.04 to –12.78 respectively. Our results show that the sedimentary load from the Godavari and Krishna rivers is primarily derived from the older rocks in their drainage basins. It is possible that the sediments transported through peninsular Indian rivers predominantly control Sr and Nd isotope sedimentary budget in the western Bay of Bengal.

Keywords: Bay of Bengal, Deccan Traps, river sediments, Sr and Nd isotopic compositions.

RIVERS are the main source of detrital particles delivered to the oceans and thus exert a major control on coastal and deep-sea sediment evolution. Terrigenous sediments drained from the Himalaya and Indian subcontinent are transported to the Bay of Bengal by rivers such as the Ganga, Brahmaputra, Godavari, Mahanadi, Krishna, etc. These sediments are derived primarily from weathering of continental rocks with a wide range of strontium (Sr) and neodymium (Nd) isotopic composition[1–4]. Radiogenic isotopic composition of these sediments reflects those of their continental source and hence provides useful information about their provenance[3]. The merits of Sr and Nd isotopes as fingerprints of source region and transport pathways of detrital sediments have been well documented by several workers[1–8].

Isotopic ratios of Sr and Nd vary according to the age and geological history of crustal rocks with an inverse relationship between $^{87}Sr/^{86}Sr$ and ε_{Nd} and are useful in petrogenesis. Sediments of rivers draining older crust have more radiogenic Sr and non-radiogenic Nd than rivers draining the younger crust[7–10]. The Sr isotope composition is influenced by grain-size sorting as well as early diagenesis of the sediment[4–6]. The Nd isotope composition is considered to be a more reliable tracer of the source rock because Nd isotopes are less affected by grain-size differences of the sediment fractions and do not change during weathering, transport and winnowing processes[7,9]. Sr isotopic composition is also controlled by the degree of chemical weathering of source rock and strongly affected by the weathering of authigenic precipitates[11]. The continent-derived material exerts an important control on the Nd isotopic budget in marine sediments[8]. Nd isotopic composition in sediments along the western margin of India clearly shows that Nd is a better tracer than Sr in identifying the source of terrigenous sediments[6]. Several workers studied Sr–Nd isotopes in different size fractions of the terrigenous sediments and determined the sources of sediments[11,12].

The suspended load from the Ganga–Brahmaputra (G–B) river system to the Bay of Bengal is estimated to be between 700 and 1900 million tonnes/year[1,4], whereas that of the Godavari and Krishna is about 125 million tonnes/year[2]. Since large volumes of sediments in the Bay of Bengal are brought down by these river systems, they preserve imprints of the erosion and weathering history of rocks in their drainage basins[13]. The Sr and Nd isotopic composition of sediments in the western, eastern and distal Bay of Bengal vary considerably due to changes in the source and transport pathways of terrigenous material[13–15]. Moreover sedimentary input into the Bay of Bengal depends on climate and monsoonal precipitation[13,16]. An increase in monsoonal precipitation results in an increase in the chemical weathering rates in a drainage basin and therefore enhances the sedimentary flux to the Bay of Bengal[16].

There are three major sedimentary basins along the east coast of India, viz. Cauvery, Palar and Godavari–Krishna basin. These basins are represented by rocks ranging in age from Permian to Pleistocene. Colin *et al.*[14] reported that the sediments in the western part of the Bay of Bengal are mainly derived from the G–B system, whereas the eastern Bay of Bengal sediments represent a mixed source from the G–B derived sediments, the Irrawaddy sediments and the Arakan coast sediments. The $^{87}Sr/^{86}Sr$ and ε_{Nd} values in the western Bay of Bengal sediments lies between 0.7238 and 0.7316, and –15.1 and –16.2 respectively.

The Godavari river is the third largest river in the Indian subcontinent. It originates in Deccan Traps and drains an area of 3.1×10^5 km^2. The upper reaches of Godavari basin is occupied by the Deccan Traps, whereas the middle part is mainly occupied by Archean granites, phyllites, quartzites, amphibolites and gneisses. River Godavari

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flows nearly 48% on Deccan Traps, 39% on the granites and gneisses, 11% Precambrian and Gondwana sediments, and 2–3% recent alluvium[16–20]. The basaltic rocks weather to laterite and bauxite and the soil formed contain up to 80% smectite, illite and kaolinite[21]. Basaltic rocks are also reported on both sides of the Godavari river, north of Rajahmundry city. However on the east bank, these Traps rest upon the metamorphic rocks[22]. These basalts were formed at a time close to K–T boundary event[23,24] and their $^{87}Sr/^{86}Sr$ ratio is also similar to those of Deccan Traps ($^{87}Sr/^{86}Sr = 0.706–0.707$)[23].

The Krishna river also originates from the Deccan Traps and flows for a distance of ~1400 km before draining into the Bay of Bengal. The geology of the basin is dominated by the Traps in the northwest, crystallines in the central and Cuddapah Group in the east. Archean and younger crystalline rocks occupy nearly 80% of the Krishna basin, and the remaining 20% comprises Tertiary Deccan Traps and recent sediments. The deltaic region consists of Pleistocene to recent sediments. The upper Pennar river basin is located in Anantapur district in the southwestern part of Andhra Pradesh. Geology of the Pennar drainage basin predominantly consists of Archean rocks comprising schists, gneisses, migmatites and granites. Other rock types in Pennar basin are the medium to high-grade Dharwar metamorphic rocks, including quartzite and greenstone belts[18]. In the central part of the basin, dominant rocks belong to the Cuddapah and Kurnool groups consisting of conglomerates, sandstones, shales, dolomites, limestones and cherts. In the coastal regions, the major sediments are laterites and recent alluvium. Generally sediments of the peninsular Indian rivers are highly plastic and fine grained than those of the Ganga, which are less plastic and dominated by silt. This size difference is due to the variations in weathering regimes, dominantly by physical weathering in the Himalayas and chemical weathering in peninsular India.

Sediment samples were collected from river beds along the channels during November 2002 as shown in Figure 1. Samples were collected from eight locations of Godavari, Krishna and Pennar rivers by simply scooping with a plastic spade, transferred to precleaned plastic bags, sealed and brought to the laboratory. Sediments were treated with hydrogen peroxide to remove organic matter, oven dried and finely powdered before digesting with $HF–HNO_3$ mixture. Strontium and rare earth elements were separated using columns packed with cation exchange resin (DOWEX50X8). Nd was separated from the REE fraction with columns packed with HDEHP coated Biobead resin. The Sr and Nd isotope ratio measurements were performed on VG 354 Thermal Ionization Mass Spectrometer (TIMS) in the dynamic triple collector mode at NGRI, Hyderabad. The $^{87}Sr/^{86}Sr$ ratio were corrected for fractionation with $^{86}Sr/^{88}Sr = 0.1194$ and normalization to SRM 987 standard value of 0.710220 ± 0.000024 (2 Sigma SD; $n = 10$). $^{143}Nd/^{144}Nd$ ratio was corrected for fractionation with $^{146}Nd/^{144}Nd = 0.7219$ and normalized to La Jolla standard value of 0.511850 ± 0.000010 (2 Sigma SD; $n = 8$). Blank contribution for Sr, Nd isotopic measurements was negligible <250 pg and <25 pg respectively. The ε_{Nd} was calculated using the following equation:

$$\varepsilon_{Nd} = (^{143}Nd/^{144}Nd_{SAM}/^{143}Nd/^{144}Nd_{CHUR} - 1) \times 10^{-4},$$

where CHUR $^{143}Nd/^{144}Nd = 0.512638$.

The $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$ and ε_{Nd} values in Godavari, Krishna and Pennar river sediments are listed in Table 1 and Figure 2. The results show wide range of $^{87}Sr/^{86}Sr$ and ε_{Nd} values. The highest $^{87}Sr/^{86}Sr$ of 0.76102 and less radiogenic ε_{Nd} –23.68 values are recorded in a sample from the Pennar basin. The $^{87}Sr/^{86}Sr$ and ε_{Nd} values in Godavari sediments range from 0.71963 to 0.72998 and –15.31 to –18.22 respectively. One sample collected from the Godavari basin has a relatively high $^{87}Sr/^{86}Sr$ (0.72998) and a low ε_{Nd} (–18.22) value. This difference in isotopic compositions is due to the weathering of various rock types with different isotopic composition.

Erosional products of the older rock formations have high $^{87}Sr/^{86}Sr$ ratio and less radiogenic ε_{Nd} values, whereas those derived from the younger rocks have low $^{87}Sr/^{86}Sr$ ratio and more radiogenic ε_{Nd}. For example, sediments of the Ganga river have very high $^{87}Sr/^{86}Sr$ (0.7474 to 0.8424) and less radiogenic ε_{Nd} (–15.5 to

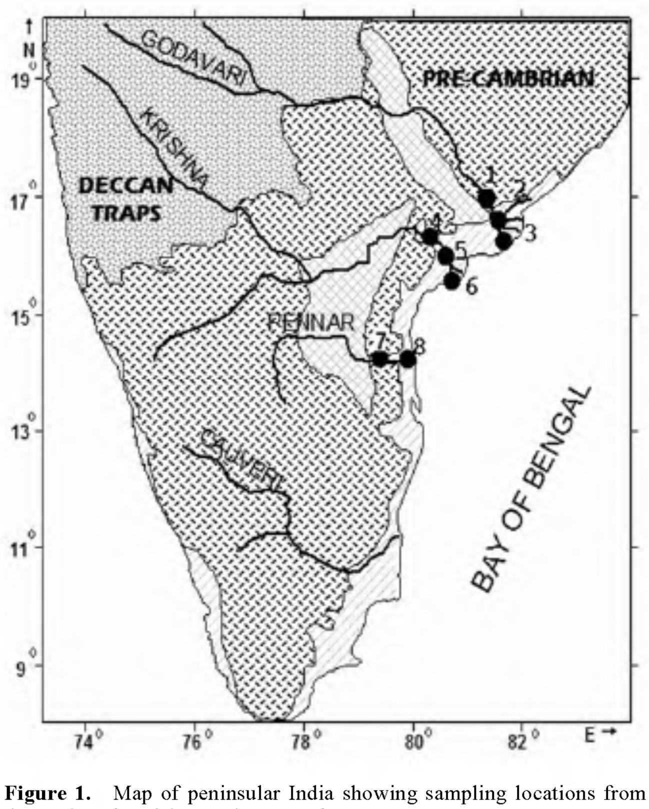

Figure 1. Map of peninsular India showing sampling locations from the Godavari, Krishna and Pennar river systems.

Table 1. $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$ and ε_{Nd} values in sediments from Godavari, Krishna and Pennar river systems. Standard deviation (SD) (1 Sigma) is given for $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios

Sample number	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	ε_{Nd}
Godavari-1	0.729981 ± 18	0.511704 ± 12	–18.22
Godavari-2	0.724687 ± 24	0.511853 ± 10	–15.31
Godavari-3	0.719629 ± 22	0.511838 ± 12	–15.60
Krishna-4	0.730060 ± 28	0.511983 ± 12	–12.78
Krishna-5	0.721728 ± 20	0.512021 ± 08	–12.04
Krishna-6	0.720690 ± 18	0.512006 ± 10	–12.33
Pennar-7	0.761018 ± 18	0.511424 ± 10	–23.68
Pennar-8	0.752502 ± 18	0.511525 ± 08	–21.71

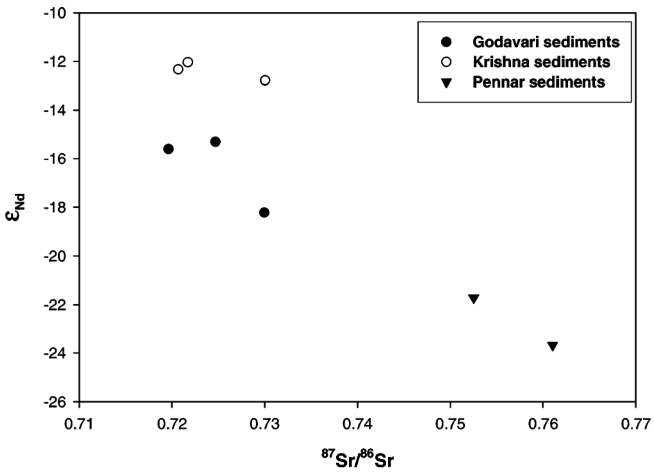

Figure 2. $^{87}Sr/^{86}Sr$ vs ε_{Nd} diagram indicating distinct and characteristic isotopic values of Godavari, Krishna and Pennar river sediments.

–25.5)[25]. These sediments are also characterized by high Re/Os ratios and extremely radiogenic $^{187}Os/^{188}Os$ ratios[26]. In contrast, sediments from the Brahmaputra river and its tributaries have highly variable Sr and Nd isotopic compositions, ranging from 0.7053 to 0.8250 for $^{87}Sr/^{86}Sr$ and –6.9 to –20.5 for ε_{Nd} (ref. 4). This large range of Brahmaputra river sediments is attributed to the variable proportion of sediments derived from weathering of different rock types in the Himalayan region[4]. It has been suggested that the weathering and erosion in the Himalayan region has a pronounced effect on the evolution of seawater $^{87}Sr/^{86}Sr$ ratio[1].

Our Sr and Nd isotopic data of Godavari sediments suggest that the sedimentary load from the younger rocks of Deccan Traps has a very negligible effect on their isotopic composition as indicated by their high $^{87}Sr/^{86}Sr$ and low ε_{Nd} values. Also, these results do not show any evidence of sediments derived by weathering of the Rajahmundry Traps at the studied locations. It may be noted that the weathering products from basalts should have low $^{87}Sr/^{86}Sr$ (0.704–0.707) and high radiogenic Nd (ε_{Nd} = –7.06 to –6.59)[23,27]. The mineralogy of the fine-grained sediments of the Godavari river is dominated by smectite, kaolinite and minor illite[28]. The Sr–Nd isotopic compositions of the Godavari sediments are thus in contrast with that of their mineralogy. This may be due to the Sr–Nd analyses on bulk sample with various proportions of clay, silt and sand fractions. Similarly, Sr and Nd isotopes in Krishna river sediments also show a mixed source. However sediments from the Krishna river have relatively more radiogenic Nd (ε_{Nd} = –12.04 to –12.78), probably suggesting some contribution from the weathering of relatively younger Deccan Traps also. Moreover the average $^{87}Sr/^{86}Sr$ and ε_{Nd} values in the bed sediments of Godavari and Krishna rivers (mean $^{87}Sr/^{86}Sr$ = 0.7255 and mean ε_{Nd} = –14.38) are similar to the five core-top sediment samples from the western Bay of Bengal (mean $^{87}Sr/^{86}Sr$ = 0.7249 and mean ε_{Nd} = –15.7, n = 5)[14] indicating the significance of detrital fluxes from the peninsular Indian rivers in determining Sr and Nd isotopic budget of the western Bay of Bengal.

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Multi-shelled orbicular olivine gabbronorite from Leh, Jammu and Kashmir, Ladakh Himalaya

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We report here a multi-shelled orbicular olivine gabbronorite with anorthositic rims from Leh, J&K, India. The rock occurs as a transported boulder near Nimoo (12°95′33.40″N; 38°54′45.47″E) in Leh, over the Indus Group of sediments at an elevation of 3110 m, and is most likely derived from the Ladakh Granitic Complex. We present here the morphological details, and preliminary mineralogy and petrology of the orbicular rock.

Keywords: Anorthosite, comb-layering, Ladakh Granitic Complex, olivine gabbronorite, orbicular rock.

ORBICULAR rocks are rare in nature[1,2], mostly found as small outcrops[3,4]. Every orbicular rock is petrochemically distinct[1,5], occurs along pluton margins[3,6–8] and requires

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