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Environmental magnetism and application in the continental shelf sediments of India

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ABSTRACT

Mineral magnetic and geochemical analyses were carried out on surface sediments from the continental shelf of India. The purpose of this study is to examine the environmental assessment of heavy metal concentrations and its impact in the coastal environment using magnetic techniques and to gain an understanding on the factors controlling metal concentrations and distributions in the east and west coast of India. The strong relationships between Anhysteretic Remanent Magnetization (χ_{ARM}) and heavy metals can be explained by the role of iron oxides controlling metal concentrations, though the link is also reinforced by the strong tendency of χ_{ARM} to be associated with the finer particle sizes. Higher values of magnetic susceptibility, $IRM_{20\ mT}$ and SIRM are associated with the east coast shelf sediments suggest the presence of high ferrimagnetic content, which can be derived from the weathering products of the Deccan Basalts. χ_{ARM} can be used as a normalizer for particle size effects in the way that Aluminium (Al) is often used. The relationship between magnetic parameters and heavy metal concentrations (Fe, Cu, Cr and Ni) showed a strong positive correlation in the east coast sediments, much less so in the case of the west coast. This finding suggests that the simple, rapid and non-destructive magnetic measurement can be used as an indicator for the heavy metal contamination and proxies for the measurement of heavy metals content in the coastal environment.

1. Introduction

Magnetic measurements are being used as a powerful tool for the assessment of heavy metal contamination in soils and sediments and in the investigation of the compositional properties of rocks, sediments and soils (Thompson and Oldfield, 1986; Walden et al., 1999; Maher and Thompson, 1999). Magnetic minerals in soils are derived either from the parent rocks (lithogenic origin), pedogenesis or as a result of anthropogenic activities. Susceptibility measurements play an important role for monitoring environmental pollution in the case of minor contributions of the first two sources to the magnetic properties of soils. Accumulation of anthropogenic ferrimagnetic particles, originating during high temperature combustion of fossil fuels (e.g., Vassilev, 1992; Dekkers and Pietersen, 1992), results in significant enhancement of topsoil magnetic susceptibility. Therefore, under favourable circumstances, magnetic properties of soils and sediments can be used for the assessment of emissions, both from local pollution sources and on a wider regional scale. Already a pioneering work of Thompson and Oldfield (1986) reported that soils near urban areas and industrial zones have an increased magnetic susceptibility, due to the deposition of magnetic particles, such as, dusts of the metallurgical industries and fly ashes of the coal combustion. Magnetic measurements are relatively simple and non-destructive and due to high sensitivity and speed are often applied for detecting industrial pollution. Because there is a need for fast and cost effective screening and monitoring tools for industrial pollution, magnetic methods have drawn the attention of modern researchers as an approximate tool, to detect and characterize environmental pollution (e.g., Dearing et al., 1996; Petrovský and Ellwood, 1999; Hoffmann et al., 1999; Magiera and Strzyszcz, 2000; Petrovský et al., 2001; Hanesch and Scholger, 2002; Veneva et al., 2004, and others). This work has been used to identify the sources of industrial pollution (Scoullos et al., 1979; Hunt et al., 1984; Matzka and Maher 1999; Petrovský et al., 2000, 2001; Klose et al., 2001; Knab et al., 2001; Lecoanet et al., 2001; Hanesch and Scholger 2002; Muxworthy et al., 2002; Hanesch et al., 2003; Kapička et al., 2003; Moreno et al., 2003; Desenfant et al., 2004; Jordanova et al., 2004; Spiteri et al., 2005) and to characterize various depositional environments (e.g., Arkell et al., 1983; Oldfield et al., 1985, 1999; White et al., 1997; Walden et al., 1995, 1997; Schmidt et al., 1999; Wheeler et al., 1999). The relationship between mineral magnetic measurements and chemical/physical properties of sediments and soils have been established in several studies (Oldfield et al., 1985; Oldfield and Yu, 1994; Clifton et al.,

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1997, 1999; Chan et al., 1998; Petrovsky et al., 1998; Xie et al., 1999, 2000; Booth, 2002). Mineral magnetic measurements were used as a tool for determining sediment provenance (Oldfield and Yu, 1994), transport pathways (Lepland and Stevens, 1996), as a proxy for geochemical, radioactivity, organic matter content and particle size data (Bonnett et al., 1988; Oldfield et al., 1993; Hutchinson and Prandle, 1994; Clifton et al., 1997, 1999; Xie et al., 1999, 2000; Zhang et al., 2001; Booth et al., 2005). Magnetic measurements as a proxy for industrial contamination have also been employed in India (Goddu et al., 2004). Hence, the present study is undertaken in order to examine the environmental assessment of heavy metal concentrations and its impact in the coastal environment using magnetic techniques and to gain an understanding on the factors controlling metal concentrations and distributions along the east and west coast of India.

2. Materials and methods

2.1. Study area

2.1.1. Geographic setting

The subcontinent of India, geographically covers tropical to subtropical climatic zones and exhibits strong seasonality from warm humid to arid and cold arid conditions. The climate of the subcontinent is dominated by Monsoon systems; this region remains humid during summer and dry during winter. It has basically two main seasons, the wet and dry, instead of four seasons. The gradient of climatic zones is largely affected by the sharp altitudinal changes in the northern half where the Himalaya forms the major relief. The Indian subcontinent experiences mostly a tropical monsoon climate, with significant seasonal variations in rainfall and temperature. The Himalayas, acting as a barrier to the cold northerly winds from Central Asia, maintain the pattern of the Indian Ocean monsoon circulation. The Thar Desert allows oceanic atmospheric circulation and sediment dust-aerosol influx deep into the continent. The southwest (SW) monsoon is divided into Arabian Sea Branch of the SW Monsoon and Bay of Bengal Branch of the SW Monsoon. The Arabian Sea branch extends the low-pressure area over the Thar Desert in Rajasthan whereas the Bay of Bengal branch results in turbulence in the region due to the rapid altitudinal differences and narrowing orography. The Arabian Sea branch is roughly three times stronger than the Bay of Bengal branch. This branch of the monsoon moves northwards along the Western Ghats giving rain to the coastal areas west of the Western Ghats and the eastern parts of the Western Ghats do not receive much rain from this monsoon. The climate-induced sedimentation processes take place in large-scale during strong monsoons as cyclones occur in the coastal region (Sangode et al., 2007).

2.1.2. East coast-geology-climate

The outer limit of the eastern continental shelf of India lies at ~200 m (Fig. 1) and the inner shelf and the continental slope are covered by clastic sediments (Rao, 1985). The outer shelf is covered by calcareous relict sediments and off the river mouths the shelf is covered by fine-grained terrigenous sediments. The shelf at the mouths of the rivers receives a large part of its sediment from the rivers Ganges, Brahmaputra and Mahanadi in the north, Godavari and Krishna in the central region, all forming fertile, heavily populated deltas. Sediment from the rivers has made the bay a shallow sea, and the waters have reduced the salinity of surface waters along the shore. Sediment input and annual discharge is less from the smaller rivers such as Pennar and Cauvery in the south (Rao, 1979, 1985).

The presence of the Deccan Basalt is observed along the tributaries of the Godavari and discharged into the Bay of Bengal from

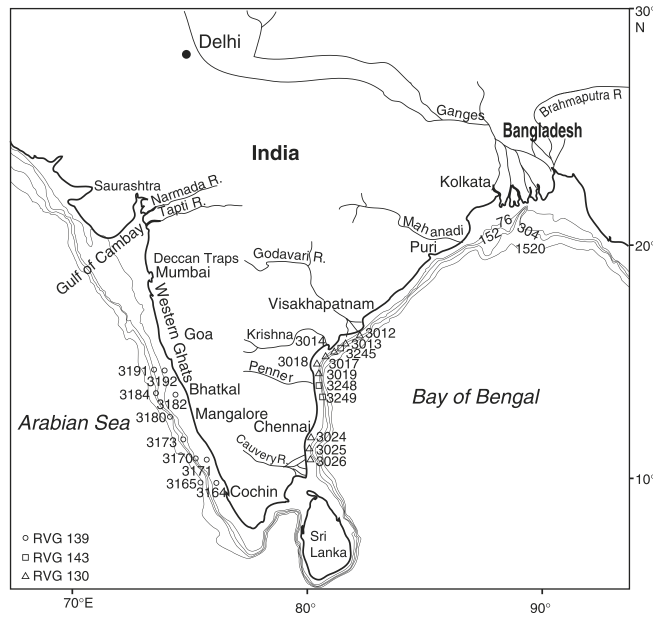

Fig. 1. Location of sediment sampling stations along the east and west coast of India. △-RVG 130; □-RVG 143; o-RVG 139 represent the sampling sites of different cruises.

the east coast of the Peninsular India through the Mahanadi, Godavari and Cauvery river systems (Sangode et al., 2007). Deccan Province also covers the studied stations in the east coast of India (Raman et al., 1995).

2.1.3. West coast-geology-climate

The Indus river is the largest source of sediments in the Arabian Sea, which extend outward to a distance of ~1000–1500 km (Rao and Rao, 1995). It predominantly drains the Precambrian metamorphic rocks of Himalayas and to a lesser extent the semi arid and arid soils of West Pakistan and NW India (Krishnan, 1968). Deccan Trap basalts (Fig. 1) are the predominant rock types cropping out in the Saurashtra and the drainage basins of the Narmada and Tapti rivers, which annually discharge ~60 × 10^6 tonnes sediment through the Gulf of Cambay (Rao, 1975) where a semi-arid climate prevails. The Western Ghats are composed of basalts between Mumbai and Goa, and Precambrian granites, gneisses, schists and charnockites between Goa and Cochin (Krishnan, 1968). The Ghats are located on the coast between Goa and Bhatkal but are 50–80 km from the coast south of Bhatkal. The source of sediments in rivers originating in the western part of India is derived the black "cotton soils", covering the Deccan Traps, a large percentage of which is mainly composed of montmorillonite. The drainage area in the upper reaches of these rivers is a montmorillonite-rich, zone but in the lower reaches, they drain through Precambrian formations that contain kaolinite rich soils that are of secondary significance in the shelf sediments derived from the Godavari and Krishna rivers (Rao, 1991). It is well established that source rock compositions and weathering mechanisms basically control the distinct geochemical compositions of sediments in the east and west coast of India (Alagarsamy and Zhang, 2005).

2.2. Sampling and analysis

Surface sediments from the east and west coasts of India were collected using a Van Veen Grab/Snapper during several cruises of the R.V. Gaveshani (130, 139 and 143) (Fig. 1; Table 1). Subsamples were collected from the uppermost layer of the sediment taking care to minimize contamination. Samples were frozen after