High incidence of scandium and REY in garnets from coastal sands of India

The economic heavy mineral suite in beach, dune and offshore sands of Odisha, Andhra Pradesh (AP), Tamil Nadu (TN) and Kerala coasts in India mainly comprises ilmenite, garnet, sillimanite, rutile, monazite and zircon. The garnet collected from Kalingapatnam coast, AP reported high incidence (point analysis by EPMA) of rare earth elements (REE) (1500–5300 ppm) especially HREE[1]. EPMA of a few garnet grains collected off Anjengo, Kerala, also showed encouraging REE (1200–5000 ppm) values[2]. Nine sand samples were collected from Taingapatnam, Nanjam, Manavalakurichi, Kanyakumari and Uvary in TN, and Santepalle, Bhavanapadu and Yarada in AP (Figure 1) from Indian coast to understand the REE concentrations in garnets. Among the nine, seven samples, viz. GRT-1 (ST-216), GRT-2 (ST-171), GRT-3 (ST-171), GRT-5 (SS-106), GRT-6 (SS-106), GRT-7 (SS-140) and GRT-8 (SS-140) were collected during cruises of Marine and Coastal Survey Division (MCSD), Geological Survey of India (GSI) and the remaining two samples, viz. GRT-10 and GRT-11 were collected from IREL Research Centre, Kollam and AMD, Thiruvananthapuram respectively. These samples contain economically important heavy minerals in different proportions and were subjected to multiple processes for enriching garnet at IREL Research Centre, Kollam, using REDMS (rare earth drum magnetic separator), CSS (corona static separator), EPS (electrostatic plate separator), IRMS (induced roll magnetic separator) and diiodomethane (3.3 specific gravity) to make the samples >95% enriched in garnet. The enriched garnet samples were subjected to HR-ICPMS and XRD analyses for trace elements and mineral phases respectively, at the National Institute of Oceanography (NIO), Goa.

For analysis of trace elements, about 20 mg of sample aliquots was moistened with ultrapure water and 10 ml of 7 : 3 : 1 HF : HNO_3 : $HClO_4$ acid mixture was added to this and kept for 3 h. Subsequently, the samples were heated on a hot plate (130°C) to near complete dryness. To the dry residue, additional 5 ml of acid mixture was added. To the dried cakes, 1 ml HCl was added and heated to near complete dryness and the samples were redissolved in 4 ml 1 : 1 HNO_3 and made up to 100 ml after filtration using Whatman No. 41 grade filter paper. The samples were further diluted with the addition of 1 ml 1 ppm rhodium and analysed. Granodiorite reference rock standard (GSP 2) of the United States Geological Survey (USGS) was used to externally calibrate element concentrations. Method accuracy error % for REE and Scandium (Sc) are <5 and for Yttrium (Y) it is 10. Analytical precision for REE is <5%, 8% for Sc and 9% for Y.

Among the nine garnet samples, five (GRT-1, GRT-2, GRT-3, GRT-6 and GRT-11) have high concentrations of Sc (244–386 ppm), seven (GRT-1, GRT-2, GRT-3, GRT-6, GRT-8, GRT-10 and GRT-11) have good contents of Y (530–900 ppm) and six samples (GRT-1, GRT-2, GRT-3, GRT-6, GRT-8 and GRT-10) show encouraging results of REE (816–7472 ppm) (Table 1). XRD analysis revealed that the major mineral phase in all the samples is garnet with minor presence of quartz. Garnet in all the samples belongs to almandine–pyrope series type. Under binocular microscope, garnet grains were mostly red or light pink in colour.

At present, garnet is being widely consumed for its low-end uses like abrasives in sand blasting, water-jet cutting and

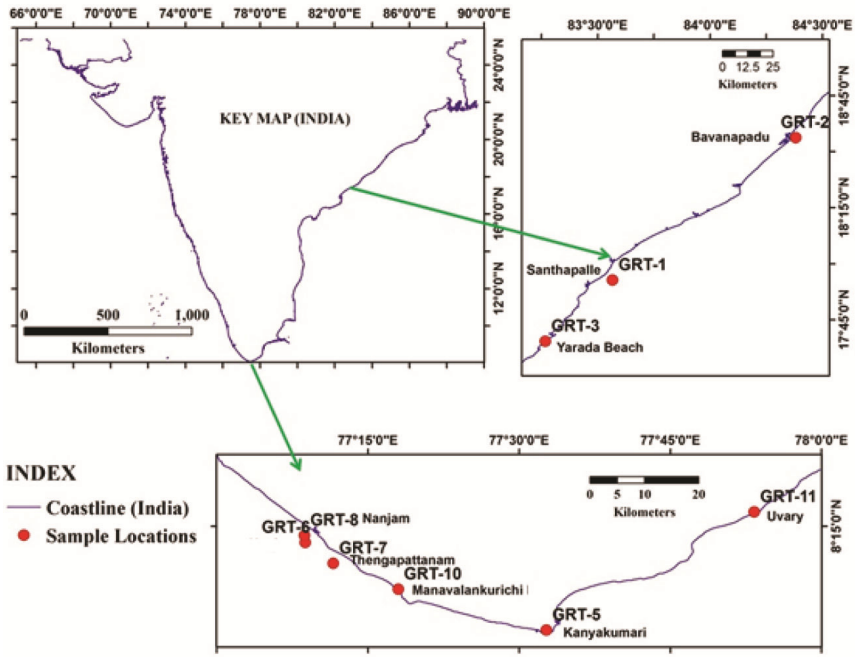

Figure 1. Map showing sample locations.

Table 1. Scandium and REY concentrations (ppm) in garnet from different locations

Sample no.	REE	Scandium	Yttrium	Domain	Location
GRT-1	816.705	261.949	751.875	Offshore	Santhapalle
GRT-2	7472.295	352.788	900.248	Offshore	Bavanapadu
GRT-3	1590.518	258.58	640.12	Beach	Yarada
GRT-5	317.062	117.513	418.268	Beach	Kanyakumari
GRT-6	3366.543	244.074	583.374	Offshore	Nanjam
GRT-7	191.676	56.527	178.857	Offshore	Taingapatnam
GRT-8	3856.351	93.979	530.504	Offshore	Nanjam
GRT-10	993.753	93.324	553.126	Beach	Manavalakurichi
GRT-11	385.48	386.668	669.111	Beach	Uvary

polishing industries. Its utility has widened to water filtration industries in recent years. India is endowed with vast garnet resources of beach and dune sand origin all along its coastal zone. Bulk of the garnet production in the country comes from beach and dune sand deposits of TN with subordinate amounts from AP and Odisha[1]. However, GSI has estimated about 17 million metric tonnes of garnet in the top 1 m of seabed in shallow waters off Odisha, AP and the southwest coast of India (Kerala–TN sector).

The concentration of rare earth elements and yttrium (REY) in some samples is encouraging, especially in view of the heavy demand for REY in strategic applications, hybrid vehicles, magnets, rechargeable batteries, etc.

Sc occurs in many ores in trace amounts, but has not been found in sufficient concentration to be mined as a primary product. The crustal abundance of Sc is 21.9 ppm (ref. 3). As a result of its low concentration, Sc has been produced exclusively as a by-product during processing of various ores or recovered from previously processed tailings or residues. Coal can contain significant Sc. Average Sc concentration in a wide variety of coals from Asia ranges from 0.85 to 16.0 ppm, with an overall average of 4.3 ppm and maximum value of 230 ppm (ref. 4). Consequently, coal fly ash can also contain significant Sc, generally several tens of parts per million[5]. The Sc concentration in monazite pertaining to Chavara and Varkala beaches in Kerala varies from 4.5 to 11 ppm (ref. 6). Scandium rarely concentrates in nature. It does not selectively combine with the common ore-forming anions; so time and geologic forces rarely form Sc concentrations over 100 ppm (ref. 7).

Commercially viable grades (>200–300 g/t) of Sc are rare[8]. The Sc concentration in some of the garnets analysed in this study is found to be between 244 and 386 ppm, which are promising and commercially viable.

Sc is a costly metal and its global production is small (~10 tonnes per year) as a by-product from mining of ores of titanium, rare earths, apatite and uranium[9]. Despite its scarcity, over the past two decades, there have been multiple potential, high-value commercial uses for Sc. The principal uses are in Sc–Al alloys and in solid oxide fuel cells. Minor amounts of Sc are also used in a variety of other applications, including electronics, lasers, mercury vapour lamps and lighting.

All garnet samples collected from different domains do not have high concentrations of Sc and REY. Hence, characterization of garnets having high values of Sc, Y and REE, and their delineation in the coastal sands are of paramount importance.

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Seediness as an invasive trait in *Mimosa diplotricha* Sauvalle in a tropical grassland

For successful invasion into an ecosystem, a species always depends upon some traits such as high growth rate, successive reproduction, higher number of seeds with low mass, seed viability and seedling mortality[1]. Among these traits, the reproductive behaviour of a plant is mainly associated with its invasiveness[2]. Seed production and germination are the two key processes associated with the initial phase of plant establishment, which determine the fate of an invasive plant in a new region[1], and that is especially true for annuals reproducing exclusively by seed[3].

Mimosa diplotricha Sauvalle is a fast-growing, thorny, biennial or perennial shrub native to Tropical America. In India, the plant is invasive from Kerala and Northeast Indian states (http://www.fao.org/forestry/13377-0977cb34791475-aa6a7a360640f09778.pdf accessed on 25 March 2014). In Northeast India, it had become invasive in the protected grasslands of Brahmaputra floodplains including Kaziranga National Park and Rajiv Gandhi Orang National Park which are