environmental learning activities. The impacts of culture on pedagogy have been well-discussed[17,26] and we do not refer only to this. Instead we submit that as the environment is intrinsically a value-laden subject (in the words of Gibson[27], 'Any substance, any surface, any layout has some affordance for benefit or injury to someone. Physics may be value-free, but ecology is not'), teaching and learning practices in the specific context of environmental education assume a greater than usual burden of cultural imperatives and that an insufficient understanding of this factor can fatally disrupt a collective exercise in exploring science.

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Exploration for rare earth elements in North East India

Harbans Singh, Mohd. Sadiq and B. B. Sharma

The rare earth elements (REE) are widely dispersed but rarely occur as ore deposits. They have high density, high melting point, and high electrical and thermal conductance, which make them essential for a variety of emerging and critical technology applications. Thus these metals are increasingly becoming a critical strategic resource.

Rare earth metals and alloys that contain REE are used in many high-tech gadgets in advanced military technology, mobile phones and many other devices of everyday use[1,2]. For geologists, REE are of utmost importance to understand petrogenesis of rocks.

REE minerals occur in a diverse range of igneous, sedimentary and metamorphic rocks in various geological environments such as in beach placers, peralkaline granites, syenites, pegmatites, carbonatites, residual lateritea, phosphoritea, iron–REE (hematitic granite breccia), ion adsorption clays, etc. There are many propitious geological environments in India where REE mineralization can be explored. The Geological Survey of India (GSI) is engaged in REE exploration and is expected to take up 75 exploration projects between 2012 and 2017 in the 12th Five-Year Plan[3].

Exploration for REE deposits in North East India has been intensified since 2010. During 2010–2012, two types of geological environments suitable for REE mineralization were identified and encouraging results of ∑REE (La–Lu) were reported in carbonatites of the Sung Valley ultramafic–alkaline–carbonatite Complex, West Jaintia Hills and East Khasi Hills districts of Meghalaya. The analysed ∑LREE values range from 895.17 to 1264.85 ppm and ∑HREE values range from 60.98 to 81.92 ppm. EPMA study of the carbonatite showed that the main REE-bearing minerals are bastnasite, ancylite, euxenite and britholite associated with calcite and apatite[1,4] (Figure 1 *a* and *b*). Appreciable amount of REE was also found in pyrochlore associated with magnetite in carbonatite sections (Figure 1 *c*). Anomalous REE concentration was also reported from the titaniferous bauxite capping, developed within the Sung Complex near Lumkynthang village. ∑REE in titaniferous bauxite ranges from 3645.98 to 5099.56 ppm (∑LREE from 3525.85 to 4928.46 ppm and ∑HREE from 120.13 to 171.10 ppm)[1,4].

Sadiq *et al.*[5] reported encouraging REE values in variants of granite of Nongpoh Pluton, Ri-Bhoi district, Meghalaya.

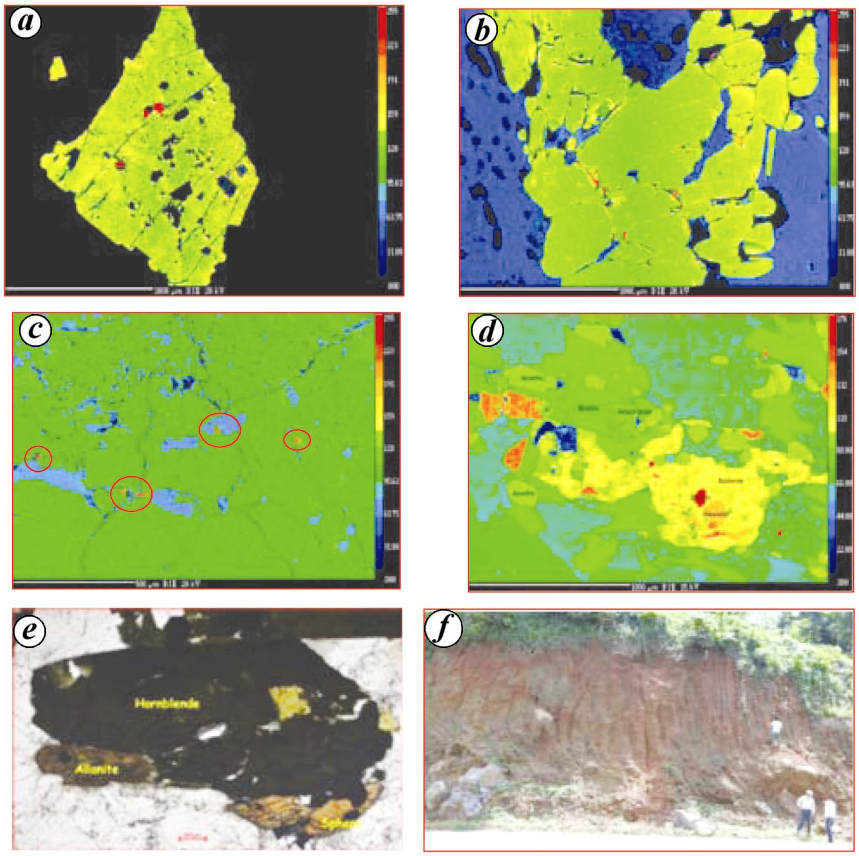

Figure 1. ***a***, FCC-BSE image showing pyrochlore in carbonatite section from Sung Valley Complex, West Jaintia Hills, Meghalaya. ***b***, FCC-BSE image showing ancylite (red colour) (Sr–REE) associated with apatite in carbonatite section from Sung Valley Complex. ***c***, FCC-BSE image showing belovite (circled) associated with calcite and dolomite in carbonatite section from Sung Valley Complex. ***d***, FCC-BSE image showing REE-bearing phases (sphene, zircon and apatite) in granite section from Nongpoh Pluton, Ri-Bhoi, Meghalaya. ***e***, Photomicrograph showing allanite and sphene associated with hornblende, Garikhana, Ri-Bhoi. ***f***, Thick weathered crust developed over Nongpoh Granite, north of Nongpoh, Ri-Bhoi.

Relatively high values of REE were obtained in bed rock and soil samples collected from porphyritic granite and soil developed over it as well as from non-porphyritic granites of Nongpoh pluton. Four samples of bedrock of porphyritic granite contain ∑REE (La–Lu) values that range between 406.07 and 910.59 ppm, with an average value of 707.12 ppm. Soil sample contains ∑REE value of 1089.18 ppm. REE-bearing phases identified in Nongpoh granitoids are the minor mineral phases, viz. parasite, titanite, allanite, apatite and zircon (Figure 1 *d* and *e*). The soil cover/weathered crust developed over the granite shows higher concentration of total REE, which is a possible indication of secondary/ion adsorption-type REE enrichment (Figure 1 *f*). Samples of non-porphyritic granite show almost identical values of ∑REE and range from 720.76 to 721.07 ppm (ref. 5).

The Atomic Mineral Division (AMD) investigated Samchampi alkaline–carbonatite Complex and reported 17,738 metric tonnes of REE from secondary phosphatic rock. However, detailed evaluation by subsurface exploration and techno-feasibility studies on extraction and their utilization is yet to be taken up[6].

Despite reported occurrence of REE in the northeastern region, potential zones of REE are to be searched and delineated. Systematic exploration needs to be carried out to meet the emerging demand.

Recent exploration for REE in Rajasthan has resulted in establishing the potential REE resources. Bhushan and Kumar[7] discovered carbonatite plugs, sills and dykes hosting REE deposits at Kamthai, Barmer district, Rajasthan with the total resource of 4.91 mt estimated up to 84 m depth under proved, probable and possible categories[7].

Bhattacharya *et al.*[8] reported total REE concentration more than 2% in the Dhani Granite around Rani, Pali district, Rajasthan. Dhani granite is highly brecciated and extensively ramified by iron-rich silica veins and indicates iron oxide-type of REE mineralization[8].

China is the dominant producer and consumer of REE and is responsible for over 95% of the world's REE production. In 2010, China announced that it would significantly restrict its rare earth exports to ensure a supply for domestic manufacturing of electronics products for both domestic and export markets[2]. This announcement triggered some panic buying and rare earth prices shot up to record high levels, which has led the other countries to vigorously explore for REE minerals[2,9]. If exploration gears up, many favourable REE deposits can be brought out, since there are several geological provinces in India where REE exploration needs greater attention[1,2,5,10].

NE India is relatively unexplored due to inaccessibility, difficult terrain conditions and thick forest cover. It can be extensively explored for REE mineralization in different favourable geological environments. It is suggested that all carbonatite–alkaline complexes occurring in the northeastern part of the country should be targeted for detailed REE exploration on priority. Uranium anomalies in the Precambrian crystalline terrain of West Garo Hils district, have been identified by GSI as the potential target for iron oxide breccia-type of uranium and associated REE mineralization[10]. Moreover, at Gamak, Kaunala, Maro-Basirijo, New Badak in the Upper Subansiri district, Arunachal Pradesh, uranium mineralization is associated with Fe–Cu–REE and is hosted by the metamorphosed volcano-sedimentary rocks of Siang Group, which need attention for REE exploration[10]. Pre-Cambrian rocks of the northeastern region are profusely intruded by rocks of alkaline affinity, which should be checked for REE. Various granitoid plutons of NE India, namely Kyrdem, Mylliem, South Khasi, Rongjeng, Sindhuli granitoids should be studied from the point of view of REE mineralization. Secondary laterite/bauxite developed in NE India over different types of rocks should be checked for REE enrichment.

Reconnoissance sampling of soil, residual clays and/or weathered crust developed in association of carbonatites and granitoids of NER can be taken up for studying the possibility of ion adsorption-type REE ores. Ion-adsorption ores are known only from China[11] and appreciable area of NER experiences climatic conditions favourable for the development of thick lateritic profile.

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