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Scandium potential of some ixiolite-bearing pegmatites and tin slag of Bastar district, Madhya Pradesh, India

Scandium (Sc) is grouped along with rare earths because of its chemical similarities. It is a strategic element classified as a high-tech material by the US Department of Defence for special consideration in US policy making[1]. Sc is used in high intensity mercury vapour lamps, laser crystals and coatings, high strength carbide, high temperature superconductors, automobile catalysts, radioisotope tracer in refinery cracking and in nuclear reactor as neutron filter. In these applications there is no suitable substitute for Sc. The demand for Sc has grown in recent years due to an increase in laser research[2].

Sc is typically a dispersed element, which is evenly distributed in small quantities among various rocks and minerals. But it is found that minerals richest in Sc (0.001–0.03%) are those usually occurring in granites pegmatites. However bulk of Sc present in the upper lithosphere is concentrated in the ferromagnesian minerals of ultrabasic and basic rocks such as pyroxenite, gabbro, amphibolite, etc. Sc also occurs in the ferromagnesian minerals of silicic rocks[3]. The part of Sc which has not substituted into the rock-forming minerals (pyroxene, amphibole, biotite, etc.) during the main stage of crystallization remains in the residual liquids and becomes enriched in pegmatites and pneumatolytic stages. Sc gets concentrated in minerals like garnet, tourmaline, biotite, muscovite, columbite, xenotime, zircon, wolframite, etc. Important Sc-bearing minerals include thortveitite ($Sc_2Si_2O_7$), sterrettite ($ScPO_4 \cdot 2H_2O$), kolbectite (Sc, Be, Ca) (SiO_4, PO_4) and bazzite (scandium beryl). Thortveitite has been reported from pegmatites of Southern Norway and Madagascar. Sterrettite is reported from phosphate deposits of Utah, USA. Scandian ixiolite has also been reported from pegmatites of Madagascar. All these minerals are extremely rare. Economic concentration of Sc (< 0.01 to 0.03%) is found in pegmatitic minerals and greisens which also, in fact, rarely occurs, the most abundant of them are tantaloniobates of rare earths, wolframite, cassiterite, beryls and zircons. However the Sc_2O_3 content of even these minerals reaches tenths of a per cent extremely rarely[4].

Sc, in different parts of the world, is occasionally recovered as a byproduct from wolframite, tin, zinc, phosphate, zircon, tantalum wastes, phosphoric acid, clays, bauxite, etc. In these materials Sc, if present, is concentrated in trace amounts (< 100 ppm) only[5]. However, the US Bureau of Mines has identified a significant new source of Sc in an Oklohoma tantalum–niobium waste residue (0.24% Sc)[6]. In India, the possibility of recovering Sc from hafnium raffinates (Sc 30 ppm) was demonstrated[7].

The prices of Sc and its compounds are high, e.g. Sc metal prices for 1999: for powder metal, $270 per gram, sublimed metal, $175 per gram; scandium bromide 99.99% purity; $91.80 per gram; scandium chloride 99.9% purity, $39.6 per gram; scandium iodide 99.999% purity, $151 per gram and scandium fluoride 99.9% purity, $80.1 per gram. Scandium oxide with 99.999% purity, $4000 per kilogram; scandium oxide 99.99% purity, $2100 per kilogram; scandium oxide 99.9% purity, $1400 per kilogram, and scandium oxide 99% purity, $900 per kilogram[8].

In view of the scarcity, and its high-tech applications, there is a need for locating resources of this rare metal. As indicated earlier, Sc is sometimes found to be associated with minerals of niobium–tantalum and tin. While studying various niobium–tantalum minerals from pegmatites around Metapal,

Table 1. Analysis* of scandium, niobium–tantalum and tin from Nb–Ta minerals and tin slag from Bastar district, Madhya Pradesh in (wt% or ppm)

Mineral	Location	Sample no.	Nb_2O_5%	Ta_2O_5%	SnO_2%	Sc_2O_3	Published value of Sc_2O_3
Ixiolite	Metapal	ROA-9	58.9	13.6	< 0.5	0.48%	Over 10 % in a rare
		ROA-16	59.4	11.6	< 0.5	0.327%	scandian ixiolite, but
		MTP/AUG/95/2	58.5	14.2	0.3	0.52%	normally below
		MTP/CT/5	37.3	33.1	3.2	0.327%	0.01% (refs 13, 14)
		MTP/CT/6	42.2	30	2.52	0.371%	
		MTP/93/7	57.8	14.1	0.4	0.528%	
Columbite	Bodenar	BDR/97/19S6	40.8	39.2	0.35	0.01%	0–6% but normally below
		BDR/97/C-7	62	14	<0.10	0.00%	0.01% (refs 4, 17)
Wodginite	Challanpara	ROA-47	5.2	64.8	9	9.2 ppm	
		ROA-48	2	67.8	9.9	8.3 ppm	
		ROA-49	4	69.6	10.1	4.9 ppm	
		ROA-50	3.6	67.2	8.9	5.0 ppm	
Tin slag	**MPSMC, Ltd	AMD/MP/TS/7	5.9	17.6	12	92 ppm	30–168 ppm (ref. 5)
	Raipur	AMD/MP/TS/8	4.6	14.3	15.1	49 ppm	
		AMD/MP/TS/9	5.5	16.2	13.5	92 ppm	
		AMD/MP/TS/10	4.9	14.3	22.7	86 ppm	

*ICP-AES, Chemical Laboratory, Hyderabad; **Madhya Pradesh State Mining Corporation Limited, Raipur.

Bodenar and Challanpara areas of Bastar district, Madhya Pradesh, it was observed that ixiolite from Metapal showed remarkable concentration of Sc (Table 1). However, other minerals such as columbite, wodginite and those from Bodenar and Challanpara indicated poor Sc concentration, but muscovite from these localities showed high Sc concentration (Table 2), indicating a possibility of Sc mineralization. Tin slag from the Tin Demonstration Plant of Madhya Pradesh State Mining Corporation (MPSMC) Limited, Raipur, analysed significant Sc apparently inherited from niobium–tantalum minerals in cassiterite concentrate. The cassiterite concentrate being smelted in this smelter comes from different areas of Bastar Pegmatite Belt extending over a length of 80 km striking northwest-southeast. Part of this belt falls in Malkangiri distrist of Orissa. The most important areas of cassiterite production are Tongpal, Katekalyan and Bacheli sectors in Madhya Pradesh and Mundaguda area in Orissa. The occurrence of pegmatites over a large area has opened a scope for Sc investigation.

Table 2. Scandium analysis of muscovite, beryl and granite from Bodenar–Challanpara area of Bastar district Madhya Pradesh

Mineral	Location	Sample no.	Sc_2O_3	Published value of Sc_2O_3
Muscovite	Bodenar	BDR/A126/M	0.0254%	0–0.02%, usually
		BDR/A70/M	0.0061%	below 0.005% (ref. 18)
		BDR/A51/M	0.0085%	
		BDR/A124/M	0.0096%	
		BDR/A123/M	0.00561%	
		BDR/A29/M	0.0078%	
	Challanpara	CHP/5M	< 0.001%	
Beryl	Bodenar	BDR/A27/B	1.5 ppm	0–1.5%, usually below
		BDR/A124/B	4.6 ppm	0.1% (refs 4 and 19)
Granite	Bodenar	BDR/GR/5	2.9 ppm	1.53–21.4 ppm (ref. 20)
		BDR/A9/G	3.7 ppm	
		BDR/A11/G	1.7 ppm	
		BDR/A22/G	10.7 ppm	
		BDR/A62/G	1.8 ppm	
		BDR/A99/G	2.0 ppm	

Analysis by ICP-AES, Chemical Lab, AMD, Hyderabad.

The pegmatites in this area are both zoned and un-zoned types and have intruded at the contact of granite and basic dykes (Figure 1). These intrusive rocks are emplaced into rocks of Bengpal Group of Lower Proterozoic age, i.e. andalusite–sericite–biotite schist, gneisses, sericite quartzite and iron formation[9]. The major minerals of the pegmatites are quartz, albite, microcline, perthite and muscovite. The rare metal and rare earth minerals in these pegmatites include beryl, columbite–tantalite, ixiolite, wodginite, microlite, fersmite, euxenite, aeschynite and monazite[10–12].

During the course of investigation and evaluation for rare metal and rare earths in the pegmatitic belt of Bastar district, Madhya Pradesh, various minerals were analysed chemically for the concentration levels of beryllium (in beryl with 10–12.8% BeO), niobium–tantalum (in columbite–tantalite), tin (in cassiterite with 85–95% SnO_2), rare earths (in monazite with 42% LREE, 2.5% HREE and 1.7% Y_2O_3 and euxenite with 6% REE and 5.4% Y_2O_3), scandium (in niobium–tantalum minerals, beryl and tin slag); also certain common minerals such as muscovite were analysed for elemental concentration of Nb, Ta, Sn, Sc and Rb, etc. as a geo-chemical guide. In granite except for one sample (10.7 ppm Sc_2O_3), others have not shown significant Sc content. However, granites may not show high concentration of Sc, as it is normally concentrated in ferromagnesian miner-

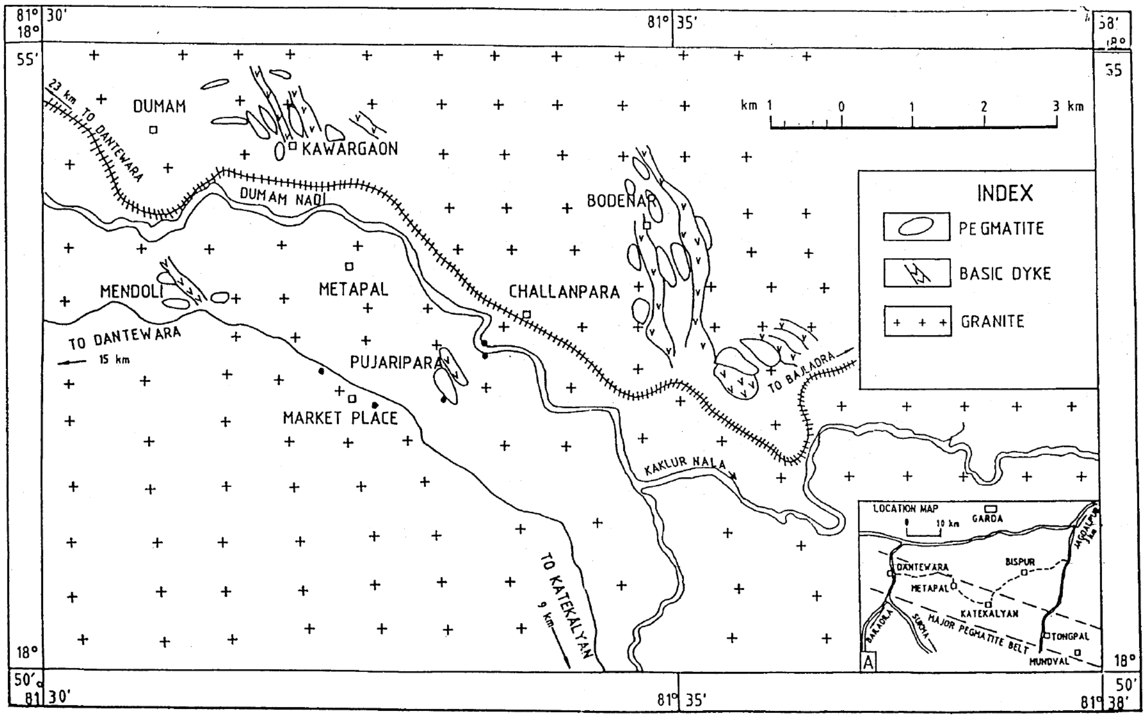

Figure 1. Geological map of Metapal–Bodenar–Challanpara area, Bastar district, Madhya Pradesh, India.

als. Whereas in the pegmatitic stage the residual melt enriched in Sc and other rare metals are responsible for the minerals of these elements. These elements are enriched in residual melt as they are not accommodated by early formed minerals.

Details of few observations made on different minerals from the study area are presented below.

Ixiolite is a columbite substructure and has so far been reported only from pegmatites of Bastar district, Madhya Pradesh in India. The chemical analysis of various samples of ixiolite indicates a wide variation with respect to Nb, Ta, Sn and Sc. The Nb_2O_5 varies from 37 to 59%, Ta_2O_5 varies from 11 to 33% and SnO_2 varies from <0.5 to 3.2%. The samples analysed Sc_2O_3 0.327–0.528%. From the economic point of view, the niobium–tantalum minerals such as ixiolite and columbite–tantalite are subjected to metallurgy using techniques such as solvent extraction, for the extraction of niobium and tantalum. The higher concentration of Sc in ixiolite from Metapal suggests a possibility of extraction of Sc as a byproduct of niobium–tantalum metallurgy. Sc content in ixiolite is generally below 0.01%. A rare scandian ixiolite (10% Sc_2O_3) has been described from pegmatites of Mozambique and Madagascar[13,14].

Muscovite, with its sheet structure, shows a remarkable trace elemental signature with respect to Nb, Ta, Sn, Sc, etc. if they are present in the system. The trace element concentration in muscovite of pegmatite is a very useful guide in the exploration of rare metals. Muscovite from the study area analysed Nb (96–200 ppm), Ta (10–66 ppm) and Sn (36–1062 ppm). These trace elements are high compared to normal abundance of the order of less than 10 ppm. Ten samples from pegmatites of the study area analysed Sc_2O_3 < 0.001–0.0254%. Muscovite usually contains < 0.005% Sc_2O_3, only in exceptional cases it reaches 0.2% Sc_2O_3 (ref. 15). However, there is no reference of Sc recovery from muscovite, but it has a geo-chemical significance, giving a clue to the Sc mineralization in the host rock.

Other minerals such as beryl, wodginite and columbite have shown very little concentration of Sc though it can take place in these minerals; for example a variety of beryl, known as bazzite is known to contain 3–10% Sc_2O_3 and columbite from Madagaskar analysed 6% Sc_2O_3 (ref. 4). In the study area, Sc seems to be concentrated only in ixiolite. There is also a possibility of finding true minerals of Sc such as thortveitite.

The cassiterite concentrate from pegmatites of Bastar distrist is subjected to carbothermic reduction at Tin Demonstration Plant, Raipur which was owned by MPSMC Ltd (at the time of sampling it was owned by MPSMC Ltd, now the plant has been sold to a private firm, Dravya Industrial Chemicals Ltd). A systematic sampling of tin slag, being generated after recovery of tin metal, has been carried out. Tin slag has been found to be a potential source of tantalum and niobium. A further study revealed about significant Sc content. The samples have analysed 49 to 92 (Table 1) ppm Sc_2O_3 together with approximately 15% Ta_2O_5 and 5% Nb_2O_5 on an average.

The south-east Asian countries such as Thailand and Malaysia are the chief producers of cassiterite and tin metal. The tin slag produced by their smelters and other countries such as Australia, South Africa, Zaire, etc. analyses 0.1–12% Ta_2O_5, 0.2–12% Nb_2O_5 and 30–168 ppm Sc_2O_3 (refs 5 and 16). Tin slag is responsible for more than one-third of the world tantalum production. During the year 1999, out of 4.1 million lb world tantalum production, about 1.7 million lb was recovered from tin slag and the remaining 2.4 million lb was recovered from tantalite concentrate[17]. The tin slag recovered after smelting of cassiterite concentrate from Bastar district, Madhya Pradesh and adjoining Orissa is in fact a key material for tantalum and niobium together with Sc[15]. This is particularly important as conventional resources of niobium–tantalum, mainly columbite–tantalite, are little.

The present finding of high content of Sc in various minerals of pegmatites of Metapal, Bodenar and Challanpara areas and in tin slag of Bastar district, Madhya Pradesh signifies a probable Sc province. More efforts are required to identify additional areas of Sc in other sectors of the Bastar Pegmatite Belt. Possibility of finding true minerals of Sc also exists. Considering the strategic application of this metal and extremely rare occurrence, a great potential exists to recover the metal as a by product of niobium–tantalum extraction from their ores. Tin slag may prove important as it is also a source of tantalum and niobium.

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