present tectonic set up of the region. Hence, further modification in folding and faulting may be anticipated under continued compressional tectonism in this region.

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Thorium-rich monazites from the beach sands of Kalingapatnam–Baruva Coast, Andhra Pradesh, East Coast of India

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Of the five microprobe analyses of monazites, one shows a very high concentration of ThO_2 (30.81%) and relatively high Ca and low LREE (Ce, Nd, La, Pr, Sm) indicating that it is a cheralite variety of monazite. The other four monazites also show high concentration of ThO_2 ranging from 12.30 to 15.89. Charnockites and pegmatites occurring in the drainage basin of the hinterland are the source rocks for the monazites. The monazites have an obvious bearing on the economic potential of these sands in exploring them along with the other associated heavy minerals like ilmenite, garnet, sillimanite and zircon.

THE east coast beaches of India are known for the occurrence of heavy minerals like monazite, zircon, rutile, ilmenite, magnetite, garnet and sillimanite. The monazite is a principal economic source of rare earths and thorium. The occurrence of monazite in the beach sands of Visakhapatnam[1,2], Visakhapatnam–Bhimunipatnam[3], Kalingapatnam-Baruva[4,5] and in the deltas of Andhra Pradesh[6] along the east coast has been reported. The earlier studies were oriented towards the quantification of individual heavy minerals in the beach sands including the monazites. However, a few attempts were made to know the chemical composition of the monazites from the beach sands along the east coast of India. The occurrence of cheralite, a thorium-rich variety of monazite in the beach sands of Visakhapatnam–Bhimunipatnam area has been reported[7]. This paper presents the geochemistry of the monazites from the beach sands between Kalingapatnam and Baruva (Figure 1), based on the microprobe analysis.

The beaches between Vamsadhara and Mahendratanaya rivers are enriched in heavy minerals like ilmenite, garnet, sillimanite, orthopyroxenes, monazite, zircon, rutile, etc. and the concentration of heavies ranges from 11 to 53 (wt%) in dunes, 4 to 33 in backshore, 2 to 48 in upper foreshore and 2 to 33 in lower foreshore. The heavy minerals are concentrated more in the finer fractions (–0.25 to +0.125 and –0.125 to 0.062 mm) than in the coarser fraction (> 0.25 mm) and also the concentration of heavy minerals is high nearer to the mouths of streams and small creeks[5].

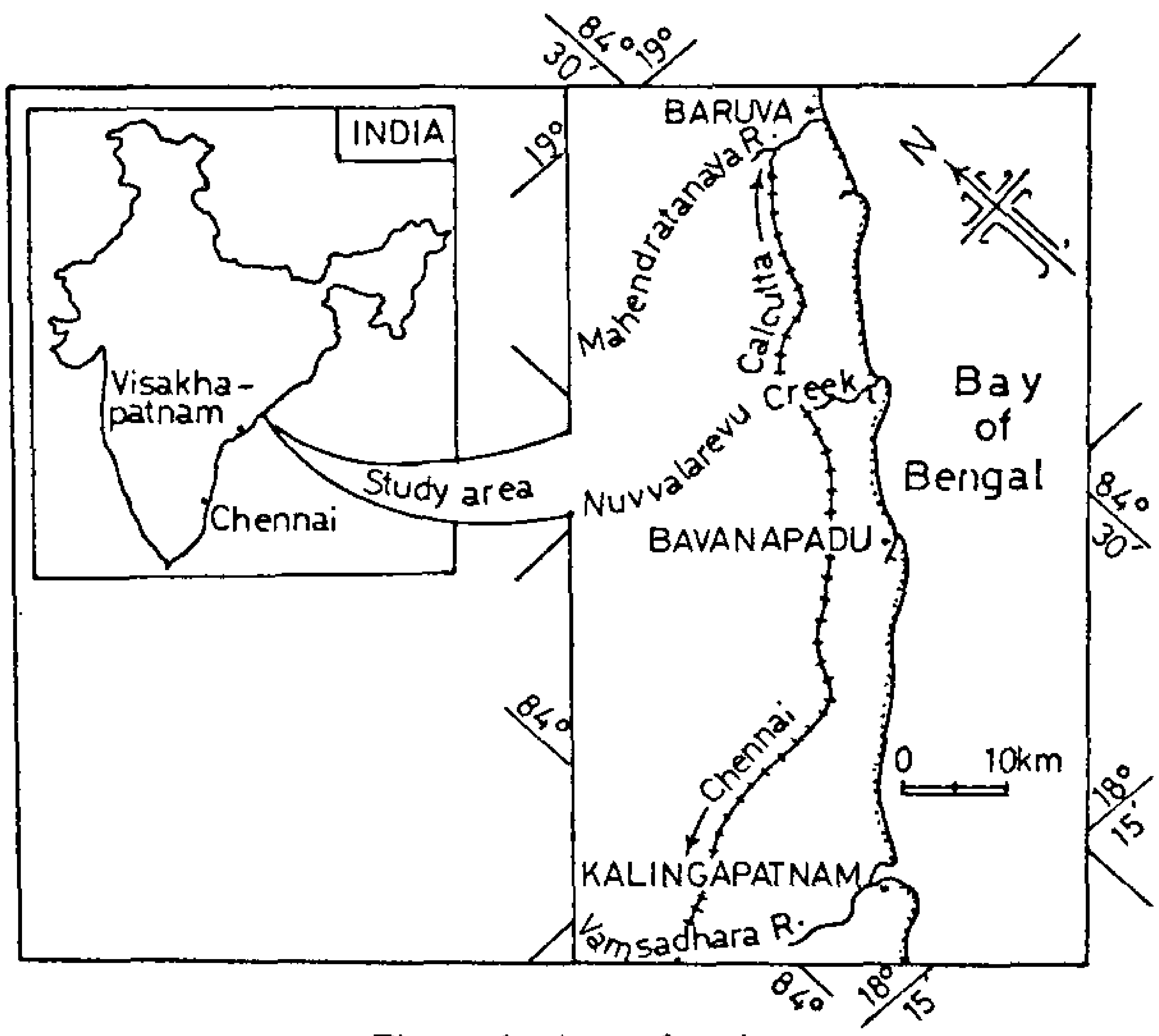

Figure 1. Area of study.

Table 1. Microprobe analyses of monazites

	From area of study					From other areas			
	Sample								
Composition	I	II	III	IV	V	1*	2*	3*	4*
La_2O_3	5.69	11.67	11.51	12.31	11.99	15.3	18.84	9.68	14.38
Ce_2O_3	19.39	30.48	30.76	31.71	30.91	21.26	42.30	19.43	27.18
Pr_2O_3	2.66	4.01	4.14	4.17	4.11	–	–	3.02	3.79
Nd_2O_3	8.54	9.80	10.19	10.29	10.65	–	–	5.56	10.23
Sm_2O_3	1.20	–	–	–	–	–	–	4.31	3.22
ThO_2	30.81	15.56	14.67	12.30	15.89	23.99	9.32	19.82	9.76
P_2O_5	25.04	24.63	27.03	27.44	25.49	26.75	–	28.47	24.49
CaO	3.14	0.71	1.44	1.28	0.65	4.01	–	1.35	0.37
PbO	0.87	0.58	–	–	–	0.51	–	–	–
SiO_2	2.50	2.27	0.95	0.88	1.99	2.65	–	1.22	2.73
Y_2O_3	–	–	–	–	–	–	0.66	2.10	1.19
U_3O_8	–	–	–	–	–	3.08	–	–	–
Total	99.8	99.71	100.69	100.38	101.68	97.55	71.12	95	97.34

1*, Monazite from Visakhapatnam–Bhimunipatnam beach sands[7].
2*, From Visakhapatnam beach sands[12].
3* and 4*, From charnockites of Eastern Ghats[10].

Table 2. Elemental percentage

	Sample				
Element	I	II	III	IV	V
La	4.85	9.95	9.82	10.50	10.23
Ce	16.55	26.03	26.21	27.07	26.39
Pr	2.28	3.43	3.54	3.56	3.52
Nd	7.32	8.34	8.74	8.83	9.13
Sm	1.04	–	–	–	–
Th	27.08	13.68	12.89	10.81	13.96
Ca	2.25	0.51	1.03	0.91	0.47
P	10.93	10.75	11.80	11.98	11.12
Si	1.17	1.06	0.45	0.41	0.92
Total	72.3	72.69	74.03	73.66	74.82
ΣLREE	32.04	47.75	48.31	49.96	49.27
Nd/Ce	0.44	0.32	0.33	0.32	0.35
La/Ce	0.29	0.38	0.37	0.39	0.39

The heavy minerals were separated from the light minerals using bromoform. Monazites were separated from the heavy mineral fraction under microscope. The microprobe analyses were carried out at Dalhousie University, Canada, on a JEOL 733 electron microprobe equipped with four wavelength dispersive spectrometers and an Oxford Link eXL energy dispersive system. The energy dispersive system was used for all elements. Resolution of the energy dispersive detector was 137 eV at 5.9 keV. Each spectrum was acquired for 40 seconds with an accelerating voltage of 15 kV and a beam current of 15 nA. Probe spot size was approximately 1 micron. The raw data was corrected using Link's ZAF matrix correlation program.

Monazite is a light yellow or yellowish-brown coloured mineral and in general contains 4 to 12 per cent of ThO_2. Cheralite is a variety of monazite which contains around 30% ThO_2 (ref. 8). The replacement of La by Th and Ce by Ca makes the monazite a cheralite variety[9]. It is evident from the data that the monazites from the study area are enriched in ThO_2 ranging from 12.29 to 30.81% (Table 1). The samples II to V differ significantly in their chemical composition from Sample I. Sample I shows the concentration of ThO_2 as high as 31% while in others it varies from 12 to 16%. The chemical composition of sample I compares well with the cheralite reported by Rao and Prakasa Rao[7] and Kamineni *et al.*[10], where the cheralite shows high Th and Ca and low LREE (La, Ce, Pr, Nd, Sm). Sample I differs from the other monazites (samples II to V) in having lower La, Ce, Pr and Nd and higher Th and Ca (Table 2). The Nd/Ce ratio is higher in the cheralite than in other monazites (samples II to V). The Nd/Ce ratios for samples II to V are comparable with the average ratios reported earlier for monazites from eastern Minas Gerias, Brazil[11]. La/Ce ratio is lesser in the cheralite than in the other four monazites, Further, the Nd content is more in the cheralite than in the others and the order of abundance of LREE is Ce > Nd > La > Pr > Sm in cheralite and Ce > La > Nd > Pr in the other four monazites. Though the samples II to V contain lower Th compared to sample I, Th content in them is much higher than the Th content in the monazite reported from Visakhapatnam beach sands[12].

The Eastern Ghat suite of rocks comprise various rock types such as charnockites, khondalites, leptynites and granites. Pegmatitic veins cut across the charnockites and khondalites. Monazite is reported from the charnockites[11,13], pegmatitic veins[14] and from carbonatites[12] of the Eastern Ghats. The charnockites show a high radioactivity (2.5 ± 0.05 β/c/g/min) than the khondalites (0.5 ± 0.05 β/c/g/min) due to the presence of monazite as an accessory mineral[7]. Thorium strongly concentrates in acidic igneous rocks[15] and its content in them is around 13 g/ton[16]. The concentration of thorium continues during pegmatitic stage even after the close of the main stage of crystallization[15]. Hence it is concluded that the monazites are derived from charnockites and pegmatites which occur in the drainage basin of the hinterland.

The concentration of monazite in considerable proportions and its high thorium content calls for an evaluation of the commercial potential for exploitation along with other associated minerals like ilmenite, garnet, sillimanite and zircon from this area, keeping in view among other uses, also the requirement of thorium in fast breeder reactors.

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Erratum

Observed and theoretical acceleration response spectra in the Tehri region: Implications for the seismic hazard in the region

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Due to an inadvertent oversight, Table 1 showing the velocity and Q model is in error. The correct model is given below.

Table 1. Velocity and Q model

Thickness (km)	V_P (km/s)	Q_P	V_S (km/s)	Q_S	Density (g/cc)
0.05	0.9	10	0.5	5	1.8
0.5	1.75	30	1.0	15	1.8
2.0	4.0	100	2.8	50	2.4
14.0	5.2	4000	2.97	2000	2.6
30.0	6.0	4000	3.43	2000	2.9
Infinity	8.33	1000	4.83	500	3.3