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Garnet mineral chemistry as a provenance indicator for the modern beach sediments of north-eastern Andhra Pradesh, east coast of India

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The provenance of garnets from coastal sediments between the Nagavali and Vamsadhara river mouths, east coast of India were studied using garnet molecular proportions. This mineral chemical electron micro probe analytical data have been correlated with published garnet chemistry from various litho units of the eastern ghats granulite belt to understand provenance. The present study reveals that the garnets with molecular proportions of almandine (Alm. 50-56%), pyrope (Py. 33-43%) and traces of grossular (Gr. <5%) were derived from khondalite suite of rocks (khondalites, leptynites and quartzo-feldspathic gneisses) and migmatites. The garnets with molecular proportions of almandine (Alm. 59-63%), pyrope (Py.<30 %) and considerable proportion of grossular (Gr.>5%) were derived from charnockite suite of rocks. The major portion (83%) of the studied garnets is derived from khondalite (metapelitic) suite of rocks susceptible for physical weathering due to large areal exposure and minor proportion (17%) is derived from charnockite suite of rocks which due to less coverage in drainage basis is not susceptible for mechanical weathering.

[Keywords: Major elements; Garnets; Almandine; Nagavali; Vamsadhara Rivers; EPMA]

Introduction

The geochemical studies are mainly related to major, minor, trace and rare earth elements concentration and distribution in different materials of earth. These studies are useful to know the provenance, stratigraphic correlation, age determination, and mineral beneficiation. Garnet is a useful mineral in provenance studies because of its wide range of major element compositions, defining the crystallization and metamorphic conditions and its stability during transportation and diagenesis[1, 2]. In the present study, we made an attempt to know provenance of the garnets. A total of 46 garnet grains from coastal sands between Nagavali and Vamsadhara river mouths were used for mineral chemical analysis by electron probe micro analyzer (EPMA). For the last few decades, the chemistry of heavy minerals has been widely used to indentify, discriminate and characterize the sediment provenance. Many researchers[3,7] made an attempt to determine the provenance of sediments based on garnet chemistry. Geochemistry of garnets from various litho units of Central Eastern Ghat Granulite Belt (EGGB)[8,12] was studied.

Study area and regional geology

The coastal stretch extending for 33 km between Nagavali and Vamsadhara river mouths of Srikakulam district, Andhra Pradesh, east coast of India, was selected as the sample locations for provenance studies (Fig. 1). The present investigated coastal region is a part of sedimentary basin adjacent to Central Eastern Ghats Granulite Belt (EGGB). The major lithologies are: (a) Khondalite suite of rocks derived as metamorphic products of pelitic sediments; (b) Charnockite suite of rocks formed by different processes, i.e. massive type-fraction crystallization of basaltic melt, coarse grained assimilation and fractional crystallization of tholeitic magma, porphyritic-melts of tonalite-trondhjemite-granodiorite, and melts of metapelitic rocks; and (c) Basic granulites derived from tholeitic magma[12].

Drainage

The ephemeral rivers like Nagavali and Vamsadhara that originate in high hills of the Eastern Ghats, few hundred kilometers away from the coast, are t00he major sources of supply of terrigenous sediments to the coastal plains these rivers swell only in monsoon season generally from June to November. Small creeks viz. Ippili Gedda, Pedda Vatsavalasa and Bhairi Kaluva contribute sediments to the study area in between Nagavali and Vamsadhara rivers. The Mahanadi River in the further north and the Godavari and Krishna rivers in

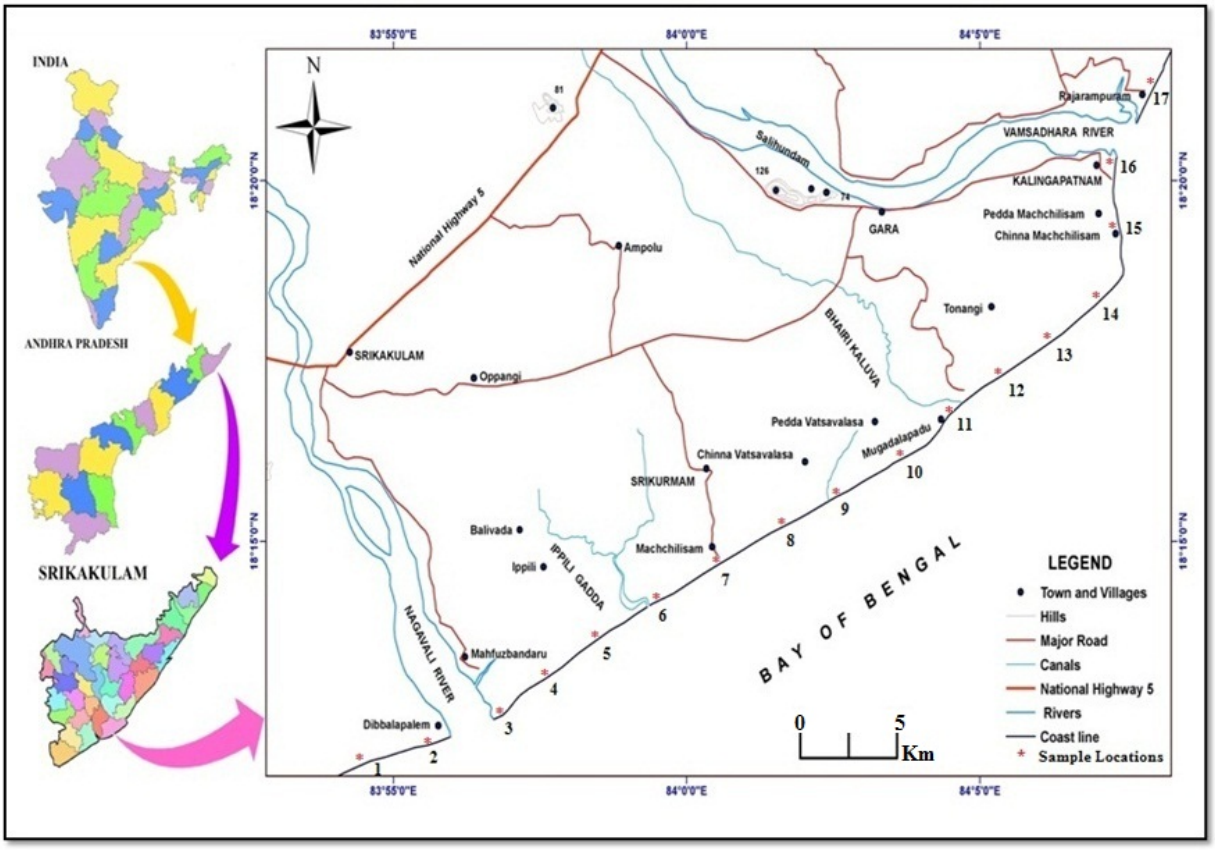

Fig. 1 — Map of the study area and sample locations

the further south of the study area the major rivers that join into the Bay of Bengal.

Materials and Methods

Sampling collection

A total of 39 surficial sediment samples from coastal sands were collected along 17 traverses perpendicular to the coast with two kilometer interval between successive traverses in the study area. The sample locations are given in Figure 1. At each location, sediment sample was collected using a PVC pipe of 3 inch diameter and 30 cm length, penetrated into the sediment layers up to a depth of 10 cm. The sediment samples were reduced by coning and quartering method and representative proportion was collected for sediment treatment to separate heavy minerals. In each sample, garnet grains were identified under binocular petrological microscope based on their optical properties and a total of 46 garnet grains were picked for mineral chemical analysis.

Sample preparation

Selected individual garnet mineral grains in each sample were mounted onto standard size glass slide with epoxy resin for further lapping and polishing and grinding to ensure that the top and base of the resin blocks are parallel. Lapping was carried out to produce a smooth surface by using fine (600 grade) abrasive usually silicon carbide. Samples were polished with fine SiC paper and slurry of very fine alumina ranging in size from 6 to 0.30 microns. The polished samples were then washed with clean water in an ultrasonic cleaner to remove the polishing grit and other surface dirt. The sample is then dried in air and cleaned with blow duster. Samples were carbon coated to get better electron interaction and conductivity.

Analytical technique

The mineral grains were analyzed using a CAMECA SX-100 Electron Probe Micro Analyzer (EPMA) housed at the Geological Survey of India (GSI), Hyderabad. Polished surface of 46 garnet grains were exited by an electron beam with an accelerating voltage of 15 kV and beam current of 20 nA. The beam radius was kept at ~1 µm. For calibration, natural mineral standards were used for most of the elements (Orthoclase for Si and K;

Corundum-Al; Wollastonite-Ca; Hematite-Fe; Chromite-Cr; Albite-Na, Al; Diopside-Mg, Ca; Rhodonite-Mn; TiO_2-Ti; and Almandine-Fe).

Results and Discussion

Optical properties of garnets

Garnet grains are colourless, pale pink and pink in colour under polarized light and are isotropic under crossed nicols. The garnet grains are rounded (Plate 1 a-d), subhedral (Plate 1e-h), anhedral (Plate 1 i-l), angular (Plate 1 m-p) and elongated (Plate 1 q-t) in shape with conchoidal fracture. Some grains have etching spots, peaked edges, pits and inclusions of opaque minerals.

Mineral chemistry of garnets from coastal sands

The mineral chemical data of garnets of the study area is given in Table 1. In the study area, a majority

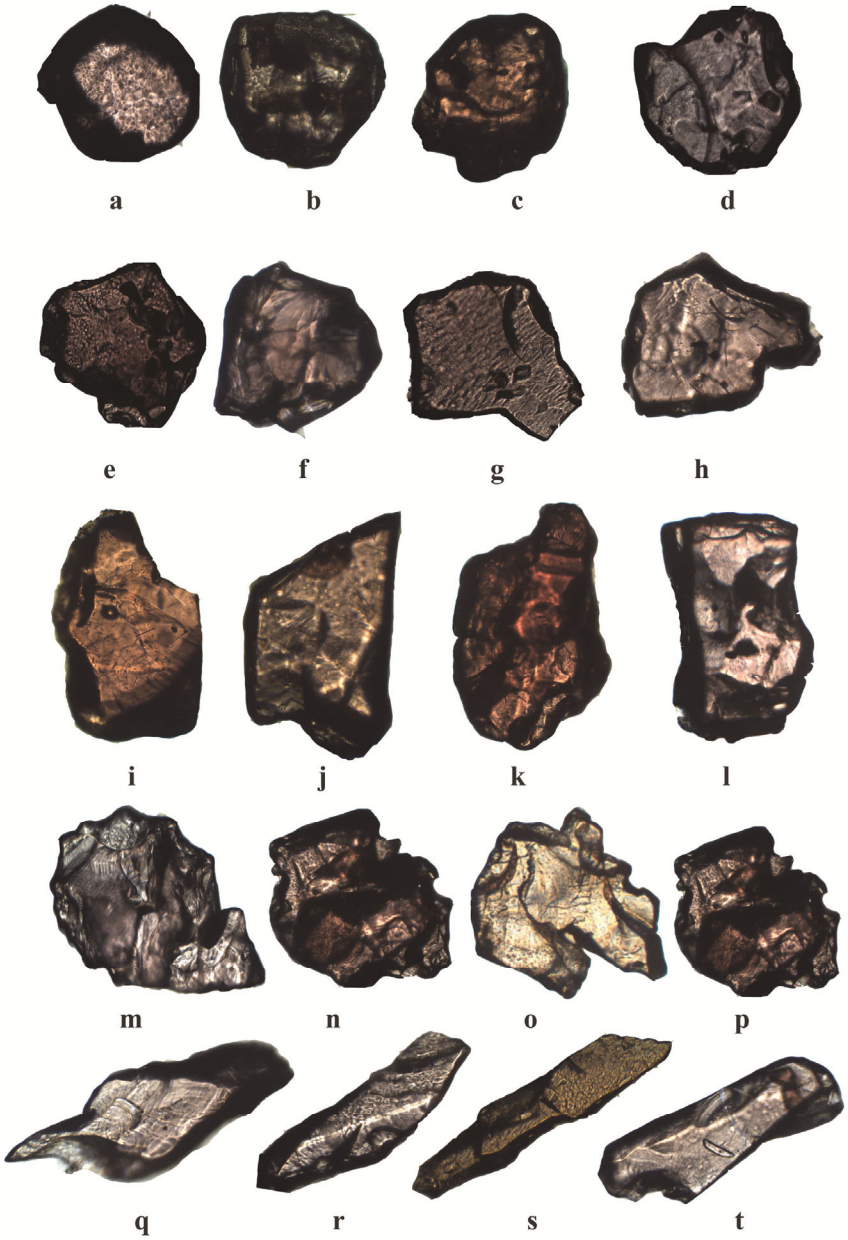

Plate 1 — Garnet grains i.e. rounded (a-d), subhedral (e-h), anhedral (i-l), angular (m-p) and elongated (q-t) from the coastal sediments between Nagavali and Vamsadhara River mouths, east coast of India.

Table 1 — Chemical composition of garnets from coastal sediments between Nagavali and Vamsadhara River mouths, east coast of India.

Traverse No.	1				2				3						4			5			8			
Grain No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
SiO_2	37.20	37.46	37.26	37.19	37.32	37.35	37.32	37.72	37.69	37.60	37.95	37.83	37.06	36.73	36.83	37.85	37.16	37.78	37.19	37.46	36.35	37.36	36.63	37.59
TiO_2	0.00	0.04	0.00	0.07	0.05	0.01	0.04	0.05	0.00	0.00	0.05	0.02	0.09	0.04	0.05	0.01	0.01	0.00	0.02	0.08	0.08	0.00	0.07	0.02
Al_2O_3	20.64	20.29	20.76	20.70	20.76	20.81	21.05	20.92	20.90	21.24	21.36	21.02	20.66	20.72	20.48	21.00	21.10	21.18	21.39	20.83	20.11	21.10	20.58	21.33
FeO	33.54	29.83	30.65	30.83	32.80	32.70	31.70	27.10	29.60	32.77	29.15	30.94	33.86	33.77	33.41	31.83	34.45	31.22	30.93	32.19	31.22	34.02	33.17	30.39
MnO	0.71	1.04	0.93	0.97	1.03	1.14	0.76	1.38	0.69	0.54	0.40	0.32	1.01	0.88	1.11	1.22	0.63	0.63	0.86	0.96	1.25	0.91	1.04	2.27
MgO	3.56	4.08	6.56	6.61	5.73	5.68	7.20	9.47	7.85	7.95	8.96	8.16	5.74	4.65	5.76	7.32	5.67	7.75	4.96	7.18	5.63	6.78	3.48	7.31
CaO	4.72	6.69	2.80	2.95	1.63	1.57	1.78	1.88	2.66	0.59	1.46	1.50	2.11	3.02	1.76	1.36	1.91	1.86	4.87	1.37	4.31	0.54	5.51	2.06
Na_2O	0.06	0.01	0.02	0.02	0.01	0.03	0.04	0.02	0.03	0.02	0.02	0.02	0.05	0.05	0.04	0.01	0.00	0.04	0.04	0.02	0.00	0.00	0.03	0.02
K2O	0.01	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.03
Cr_2O_3	0.00	0.11	0.06	0.04	0.02	0.05	0.05	0.06	0.04	0.02	0.05	0.03	0.01	0.02	0.09	0.03	0.02	0.01	0.01	0.02	0.10	0.00	0.04	0.02
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Structural formula normalized to 12 oxygens																								
Si	2.97	2.99	2.96	2.95	2.98	2.98	2.94	2.96	2.96	2.94	2.96	2.96	2.94	2.94	2.95	2.96	2.93	2.95	2.94	2.95	2.92	2.94	2.93	2.93
Al iv	0.03	0.01	0.04	0.05	0.02	0.02	0.06	0.04	0.04	0.06	0.04	0.04	0.06	0.06	0.05	0.04	0.07	0.05	0.06	0.05	0.08	0.06	0.07	0.07
Al vi	1.92	1.90	1.91	1.89	1.94	1.94	1.90	1.90	1.90	1.90	1.93	1.91	1.87	1.90	1.89	1.90	1.90	1.90	1.94	1.89	1.83	1.90	1.87	1.90
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Fe^{3+}	0.07	0.08	0.07	0.09	0.05	0.05	0.08	0.09	0.09	0.09	0.06	0.08	0.11	0.08	0.09	0.08	0.09	0.08	0.05	0.09	0.14	0.08	0.11	0.09
Fe^{2+}	2.16	1.91	1.96	1.96	2.14	2.14	2.01	1.69	1.86	2.05	1.84	1.94	2.14	2.18	2.14	2.00	2.19	1.95	1.99	2.03	1.95	2.15	2.11	1.89
Mn	0.05	0.07	0.06	0.06	0.07	0.08	0.05	0.09	0.05	0.04	0.03	0.02	0.07	0.06	0.07	0.08	0.04	0.04	0.06	0.06	0.09	0.06	0.07	0.15
Mg	0.42	0.48	0.78	0.78	0.68	0.68	0.85	1.11	0.92	0.93	1.04	0.95	0.68	0.55	0.69	0.85	0.67	0.90	0.58	0.84	0.67	0.80	0.41	0.85
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.40	0.57	0.24	0.25	0.14	0.13	0.15	0.16	0.22	0.05	0.12	0.13	0.18	0.26	0.15	0.11	0.16	0.16	0.41	0.12	0.37	0.05	0.47	0.17
Total	8.02	8.02	8.03	8.04	8.02	8.02	8.04	8.04	8.04	8.05	8.03	8.03	8.05	8.04	8.04	8.04	8.05	8.04	8.04	8.04	8.07	8.05	8.05	8.05
End member composition																								
Almandine	70.52	62.28	63.60	62.83	70.09	70.24	64.42	54.14	59.84	65.58	59.77	62.89	68.51	70.31	69.05	64.59	70.31	62.73	64.16	65.37	61.28	69.34	67.31	60.04
Andradite	3.76	4.14	3.74	4.58	2.70	2.36	4.17	4.35	4.34	1.61	2.90	4.07	5.41	4.18	4.76	3.75	4.35	4.31	2.71	3.86	7.25	1.56	5.43	4.58
Grossular	9.82	14.65	4.12	3.80	1.91	2.00	0.78	0.79	3.11	0.00	1.07	0.10	0.63	4.58	0.08	0.00	1.12	0.92	11.27	0.00	5.13	0.00	10.55	1.23
Pyrope	14.27	16.23	26.25	26.48	22.90	22.67	28.76	37.42	31.05	31.52	35.20	32.14	23.08	18.86	23.29	28.82	22.74	30.60	19.87	28.56	23.11	27.05	14.17	28.97
Spessartine	1.61	2.36	2.11	2.20	2.34	2.58	1.73	3.10	1.55	1.22	0.90	0.72	2.31	2.02	2.54	2.73	1.44	1.41	1.95	2.17	2.92	2.05	2.40	5.12
Uvarovite	0.01	0.34	0.18	0.11	0.05	0.15	0.15	0.19	0.11	0.07	0.16	0.09	0.04	0.05	0.27	0.11	0.05	0.04	0.04	0.05	0.33	0.00	0.14	0.06
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

(*Contd.*)

Table 1 Continued....

Traverse No.	11		14				15						16				17					
Grain No.	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
SiO_2	37.74	37.55	37.81	37.69	35.95	39.84	36.92	38.84	37.58	36.85	37.17	37.34	37.01	37.19	36.48	37.08	35.78	36.08	37.87	36.95	37.00	36.88
TiO_2	0.09	0.03	0.03	0.00	0.02	0.01	0.03	0.04	0.00	0.00	0.08	0.03	0.02	0.07	0.07	0.03	0.00	0.00	0.06	0.05	0.02	0.00
Al_2O_3	20.61	20.59	20.94	20.58	20.19	19.93	20.64	21.11	20.84	20.64	21.50	20.55	20.64	20.43	20.44	20.81	20.00	19.68	20.96	20.64	20.79	20.57
FeO	31.74	32.67	30.98	30.61	37.96	28.25	31.43	26.22	31.46	32.58	32.22	33.52	33.83	35.39	38.49	34.12	40.15	34.55	31.02	33.32	32.61	35.37
MnO	0.63	0.60	0.81	0.77	1.94	2.52	1.02	0.45	0.59	0.80	0.71	0.70	1.25	0.85	0.93	0.79	1.20	1.79	0.79	0.70	0.79	0.78
MgO	6.86	7.50	7.77	7.56	2.34	8.41	4.66	11.30	7.94	7.06	7.46	6.17	6.07	5.06	3.53	5.55	2.54	1.46	6.01	4.62	6.35	5.15
CaO	2.56	1.17	1.55	1.86	1.66	1.16	5.36	1.46	1.23	1.52	1.12	1.59	1.47	0.95	0.98	1.76	0.75	6.18	3.01	2.70	1.54	1.22
Na_2O	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.02	0.01	0.01	0.03	0.02	0.04	0.00	0.00	0.01	0.03	0.04	0.02	0.02	0.01	0.01
K2O	0.00	0.01	0.00	0.01	0.02	0.02	0.02	0.03	0.01	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr_2O_3	0.00	0.07	0.07	0.02	0.00	0.08	0.04	0.05	0.06	0.00	0.04	0.02	0.00	0.02	0.03	0.02	0.07	0.03	0.04	0.04	0.00	0.00
Total	100	100	100	99	100	100	100	100	100	99	100	100	100	100	101	100	101	100	100	99	99	100
Structural formula normalized to 12 oxygens																						
Si	2.97	2.95	2.96	2.98	2.94	3.08	2.94	2.98	2.95	2.93	2.92	2.96	2.94	2.98	2.94	2.95	2.92	2.95	2.99	2.97	2.95	2.95
Al iv	0.03	0.05	0.04	0.02	0.06	0.00	0.06	0.02	0.05	0.07	0.08	0.04	0.06	0.02	0.06	0.05	0.08	0.05	0.01	0.03	0.05	0.05
Al vi	1.88	1.87	1.90	1.90	1.89	1.82	1.88	1.90	1.89	1.87	1.91	1.89	1.88	1.91	1.88	1.91	1.86	1.85	1.94	1.94	1.92	1.90
Ti	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.10	0.11	0.08	0.08	0.10	0.08	0.10	0.09	0.09	0.11	0.07	0.09	0.11	0.08	0.10	0.08	0.12	0.13	0.04	0.05	0.07	0.09
Fe^{2+}	1.98	2.04	1.95	1.94	2.50	1.75	1.99	1.59	1.98	2.05	2.05	2.13	2.14	2.29	2.49	2.19	2.62	2.23	2.00	2.19	2.10	2.28
Mn	0.04	0.04	0.05	0.05	0.13	0.17	0.07	0.03	0.04	0.05	0.05	0.05	0.08	0.06	0.06	0.05	0.08	0.12	0.05	0.05	0.05	0.05
Mg	0.80	0.88	0.91	0.89	0.28	0.97	0.55	1.29	0.93	0.84	0.87	0.73	0.72	0.60	0.42	0.66	0.31	0.18	0.71	0.55	0.76	0.61
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.22	0.10	0.13	0.16	0.15	0.10	0.46	0.12	0.10	0.13	0.09	0.14	0.12	0.08	0.08	0.15	0.07	0.54	0.25	0.23	0.13	0.10
Total	8.03	8.04	8.03	8.03	8.05	7.97	8.05	8.03	8.04	8.06	8.05	8.03	8.05	8.02	8.05	8.04	8.06	8.05	8.01	8.02	8.04	8.04
End member composition																						
Almandine	64.20	65.51	63.15	63.11	80.80	56.37	63.29	51.61	63.65	65.19	65.22	69.19	68.46	75.04	80.54	70.81	84.33	71.42	66.08	71.92	68.15	73.87
Andradite	5.09	3.11	4.04	4.28	4.94	3.13	5.30	3.88	3.33	4.40	3.09	4.52	4.25	2.66	2.79	4.09	2.03	6.72	2.25	2.58	3.72	3.53
Grossular	2.18	0.00	0.13	0.93	0.00	0.00	10.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	11.53	6.15	5.13	0.75	0.00
Pyrope	27.11	29.78	30.64	29.88	9.70	34.38	18.83	43.38	31.50	28.57	29.93	24.65	24.44	20.30	14.43	22.31	10.59	6.02	23.64	18.64	25.57	20.81
Spessartine	1.42	1.36	1.82	1.73	4.56	5.86	2.34	0.98	1.34	1.83	1.62	1.59	2.86	1.93	2.15	1.80	2.83	4.21	1.77	1.60	1.81	1.79
Uvarovite	0.00	0.23	0.22	0.06	0.00	0.27	0.13	0.15	0.18	0.01	0.14	0.05	0.00	0.07	0.08	0.05	0.22	0.10	0.12	0.13	0.00	0.00
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

(83%) of the studied garnets molecular proportion is predominantly almandine and pyrope with subordinate amounts of andradite, grossular and spessartine. Remaining garnet samples (17%) have molecular proportions predominantly almandine+ pyrope+ grossular and subordinate amounts of andradite, spessartine and uvarovite component.

To understand the provenance of the beach sediments, the mineral chemistry of studied garnets was plotted on a ternary diagram[6] with molecular proportion of pyrope-almandine+spessartine and grossular as apices (Fig. 2a). The studied garnet samples fall in the fields of Type A and Type Bi of the diagram suggesting that the garnets of the study area are derived from high grade granulite facies metasediments or charnockites (Type-A) and intermediate felsic igneous rocks (Type Bi).

Mineral chemistry of garnets from various litho units of central-eastern ghats

The mineral chemical data of garnets from different litho units of EGGB are summarized in Table 2 and plotted in Figure 2b. These samples fall in Type A and Type Bi of the above diagram. We made an attempt to sub-divide the Type A and Type Bi regions of the ternary diagram[6] into khondalite and

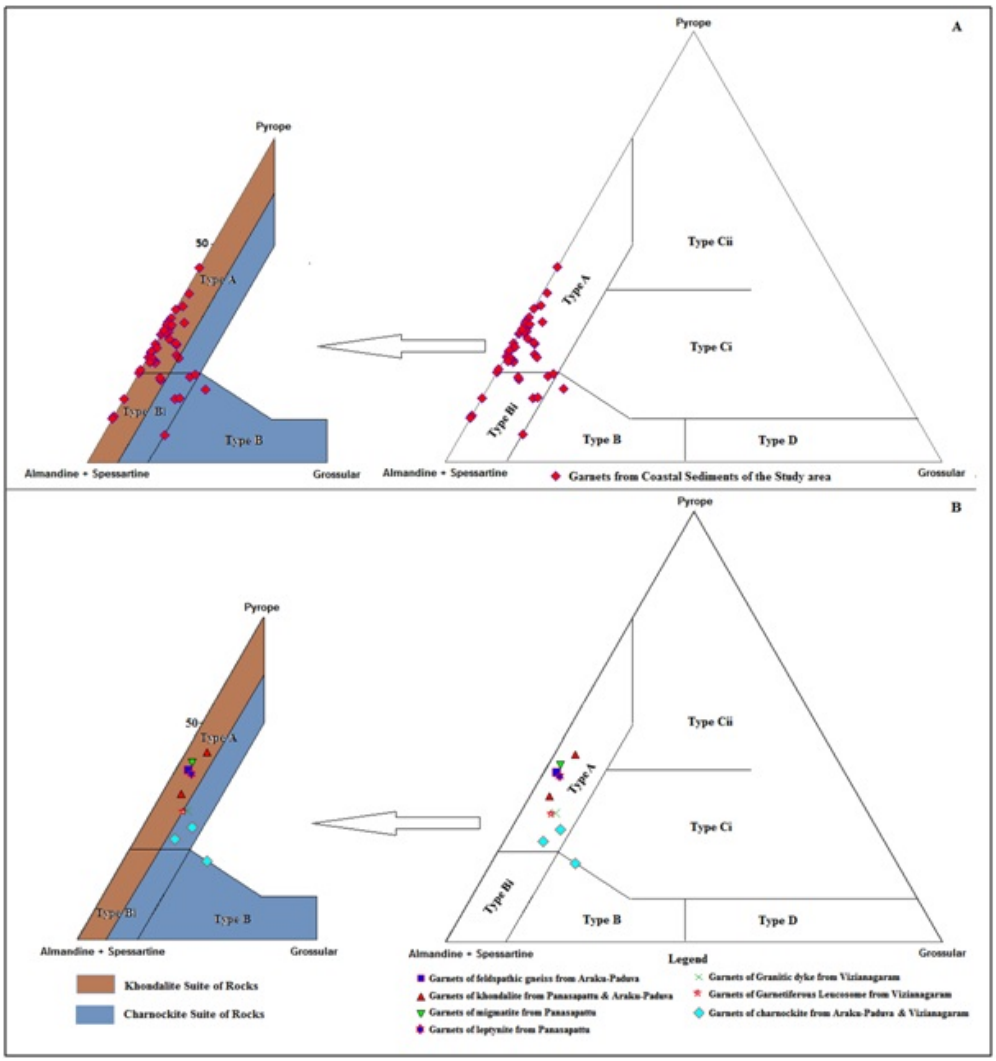

Fig. 2 — Ternary diagrams with proportion of pyrope, almandine + spessartine and grossular as poles[6] used for garnet discrimination. A) Garnets from coastal sediments of the study area and B) Garnets of various litho units from Eastern Ghat Granulite Belt. Type-A mainly from high grade granulite facies metasediments or charnockites and intermediate felsic igneous rocks, Type-B is amphibolites facies metasedimentary rocks, Type-Bi is intermediate to felsic igneous rocks, Type-Ci is mainly from high grade mafic rocks, Type-Cii is ultramafics with high Mg (pyroxenites and peridotites) and Type-D is metasomatic rocks, very low grade metamafic rocks and ultrahigh temperature metamorphosed calc-silicate granulites.

Table 2 — Chemical composition of garnets from various litho units of EGGB of India

	Khondalite Suite of Rocks					Charnockite Suite of Rocks				
Location	Araku-Padua[9]			Panasapattu[11]		Araku-Padua[9]			Vizianagaram[10]	
Litho Types	Feldspathic Gneiss	Khondalite		Migmatite	Leptynite	Porphyritic Charnockite	Charnockite		Granitic Dyke	Garnetiferous Leucosome
SiO_2	38.52	37.67	39.89	38.55	39.04	37.55	36.86	38.44	38.44	38.58
TiO_2	0.03	0.02	0.11	0.10	0.08	0.06	0.03	0.25	0.04	0.16
Al_2O_3	23.06	22.21	22.54	22.30	22.27	22.98	21.34	21.31	21.45	21.45
Cr_2O_3	0.00	0.06	0.00	0.00	0.00	0.04	0.15	0.07	0.10	0.00
Fe_2O_3	0.03	0.00	0.00	0.64	0.17	0.00	3.08	0.28	0.23	0.21
FeO	27.73	27.33	24.19	26.18	26.70	28.83	30.82	28.82	28.67	29.29
MnO	0.61	1.42	0.63	0.71	0.69	0.97	0.99	0.41	0.05	0.07
MgO	10.17	8.49	11.53	10.51	10.02	4.61	5.22	6.58	7.63	7.59
NiO	0.02	0.02	0.00	0.00	0.00	0.01	0.10	0.00	0.00	0.00
ZnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	0.95	1.48	1.68	1.52	1.49	5.95	5.87	3.87	2.85	2.41
Total	101.11	98.68	100.56	100.49	100.45	100.97	104.44	38.44	38.44	38.58
Structural formula normalized to 12 oxygens										
Si	2.93	2.95	3.00	2.94	2.98	2.92	2.84	3.00	3.00	3.01
Al iv	0.07	0.05	0.00	0.06	0.02	0.08	0.16	0.00	0.00	0.00
Al vi	2.00	2.00	2.00	1.95	1.98	2.03	1.79	1.96	1.98	1.97
Ti	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.01
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00
Fe3+	0.00	0.00	0.00	0.04	0.01	0.00	0.18	0.02	0.01	0.01
Fe2+	1.76	1.80	1.53	1.67	1.70	1.91	1.98	1.88	1.87	1.91
Mn	0.04	0.09	0.04	0.05	0.04	0.06	0.06	0.03	0.00	0.00
Mg	1.15	0.99	1.29	1.20	1.14	0.53	0.60	0.77	0.89	0.88
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Zn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.08	0.12	0.13	0.12	0.12	0.49	0.48	0.32	0.24	0.20
Total	8.03	8.02	8.00	8.03	8.01	8.04	8.11	8.00	8.00	7.99
End member composition										
Almandine	56.67	59.03	50.97	53.62	56.18	62.55	59.60	62.45	62.22	63.45
Andradite	0.08	0.00	0.00	1.86	0.50	0.00	9.44	0.82	0.68	0.61
Grossular	2.57	4.01	4.51	2.35	3.59	16.84	7.12	9.87	6.99	6.16
Pyrope	39.36	33.58	43.18	40.62	38.24	18.30	21.09	25.75	29.70	29.64
Spessartine	1.33	3.19	1.34	1.55	1.49	2.18	2.26	0.91	0.10	0.14
Uvarovite	0.00	0.19	0.00	0.00	0.00	0.13	0.48	0.20	0.31	0.00
Total	100	100	100	100	100	100	100	100	100	100

charnockite suite of rocks based on grossular molecular proportions <5% and >5%, respectively, to understand relative contribution of garnets from high grade granulite facies metasediments or charnockites (Type-A) and intermediate felsic igneous rocks (Type Bi).

The important observations from the data are: (a) Khondalite suite of rocks (Metapelitic rocks): Solid solution of the garnets from these rocks is almandine (Alm. 50-59%) and pyrope (Py. 33-43%) and less content of grossular (Gr. <5%) and (b) Charnockite suite of rocks: Solid solution of garnets from these rocks is almandine (Alm. 59-63%), pyrope (Py. <30%) and grossular (Gr. >5%). This data was correlated with the present data to understand the provenance.

Conclusion

1 The major portion (83%) of garnets with molecular proportions of almandine (Alm. 50-59%) and pyrope (Py. 33-43%) and less content of grossular (Gr. <5%) is derived from khondalite suite (metapelitic) of rocks.

2 The minor portion (17%) of garnets with molecular proportions of almandine (Alm. 59-63%), pyrope (Py. <30%) and grossular (Gr. >5%) is derived from charnockite suite of rocks.

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