Chapter-VII

Discussion & Conclusions

Beach refers to debris coarser than mud deposited in the shore zone and portrays annual sum of the seasonal products including skeletal parts of fauna and flora of the near shore zones.

This is a first attempt to sample the 16 beaches systematically for sedimentological studies under a single comprehensive sampling program to develop the provenances of their deposition vis-à-vis preparing a monograph of the varieties of the heavy minerals that occur in the beaches.

The exposed geological formations show the entire east coast, except for deltaic regions of larger rivers, is emerging gradually, as a result of which the sea is regressing along most of its parts.

Fairbridge (1966 and others) opined that the east coast beaches of India derive sands from rivers to the south and also from shore erosion. The coast is traversed by numerous rivers, and also flanked by marginal marine bodies (lagoons, sand bars, deltas and estuaries). Since the concentration of valuables (monazite, micro-diamonds and others) takes place due to sorting of detritals under true beach regime the present study was carried out to identify 'true beaches' from 'river fines dominated' one or 'sand bars' vis-à-vis granulometric and mineralogical studies amidst the reports of monazite (Vishakhapatnam, Mahadevan and Sriramdas, 1948); heavy minerals from Chandrapur beach, Sahu *et al.,* 1984), Kanniyakumari and other beaches (Angusamy and Rajamanickam, 2000); zircon and ilmenite (beach of Tamil Nadu, Angusamy, *et al.*, 2004); thorium-rich monazites (Kalingapatnam-Baruva, Reddy *et al.*, 1997); radiogenic heavy minerals (Chhatrapur beach,

Mohanty *et al.,* 2003); and diamonds (Kanniyakumari, Rau, 2006); and trace metals in estuaries and tides (Chennai and Pondicherry, Achyuthan *et al.*, 2002).

The work embodies mineralogy and 'whole grain study' of mounted-heavy minerals; granulometry of the sieved fractions; statistical treatment to their skewness and sorting parameters; x-ray diffraction analyses (six beaches); inductively coupled plasma mass spectroscopy (ICP-MS) of the beaches and the rare earth elements (REE) of six selected beaches to establish the provenances of their deposition.

The conclusions follow:

A. Heavy mineral analysis

Based on counting and study of around 12,35,000 grains of heavy minerals (Puri: 35,000; Gopalpur 24,500; Kalingapatinam: 1,14,000; Vishakhapatnam 27,000; Kakinada 1,20,000; Chirala 27,000; Chennai 1,00,000; Nagapattinam 1,47,000; Vedaranniyam 1,09000; Kottipattinam 1,50,639; Rameshwaram 1,28,000; Kanniyakumari-I: 1,25,000 and Kanniyakumari-II: 1,01,000) the study reveals that:

1. The heavy mineral suites along the coast is dominated by stable to ultrastable minerals such as zircon, garnet, tourmaline, rutile, epidote, ilmenite, magnetite, staurolite, anatase, monazite, hypersthene and diamonds with various intermediate titanates, sillimanite, andalusite, chrome spinel/chromite, biotite, muscovite and chloritoid;
2. Several varieties of heavy minerals include **micro-diamonds** at two- and **monazite** at ten stations, besides green-garnet, **'uvarovite'** at Chirala and chrome spinel that shows presence of ultrabasic rocks like kimberlite in the vicinity of a beach and. The report of micro-diamonds at both the places and monazite at 6 beaches is first;

3. The varieties of other common heavies are as follows:

   - Zircon: including rare varieties like hyacinth, thorite
   - Garnet: grossularite, spessartite, pyrope, uvarovite and almandine
   - Monazite: cryptolite and monimolite
   - Tourmaline: including rare varieties, rubelite and dravite
   - Epidote: two varieties
   - Hornblende: including paragasite, riebeckite
   - Rutile: two varieties
   - Staurolite: two varieties

4. These major heavy minerals are accompanied by kyanite, andalusite, sillimanite, anatase, sphene and biotite.

5. In a general order of predominance of the beaches of the entire coast (Tab 4.1 A) the minerals are:

   Zircon (about 8,00,000 grains) > garnet (1,96,000) > tourmaline (30,000) > staurolite (9,000) > hornblende (5,000) > rutile (4,000) > sillimanite (3,000) > kyanite (3,500) > biotite (2,300) > epidote (2,500) > andalusite (2,000)> monazite & anatase (10,00 grains each)> sphene (500)> diamond (26)

6. No change occurs in the order of predominance of ultrastable minerals like zircon, garnet, tourmaline, staurolite hornblende (Tab 4.1 A); but changes in their order occur in rest of the minerals listed (Tab 4.1, Fig 4.1 A).

7. Population of metamorphic minerals in stations (Tab 4.1 A) except Puri reveals dominance of metamorphic minerals (hornblendes, product of dual origin) over the igneous minerals, in general point to 'metamorphics' provenances. At Puri dominance of igneous suite may be due to the proximity of the crystallines (Table 4.1 and Table 4.1A).

B. Granulometry

Granulometry has helped delineating provenances and the history of deposition of the detrital in beache regimes as follows:

1. Out of 15 beaches, only five fall in the true beach conditions based on their frequency distribution and cumulative frequency curves;

2. The statistical treatment of grain parameters (skewness and sorting, Fig 5.14 A & 5.14 B) and scatter plotting (Simple Skewness Measures (α_s) verses Simple Sorting Measure (So_s), and Inclusive Graphic Skewness (SK_I) verses Inclusive Graphic Standard (σ_1)) through a statistical computer program shows that **Puri, Kakinada, Nagapattinam, Vedaranniyam and Kanniyakumari II** beach fall in the 'beaches' categories and rest in the field of deposits with 'dominance of river-sands' or ' sand bars', based on Fig. 4.10 and 4.11 of Friedman and Johnson (1982);

The provenances of stations where true beach conditions exist are namely, Puri, Kakinada, Vedaranniyam and Kanniyakumari-II, follows:

1. Puri beach

a. The dominance of igneous minerals due to the gneisses and granites with patches of charnockites and khondalites of the Northern Circar abutting the beaches from Puri to Kakinada, with a belt of Recent alluvium in between;

b. The percentage of the heavies: zircon (52.9 %), garnet (10.5), tourmaline (0.6), **monazite** (0.19), biotite (0.07), kyanite (0.05), staurolite (0.05) epidote (0.04), hornblende (0.03) are present in sillimanite (0.02), andalusite (0.02) and anatase (0.01);

c. The detritals are dominated by coarse mesokurtic sediments. A 'sharp peak' of frequency curve shows enormous supply of sediments from rivers (possibly Mahanadi that flows across the crystallines).

2. Kakinada beach

a. The sediments are mesokurtic (dominated by coarser sediments) with little dominance of fines from rivers owing to the proximity of the two large tributaries of Godavari that seems to supply riverine sediments for development of this beach (Map 1.6); and

b. The percentage heavy mineral suite: zircon (65.54), garnet (17.20), tourmaline (2.16), **monazite** (0.38), biotite (0.07), kyanite (0.29), staurolite (1.27), epidote (0.18), hornblende (0.48), sillimanite (0.18) and andalusite (0.22).

3. Vedaranniyam beach

a. A huge deposition of sands near Vedaranniyam might have occurred due to the obstruction, caused by change in strike of the coast line in the path of long shore currents advancing in the NE direction.

b. The percentage of heavies: zircon (59.34), garnet 915.36), tourmaline (7.44), epidote (0.25), hornblende (0.59), rutile (0.48), kyanite (0.34), staurolite (0.78), andalusite (0.33), sillimanite (0.25), andalusite (0.01), biotite (0.09) and **diamond** (0.008).

4. Kanniyakumari beach - II

a. The sediments fall under leptokurtic category with little dominance of fines from riverine material in the beach-sands.

b. The scatter plot (5.14 A and 5.14 B) the station shows true beach conditions.

c. The crystalline gneisses of the Coraman hills seem to have contributed sediments.

d. The percentage of the heavies minerals here is: zircon (66.19), garnet (14.26), tourmaline (0.83), epidote (0.21), hornblende (0.38), rutile (0.20), kyanite (0.11), staurolite (0.35), andalusite (0.12), sillimanite (0.24), sphene (0.08) and biotite (0.47).

5. Beaches showing 'mixed river sand-' or 'sand bar categories': Gopalpur, Kalingapatnam, Vishakhapatnam, Kakinada, Chirala, Chennai, Kottipattinam, Rameshwaram and Kanniyakumari-II

The scatter plots (Fig 5.14 A and 5.14 B) of these beaches show 'mixing of river-sands' or 'sand bars' conditions and their heavy mineral suites shows dominance of metamorphic rocks:

a. Gopalpur beach sediments:

i. Mesokurtic category, sharp peak of the frequency curve, dominance of coarser sediments due to proximity of a substrate of coarse sand on the gently sloping shelf along here;

ii. Heavies: zircon (54.0), garnet (9.82), **monazite** (0.16) tourmaline (2.5), epidote (0.26), hornblende (0.31), rutile (0.15), kyanite (0.09), staurolite (0.34), andalusite (0.02), sillimanite (0.11), anatase (0.46), sphene (0.03) and biotite (0.17).

b. Kalingapatnam beach sediments:

i. Mesokurtic category with dominance of coarser sediments of well sorted grains; and

ii. The heavy mineral suite (%): zircon (58.43), garnet (18.34), **monazite** (0.47), tourmaline (2.63), epidote (0.3) hornblende (0.17) rutile (0.71), kyanite (0.21), staurolite (0.35), andalusite (0.10), sillimanite (0.13), anatase (0.58), sphene (0.10) and biotite (0.25).

c. Vishakhapatnam beach sediments:

i. Mesokurtic category of the sediments with dominance of coarser sediments and well sorted grains;

ii. The heavy mineral suite (%): zircon (51.07), garnet (9.4), **monazite** (0.07), tourmaline (2.65), epidote (0.25), hornblende (0.14), rutile (1.42), kyanite (0.20), staurolite (0.35), andalusite (0.1), sillimanite (0.12), anatase (0.56), sphene (0.57) and biotite;

iii. The detritals of medium to fine sands, composed of magnetite, ilmenite and quartz have been derived from charnockites of the adjoining area; substrate of clay, however, borders the coast; and

iv. The Vishakhapatnam (90m) and Yarda Beaches (150m) with rows of sediments experiences erosion, during SW- and deposition during NE monsoon with calm periods in between this observation corroborates the opinions of LaFond and Prasad Rao (1954, *vide* Chandramohan and Narsimha Rao, 1984).

d. Chirala beach sediments:

i. The mesokurtic category of the sediments dominated by coarser sediments of well sorted grains; a substrate bordering the coast is of sand, followed sea-wards, by sand & clay, and ultimately by clay.

ii. The heavy mineral suite (%): zircon (64.19), garnet (9.01), **monazite** (0.03), tourmaline (5.79), epidote (0.76), hornblende (0.92), rutile (0.14), kyanite (1.03), staurolite (0.29), andalusite (0.44), sillimanite (0.9), anatase (0.09), sphene (0.15) and biotite (0.51).

iii. The present study confirms the observation of Rao and Pichaiah (1985) that the sand deposits of Chirala coast is actually a sand bar formed by a mixing of sediments belonging to fluvial and marine environments brought by Gundlakamma River and subsequently sorted by oceanic waves and transported by long shore currents from SW to NE.

e. Chennai beach sediments:

i. Mesokurtic category of the sediments with dominance of coarser sediments of well sorted grains;

ii. The percentage of the heavies present here is: zircon (54.65), garnet (21.65), **monazite** (0.09), tourmaline (12.66), epidote (0.30), hornblende (0.49), rutile (0.06), kyanite (0.37), staurolite (0.62), andalusite (0.23, sillimanite (0.44), anatase (0.00), sphene (0.03) and biotite (0.2); and

iii. The submarine contours along shore are mostly parallel and show gently sloping shelf, lined by substrate of sand and clay. Rao and Murty (1968), however, noticed that sediments of near-shelf and outer-shelf, along Chennai, constitute fine to very fine sands and those of the middle-shelf contain medium to coarse sands.

f. Nagapattinam beach sediments:

i. The coastal zone along with beaches is traversed by numerous rivers up to 10km, as well as in the south of Nagapattinam town. The beach sediments contain a fair amount of fine sand and clay. Patches of clay emerge, here and there, on the beaches; and

ii. The percentage of the heavies here is: zircon (78.22), garnet (12.20), **monazite** (0.35), tourmaline (1.88), epidote (0.19), hornblende (0.50), rutile (0.43), kyanite (0.38), staurolite (1.24), andalusite (0.22), sillimanite (0.24), biotite (.09) and **diamond** (0.01).

g. Kottipattinam beach sediments:

i. Mesokurtic category of the sediments with dominance of coarser sediments of well sorted grains;

ii. The heavy mineral suite: zircon (65.08), garnet (16.18), **monazite** (0.46), tourmaline (1.90), epidote (0.18), hornblende (0.44), rutile (1.35), kyanite (0.26), staurolite (1.12), andalusite (0.2), sillimanite (0.23) and biotite (0.08); and

iii. The beaches are backed by sand-hills (1 sq km) the foreshore is steep and narrow having width between 50 to 200m with gentle and wider backshore.

h. Rameshwaram beach sediments:

i. Mesokurtic category with dominance of coarser sediments of well sorted grains and a sharp peak in frequency curve showing dominance of river fines;

ii. A canal joining the Palk Bay and Gulf of Mannar namely Sethusamudram Ship Canal has been under excavation with possibility of causing environmental and ecological unbalance in the region (Kathal, 2005); and

iii. The percentage of the heavies present here is: zircon (61.6), garnet (16.95), tourmaline (1.48), epidote (0.17), hornblende (0.4), rutile (0.24), kyanite (0.25), staurolite (0.66), andalusite (0.15), sillimanite (0.21), sphene (0.02) and biotite (0.07).

i. Kanniyakumari-I beach sediments:

i. It is important to note that the Kanniyakumari–II shows true beach conditions while Kanniyakumari-I fall in river mixing/ sand bar categories.

ii. The leptokurtic category of the sediments with dominance of fines, poorly sorted grains and a sharp peak in frequency curve showing considerable amount of mixing of the river fines;

iii. The percentage of the heavies: zircon (76.74), garnet (19.39), **monazite** (0.43), tourmaline (1.27), epidote (0.32), hornblende (0.31), rutile (0.07), kyanite (0.11), staurolite (0.48), andalusite (0.06), sillimanite (0.31), sphene (0.08) and biotite (0.37).

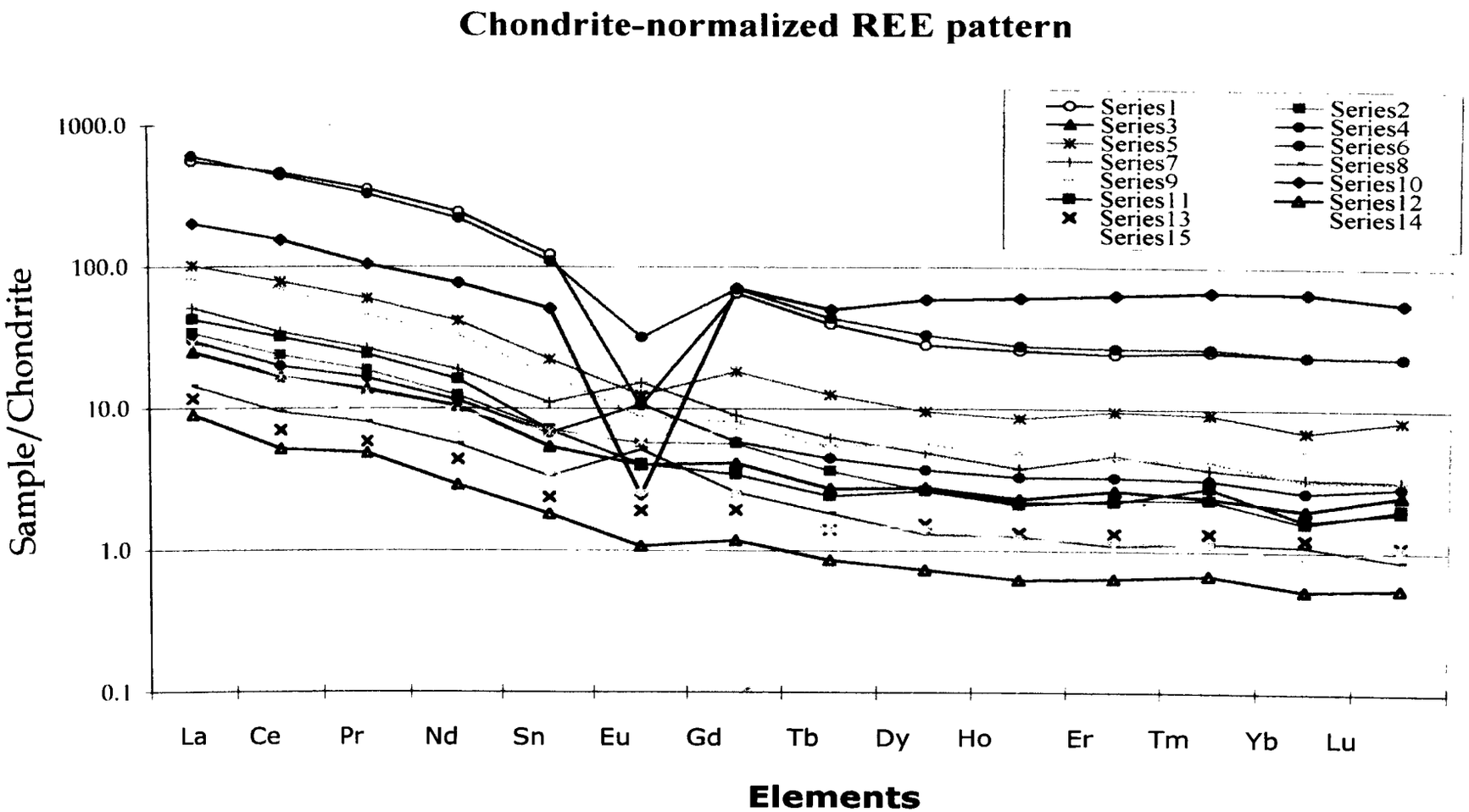
Table 7.1 show the conclusions of the provenance drawn about the of the studied coastal stations based on the results of the mineralogical, whole grain, granulometric, scatter plotting (skewness and sorting relation) and inductively coupled plasma mass spectroscopy (ICPMS) carried out in the present project.

Table 7.1 Provenance based on different parameters (ICPMS, Ig./Meta. heavy Minerals and scatter plots)

S. No.	Beach	Provenance (ICPMS)	Provenance Ig. Meta. Minerals	Provenance Scatter Plot (α_s) vs (So_s)	Provenance Scatter Plot (SK_I) vs (σ_1)
1	Puri	Igneous	Igneous	Beach	Beach
2	Gopalpur	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
3	Kalingapatnam	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
4	Vishakhapatnam	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
5	Kakinada	Metamorphic	Metamorphic	Beach	Beach
6	Chirala	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
7	Chennai	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
8	Nagapattinam	Igneous	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
9	Vedaranniyam	Metamorphic	Metamorphic	Beach	Beach
10	Kottipattinam	Metamorphic	Metamorphic	Beach	River sand mixing/sand bar
11	Tondi	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
12	Mandapam	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
13	Rameshwarm	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
14	Tuticorin	Metamorphic	Metamorphic	River sand mixing/sand bar	River sand mixing/sand bar
15	Kanniyakumari-II	Igneous	Metamorphic	Beach	Beach

Fig 7.1 Chondrite normalized pattern of the studied beaches

(Series 1 to 15: 1. Puri, 2. Vishakhapatnam 3. Chirala, 4. Kakinada, 5. Kalingapatnam, 6. Nagapattinam, 7. Vedaranniyam, 8. Tondi, 9. Tuticorin, 10. Kanniyakumari-II, 11. Gopalpur, 12. Kottipattinam 13. Rameshwaram, 14. Mandapam, 15. Chennai)



C. X-Ray diffraction analysis

The XRD study of the finer-fractions of samples from 6 selected beaches confirms the mineralogical identification of the heavy minerals of the study. It also shows:

i. Presence of radioactive mineral monazite with rare earth elements namely, Cerium (Ce), Lanthanum (La), Yttrium (Y) and Thorium (Th); and

ii. The population of monazite grains per 20 gm sample from these stations vary from 21 to 538 (Kottipattinam: 696; Kalingapatinam: 538; Nagapattinam: 537; Kanniyakumari-I: 515; Kakinada: 468; Puri: 65; Gopalpur: 40; and Vishakhapatnam: 21).

D. Inductively Coupled Plasma Mass Spectroscopy (ICP-MS)

The Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) for trace and ultra-trace elements including Rare Earth Elements (REE) of samples from 8 selected namely, Puri, Vishakhapatnam, Chirala, Kakinada, Kalingapatinam, Nagapattinam, Vedaranniyam and Tondi.

The ICP-MS analysis shows:

i. Distribution of Manganese (Mn), Gallium (Ga), Rubidium (Rb), Strontium (Sr), Yttrium (Y), Niobium (Nb), Tin (Sn), Antimony (sb), Caesium (Cs), Barium (Ba), Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb), Lutetium (Lu), Hafnium (Hf), Thorium (Th), and Uranium (U);

ii. The Chondrite-normalized REE patterns show igneous provenance for four beaches namely, **Puri, Chennai, Nagapattinam and Kalingapatinam** and metamorphic affinities at rest of the beaches of the study (**Tab 6.1**);

iii. The study also shows higher value (in ppm) of Pr (100), Sm and Tm (80 each), U and Hf (10 each) at Puri; Ba (over 1000), Rb, Sr, Ce (100 each), Nd and Th (45 each) at Kalingapatinam; Ba (1000), Rb and Sr (100), Th (8) and La, Ce, Nd Sm, Gd and Hf, (around 6 each) at Vishakhapatnam; Sr (500) and Rb (100), Th (8) at Kakinada; Ba (7000), Sr and Rb (around 1000 each), La and Ce (around 80 each), Nd and Th around 50 each) and U (7) at Chirala; Sr, Ba, La and Ce around (1000 each), Nd and Th (around 100 each); Sr (8000), Ba (600) at Vedaranniyum; and Ba (5000), Sr (100) at eight beaches.

E. Suggestions:

Based on the present study carried out on the beaches of the east coast of India the following suggestions may be made:

1. Sedimentological aspects of the beaches of the east coast of India still have ample scope for future studies specifically from the economic points of views;

2. The Placer deposits occur where the detrital of minerals are sorted time and again under beach conditions;

3. Some of the beaches of the present have shown incidences of monazite and micro-diamonds, beside presence of uvarovite and chrome spinel. These beaches are namely, Vedaranniyam, Nagapattinam and Chilara where extensive sampling may be carried out;

4. Percentage of detrital grains of hornblende is considerably high in some beaches. It is difficult to find out the nature of its origin as it could have been released either from igneous or metamorphic suites. It is, therefore, proposed that hornblende of the studied beaches may be studied through 'micro-probe' analysis of hornblende grains and its varieties;

5. The study reports monazite from various stations. Detailed sampling and geochemical exploration based on the present findings may be under taken in future studies.

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