JOURNAL INDIAN ASSOCIATION OF SEDIMENTOLOGISTS ISSN NO 2582 – 2020
Vol. 39, Issue 1, 2022, pp. 52-63
DOI: https://doi.org/10.51710/jias.v39i1.206

Nature and Provenance of Heavy Mineral Distribution at Krishna River Delta, East Coast of India

K. N. Murali Krishna[1], K. S. N. Reddy [2] Ch. Ravi Sekhar[2]

[1]Department of Civil Engineering, Sasi Institute of Technology & Engineering,
[2] Department of Geology, Andhra University
Email: draukrishn@sasi.ac.in

Abstract

The present study deals with four sedimentary cores viz. Turumella (120m), Inturu (160m), Ponnapalli (110m) and Nizampatnam (150m) which were recovered from the Krishna delta. Total heavy minerals wt% varies from 0.32 to 7.00 (av. 2.44%) in the study area. The major heavy minerals were noticed in four studied cores i.e. opaques (Ilmenite + magnetite), pyriboles (pyroxenes + amphiboles), garnet, zircon, monazite, rutile and other heavy minerals (epidote, kyanite, tourmaline, etc.). Heavy mineral substance in Krishna river sediments forced by basement rocks, drainage basin and weathering conditions of the river environment. The occurrence of different lithological units in the drainage basins is contributing sediments, mainly opaques (Ilmenite + magnetite) and pyriboles (Amphibole + pyroxenes) from Deccan traps as well as Archean provenance which covered more than 55% of drainage basin. The red garnets (almandine), prismatic sillimanites and rounded zircons are derived from khondalites (metapeletic rocks) and pink garnets, elongated zircons and ortho- pyroxenes are derived from charnockites of Eastern Ghat Granulite Belt (EGGB). The fresh appearance of heavy minerals indicates short residence time in depositional environment without any chemical dissolution effect. The rounded and sub rounded grains of magnetite and ilmenite indicate long distance of transportation and/or reworked nature. The sub angular grains of magnetite and ilmenite indicate that they might have been derived from nearby sources, i.e. mainly an Eastern Ghat Group of rocks. The prismatic characteristic of the sillimanite mineral grains also suggests that their derivation is from khondalitic rocks. Opaques are from Deccan traps as well as Archean provenance. Garnets, sillimanites and zircons are derived from khondalites (metapeletic rocks) and charnockites of Eastern Ghat Granulite Belt.

Key words: Heavy minerals, Deccan traps, Eastern Ghat Granulite Belt and Archean rocks.

INTRODUCTION

Heavy mineral analysis is one of the most sensitive and effective tools for provenance discrimination and can determine the source terrain and depositional environment of sediments (Morton, 1985; Morton and Hallsworth, 1994, 1999; Kwon et al., 1999; Mange and Wright, 2007; Akaram et al., 2015; Liu et al., 2015 and Meng et al., 2016). Source-rock composition, climate, relief, slope, vegetation and dynamics of the fluvial environment play an important role in controlling the composition of fluvial sand (Blatt, 1967; Suttner et al., 1981; Johnson et al., 1991). Although most sands in the geologic record at one time passed through a fluvial system, little research has been directed at evaluating controls on sand composition in river systems.

In India, detailed studies on heavy mineral variations have been restricted to some major river systems which include Godavari (Naidu, 1966), Krishna (Swamy, 1970; Krishna Rao and Swamy, 1991 and Sreenivasa Rao et al., 1995), Mahanadi (Satyanarayana, 1973), Vasishta-Godavari (Dora, 1978) and Cauvery (Seralathan, 1979). Unlike river systems, a considerable amount of information exists on the heavy mineral occurrences of the beach environments. Reddy et al. (2012) carried out a distribution study of heavy minerals in Nizampatnam-Lankavanidibba coastal sands, Andhra Pradesh, East coast of India. Nayak (2021) identified changing tropical estuarine sedimentary environments with time and metals contamination in the West Coast of India.

The objective of the present investigation is a) to study the heavy mineral distribution in different cored samples of the Krishna River delta b) to identify provenance of the heavy minerals. The details presented above clearly illustrate that though a number of studies have been carried out primarily based on surface features and samples from various subenvironemnts on different aspects of Krishna Delta. There is a distinct gap in knowledge on sub-surface studies of Krishna Delta. Hence, in order to bridge this gap in scientific information, the present study incorporates cored subsurface information to study the evolution of Krishna Delta.

STUDY AREA

The study area covers western part of a lower delta of Krishna River adjacent to Nizampatnam Bay. The cored holes fall in the area bounded in between E 80° 37' 40" and 80° 42' 03" and N 15° 54' 04" and 16° 06' 12' ' (Fig.1).

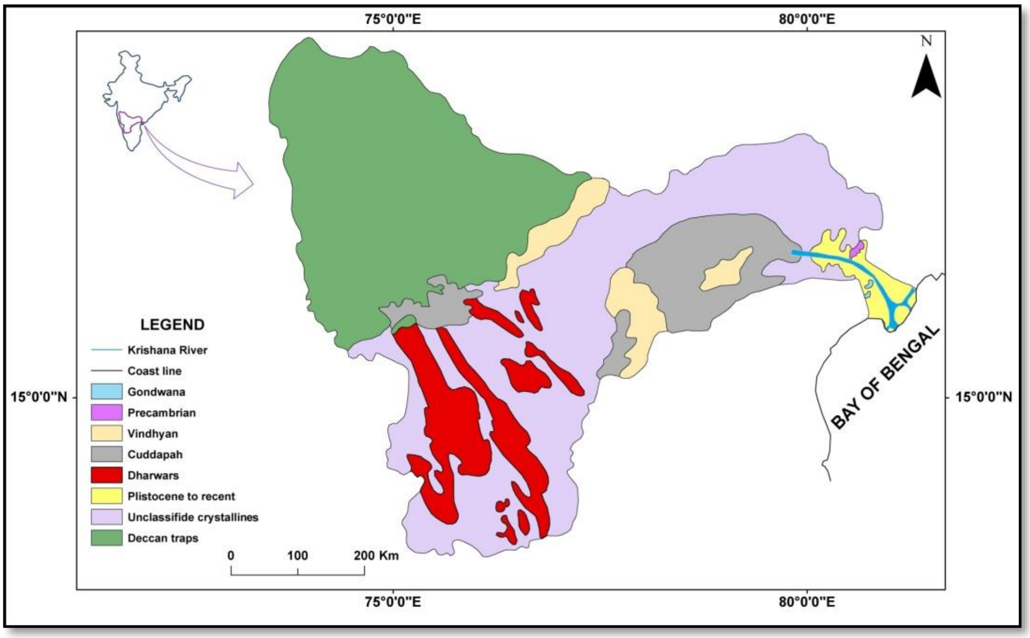

Fig. 1 Location map of the study area

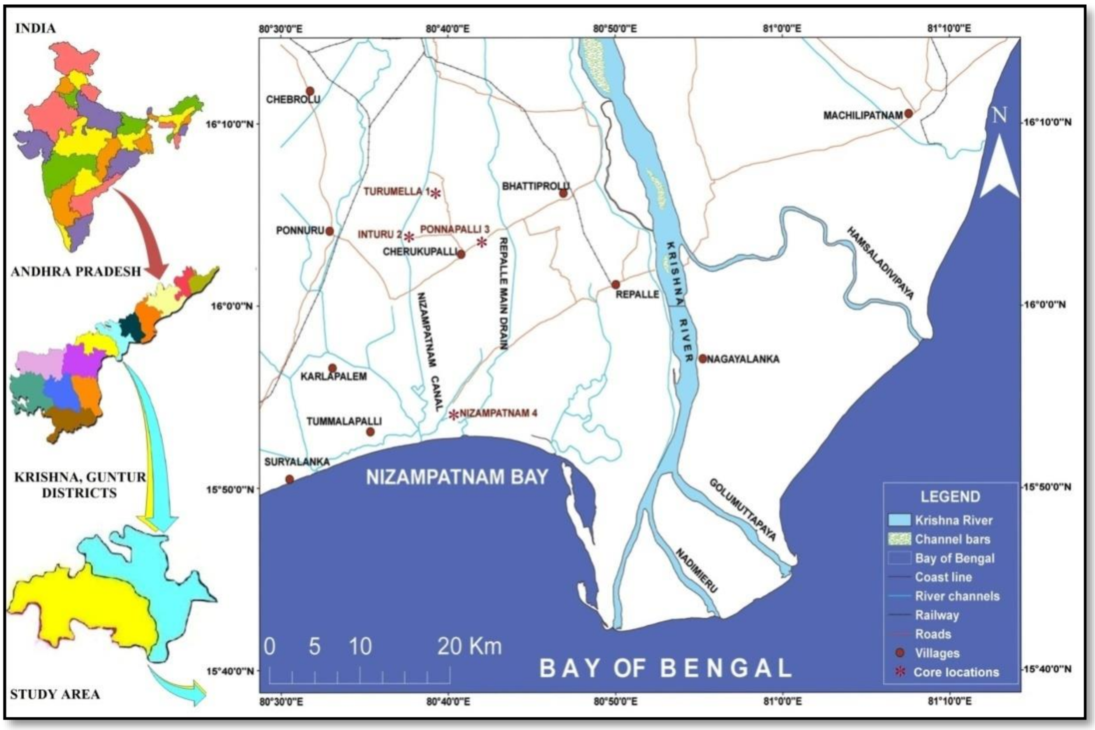

Fig. 2 Geology of the Drainage basin of Krishna River (Source: Geological Survey of India)

Geology of the Krishna River Basin

The geological formations in the Krishna River basin mainly comprise of Deccan Traps (50%), unclassified crystalline rocks of Archaeans and Precambrian sediments of Cuddapah, Vindhyan and Kurnool Super groups and Khondalites of the Eastern Ghats (Fig. 2). They exhibit uniformity in the mineralogical character and chemical composition. The normal compact dolertic to basaltic (Thoeliite) type occurs over large areas in the upper basin. The unclassified crystallines are comprised of the Dharwarian sediments and various gneisses and granites, including charnockites. These rocks together cover the upper half of the drainage basin. The Cuddapah and Kurnool sediments consist of quartzites, limestones, shales, slates and sandstones. The Khondalites are quartz, feldspar, garnet, sillimanite gneisses with occasional presence of graphite. These rocks intruded by charnockites and pegmatites resulting in the development of a complex group of interaction rocks such as garnetiferous granulites, garnetiferous hypersthene gneisses and banded gneisses etc. Alluvial sediments of Pleistocene to recent age occur over the delta.

Material and Methods

The four sedimentary cores, viz. Turumella (120m), Inturu (160m), Ponnapalli (110m) and Nizampatam (150m) were recovered from the Krishna delta coast ~ 5 km inland from the shoreline. The bore hole samples were obtained using a rotary rig up to bedrock by the Geological Survey of India, Southern Region, Hyderabad. Drilled cores were preserved at the Delta Studies Institute, Andhra University, Visakhapatnam. Total sixty three sediment samples were subjected to heavy mineral analysis. The sand fractions were repeatedly washed with distilled water to remove salts and added stannous chloride for the removal of iron coatings. Bulk samples were separated using bromoform (sp.gr.2.89) following the procedure outlined by Krumbein and Pettijohn (1938). The heavy and light fractions were weighed and their weight percentages were calculated. Heavy minerals from bulk samples were mounted on glass slides with Canada balsam. About 300-400 grains in each slide were identified and counted using the line method (Galehouse, 1971).

DOWN CORE VARIATION OF HEAVY MINERAL ASSEMBLAGES

Turumella Core

Eighteen sand samples from various depths of Turumella core were subjected to heavy mineral analysis and results i.e. the down core variations of total heavy mineral (wt %) and individual heavy minerals (wt %) content in Turumella core sediments are given in Table 1. The heavy mineral assemblage in Turumella core sediments is opaques (Ilmenite+ magnetite), garnet, sillimanite, pyroxenes, monazite, amphiboles, zircon, and rutile in the decreasing order of abundance (Fig. 3). The total heavy minerals (THM) percentage ranges from 0.38 to 4.20 % (av. 2.59%). The maximum total heavy mineral content 4.20% occurred at a depth of 102 -103m followed by 3.92 % (105-108m), 3.90 % (67.30-70.50m), 3.80 % (119-120m) and 3.70 % (44.10-44.20m and 96-99m). The minimum heavy mineral content 0.38% occurred at a depth of 90-93m, followed by 0.80% (59.65-61.45m) (Table.1).

In Turumella core sediments the average total heavy mineral content is 2.59%, in which 37% is ilmenite, 21% magnetite, 9% garnet, 7% sillimanite, 5% pyroxene, 5% zircon, 5% monazite, 4% amphiboles, 4% other heavy minerals and 3% rutile (Fig. 4 a).

Inturu Core

Thirteen sand samples from various depths of Inturu core were subjected to heavy mineral analysis and results i.e. the down core variations of total heavy mineral (wt%) and individual heavy mineral (wt%) content in Inturu core sediments are given in Table 1. The heavy mineral assemblage in Inturu core sediments is opaques (Ilmenite + magnetite), garnet, sillimanite, pyroxenes, monazite, amphiboles, zircon, and rutile in order of decreasing abundance (Fig. 5). The total heavy mineral (wt %) varies from 1.83 to 7.00% (av. 3.61%). In Inturu core

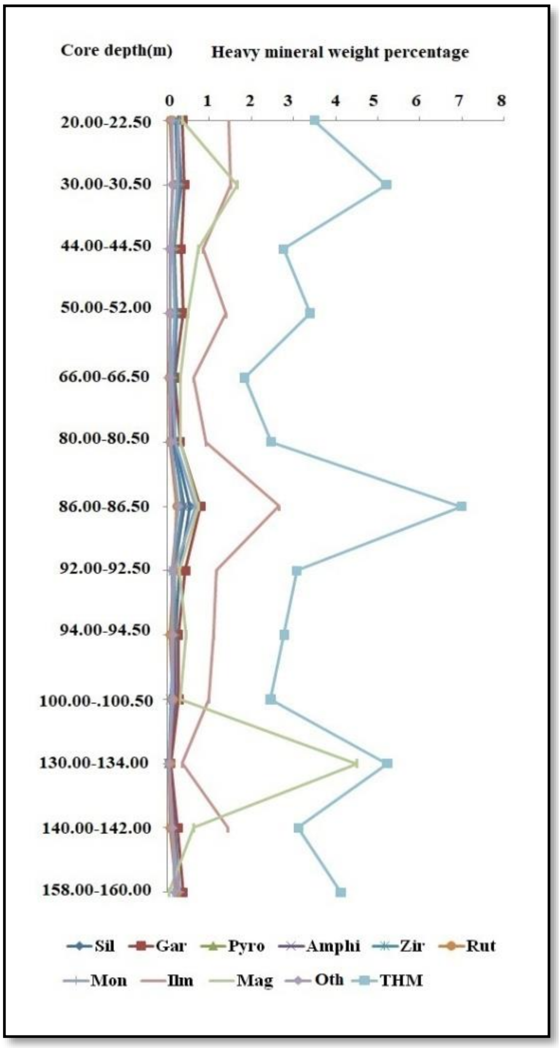

Fig. 3 Down core variation of an individual heavy mineral in Turumella sediments

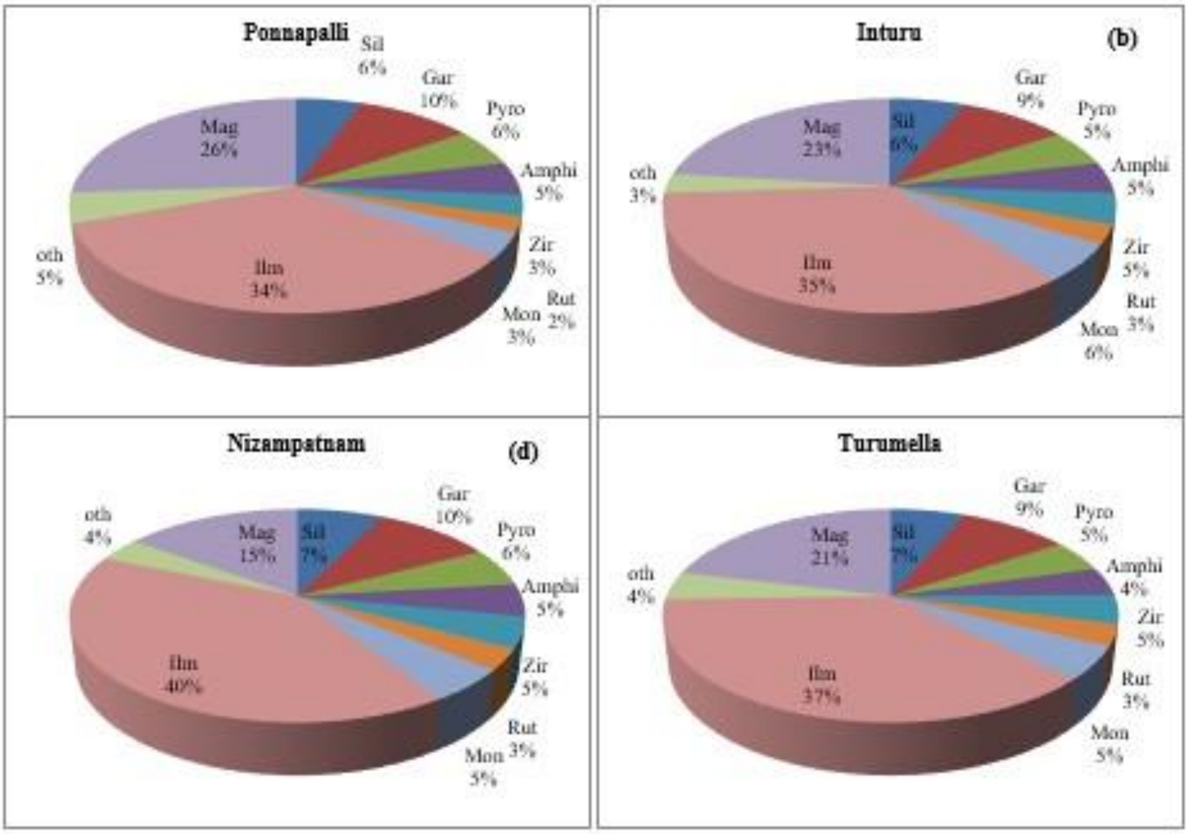

Fig. 4 Distribution Pattern of Individual Heavy Minerals in a) Turumella b) Inturu c) Ponnapalli and d) Nizampatnam core sediments

sediments the maximum total heavy mineral 7% occurred at a depth of 86.00-86.50m, followed by 5.23% (130-134m), 5.20% (30.00-30.50m) and 4.23% (160-162m). The minimum total heavy mineral content 1.83% occurred at a depth of 66.00-66.50m, followed by 2.45% (100.00-100.50m), 2.46% (80.00-80.50m), 2.76% (44.00-44.50m) and 2.77% (94.00-94.50m) (Table.1). In Inturu core, average total heavy mineral (THM) weight percentage is 3.61%, in which 35% ilmenite, 23% magnetite, 9% garnet, 6% sillimanite and monazite each, 5% pyroxenes, amphiboles and zircon each, 3% rutile and 3% other heavy minerals (Fig. 4 b).

Ponnapalli core

Twenty sand samples from various depths of Ponnapalli core were subjected to heavy mineral analysis and results i.e. the down core variations of total heavy minerals (wt %) and individual heavy minerals (wt %)

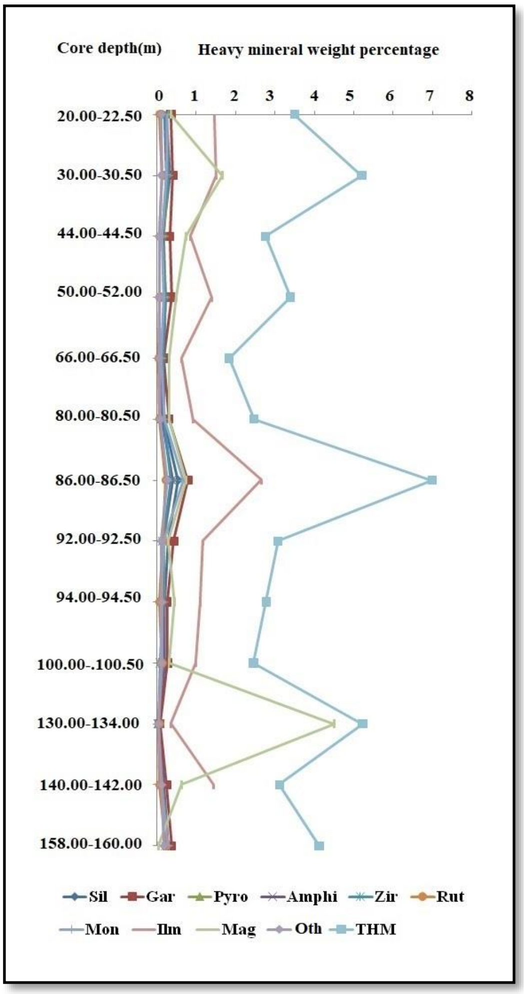

Fig. 5 Down core variation of an individual heavy minerals in Inturu sediments

Table 1: Distribution of total and individual heavy minerals (wt%) in core sediments

Sample No	Depth(m)	Sill	Gar	Pyro	Amphi	Zir	Rut	Mon	Ilm	Mag	Oth	THM%
Turumella core												
T-13	24.20-24.25	0.08	0.33	0.08	0.09	0.07	0.02	0.09	0.47	0.74	0.07	2.04
T-15	30.30-30.35	0.13	0.34	0.12	0.09	0.11	0.05	0.09	0.57	0.78	0.13	2.42
T-18	35.90-36.00	0.09	0.20	0.12	0.09	0.08	0.04	0.08	0.52	0.62	0.08	1.90
T-20	44.10-44.20	0.23	0.37	0.23	0.20	0.21	0.06	0.18	1.39	0.66	0.18	3.70
T-22	48.00-48.10	0.14	0.20	0.10	0.09	0.11	0.03	0.09	0.49	0.34	0.06	1.64
T-24	52.60-52.70	0.07	0.12	0.06	0.05	0.07	0.02	0.08	0.38	0.20	0.04	1.10
T-26	56.00-56.75	0.17	0.25	0.13	0.12	0.11	0.07	0.21	0.84	0.19	0.08	2.17
T-28	59.65-61.45	0.06	0.09	0.04	0.03	0.03	0.03	0.04	0.25	0.20	0.02	0.80
T-30	63.00-64.50	0.12	0.15	0.11	0.08	0.09	0.04	0.06	0.66	0.31	0.08	1.71
T-32	67.30-70.50	0.30	0.42	0.23	0.23	0.13	0.19	0.17	1.58	0.46	0.19	3.90
T-34	73.50-76.50	0.26	0.33	0.18	0.15	0.13	0.19	0.17	1.10	0.56	0.13	3.20
T-36	82.00-82.50	0.22	0.29	0.16	0.13	0.13	0.08	0.14	1.13	0.42	0.14	2.84
T-38	90.00-93.00	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.10	0.18	0.01	0.38
T-40	96.00-99.00	0.25	0.33	0.14	0.11	0.13	0.16	0.23	1.45	0.70	0.20	3.70
T-42	102.00-103.00	0.21	0.24	0.14	0.13	0.18	0.13	0.18	1.65	1.20	0.15	4.20
T-44	105.00-108.00	0.19	0.22	0.14	0.14	0.14	0.12	0.18	1.52	1.12	0.15	3.92
T-46	114.00-117.00	0.19	0.24	0.12	0.11	0.16	0.11	0.16	1.38	0.60	0.13	3.20
T-48	119.00-120.00	0.23	0.20	0.17	0.17	0.18	0.14	0.15	1.82	0.60	0.15	3.80
Min.		0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.10	0.01	0.18	0.38
Max.		0.30	0.42	0.23	0.23	0.21	0.19	0.23	1.82	0.20	1.20	4.20
Av.		0.16	0.24	0.13	0.11	0.11	0.08	0.13	0.96	0.11	0.55	2.59
Inturu core												
I-11	20.00-22.50	0.25	0.35	0.24	0.18	0.20	0.07	0.27	1.46	0.36	0.11	3.50
I-14	30.00-30.50	0.33	0.40	0.30	0.24	0.28	0.14	0.24	1.49	1.67	0.11	5.20
I-20	44.00-44.50	0.14	0.32	0.19	0.14	0.13	0.06	0.13	0.85	0.74	0.05	2.76
I-23	50.00-52.00	0.23	0.37	0.23	0.20	0.21	0.06	0.18	1.38	0.49	0.05	3.39

Table 1 Continued..

I-29	66.00-66.50	0.17	0.17	0.12	0.11	0.13	0.04	0.11	0.62	0.30	0.05	1.83
I-35	80.00-80.50	0.17	0.30	0.15	0.13	0.16	0.05	0.20	0.91	0.31	0.08	2.46
I-38	86.00-86.50	0.54	0.79	0.41	0.39	0.35	0.21	0.66	2.65	0.74	0.27	7.00
I-41	92.00-92.50	0.29	0.43	0.19	0.15	0.13	0.15	0.17	1.16	0.29	0.10	3.07
I-42	94.00-94.50	0.20	0.25	0.18	0.14	0.15	0.07	0.10	1.10	0.45	0.13	2.77
I-45	100.00-100.50	0.19	0.27	0.14	0.14	0.08	0.12	0.11	0.99	0.30	0.12	2.45
I-56	130.00-134.00	0.06	0.08	0.04	0.03	0.03	0.05	0.04	0.35	4.52	0.03	5.23
I-58	140.00-142.00	0.18	0.24	0.13	0.11	0.10	0.06	0.12	1.43	0.62	0.12	3.11
I-63	160.00-162.00	0.28	0.37	0.28	0.27	0.20	0.21	0.29	1.99	0.04	0.18	4.12
Min.		0.06	0.08	0.04	0.03	0.03	0.04	0.04	0.35	0.04	0.03	1.83
Max.		0.54	0.79	0.41	0.39	0.35	0.21	0.66	2.65	4.52	0.27	7.00
Av.		0.23	0.33	0.20	0.17	0.17	0.10	0.20	1.26	0.83	0.11	3.61
Ponnapalli core												
P-1	0.00-0.50	0.02	0.05	0.04	0.02	0.02	0.01	0.01	0.08	0.10	0.03	0.38
P4	6.00-6.25	0.12	0.16	0.08	0.09	0.05	0.02	0.05	0.55	0.40	0.09	1.60
P-6	10.00-10.50	0.09	0.11	0.09	0.04	0.02	0.03	0.03	0.42	0.40	0.07	1.30
P-8	14.00-14.50	0.12	0.14	0.12	0.11	0.06	0.04	0.04	0.58	0.60	0.10	1.90
P-12	22.00-22.10	0.06	0.09	0.07	0.05	0.03	0.03	0.03	0.45	0.42	0.05	1.30
P-16	30.00-30.25	0.07	0.10	0.04	0.06	0.03	0.02	0.02	0.29	0.42	0.06	1.12
P-20	38.00-38.10	0.11	0.15	0.08	0.07	0.04	0.02	0.05	0.42	0.44	0.11	1.48
P-22	42.00-42.50	0.13	0.14	0.09	0.07	0.03	0.02	0.05	0.63	0.46	0.09	1.70
P-26	50.00-50.25	0.15	0.25	0.12	0.10	0.05	0.04	0.07	1.01	0.50	0.12	2.40
P-28	54.00-54.25	0.12	0.34	0.10	0.16	0.07	0.04	0.11	0.62	0.30	0.13	2.00
P-32	62.00-62.50	0.08	0.15	0.10	0.13	0.08	0.07	0.14	0.63	0.30	0.12	1.80
P-34	66.00-66.50	0.07	0.19	0.10	0.11	0.07	0.04	0.07	0.36	0.30	0.10	1.40
P-36	70.00-70.25	0.08	0.23	0.10	0.11	0.07	0.09	0.08	0.69	0.26	0.08	1.80
P-40	78.00-78.10	0.20	0.27	0.30	0.23	0.06	0.05	0.09	0.70	0.42	0.09	2.40
P-42	82.00-82.15	0.16	0.20	0.18	0.14	0.06	0.04	0.06	0.78	0.30	0.09	2.00
P-43	84.00-84.25	0.27	0.33	0.31	0.19	0.14	0.09	0.14	1.50	0.74	0.14	3.84
P-44	94.00-95.00	0.17	0.58	0.17	0.17	0.14	0.09	0.16	1.67	3.32	0.17	6.64

Table 1 Continued..

P-46	98.00-99.00	0.20	0.36	0.19	0.15	0.12	0.09	0.09	1.27	0.56	0.16	3.20
P-47	100.00-100.50	0.12	0.25	0.11	0.10	0.10	0.08	0.08	0.98	0.50	0.10	2.40
P-50	106.00-110.00	0.13	0.24	0.13	0.11	0.14	0.10	0.14	1.29	0.60	0.12	3.00
Min.		0.02	0.05	0.04	0.02	0.02	0.01	0.01	0.08	0.03	0.10	0.38
Max.		0.27	0.58	0.31	0.23	0.14	0.10	0.16	1.67	0.17	3.32	6.64
Av.		0.12	0.22	0.13	0.11	0.07	0.05	0.08	0.75	0.10	0.57	2.18
Nizampatnam core												
N-1	0.00-0.50	0.03	0.04	0.02	0.03	0.02	0.01	0.03	0.15	0.05	0.01	0.38
N-5	8.00-8.40	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.08	0.12	0.01	0.32
N-21	40.00-40.10	0.07	0.15	0.09	0.07	0.06	0.03	0.06	0.40	0.14	0.02	1.09
N-23	46.00-46.10	0.07	0.10	0.07	0.06	0.06	0.02	0.05	0.40	0.14	0.01	0.97
N-25	48.00-48.10	0.16	0.15	0.11	0.10	0.12	0.04	0.10	0.55	0.06	0.05	1.43
N-37	72.00-72.10	0.04	0.07	0.03	0.03	0.04	0.01	0.04	0.20	0.10	0.02	0.57
N-42	82.00-83.20	0.05	0.08	0.04	0.04	0.04	0.02	0.07	0.27	0.09	0.03	0.72
N-47	92.00-92.20	0.08	0.11	0.05	0.04	0.03	0.04	0.04	0.30	0.09	0.03	0.81
N-65	132.00-133.00	0.19	0.23	0.16	0.13	0.13	0.06	0.09	0.99	0.74	0.11	2.84
N-66	135.00-138.00	0.15	0.21	0.11	0.11	0.06	0.09	0.09	0.78	0.16	0.10	1.86
N-68	142.00-143.00	0.20	0.24	0.13	0.11	0.09	0.14	0.12	1.08	0.23	0.09	2.44
N-71	148.00-150.00	0.20	0.27	0.15	0.12	0.12	0.07	0.13	1.60	0.60	0.13	3.38
Min.		0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.08	0.01	0.05	0.32
Max.		0.20	0.27	0.16	0.13	0.13	0.14	0.13	1.60	0.13	0.74	3.38
Av.		0.10	0.14	0.08	0.07	0.07	0.04	0.07	0.57	0.05	0.21	1.40

Sil-Sillimanite, Gar-Garnet, Pyro-Pyroxene, Amphi-Amphiboles, Zir-Zircon, Rut-Rutile, Mon-Monazite, Ilm-Ilmenite, Mag-Magnetite, Oth-Other Heavy minerals and THM-Total Heavy minerals

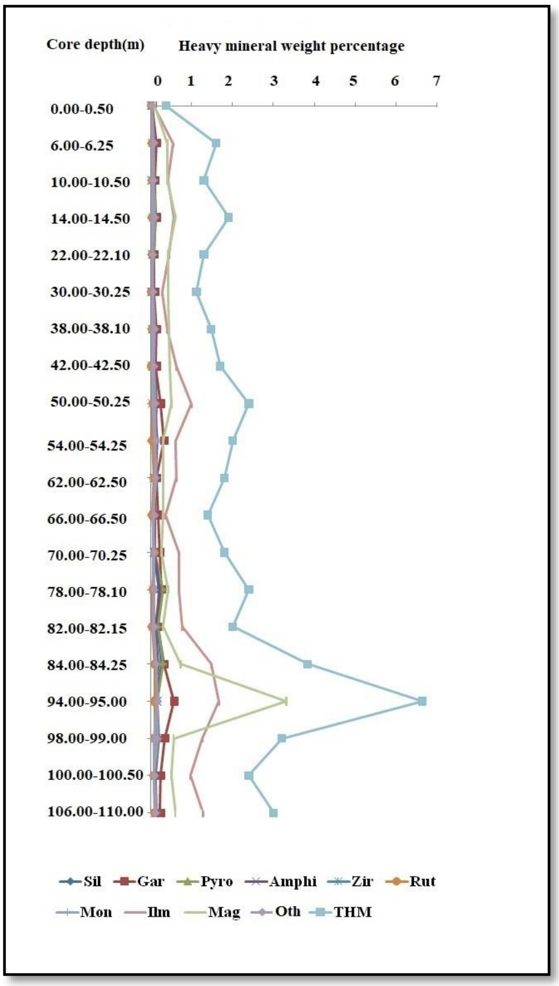

Fig. 6 Down core variation of an individual heavy minerals in

Fig. 7 Down core variation of an individual heavy minerals in Nizampatnam sediments in Ponnapalli sediments

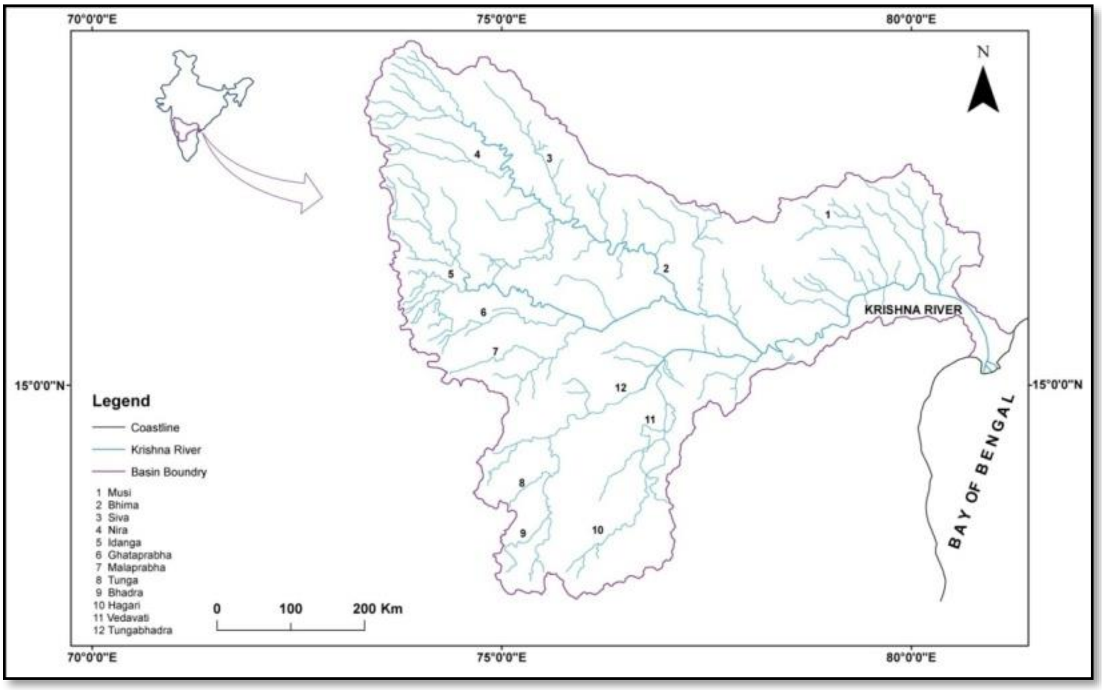

Fig. 8 Drainage map of the Krishna River basin (Source: Central Ground Water Board)

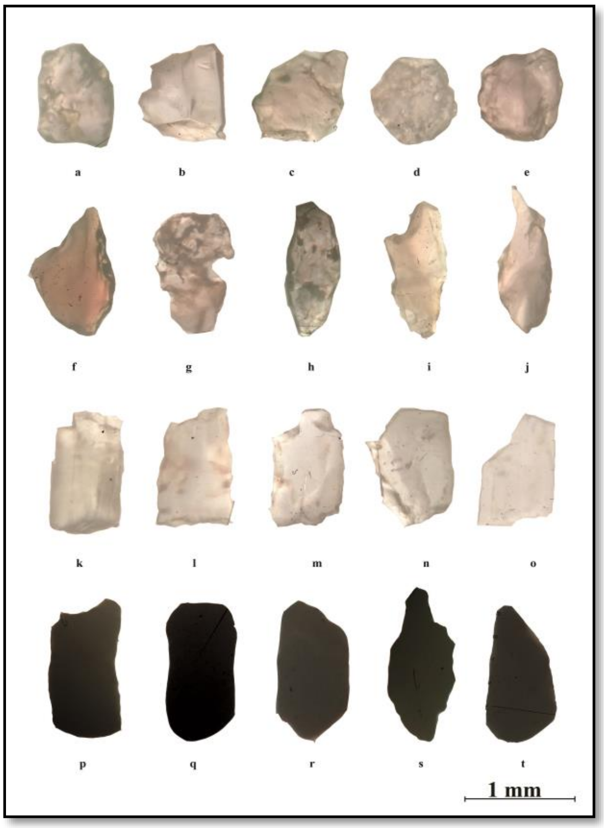

Plate 1 Microphotographs of garnets (a-j), sillimanites (k-o) and opaques (p-t) in study area

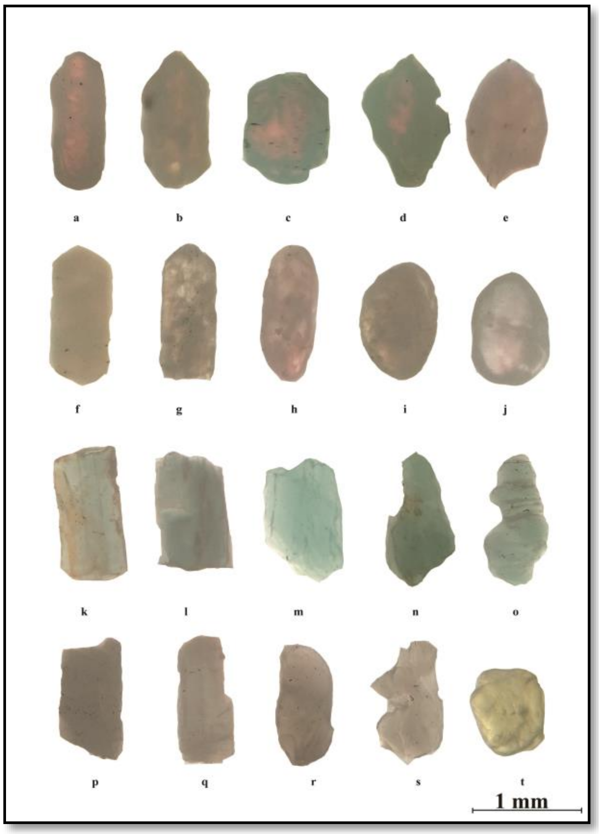

Plate 2 Microphotographs of rutile (a-e), zircon (f-j), pyroxenes (k-o), amphiboles (p-s) and monazite (t) in study area

content in Ponnapalli core sediments are given in Table 1. The heavy mineral assemblage in Ponnapalli core sediments is opaques (Ilmenite + magnetite), garnet, sillimanite, pyroxenes, monazite, amphiboles, zircon, and rutile in order of decreasing abundance (Fig .6). The total heavy mineral (wt%) ranges from 0.38 to 6.84% (av. 2.18%). The maximum heavy mineral content 6.64% occurred at a depth of (94.00-95.00m) followed by 3.84% (84.00-84.25m), 3.20% (98.00-99.00m) and 3.00% (106.00-110.00m). The minimum content of heavy mineral is 0.38% occurred at a depth of 0.00-0.50m followed by 1.12% (30.00-30.25m), 1.30% (10.00-10.50m, 22.00-22.10m) and 1.48% (38.00-38.10m). In Ponnapalli core sediments, an average total heavy mineral (THM) weight percentage is 2.18%, in which 34% ilmenite, 26% magnetite, 10% garnet, 6% sillimanite, 6% pyroxenes, 5% amphiboles and other heavy minerals each, 3% zircon and monazite each and 2% rutile (Fig. 4 c).

Nizampatnam Core

Twelve sand samples from various depths of Nizampatnam core were subjected to heavy mineral analysis and results i.e. the down core variations of total heavy minerals (wt %) and individual heavy minerals (wt %) content in Nizampatnam core sediments are given in Table 1. The heavy mineral assemblage in Nizampatnam core sediments is opaques (Ilmenite + magnetite), garnet, sillimanite, pyroxenes, monazite, amphiboles, zircon, and rutile in the order of decreasing abundance (Fig. 7). The total heavy minerals (wt %) content ranges from 0.32 to 3.38% (av. 1.40%). The maximum heavy mineral content 3.38% occurred at a depth of 148-150m and 2.84% (132-133m). The minimum heavy mineral content 0.32% occurred at a depth of 8.00-8.40m followed by 0.38% (0.00-0.50m), 0.57% (72.00-72.10m), 0.72% (82.00-83.20m), 0.81% (92.00-92.20m) and 0.97% (46.00-46.10m).

In Nizampatnam core sediments, an average total heavy mineral (THM) weight percentage is 1.40%, in which 40% ilmenite, 15% magnetite, 10% garnet, 7% sillimanite, 6% pyroxenes, 5% amphiboles, zircon and monazite each, 4% other heavy minerals and 3% rutile (Fig. 4 d).

DISTRIBUTION PATTERN OF INDIVIDUAL HEAVY MINERALS IN DIFFERENT CORE SEDIMENTS

The main heavy minerals of the Krishna River sands consist of opaques (Ilmenite + magnetite), garnets and sillimanites. The lesser content of heavy minerals are pyroxenes, amphiboles, zircon, rutile and monazite (Plates 1 and 2).

Garnets

The concentration of garnets in Turumella core sediment ranges from 0.02 to 0.42% with an average of 0.24%. In Inturu core sediments, the concentration of garnet ranges from 0.08 to 0.79% with an average of 0.33%. In Ponnapalli core sediments, the concentration of garnet ranges from 0.05 to 0.58% with an average of 0.22%. In Nizampatnam core sediments, the concentration of garnet ranges from 0.02 to 0.27% with an average of 0.14%. The average concentration of garnets in decreasing order of abundance, among the four cores are Inturu (0.33%), Turumella (0.24%), Ponnapalli (0.22%) and Nizampatnam (0.14%).

Sillimanite

The concentration of sillimanite in Turumella core ranges from 0.02 to 0.30% with an average of 0.16%. In Inturu core sediments, the concentration of sillimanite ranges from 0.06 to 0.54% with an average of 0.23%. In Ponnapalli core sediments, the concentration of sillimanite ranges from 0.02 to 0.27% with an average of 0.12%. In Nizampatnam core sediments, the concentration of sillimanite ranges from 0.02 to 0.20% with an average of 0.10%. The average concentration of sillimanite in decreasing order of abundance, among the four cores are Inturu (0.23%), Turumella (0.16%), Ponnapalli (0.12%) and Nizampatnam (0.10%).

Opaques

The concentration of opaques (Ilmenite + magnetite) in Turumella core ranges from 0.28 to 2.85% with an average of 1.51%. In Inturu core sediments, the concentration ranges from 0.92 to 4.87% with an average of 2.09%. In Ponnapalli core sediments, the concentration ranges from 0.18 to 4.99% with an average of 1.31%. In Nizampatnam core sediments, the concentration ranges from 0.19 to 2.20% with an average of 0.78%. The average concentration of opaques (Ilmenite + magnetite) in decreasing order of abundance, among the four cores Inturu (2.09%), Turumella (1.51%), Ponnapalli (1.31%) and Nizampatnam (0.78%.).

Pyroxenes

The concentration of pyroxenes in Turumella core varies from 0.01 to 0.23% with an average 0.13%. In Inturu core sediments, the concentration of pyroxene ranges from 0.04 to 0.41% with an average 0.20%. In Ponnapalli core sediments, the concentration of pyroxene varies from 0.04 to 0.31% with an average 0.13%. In Nizampatnam core sediments, the concentration of pyroxene ranges from 0.02 to 0.16% with an average 0.08%. The average concentration of pyroxenes in decreasing order of abundance, among the four cores Inturu (0.20%), Turumella (0.13%), Ponnapalli (0.13%) and Nizampatnam (0.08%.).

Amphiboles

The concentration of amphiboles in Turumella core varies from 0.01 to 0.23% with an average 0.11%. In Inturu core sediments, the concentration of amphiboles ranges from 0.03 to 0.39% with an average 0.17%. In Ponnapalli core sediments, the concentration of amphibole varies from 0.02 to 0.23% with an average 0.11%. In Nizampatnam core sediments, the concentration of amphibole ranges from 0.01 to 0.13% with an average 0.07%. The average concentration of amphiboles in decreasing order of abundance, among the four cores Inturu (0.17%), Turumella (0.11%), Ponnapalli (0.11%) and Nizampatnam (0.07%.).

Zircons

The concentration of zircons in Turumella core varies from 0.01 to 0.21% with an average 0.11%. In Inturu core sediments, the concentration of zircon ranges from 0.03 to 0.35% with an average 0.17%. In Ponnapalli core sediments, the concentration of zircon varies from 0.02 to 0.14% with an average 0.07%. In Nizampatnam core sediments, the concentration of zircon ranges from 0.02 to 0.13% with an average 0.07%. The average concentration of zircons in decreasing order of abundance, among the four cores Inturu (0.17%), Turumella (0.11%), Ponnapalli (0.07%) and Nizampatnam (0.07%.).

Rutile

The concentration of rutile in Turumella core varies from 0.01 to 0.19% with an average 0.08%. In Inturu core sediments, the concentration of rutile ranges from 0.04 to 0.21% with an average 0.10%. In Ponnapalli core sediments, the concentration of rutile varies from 0.01 to 0.10% with an average 0.05%. In Nizampatnam core sediments, the concentration of rutile ranges from 0.01 to 0.14% with an average 0.04%. The average concentration of rutile in decreasing order of abundance, among the four cores Inturu (0.10%), Turumella (0.08%), Ponnapalli (0.05%) and Nizampatnam (0.04%.).

Monazite

The concentration of monazite in Turumella core varies from 0.01 to 0.23% with an average of 0.13%. In Inturu core sediments, the concentration of monazite ranges from 0.04 to 0.66% with an average 0.20%. In Ponnapalli core sediments, the concentration of monazite varies from 0.01 to 0.16% with an average 0.08%. In Nizampatnam core sediments, the concentration of monazite ranges from 0.01 to 0.13% with an average 0.07%. The average concentration of monazite in decreasing order of abundance among the four cores is Inturu (0.20%), Turumella (0.13%), Ponnapalli (0.08%) and Nizampatnam (0.07%).

DISCUSSION

The core sediments of the Krishna delta under this study same heavy mineral assemblages i.e. opaques (Ilmenite + magnetite), pyriboles (pyroxenes + amphiboles), garnet, zircon, monazite, rutile and other heavy minerals (epidote, kyanite, tourmaline, etc.). The average heavy minerals wt% in the core sediments of Turumella, Inturu, Ponnapalli and Nizampatnam are 2.59%, 3.60%, 2.40% and 1.40% respectively, there is no systematic variation either increase or decrease of heavy minerals content from top to bottom of studied cores.

The variation of heavy mineral content in river sediments is controlled by (a) source rocks, (b) weathering conditions, (c) which part of the drainage basin area exposed to erosion (river erosion) linked with the rainfall, (precipitation) (d) energy of the river environment.

Present day Krishna River basin has 12 tributaries (Fig. 8), each carries the sediment load and joins in the main river channel. Depending on the rainfall and source rocks of sub basins, the nature of sediment depends similarly in the geological past also the Krishna River had a number of tributaries controlled by sediment load.

Most of the sediment in the studied cores are of polymodal nature, it indicates that the sediments were derived from many sources. The occurrence of different lithological units in the drainage basins is contributing sediments, mainly opaques (Ilmenite + magnetite) and pyriboles (Amphibole + pyroxenes) are from Deccan traps as well as Archean provenance which covered more than 55% of drainage basin. The red garnets (almandine), prismatic sillimanites and rounded zircons are derived from khondalites (metapeletic rocks) and pink garnets, elongated zircons and ortho- pyroxenes derived from charnockites of Eastern Ghat Granulite Belt (EGGB). Similar observations were made in sub environments of Godavari delta (Sambasiva Rao, 1979) and in Pudimadaka - Pentakota coastal sediments along the east coast of India (Rajasekhar Reddy et al., 1998). The fresh appearance of heavy minerals indicates that short residence time in depositional environment without any chemical dissolution effect.

The rounded and sub rounded grains of magnetite and ilmenite indicate long distance of transportation and/or reworked nature. The sub angular grains of magnetite and ilmenite were indicating that they might have been derived from nearby sources, i.e. mainly an Eastern Ghat Group of rocks. The prismatic characteristic of the sillimanite mineral grains also suggests that these were derived from khondalitic rocks. The heavy mineral assemblages of present day Krishna River sediments (Krishna Rao and Swamy, 1991) and studied cores are same.

CONCLUSIONS

1. Total heavy minerals wt% varies from 0.32 to 7.00 (av. 2.44%) in the study area. The heavy mineral concentration is higher in Inturu (3.61%), followed by Turumella (2.59%), Ponnapalli (2.18%) and Nizampatnam (1.40%).
2. The opaques (Ilmenite + magnetite) and pyriboles (Amphiboles + pyroxenes) are dominant in the present study; these are from Deccan traps as well as Archean provenance.
3. Garnets, sillimanites and zircons are derived from khondalites (metapeletic rocks) and charnockites of Eastern Ghat Granulite Belt.
4. Presence of rounded zircons and rutiles in some samples indicate that, they are sourced from reworked sediments. In some places anhedral rutiles are also present. They are probably derived from the adjoining acid igneous and metamorphic rocks. Presence of monazites indicates that they have been derived either from the Eastern Ghat Group of rocks or from reworked sediments of Western Ghat rocks or from both.
5. The fresh appearance of heavy minerals indicates that short residence time in depositional environment without any chemical dissolution effect.

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Received: 6th December, 2021
Revised Accepted 21st May, 2022