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Provenance and Tectonic Setting of the late Paleoproterozoic Clastic Sedimentary Rocks of the Cuddapah Basin, South India

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Abstract

A geochemical study on mudstone from sandstone-mudstone heterolith of Paleoproterozoic Gulcheru Formation of the Cuddapah Supergroup reveals two simultaneous sources, contributing sediments to the basin, one is a weathered source and the other is juvenile input as indicated by the CIA (average 67) values ranging from 53 to 90. A weak to moderate positive correlation between Fe_2O_3 + MgO and Al_2O_3 (r=0.4) contents indicate the dominance of mafic rock fragments, clay minerals and/or micas. The trace element ratios like Th/U of <4 are indicative of first cycle sediment input and >4 were recycled sediments with some degree of weathering. The REE patterns of the shales (normalized to chondrite) are LREE enriched with a flat HREE, lacking strong Eu deficiency while some of the samples show pronounced positive Eu anomaly indicating both felsic and mafic derivation. This mixed source is also indicated by a wide range in the La/Th ratios (avg., 3.4; range 0.9-7.1) and high positive correlation (r = 0.8) between Cr and Ni. These observations imply that sediments were mainly derived from dissected arc-systems and mixed with continental derived sediments. Thus the involvement of the arc systems place constraints on the nature of plate boundary in eastern part of the Cuddapah basin and relate it to the supercontinent episodes during the Proterozoic thus involving a more complex paleogeodynamic evolution of the Cuddapah basin.

Keywords: Cuddapah, Shales, Geochemistry, Provenance, Weathering.

Introduction

Many studies have successfully infer the geochemical composition of terrigenous sediments leading to delineation of provenance types[1,2], source-area weathering conditions[3], and tectonic settings of a sedimentary basin[4]. The purpose of the present geochemical study is to highlight a detailed provenance characterization including geodynamic evolution during the deposition of the basal Palaeoproterozoic Gulcheru Formation, Cuddapah basin[5-8], India near and around Kottalu area based on some mudstone samples.

The present work is based on detailed study of vertical sections of sandstone-mudstone heterolithic horizon around the village Kottalu (70º3'30", 14º1'37", SOI toposheet No. 57J/3) in the Palkonda hill-range along Pullivendla-Kadiri Highway, 12 km SW of Pullivendla town (Figure-1, 2).

Methodology

Geochemical analysis was carried out for fifteen representative mudstone samples of the study area elements by the X-ray fluorescence spectrometry (XRF) for major chemical elements and the data was presented in Table-2a, b and c**.** The rock chips were powdered using TEMA swing mill to –200 mm mesh size. The major and trace elements were analyzed by Wave Length Dispersive XRF system (Siemens SRS 3000) at Wadia Institute of Himalayan Geology (WIHG), Dehradun. Analysis was carried out using pressed powder pellets glued with polyvinyl alcohol. The analytical procedure followed was as given by Lucas-Tooth and Pyne[9]. REE was measured by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS; Perkin Elmer) at WIHG, with 0.04 g of the sample subjected to standard acid digestion with HF–HNO_3.

The standard acid treatment was repeated until a clear solution was obtained. The clear solution was then treated with 1 N HNO_3. The accuracy and precision was ± 1–3% for major oxides and for trace and REEs ± 5–10%.

Results and Discussion

From the data (Table-1a, b, c) it is clear that the range of compositions for the mudstone samples of the study area is narrow. The studied samples are low in average TiO_2 (~ 0.5 wt.%) and Al_2O_3/SiO_2 ratios (~ 0.19). The average Fe_2O_3 + MgO (i.e., total Fe as Fe_2O_3) concentration is 12%. The K_2O/Na_2O ratios are showing wide variation, which range from 3.8 to 38 (avg. 18.12). The low concentration of Na_2O may be the reason for the high K_2O/Na_2O ratios. The low concentration

of the Na_2O content in the studied sediments may be attributed to its depletion process in the area or its strong by weathering mobility at the area of deposition. TiO_2 reveals strong correlation with the Al_2O_3. There appears to be a weak-moderate positive correlation between Fe_2O_3 + MgO and Al_2O_3 (r=0.4) contents and this may probably with clay minerals and/or micas. The ternary CIA plot shows two sets of samples with one set having affinity towards illite (one sample towards muscovite) and the other set tends to be inclined towards K-feldspars which indicates both high to low degree of weathering intensity. The CIA vs SiO_2 plot also supports this fact and showing distinct sample sets, indicating both weathered and un-weathered sources with affinity towards average shale and granitic composition, respectively. Hydraulic sorting also influence the chemical composition of sedimentary rocks thereby concentrating weathering-resistant phases such as zircon, apatite, monazite and Cr-spinel, and these minerals in turn may create irregularities in chemical concentrations of some trace elements[10].

The Gulcheru Formation samples have relatively moderate Th/Sc ratios (average 0.78) and therefore reflect input from fairly evolved crustal igneous sources and still lower Th/Sc ratios suggest contribution from mafic source. The sedimentary sorting and recycling as-well-as provenance may monitored by a diagramating representation of Th/Sc against Zr/Sc[11] (Figure-3). The Gulcheru sediments show two sets of Cr enrichment, with one set having a range varying between 5-86 and the other 101-221 ppm, compared with the average upper continental crust of approximately 80 ppm. Cr and Ni elements are probably derived from mafic volcanic rocks[12]. The high Cr/Ni ratio and a high correlation coefficient between chromium and nickel (r=0.8) and low correlation of Cr versus Co (r=0.2), and Ni with Co (r=0.5) suggests the existence of mafic/ultra-mafic rocks were most likely in the source region. The samples having higher V concentrations (25–139 ppm) further attest to mafic input[13].

The trace element ternary diagrams La-Th-Sc and Sc-Th-Zr/10 (Figure-4) of Gulcheru sediments also demonstrate a wide range of sediment derivation from arc settings. Within the sediments of the Gulcheru Formation, different types of REE patterns are observed. In general, the chondrite normalized REE patterns of these mudstones are characterized by enriched LREE, relatively flat HREE, with negative and positive Eu anomalies (Figure-5). The high La/Th ratios (between 4.8 and 7.1) in the studied samples indicate a mafic input. This is also further substantiated by a wide variation in the Cr and Ni values (Table-1b) together with a significant positive correlation (r = 0.8). Thus a change in the pattern of REE distribution reflects a change in the source area.

Table-1a
Major element concentrations in wt.% for shales of the Gulcheru Formation

Sample No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
MV2	71.04	0.61	12.05	9.52	0.01	0.61	0.10	0.12	0.94	0.04
MV10	74.16	0.50	10.33	8.66	0.01	0.55	0.23	0.10	0.74	0.08
TFM2	60.79	0.45	13.11	8.00	0.03	6.82	0.49	0.18	6.40	0.17
MV6	63.20	0.48	8.11	5.05	0.01	0.54	9.01	0.07	0.72	0.03
P1/1	63.14	1.08	12.38	3.27	0.03	5.06	1.49	0.23	8.82	0.14
MV1	69.25	0.64	13.08	9.09	0.01	0.84	0.28	0.28	1.07	0.05
MV8	47.97	0.43	9.43	2.48	0.01	0.53	17.59	0.08	0.82	0.04
TFM4	58.77	0.63	10.51	7.56	0.03	12.17	1.44	0.25	2.88	0.18
P15/1	61.50	0.65	11.26	9.99	0.09	5.43	0.42	0.18	8.10	0.09

Table-1b
Trace element concentrations in ppm for shales of the Gulcheru Formation

Sample No	Ba	Cr	V	Co	Ni	Cu	Zn	Ga	Pb	Th	Rb	U	Sr	Y	Zr	Nb	Sc
MV2	1160	221	139	9	48	37	21	18	0.1	8	49	9.70	24	29	107	8	16.1
MV10	2287	215	119	9	34	29	11	15	0.1	10	40	3.66	36	20	97	6	13.7
TFM2	511	200	106	20	53	15	20	16	0.1	8	144	3.41	19	21	86	8	8.3
MV6	*4844*	102	42	7	24	22	7	10	0.1	5	24	0.21	95	13	50	5	9.4
P1/1	*6287*	20	72	13	29	9	7	13	0.1	8	101	2.44	85	19	136	13	19.6
MV1	1291	210	138	12	44	36	19	19	0.1	14	51	5.83	37	30	126	9	14
MV8	*14583*	26	16	7	17	18	3	4	0.1	3	17	0.14	161	13	21	5	7.6
TFM4	234	197	137	61	60	9	40	18	0.1	10	76	4.61	25	19	119	8	11.4
P15/1	633	60	101	18	48	10	8	13	0.1	8	131	4.01	11	21	100	7	14

Table-1c
Rare earth element concentrations in ppm for shales of the Gulcheru Formation

Sample No.	MV-2	MV-10	TFM 2	MV-6	P 1/1	MV-1	MV8	TFM 4	P 15/1
La	29.6	27.2	28.8	23.8	24.1	32.4	21.4	21.2	25.3
Ce	51.4	47.4	52	42.5	46.8	55.4	34.8	40.4	49.3
Pr	5.5	5.8	4.9	4.6	4.6	6	3.8	3.8	4.3
Nd	21.7	24.4	18.7	17.9	18.7	23.6	15.1	15.2	17.2
Sm	4.31	4.31	3.3	3.31	3.56	4.61	3.38	2.83	3.01
Eu	1.15	1.33	0.79	1.98	2.48	1.27	5.06	0.56	0.86
Gd	3.84	3.44	2.72	2.71	3.27	4.05	3.09	2.38	2.68
Tb	0.65	0.57	0.44	0.44	0.61	0.69	0.5	0.41	0.46
Dy	3.85	3.21	2.44	2.56	3.83	3.89	2.77	2.51	2.76
Ho	0.8	0.66	0.49	0.53	0.85	0.85	0.59	0.56	0.59
Er	2.44	2.06	1.55	1.66	2.57	2.49	1.68	1.8	1.84
Tm	0.36	0.3	0.24	0.24	0.39	0.35	0.23	0.28	0.28
Yb	2.07	1.78	1.46	1.42	2.31	2.07	1.31	1.75	1.66
Lu	0.33	0.28	0.23	0.23	0.37	0.32	0.25	0.28	0.27
ΣREE	128	122.74	118.06	103.88	114.44	137.99	93.96	93.96	110.51
Eu/Eu*	0.86	1.06	0.81	2.02	2.22	0.90	4.79	0.66	0.93
(Gd/Yb)N	1.53	1.60	1.54	1.58	1.17	1.62	1.95	1.13	1.34
(La/Yb)N	10.26	10.96	14.15	12.02	7.48	11.23	11.72	8.69	10.93
(La/Sm)N	4.43	4.07	5.63	4.64	4.37	4.54	4.09	4.84	5.43

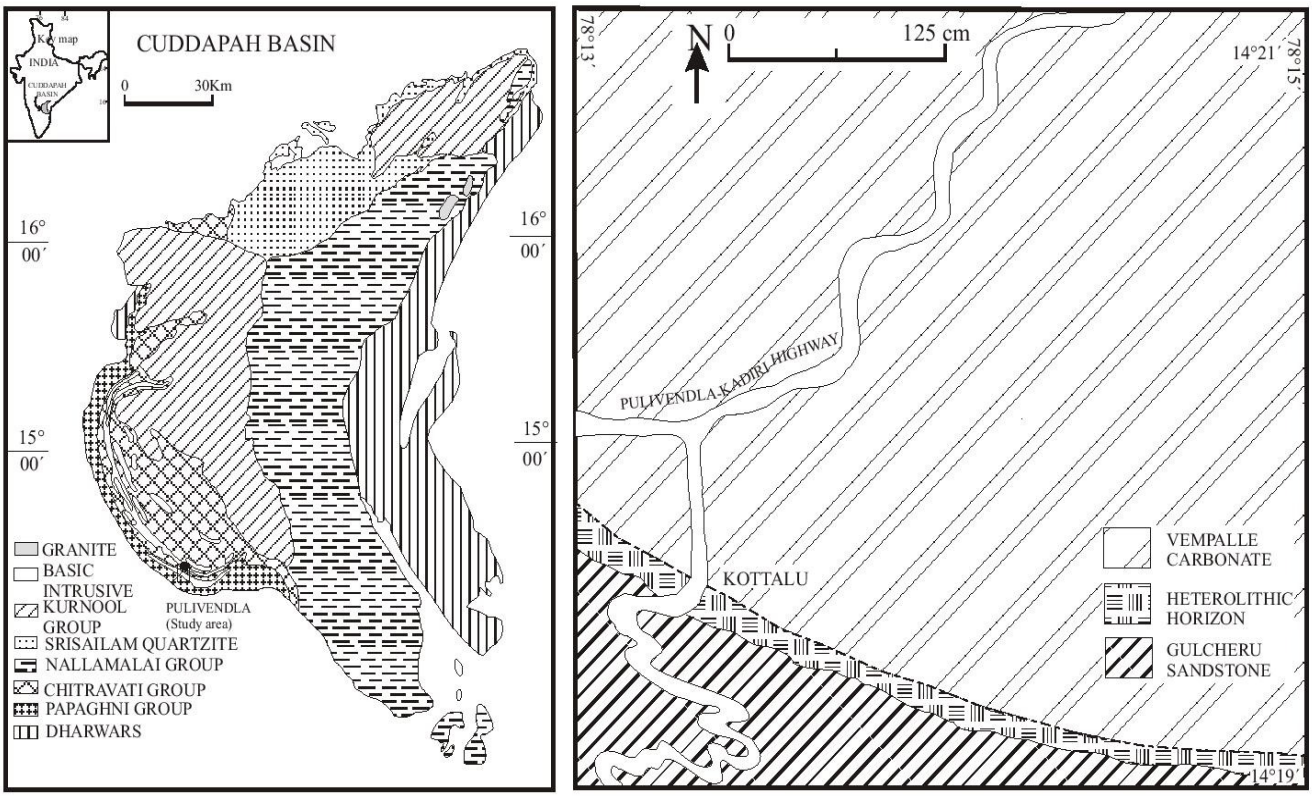

Figure-1
Geological map of the Cuddapah basin showing the location of the study area[17]

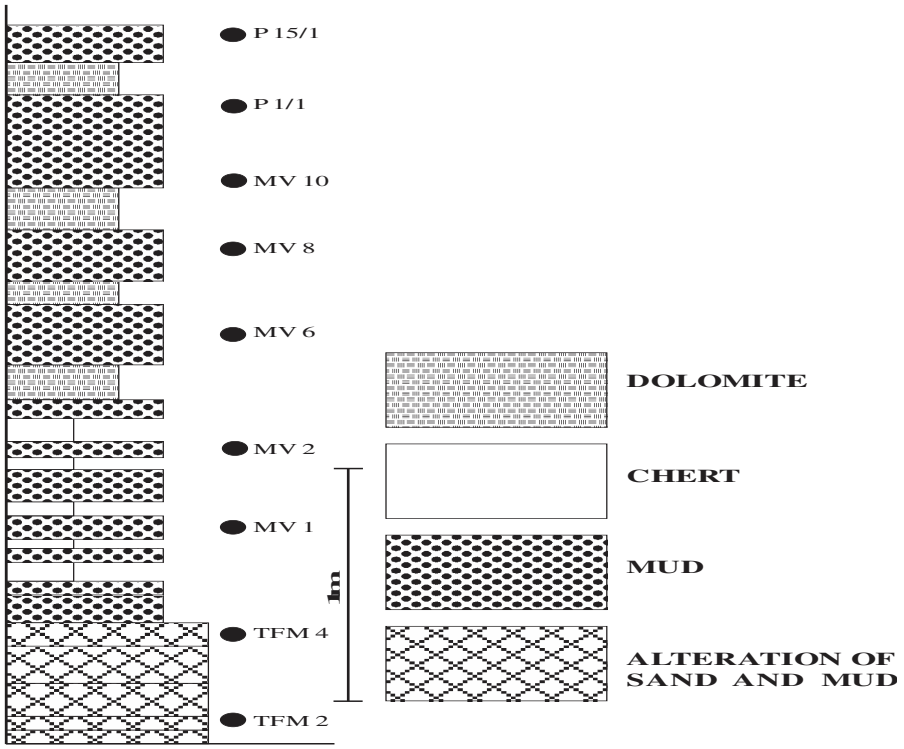

Figure-2
Stratigraphic section of the Gulcheru Formation showing sample locations

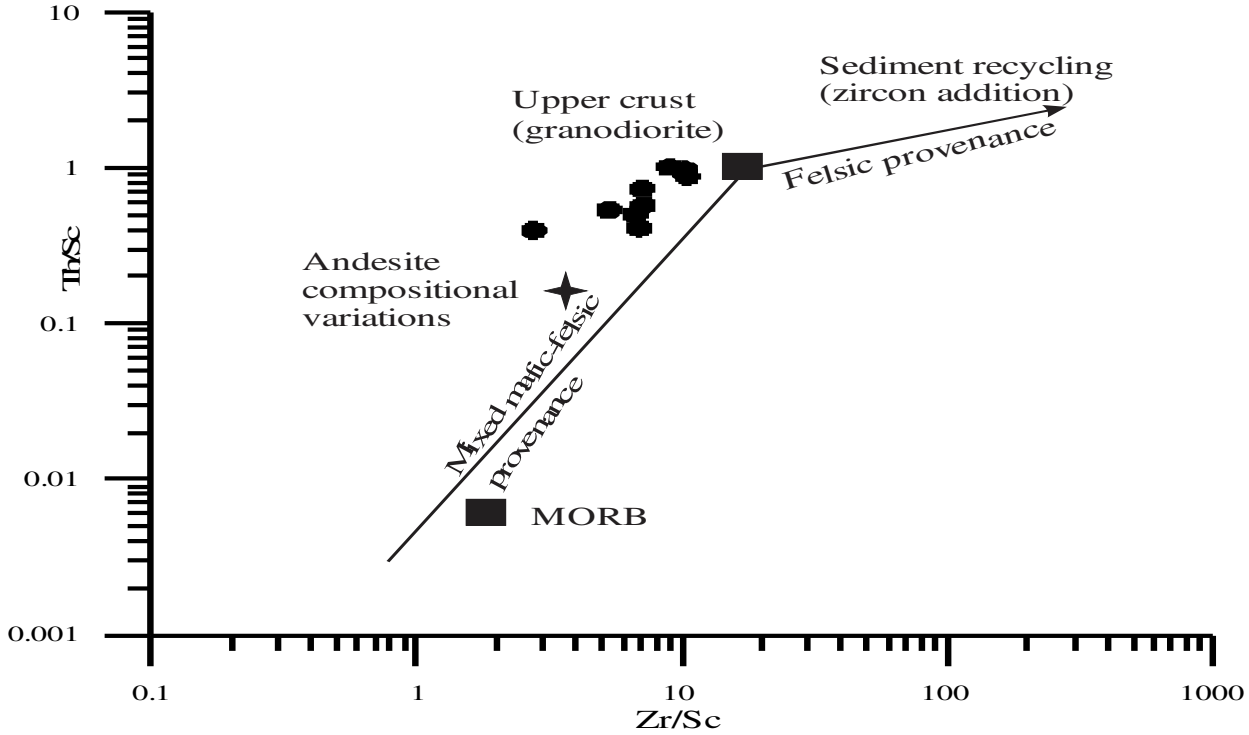

Figure-3

Th/Sc vs. Zr/Sc binary diagram indicating a compositional variation between andesite and granodiorite[18]

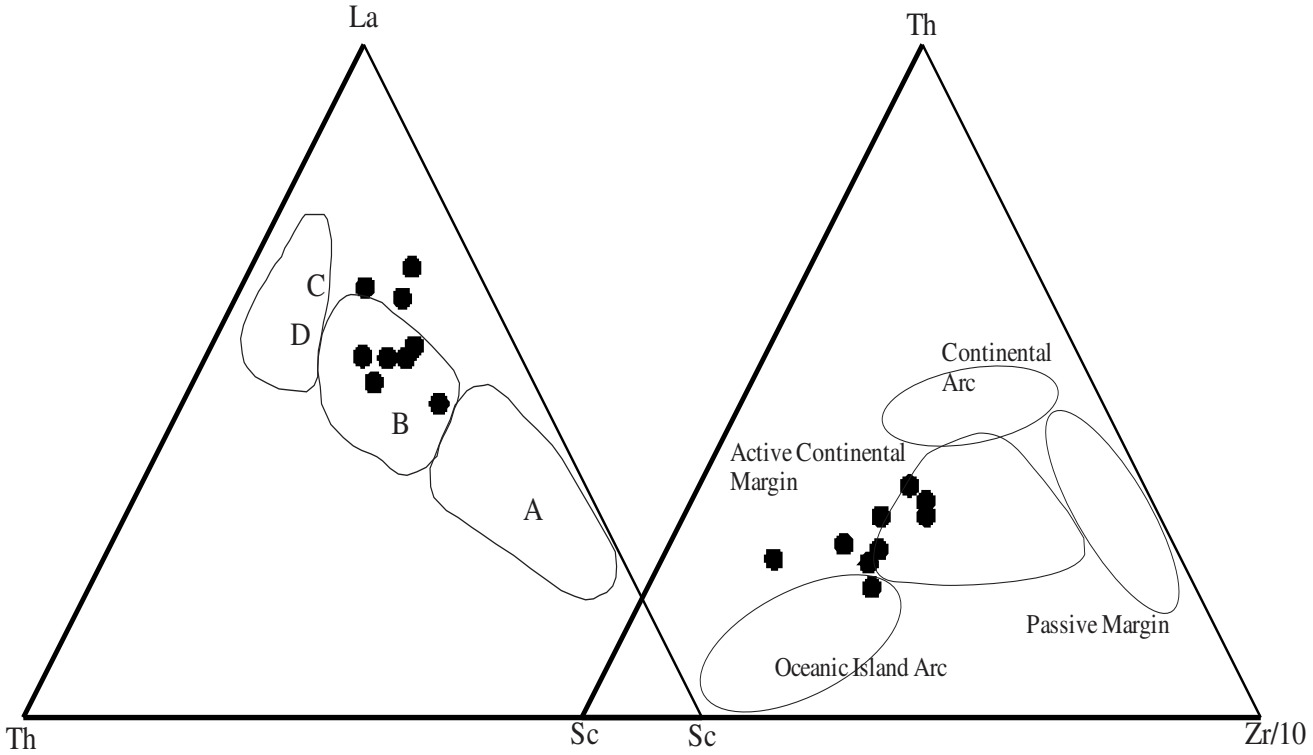

Figure-4

Ternary diagrams La-Th-Sc and Sc-TH-Zr/10. A= Oceanic island arc; B= Continental island arc; C=Active continental margin; D= Passive margin[16]

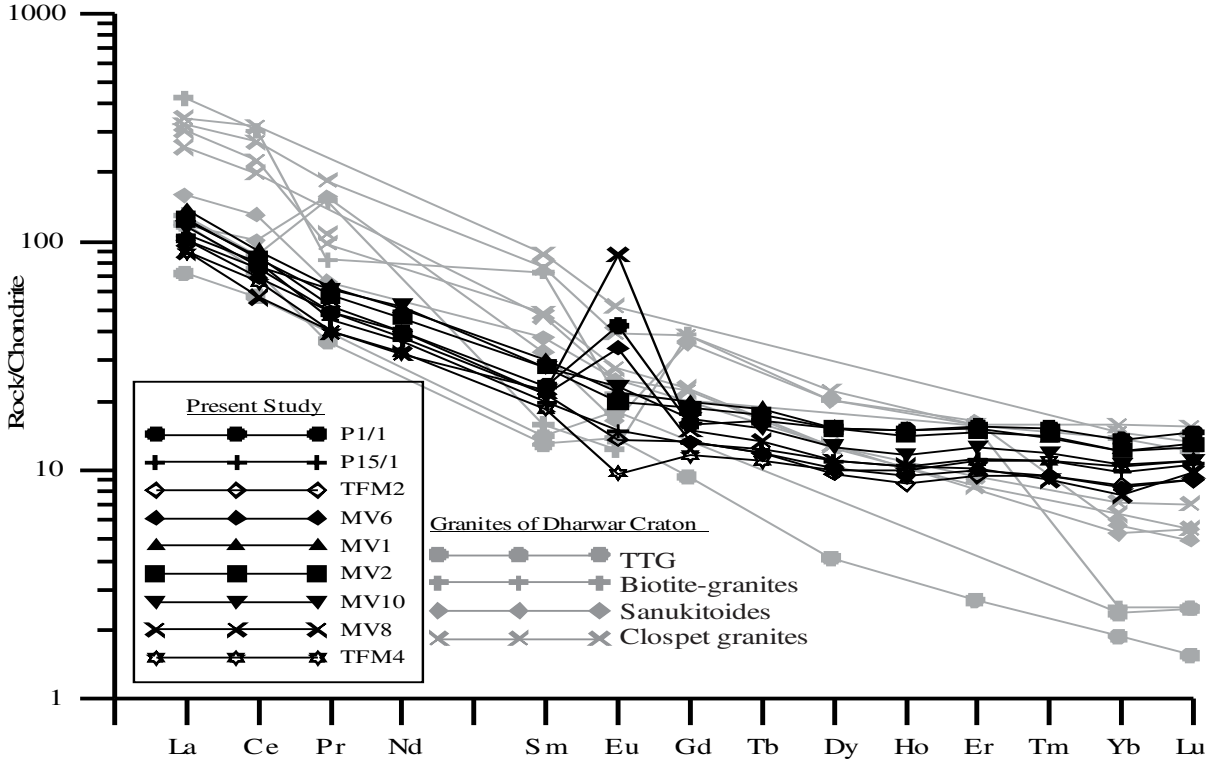

Figure-5

Chondrite normalized REE diagrams for the Gulcheru Formation showing low-moderate LREE enrichment and flat HREE with negative to near positive to high positive Eu anomalies[19]

Conclusion

The major, trace and REE characteristics of the Gulcheru sediments are compatible with those of the detritus derived from active continental margin to continental arc settings. This suggests that a marginal or interarc basin and the juvenile sediments were mainly derived from dissected arc-systems and are variably mixed with sediments derived from older upper continental crust along with some mafic input. These observations thus place constraints on the nature of plate boundary in eastern part of Cuddapah basin during the Proterozoic suggesting a more complex paleogeodynamic evolution of the Cuddapah basin at the backdrop of global supercontinent episodes during the Palaeoproterozoic[14-16] time.

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