JOURNAL INDIAN ASSOCIATION OF SEDIMENTOLOGISTS ISSN NO. 2582 - 2020
Vol. 37, Issue 2, 2020, pp. 115-130
DOI: http://dx.doi.org/10.51710/jias.v37i2.112

Sedimentological and Geochemical Charectesization of Manaveli and Cuddalore Formations, Puducherry Basin, India

Shyam N. Mude, Shyam Yawale and Vishal Choudhari
Department of Geology, Fergusson College (Autonomous), Pune- 411004, India
Email: shyam.mude@fergusson.edu; shyammude25@yahoo.co.in

Abstract

The rocks of Puducherry basin have been classified as Valudavur, Mettuveli, Karasur, Manaveli, Cuddalore formations in chronological order. The sedimentological and geochemical studies of the sediments from Manavali (Paleocene) and Cuddalore (Mio-Pliocene) formations were carried out to understand the grain-size variation and distribution of major oxides to deduce depositional environment, provenance, paleoclimate and source area weathering conditions. The sieve analysis was used to study grain size variations evaluated for various geo-statistical parameters to understand the depositional environment. The discriminant function analysis of the sediments from the Cuddalore Formation infers that mostly the sedimentation occurred in fluvio-deltaic environment with incursions of shallow marine environment whereas bivariate plots suggest that the deposition occurred in riverine to deltaic environments. The values of CIA (chemical index of alteration), CIW (chemical index of weathering), ICV (index of compositional variability) and PIA (plagioclase index of alteration) of the sediments infer intense weathering conditions prevailed in the source area during the deposition of Manaveli and Cuddalore formations. The ratio of (Al_2O_3+K_2O+Na_2O)/SiO_2 indicate semi-humid climatic conditions during deposition of the Cuddalore Formation whereas Manaveli Formation was deposited in semi-arid climatic conditions. The discriminant function diagram suggests sedimentary provenance for Cuddalore and Mafic igneous provenance for Manaveli Formation.

Keywords: Grain-size, Depositional environment, Geochemistry, Manaveli, Cuddalore, Puducherry Basin

Introduction

The Cretaceous-Paleocene sediments of the Cauvery Basin are classified into five formations viz., Sillakudi, Kallankurichchi, Ottakoil, Kallamedu and Niniyur (Sundaram and Rao 1986). A lot of work has been carried out in the field of stratigraphy, sedimentology and palaeontology (Ayyasamy, 1990; Blanford, 1862; Chandrasekaran et al., 1996; Govindan et al., 1996, 2000; Hart et al., 2000; Kossmat, 1897; Muthuvairvasamy et al., 2003; Mamgain et al., 1968, 1973; Nair and Vijayam 1980; Radulovic and Ramamoorthy 1992; Ramasamy and Banerji, 1991; Sastry and Rao 1964; Sastry et al., 1972, 1968, 1977; Srivastava and Tewari, 1967; Tewari et al., 1996; Venkatachala, 1974; Venkatachalapathy and Ragothaman 1995; Yadagiri and Govindan, 2000; Nagendra et al., 2010, 2011; Prasad et al., 2013; Reddy et al., 2013; Sarkar et al., 2014, Nagendra and Reddy, 2017; Jaiprakash et al., 2016; Nagendra et al., 2019). Cretaceous fossil calcareous algae from the Cauvery Basin has been documented by various researchers (Rajanikanth 1992; Rao and Prasannakumar 1932; Rao and Pia. 1936; Rao and Gowda, 1954; Misra and Kumar, 1988; Misra et al., 2004 and 2006) whereas Cenozoic fossil calcareous algae have been also reported from Cauvery Basin (Misra et al., 2000, 2001, 2003; Kishor et al., 2003; Kishor, 2004a, 2004b; Kishor and Singh, 2004).

Puducherry region is situated on the Coromandel Coast between 11°45´ to 12°03´N and 79°37´ to 79°53´E with an area of 293 sq. km. The Cauvery rift basin trending NE-SW, ranges from Late Jurassic to Early cretaceous (Powell et al., 1988). A complete section of upper Cretaceous to Paleocene is exposed in the Ariyalur – Puducherry sub basin (Sastry & Rao, 1964). The rocks exposed in and around Puducherry are represented by Valudavur, Mettuveli, Karasur, Manaveli, Cuddalore formations in chronological order. Grain size data play a significant role in interpretation of depositional environment and specific grain size distribution can be used to estimate the environment of deposition of clastic rocks (Udden,1898; Krumbein, 1934; Folk and Ward, 1957; Greenwood, 1969; Visher, 1969 and Friedman, 1979, Ghosh and Chatterjee, 1994; Ghaznavi et al., 2019; Quasim et al., 2020). On the basis of grain size, interpretation can be obtained by two methods, first is statistical method which includes mean, standard deviation, skewness, kurtosis etc. It can be calculated by graphic or moment method and with the combination of statistical methods like mean vs standard deviation, standard deviation vs skewness, skewness vs kurtosis

(Friedman, 1962, 1967, 1979). The second method is qualitative observation of shape of cumulative frequency curves on probability paper (Spencer, 1963 and Visher, 1969). Multivariate discriminant analysis is also useful to understand depositional environment using parameters like mean, standard deviation, skewness, kurtosis by graphic or moment method (Mahalanobis, 1930; Greenwood, 1969). The interpretation of depositional environment, the interrelationship of specific grain size parameter is very important, as textural parameters of sediment are much sensitive towards depositional environment (Folk and Ward, 1957; Mason and Folk, 1958; Friedman, 1967; Moiola and Weiser, 1968; Visher, 1969; Rajamanickam and Gujar, 1984; Srivastava and Mankar, 2008; Rajganapati, 2013; Ghaznavi et al., 2019). The geochemical studies of sedimentary rocks are significant to interpret the provenance, source rock composition, weathering intensity and the tectonic settings. (Dickinson and Suczek, 1979; Nesbitt and Young, 1982; Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1986, 1988; McLennan and Taylor, 1991; McLennan, 1989, 1993, 2001; McLennan et al., 1993; Madhavaraju and Ramasamy, 2002; Nagarajan et al., 2007a,b; Madhavaraju and Lee, 2010; Madhavaraju and Gonzalez-Leon, 2012; Madhavaraju et al., 2016; Armstrong-Altrin et al., 2013, 2015; Madhavaraju, 2015; Pandey and Parcha, 2017; Lone et al., 2017; Shah et al., 2017; Khan et al., 2019; Mude et al., 2019). The mutual relationship of the major, trace and rare earth elements play a significant role in understanding the weathering condition of the source area and provenance (Nesbitt and Young, 1982; McLennan, 1993).

Grain size variation and geochemical changes form the sediments of Manaveli and Cuddalore formations were not carried out earlier although these two parameters are very significant to deduce depositional and paleoenvironment. Only Selvaraj and Ramasamy (1998) have carried out granulometric analysis of Cuddalore Formation from Neyveli and Ariyalur area. Therefore, in the present paper, it is attempted to understand geochemical variation in the sediments of Manaveli and Cuddalore formations to interpret source area weathering conditions and paleoclimate. Further it is attempted to study the grain size variation from these sediments to know depositional environment.

Geological Setting

The sediments of Ariyalur Group (Late Cretaceous and Paleogene) are poorly exposed as an inlier of NW Puducherry, which is surrounded by Quaternary alluvium and Cuddalore Formation (Mio-Pliocene). The sediments of Puducherry area are further divided into Valudavur, Mettuveli, Karasur and Manaveli formations (Figure 1). The Valudavur Formation contains informal units A and B of Warth (1895) (Rajagopalan, 1965). The lower bed of the formation is pale yellow, fine to very coarse sandstone consisting of mica as minor component and rounded quartz pebbles. Upper bed has pale sandstone generally uncemented and bioturbated. It also contains concretionary shale and this formation has thickness of about 180m (Sundaram et al., 2001). Neogene strata of the Cuddalore Formation overlap the Valudavur Formation from north and west. Mettuveli Formation is conformably overlying Valudavur Formation. Upper part of the formation contains Ammonites of Late Maastrichtian age whereas the lower part consists of plankton foraminifera (*Globotruncana tricarinata*) of the late Campanian (Govindan, 1972).

The Mettuveli Formation consists of sandy shale and fine sandstone consisting of moulds and phosphatic cast of shell debris. The thickness of formation is around 150m with more amounts of Molluscan fossils (Sundaram et al., 2001). On the basis of planktonic foraminiferal zone of *Abathomphalus mayaroensis* the age of the Mettuveli Formation is determined as Late Maastrichtian (Govindan,1972). The Karasur Formation consists of coarse impure calc-arenites, bioturbated at places and contains corals. It is massive bedded, exhibiting nodular fabric and thickness is about 120m (Sundaram et al., 2001). Contact of the formation is conformable both below and above. On the basis of Planktonic foraminifera, the age for the Karasur Formation is assigned as Paleocene (Rajagopalan, 1965; Govindan, 1972). The Manaveli Formation consists of buff sandy shale, poorly lithified with siltstone and fine grained sandstone containing poorly preserved molluscan fossils. The thickness of this formation is approximately 100m (Sundaram et al., 2001). It has conformable contact with the Karasur Formation and dis-conformable contact with Cuddalore Formation. Rajagopalan (1968) suggested Paleocene age for the Manaveli Formation on the basis of planktonic foraminifera. The Cuddalore Formation consists of ferruginous arkosic sandstone associated with clay and gravel beds. The sedimentary structures viz., planar cross bedding, small scale herringbone cross bedding, cross lamination and ripple drift lamination are well developed and the thickness of formation is about 150m. It has dis-conformable contact with Manaveli Formation below and conformable with alluvium above. The Cuddalore Formation is dated as Miocene-Pliocene (Vredenburg 1908; Wadia 1953; Krishnan 1960; Ramanujam 1968).

Methods and Material

Total thirteen samples were taken from the Cuddalore Formation and selected for grain size studies. The Sieve analysis of these samples was carried out in Department of Geology, Fergusson College (Autonomous), Pune. Thirteen samples from the Cuddalore Formation were selected for sieve analysis. Hundred and fifty grams of sample were

taken from sediments by conning and quartering. These samples were treated with 10N HCL to remove any carbonate impurities and coatings of grains. The samples were dried in laboratory oven at 70°c. Hundred grams of samples were taken for sieve analysis using sieves of 2mm, 1mm, 500µ, 250µ, 125µ and 63µ mesh. Samples were put into the sieve-shaker to shake in circular motion for 15 min on 50Hz frequency. After sieving, fraction from each sieve was collected and by using electronic balance, the weight of the sample was calculated and used for further calculations.

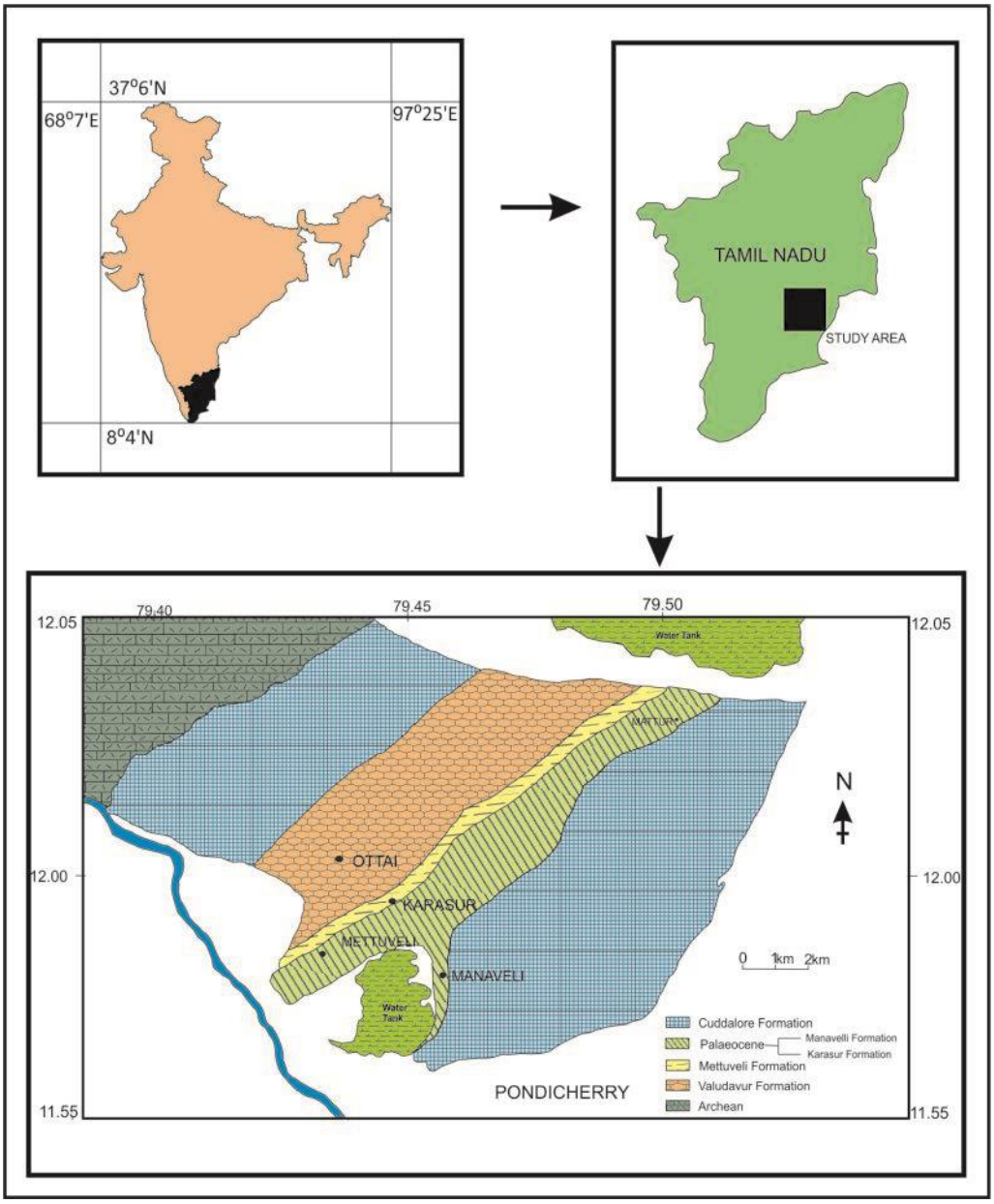


Figure 1: Geological map of the Puducherry area (after Malarkodi, et al., 2009)

Seven samples from Cuddalore Formation and six samples from Manaveli Formation were selected for geochemical analysis. The XRF analysis of these samples for major and trace elements were carried out in the Wadia Institute of Himalayan Geology, Dehradun. Ten grams of the sample were prepared by powdering in an agate mortar. The pressed power pellet mode for sample preparation was employed for the major and trace elements analysis (Watsan, J. S., 1996). The average error of the analysed major and trace elements was less than ± 5%.

Field Observations

Manaveli Formation

This section is exposed on Manaveli main road, 100m N-E of Puducherry maritime academy (latitude - 11°58′0.15″ N; longitude - 79°46′13.67″ E; elevation - 24m) and the section is about 3 m thick. The section consists of 4 lithounits of alternate white and yellow clays and 1 unit of iron concretion. At the base of this section, 0.3m thick unit of yellow clay is present and horizontal as well as vertical burrows were seen. This unit is followed by 0.6m thick white clay. Above this unit 0.3m thick bed of yellow clay is present, which is followed by 0.9m thick unit of white clays and upper most units is about 0.9m thick consisting of pebbles and iron concretions.

Manaveli Formation

The section of the Manaveli Formation is exposed on NE of Manaveli village around 800m (latitude – 11°58′21.20″ N; longitude – 79°46′32.02″ E; elevation – 33m). The thickness of the section is 2.2 m. Three samples were collected from two lithounits of this section. Lower unit of this section is 1.2m thick, white colored claystone; upper unit of this section is 1m thick red colored sandy pebbly horizon, pebbles are more than 3mm in size, rounded and moderately sorted.

Cuddalore Formation

The section of the Cuddalore Formation is exposed in a quarry section, 1.2 km from Manaveli village (latitude - 11°57′56″N; longitude - 79°46′49.5″ E; elevation - 32m) towards east and hardly 3-4 km west of Puducherry airport. The thickness of the section is about 18 m and 8 samples were collected from the different stratigraphic levels of this section. At the base of the section, 0.5m thick reddish weathered sandstone is exposed, which is poorly sorted and has medium to coarse, angular grains. Above this red sandstone, there is 0.1m thin layer of gravels and pebbles, which is followed by 0.8m thick red sandstone consisting of minor amount gravels and pebbles. This lithounit shows laminations and has fine to medium grained, moderately sorted angular to sub angular grains of quartz and feldspar, rock fragments and at the top of this lithounit, laminations are present. Above this unit, there is 1.2m thick pale brown coloured, very poorly sorted gravelly/pebbly horizon present, some grains are more than 3cm across, they are rounded to sub-rounded which are slightly laminated. Above this unit 0.6m thick moderately sorted, fine to medium, sub-angular, red colored sandstone is present. This unit is followed by reddish brown colored, moderately sorted, medium size; sub-angular sandy horizon which is 3m thick containing 5 to 10 % small pebbles. Above this unit 1.8m thick brown colored moderately sorted, medium size, sub-angular sandy pebbly horizon which contains 30 to 35% small to medium pebbles about 2mm across. This unit is followed by sandy horizon, brown colored, poorly sorted, medium to fine grains and containing 5 to 10% pebbles, clay material is also present, and this unit is 2.5m thick. Upper most units is red brown colored, moderately sorted and medium to fine grain silty-sandy horizon, this unit is 7.3m thick.

Cuddalore Formation

In a quarry section, 300m towards west of Pon Pure Chemical Private Limited (latitude - 11°56′14.5″ N; longitude - 79°45′29.3″ E; elevation – 17m) sequence of Cuddalore Formation is exposed. This section is about 6.8m thick and 8 samples were collected from different stratigraphic levels. At the base of this section 1m thick reddish-brown colored, moderately sorted, medium to coarse grained fossiliferous sandstone is present with some calcareous matter. Above this unit 2m thick red colored, well sorted, fine grained, laminated unfossiliferous, friable sandstone is present. This unit is followed by white colored laminated shale having thickness of about 0.3m which is further followed by sandstone with intercalation of shale. Sandstone in this unit is reddish in color, moderately sorted and fine to medium grained whereas, white shale has a thickness about 0.6 m. Above this unit, 1m thick reddish white colored claystone is present. This unit is followed by yellowish red, well sorted, fine to medium, rounded grained sandstone having thickness of 0.3m. Above this unit, 1m thick bed of reddish white claystone is present. On the top of this formation, 0.6m thick bed of yellowish red colored, well sorted, medium to fine grain sandstone is present.

Recent Deposits

Recent sediments are exposed on Manaveli main road near Mettuveli village in front of Foseco India Limited (latitude - 11°57′27.3″ N; longitude - 79°46′59 E; elevation - 42 m). Total thickness of the sequence is 3.5m and 3 samples were collected from this section. This horizon is reddish brown colored, course to fine grained; weathered sandy and silty clay.

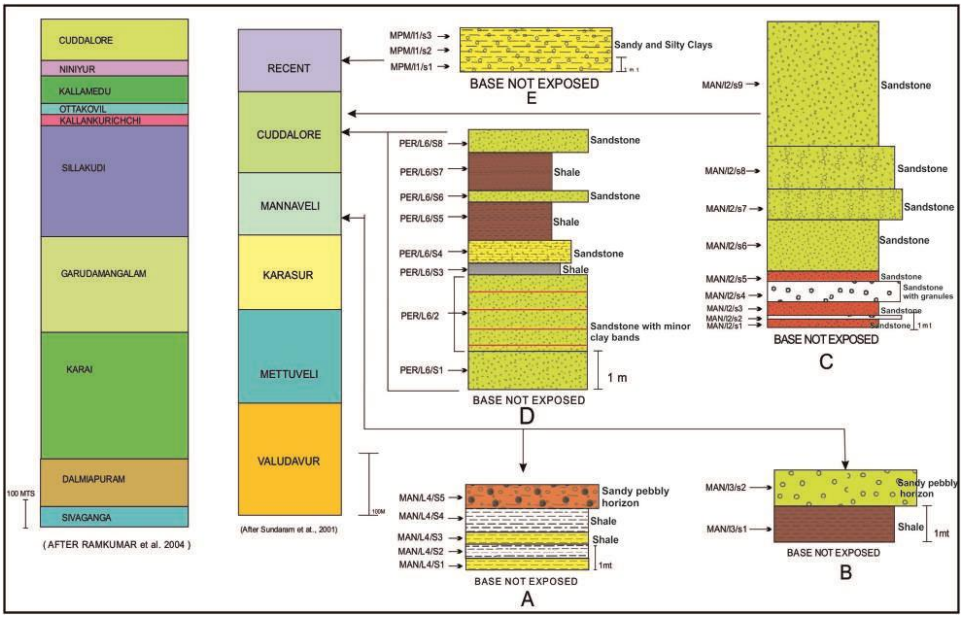


Figure 2: Litholgs of studied section of Manaveli Formation, Cuddalore Formation and recent deposits from Puducherry basin; A: litholog of Manaveli Formation at Manaveli village, 100m NE of Puducherry maritime academy; B: litholog of Manaveli Formation at 800m towards N-E of Manaveli village and 600m east of Kasipalayam village; C: litholog of Cuddalore Formation at quarry section 1.2 km from Manaveli village towards east and hardly 3-4 km west of Puducherry airport; D: litholog of Cuddalore Formation at quarry section, 300m towards west of Pon-Pure Chemical Private Limited, near Perambai village, E: litholog of recent deposits at open pit on Manaveli main road near Mettuveli village in front of Foseco India Limited.

Recent Deposits

Recent sediments are exposed on Manaveli main road near Mettuveli village in front of Foseco India Limited (latitude - 11°57′27.3″ N; longitude - 79°46′59 E; elevation - 42 m). Total thickness of the sequence is 3.5m and 3 samples were collected from this section. This horizon is reddish brown colored, course to fine grained; weathered sandy and silty clay.

Results

Grain Size Analysis

The standard methodology of granulometric analysis was used and grain size distribution is given in Table 1. Cumulative weight percent and frequency of each sample were individually plotted on a graph and ϕ values from the graph were calculated. Value of ϕ5, ϕ16, ϕ25, ϕ50, ϕ75, ϕ84, ϕ95 from the cumulative curves were obtained & used to calculate four graphic measures (Folk and Ward 1957) viz.,

Mean (Mz) = (ϕ16 + ϕ50 + ϕ 84)/3.

Std deviation (S_i) = (ϕ 84 - ϕ 16)/4 + (ϕ 95 - ϕ 5)/6.6

Skewness (Sk_G) = (ϕ 84 + ϕ 16 -2 ϕ5)/2 (ϕ84 - ϕ16) + (ϕ95 + ϕ5 -2 ϕ50)/2 (ϕ96 - ϕ5).

Kurtosis (K_G) = (ϕ95 - ϕ5)/2.44(ϕ75 - ϕ25).

Sahu (1964) described the depositional environments on the basis of discriminant functions. On the basis of graphic measurements (Folk and Ward, 1957), Y1, Y2 and Y3 discriminant functions were calculated as follows (Sahu,1964),

Y1 = -3.5688(Mz) + 3.701(Si) – 2.0766(SK_G) + 3.1135(K_G).

Y2 = 15.6534(Mz) + 65.7091(Si) + 18.1070(SK_G) + 18.5043(K_G).

Y3 = 0.2852(Mz) - 8.7694(Si) - 4.8932(SK_G) + 0.0482(K_G).

If Y1 is less than -2.7411, it indicates depositional environment is aeolian and when it is greater than -2.7411 it suggested as beach environment. If Y2 is less than 65.3650 it suggests beach environment and greater than 65.3650 shallow marine environment. If value of Y3 is less than -7.419 it suggests fluvio-deltaic deposits and greater than -7.419 is shallow marine depositional environment.

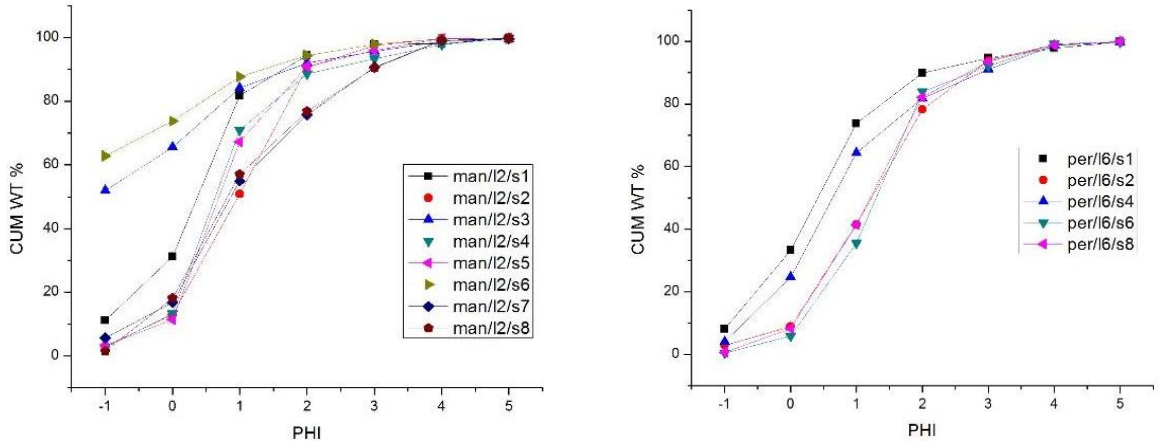
Bivariate plots viz., Mean (M_Z) Vs. Standard Deviation (S_i); Graphic Skewness (Sk_G) Vs. Graphic Standard Deviation (S_i); Graphic Kurtosis (K_G) Vs. Graphic Skewness (Sk_G); Graphic Skewness (Sk_G) Vs. Mean (M_Z) were extensively used to understand the depositional environment of sediments (Folk and Ward, 1957; Mason and Folk, 1958; Friedman, 1967; Moiola and Weiser, 1968; Visher, 1969; Rajamanickam and Gujar, 1984).

Table 1: Grain size distribution of samples from Cuddalore Formation

Sample No.	PER/L6/S1		PER/L6/S2		PER/L6/S4		PER/L6/S6		PER/L6/S8	
Phi no.	Wt%	Cum Wt %	Wt%	Cum Wt %	Wt%	Cum Wt %	Wt%	Cum Wt %	Wt%	Cum Wt %
-1	8.16	8.15	2.84	2.84	4.11	4.1	0.43	0.43	0.70	0.7
0	25.13	33.25	6.08	8.92	20.56	24.6	5.52	5.943	7.48	8.18
1	40.55	73.75	32.59	41.48	39.83	64.32	47.71	35.52	33.22	41.4
2	16.16	89.89	36.79	78.24	17.59	81.86	30.48	83.92	40.78	82.18
3	4.70	94.59	15.58	93.81	9.22	91.06	8.22	92.123	11.41	93.59
4	3.22	97.81	5.19	99.00	7.62	98.66	7.10	99.208	5.19	98.78
5	2.05	99.86	0.91	99.91	1.04	99.70	0.51	99.718	1.20	99.98
Sample No.	MAN/L2/S1		MAN/L2/S2		MAN/L2/S3		MAN/L2/S4			
Phi no.	Wt%	Cum Wt %	Wt%	Cum Wt %	Wt%	Cum Wt %	Wt%	Cum Wt %		
-1	11.17	11.17	2.97	2.97	52.25	51.94	2.71	2.71		
0	20.06	31.22	9.944	12.9	13.66	65.52	10.50	13.21		
1	50.59	81.78	38.03	50.88	18.68	84.09	57.80	70.96		
2	12.60	94.38	39.74	90.57	7.92	91.97	17.64	88.59		
3	3.53	97.91	6.97	97.53	3.78	95.73	4.80	93.39		
4	0.08	97.99	2.17	99.7	3.18	98.9	4.35	97.74		
5	1.95	99.94	0.15	99.85	0.60	99.5	2.17	99.91		
Sample No.	MAN/L2/S5		MAN/L2/S6		MAN/L2/S7		MAN/L2/S8			
Phi no.	Wt%	Cum Wt %	Wt%	Cum Wt %	Wt%	Cum Wt %	Wt%	Cum Wt %		
-1	3.24	3.24	63.08	62.83	5.66	5.65	1.52	1.52		
0	8.09	11.33	11.00	73.79	11.19	16.81	16.57	18.09		
1	55.93	67.23	14.00	87.74	38.30	54.98	38.97	57.05		
2	23.81	91.03	6.71	94.43	20.83	75.74	19.75	76.8		
3	4.90	95.93	3.56	97.98	15.00	90.69	13.67	90.46		
4	3.82	99.75	1.64	99.62	8.48	99.15	8.69	99.15		
5	0.20	99.95	0.04	99.66	0.51	99.66	0.73	99.88		

Table 2: Calculated phi (ϕ) values of the samples

Name of sample	**5ϕ**	**16ϕ**	**25ϕ**	**50ϕ**	**75ϕ**	**84ϕ**	**95ϕ**
PER/l6/s1	1.22436	-0.57536	-0.25765	0.39853	1.09069	1.46591	2.5268
PER/l6/s2	-0.4587	0.26153	0.58505	1.22817	1.87938	2.21571	3.01935
PER/l6/s4	-1.04164	-0.39132	-0.04557	0.69566	1.49578	1.93319	3.18333
PER/l6/s6	-0.05781	0.5141	0.76516	1.26253	1.77302	2.04558	2.78577
PER/l6/s8	-0.29375	0.33005	0.61586	1.1893	1.77743	2.08667	2.87033
MAN/l2/s1	-1.28148	-0.46946	-0.18734	0.33707	0.85498	1.12602	1.82794
MAN/l2/s2	-0.51492	0.15872	0.43547	0.96942	1.49931	1.76952	2.39726
MAN/l2/s3	-1.93993	-1.73689	-1.5501	-0.88349	0.24697	0.96497	2.76128
MAN/l2/s4	-0.44528	0.04767	0.25751	0.67229	1.10965	1.35885	2.41796
MAN/l2/s5	-0.41058	0.10598	0.32121	0.74109	1.17028	1.40107	2.05489
MAN/l2/s6	-1.95608	-1.80487	-1.66532	-1.16315	-0.28811	0.29487	2.00942
MAN/l2/s7	-0.99042	-0.22457	0.16811	0.99094	1.84899	2.29509	3.35611
MAN/l2/s8	-0.86928	-0.20584	0.15521	0.9353	1.76976	2.21249	3.32291



a) b)

Figure 3: Phi (ϕ) values vs cumulative weight percentage of Cuddalore Formation.

Table 3: Calculated values of Mean, Standard Deviation, Skewness and Kurtosis of Cuddalore Formation

Name of sample	Median	Mean (Mz)	Standard Deviation (S_i)	Skewness (SK_Z)	Kurtosis (K_G)
PER/l6/s1	0.39	-0.2241	1.0786	0.09026	1.1401
PER/l6/s2	1.2281	1.2351	1.0155	0.0203	1.1012
PER/l6/s4	0.6956	0.7458	1.2212	0.1211	0.1233
PER/l6/s6	1.2625	1.274	0.8137	0.0468	1.1563
PER/l6/s8	1.1893	1.202	0.9185	0.0421	1.1163
MAN/l2/s1	0.337	0.3312	0.8694	-0.2805	1.2226
MAN/l2/s2	0.9694	0.9658	0.8439	-0.0129	1.1218
MAN/l2/s3	-0.8834	-0.5518	1.3877	1.1934	1.0721
MAN/l2/s4	0.6722	0.6924	0.7616	0.1333	0.9999
MAN/l2/s5	0.741	0.7493	0.6973	0.0424	0.6391
MAN/l2/s6	-1.1631	-0.891	1.1257	0.4944	1.18
MAN/l2/s7	0.9909	1.0204	1.2884	0.0617	1.0597
MAN/l2/s8	0.9353	0.9806	1.2397	0.0976	1.0641

Table 4: Discriminant Function values of Cuddalore Formation.

Name of sample	Y1	Y2	Y3
PER/l6/s1	8.153934	90.097	-9.9093
PER/l6/s2	2.736972	106.8056	-8.59933
PER/l6/s4	1.990468	96.3926	-11.0831
PER/l6/s6	1.967808	95.65386	-6.94558
PER/l6/s8	2.497846	100.5878	-7.86408
MAN/l2/s1	6.424714	79.85624	-6.09819
MAN/l2/s2	3.196039	91.09451	-7.00786
MAN/l2/s3	7.96491	123.9943	-18.1145
MAN/l2/s4	3.184022	81.79858	-7.08537
MAN/l2/s5	1.808395	70.14188	-6.07787
MAN/l2/s6	9.993275	90.80873	-12.4881
MAN/l2/s7	4.298015	121.3585	-11.2583
MAN/l2/s8	4.198964	118.267	-11.018

Geochemical Analysis

The average percentage of major oxides was compared with Post-Archean Australian Shale (PAAS) and Upper Continental Crust (UCC) (Table.5). The average percentage of Na_2O, MgO, Al_2O_3, P_2O_5, K_2O, CaO, MgO and Fe_2O_3 is less

compared to PAAS and UCC (Taylor and McLennan,1985). The average percentage of SiO_2 is more as compared to PAAS and UCC (Taylor and McLennan, 1985) whereas the average percentage of TiO_2 is more than UCC and less than PAAS.

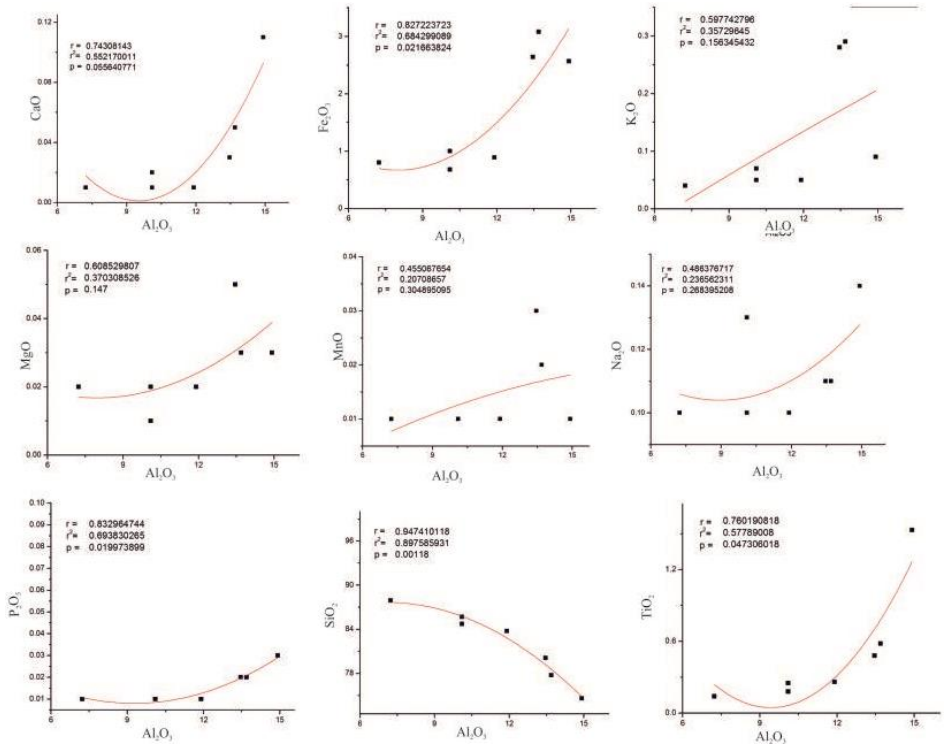


Figure 4: Distribution of major elements against Al_2O_3 from sediments of Cuddalore Formation (Litholog C)

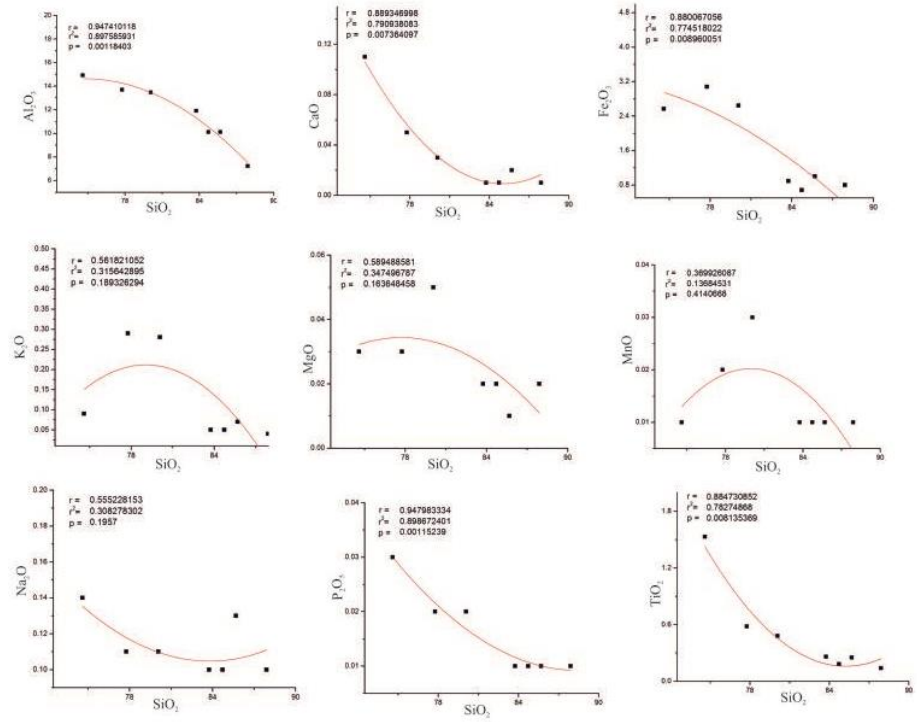


Figure 5: Distribution of major elements against SiO_2 of the Samples of Cuddalore Formation. (Litholog C)

Table 5: Major and trace element distribution of the Cuddalore and Manaveli sediments (PAAS and UCC data from; Taylor and McLennan 1985).

Sample	MAN/ L2/S1	MAN/ L2/S2	MAN/ LL2/S3	MAN/ LL2/S4	MAN/ LL2/S5	MAN/ LL2/S6	MAN/ LL2/S7	MAN/ L3/S1	MAN/ L3/S2	MAN/ L4/S1	MAN/ L4/S2	MAN/ L4/S3	MAN/ L4/S4	AVG	PAAS	UCC
	Cuddalore Formation							Manaveli Formation								
Na_2O %	0.13	0.10	0.14	0.10	0.10	0.11	0.11	0.42	0.29	0.78	0.48	0.26	0.43	0.2653	1.2	3.90
MgO %	0.01	0.02	0.03	0.02	0.02	0.03	0.05	1.09	1.21	1.09	1.96	2.16	1.45	0.7030	2.2	2.2
Al_2O_3 %	10.10	7.23	14.92	10.10	11.91	13.69	13.46	19.84	22.16	16.92	18.60	16.55	19.70	15.013	18.90	15.20
SiO_2 %	85.69	87.91	74.59	84.73	83.76	77.76	80.08	60.09	57.72	62.39	58.19	50.34	59.47	70.978	62.3	66
P_2O_5 %	0.01	0.01	0.03	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.02	0.04	0.03	0.018	0.16	0.17
K_2O %	0.07	0.04	0.09	0.05	0.05	0.29	0.28	1.97	1.62	2.09	1.80	1.56	1.90	0.908	3.70	3.40
CaO %	0.02	0.01	0.11	0.01	0.01	0.05	0.03	1.26	1.36	1.30	1.59	1.50	1.42	0.666	1.30	4.20
TiO_2 %	0.25	0.14	1.53	0.18	0.26	0.58	0.48	0.58	0.56	0.48	0.67	0.54	0.55	0.523	1.00	0.50
MnO %	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.012	0.11	0.1
Fe_2O_3 %	1.00	0.80	2.57	0.68	0.89	3.08	2.64	4.04	4.46	5.46	4.58	12.85	5.48	3.733	7.23	4.5
SiO_2/Al_2O_3	8.48	12.15	4.99	8.38	7.03	5.68	5.94	3.02	2.60	3.68	3.12	3.04	3.018	--	--	--
K_2O/Na_2O	0.53	0.4	0.64	0.5	0.5	2.63	2.54	4.69	5.58	2.67	3.75	6	4.41	--	--	--
K_2O/Al_2O_3	0.0069	0.005	0.006	0.005	0.004	0.021	0.02	0.099	0.073	0.123	0.096	0.094	0.09	--	--	--
Fe_2O_3/K_2O	14.28	20	28.55	13.6	17.8	10.62	9.42	2.05	2.75	2.61	2.54	8.23	2.88	--	--	--
Na_2O/K_2O	1.85	2.5	1.55	2	2	0.37	0.39	0.21	0.17	0.37	0.26	0.16	0.22	--	--	--
Al_2O_3/TiO_2	40.4	51.64	9.75	56.11	45.80	23.60	28.04	34.20	39.57	35.25	27.76	30.64	35.81	--	--	--
CIA	97.86	97.96	97.77	98.44	98.67	96.81	96.97	84.46	87.14	80.22	82.77	83.29	84	--	--	--
ICV	0.98	0.83	1.05	0.69	0.62	2.83	2.74	11.81	8.78	14.79	11.59	12.13	11.59	--	--	--
PIA	98.52	98.49	98.34	98.91	99.08	98.82	98.94	91.40	92.56	87.69	89.03	89.49	90.58	--	--	--
CIW	98.53	98.50	98.35	98.92	99.08	98.84	98.97	92.19	93.07	89.05	89.98	90.38	91.41	--	--	--

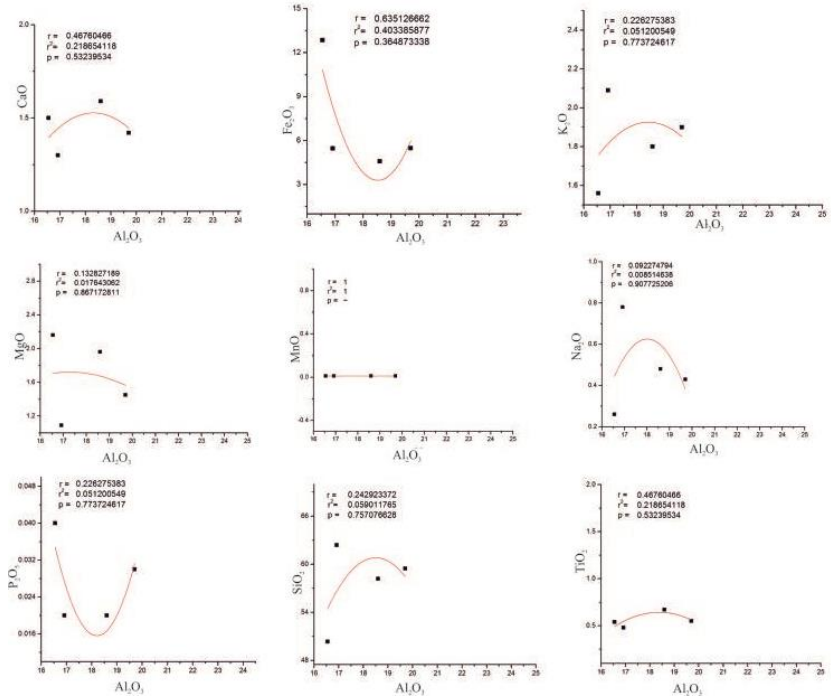


Figure 6: Distribution of major elements against Al_2O_3 of the Samples of Manaveli Formation. (Litholog A)

Discussion

The depositional environments of the Manaveli and Cuddalore formations were discussed here based on granulometric data whereas weathering intensity, compositional maturity, paleoclimate and provenance were deduced on the basis of geochemical data.

Depositional Environment

Discriminant Function Y1, Y2 and Y3 calculated using formula given by Sahu (1964), based on graphic measurements (Folk and Ward, 1957) were employed to understand depositional environment of sediments.

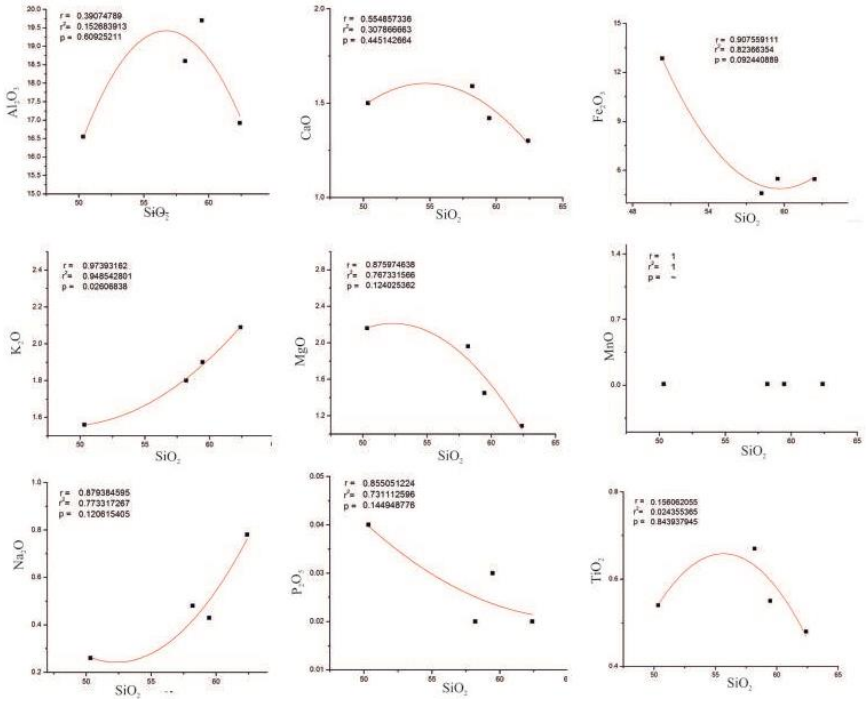


Figure 7: Distribution of major elements against SiO_2 of the Samples of Manaveli Formation (Litholog A)

Litholog C: Discriminant Function values suggested that 100% of MAN/L2 samples of Cuddalore Formation used to calculate Y1 fall in beach environment. 100 % Y2 values fall in shallow marine environment and 50% Y3 values fall in fluvio-deltaic environment and 50% of samples fall in shallow marine environment. Litholog D: Discriminant function values suggested that 100% of PER/L6 samples of Cuddalore Formation used to calculate Y1 fall in beach environment. 100 % Y2 values fall in shallow marine environment and 83.4% Y3 values fall in fluvio-deltaic environment and 16.6% of samples fall in shallow marine environment.

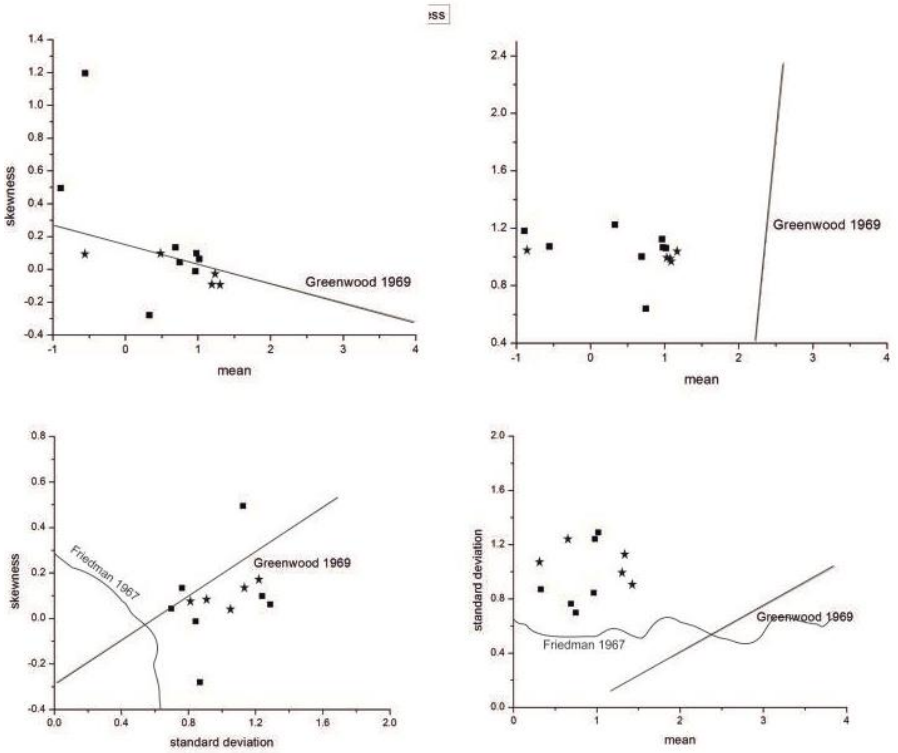


Figure 8: Grain size bivariate plot of MAN/L2 section of Cuddalore Formation (Litholog C), Bivariate plots viz., mean vs. kurtosis, mean vs. skewness, mean vs. standard deviation and standard deviations vs. skewness are prepared in figure 8. The samples from section MAN/L2 and PER/L6 of Cuddalore Formation show deposition of sediments dominantly in riverine to deltaic environment.

Weathering Intensity and Compositional Maturity

The discriminant function analyses of the sediments from the Cuddalore Formation infer that mostly the sedimentation was in fluvio-deltaic environment with incursions of shallow marine environment. Bivariate plots / graphs are widely used to understand the depositional environments (Friedman,1961,1962 and 1967; Greenwood ,1969). Various bivariate plots were prepared and interpreted as follows. In order to interpret the degree of chemical weathering and compositional maturity, various chemical weathering indices have been proposed (Nesbitt and Young, 1982). These Chemical weathering indices characterizes different weathering profiles (Price and Velbel, 2003).

The Chemical Index of Alteration (CIA ={ Al_2O_3 / (Al_2O_3+ CaO*+Na_2O+K_2O) } × 100) by Nesbitt and Young (1982),

Index of Compositional Variability (ICV={(Fe_2O_3 +K_2O+Na_2O + CaO*+MgO+MnO+TiO_2) /Al_2O_3} × 100) by Cox and Lowe, (1995),

Plagioclase Index of Alteration (PIA={(Al_2O_3-K_2O)/ (Al_2O_3 + CaO* +Na_2O-K_2O)} × 100) by Fedo et al., (1995)

The Chemical Index of Weathering (CIW = {(Al_2O_3 / (Al_2O_3+ CaO* + Na_2O)} × 100) (Harnois 1988) were used in the present work to deduce source area weathering conditions.

These chemical signatures of sedimentary records have been found useful to define the source area weathering conditions (Nesbitt and Young, 1982, 1984; McLennan et al.,1993; Fedo et al., 1995).

The CIA values of sediments from Cuddalore Formation (Fig. 9, A) were plotted against Al_2O_3 to understand weathering condition of source rock. All plotted CIA values occupied space in the region of intensive weathering, thus it indicates that the sediments of the Cuddalore Formation were derived from the area which was intensively weathered.

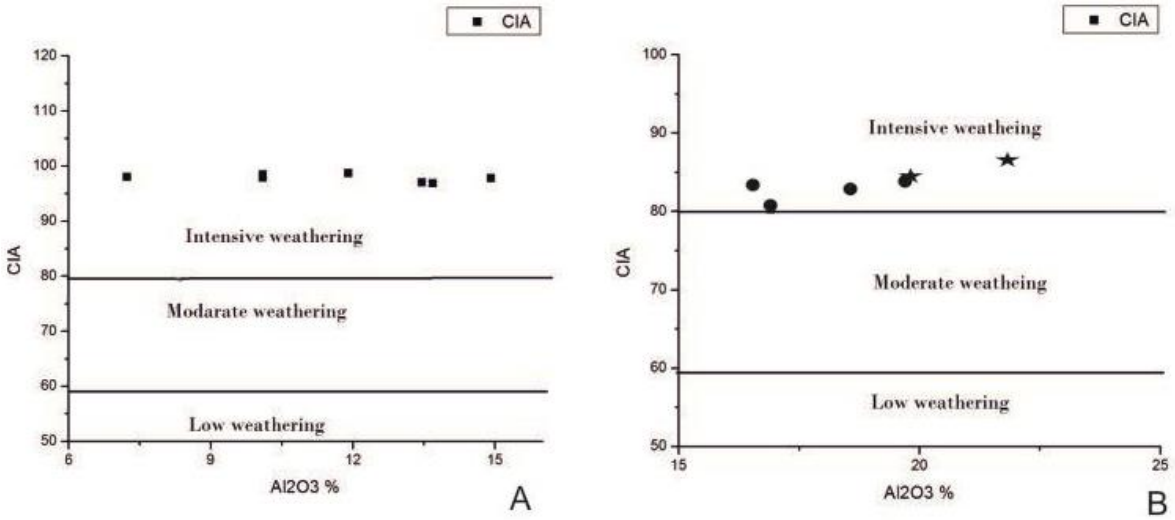


Figure 9: Bivariate plot of CIA against Al_2O_3 showing weathering conditions of source rock of Cuddalore (A) and Manavali formations (B) (after Nesbitt and Young 1982).

The CIA values of sediments from Manaveli Formation (Fig. 9, B) were plated against Al_2O_3 to understand weathering condition of source rock. All plotted CIA values occupied space in the region of intensive weathering, thus it indicates that the sediments of the Manaveli Formation were derived from the area which was intensively weathered.

In the present study, the ICV value of the sediments from Cuddalore Formation varies from 0.61 to 2.4 (average 1.39) indicating that sediments of Cuddalore Formation are compositionally moderate to well matured whereas the ICV values of the sediments from Manaveli Formation ranges from 8.77 to 14.79 (average 11.78) suggesting that sediments are compositionally moderately matured. The K_2O/Na_2O ratios for the studied samples from the Cuddalore Formation vary from 0.4 to 2.63, which infer moderate to high maturity whereas the values K_2O/Na_2O ratios for Manaveli Formation range from 2.67 to 6 indicate moderate maturity. The PIA and CIW values range from 98.34 to 98.94 and 98.53 to 98.97 for the Cuddalore Formation whereas, 87.69 to 92.56 and 89.05 to 92.19 for the Manaveli Formation, infer intense source area weathering.

The binary relation of major oxides ratios and their logs can be implemented to understand the chemical maturity of the sediments. The logs of SiO_2/Al_2O_2, Na_2O/K_2O and Fe_2O_3/K_2O are commonly used for determining the chemical maturity. Bivariate plots of these ratios are useful to discriminate mature and immature sediments (Pettijohn et al., 1972; Herron, 1988; Vital and Stattegger, 2000).

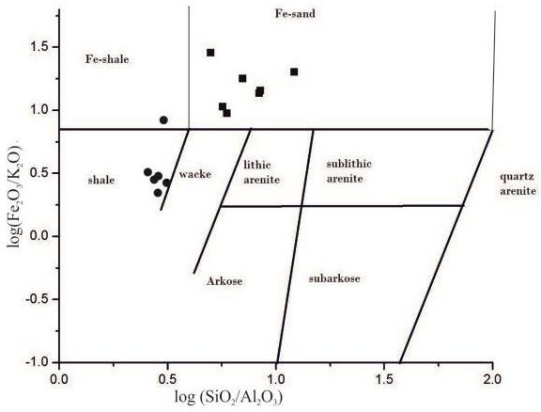


Figure 10a: Bivariate plots of log (SiO_2/Al_2O_3) vs. log (Fe_2O_3/K_2O) of the MAN/L2 sample of Cuddalore and Manaveli formations (after Herron, 1988).

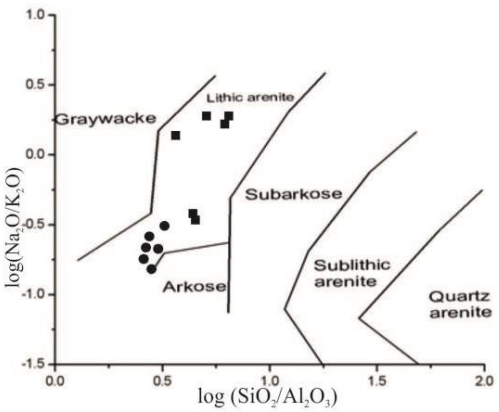


Figure 10b: Bivariate plot of log (SiO_2/Al_2O_3) vs. log (Na_2O/K_2O) of the MAN/L2 sample of Cuddalore and Manaveli formations (after Pettijohn et al., 1972)

Paleoclimate and Provenance

Bivariate plots of log (SiO_2/Al_2O_3) vs. log (Fe_2O_3/K_2O) and log (SiO_2/Al_2O_3) vs. log (Na_2O/K_2O) indicate that the sediments from Cuddalore and Manaveli formations were moderately matured.

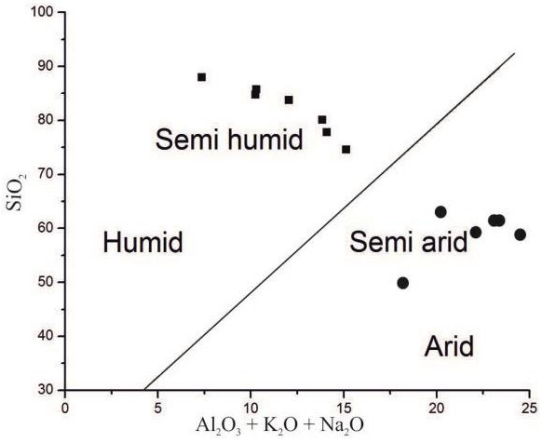


Figure 11 Bivariate plot of Al_2O_3 +K_2O+Na_2O against SiO_2 showing climatic condition of Cuddalore and Manavali formations (after Suttner and Dutta, 1986).

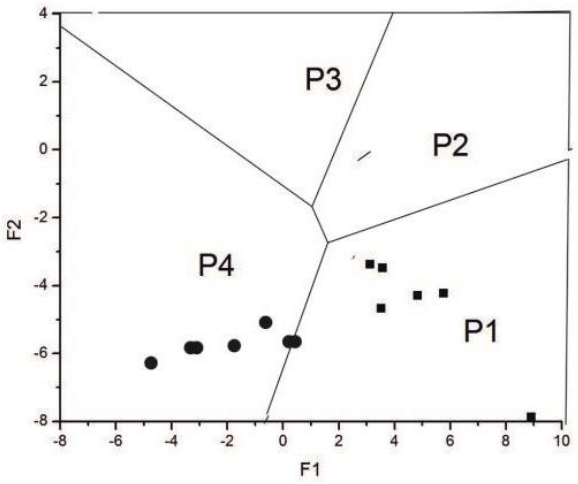


Figure 12: Discriminant function F1 against discriminant function F2 variation diagram of Cuddalore Formation and Manaveli Formation, fields after Roser and Korsch (1988), Provenance fields: (P1) Mafic igneous provenance, (P2) Intermediate igneous provenance, (P3) Felsic igneous provenance, and (P4) Quartzose sedimentary provenance (after Roser and Korsch, 1988).

Suttner and Dutta (1986) have established a relationship between (Al_2O_3+K_2O+Na_2O) and SiO_2 that can be used to discuss chemical maturity and climatic condition of source rock area. In the Bivariate plot of (Al_2O_3+K_2O+Na_2O) against SiO_2 (Suttner and Dutta, 1986), all the samples of the Cuddalore Formation fall in semi-humid zone (Fig.11) and Manaveli Formation fall in semi-arid zone (Fig.11). Thus, the bivariate plot of the samples of the Cuddalore Formation infers that the sediments are chemically well mature and deposited in semi-humid and samples of Manaveli Formation are chemically moderately mature and deposited in semi-arid climatic conditions.

The discriminant function diagram is widely used in the provenance study. Roser and Korsch (1988) have given the discriminant function diagram. They have proposed 2 discriminant functions which are as F1 = (−1.733TiO_2 + 0.607Al_2O_3 + 0.76Fe_2O_3 − 1.5MgO + 0.616CaO + 0.509Na_2O − 1.224K_2O − 9.09) and F2 = (0.445TiO_2+ 0.07Al_2O_3− 0.25 Fe_2O_3 −1.142MgO + 0.438CaO + 1.475Na_2O + 1.426 K_2O − 6.86) and 4 provenance fields which are as (P1) Mafic igneous provenance, (P2) Intermediate igneous provenance, (P3) Felsic igneous provenance, and (P4) Quartzose sedimentary provenance. The bivariate plot (Roser and Korsch, 1988) of F1 against F2 can be used for interpreting the provenance.

In the discriminant function diagram, all the samples of Cuddalore Formation fall in P4 region indicating the sedimentary provenance and samples of Manaveli Formation fall in P1 region indicating the Mafic igneous provenance. Hayashi et al. (1997) suggested Al_2O_3 /TiO_2 ratio increases from 3 to 8 for mafic igneous rocks, from 8 to 21 for intermediate rocks and from 21 to 70 for felsic igneous rocks. The values of Al_2O_3/TiO_2 ratios vary from 9.75 to 51.64 (average 36.47) for Cuddalore Formation and 27.76 to 39.57 (average 33.87) for Manaveli Formation, inferring felsic igneous provenance for both.

Conclusions

The discriminant function analysis of the sediments from the Cuddalore Formation infers that mostly the sedimentation occurred in fluvio-deltaic environment with incursions of shallow marine environment whereas bivariate plots suggests that the deposition occurred in riverine to deltaic environment. The weathering indices of the sediments from Manaveli and Cuddalore formations infer high/intense weathering prevailed in source area of sediments for Manaveli and Cuddalore formations. The sediments of Cuddalore Formations are chemically moderately to well mature whereas, the sediments from Manaveli Formation are moderately mature. The ratio (Al_2O_3+K_2O+Na_2O)/SiO_2 indicate semi-humid climatic conditions during deposition of Cuddalore Formation whereas, Manaveli Formation was deposited in semi-arid climatic conditions. The discriminant function diagram suggests quartzose sedimentary provenance for Cuddalore and Mafic igneous provenance for Manaveli Formation. The Al_2O_3/TiO_2 ratios of Cuddalore and Manaveli formations, infer felsic igneous provenance for both.

Acknowledgments

We would like to thank Principal and Head of Geology Department, Fergusson College (Autonomous) Pune for his moral support and constant encouragement. We are also thankful for financial assistance from BCUD Savitribai Phule Pune University, Pune under Minor Research Project

2016-2018. We are greatly indebted to anonymous reviewer for critical reviews of the manuscripts.

References

Armstrong-Altrin, J. S., Nagarajan, R., Madhavaraju, J., Rosalez-Hoz, L., Lee, Y. I., Balaram, V., Cruz-Mart´ınez, A. and Avila-Ram´ırez, G. (2013). Geochemistry of the Jurassic and Upper Cretaceous shales from the Molango Region, Hidalgo, eastern Mexico: Implications for source-area weathering, provenance, and tectonic setting. Comptes. Rendus. Geosci., v. 345, 185–202.

Armstrong-Altrin, J. S., Machain-Castillo, M. L., Rosales-Hoz, L., Carranza-Edwards, A., Sanchez-Cabeza, J. A. and Ru´ız-Fern´andez, A. C. (2015). Geochemistry of deep sea sediments from the south-western Gulf of Mexico, Mexico: Implication for depositional environment. Cont. Shelf. Res., 95, 15–26.

Ayyasamy, K. (1990). Cretaceous heteromorph ammonoid biostratigraphy of southern India: Newsletters on Stratigraphy, 22 (2-3), 111-118.

Bhatia, M. R. (1983). Plate tectonics and geochemical composition of sandstones. Jour. Geol., 91, 611–627.

Bhatia, M. R. and Crook, K. A. W. (1986). Trace element characteristics of graywackes and tectonic setting discriminant of sedimentary basins. Contrib. Mineral. Petrol., 92, 181–193.

Blanford, H. F. (1862). On the Cretaceous and other rocks of the South Arcot and Trichinopoly districts. Memoirs of the Geological Survey of India, 4, 1–217.

Chandrasekaran, V.A. Ramkumar, M. and Jacob, M., (1996). Sediment deformational structures from the Sillakkudi Formation (Campanian) Ariyalur Group, Tiruchy district, Tamil Nadu. Journal of the Indian Association of Sedimentologists, 15, 43–49.

Cox, R. and Lowe, D. R. (1995). A conceptual review of regional scale controls on the composition of clastic sediment and the coevolution of continental blocks and their sedimentary cover. Jour. Sediment. Res., 65, 1–12.

Condie, K. C. (1993). Chemical composition and evolution of the upper continental crust: contrasting results from surface samples and shales. Chem. Geol., 104, 1-37.

Dickinson, W. R, and Suczek, C. A. (1979). Plate tectonics and sandstone composition. AAPG Bull., 63, 2164–2182.

Fedo, C. M., Nesbitt, H. W, and Young, G. M. (1995). Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosoils, with implications for paleoweathering conditions and provenance. Geology., 23, 921–924.

Folk, R. L. and Ward, W. (1957). Brazos river bar: a study in the significance of grain size parameter. Jour. Sedim. Petrol, 27, 3-26.

Friedman, G.M. (1961). Distinction between dune, beach, and river sands from their textural characteristics. Jour. Sedi. Petrol., 31, 514-529.

Friedman, G.M. (1962). On sorting coefficient and the log normality of grain size distribution in sandstones. Jour. Geo., 70, 737-753.

Friedman, G.M. (1967). Dynamic processes and parameters compared for size frequency distribution of beach and river sands. Jour. Sedi. Petrol., 37(2), 327-354.

Friedman, G. M. (1979.) Differences in size distributions of populations of particles among sands of various origins. Sedimentol ,26,3–32,

Greenwood, B. (1969). Sediment parameters and environment discrimination: an application of multivariate statistics. Canadian Jour. of Earth Sciences, 6, 1347-1358.

Ghaznavi, A. A., Quasim, M. A., Ahmad, A. H. M., and Ghosh, S. K. (2019). Granulometric and facies analysis of Middle–Upper Jurassic rocks of Ler Dome, Kachchh, western India: An attempt to reconstruct the depositional environment. Geologos, 25(1), 51–73.

Ghosh, S. K., and Chatterjee, B. K. (1994). Depositional mechanism as revealed from grain-size measures of the Palaeoproterzoic Kolhan siliciclastics, Keonjhar District, Orissa, India. Sedimentary Geology, 89,181–196.

Govindan, A., Ananthanarayanan, S. and Vijayalakshmi, K.G., (2000). Cretaceous petroleum system in Cauvery basin, India. In: Govindhan, A. (ed.), Cretaceous stratigraphy – An update. Memoirs of the Geological Society of India, 46, 365–382.

Govindan, A., Ravindran, C.N. and Rangaraju, M.K., (1996). Cretaceous stratigraphy and planktonic foraminiferal zonation of Cauvery basin, South India. In: Sahni, A. (ed.), Cretaceous stratigraphy and palaeoenvironments. Memoirs of the Geological Society of India, 37, 155–187.

Govindan, A. (1972). Upper Cretaceous planktonic foraminifera from the Pondicherry area, south India. Micropaleontology, 18, 160–183.

Hart, M.B., Bhaskar, A. and Watkinson, M.P., (2000). Larger foraminifera from the upper Cretaceous of the Cauvery basin, S.E. India. In: Govindhan, A. (ed.), Cretaceous stratigraphy – An update. Memoirs of the Geological Society of India, 46, 159–171.

Hayashi Ken-I, H., Fujisawa H.D., Holland & H. Ohmoto (1997) Geochemistry of 1.9 Ga sedimentary rocks from northeastern Labrador, Canada Geochim Cosmochim, Acta 61, 4115–4137

Harnois, L. (1988). The CIW index: A new chemical index of weathering. Sediment. Geol., 55, 319–322.

Herron, M. M. (1988). Geochemical classification of terrigenous sands and shales from core or log data. Jour. Sediment. Petrol., 58, 820-829.

Jaiprakash, B. C., Venkatesh, P., Maya V. P., Gilbert, H. and Selvin, S. P. (2016) Biochron and tectonic framework for the origin of KTB Canyon in Nagapattinam sub-basin, Cauvery Basin. Proceedings of Indian National Science Academy, 82: 905–921.

Kishor, S. (2004a). Palaeo-ecological significance of Palaeocene Calcareous algae from th Cauvery Basin, India, Ecoprint, 11 (1), 59-63.

Kishor, S. (2004b). Occurrence and significance of the Palaeocene Green alage (Dasycladacean and Utoteacean) from Cauvery Basin , India. Geophytology, 33 (1&2), 39-46.

Kishor, S. and Singh S.K. (2004). Coralline alage from the Ninniyur Formation (Thnetian) of the Cauvery Basin, South India,. Our Nature, 2, 1-6.

Kishor, S., Misra, P.K ., Jauhri, A.K. and Singh , S. K. (2003). Calcareous algal association from the Ninniyur Formation (Palaeocene) of the Cauvaery Basin, India, Ecoprint, 10(1), 13-17.

Khan Z, Quasim M.A., Amir M,and Ahmad AHM.(2019) Provenance, tectonic setting, and source areaweathering of Middle Jurassic siliciclastic rocks of Chari Formation, Jumara Dome, Kachchh Basin, Western India: Sedimentological, mineralogical, and geochemical constraints. Geological Journal, 55 (5), 3537-3538.

Krishnan, M.S. (1960). Geology of India and Burmah. Higginbothams Pvt. Ltd.,Madras.

Krumbein, W. C. (1936). Application of logarithmic moments to size- frequency distribution of sediments. Jour. Sediment. Petrol., 6, 35-47.

Kossmat, F. (1897) The Cretaceous deposits of Pondicherry. Records of the Geological Survey of India, 30, 51–110.

Lone, A., Babeesh, C., Achyuthan, H. and Chandra, R. (2017). Evaluation of environmental status and geochemical assessment of sediments, Manasbal Lake, Kashmir, India, Arab J Geosci, 10:92, 1-18, DOI 10.1007/s12517-016-2826-7.

Madhavaraju, J. (2015). Geochemistry of Campanian–Maastrichtian sedimentary rocks in the Cauvery basin, south India; In: Constraints on paleoweathering, provenance and Cretaceous environments (ed.) Ramkumar M, Chemostratigraphy: Concepts, Techniques and Applications; Elsevier Spl. Volume., 185–214.

Madhavaraju, J. and Ramasamy, S. (2002). Petrography and major element geochemistry of Late Maastrichtian–Early Paleocene sediments of Tiruchirapalli, Tamil Nadu – Paleoweathering and provenance implication. Jour. Geol. Soc., 9, 133–142.

Madhavaraju, J. and Lee, Y. I. (2010). Influence of Deccan volcanism in the sedimentary rocks of Late Maastrichtian–

Danian age of Cauvery basin, southeastern India: Constraints from Geochemistry. Curr. Sci., 98, 528–537

Madhavaraju, J. and Gonz´alez-Le´on, C. M. (2012). Depositional conditions and source of rare earth elements in carbonate strata of the Aptian–Albian Mural Formation, Pitaycachi section, northeastern Sonora, Mexico. Rev. Mex. Cienc. Geol., 29, 478–491.

Madhavaraju, J., Erik Ramirez-Montoya, E., Monreal, R., Gonz´alez–Leon, C. M., Pi-Puig, T., spinoza-Maldonado, I. G. and Grijalva-Noriega, F. J. (2016). Paleoclimate, paleoweathering and paleoredox conditions of Lower Cretaceous shales from the Mural Limestone, Tuape section, northern Sonora, Mexico: Constraints from clay mineralogy and geochemistry. Rev. Mex. Cienc. Geol., 33(1), 34–48.

Mahalanobis, P. C. (1930). On tests and measures o group divergence. J. and Proc. Asiatic Soc. of Bengal, 27, 541-588.

Malarkodi, N., Patel, S. J. Fayazudeen P. J. and Mallikarjuna U. B. (2009) Paleoenvironmental Significance of Trace fossils from the Palaeocene sediments of the Pondicherry area, South India. Jour. Geol. Soc. Ind. 74, 738-748.

Mamgain, V. D., Rao, B. R. J. & Sastry, M. V. A. (1968). The Niniyur Group of Trichinopoly, south India (Cretaceous–Tertiary formations of South India). Memoirs of the Geological Society of India, 2, 85–91.

Mamgain, V. D., Sastry, M. V. A. and Subbaraman, J. V. (1973). Report of ammonites from Gondwana plant beds at Terani, Tiruchirapalli district, Tamil Nadu. Journal of the Geological Society of India., 14, 189–200.

Mason, C.C., Folk, R.L., (1958). Differentiation of beach, dune and aeolian flat environments by size analysis. Mustang Island, Texas. Journal of Sedimentary Petrology, 28, 211-226.

McLennan, S. M. and Taylor, S. R. (1991). Sedimentary rocks and crustal evolution: Tectonic setting and secular trends. Jour. Geol., 99, 1–21.

McLennan, S. M., Hemming, S., McDaniel, D. K. and Hanson, G. N. (1993). Geochemical approaches to sedimentation, provenance and tectonics; In: Processes Controlling the Composition of Clastic Sediments (eds) Johnson M J and Basu A, Geological Society of America Special Paper, USA , 21–40.

McLennan, S. M. (1989). Rare earth elements in the sedimentary rocks: Influence of provenance and sedimentary processes. Rev. Mineral., 21, 169-200.

McLennan, S. M. (1993). Weathering and global denudation. Jour. Geol., 101, 295-303.

McLennan, S. M. (2001). Relationships between the trace element compositions of sedimentary rocks and upper continental crust. Geochem. Geophys. Geosyst., 2, 2000GC000109.

Misra, P.K. and Kumar, P. (1988). Fossil algae from the Cretaceousof Varagur, Tiruchirapalli District, Tamil Nadu. Palaebot., 37(1), 36-51.

Misra, P.K., Jauhri, A.K., Kishor, S. and Chowdhury , A. (2000). Calcareous algae (Dasycladaceans and Gymnocodiacean) from the Palaeocene deposits of the Tiruchirapalli (= Trichinopolly) are, Tamil Nadu, India. Jouranl of Palaeontological Society of India, 45 , 151-164.

Misra, P.K., Jauhri, A.K., Chowdhury , A. and Kishor, S. (2001). Palaeocene Rhodophycean alage from the Ninniyur Formation of the Cauvery Basin, Southern India, Palaeobotanists, 50 (2 and 3) , 311-339.

Misra, P.K., Kishor, S., Jauhri, A.K. and Singh, S. K. (2003). Coralline alage from the Ninniyur Formation, Cauvery Basin, South India, 48,89-97.

Misra, P.K., Rajanikanth, A., Jauhri, A.K., Kishore, S. and Singh,S.K. (2004). Albian limestone building algae of Cauvery Basin,South India. Curr.Sci., 87, 1516-1518.

Misra, P.K., Jauhri, A.K., Singh, S.K., Kishore, S. and Rajanikanth, A. (2006). Non-geniculate coralline algae fromthe Uttatur Group (Early Cretaceous), south India.Palaeobotanist, 55(1-3), 29-40.

Moiola, R.J. and Weiser, D., (1968). Textural parameters: An evaluation. Journal of Sedimentary Petrology, 38(1), 45-53.

Mude, S. N., Parcha, S. K., Pandey, S. and Madane, S. (2019). Geochemistry, Provenance, Compositional Maturity and Source area weathering of Mastani Lake sediments, India, Journal of Geosciences Research, India , 4 (2): 143-154.

Muthuvairvasamy, R., Stüben, D. and Berner, Z., 2003, Lithostratigraphy, depositional history and sea level changes of the Cauvery Basin, southern India: Geoloski anali Balkanskog poluostrva, 65, 1-27.

Nagarajan, R., Madhavaraju, J., Nagendra, R., Armstrong- Altrin, J. S. and Moutte, J. (2007a). Geochemistry of Neoproterozoic shales of the Rabanpalli Formation, Bhima basin, Northern Karnataka, southern India: Implications for provenance and paleoredox conditions. Rev. Mex. Cienc. Geol., 24, 150–160.

Nagarajan, R., Armstrong-Altrin, J. S., Nagendra, R., Madhavaraju, J. and Moutte, J. (2007b). Petrography and geochemistry of terrigenous sedimentary rocks in the Neoproterozoic Rabanpalli Formation, Bhima basin, southern India: Implications for paleoweathering condition, provenance, and source rock composition. Jour. Geol. Soc., 70, 297–312.

Nagendra , R., Reddy, A. N., Jaiprakash , B. C., Gilbert , H., Zakharov, Y. D. and Venkateshwarlu, M. (2019) Integrated Cretaceous stratigraphy of the Cauvery Basin, South India, Stratigraphy, 15 (4) : 245–259.

Nagendra, R., Kamalakkannan, B. V., Gargi Sen, G., Bakkiaraj, H., Nallapa Reddy, A. and Jaiprakash, B. C. (2011) Sequence surfaces and paleobathymetric trends in Albian to Maastrichtian sediments of Ariyalur area, Cauvery Basin, India. Journal of Marine and Petroleum Geology, 28: 895–905.

Nagendra, R. and Nallapa Reddy, A. (2017) Major geological events of the Cauvery Basin, India and their correlation with global signatures-A review. Journal of Palaeogeography, 6: 69–83.

Nagendra, R., Patel, S. J., Deepankar, R. and Reddy, A. N. (2010) Bathymetric significance of the ichnofossil assemblages of the Kulakkalnattam sandstone, Ariyalur area, Cauvery Basin. Journal of Geological Society of India, 76: 525–535.

Nair, K.M. and Vijayam, B.E., (1980). Sedimentology of limestones in Ninniyur Formation, Palaeocene, Cauvery basin, South India. Journal of the Geological Society of India, 21, 503–510.

Nesbitt, H. W. and Young, G. M. (1982). Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. Nature, 299, 715–717.

Nesbitt, H. W. and Young, G. M. (1984). Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic considerations. Geochim. Cosmochim. Acta., 8, 1523–1534.

Pandey, S. and Parcha, S. K. (2017). Provenance, tectonic setting and source-area weathering of the lower Cambrian sediments of the Parahio valley in the Spiti basin, India. Jour. Earth. Syst. Sci., 126 (27), 1-16.

Pettijohn, F. J., Potter, P. E. and Siever, R. (1972). Sand and Sandstones. New York Springer-Verlag,.618.

Price, J. R. and Velbel, M. A. (2003). Chemical weathering indices applied to weathering profiles developed on heterogeneous felsic metamorphic parent rocks. Chem. Geol., 202 (3&4), 397-416.

Prasad, G. V. R., Verma, O., John, J. F. and Anjali, G. (2013) A new Late Cretaceous vertebrate fauna from the Cauvery Basin, South India: Implications for Gondwanan paleobiogeography. Journal of Vertebrate Paleontology, 33: 1260–1268.

Powell, C. McA., Roots, S. R. and Veevers, J. J. (1988). Pre-breakup continental extension in east Gondwanaland and the early opening of the Indian Ocean. Tectonophysics., 155, 261–283.

Quasim M. A., Ghosh S.K., Ahmad A.H.M, Srivastava, V.K. and Albaroot M.(2020) Integrated approach of lithofacies and granulometric analysis of the sediments of the Proterozoic Upper Kaimur Group of Vindhyan Supergroup, Son Valley, India: Palaeo-environmental implications. Geological Journal, 55 (9), 5591-6021. https://doi.org/10.1002/gj.3781

Radulovic, V. and Ramamoorthy, K., (1992). Late Cretaceous (Early Maastrichtian) brachiopods from south India. Senkenbergiana Lethaea, 72, 77–89.

Rajnikanth, A. (1992). Rock building Cretaceous-Tertiary algae from India - An ecological perspective. Palaeobotany, 40, 399-412.

Rajagopalan, N. (1965). Late Cretaceous and Early Tertiary Stratigraphy of Pondicherry, South India, Jour. Geol. Soc. India., 6, 104–121.

Rajagopalan, N. (1968) A restudy of the Pondicherry Formation. Mem. Geol. Soc. India., 2, 128–129.

Rajamanickam, G. V. and Gujar, A. R. (1984) Sediment depositional environment in some bays in the Central West Coast of India; Indian J. Mar. Sci. 13, 53-59.

Rajganapathi, V.C., Jitheshkumar, N., Sundararajan, M., Bhat, K.H. and Velusamy, S. (2013) Grain size analysis and characterization of sedimentary environment along Thiruchendur coast, Tamilnadu, India. Arabian Journal of Geosciences, 6: 4717–4728, DOI 10.1007/s12517-012-0709-0

Ramasamy, S. and Banerji, R.K., (1991). Geology, petrography and systematic stratigraphy of pre-Ariyalur sequence in Trichirapalli district, Tamil Nadu, India. Journal of the Geological Society of India, 37, 577–594.

Ramanujam, C.G.K. (1968). Some observations on the flora of the Cuddalore Series. Memoir of Geological Society of India, 2, 271-285.

Rao, L.R. and Prasannakumar, C. (1932). Occurrence of Lithothamnion in the South Indian Cretaceous. Nature, 129, 776-777.

Rao, L.R. and Pia, J. (1936). Fossil algae from the uppermost Cretaceous beds (The Ninniyur Group) of the Trichinopoly District, S. India. Mem. Geol. Surv. India, Pal. India, 21(4), 13-40.

Rao, L.R. and Gowda, S.S. (1954). Solenoporaceae in the Cretaceous rocks of south India. Curr. Sci., 23, 177-178.

Reddy, A. N., Jaiprakash, B. C., Rao, M. V., Chidambaram, L. and Bhaktavatsala, K. V., (2013) Sequence stratigraphy of Late Cretaceous successions in the Ramnad Sub-basin, Cauvery Basin, India. Geological Society of India Special Publication, 1: 78–97.

Roser, B. P. and Korsch, R. J. (1986). Determination of tectonic setting of sandstone–mudstone suites using SiO2 content and K2O/Na2O ratio. Jour. Geol., 94, 635–650.

Roser, B. P. and Korsch, R. J. (1988). Provenance signature of sandstone–mudstone suite determined using discriminant function analysis of major element data. Chem. Geol., 67, 119–139.

Sastry, M.V.A. and Rao, B.R.J., (1964). Cretaceous–Tertiary boundary in south India. Proceedings on the XII International Geological Congress on Cretaceous–Tertiary boundary including volcanic activity, 3 (3),92–103.

Sastry, M.V.A., Mamgain, V.D. & Rao, B.R.J., (1972). Ostracod fauna of the Ariyalur Group (Upper Cretaceous), Trichinopoly district, Tamil Nadu. Palaeontologica Indica, 40, 1–48.

Sastry, M.V.A., Rao, B.R.J. & Mamgain, V.D., (1968). Biostratigraphy zonation of the Upper Cretaceous formation of the Trichinopoly district, south India. Memoirs of the Geological Society of India, 2, 10–17.

Sastry, V.V., Raju, A.T.R., Sinha, R.N. & Venkatachala, B.S., (1977). Biostratigraphy and evolution of the Cauvery basin, India. Journal of the Geological Society of India, 18, 355–377.

Sarkar, S., Nivedita, C., Mandal, A., Banerjee, S. and Bose, P.K. (2014) Siliciclastic-carbonate mixing modes in the river-mouth bar paleogeography of the Upper Cretaceous Garudamangalam Sandstone (Ariyalur, India). Journal of Paleogeography, 3: 233–256.

Shah, R. A., Achyuthan, H., Lone, A. M., Ramanibai, R. (2017). Diatoms, spatial distribution and physicochemical characteristics of the Wular lake sediments, Kashmir valley, Jammu and Kashmir. Jour. Geol. Soc. India, 90(2), 159–168.

Sahu, B. K. (1964). Depositional mechanical from the size analysis of the classic sediments. Jour. Geol. Sedi. Petro., 36, 73-83.

Selvaraj, K. and Ramasamy, S. (1998). Depositional environment of Cuddalore Sandstone Formation, Tamil Nadu, Jiur. Geol. Soc. India, 50 , 803-812.

Spencer, D.W. (1963). The interpretation of grain size distribution curves of clastic sediment. J. Sediment. Petrol., 37,. 180-190.

Srivastava, R. P. and Tewari, B. S. (1967). Biostratigraphy of the Ariyalur Stage, Cretaceous of Trichinopoly. Jour. Paleo. Soc. India., 12, 48–54.

Srivastava, A.K. and Mankar, R.S. (2008) Grain size analysis and depositional pattern of upper Gondwana sediments (Early Cretaceous) of Salbardi area, districts Amravati, Maharashtra and Betul, Madhya Pradesh. Journal of Geological Society of India 73: 393–406.

Sundaram, R. and Rao, P. S. (1986). Lithostratigraphy of Cretaceous and Paleocene rocks of Tiruchirapalli district, Tamil Nadu, south India. Records of the Geological Survey of India, 116, 11–23.

Sundaram, R., Henderson, R.A., Ayyasami, K. and Stilwell, J.D. (2001). A lithostratigraphic revision and palaeoenvironmental assessment of the Cretaceous System exposed in the onshore Cauvery Basin, southern India: Cretaceous Research, 22, 742-762

Suttner, L. J. and Dutta, P. K. (1986). Alluvial sandstone composition and paleoclimate. I Framework mineralogy. Jour. Sediment. Petro., 56, 329-345.

Taylor, S. R. and McLennan, S. M. (1985). The Continental Crust: Its Composition and Evolution. Oxford, Blackwell, 349.

Tewari, A., Hart, M. B. and Watkinson, M. P. (1996). A revised lithostratigraphic classification of the Cretaceous rocks of the Trichinopoly district, Cauvery Basin, southeast India. *In* Contributions to the XV Colloquium on Micropaleontology and Stratigraphy, 789–800. (Published by Paleontological Society of India).

Udden, J. (1898). Mechanical composition of wind deposits. Aug. Lib. Publ., 1, 69.

Venkatachala, B.S., (1974). Palynological zonation of the Mesozoic and Tertiary subsurface sediments in the Cauvery basin. In: Surange, K.R. et al. (eds.), Aspects and appraisal of Indian Palaeobotony, 476–495. (Published by British Institute of Palaeontology, Lucknow).

Venkatachalapathy, R. and Ragothaman, V. (1995). A foraminiferal zonal scheme for the mid-Cretaceous sediments of the Cauvery Basin, India. Cretaceous Research., 16, 415–433.

Vital, H. and Stattegger, K. (2000). Lowermost Amazon River: evidence of late Quaternary sea-level fluctuations in a complex hydrodynamic system. Quaternary Internat., 72, 53-60.

Visher, G.S. (1969). Grain size distributions and depositional processes, Jour. Sedi. Petrol., 39, 1074-1106.

Vredenburg, E.W. (1908). Consideratons regarding the age of the Cuddalore series. Record of the Geological Survey of India, 36, 321-323

Warth, H. (1895). The Cretaceous Formation of Pondicherry. Records of the Geological Survey of India., 28, 15–21.

Wadia, D.N. (1953). Geology of India. Macmillan and Company Ltd. St.Martin's streets, London.

Watsan, J. S. (1996). Fast, simple method of pellet preparation for X-Ray Fluorescence. X-Ray Spectometry, 25, 173-174.

Yadagiri, K. and Govindan, A., (2000). Cretaceous carbonate platforms in Cauvery basin: Sedimentology, depositional setting and subsurface signatures. In: Govindhan, A. (ed.), Cretaceous stratigraphy – An update. Memoirs of the Geological Society of India, 46, 323–344.

…….