International Research Journal of Earth Sciences ISSN 2321–2527
Vol. **3(9),** 1-7, September **(2015)** *Int. Res. J. Earth Sci.*

Petro-Mineralogy and Major Elements Geochemistry of Regolith profile of Calcrete deposits at Pandalgudi, Viruthunagar District, Tamilnadu, India

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Available online at: www.isca.in, www.isca.me
Received 10th July 2015, revised 20th August 2015, accepted 4th September 2015

Abstract

Calcrete is one of the essential impure limestone components of arid and semi-arid depositional system. It is widespread in the regolith part of Pandalgudi Village (Latitude N9^{0}22'21.6'' and Longitude E78^{0}16'23.3'') Viruthunagar district of Tamilnadu. The Schematic stratigraphic succession of the profile of calcrete deposits is cited. The calcrete layers are in the form of gravel, nodular hardpan, lumpy and chalky states. The petrological observation reveals that micritic calcite precipitation developing = around detrital quartz, feldspar and other sap rock grains such as biotite hornblende, hypersthene which results as rimming, veining, void lining, lensoidal, meshwork, displacive and replacive structures. The study of major elementgeochemistry of calcrete indicates that CaO, MgO, SiO_2, Al_2O_3 and Fe_2O_3 are in elevated concentration (> 1%) whereas MnO, Na_2O, K_2O, TiO_2 and P_2O_5 in low level concentration (< 1%). The major element geochemistry of calcreteillustrates the geochemical environment of the study area.

Keywords: Regolith, Micritic calcite, Sap rock grains, Major element geochemistry.

Introduction

Calcretes are the calcium carbonate crust widely developed at the surface of the earth in semi-arid regions[1]. It is one of the impure limestone varieties which is originated either from pedogenic leaching of meteoric water or also from evapotranspiration of groundwater in the regolith part under arid and semi-arid climatic conditions[2]. Numerous research workers have concentrated their research on calcrete deposits, not only in India, but also in many parts of the world[3-15]. But no much research work has been carried out on calcrete deposits of Pandalgudi region in Viruthunagar district of Tamilnadu, India (figure-1)

Geological setting: The topography of the study area is almost flat and plain which receives an average rainfall of 600 mm yearly. The Proterozoicbasement rock orsaprock is mainly composed of Hornblende-Biotite gneiss those enclaves Charnockite, Pyroxene granulite, Crystalline limestone, Calc-Granulite associates and Granite.

Table-1
General Stratigraphic Succession of the study area

Age	Thickness	Strata	Depth
Recent	1.25 m	Black Cotton soil	0-1.25 m
Holocene to Pleistocene	1.20 m	Calcrete layer	1.25m -2.45m
Proterozoic	Infinitive	Sap rock or Basement rock	Below 2.45 m

The black soil is exposed as surface outcrop at the top of the hard rock. In between black soil and basement rock, calcrete has been developed as athickness of 1.20m at the selected site. The general stratigraphic succession of the study area is given in (table-1)

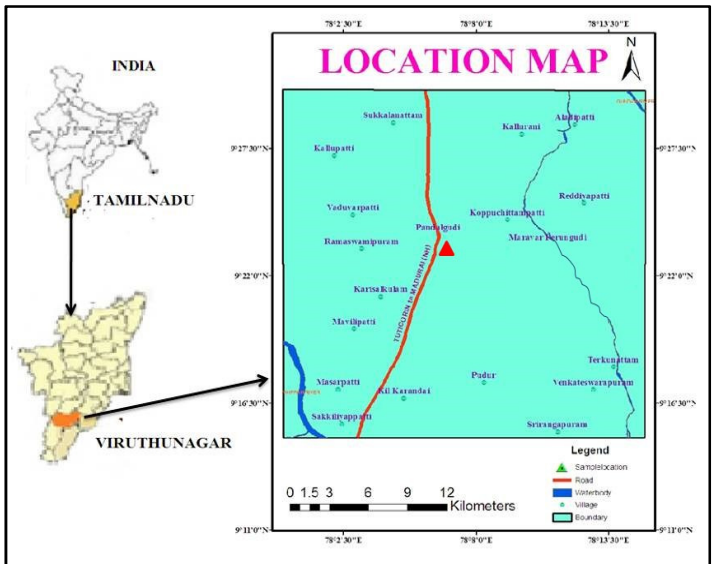

Figure-1
Location map of the study area

Methodology

Seven different kinds of calcrete samples were collected from onestratigraphic regolith profile succession at different depth located near Pandalgudi town (Latitude N9^{0}22'21.6'' and

Longitude E78^{0}16'23.3''). While collecting samples, the general geological settings and field characteristics of the calcrete deposited of study area is also observed (figure-2). A part of the samples were prepared for the thin section at Suchitra Polishing Unit at Ennore, Chennai. These thin sections were studied and photographed under the camera attached, binocular visioned polarized petrological microscope from the laboratory of Department of Geology, V.O. Chidambaram College, Tuticorin for Petro-mineralogical studies.

Another part of the same samples were used for major element geochemical analysis through XRF (X-ray Fluorescence Spectrometry) method by the instrument (Philips-Magix PRO-PW 2440) at National Geophysical Research Institute (NGRI), Hyderabad. International geochemical reference material from the US Geological Survey, the International working group (France) and NGRI CSIR Lab (INDIA) were used toprepare calibration curves for the major oxides[16].

Results and Discussion

Field observation: Calcrete occurs as granular or gravel layer at the top profile section, but alternate layers of massive, laminated, nodular hardpan, lumpy and chalky nature of calcrete are found above the sap rock or bed rock at the bottom profile section. Such regolith carbonates are widespread in many areas of arid and semi-arid region of Australia and its regional distribution is largely controlled by the degree of leaching of carbonate and availability of carbonate sources from groundwater in the regolith[17]. The calcrete deposit of this study area is well exposed as the top profilein the gully section along the stream. But the entire study area is covered with black soil underlain by 1m thick calcrete profile resting on the sap rock of hard Calc – per-alkaline group of metamorphic rocks. These sap rocks are contributing more calcium carbonate content to groundwater. Then the calcrete is formed by evapotranspiration of ground water that is drawn up through the soil by capillary rise action. The occurrence of granular calcrete in the black soil above the full calcrete profile indicates the evidence for the, capillary rise and evapotranspiration process. The different kinds of calcrete occurrences incalcrete profile may be due to the landscape setting. The field relationship of calcrete and other subsurface saprock of the study area are shown in photographs (figure.3a-f).

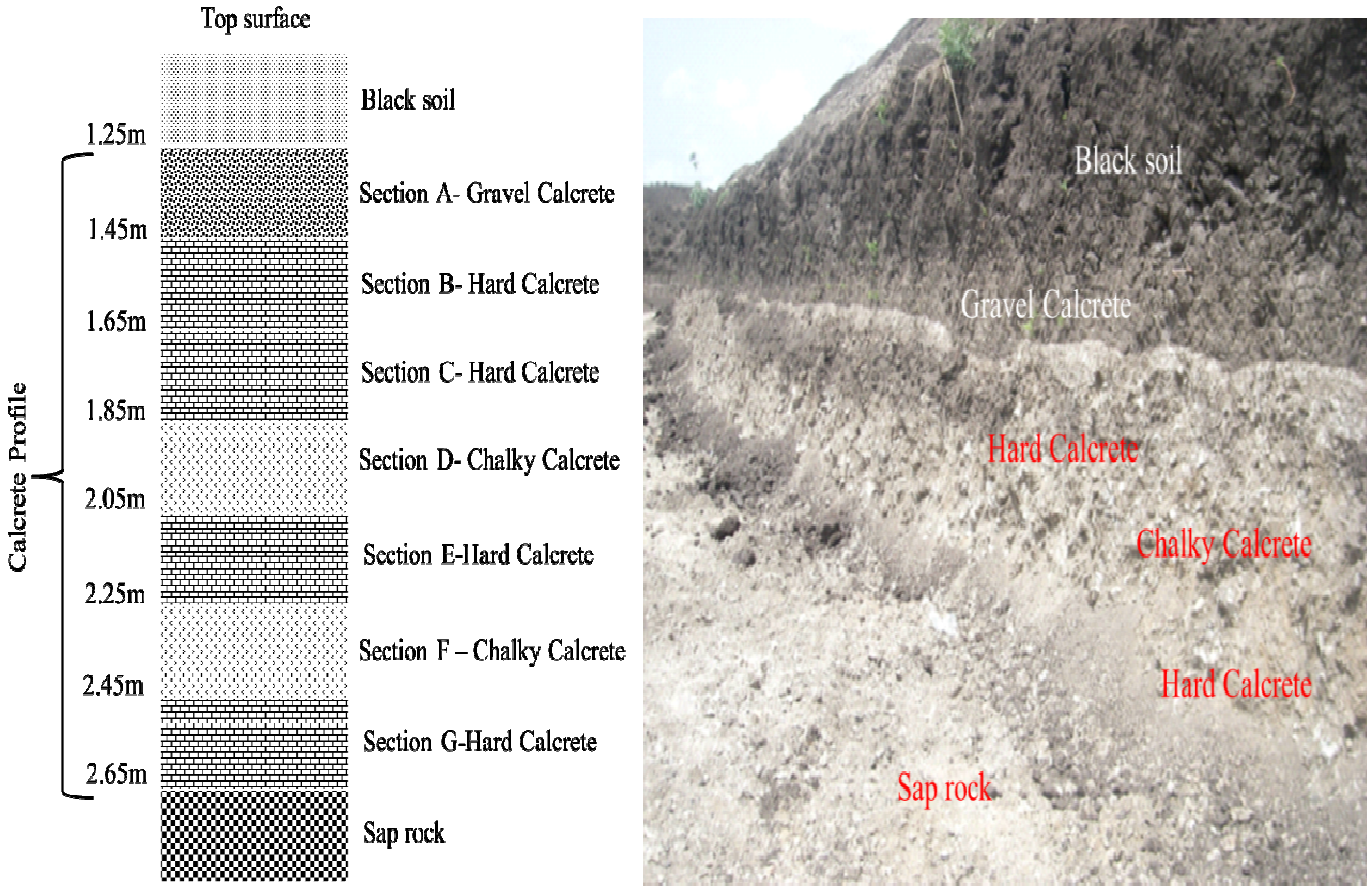

Figure-2
Calcrete profile in and around Pandalgudi village

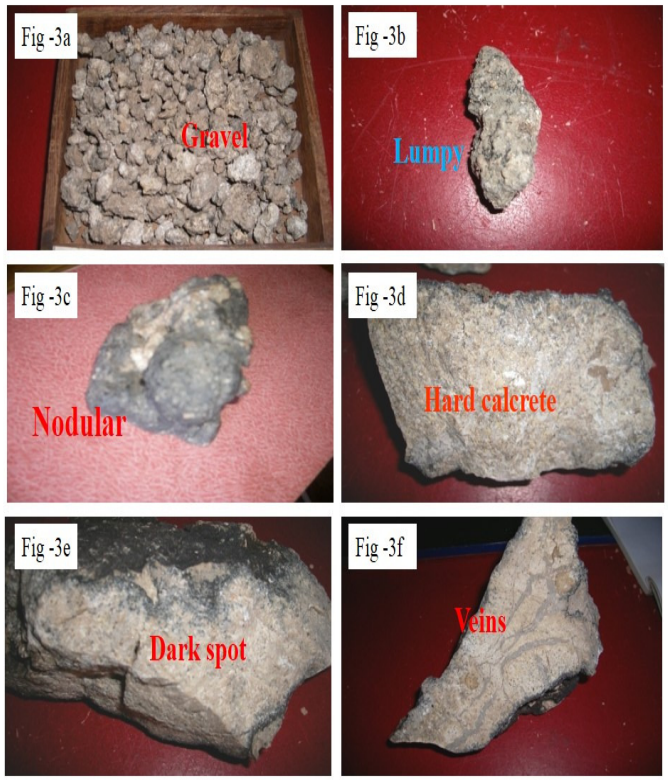

Figure-3
(a-f) Petrological Observation – (Megascopic Features). Figure-3a, Gravel form. Figure-3b, Lumpy form. Figure- 3c, Nodular form. Figure-3d, Hard calcrete. Figure-3e, Dark spot, Figure-3f, Veins.

Petrological observation: The calcrete profile contains gravel or granular, chalky, lumpy nodular, massive and laminated forms. They show vein, dark spotted structure and vugs macroscopically. The microscopic study shows the micritic or microspariti ccalcite precipitation which surrounds the phenocryst of quartz, feldspars such as orthoclase, microcline and plagioclase feldspar and other sap rock grains of Hypersthene, Hornblende and Biotite forming nucleation effect. Sometimes, the carbonate deposition shows displacive orreplacive structures in the mineral grains and soil clay matrix. Depositional environment of the calcrete in the regolith part of the study area contains two stages. The calcrete is first deposited in the voids and cracks in the soil and weathered saprolite. Then, the clay components in the soil or saprolite are replaced by micritic calcite precipitation. The partial or complete veininfill or pseudomorphous replacement textures are seen in the study area. Such replacement is observed as is volumetric. The dissolution and simultaneous removal or replacement of aluminium silicate is accompanied by the deposition of carbonate. But the detrital quartz grain is unaffected by this process and shows the evidence for minor grain etching. Such above replacive and displacive structure have already been observed in Cobar- Girilambone regions, Australia[18]. The sap rock grains biotite, hornblende and hypersthene, replaced by micritic calcite precipitation along the cleavage plane are noticed from the thin section of lower profile samples of the study area. The large microcrystalline calcite vein (0.4mm), filamentous calcite vein (0.02mm), lensoidal and meshwork precipitation are commonly noticed in thin section. The veining of microcrystalline calcite precipitation may be due to the vacuum or void created by the rhizome of plant (*Prosopis Julifera Mimosaceae)* present in soil outcrops. The dark brown dendritic impregnation that is believed to be a clay mineral sesquioxide in calcitic groundmass is also observed in thin section. Such similar characters were illustrated in calcretes of Coimbatore region, India[19]. The microscopic observations are shown in photomicrographs (figure-4a-l).

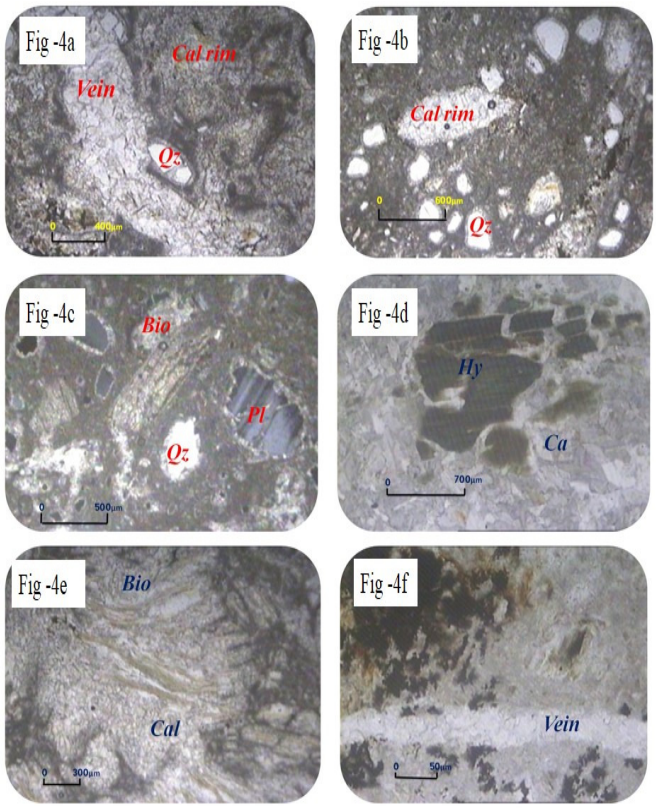

Figure-4
a-f (Photomicrograph photographs). 4(a) The photomicrograph of view of micritic calcite deposition in the void of formed by Rhizome and Quartz mineral rimmed by micritic calcite (Polarized light). 4(b) The photomicrograph shows lensoidal micritic calcite deposition and quartz rimming by micritic calcite (Polarized light). 4(c) Photomicrograph shows plagioclase grain rimmed by micritic calcite (Crossed nicolposition). 4(d) The photomicrograph shows breaking of Hypersthene displacedby micritic calcite (Polarized light). 4(e) The photomicrograph shows micritic calcite deposition replacing biotite flakes (Polarized light). 4(f) The photomicrograph vein of micritic calcite deposition and sesquioxide preservation (Polarized light).

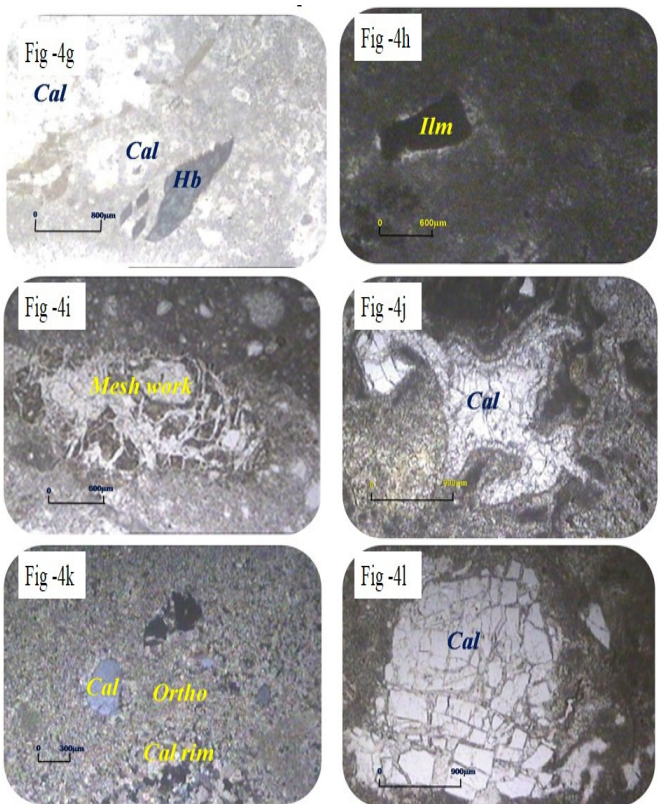

Figure-4
g-l (Photomicrograph photos). 4(g) The photomicrograph shows Hornblende replaced by micritic calcite (Polarized light). 4(h) The photomicrograph shows the opaque grains Ilmenite by micritic calcite (Polarized light). 4(i) Photomicrograph shows meshwork micritic calcite deposition (Polarized light). 4(j) The photomicrographs shows vacuum or void formed by Rhizome filled by micritic calcite deposition (Polarized light). 4(k) Photomicrograph shows the micritic rimming around orthoclase feldspar (Crossed nicol position). 4(l) Photomicrograph shows microcline feldspar breaking down by micritic deposition (Polarized light).

Geochemical observations: The major element composition of calcrete samples of the profiles of the study area indicates that CaO, MgO, SiO_2, $Al_2O_3$and Fe_2O_3 are in elevated concentrations above 1% whereas other oxides such as MnO, Na_2O, K_2O, TiO_2, P_2O_5 are in low-level concentration and its distribution percentage is shown (tables-2, figure-5). The calcrete profiles in the study area are showing more or less similar distribution trend. The carbonate content in profiles varies with more calcium carbonate to low magnesium or high magnesium-rich carbonate from top to bottom profile. This may be attributed to the inclusion of the variable amount of clay and other regolith components including detrital quartz and iron oxide in the hardpan carbonate zone and also within the nodular carbonate. This same condition exists in Cobar-Girilambone region, Australia[18]. The major element composition indicates that the carbonate composition is largely of calcite and low magnesium or high magnesium calcite formed in the study area (figure-6).Despite the formation of calcite and low or high magnesium calcite in the same regolith profile, calcite is typically more abundant in the profiles. The abundance of calcite preservation may be due to the dissolution of carbonate by downward percolating from surface (rain) water and neo-precipitation of calcite before dolo -calcite (low or high magnesiumcalcite) precipitation high in the profile caused by change in pH and pCO_2. This has already been studied in the New South Wales region in Australia[2]. In general, the lower profiles of the study area are in contact with the fluctuating water table level. The high magnesium content in lower profiles reflects a greater influence in carbonate genesis fluctuating from groundwater movements along the bedrock and soil boundary. Such similar condition has already been observed in Australian[18] calcretes. The distribution of potassium (K_2O) and aluminium (Al_2O_3) content in calcrete reflects the clay mineral components. All the samples of the study area show more of kaoline and illite composition field (figure-7). Kaoline or Illite is formed by hydrothermal alteration or weathering of silicates, principally feldspar. Kaoline has a low cation exchange capacity compared with other clay mineral illite and montmorillonite. The absence of clay mineral montmorillonite indicates that there is a limited cation exchange between these minerals in the sources. The formation of illite is generally favored by the alkaline condition and accumulating the high concentration of aluminum and potassium[20]. The Fe_2O_3 content of the calcrete samples ranges from a minimum of 1.59% to maximum 1.97%. The iron (Fe_2O_3) shows negative correlations (r = 0.8) existing with carbonate (CaO) in the study area. It indicates that it is not significantly derived from carbonate phase, but they are most likely to be present in iron oxide or oxyhydroxide impurities from the soil. Such similar condition has already been observed in the Cobar-Grillambone region, Australia[18]. The sesquioxide impregnation (Fe_2O_3, Al_2O_3) are the characteristics features formed in the dense nodule at the deeper horizon. Their occurrence may be due to the result of water logging in deeper horizons generating reducing condition that favors the mobility of ferrous ion. Such similar sesquioxide preservation has also been observed in the study area which represents arid and semi-arid climatic condition. The presence of silica concentration in calcrete may be due to the presence of unaltered detrital quartz and feldspar grain. The other oxide K_2O, Na_2O, MnO, TiO_2 and P_2O_5in the calcrete are less significant in the geochemical interpretation of the study area. Ingeneral, the groundwater analysis of the study area indicates that they have more of calcium and bicarbonate-rich than that of magnesium content (table-3). The calc-alkaline and per-alkaline rich basements rocks such as Hornblende-Biotite Gneiss, Charnockite, Pyroxene granulite, Pink Granite, White granite, Calc-granulite, Crystalline Limestone, Marble and Black soil in the study area are contributing more calcium carbonate sources to groundwater and surface water respectively (tables-4 and 5).

Table-2
Distribution of major element of the calcrete samples at the Pandalgudi profile

Samples Name	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	Ti_2O	P_2O_5
Section A- Gravel Calcrete	14.08	4.03	1.67	0.13	3.92	40.56	0.57	0.01	0.28	0.3
Section B- Hard Calcrete	13.57	3.77	1.59	0.36	5.66	42.65	0.2	0.02	0.28	0.13
Section C- Hard Calcrete	13.94	3.85	1.68	0.61	9.46	37.98	0.41	0.01	0.23	0.15
Section D- Chalky Calcrete	13.92	3.84	1.67	0.6	9.24	37.9	0.42	0.02	0.23	0.16
Section E – Hard Calcrete	13.67	3.96	1.9	1.22	9.01	38.38	0.5	0.15	0.27	0.33
Section F – Chalky Calcrete	14.26	4.03	1.68	0.64	9.1	37.62	0.57	0.03	0.28	0.05
Section G. Hard Calcrete	14.51	4.15	1.97	0.33	11.3	36.77	0.54	0.13	0.3	0.11

Table-3
Water Quality Data of the study area in and around Pandalgudi

Sample Locations	Ca^{2+} mg/L	Mg^{2+} mg/L	Na^{+} mg/L	K^{+} mg/L	Total Alkaline	Cl^{-} mg/L	SO_4^{2-} mg/L	NO_3^{-} mg/L	F^{-} mg/L
Suthamadam	40	22	78	2	110	166	48	0.8	0.18
Sivalarpatti	48	38	108	2	160	202	104	1.4	0.22
Maniyakkaranpatti	40	19	58	1	80	150	42	0.6	0.18
Maravarperungudi	48	22	88	2	120	184	42	0.6	0.20
Salukkuvarpatti	44	22	96	1	110	192	62	1.4.	0.24
Pandalgudi	40	29	88	6	130	184	54	0.8	0.20

Table-4
Rock analysis of the other sub – surface rocks of the study area in and around Pandalgudi

Other Rocks of the study area	SiO_2	Al_2O_3	Fe_2O_3	MNO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5
Calc- Granulite	12.8	2.77	1.74	0.13	1.3	40.47	0.31	0.55	0.29	0.05
Pink Crystalline limestone	12.08	2.39	1.42	0.07	1.61	41.96	0.05	0.52	0.29	0.02
Marble	12.75	2.68	1.45	0.06	1.33	40.81	0.27	0.57	0.29	0.05
White crystalline limestone	12.16	2.42	1.41	0.07	1.15	42.03	0.1	0.53	0.29	0.05
Hb – Biotite Gneiss	53.38	13.21	4.21	0.01	1.1	14.45	3.04	6.2	00	0.02
Charnockite	61.46	5.66	2.81	00	1.5	22.3	2.67	0.82	00	0.001
Pink Granite	74.1	9.3	3	00	0.3	5.8	0.3	5.1	00	0.71
Tourmaline Grey Granite	65	12.9	0.4	00	0.4	5.5	4.5	3.4	1.3	1.44
Pink Granite	65.8	12.8	3.5	00	1.12	6.5	3	6.2	00	0.24

Table-5
Chemical quality of black cotton soil of study area-Pandalgudi

Depth in cm	pH	EC dsm^{-1}	OC%	OMs%	Free $CaCO_3$	CEC c.mol (+)/g	Exchangeable cation c.Mol (+) per kg				ESP
							Ca^{+2}	Mg^{2+}	Na^{+}	K^{+}	
0-14	8.5	0.3	0.33	0.57	3.3	50.6	38.75	8.25	2.25	0.85	4.4
14-33	8.5	0.11	0.25	0.43	3.4	50.1	38.75	8	2.6	0.66	5.2
33-51	8.5	0.13	0.22	0.38	3.4	50.8	39	8	2.75	0.59	5.4
51-121	7.8	2.3	0.18	0.31	5.1	50.9	39.5	9	1.5	0.46	2.9

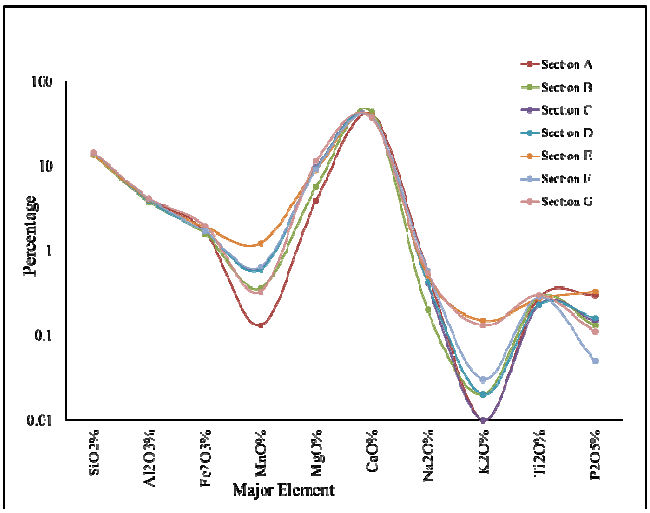

Figure-5
The distribution of Major element oxide of the calcrete samples in the study area Pandalgudi Village (Value in percentage)

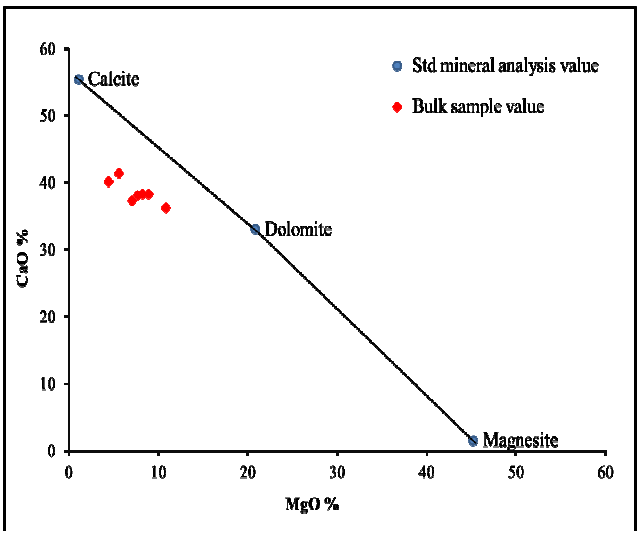

Figure-6
Bivariate plots between CaO vsMgO (After MC Queen, 2006, modified with standard analytical result of minerals analysis from Deer et al 1978, modified by Udayanapillai et al, 2014)

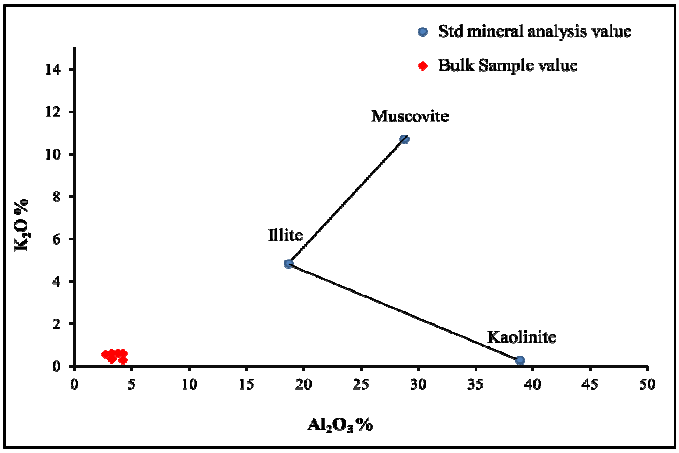

Figure-7
Bivariate plots between K_2O vs Al_2O_3 (After MC Queen, 2006, modified with standard analytical result of minerals analysis from Deer et al 1978, modified by Udayanapillai et al, 2014)

Conclusion

Thus, the study reveals the following findings. The field evidence proves that calcrete are in the form of gravel, nodular, lumpy and powder forms. The megascopic features such as veins, vugs, dark spots and microscopic features of rimming, filamentous and large vein, lensoidal, meshwork, displacive and replacive structures with sap rock grains were noted as Petro-Mineralogical observations. Geochemistry of calcrete illustrates that CaO, MgO, SiO_2, $Al_2O_3$and Fe_2O_3 are in the elevated concentration above (1%) than the other oxides such as Na_2O, K_2O, P_2O_5, MnO, and TiO_2. The calc and peralkaline rich basement rocks and black soil are the prime source contributors of rich alkaline water for the formation of calcrete under arid and semi-arid climatic condition.

Acknowledgement

Authors acknowledge with thanks to the authorities of V.O. Chidambaram Educational Institute, Tuticorin, for granting permission to publish this paper. Further, the authors are thankful to Tamilnadu State Government of India, for the Research Fellowship provided to the author V. Perumal, for the preparation of this research paper.

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