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Characterization of Possible Occurrence of Carbonatite-Lava Adjacent to Main Boundary Thrust (MBT) on the Way from Dehra Dun to Mussoorie

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Abstract: *An occurrence of carbonatite-lava is reported in the area lying between Dehra Dun and Mussoorie in road cuttings at 12.6 km from Dehra Dun adjacent to MBT zones. Carbonatite generally found in rift associated divergent plate boundaries. However, an occurrence of carbonatite-lava in a subduction zone in Lesser-Himalayan region amidst Early Paleozoic sediments as concordant and discordant bodies along their joint and bedding planes is a rare phenomenon. The carbonatite-lava is a dark-grey coloured compact very fine-grained rock with one or two vesicles visible to naked eye. Chilled margins are visible at contacts of a calcite vein. It appears to be little deformed and much younger than Pleistocene uplift by any folding and thrusting movements in the Himalayan region. The rock is under-saturated in silica. It is olivine, nepheline and sodium-carbonate normative. It is composed of higher volume proportion of normative calcite as essential minerals. Clinopyroxene, wollastonite, biotite, alkali-feldspars, quartz and magnetite are present as accessory minerals. Spherulites of calcites are commonly seen in fine-grained calcite matrix. Without association of any differentiated alkali magmatic rocks, the carbonatite-lava is considered to be an atypical nature derived from deep seated source along lower thrust zone. The carbonatite volcanic activity in this area opens new avenues for petroleum exploration in Himalayan Region.*

Keywords: *A typical Carbonatite-lava, Dehra Dun-Mussoorie, Main Boundary Thrust (MBT)*

1. INTRODUCTION

Carbonatite is a nil-silicate igneous rock [1]. It generally associates with differentiated co-magmatic alkaline magmatic rocks. Most carbonatite occur along rift zones [1, 2, 3, 4]. The magmatic carbonatite rock or volcanic carbonatite-lava flow without any association of differentiated co-magmatic sequences of alkaline rocks and it is called as atypical carbonatite [1, 4]. Such occurrence of atypical carbonatite-lava is wide-spread in several parts of Tamil Nadu [4, 5, 6, 7, 8]. A sample of carbonatite-lava [**Fig.-1**) collected at about 12.6 km from Dehra Dun on the road leading to Mussoorie [9] is shown below:

Fig 1: *Carbonatite-lava shows vitreous and conchoidal fractures with sharp edges. A Thin vein 2 to 1 mm of calcite injected has chilled margin and contact aureole of 3 to 5 mm developed on both sides of the vein.*

It is collected adjacent to Main Boundary Thrust in Himalayan sedimentary basin in the Lesser Himalaya. It is an evidence to revise the Himalayan Geology and possible localization of mineral deposits such as phosphates and petroleum deposits. Though many geologists made frequent field traverses along this geological cross section between Dehra Dun and Mussoorie, it was missed to collect the sample and to recognize it as atypical carbonatite during their field trips. However, it is rather difficult to distinguish carbonatite-lava amidst bedded carbonate sedimentary rocks especially from Blaini, Krol and Tal Formations (Fm) [10, 11}. The present paper contributes additional information [9] with later studies on this rock. Still more detailed field and petrographical studies are warranted to prove it as carbonatite-lava.

2. GEOLOGY AND STRATIGRAPHY

The Himalayan ranges stretched over 2400 km between Namche Bharwa in the South-East and Nanga Bharwa syntaxes in the North West [12]. Field traverse between Dehra Dun and Mussoorie represents typical

geological cross section (**Fig-2 and 3**). It reveals disposition of structure, tectonic deformation and staratigraphic dislocations of Himalayan metasedimentary rocks. Field Excursion Guide [10, 11] briefly-describes rocks exposed in this section. Many faults connected with Main Boundary Thrusts overturns younger sequences of Doon gravels composed fluviatile deposits of Pleistocene sediments (1); Upper Siwalics mainly composed of river-borne-conclomerte (2) and Middle Siwalics largely composed of conglomerate and sandstone (3) were over-thrusted by several thrust movcements associated with Main Boundary Thrust (MBT). Chandpur Fm (4) was composed of phyllites, shales and slates. The overlying Nagthat Fm (5) was composed of arenite, silt-stone, shale and conglomerate. The overlying Blaini Fm (6) was conlomerate of Permo-carboniferous Period. However, the record of Cambrian fauna in Upper Krol and Lower Tal Fm and trails of such fauna in the Blaini Fm, the age of the Blaini-Krol-Tal Fm were attributed to Late Proterozoic [13]. It is (6) is thickly bedded micro-crystalline limestone composed of striated erratic- glacial boulder beds and carbonate, with purple to pink shale in the upper part. The overlying Krol Fm (10, 11, 14) was supposed to be formed during Permo-Triassioc Period. It was composed *of* limestones intercalted with marls; dolomites and shale. A report on the findings of Cambrian fauna creates controversy of lithostaratigraphic correlation [15,16,17, 18, 19]. Above Krol Fm a disconformity is seen with marked erosion surfaces. Stratigraphic and lithologic correlations of rocks present in the Krol Fm are very complex carbonate rocks. They are pre-dominantly composed of unfossiliferous carbonate rocks, however here and there reports have been made on incorporated older occurrences of unconformable microfossils of Paleozoic, Cambrian, Late-Proterozoic Period. Krol Fm is subdivided into Krol A, Krol B, Krol C, Krol D and Krol E Formations.

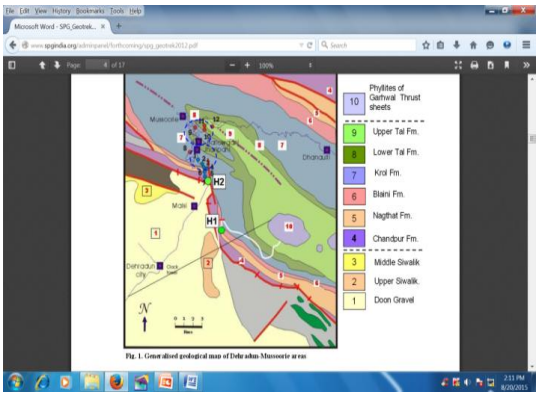

Fig 2: *Geological map of the area lying between Dehra Dun and Mussoorie (Prepared by Society of Petroleum Geophysicts).*

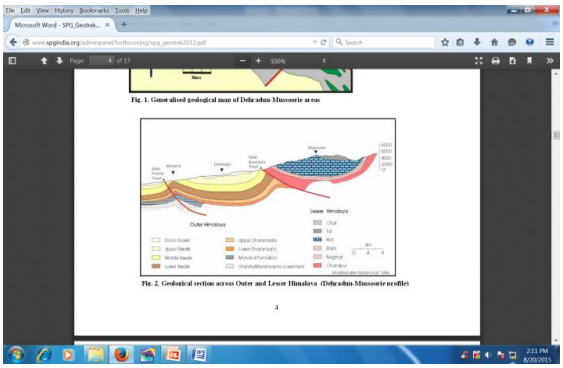

Fig 3: *Geological cross-section between Outer Himalaya and Lesser Himalaya (Dehra Dun –Mussoorie Profile (Society of Petroleum Geophysicts [10. and [11])).*

All these formations were intensively silicified and deformed by fault or shear movements. Calcite rich carbonate rock, marl and thinly bedded limestone are intercalated in calcareous shale in Krol A. Silicified and laminated shale are present in Krol B. Krol C is composed of dark grey massive limestone laminated with shale. It also shows gypsum and calcite layers. Oollite structures are prominently seen. Krol D shows brecciated and vuggy structure and composed of massive limestone interbeds with shale and dolomitic limestone. In Krol E Formation is composed of green shale interbedded with brown limestone. Solution pores are often filled up with calcite, dolomite and gypsum. Along Tehri-Dhanaulti Road in Mussoorie Krol E (11) grades into thinly bedded chert-shale with lenses of phosphate. Similarly, Lower Tal Fm (12) is composed of chert and black phosphate shale where as Middle Tal Fm (13) are composed of argillaceous rocks. Upper Tal Fm (14) is characterized by massive arenaceous shale, shale and quartzite laminas.

Southeast of Sub-Himalayan rocks are bounded by Main Frontal Thrust (MFT). Following this, they have been over-thrust by the Lesser-Himalaya along MBT fault. The steep thrust flattens with depth (nappe) developed during Pliocene time. Along MBT, Sub-Himalayan rocks have been over-thrust by Lesser-Himalayan rocks.

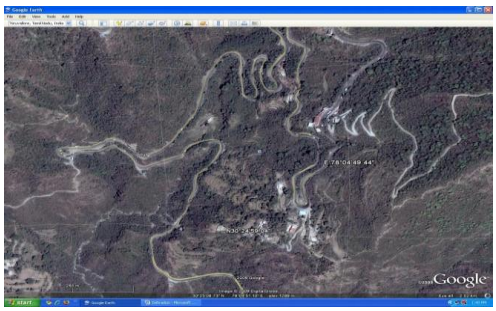

Fig 4: *Highly winding road laid on contoured hill slopes from Dehra Dun to Mussoorie is an active orogen*

Sub-Himalayan clastic sediments were uplifted, eroded and deposited by rivers. The highest rate of uplift 10 mm/y and erosion 2-12 mm/y carve incision of river beds and hill slopes [20] leading to land slide-hazards and also to lay winding roads on contoured slopes. The road laid Dehra Dun to Mussoorie (**Fig. -4**), reveals such factors that Himalayan region is still active orogen [20]. These rocks have been folded and faulted to produce the Siwalic Hills at the foot of the great Himalayan Mountains [21. 22]. The Main Central Thrust divides carbonate rocks and garnet-kyanite schist. It also marks the boundary between mountain-ranges of Lesser-Himalaya and Higher- Himalaya. Outer crystalline rocks are exposed in Higher- Himalaya. Further North-West, rocks of Tethys and ophiolites are seen [22].

A concise geological evolution is given by Valdiya [12. 21, 22]. The Early Paleozoic Period, Indian plate was rifted and separated from Eurasia by Tethys. During Late phases of Pan African-Orogeny, Indian plate moved northwards with development of rifting between Indian Plate, African plate, Australia and Antarctic plates. Further, Indian plate moved towards north very fast during Cretaceous and caused subduction of the Indian continental crust below Tibet. A volcanic-arc was caused by the melting of mantle at the base of the Tibetan bloc, triggered by dehydration of the subduction of Indian oceanic crust. The Dras volcanic rocks [23] consist of basalts, dacites, volcano-clastites, pillow lavas and minor radiolarian chert represent Island arc type of volcanism. They form a part of the ophiolite-belt along the Indus Suture Zone in the Kashmir-Himalaya. The parallel rock-units represent several phases of tectonic and deformational events (**Fig.-5**). The collision of plates at about 45Ma gave rise to an island-arc margin (22).

Foot hills of Himalaya in Indian region were largely composed of Miocene to Pleistocene Murrie and Siwalic sedimentary formations. These formations are folded and thrust over Quaternary alluvium. The Lesser-Himalayan detritus sediments intercalated with some granite and acid-volcanic rocks were thrust over the Sub-Himalaya sediments along Main Boundary Thrust (MBT). Carbonatite-lava occurs along the contact between MBT and Lesser-Himalayan Paleozoic rocks exposed.

The formation of the Himalayas is the result of a collision of India with Asia along the convergent boundary. Again, powerful earth movements between Indo-Australian Plate and Eurasian Plate created the Himalayan ranges (**Fig-5**) were produced additional energy to grow Himalaya.

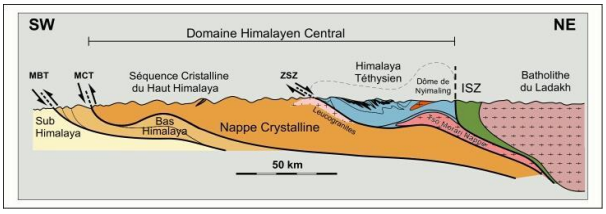

Fig 5: *Simplified cross section of Himalayan region after Dezes, 1999 [24]*

The heat generated beneath the convergent plates drives hot fluid-currents upwards and cold currents downwards. The thrust and nappe movements suddenly release the energy from high pressure to low pressure with high temperature state at greater depths along convergent margins leading to different degrees of partial melting of rocks at depth and further emplacement of igneous and effusive rocks at higher levels. Such melts also impregnated into the host rocks and remobilize them with characteristic major and trace-elemental signatures [25]. The trace element patterns of rocks from volcanic arcs subjected to ultra high pressure exhibit strong enrichment of large ion lithophile elements (LILE) and moderate enrichment of light rare earth elements (LREE) but depletion of high field strength elements (HFSE) and heavy rare earth elements (HREE) demonstrating that their crystallization from anatectic melts of crystal protoliths [25]

3. PETROGRAPHY

Using polarizing microscope (**Plate-1**) and SEM images (**Plate-2**) petrography of the sample was described. The sample appears to be carbonatite-lava. It is a very fine-grained rock. It exhibits conchoidal fracture with sharp edges. However, during examination of SEM images, the rock shows thin sheets of cleavable surfaces varying from 3 to 100 μm thickness with steep dip towards particular direction. Besides, a rough broken surface with conchoidal fracture is also seen. Varioles of calcites are strewn throughout the rock. Quartz 0.2 mm with corroded outline is seen. Wollastonite 0.4 mm is found as prisms. Needles of wollastonite 0.7x0.01 mm are also seen. Dark brown iron-rich biotite flakes are found as significant accessory mineral. Magnetite (0.2mm) forms euhedral crystal. Secondary magnetite is seen along the boundaries of other mafic minerals. The rock is

approximately composed of calcite 49, dolomite 3, clinopyroxene 15, wollastonite 3 alkali feldspars 7, biotite 2, magnetite 2, and quartz 1 and other accessory minerals 18%. A thin vein of calcite (1 to 2mm) shows chilled margin and contact aureoles 3 to 5mm size on both sides of the vein. The aureoles developed around the calcite vein are greater than 4 times of the vein.

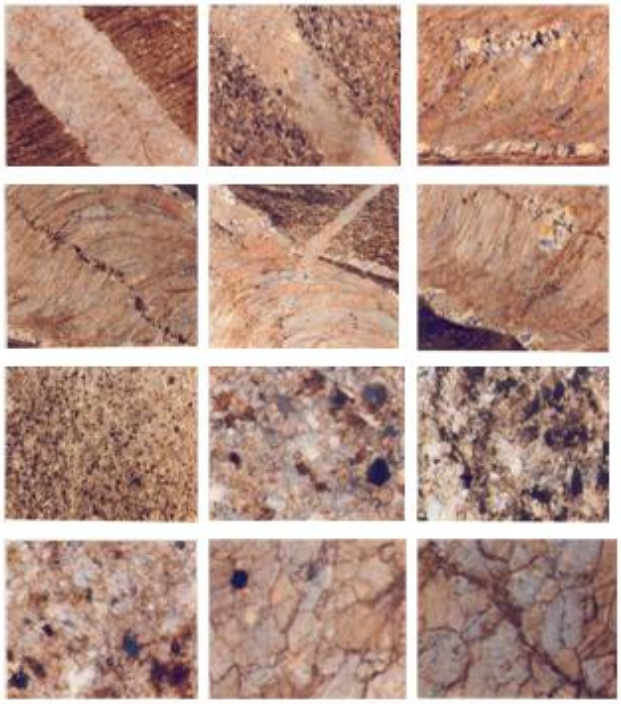

Plate 1: *Microphotographs taken under polarizing microscope*

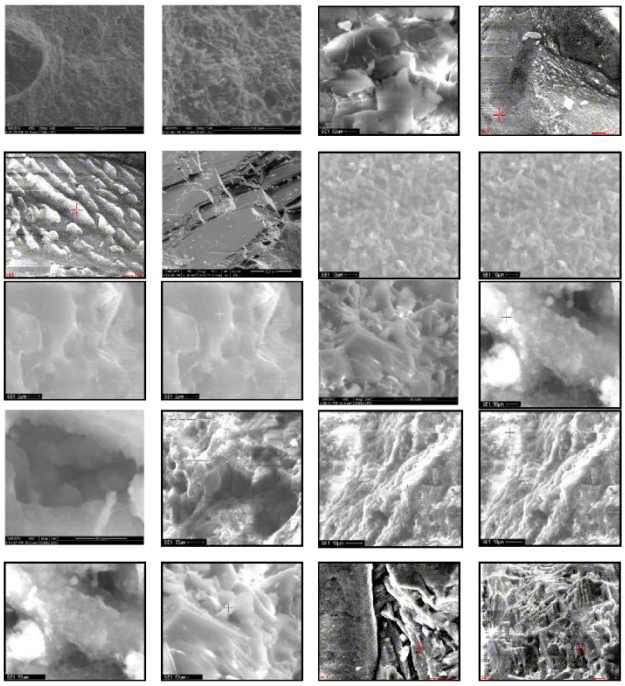

Plate 2: *SEM images of the rock sample*

Similar types of smaller veins are also found in different parts of the rock sample. Slip and joint planes are very smooth and in some places, they are oxidized.

The rock appears to be belonged to volcano-magmatic rock occurring in a sedimentary basin [26]. During examination of thin section under polarizing microscope or EDAX image analyses no relicts of any fossil remains are noticed. Amidst fine-grained calcite matrix (development of pockets with re-crystallized calcite porphyroblastic grains coarsening towards the centre are seen. Fine-grained calcites (10-20 μm) but coarser than matrix (3-5 μm) are seen on the peripheral portions of the pockets and veins. Development of coarse-grained calcite along peripheral portion of calcite vein carries, transverse growth of calcite streaks towards the centre of the vein is seen. Intrusive calcite veins in this dark coloured rock are very similar to pegmatite veins of igneous origin with central cavernous spaces (0.05-0.01 mm) are available for free growth of coarser calcites at inner portions. Similarly, smaller vein cross-cutting a larger vein having peripheral growth of coarse-grains of calcite which is larger than the matrix surrounded the vein. Most carbonate veins appear to be pegmatite in nature by coarsening of minerals inner side with central irregular cavities producing comb-like structure. Some veins carry folded fine calcite-lamellae with primary flow bandings indicate their magmatic origin. Secondary cross-cutting veins of calcite are also found. The vesicle is ellipsoidal in shape with size of 600x500μm. Inner sides of the vesicles are very smooth. They indicate volcanic origin of the rock. Around the vesicle, a coarse grained rim (20-100μm) surrounded by fine-grained calcite matrix (<5 μm) is seen. Fibers and spherulites are up to lengths and widths of 200 x 10 μm are seen. Arc shaped spherulite of 200 x 3 μm is also found. Most vesicles appear to be overturned doubly plunging basins indicating the direction of escaping gas-bubbles and their peripheral portions dip in the same directions. The gas-bubble derived from deep seated source accordingly thickness of walls of the bubbles vary with their water content. Closely spaced lenticular calcite lamellae (120x3μm) are commonly seen on the smooth surfaces. Pockets of calcites 5 to 1 μm are strewn throughout the rock. These structures appear to be very similar to thinly laminated carbonate rock indicating ocellar structure. Interpenetrating and radiating spherulites of calcites (300x50μm) are also present. Interpenetrating prisms of calcite (200x50 μm) grains indicate their magmatic

origin. Dolomite (15x2 µm) exsolved from calcite attains lenticular blebs [27]. Special type of field setting is necessary for liberation of dolomite blebs from calcite.

Table 1: *chemical composition and normative proportions mineral constituents*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO2	25.54	14.62	24.57	13.49	15.27	32.25	19.44	18.12	36.23	12.79	22.78	0.51	0.37	0.28	0.14	0.27	0.38
Al2O3	6.48	5.03	12.05	4.90	6.04	13.60	2.91	6.10	16.24	3.69	5.19	0.44	0.46	0.11	0.30	0.62	0.75
Fe2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.10	0.11
FeO	1.20	1.50	5.64	1.01	1.47	0.85	1.29	1.32	1.02	1.52	1.54	1.13	0.39	0.33	0.59	0.14	0.14
MgO	2.89	3.23	8.45	3.13	4.35	0.64	0.67	1.54	0.77	1.45	0.67	0.50	0.43	0.00	0.38	3.42	2.38
CaO	40.87	52.57	24.11	50.51	46.66	16.55	32.49	39.00	14.26	28.44	35.08	59.95	57.29	58.44	53.99	50.92	49.83
Na2O	2.91	2.36	3.84	2.98	3.33	16.38	19.58	15.31	14.06	23.63	3.81	9.21	11.55	11.12	13.36	1.62	1.53
K2O	0.73	0.54	1.01	0.62	1.45	0.40	0.65	0.58	0.65	0.65	1.71	0.92	0.41	0.82	0.79	0.18	1.95
TiO2	0.00	0.00	0.24	0.00	0.22	0.22	0.14	0.19	0.40	0.29	0.35	0.25	0.00	0.00	0.16	0.00	0.00
CO2	19.37	20.15	20.09	23.35	21.22	19.10	22.82	17.84	16.38	27.54	27.63	27.09	29.10	28.90	30.29	42.71	42.91
moi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.02	0.02
Total	100.00	100.00	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
cc	45.86	44.49	40.56	51.31	46.24	26.57	46.69	35.79	22.02	37.90	64.02	50.57	53.65	53.49	55.33	79.05	80.63
dol	0.00	0.00	5.22	0.00	0.00	4.19	0.00	0.00	5.46	8.85	0.41	0.00	0.00	0.00	0.00	14.17	12.10
na2c	0.00	0.00	0.00	0.00	0.00	15.86	0.00	0.00	13.15	8.26	0.00	0.00	0.00	0.00	0.00	0.00	3.61
il	0.00	0.00	0.30	0.00	0.29	0.00	0.09	0.18	0.49	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00
mt	0.26	0.28	1.46	0.05	0.00	0.00	0.63	0.62	0.00	0.00	0.62	0.37	0.16	0.16	0.20	0.05	0.00
sp	0.00	0.00	7.08	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cpx	33.04	0.00	0.00	2.27	3.54	4.05	39.59	25.50	0.00	35.97	9.65	18.96	22.52	22.63	26.58	3.41	1.95
ol	6.56	6.95	14.36	5.65	7.77	0.00	1.26	2.78	0.00	0.00	0.00	0.99	0.65	0.00	0.60	0.77	0.00
lar	3.75	35.60	0.00	26.81	25.18	0.00	4.05	19.22	0.00	0.00	0.00	28.00	21.92	23.48	16.57	0.82	0.00
ne	10.53	12.68	8.08	13.91	16.98	20.66	7.69	15.91	17.73	9.02	0.00	1.11	1.10	0.24	0.72	1.73	1.71
alkfels	0.00	0.00	22.94	0.00	0.00	28.67	0.00	0.00	40.52	0.00	24.99	0.00	0.00	0.00	0.00	0.00	0.00

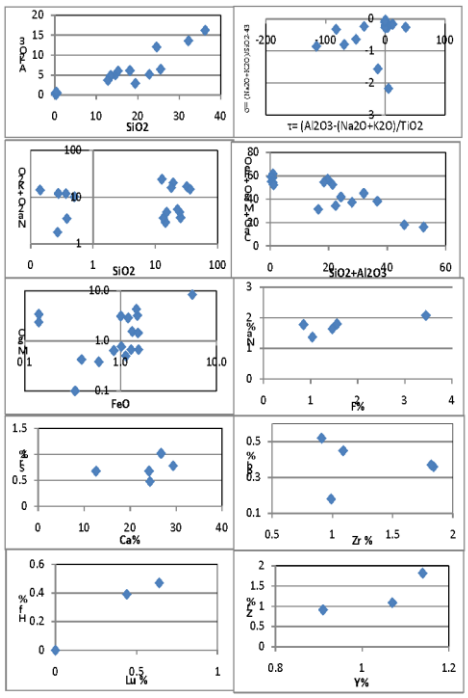

Fig 6: *The distribution of various incompatible elements in the carbonatite-lava sample*

4. GEOCHEMISTRY

The samples 11, 16 and 17 were analyzed by wet gravimetric analyses. The remaining were analyzed under EDAX analyses. The analyses were recalculated followed by Rittmann 1973 [28]. A positive linear correlation is seen between Al_2O_3 against SiO_2 (**Fig-6**). Similar distribution is also present $\sigma = (Na_2O+K_2O)/SiO_2-43$ and $\tau = Al_2O_3-(Na_2O+K_2O)/TiO_2$ [28]. (Na_2O+K_2O) against SiO_2 separate the analyses into two groups as silica poor and alkali depleted rocks and silica and alkali rich rocks. Generally, all the analyses show that $SiO_2+Al_2O_3$ from 0.44 to 52%. Their Na_2O+K_2O content too vary from 2.48 to 24.38 (Table 1). Normative sodium carbonate is present in some analyses. All the samples are siliceous carbonate rocks. Wet gravimetric analyses (11, 16, 17) show almost equal proportion of FeO and Fe_2O from total FeO. MgO is enriched up to 8.45%. A negative correlation is seen between CaO+MgO+FeO and $SiO_2+Al_2O_3$ (**Fig-6**). On the other hand positive variation is found between MgO-FeO and also between Na-F; Sr-Ca; Hf-Lu and Zr-Y. However, a negative correlation exists between Zr and Pb. A steep rise of Ca, Na, La, Eu, Lu, Dy, Y and P in the descending order (**Fig.-7**) fits carbonatite crystallization [25].

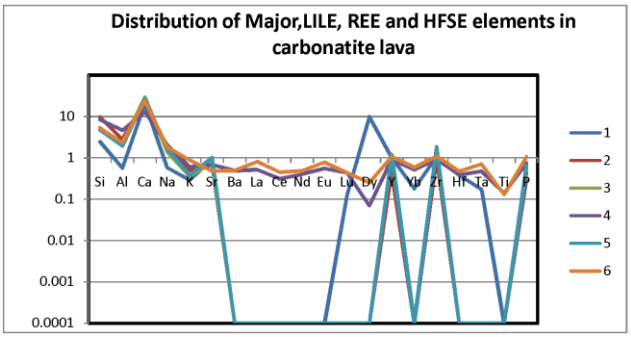

Fig 7: *The pattern of major, LILE, REE and HFSE elements in the carbonatite of Himalayan region is present.*

5. CARBONATITE AFFINITIES

The following characteristics bear evidences for carbonatite action in the study area:

1. Presence of ocellar structure (minute-pockets calcites) strewn throughout the rock.
2. Thin vein of calcite carrying contact aureole and chilled margin on both sides.
3. Pegmatite like calcite vein with comb structure sometimes with magmatic flow bandings.
4. The rock is unfossiliferous
5. Unlike the host-rock subjected extensively silicified and deformed, the rock exhibits fine laminations.
6. The rock is characteristically enriched with F from 0.71 to 3.45; and P 0.29 to1.07.
7. All the samples were enriched with silica, alumina, soda and potash
8. Geological settings of the location of the sample initially rifted later by thrusting and nappe movements.

9. Presence of oolites- pisolites- (Krol C) vugs – vesicles (Krol D) and solution cavities filled (amygdales) with calcite, dolomite and gypsum (Krol E) are to be re-considered, they may occur in association with effusive volcanic rocks.
10. The oxygen $\delta^{18}O$ SMOW +17 to +27 ‰ and carbon isotopic $\delta^{13}C$ PDB -8 to 7 ‰ signatures for Blaini-Krol-Tal Formations. They indicate igneous nature of the carbonaceous rocks [21].
11. These rocks appear to be two different groups of rocks. Some of them might have been derived from anatectic melts enriched with Ca, Si, Al, Na, K, LILE with relative impoverishment of REE and HFSE from subduction zones.
12. The characteristic enrichment of F, P, U, Pb, Zr. Hf, Nb and Ta in phosphates
13. The carbonatite is atypical one without association any co-magmatic differentiated alkaline rocks.
14. Similar types of atypical volcanic carbonatites occur in different parts of Tamil Nadu [4,5,6,7,8).
15. Younger Neocene carbonatite volcanic activities might have been remobilized Blaini-Krol-Tal fm which may lead prospectus zones for petroleum exploration

6. CONCLUSIONS

The present study reveals that the carbonate rocks present in the Blaini- Krol and Tal Formations were subjected to re-mobilization of older sediments by volcano tectonic movements have increased the complexity in the classification and staratigraphical position of the rock units. Proving the possibility of carbonatite-lava activity, the area might have high potential for petroleum exploration [17].

List Item –1Fig. 1-7

List Item Plates 1 & - 2 Microphotographs

List Item – Table 1 EDAX Analyses

List Item - SEM photogeraphs

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