PROPOSAL FOR SUNG VALLEY BLOCK, EAST KHASI AND WEST JAINTIA HILLS DISTRICTS, MEGHALAYA STATE, FOR RECONNAISSANCE SURVEY (G-3 STAGE) OF ION-ADSORPTION AND LATERITE HOSTED SUPERGENE ENRICHED REEs DEPOSITS UNDER NMET

(STRATEGIC AND CRITICAL METAL)

BY

THE DIRECTORATE OF MINERAL RESOURCES
GOVERNMENT OF MEGHALAYA
SHILLONG

Place: Shillong
Date: 20th September 2023

Summary of the Block for Reconnaissance Survey (G-3 Stage) GENERAL INFORMATION ABOUT THE BLOCK

	Features	Details
	Block ID	
	Present Exploration Agency	DMR, Meghalaya
	Previous Exploration Agency	Geological Survey of India (GSI)
	Geological Report (Previous stage Geological Report)	Preliminary search for REEs in the peripheral part of Sung Ultramafic Alkaline Carbonatite Complex, East Khasi Hills district & Jaintia Hills district, Meghalaya (G4 stage) (part of toposheet-83 C/02) (Previous stage Geological Report attached in Annexure IV)
	Commodity	Rare earth element
	Mineral Belt	Laterite, Bauxite, and Weathering profiles
	Completion Period with entire Time schedule to complete the project	1.5 years
	Objectives	1. To carry out geological mapping on 1:5000 scale and demarcate the laterite, bauxite and weathering profiles for identification of mineralized zone (Ore body). 2. To collect surface samples including exposed soil profiles for geochemical analysis of REEs and associated critical elements. 3. Identifying location and carrying out drilling to demarcate REEs enriched zone at subsurface level, on the basis of geochemical signatures for REEs enrichment in Ion-Adsorption and Laterite hosted REEs deposits. 4. To identify the REEs phases present and mineralization pattern in the laterite, bauxite and weathering profile for the understanding and future prospects regarding extraction techniques. 5. To estimate reconnaissance REEs resource as per UNFC norms and minerals (evidence of mineral content) rule-2015 at G-3 level.

	Whether the work will be carried out by the proposed agency or through outsourcing and details thereof. Components to be outsourced and name of the outsource agency	The work will be supervised and managed by the proposed agency; however, the following work will be outsourced: 1. Geological survey 2. Borehole Drilling 3. Geochemical Analysis for Trace element: Department of Geology, Panjab University. As per MoU between Panjab University and Directorate of mineral resource, Government of Meghalaya.
	Name/ Number of Geoscientists	i. Smt. E. Nongbri, In-charge, Geologist, Directorate of Mineral Resources. ii. Shri. Stephan Lamo, Assistant Geologist, Directorate of Mineral Resources. iii. Shri. Damepaia S. M.Pdah, Assistant Geologist, Directorate of Mineral Resources.
	Expected Field days (Geology) Geological Party Days	1. Large Scale Geological Mapping Geological party days: 70 Survey party days: 60 2. Drilling Geological party days: 70 Survey party days: 60
1.	**Location**	Annexure I
	Latitude	A: 25°34'56.873"N B: 25°36'01.955"N C: 25°36'27.092"N D: 25°34'4.591"N E: 25°32'55.345"N F: 25°32'18.818"N
	Longitude	A: 92°05'08.733"E B: 92°05'47.507"E C: 92°06'52.541"E D: 92°08'36.064"E E: 92°08'37.508"E F: 92°06'53.462"E
	Villages	Maskut and Mawiong Sung
	Tehsil/ Taluk	Mawryngkneng
	District	East Khasi Hills and West Jaintia Hills
	State	Meghalaya
2.	**Area (hectares/ square kilometres)**	
	Block Area	35 km^2
	Forest Area	-
	Government Land Area	-
	Private Land Area	35 km^2
3.	**Accessibility**	

	Nearest Rail Head	150 km
	Road	-
	Airport	60 km
4.	**Hydrography**	
	Local Surface Drainage Pattern (Channels)	Angular to sub-angular drainage pattern
	Rivers/ Streams	Wahsung, Umkhen and Umngot Rivers
5.	**Climate**	
	Mean Annual Rainfall	3485mm
	Temperatures (December) (Minimum) Temperatures (June) (Maximum)	October to February: 4 -10ºC April to May: 30ºC
6.	**Topography**	
	Toposheet Number	83 C/2
	Morphology of the Area	The study area is characterized by rugged and dissected terrain that is consistent with the overall physiography of Meghalaya. The topography of the area is mainly represented by undulations, gorges, and steep slopes of hillocks.
7	**Availability of baseline geoscience data**	
	Geological Map (1:50K/ 25K)	**Available**
	Geochemical Map	**Not Available**
	Geophysical Map (Aeromagnetic, ground geophysical, Regional as well as local scale GP maps)	**Not Available**
8.	**Justification for taking up Reconnaissance Survey / Regional Exploration**	1. China dominates global REEs production, while India only contributes 1%, sourced from Monazite placer deposits, making further exploration crucial. Around 30% world's production of REEs comes from the ion-adsorption clays, thus exploring such deposits are essential. 2. Two latitudinal zones between 12°-32° latitude in both hemispheres have high abundance of ion-adsorption deposits due to intense precipitation around tropics. Meghalaya, known for precipitation and forests, has lithology like Carbonatite, ijolite, pyroxinite and melilitolite that bear REEs minerals, indicating the REEs presence. 3. GSI's survey in other litho-units for REEs exploration (G4 stage) as well as in the block area shows promising results and lithologies potential to develop ion-adsorption deposit, but further studies are needed for subsurface exploration.

REGIONAL EXPLORATION PROPOSAL (G-3 LEVEL) FOR ION-ADSORPTION AND LATERITE HOSTED SUPERGENE ENRICHED REEs DEPOSITS IN THE SUNG VALLEY REGIONS OF MEGHALAYA, NE INDIA

1.0.0 Introduction

1.1.0 Background:

1.1.1 REE's are being used in modern day technologies like in permanent magnet industry, these elements are used for manufacturing of neodymium-iron-boron (NdFeB) magnet, automobile industry, wind turbines, hybrid batteries and other high-tech products (Goodenough et al., 2017). As per U.S. Geological Survey (USGS) recent estimation in mineral commodity summary 2022, about 37% of the world rare earth reserves and 60% of the 2021's rare earth production belongs to China and the rest are in USA, Vietnam, Brazil, Australia and India. India has about 6 percent of global REEs reserves and produces a minuscule 1 percent of global supply.

1.1.2 Under tropical or sub-tropical weather conditions, the thorough weathering of bedrock can lead to the development of different kinds of secondary deposits, known as supergene-type deposits and often referred as Ion-adsorption deposits/ Regolith hosted clay/ Weathering crust elution/ Laterite hosted rare earth deposits. These deposits can vary in composition, ranging from aluminous bauxites to iron and niobium, and may also contain REEs. An example of such a deposit is China's ion-adsorption deposit or south China regolith hosted REEs deposit. The pre-requisite condition like lithology, climate, and drainage is available in Meghalaya, thus it is important to explore such deposits.

1.1.3 There are several rocks and minerals that contain REEs, but the most commercially viable methods for REEs production can be grouped into four categories: bastnasite, peralkaline igneous systems, monazite-xenotime, and ion-adsorption clays. Additionally, laterite, bauxite deposits, and lateritic supergene enrichment deposits have also been found to be commercially viable for REEs production. (Freyssinet et al., 2005), This exploration work will majorly focus on ion-adsorption or laterite hosted REEs deposit.

1.1.4 The minerals that have REEs undergo degradation due to weathering, causing the ionized ions of these elements to stick to clay minerals like halloysite and kaolinite. The enrichment of REEs can be 3 to 10 times that of the source lithology, and in some cases, it can be up to 100 times (Cocker, 2014). The one of the anomalous values in GSI's G-4 works is in a Laterite sample (SV/BRS-72/2012) having TREE concentration ~5100 ppm, and this laterite profile is developed over pyroxenite (SV/BRS-66/2012) having TREE ~220 ppm, marking the enrichment upto 23 times.

1.2.0 Location of the Block:

1.2.1 Sung Valley is situated about 45 km east of Shillong, East Khasi Hills District, Meghalaya along the national highway "NH-44" towards Jowai, West Jaintia Hills District, Meghalaya. It is mainly located in the West Jaintia Hills District, with a portion of its western region falling under the East Khasi Hills District. A north-south trending stream defines the above common district boundaries. Sung valley falls under Survey of India Toposheet No. 83 C/2 and covers an area of about 35 km^2. The permanent community residing in and around the Sung Valley region are Muskut village and Mawiong Sung village. The name "Sung" basically refers to the entire igneous complex that is constituted by valleys, hillocks, barren land, paddy fields, streams and nalas.

1.3.0 Physiography and Drainage:

1.3.1 The Sung valley is a depression that has an oval and bowl shape and lies at an elevation between ~850m to ~1020m above the Mean Sea Level. The area is mostly covered by hills that are intersected by streams or nalas. It is surrounded by rugged and undulatory hills of higher elevation, ranging from ~1020m to ~1380m, and is part of the Meghalaya Plateau. The region is known for its high elevation, abundant rainfall, and rugged terrain. The Sung valley complex has a dense drainage pattern that forms a centripetal shape. The streams from valleys, hillocks, and higher ridges converge and merge to form Wahsung stream that drains to the Umkhen river flowing towards the north to the Assam plains.

2.0.0 Geology of the area (Annexure II):

2.1.0 Regional Geology and Structure of the area

2.1.1 Sung valley ultramafic-alkaline-carbonatite complex is situated in the eastern part of the Shillong plateau, which exposes mostly rocks of Assam-Meghalaya Gneissic Complex of Archaean (?) to Proterozoic age and meta-sediments and meta-volcanics of Shillong Group of Proterozoic age. It is genetically related to the Kerguelen plume present in the Indian ocean (Gupta and Sen, 1988). Tectonically, the complex is emplaced along the intersection of the major NS trending Umngot fault and EW trending lineaments. Meta-basic and ultrabasic bodies of Khasi Greenstone of Proterozoic age are also associated with the Shillong Group of rocks. Several granite plutons of Neo-Proterozoic to Lower Palaeozoic age intrude the gneissic basement as well as the Shillong Group cover sequence, prominent amongst these are the Mylliem, Nongpoh, Kyrdem Plutons, and South West Khasi Batholith. Cretaceous-Tertiary Sedimentary rocks occur as cappings in the Southern part of the plateau (Storey et al., 1992; Kent et al., 1997, 2002).

2.2.0 Geology and Structure of the block:

2.2.1 Sung valley igneous complex is an oval-shaped alkaline-ultramafic-carbonatite intrusive body of Lower Cretaceous age that has been emplaced slightly before or during the India-Antarctica break-up (Melluso et al., 2010). The country rocks into which it had intruded belongs to the Shillong Group of rocks and Khasi Greenstone mafics of Proterozoic age. Bedding is observed in the quartzite of the Shillong Group and Tertiary sandstone, and current bedding is observed in the Tertiary sandstone. Foliation is well developed in phyllitic quartzite with a NE-SW trend and moderate dip towards the northwest. An angular unconformity is observed near Mookyndur, where the Tertiary sandstone forms a sub-horizontal capping over the phyllitic quartzite of the Shillong Group. Two NE-SW faults/lineaments and three sets of geomorphic lineaments were traced from satellite imagery. Irregular, closely spaced fractures are filled by later anastomosing veins of carbonatite, apatite-magnetite rock, and mica in pyroxenite along Sung nala. Secondary silicified zones/shear zones and a silicified/brecciated zone are observed in different parts of the study area, but no significant mineralization is observed with the naked eye. Enclaves or caught-up patches of pyroxenite in carbonatite and apatite-magnetite rock are identified, and xenocryst/volcanic structure is observed in the carbonatite near Muskut area. No contact metamorphic effect is observed due to intrusion of the complex, but a narrow zone of fenite and a brecciated zone of mixed fenite and quartzite have developed at places, particularly along the peripheral part of SUACC.

2.2.2 The complex composes of carbonatites, pyroxenites, peridotites, serpentinites, ijolites, nepheline syenites, melilite-bearing rocks (Uncompahgrite), apatite-magnetite rock and fenitized rocks.

2.2.2.1 Carbonatite - Carbonatites are igneous rocks composed of more than 50% carbonates. Sung valley carbonatites are mainly coarse grained, milky white to off white, with mineral assemblages mostly of calcite and others like dolomite, magnetite, apatite. They show an intrusive nature within pyroxenite. Almost all the carbonatite rocks are magnetite bearing with different concentrations and occurs as small discontinuous veins and patches of disseminated magnetite crystals. The crystals vary in size from 1 mm scale upto 3cm.

2.2.2.2 Pyroxenite - Pyroxenite is the most dominant rock type in the Sung Valley Complex, generally occurs in the marginal part and comes in direct contact with the quartzite. It also occurs in the central part and is intruded by all the other rock types of the complex, except serpentinite and peridotite. Pyroxenite varies in grain size with the fine-grained type in the marginal part to coarse grained type in the central part of the complex. In the central part pyroxenite is generally dark, greenish black to black in colour and massive consisting dominantly of diopsidic augite in cumulus pyroxenite with individual pyroxene grain measuring upto about two centimetres across. Hornblende and biotite occur as secondary minerals, whereas sphene and magnetite as accessory minerals.

2.2.2.3 Peridotites - This unit is exposed only along the Sung nala section. They are dark grey to jet black in colour, coarse grain highly serpentinised with relicts of pyroxene and altered olivine. At places carbonates/carbonatite veins and dyke ranging in sizes from cm scale upto 1.5 m intrudes the serpentinised peridotite along the weak planes-oriented NW-SE directions. On the bank of Sung River, later coarse pyroxenite occurs as veins (of mm scale upto 15 cm width) within the host peridotite trending N30°E. The intrusive nature of the later veins of carbonates/carbonatite and rich mica/phlogopite veins indicated the carbonatites are of later phases than the peridotitic hosts.

2.2.2.4 Serpentinites - Serpentinite is one of the very common rock types of the complex and occurs in the central and eastern part of the Sung Valley complex. Good exposures were observed in the central eastern part of the complex. They are medium to coarse grained and consists of serpentine with magnetite as the main accessory. It is the only rock type of the complex other than peridotite that contains veins of pyroxenite in them. A small amount of phlogopite-mica and carbonate are almost always present. The perovskite and magnetite bearing serpentinite near Mawiong is coarse grained, massive dark grey colour and highly magnetic.

2.2.2.5 Ijolites - Ijolite is medium to very coarse grained and shows wide variation of texture and granularity. Primarily it consists of nepheline, pyroxene with garnet and apatite with sphene as the main accessory. Nepheline occurs as coarse, pinkish, smoky black, subhedral to anhedral grains. Pyroxene is represented by aegirine - augite that are prismatic. These prismatic pyroxene grains and nepheline sometimes show "comb structure" which is again a characteristic feature of Ijolite within the complex. Calcite, apatite and magnetite are the common accessory minerals.

2.2.2.6 Apatite-Magnetite Rock - Magnetite is the main ore mineral in this rock with apatite, and carbonate occurring as accessory phase filling the interstices. Pyrochlore grains are occurring with abundant inclusion of opaque oxide minerals. Disseminated grains of perovskite, bismuthinite, and specks of pyrite and arsenopyrite are observed.

2.2.2.7 Fenitized rocks - Extensive fenitization has taken place both in the serpentinite and pyroxenite in the southern part of the intrusive resulting in rocks grading from nepheline rich pyroxenite to pyroxene alkali syenite. Numerous veins of ijolite and syenite cut across the rocks with progressive development of patches and clots of mainly nepheline and at places feldspar (mainly perthite). The process is highly uneven resulting in wide variation in composition and texture within short distances. With progressive fenitisation, diopside grades into aegirine augite in pyroxenite with concomitant increase in mainly nepheline. The country rock such as amphibolites and quartzites are also observed to be fenitised. Brecciation has developed in few outcrops of the quartzites at the margin of the complex.

3.0.0 **Mineral potentiality based on geology, geophysics, ground geochemistry etc**.

3.1.0 The main minerals in Sung Valley carbonatites are calcite with other interspersed fluorapatite, serpentinised olivine and minor minerals of magnetite, fluorite, pyrochlore, perovskite, phlogopite, melanite, chalcopyrite, pyrrhotite, pyrite, ilmenite and strontionite. The REEs phases in carbonatite includes ancylite, belovite, bastnaesite, britholite associated with magnetite. The ore microscopic studies indicate presence of sulphide mineralization such as pyrite, chalcopyrite and arsenopyrite (Yusuf S. and Saraswat A.C.,1977; **Ranjith A. and Sadiq M., 2012**).

3.1.1 The REEs-bearing minerals found in carbonatites of the Sung Valley complex are as follows (Sadiq M., 2012):- → Apatite: In apatite, CaO ranges between 53.71 to 56.08%, P2O5 from 39.93 to 42.6%, low contents of ΣREO (0.17 to 0.49%), U and Th. → Monazite: Total REO in monazite ranges from 64.4 to 67.44%, and P2O5 ranges between 29.42 to 30.66%. → Pyrochlore: Pyrochlore shows 30.93 to 56.93% Nb2O5, 7.30 to 31.35% Ta2O5 ranges, 0.06 to 18.79% UO2 and 0.8 to 12.32% total REO.

3.1.2 The carbonatite surrounding region composes of chocolate brown soil that are highly radioactive and consist mainly of magnetite, fluorapatite (50-60% by weight) and clayey matter along with pyrochlore, apatite, zircon, garnet, pyriboles and altered iron-oxide minerals (Krishnamurthy, P., 1985)

3.0.0 Scope for proposed exploration:

1. To carry out geological mapping on 1:5000 scale and demarcate the laterite, bauxite and weathering profiles for identification of mineralized zone (Ore body).
2. To collect surface samples including exposed soil profiles for geochemical analysis of REEs and associated critical elements.
3. Identifying location and carrying out drilling to demarcate REEs enriched zone at subsurface level, on

the basis of geochemical signatures for REEs enrichment in Ion-Adsorption and Laterite hosted REEs deposits.

4. To identify the REEs phases present and mineralization pattern in the laterite, bauxite and weathering profile for the understanding and future prospects regarding extraction techniques.
5. To estimate reconnaissance REEs resource as per UNFC norms and minerals (evidence of mineral content) rule-2015 at G-3 level.

5.0.0 **Observation and Recommendations of previous work:**

5.0.1 Yusuf S. and Saraswat A.C. (1977) had discovered a pyrochlore-bearing carbonatite with a large cover of brown coloured soil rich in pyrochlore. The carbonatites and the dark chocolate-brown-coloured soils, capping the carbonatite, are highly radioactive. The soils consist mainly of magnetite, fluorapatite (50-60% by weight) and clayey matter along with pyrochlore, zircon, garnet, pyriboles and altered iron-oxide minerals. Preliminary analysis of rock and soil samples from the carbonatite complex has indicated the presence of Nb, Ta, U, Ce, Sr, Y and phosphate content in significant concentrations. Thus, it is important to assess soil and/or weathering profiles developed over Sung valley lithology for the search of REEs and other critical metal enrichment.

5.0.2 Krishnamurthy, P. (1985) observed fenitization, due to both ijolites and carbonatites, has affected older rocks resulting in wollastonite-rich aegirine-augite bearing rocks, K-feldspar-aegirine-augite veins and oversaturated potassic syenites. Average abundances of trace elements (values in ppm) characterizing carbonatites such as Ba (549), Sr (3134), La (50-100), Ce (489), Y (50), Nb (372), Zr (179) and P2O5 (5.7) wt% are comparable to those found in reported intrusive carbonatites. Evaluations over a 5 km2 soil covered area at 250 m grid intervals and up to a depth of 1 m has indicated a reserve of 1300 tons of Nb in the soil (6.75 million tons of Nb ore with 0.02% Nb2O5). It is reported that bulk soil samples having up to 65% apatite (Krishnamurthy et al., 2000 and references therein). Similarly, as stated above higher phosphate content suggest the presence of REEs enriched zone in weathering profiles.

5.0.3 Chattopadhyay N. (1979), during field season 1976-77, had established that Sung Valley intrusive is an alkaline ultramafic carbonatite complex and this opened up search for Nb, Ta, rare earths, phosphate and associated elements within the complex.

5.0.4 Kumar Y. (1988), during the field season 1984-85 reported that after the discovery of the bauxite in Lumkynthang. In 1983, Verma, N.P. had carried out shallow drilling of boreholes by a mini-drill for studying the weathered profile. The important minerals present are diaspore, gibbsite, goethite and anatase. Tentative reserve estimation of the bauxite was +40% Al2O3 grade -1.13mt, +45% Al2O3 grade -0.89mt and +48% Al2O3 grade -0.45mt. The titaniferous materials were present all through the bauxitic/ lateritic layers upto the underlying lithomargic clay zone. The reserves of +10% TiO2 grade material are 3.35mt, of which 0.42mt are of +20% TiO2 grade.

5.0.5 **According to Ranjith A. and Sadiq M. (2012)**, pyroxenite is the most common rock type in the complex and encloses the serpentinised peridotite forming the core of the complex. Ijolite forms a ring structure around the pyroxenite. Apatite-magnetite, melilitolite and nepheline-syenite occur as small dykes and veins in the complex. Laterite occurs as thin caps in the northeastern part of the complex. Different carbonatite bodies yielded higher concentration of Σ LREE 660.00 ppm to 1264.85 ppm and

Σ HREE 46.80 ppm to 81.92 ppm and is followed by pyroxenite (ΣLREE 681.47 to 1003.97ppm and Σ HREE 28.49 to 58.35ppm) and ijolite (Σ LREE 424.35 to 906.09ppm and ΣHREE 58.19 to 190.80ppm). Samples from the laterite cappings developed over pyroxenite, Lumkynthang village shows the higher concentration of total rare earth elements viz; ΣREE ranges between 3645.98 to 5099.56ppm (ΣLREE ranges between 3525.85 to 4928.46ppm and ΣHREE ranges between 120.13 to 171.10ppm). REEs bearing phases in carbonatite were identified through EPMA includes ancylite, belovite, bastnaesite and britholite. Sadiq M. and Umrao R. K. suggested further subsurface exploration to find viable resource grades of REEs, niobium (Nb), tantalum (Ta), zirconium (Zr), hafnium (Hf), aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), vanadium (V), nickel (Ni), and chromium (Cr) and particularly the exploration of residual laterite deposit.

5.0.6 **Recommendations of G4 Stage Mineral Exploration Report:** The previous exploration conducted by Geological survey of India (GSI) encountered the potential of lithologies in the Sung valley. This along with the combined precipitation and weathering in this area could be the India's first Ion-Adsorption REEs deposit. The recommendation of GSI's G-4 exploration are as follows:

- Performing detailed mapping of the area to better understand the geological features and mineralization potential.
- Implementing systematic sample collection through pitting and trenching to gather subsurface data.
- To drill stratigraphic borehole to obtain a clear sub-surface view of the target area's geology.
- Assessing the potential for REEs mineralization in laterite developed over pyroxenite of the Sung Complex through detailed sampling.

6.0.0 Previous Work

6.1.0 Previous Exploration in adjoining area (Regional area) (Annexure II);

6.1.1 Survey 1: **"Reconnaissance survey for REEs and associated elements in laterite in Nongjyllieh block, West Khasi Hills District, Meghalaya (G4)"** by the Geological Survey of India (GSI).

6.1.1.1 A survey was conducted by GSI to locate aluminum-rich laterite capping and rare earth elements in the Nongjyllieh block of the West Khasi Hills District, Meghalaya. Large-scale mapping, section measurements, and excavation were carried out on a 1:12,500 scale in the area, which consists of rocks from the Proterozoic Assam Meghalaya Gneissic Complex. Laterite cappings were found over charnockites as isolated patches, and two sets of lineaments were identified by remote sensing studies trending in NW-SE and NE-SW directions. The major Kynshi lineament was mapped as Kynshi Fault, trending NW-SE.

6.1.1.2 Lateritic soil layers were found in several villages in the northern part of the area, and soil samples were taken for analysis. A total of 0.40 sq km of laterite was mapped in the area, with three aluminum laterite bodies located in Lawse, Mawduh, and Nongjyllieh villages. The aluminous laterite bodies are developed over gneissic charnockite and have a higher drainage density than the surrounding areas. The color of the aluminous laterite varies from white to pinkish red. Soil samples collected from the area indicate a high concentration of total rare earth elements, with the highest concentration found in the mottled clay layer below the duricrust of aluminous laterites. In other words, this means that the weathered zone above the saprolith is the REEs enriched zone.

6.1.1.3 Chemical analysis showed that the Lawse aluminous laterite body has Al2O3 values 4 ranging from 27.04% to 37.17% and SiO2 values ranging from 43.49% to 62.70%. In Mawduh, the Al2O3 values range from 5.76% to 27.95% and SiO2 values range from 59.75% to 77.04%. Meanwhile, in the Nongjyllieh aluminous laterite body, Al2O3 values range from 12.15% to 31.24% and SiO2 values range from 54.35% to 48.3%. Soil samples collected from the B horizon over gneissic charnockite showed a total REEs value ranging from 219.11 ppm to 2064.69 ppm, while the C horizon showed a range of 79.72 ppm to 2206.64 ppm. The TREE values of the soil samples collected from the B horizon over gneissic charnockite range from 95.10 ppm to 1976.99 ppm, while those collected from the C horizon range from 79.72 ppm to 1799.74 ppm. The mottled clay (C horizon) beneath the duricrust of aluminous laterites had the highest concentration of TREE. The lateritic horizons (i.e., gneissic charnockite) were observed to contain REEs bearing mineral phases such as allanite, apatite, and zircon. The Lawse and Mawduh aluminous laterite bodies did not show depth persistence, whereas a 1.5 m thick aluminous lateritic profile was observed in Nongjyllieh village.

6.1.1.4 In summary the investigation area has a sub-tropical climate with high precipitation and a plateau region with rolling topography. The geology of the area is dominated by gneissic charnockite, porphyritic granite, sandstones, and laterites. Three aluminous lateritic bodies were mapped in Lawse, Mawduh, and Nongjyllieh areas, with a total bauxite area of 0.033 sq km. The depth persistence of bauxite in Mawduh and Lawse was less, and the elevation range of occurrence of bauxite was between 1475-1570 m, mostly over charnockite patches within granite gneiss. Systematic soil sampling for REEs was carried out in laterite/soil profiles. Mild enrichment of REEs occurs mostly in the C horizon and subordinately in the B and A horizon, indicating that REEs were contained in residual minerals and secondary minerals and were adsorbed onto the surface of weathering products. The soil samples collected from the B horizon over gneissic charnockite show a total REEs value ranging from 219.11 ppm to 2064.69 ppm, while the C horizon showed a range of 79.72 ppm to 2206.64 ppm. The maximum concentration of total REEs was observed in the C horizon (2206.64 ppm) of the lateritic soil. Petrographic study revealed REEs bearing mineral phases such as allanite, apatite, and zircon in the host rock for the lateritic horizons i.e., in gneissic charnockite. Sulphide mineralisation was observed at Nongjyllieh area in the contact of a mafic body in the gneissic charnockite, and Au values in the range of 50 ppb to 60 ppb were obtained.

6.1.2 Survey 2: **Report on Reconnaissance Survey for REEs in the area around Jirang and area between Umsophria- Warmawsaw, Ri-Bhoi District, Meghalaya** by the Geological Survey of India (GSI).

6.1.2.1 An evaluation of rare earth element (REEs) potential was conducted in two different areas, Warmawsaw and Jirang, in the Ri-Bhoi districts of Meghalaya as part of a two-year program (FS: 2016-18) by the Geological Survey of India. These areas fall within parts of the SOI toposheet no 78 O/9. The evaluation of REEs potential was based on large-scale geological mapping at a 1:12,500 scale, chemical analysis of bedrock samples (BRS), soil samples (SS), and heavy mineral study of soil and regolith zones. The study area consists of various litho-units belonging to the Assam Meghalaya Gneissic Complex (AMGC) and later intrusive. Granite gneiss is the most dominant rock type in both Warmawsaw and Jirang areas. Other rock types include banded gneiss, sillimanite cordierite gneiss, amphibolite, migmatite, and pegmatite veins.

6.1.2.2 The results of the analysis showed that the total Rare Earth Element (REEs) values in bedrock samples of the Warmawsaw area ranged from 142.54 to 1042.67 ppm with an average of 451.87 ppm. The soil horizon samples had a range of 137.38 to 714.7 ppm with an average of 425.38 ppm, while the pitting trenching samples ranged from 303.85 to 1172.7 ppm with an average of 471.06 ppm. In the bedrock samples of the Jirang area, the range was from 48.22 to 1758.45 ppm with an average of 512.05 ppm. The 6 soil samples had a range of 214.05 to 1075.60 ppm with an average of 423.32 ppm, and the pitting trenching samples ranged from 154.20 to 1027.21 ppm with an average of 429.61 ppm.

6.1.2.3 Based on the enrichment patterns of REEs in the A and B-horizons, and using a cutoff grade of 0.035% Total Rare Earth Oxide (TREO), three blocks with potential REEs deposits were identified in the Warmawsaw area - Warmawsaw block, Umtang block, and Umshaid block. The inferred resources of these three blocks were calculated to be 18770, 5920, and 8670 MT. The anomalous zones with high levels of REEs in the rest of the grid area were limited in their extension and not significant. Although there were some anomalous REEs values found in bedrock samples in the Warmawsaw and Jirang areas, they were not continuous zones and could not be considered as REEs ores. Instead, the REEss were present in the bulk rock in small amounts as a minor accessory phase.

6.2.0 Previous Exploration in the proposed block area:

6.2.1 Survey 1: **Preliminary search for REEs in the peripheral part of Sung Ultramafic Alkaline Carbonatite Complex, East Khasi Hills District, Meghalaya (G-4 Stage),** by the Geological Survey of India (GSI).

6.2.1.1 GSI was taken up preliminary search for REEs in parts of Sung Valley Ultramafic-Alkaline-Carbonatite-Complex (SUACC), East Khasi Hills and Jaintia Hill Districts, Meghalaya (G4) for the field session 2012-13, **Complete report attached in Annexure IV**.

6.2.1.2 The Shillong Group contains intrusive rock types. During soil geochemical sampling in the Muskut carbonatite zone, phosphate enrichment was reported. A black carbonatite vein showed rare earth enrichment, indicating highly radioactive Nb rich pockets. Fenitisation was evident along a NE-SW trending fault south of the Muskut block. Hydrothermal solutions accompanying apatite-magnetite rocks may have been channelized along weak zones in the country rocks around the complex. These rocks are exposed in the northwestern part of the complex in the area around 5 kilometers northwest of Sung. Limonitisation in these rocks needs evaluation for REEs. The sheared and limonitised rock types are likely to accommodate hydrothermal solutions associated with the various mafic-ultramafic rocks of this complex. Previous efforts to find significant mineral deposits were focused on the main body, which revealed Nb enrichment in magnetite and perovskite-rich serpentinite pyroxenite. An anomalous concentration of 100-800 ppm Nb was found in a carbonatite vein, but no sampling has been done on the peripheral zones yet. The study area is situated within Toposheet no. 83 C/2 and is bounded by latitude N25°30'00" to N25°35'30" and longitude 92°07'00" to 92°09'00". It is located in parts of the East Khasi Hills and Jaintia Hills district in Meghalaya, approximately 22 km east of the state capital Shillong. The intrusive body is situated in this area.

6.2.1.3 To identify, classify, and describe various lithologies, as well as to locate and assess REEs mineralization, a diverse range of samples were collected, including 74 bedrocks, 31 stream sediment, 23 fluid inclusion, 20 ore microscopic, 13 petrological, and 25 whole rock analysis samples (**all the sample locations plotted on Sung valley's map in Annexure III**). The samples were collected from various sources, such as carbonatite, pyroxenite, ijolite, serpentinite/peridotite, veins of carbonatite within pyroxenite /peridotite, apatite-magnetite rock (AMR), and amphibolites. Additionally, 13 samples were collected specifically for EPMA study, which aims to determine the nature and type of REEs phases present in the carbonatite.

6.2.1.4 Disseminated and fracture filling/veins are the common forms in which sulphides occur in most of the rock types examined. Polished sections revealed that apatite and pyrochlore are the primary hosts for REEs minerals. However, the main REEs phases identified in carbonatite are ancylite, euxenite, and britholite, which are associated with calcite and apatite. Pyrochlore grains that are linked with magnetite in carbonatite sections also exhibited a significant amount of REEs.

6.2.1.5 Chemical analysis of 27 BRS collected from eleven different carbonatite bodies revealed higher concentrations of ∑ LREE ranging from 660.00ppm to 1264.85ppm and ∑ HREE ranging from 46.80ppm to 81.92ppm, compared to other rock types in the complex. Apatite-carbonatite veins in apatite-magnetite rock, pyroxenite, and Ijolite followed in concentration levels. Additionally, three samples collected from apatite-carbonatite veins NE of Maskut showed comparatively higher values of Sn, Ta, W, and U. During the regional traverse, two samples collected from laterite cappings over pyroxenite in Lumkynthang village showed higher concentrations of total rare earth elements, with ∑REES ranging from 3645.98ppm to 5099.56ppm, ∑LREE ranging from 3525.85ppm to 4928.46ppm, and ∑HREE ranging from 120.13ppm to 171.10ppm. (NER 1730)

6.2.2 **Assessment of REEs concentration in the Regolith profiles of Sung Valley, Meghalaya**. Jointly done by Directorate of Mineral Resources, Government of Meghalaya and Panjab University Chandigarh, during August-September 2023.

6.2.2.1 In August-September 2023, a collaborative study was carried out by Directorate of Mineral Resources, Government of Meghalaya, and Panjab University, Chandigarh. The primary goal of this research was to assess the presence of REEs and other critical minerals in regolith profiles within the Sung Valley region, complementing the Geological Survey of India's (GSI) G4 exploration work, which focused solely on bedrock and stream sediment analysis, without regolith profiles.

6.2.2.2 Due to limited financial resources and field challenges, we were able to collect samples from only two exposed regolith profiles along the Sung Valley Road section **(Sampling location plotted on Sung Valley's map, Annexure III)**. One profile, developed over alkali pyroxenite, consisted of five samples from the profile thickness of 3 meters, while the other, developed over ijolite, comprised eight samples from the profile thickness of 4 meters. We used a Pillar/Column sampling method to investigate the vertical fractionation and enrichment of REEs within the regolith profiles. It is important to note that we sampled only the exposed sections in the upper part of the weathering profile zones A, B, and some parts of C. No pitting or trenching was conducted, and therefore, saprolith and bedrock samples were not obtained.

6.2.2.3 The collected samples underwent a series of preparations, including drying, crushing, sieving, and digestion. Microwave digestion units (Milestone Ethos UP) and hotplates were used for digestion, following the 4-acid digestion method (Hf+HNO3+HCl+HClO4) as per Balaram et al. (2003). To ensure the accuracy of digestion, we verified the process using a Carbonatite Supergene REEs-Nb ore Certified Reference Material (CRM) (OREAS 463), with elemental recoveries falling within the range of 85-115%. Subsequently, all samples were analyzed using ICP-MS (Agilent 7850), calibrated through an 8-point calibration of 1-500 ppb.

6.2.2.4 The TREE+Sc+Y concentration, in the pyroxenite regolith samples ranged from 225.42 to 418.52 ppm. The LREE fell within the range of 92.92 to 190.64, while the HREE were observed in the range of 5.49-16.53 ppm. Geochemical indicator like δCe, suggest enrichment in the subsurface zone. A positive anomaly in δCe (ranging from 1.29 to 1.09) observed in the upper three samples - 2335 A, 2335 B, and 2335 C, indicates fractionation and transportation of REEs at deeper horizons due to weathering. Conversely, a negative anomaly in δCe (0.84-0.85), suggests REEs enrichment in the bottom two samples (2335 D and 2335 E) of the regolith profile. However, the demarcation of this enrichment zone could not be precisely established due to limited sampling in the vertical extent of the profile. The obtained geochemical signatures are similar with already reported and preexisted ion-adsorption deposits of South China, Mount weld's deposit Australia and newly discovered deposits of Madagascar in the prestigious journals like Nature Communication, Nature scientific reports and Ore Geology reviews (Borst et al., 2020, Estrade et al., 2019, Mukai et al., 2020).

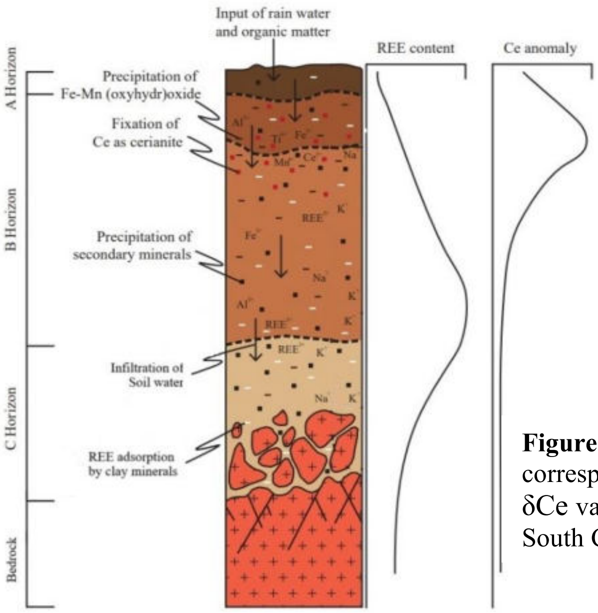


Figure 1: Illustration of a soil profile alongside the corresponding Rare Earth Element (REE) concentration and δCe variation profile for the Zudong Ion-Adsorption deposit of South China, adapted from Hei Li and Zhou's 2020 study.

6.2.2.5 In the ijolite regolith samples, the TREE+Sc+Y concentration ranged from 84.36 to 353.51 ppm, with LREE concentrations within the range of 65.32 to 260.21 ppm and HREE ranging from 6.81 to 20.74 ppm. Geochemical indicator exhibited a similar pattern to the pyroxenite profile, with positive δCe values (1.13 to 1.31) in the top four samples (2338 A, 2338 B, 2338 C, and 2338 D), indicating the presence of an enrichment zone at subsurface levels. Subsequently, negative δCe values (ranging from 0.67 to 0.90) was encountered, reaffirming the presence of an enrichment zone at the subsurface level.

6.2.2.6 In addition to REEs, our analysis also revealed the presence of other critical minerals, notably Germanium, which exhibited enrichment in both regolith profiles. In the pyroxenite profile, Germanium concentrations ranged from 59.19 to 72.49 ppm, while in the ijolite profile, concentrations ranged from 24.16 to 124.58 ppm. Given its similar enrichment trend to REEss, the possibility of good abundance of Germanium in deeper horizons is also probable.

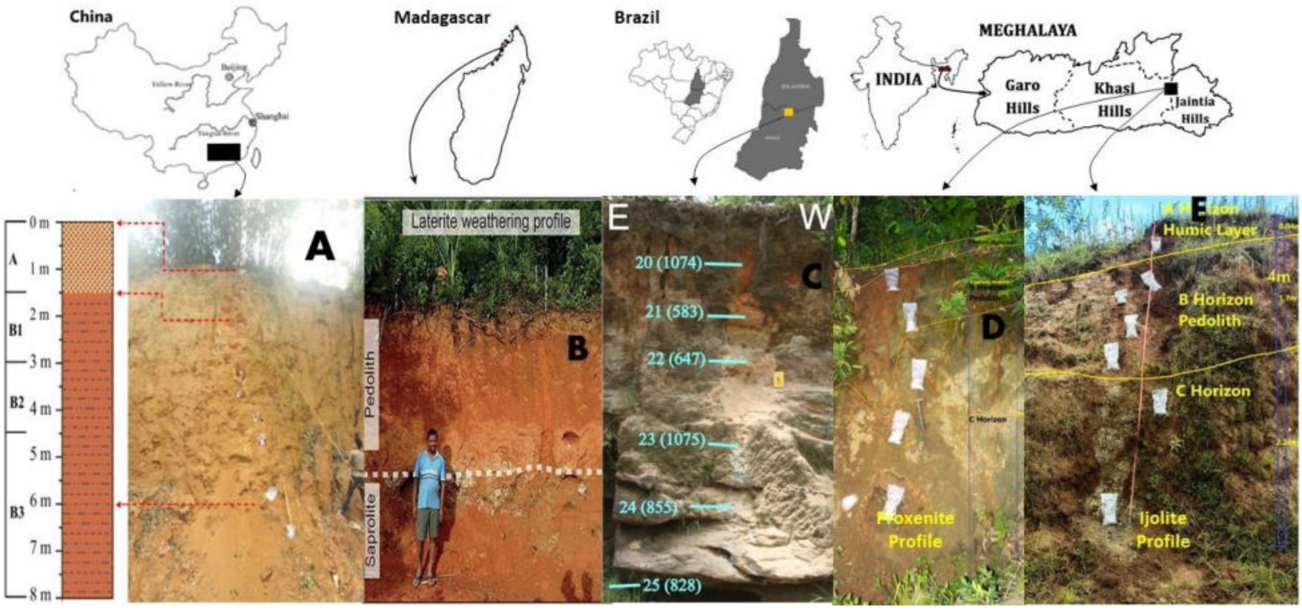


Figure 2: (A) Regolith profile (0–8 m) in Maofeng Mountain, South China (adapted from Wang et al., 2023). (B) Regolith profile developed over the Ambohimirahavavy alkaline complex, Madagascar (adapted from Estrade et al., 2019). (C) Regolith profile over the Serra Dourada granite in Brazil, with Total Rare Earth Element (TREE) concentrations indicated within the bracket (adapted from Santana et al., 2022). (D and E) Regolith profiles obtained in the present study from the Sung Valley ultramafic-alkaline-carbonatite complex in Meghalaya.

6.2.2.7 **Conclusion:** In summary, our collaborative study with the Directorate of Mineral Resources and Panjab University in the Sung Valley region during August-September 2023 reveals strong evidence of an ore deposit or enrichment zone of Rare Earth Elements (REEs) lying beneath the regolith cover. Through geochemical analysis of regolith profiles, we observed distinct patterns of REEs concentration and geochemical anomalies. These findings indicate the potential for valuable mineral resources in the area. However, the precise depth and extent of this enrichment zone remain uncertain due to limited sampling. Further investigation is essential to unlock the full mineral potential of the Sung Valley region.

6.2.2.8 **Recommendations for Future Work:** To advance our understanding the mineral wealth in the Sung

Valley region, we propose several critical steps for future exploration work. First and foremost, there is a pressing need to collect and analyze subsurface data. This can be accomplished through drilling or conducting pitting and trenching at strategic locations. Extending the sampling along the vertical profile will also provide vital insights into the distribution of REEs and other critical minerals. Additionally, geochemical mapping should be employed along with regolith profile sampling for exploration.

Profile	Sample ID	TREE+Sc+Y	LREE (La-Eu)	HREE (Gd-Lu)	δCe	Ge
Pyroxenite Profile	2335 A	225.41	92.92	5.49	1.29	61.99
	2335 B	243.16	101.94	8.03	1.24	63.93
	2335 C	296.18	140.32	10.66	1.09	59.19
	2335 D	355.61	138.59	12.93	0.84	72.49
	2335 E	418.52	190.64	16.53	0.85	68.73
Ijolite Profile	2338 A	84.36	65.32	6.81	1.31	24.16
	2338 B	157.13	126.73	11.79	1.19	52.59
	2338 C	166.04	136.63	12.18	1.13	52.43
	2338 D	172.77	130.03	11.93	1.19	81.61
	2338 E	243.67	189.34	15.96	0.83	81.52
	2338 F	279.46	206.14	18.55	0.90	81.61
	2338 G	353.51	260.21	20.74	0.67	124.58

Table 1: REEs concentration and geochemical characteristics of the regolith profile samples collected in the present study

7.0.0 **Block description:** The coordinated for the corner points of the block is given below (Annexure I):

Block Border point	Latitude	Longitude
A	25°34'56.873"N	92°05'08.733"E
B	25°36'01.955"N	92°05'47.507"E
C	25°36'27.092"N	92°06'52.541"E
D	25°34'4.591"N	92°08'36.064"E
E	25°32'55.345"N	92°08'37.508"E
F	25°32'18.818"N	92°06'53.462"E

Table 2: Boundary coordinates for the proposed block

8.0.0 Planned Methodology: The exploration program is created based on the objectives set for the area, following the Minerals (Evidence of mineral contents) Rule-2015. To attain these objectives, a specific exploration plan has been developed, and the steps for each activity are outlined in the following pages.

8.1.0 Geological mapping:

8.1.1 Remote sensing studies and field visits will be the essential parts of this exploration work whereby aspects such as deformation, weathering pattern, drainage, climate and source rock of the deposit will be ascertained. The entire block will be subjected to geological mapping at a scale of 1:4,000. The mapping will entail identifying the type of rocks, their contact points, and any structural features. Additionally, any visible signs of mineralized zones on the surface will be indicated on the map. As part of the geological mapping process, various samples of litho-units from the enrichment zone will be collected for further geochemical and petrological analysis.

8.1.2 A second field trip will again be carried out after the first round of analysis and interpretation of the data generated, which will help in the identification of prospective sites. This second field trip would mostly focus on the accessibility of location for borehole drilling and borehole's core collection.

8.2.0 **Sampling:**

8.2.1 Surface Sampling: During the course of Geological mapping the bed rock and weathering profile developed over it will be sampled by using pillar sampling method to collect sample from each horizon of the profile. Petrological sampling will be carried out. Random chip sampling and grab sampling method will be used where weathering profile is not exposed or the host rock is exposed. Each sample will be collected as per systematic random sampling based on lithology exposure and spatial distribution. As per this estimation, on the total area of 35 km^2, around **265 samples will be collected (40 Bedrock samples, 200 Regolith/Soil profile samples, 25 check samples).** In case of shallow weathering profile and identification of ideal location for borehole, pitting and trenching will be done upto the depth of 3-4 meters and **75 samples** will be collected.

8.3.0 **Drilling:**

8.3.1 Borehole Core Drilling and Sampling**:** Following the UNFC G-3 exploration guidelines, in the study area, about 5 boreholes are proposed to be drilled upto the depth of 130 meters each. In each drilled core, horizons of soil profiles will be marked and from each profile 30 samples will be collected on a fixed interval. The sampling distance interval would be decided on the basis of thickness of horizon and change in lithology. As per the previous studies and data, majority of profiles have 4 horizons i.e., O, A, B, and C. As per this estimation from each borehole ~30 sample will be collected and total number of samples will be **~250**. For the preservation, drilling, sample's archive all the guidelines of NMET will be followed. During the drilling it must be taken care that the core recovery would be >95%.

8.3.2 Borewell Drilling and Water Sampling: 2 Borewells need to be drilled in the study area. The use of these borewells is the collection of **10±2** groundwater sample for its hydrogeochemical parameters like pH, Eh, and species present such as $REECO_3^+$, $REE(CO_3)_2^-$, $REEHCO_3^{2+}$, $REE(OH)_2^+$, $REE(OH)_3$, $REEF^{2+}$, $REEF_2^+$, $REEsCl^{2+}$, $REESO_4^+$, and $REENO_3^{2+}$ in the water (surface and aquifer). Analyzing hydrogeochemistry is essential for exploring ion-adsorption REE deposits because it provides crucial insights into the mobilization, fractionation, and enrichment of rare earth elements (REEs) during supergene processes. Factors such as pH and carbonate concentration in groundwater significantly influence the speciation and transport of REEs, impacting their adsorption onto regolith materials. **This knowledge is critical for identifying favorable conditions for REE concentration, a key factor in the formation of economically significant regolith-hosted REE deposits, particularly heavy REEs.** Therefore, understanding hydrogeochemistry helps in targeting and assessing the potential of such deposits in specific geological environments.

8.4.0 **Sample Preparation**: After the field visit and geological mapping, surface and sub-surface samples will be packed and transported to a geochemical laboratory. It will be opened and left for 24-48 hours in an open room for drying. If there is still excess amount of moisture in the sample, then the hot air oven will be used. After the moisture removal, sample will be crushed in the rock crusher, and then powdered using the vibratory cup mill. Some portion of the pulverized samples will be sent for XRF analysis. And some known quantity of the samples will be digested in a microwave digestion unit along with hotplate evaporation and then diluted for the chemical analysis. During all the above-mentioned process, it would be taken care and precaution that samples do not get contaminated.

8.5.0 **Sample Analysis:**

8.5.1 **Petrography:** Around **50 samples** will be subjected to petrography for the identification of microscopically visible texture and mineralogy of the host as well as the weathering product.

8.5.2 **XRF Analysis:** Major elements composition of **175 samples** will be analyzed for 10 major oxides (SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, and MnO) through an X-Ray Florescence (XRF) machine. The Major oxide composition will help in the findings of Chemical index of Alteration (CIA), Chemical index of Weathering (CIW), and Plagioclase index of Alteration (PIA).

8.5.3 **ICP-MS Analysis:** Trace and REEs analyses of **~600 samples** will be prepared and analysed in the Department of Geology, Panjab university, Chandigarh through an Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) for 48 radicals (Al, As, Ba, Be, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Ho, La, Li, Lu, Mn, Nb, Nd, Ni, P, Pb, Pr, Rb, Sb, Sc, Si, Sm, Sn, Sr, Ta, Tb, Th, Ti, Tm, U, V, W, Y, Yb, Zn, and Zr) (Make "Agilent" and Model "ICPMS 7850") as per the MoU between Directorate of Mineral resource, Government of Meghalaya, and Panjab University, Chandigarh.

8.5.4 **XRD Analysis:** REEs can concentrate in minerals in different forms such as colloids, secondary phosphate, adsorbate in the clay minerals like kaolinite and halloysite. The XRD analysis of selected samples from the enriched locations will identify the phase in which REEs is present in the sample. This phase identification will be helpful for the further metallurgical studies for the extraction and ore beneficiation. The total number of **XRD sample will be 85** which would be taken from the first field's bed rock samples and second field's borehole core's sample.

8.5.5 **QEMSCAN Analysis for mineral mapping:** QEMSCAN is an acronym for Quantitative Evaluation of Materials by Scanning Electron Microscopy, a system that differs from image analysis systems in that it is configured to measure mineralogical variability based on chemistry at the micrometer-scale. QEMSCAN can help in bulk modal analysis, particle maps, locked and liberated textural analysis of REEs bearing mineral, size-by-size, mineral-by-mineral chemical assay and hunt for the trace mineral which constitute the REE's presence in the samples. **Around 70** samples will be analyzed in QEMSCAN for above mentioned purposes.

8.6.0 Data Analysis, Data Interpretation and Report Preparation:

8.6.1 Data Analysis and Interpretation: A Petrological, Mineralogical and Geochemical Report will be prepared. REEs are found to be mineralized at the deeper level i.e., at the B and C horizon. The positive anomaly of Ce can be detected and can be the pathfinder for REEs enriched zone within the soil profile.

This interpretation will be useful in the identifying mineralized zone in the study area. Borehole sample analysis will also help to identify the occurrence, depth, and richness of the REEs deposit. These data will be used in the reserve estimation of the deposit.

8.6.2 Drafting and Report Submission: On the basis of above-mentioned processes the final report will be drafted for the abundance and enrichment of REEs deposits in parts of Sung valley, Meghalaya.

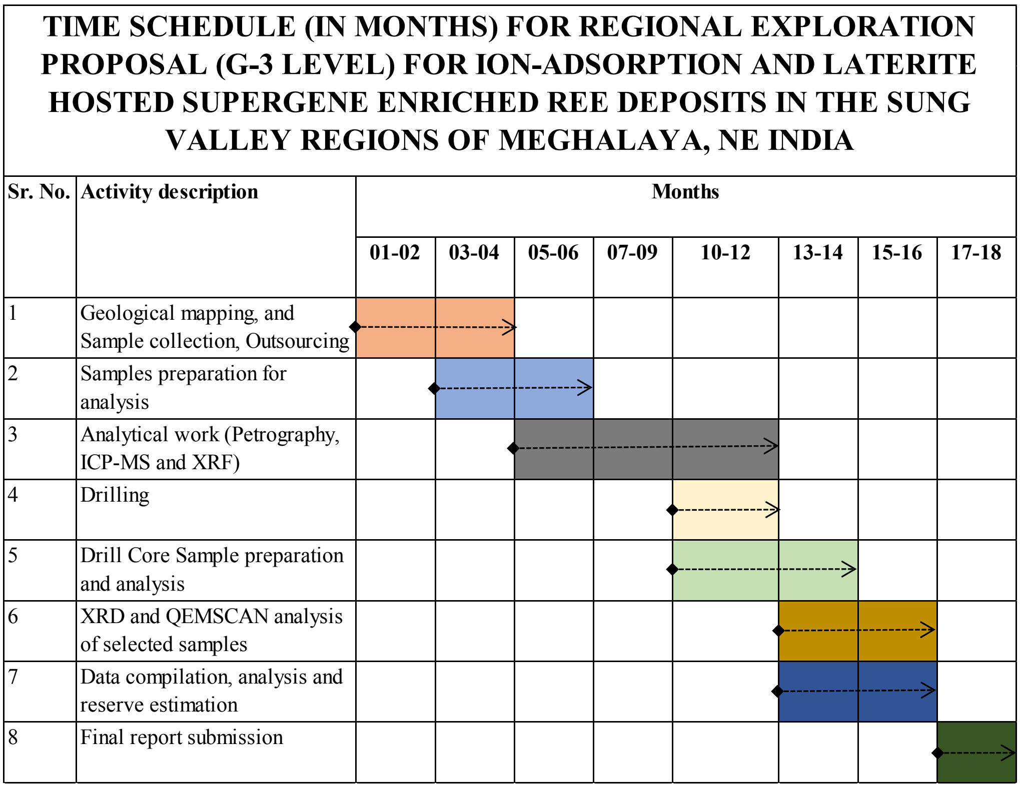
9.0.0 Nature of Quantum and Target

PROPOSED QUANTUM OF WORK IN THE SUNG VALLEY REGIONS OF MEGHALAYA, NE INDIA			
Sl. No.	Item of work	Unit	Proposed Quantum of Work
1	**Geological mapping (on 1:4,000 Scale)**	Sq. Km	35 km^2
	Borehole location fixation	NOS	12
2	**Geochemical sampling**		
	a) Bed rock sampling	NOS	40
	b) Weathering profile sampling	NOS	200
3	**Exploratory Mining**		
	Excavation (Trenching/Pitting)	Cu. m.	160
4	**Drilling**		
	a) Geological Core Logging	m	1560 (12 BHs)
	b) Borewell Drilling	m	300 (2 BWs)
5	**Sample Collection**		
	i) Surface Sampling (Bedrock)	Nos.	40
	ii) Weathering profile Samples	Nos.	200
	iii) Check Samples	Nos.	25
	v) Trench and Pit Samples	Nos.	75
	vi) Drill core primary sample	Nos.	250
	vii) Borewell Water samples	Nos.	10
6	**Petrological Studies**	Nos.	50
7	**Geochemical Analysis**		
	i) ICP-MS Analysis for 48 radicals	Nos.	600
	ii) XRF Analysis for 10 major oxides	Nos.	175
8	**Mineralogical studies**	Nos.	
	iii) XRD Analysis	Nos.	85
	iv) QEMSCAN Analysis	Nos.	70
9	Report Preparation [As per Mineral (Evidence of Mineral Contents) Rule-2015]	Nos.	1

10.0.0 Time schedule and Cost Estimate:

10.1.0 Time Schedule

10.1.1 The details of the exploration programme execution are indicated in the bar chart given below.



10.2.0 The project cost with provisional escalation is estimated at say Rs. 485.71 Lakhs. The details of item wise cost estimate with inbuilt actual escalation as on 30.05.2023 And provisional escalation rate for 2023-2024 has been taken and given below.

Sl. No	Item	Estimated Cost in INR
1	Drilling	2,68,50,800
2	Geological work	38,91,680
3	Manpower	6,17,760
4	Laboratory Studies	69,34,400
5	Petrographic study	4,02,500
6	Exploration Proposal preparation	7,73,943
7	Report preparation	11,60,914
8	Peer review charges	30,000
9	Contingency	5,00,000
10	GST (18%)	74,09,159
	Grand Total	**4,85,71,156**

11.0.0 Justification:

12.0.0 China dominates global REEs production, while India only contributes 1%, sourced from Monazite placer deposits, making further exploration crucial. Around 30% world's production of REEs comes from the ion-adsorption clays, thus exploring such deposits are essential.

12.1.0 Two latitudinal zones between 12°-32° latitude in both hemispheres have high abundance of ion-adsorption deposits due to intense precipitation around tropics. Meghalaya, known for precipitation and forests, has lithology like Carbonatite, ijolite, pyroxinite and melilitolite that bear REEs minerals, indicating the REEs presence.

12.2.0 GSI's survey in other litho-units for REEs exploration (G4 stage) as well as in the block area shows promising results and lithologies potential to develop ion-adsorption deposit, but further studies are needed for subsurface exploration.

12.3.0 Manpower Deployment:

12.4.0 PERSONNEL:

Smt. E. Nongbri, In-charge, Geologist, Directorate of Mineral Resources.

Shri. Stephan Lamo, Assistant Geologist, Directorate of Mineral Resources.

Shri. Damepaia S. M. Pdah, Assistant Geologist, Directorate of Mineral Resources.

12.5.0 **Man-Power Requirement:** Two positions of Project Associates will be required to carry out the proposed project have following criteria and experiences:

12.6.0 (i) Post-1: MSc Geology degrees qualification or its equivalent with basics on operating GIS softwares.

12.7.0 (ii) Post-2: MSc Geology degrees qualification or its equivalent with working experience in geochemical sampling, and geochemical sample preparation.

12.8.0 The renumeration for the above two posts will be Rs.25,740/- per month or as per approved guidelines laid by the NMET.

13.0.0 Cost Estimates / Breakup of expenditure:

PROPOSAL FOR SUNG VALLEY BLOCK, EAST KHASI AND WEST JAINTIA HILLS DISTRICTS, MEGHALAYA STATE, FOR RECONNAISSANCE SURVEY (G-3 STAGE) OF ION-ADSORPTION AND LATERITE HOSTED SUPERGENE ENRICHED REE DEPOSITS UNDER NMET
Name of the Exploration Agency - The Directorate of Mineral Resources, Government of Meghalaya, Shillong
Total Area - 35 sqkm; Nos. of Borehole -12 ; Completion Time - 18 Months

S.N	Item of Work	Unit	Rates as per NMET SoC		Estimated Cost of the Proposal	
			SoC-Item -Sl No.	Rates as per SoC	Qty.	Total Amount (Rs)
A	**GEOLOGICAL WORK**					
1	**Geological mapping (1:5000) & sampling**					
a	Charges for one Geologist per day at HQ	one Geologist per day	1.3	9,000	70	6,30,000
b	Charges for two Geologist per day at field (2 Nos)	one Geologist per day	1.3	11,000	140	15,40,000
c	Labour (2Nos/ geologist)	per Labor day	5.7	494	280	1,38,320
e	Charges for one Sampler per day (1 Party)	one sampler per day	1.5.2	5,100	120	6,12,000
f	Labour (4 Nos/ sampler)	per Labor day	5.7	494	240	1,18,560
2	**Trenching**					
a	Excavation of Trenches upto 2m depth	per cu m	2.1.3	5,330	160	8,52,800
	Sub-Total -A					**38,91,680**
B	**Petrological samples (Surface & BH Core Samples)**					
i	Preparation of standard thin sections	Nos	4.3.1	2,353	50	1,17,650
ii	Complete Petrographic/Ore microscopy Study/Mineragraphic	Nos	4.3.4	4,232	50	2,11,600
iii	Preparation of unmounted polished section of rock	per sample	4.3.3	1,185	50	59250
	Sub-Total -B					**3,88,500**
C	**Digital Photograph of thin polished section**					
i	Digital Photographs	Nos	4.3.7	280	50	14,000
	Sub-Total -C					**14,000**
D	**LABORATORY STUDIES**					
1	**<u>Chemical Analysis</u>**					
a	Samples for REE and Trace using ICP-MS 48 radicals (40 BRS+ 200 Soil+ 25 Check + 75 Pit + 250 Borehole + 10 water sample = 600)	Nos	4.1.14	7,371	600	44,22,600
b	Samples for Major Oxide by XRF (20 BRS+ 50 Soil + 5 Check + 25 Pit + 75 Borehole = 175)	Nos	14.1.15a	4,200	175	7,35,000
c	Samples for Mineral identification using XRD (10 BRS+ 20 Soil + 3 Check + 17 Pit + 35 Borehole = 85)	per sample	4.5.1	4000	85	340000
d	Samples for Mineral mapping using Qemscan (14 BRS+ 15 Soil + 1 Check + 10 Pit + 30 Borehole = 70)	per sample	--	20000	70	1400000
d	Samples for ion chromatography 10 water sample	per sample	4.1.8a	3680	10	36800
	Sub-Total -D					**69,34,400**
E	**Manpower**					
i	i) Project Associate	Nos	5.7	25,740	2	6,17,760
	Sub-Total E					**6,17,760**
F	**DRILLING (After Review)**					
i	Drilling up to 1560m (Hard Rock)	m	2.2.1.4a	11,500	1560	1,79,40,000

ii	Drilling Borewell for Groundwater sample	m	nil	4,000	300	12,00,000
iii	Drilling camp setting cost	per drill	2.2.9a	2,50,000	5	12,50,000
iv	Drilling camp winding cost	per drill	2.2.9b	2,50,000	5	12,50,000
v	Approach road making for rugged-Hilly terrain	per km	2.2.10b	32,000	60	19,20,000
vi	Transportation of drill rig & truck associated per drill	per km	2.2.8	36	200	7,200
vii	Monthly accommodation charges for drilling camp	Monthly basis	2.2.9	50,000	5	2,50,000
viii	Drill core preservation	per m	5.3	1,560	1560	24,33,600
ix	Land/crop compensation	per BH	5.6	50,000	12	6,00,000
	Sub Total F					**2,68,50,800**
Total -(A to F)						**3,86,97,140**
G	**Contingency (F)**	**Nil**	**Nil**	**Nil**	**Nil**	**5,00,000**
G	**Preparation of Exploration Proposal (5 Hard copies with a soft copy)**	**5 Hard copies with a soft copy**	**5.1**	2% of the Cost subject to a maximum of Rs. 5 lakh		**7,73,943**
H	**Geological Report Preparation**	**5 Hard copies with a soft copy**	**5.2**	For the projects having cost exceeding Rs. 150 lakhs but less than Rs. 300 lakh - A minimum of Rs. 7.5 lakhs or 3% of the value of work whichever is more.		**11,60,914**
I	**Peer review Charges**		**As per EC decision**			**30,000**
J	**Total Estimated Cost without GST**					**4,11,61,997**
K	**Provision for GST @ 18%**					**74,09,159**
L	**Total Estimated Cost with GST**					**4,85,71,156**
			or Say in Lakhs (Rs.)			***485.71***

1. If any part of the project is outsourced, the amount will be reimbursed as per the Paragraph 3 of NMET SoC and Item no. 6 of NMET SoC.

2. In case of execution of the project by EA on its own, a Certificate regarding non outsourcing of any component/project is required.

14.0.0 References:

- Balaram, V. & Rao, T. (2003). Rapid Determination of REEs and Other Trace Elements in Geological Samples by Microwave Acid Digestion and ICP-MS. Atomic Spectroscopy. 24. 206-212.
- Borst, A.M., Smith, M.P., Finch, A.A. et al. Adsorption of rare earth elements in regolith-hosted clay deposits. Nat Commun 11, 4386 (2020). https://doi.org/10.1038/s41467-020-17801-5
- Chakhmouradian, A. R., and Wall, F. (2012); Rare earth elements: minerals, mines, magnets (and more). *Elements*, *8*(5), 333-340.
- Chattopadhyay N., 1979; Report on the Sung Valley alkaline ultramafic carbonatite complex, Khasi and Jaintia Hills districts, Meghalaya; Progress report of Geol. Surv. Ind. for the F.S. 1976-77 (unpublished); Acc.No.487.
- Chi, R., and Tian, J., 2008, Weathered Crust Elution-deposited Rare Earth Ores: Nova Science Publishers, New York, 288 p.
- Cocker, M. D. (2014); Lateritic, supergene rare earth element (REE) deposits.
- Ferris, A. P., and Jepson, W. B. (1975). The exchange capacities of kaolinite and the preparation of homoionic clays. *Journal of Colloid and Interface Science*, *51*(2), 245-259.
- Freyssinet, P.H., Butt, C.R.M., Morris, R.C. and Piantone, P., 2005; Ore-forming processes related to lateritic weathering Economic Geology. 100th Anniversary Volume (2005), pp. 681-722
- Goodenough, K.M., Wall, F. and Merriman, D., 2017; The rare earth elements: demand, global resources, and challenges for resourcing future generations Nat. Resour. Res., 27 (2) (2017), pp. 201-216
- Guillaume Estrade, Eva Marquis, Martin Smith, Kathryn Goodenough, Peter Nason, REE concentration processes in ion adsorption deposits: Evidence from the Ambohimirahavavy alkaline complex in Madagascar, Ore Geology Reviews, Volume 112, 2019, 103027, ISSN 0169-1368, https://doi.org/10.1016/j.oregeorev.2019.103027.
- Gupta, R. P. and Sen, A. K., 1988; Imprints of Ninety-East Ridge in the Shillong Plateau, Indian Shield. Tectonophysics vol.154: p. 335– 341.
- Hei Li, M. Y., & Zhou, M. F. (2020, January 1). The role of clay minerals in formation of the regolith-hosted heavy rare earth element deposits. De Gruyter. https://doi.org/10.2138/am-2020-7061
- Hoshino, M., Sanematsu, K., and Watanabe, Y. (2016); REE mineralogy and resources. *Handbook on the physics and chemistry of Rare Earths*, *49*, 129-291.
- Kanazawa, Y., and Kamitani, M. (2006); Rare earth minerals and resources in the world. *Journal of Alloys and Compounds*, *408–412*, 1339–1343. doi: 10.1016/j.jallcom.2005.04.033
- Kent, R. W., Pringle, M. S., Müller, R. D., Saunders, A. D., and Ghose, N. C., 2002; 40Ar/39Ar Geochronology of the Rajmahal Basalts, India, and their Relationship to the Kerguelen Plateau. Journal of Petrology, Volume 43, Issue 7, p 141–1153.
- Kent, R. W., Saunders, A. D., Kempton, P. D. and Ghose, N. C., 1997; Rajmahal basalts, eastern India: mantle sources and melt distribution at a volcanic rifted margin. In:
- Krishnamurthy, P. (1985); Petrology of the carbonatites and associated rocks of Sung Valley, Jaintia Hills district, Meghalaya; India. Jour. Geol. Soc. India, v.26, pp.361-379.

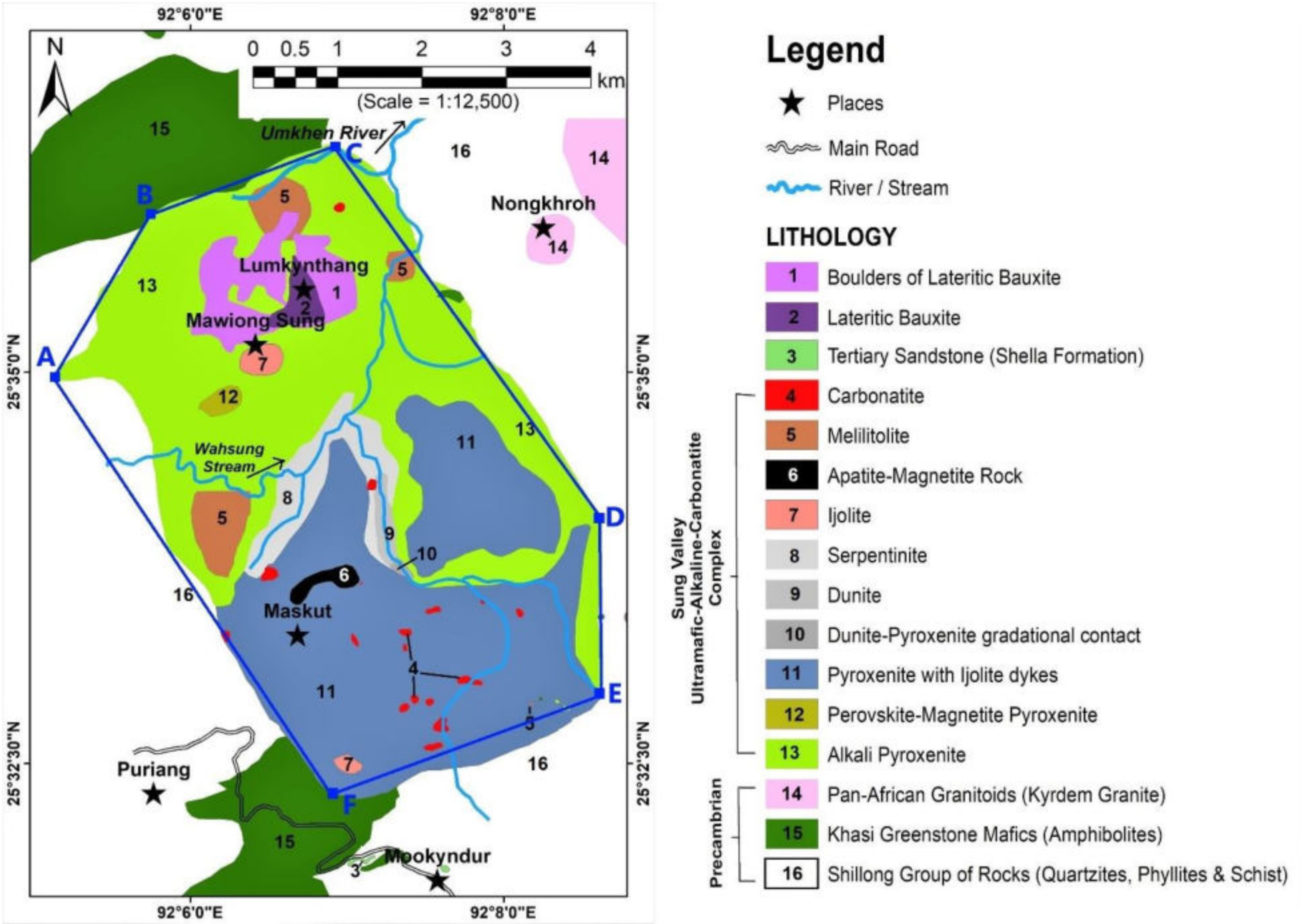
- Krishnamurthy, P., Hoda, S.Q. Hoda., Sinha, R.P., Banerjee, and Dwivedy, K. K., 2000; Economic aspects of carbonatites of India. Jour. Asian Earth Sci., v.18, pp.229-235.
- *Kumar Y.,* 1988; An interim report on the investigation of bauxite occurrence near Lumkynthang village, East Khasi Hills district, Meghalaya; Geological Survey of India progress report for the field season 1984-85; Acc.No. 1730.
- Kumar Y., 1988; An interim report on the investigation of bauxite occurrence near Lumkynthang village, East Khasi Hills district, Meghalaya; Geological Survey of India progress report for the field season 1984-85; Acc.No. 1730.
- Mahoney, J. J. and Coffin, M. F. (eds) Large Igneous Provinces: Continental, Oceanic and Planetary Flood Volcanism. Geophysical Monograph, American Geophysical Union.100,145–182.
- Melluso, L., Srivastava, R. K., Guarino, V., Zanetti, A. and Sinha, A. K. (2010). Mineral compositions and petrogenetic evolution of the ultramafic-alkaline-carbonatitic complex of Sung valley, northeastern india; The Canadian Mineralogist 48:205-229.
- *Mohanty S.R., Singh H.K. and Layek S.,* 2019; Final report on reconnaissance survey for lateritic bauxite and associated minerals in the eastern part of Umsung area, West Khasi Hills district, Meghalaya (G-4 state). Geological Survey of India final report for the field season 2017-18 and 2018-19. Acc.No. 11180, 17994 and 27620.
- Mukai, H., Kon, Y., Sanematsu, K. et al. Microscopic analyses of weathered granite in ion-adsorption rare earth deposit of Jianxi Province, China. Sci Rep 10, 20194 (2020). https://doi.org/10.1038/s41598-020-76981-8
- Papangelakis, V. G., and Moldoveanu, G. (2014, September); Recovery of rare earth elements from clay minerals. In *Proceedings of the 1st Rare Earth Resources Conference, Milos* (Vol. 191, p. 202).
- Ranjith A. and Sadiq M., 2012; Preliminary search for REE in the peripheral part of Sung ultramafic alkaline carbonatite complex, East Khasi Hills district and Jaintia Hills district, Meghalaya; Geological Survey of India final report for the field season 2010- 2012; Code No: ME/NER/SME/2010/018, Proposal Id: 2010436; Acc.No. 3095.
- *Rath P.C.,* 1991; Report on bauxite investigation near Lumkynthang Village, East Khasi Hills districts, Meghalaya; Geological Survey of India progress report for the field season 1985-86; Acc.No. 1939; Acc.No. 1939.
- Santana, I. V., & Botelho, N. F. (2022). REE residence, behaviour and recovery from a weathering profile related to the Serra Dourada granite, Goiás/Tocantins states, Brazil. Ore Geology Reviews, 143, 104751. https://doi.org/10.1016/j.oregeorev.2022.104751
- Sreenivasaiah V., Whuorie D.V. and Deka., 2014; Final report on investigation around Rambrai in West Khasi Hills District, Meghalaya (G-4 stage); Geological Survey of India final report 2012-13 and 2013-14; Acc.No. 3184.
- Storey, M., Kent, R. W., Saunders, A. D., Hergt, J., Salters, V. J. M., Whitechurch, H., Sevigny, J. H., Thirlwall, M. F., Leat, P., Ghose, N. C. and Gifford, M. (1992). Lower cretaceous volcanic rocks on continental margins and their relationship to the Kerguelen Plateau. Proc. Ocean Drill. Program Sci.

Result. 120:33-53 68.

- U.S. Geological Survey (USGS). Mineral Commodity Summaries—Rare Earths. 2016. Available online: Mineral Commodity Summaries 2022 - Rare-Earths (usgs.gov) (accessed on 17 January 2023).
- Wang, Y., Liu, L., Sun, M., Huang, J., Huang, Y., Liang, X., Tan, W., He, H., & Zhu, J. (2023, September 12). Distribution and Fractionation of Rare Earth Elements (REE) in the Ion Adsorption-type REE Deposit (IAD) at Maofeng Mountain, Guangzhou, China - Clays and Clay Minerals. SpringerLink. https://doi.org/10.1007/s42860-023-00251-7
- *Wu, C.Y., Huang, D.H., Guo, Z.G., 1990*. REE geochemistry in the weathered crust of granites, Longnan area, Jiangxi Province. Acta Geol. Sin. 3, 193–210.
- Yusuf S. and Saraswat A.C., 1977; A Prelimanary Note on Carbonatite in Wah Sung Valley of Jaintia Hills District, Meghalaya; Current Science, Letters to the editor, Vol. 46, No.20, Oct. 20, 1977, page 703

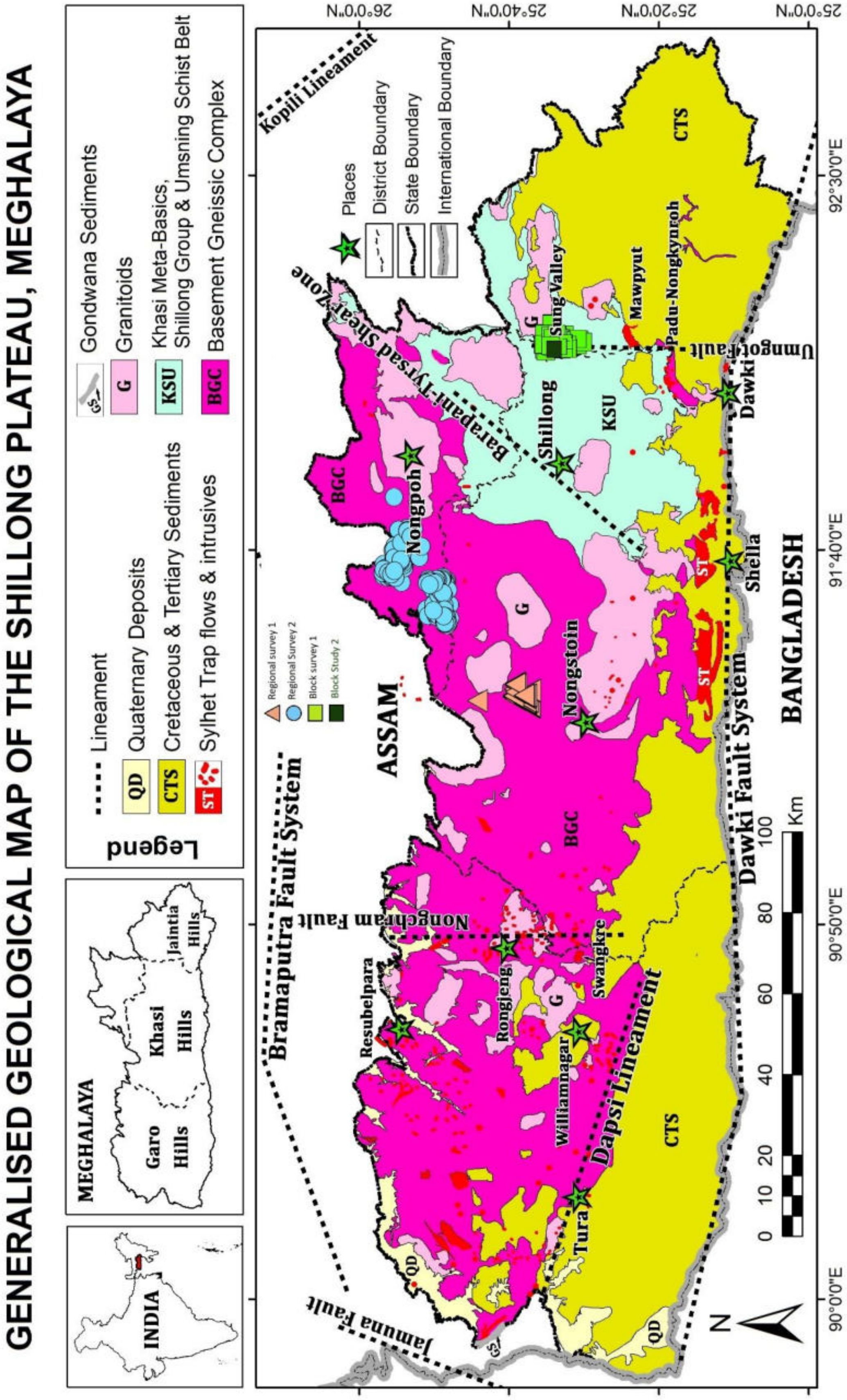
ANNEXURE – I

Geological map of Sung Valley, showing the block boundary



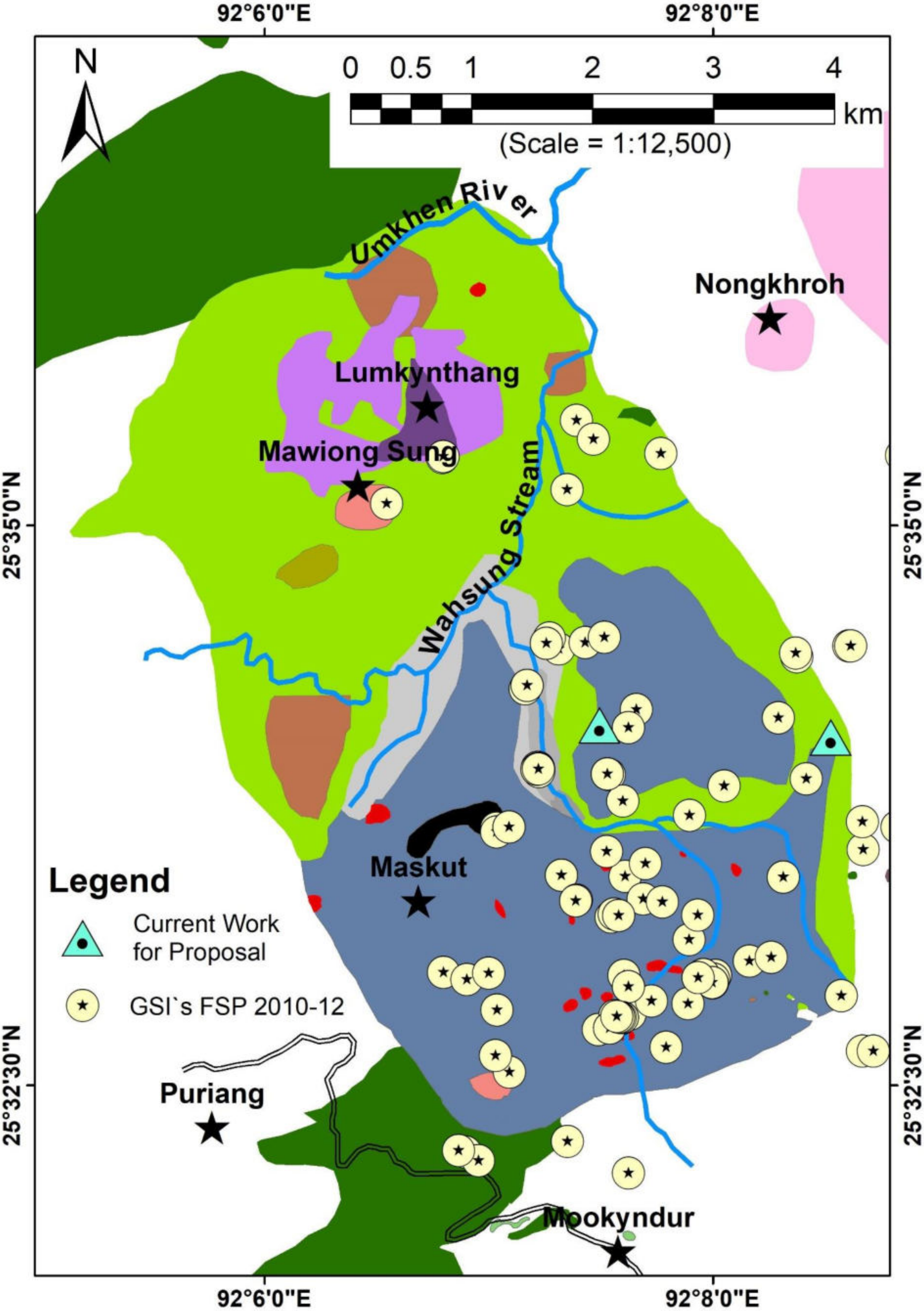
ANNEXURE – II

Generalized geological map of Meghalaya, showing the regional and block surveys.



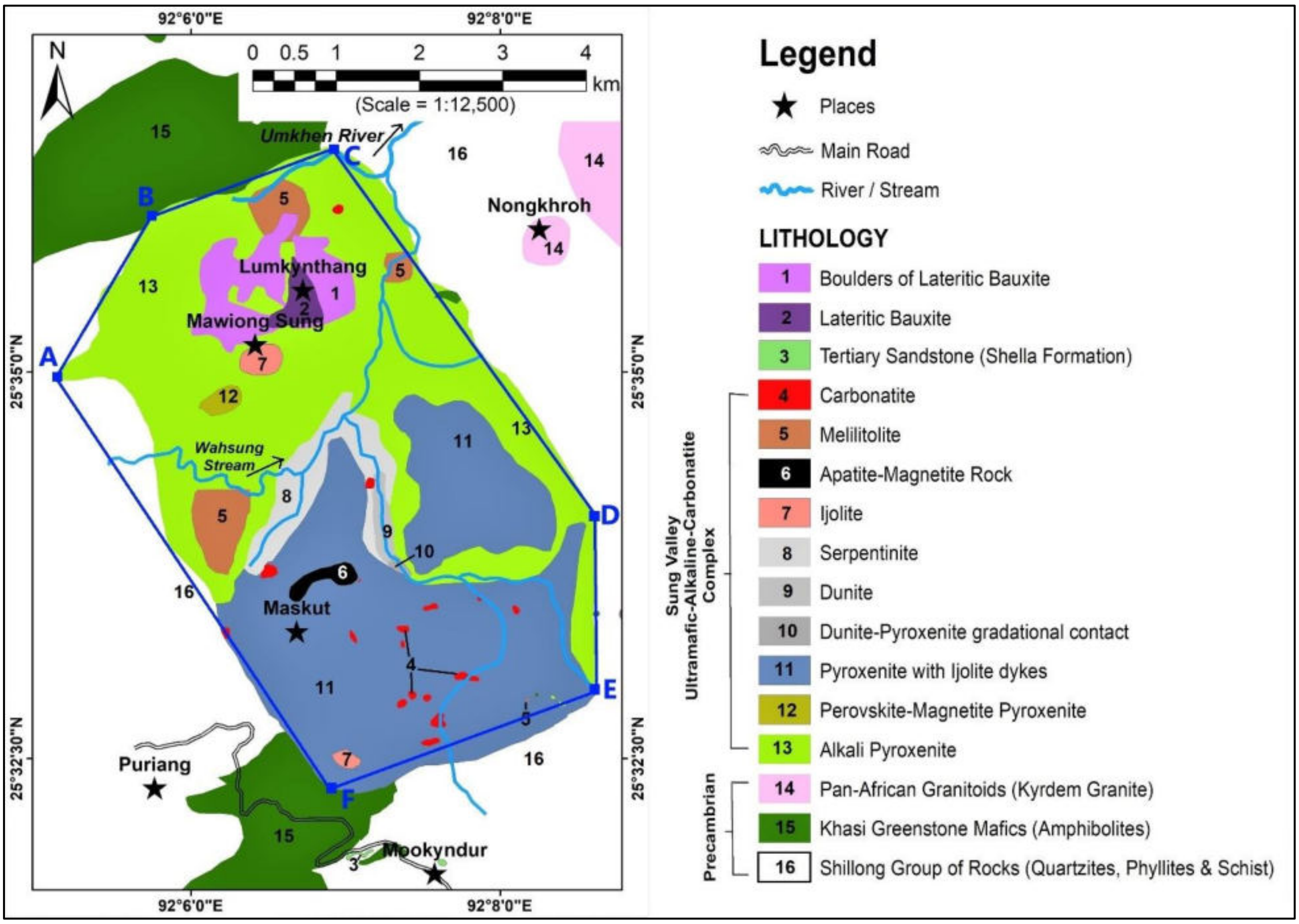
ANNEXURE – III

Generalized geological map of Meghalaya, showing the previous G4 survey's sample location and DMR's study for proposal



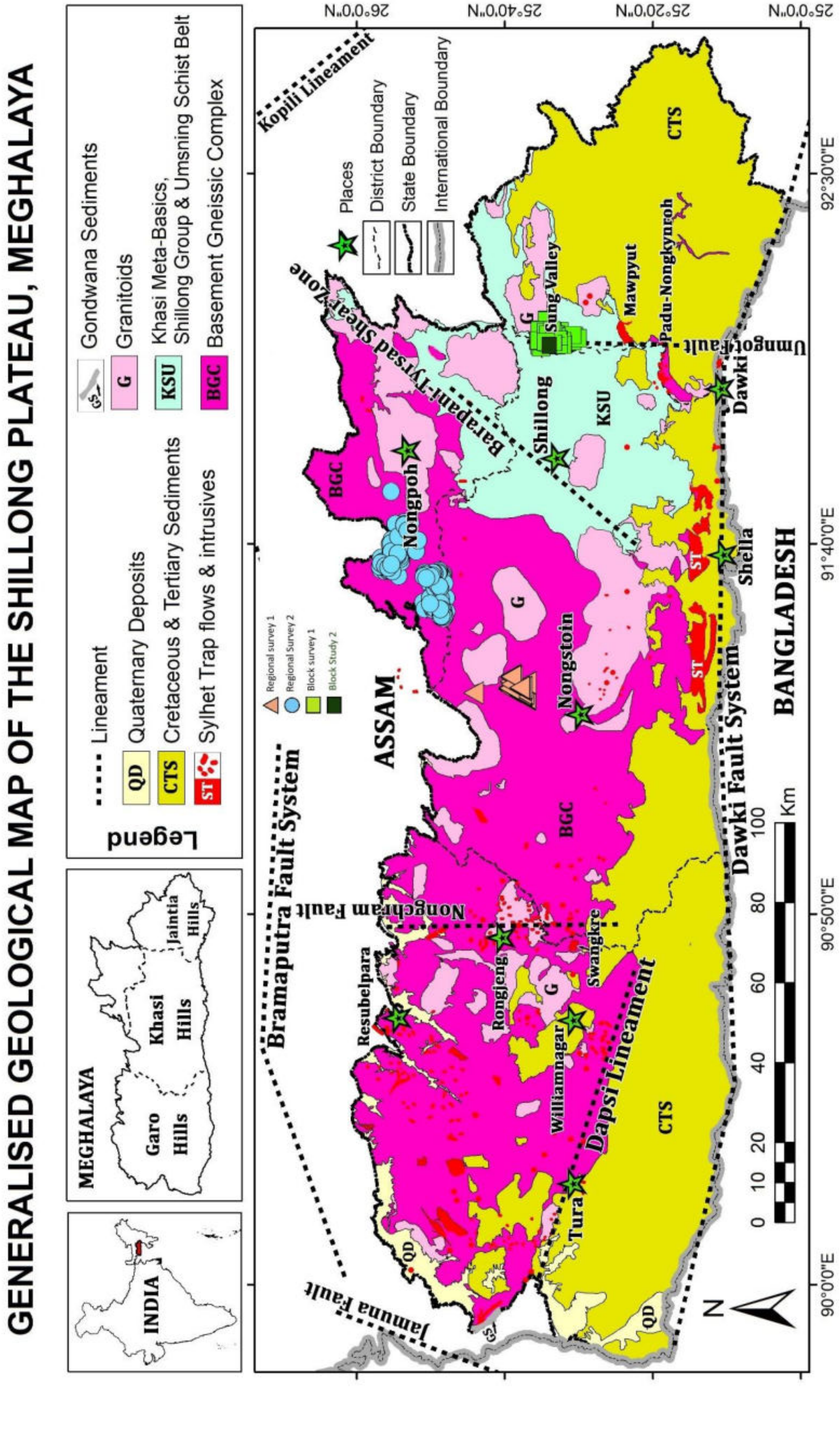
ANNEXURE – I

Geological map of Sung Valley, showing the block boundary



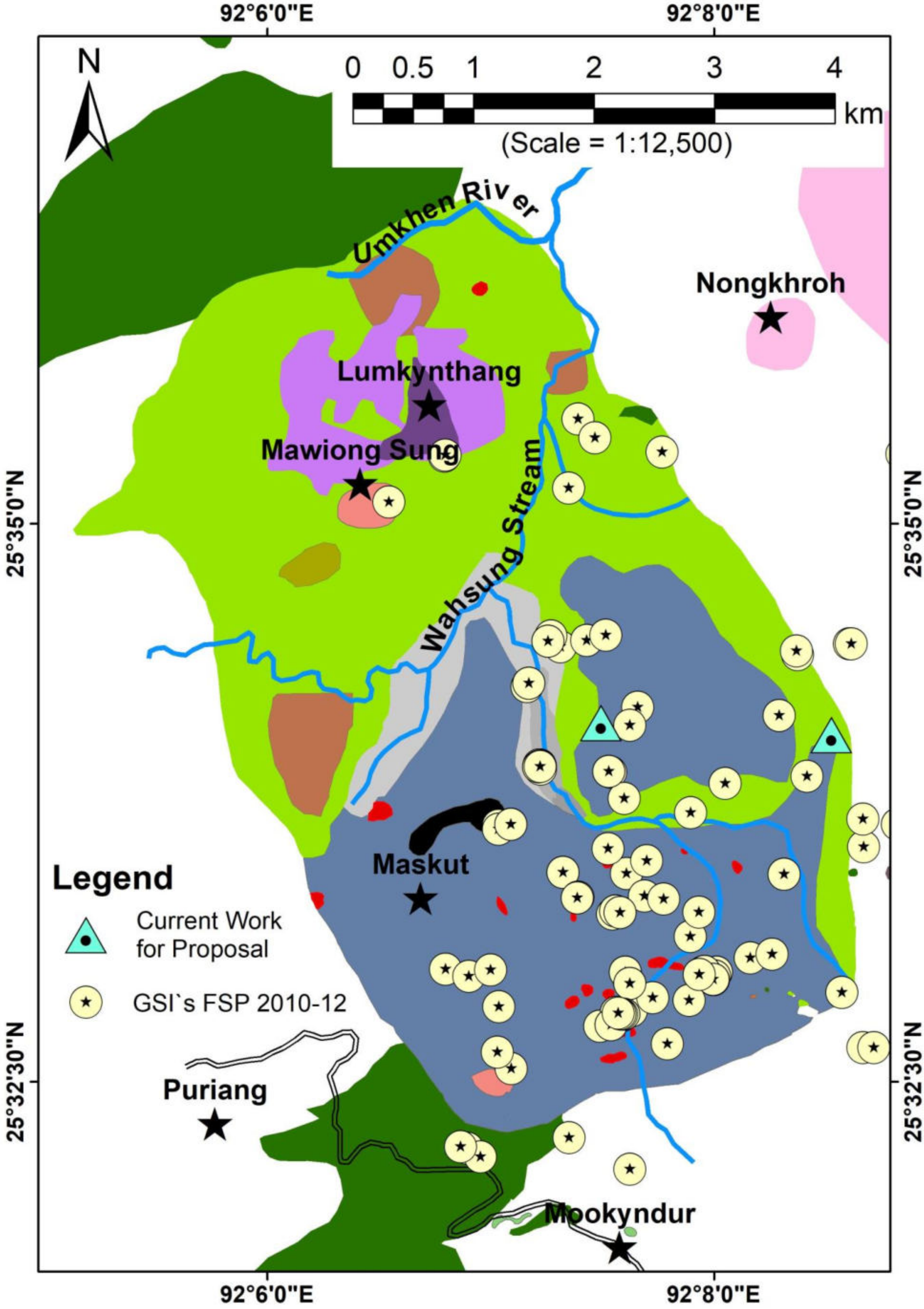
ANNEXURE – II

Generalized geological map of Meghalaya, showing the regional and block surveys.



ANNEXURE – III

Geological map of Sung Valley, showing the previous G4 survey's sample location and DMR's current work for this proposal



भारत सरकार

GOVERNMENT OF INDIA

भारतीय भूवैज्ञानिक सर्वेक्षण

GEOLOGICAL SURVEY OF INDIA

मेघालय खनिज़ अनुसंधान परियोजना **–II**

MEGHALAYA MINERAL INVESTIGATION & PROJECT-II

मेघालय के पूर्व खासी पहाडी ज़िले कें सुंण अतिमैफिक – क्षारीय- कार्बोनेटाइटं संम्मिश्र के परिधीय भाणे में आर ई ई के लिए प्राथमिक खोज (जी4 चरण)

(टोपोशीत सं.83 सी/2)

PRELIMINARY SEARCH FOR REE IN THE PERIPHERAL PART OF SUNG ULTRAMAFIC ALKALINE CARBONATITE COMPLEX, EAST KHASI HILLS DISTRICT & JAINTIA HILLS DISTRICT, MEGHALAYA (G4 STAGE) (PART OF TOPOSHEET-83 C/02)

कोड सं: एमईऊंपूक्षेएसएमई/2010/018,प्रस्ताव क्षायंडी.2010436

Code No: ME/NER/SME 2010/018. Proposal Id: 2010436

(Final Report for F. S. 2010 - 2012)

(फील्ड सत्र2010 - 12 के लिए अंतिम रिपॉट)

द्वारा By

रंजीथ ए **Ranjith. A** मो.सादिक **Md Sadiq**

(भूवैज्ञानिक)**(Geologist)** (भूवैज्ञानिक)**(Geologist)**

भारतीय भूवैज्ञानिक सर्वेक्षण

Geological Survey of India

पूर्वोत्तर क्षेत्र

North Eastern Region

शिलांगं, मेघालेयं

Shillong, Meghalaya

2012

Acc. No. 3095

GOVERNMENT OF INDIA

GEOLOGICAL SURVEY OF INDIA

MEGHALAYA MINERAL INVESTIGATION & PROJECT-II

PRELIMINARY SEARCH FOR REE IN THE PERIPHERAL PART OF SUNG ULTRAMAFIC ALKALINE CARBONATITE COMPLEX EAST KHASI HILLS DISTRICT & JAINTIA HILLS DISTRICT, MEGHALAYA

(G4 STAGE)

(PART OF TOPOSHEET 83 C/02)

Code No: ME/NER/SME/2010/018, Proposal Id: 2010436

(Final Report for F.S. 2010-2012)

By

Ranjith, A. (Geologist)

and

Md. Sadiq (Geologist)

Geological Survey of India

North Eastern Region

Shillong, Meghalaya

2012

Acc. No. 3095

PRELIMINARY SEARCH FOR REE IN THE PERIPHERAL PART OF SUNG ULTRAMAFIC ALKALINE CARBONATITE COMPLEX EAST KHASI HILLS DISTRICT & JAINTIA HILLS DISTRICT, MEGHALAYA

By
Ranjith, A. (Geologist)
and
Md. Sadiq (Geologist)

CONTENTS

LIST OF APPENDICES **61-79**

LIST OF PLATES

LIST OF FIGURES

LIST OF TABLES

LIST OF PLOTS

LIST OF ABBREVIATIONS

AMD - Atomic Mineral Department

AMR - Apatite Magnetite Rock

BRS - Bed Rock Sample

EPMA-Electron Probe Micro Analyser

FSP - Field Season Programme

HREE - Heavy Rare Earth Element

ICP-MS - Inductively Coupled Plasma Mass Spectrometer

IRMS - Isotope Ratio Mass Spectrometer

IRS - Indian Remote Sensing Satellite

LREE - Light Rare Earth Element

LSM - Large Scale Mapping

NQT - Nature Quantum and Time Schedule

PPM - Parts Per Million

REE - Rare Earth Elements

REO – Rare Earth Oxide

PGE - Platinum Group of Elements

SOI - Survey of India

SSS - Stream Sediment Sample

SUACC - Sung Valley Ultramafic-Alkaline-Carbonatite Complex

WES - Water Equilibrium System

सारांश

सुंगघाटी अतिमैफिक-६तारीय -कार्बोनेटाइट समिश्र /शैलसमूह (सु अक्षकारौ) एक अंडाकार काय है जो लगभग 26 वर्ग किमी के क्षेत्र में फैला हुआ है और यह पूर्वोत्तर भारत में शिलांग पठार में हॉस्ट जैसे लक्षणों वाले त्थिउत रूप में अभिस्थापितं है। अध्ययन क्षेत्र टोपोशीट सं 83 सी /02 में आता है और अक्षांश 25°30'00" उत्तर से 25°35'30" उत्तर तथा देशांतर 92°07'00" पूर्व से 92°09'00" पूर्व द्वारा घिरा हुआ हैं। उन्नतांश 890 से 1365 मीटर प्रक्षेत्र में है।

शिलांग समूह क्वार्टजाइट, फैलिटिकं क्वार्टजाइट और पोलिमिक्टिक कगलोमिरिट से निर्मित है। इसके अल्लावा ग्रेनाइट और एम्फिबाइलाइट अध्ययन क्षेत्र के उत्तरंपूर्वी और दक्षिणपश्चिमी भाग में अधिकम्रण के रूप में पायी जाती है। सुंग घाटी सम्मिश्र पाइरॉकिसनाइट,सर्पन्टीनाइज पेरिडोटाइट, मेलिलिटोलाइट्, आइजोलाइट, नेफिलाइन सायनाइट और कार्बोनेटाइट आदी से निर्मित है। पाइरॉकिसल्लाइट प्रमुख आश्मिकी है और सम्मिश्र के बीच में सर्पन्टीनाइज पेरिडोटाइट को परिबद्ध करता है। आइजोत्आइट दलयी संरचना बनाता है | ऐपाटाइट-मेग्निटाइट, मेलिलिटोलाइट एवं नेफिलाइट - साइनाइट सम्मिश्र में छोटे डाइक और शिरा के रूप उत्पन्न होता है। पेरिडोटाइट सुंघाटी का एक महत्वपूर्ण और दुर्लभ सदस्य है जो कुछ ही जगहों में पाया जाता है। कुछ जगहों में तृतीय बालूश्म छोटे आकारों के रूप में मुकुनडोर गांव के पास उत्पन्न होता है। लेटिराइट पतली टोपी के रूप में अध्ययन क्षेत्र के उत्तरपूर्वी भाग में उत्पन्न होता है।

कुछ जगहों में बालूश्म में संस्तरण को मुख्य आवसादी संरचना के रूप में देखा गया है। संस्तर का झुकाव ठत्तरपूर्वी -दक्षिणपश्चिमी की ओर सामान्य और उतरपूर्वी की ओर मध्यम गहराई तंक है। क्वार्टजाइट /फिलेटिक क्वार्टजाइट में शल्कन विकसित है जो उत्तरपूर्वी -दक्षिणपश्चिम की ओर झुकी हुई है और उतरपश्चिम की ओर 28°से 40°नत है। कोणीय विषमविन्यास एक महत्वपूर्ण संरचना है जिसे मूक्यूनडूर गांव के पास देखा गया है। फिलिटिक क्वार्टजाइट के शिलांग ग्रुप ऊपर तृतीयक बालूश्म संरूरण उपक्षेतिजीय छद और शिष्ट के संक्रमण क्षेत्र के साथ एक प्रमुख अपरदन विषमविन्यास को मूक्यूनडूर गांव के पास देखा गया है। इसके अलावा दो द्वितीयक सिलिकीभूत क्षेत्र की पहचान हुई है - एक उत्तर 10°पूर्व –द 10°पश्चिम की ओर उपनति हैं और दूसरा उत्तरपश्चिम-दक्षिण पूर्व की तरफ उपनति है को अध्ययक्ष क्षेत्र के पूर्वी भाग में चिन्हित किया गया | सुंण अंतिक्रमण के परिधि में कोई भी संस्पर्श कायांतरी प्रभाव नहीं देखा गया। कुल 74 आधार शैल नमूनों को एकत्रित किया गया है जिससे सुंग घाटी परिसर में पाए गए विभिन्न लिथो यूनिट मिली आर ई ई खनिजन का मूल्यांकन किया जा सके। मद के

उद्देशय को प्राप्त करने के लिए परिसर के परिधीय क्षेत्र (पी-3 ब्लाक) में नियमित अंतराल में प्रतिचयन भी किया गया |

ग्यारह अलग कार्बोनेटाइट कार्यों से संकलित किये गए आधार शैल नमूनें ∑LREE (0.01% से 0.13% परिसर तक) और ∑HREE (0, 001% से 0.019% परिसर तक) के असंगत मूल्य दिखाता है। धारा अवसाद नमूने ∑LREE सांद्रण के असंगत मूल्य दिखाते है।

जिसका परिसर 64:153ppm से 1380.16ppm के बीच है और ∑HREE सांद्रण का परिसर 9.49 ppm से 103.46 ppm के बीच है। कार्बोनेटाइट में REE प्रावृंस्थ्रा को EPMAअध्ययन के द्वारा चिन्हित किया गया जिसमें है ; ऐन्सीलाइट, बेलोभाइट, बैस्टोनाइट ब्रिथोलाइट जो मैग्निटाइट के साथ संबंध है। अयस्क सूक्ष्मदर्शी अध्ययन सल्फाइट खनिजीकरण जैसे पाइराइट, चैल्कोपाइराइट और आर्सेनोपाइराइट के उपस्थित होने का इशारा करता है।

तरल अंतर्वेशन अध्ययन नंमूनों में प्राथमिक और द्वितीयक एक प्रावस्था /द्विप्रावस्था अंतर्वेशन के उपस्थित होने का प्रमाण देता है । समांगी तापमान 185° से से 362°से (औसत 258.95° से) के अंतराल मे है जो 0.83 से 8.65 वाट% NaCl तुल्य के लवणता परिसर के संगत रखता है।

समस्थानिक अध्ययन दिखाता है कि कार्बोनेटाइट नमूना के 8^{13}c मूल्य और 8^{18}0 मूल्यं -3.28 से- 2.25%PDB और 6.68 से 7.43% 0 PDB के परिसर में पड़ता है। ये मूल्य कार्बोनेटाइट् के प्राथमिक आग्नेय प्रकृति का सूचक है। मद का कोडीकरण UNFC वर्गीकरण के 334 के अंतर्गत किया गया।

PRELIMINARY SEARCH FOR REE IN THE PERIPHERAL PART OF SUNG ULTRAMAFIC ALKALINE CARBONATITE COMPLEX EAST KHASI HILLS DISTRICT & JAINTIA HILLS DISTRICT, MEGHALAYA

By
Ranjith, A. (Geologist)
and
Md. Sadiq (Geologist)

ABSTRACT

The Sung Valley Ultramafic-Alkaline–Carbonatite complex (SUACC) is an oval shaped body covering an area of about 26 Km^2 and is emplaced within the Shillong Plateau, an uplifted horst-like feature in North Eastern India. The studied area falls in Toposheet no 83C/02 and is bounded by latitude of N 25° 30' 00" to N 25° 35' 30" and longitude of E 92°07'00" to E 92°09'00". The altitude ranges from 890 to 1365 m.

The Shillong Group consists of quartzite, phyllitic quartzite and polymictic conglomerate. Besides granite and amphibolite occurs as intrusive in NE and SW part of the studied area. Sung Valley complex consists of pyroxenite, serpentinized peridotite, melilitolite, ijolite, nepheline syenite and carbonatite. Pyroxenite is the dominant lithology and encloses serpentinized peridotite forming the core of the complex. Ijolite forms a ring structure. Apatite-magnetite, melilitolite & nepheline-syenite occur as small dykes and veins in the complex. Peridotite is an important and rare member of Sung valley occurring only in few places. Some places Tertiary sandstone occurring as small patches near Mookyndoor village. Laterite occurs as thin caps in NE part of the studied area.

Bedding is the primary sedimentary structure observed in sandstone at few places. The general trend of the bedding is along NE-SW with moderate dip towards NE. Foliation is developed in quartzite/phyllitic quartzite showing NE-SW trend, dipping 28° to 40° towards NW. Angular unconformity is an important structure observed near Moo Kyndoor village. Tertiary sandstone forming sub-horizontal capping over the Shillong Group of phyllitic quartzite and transitional zone of schist with a pronounced erosional unconformity is observed near Moo Kyndoor village. Besides, two secondary silicified zones were identified; one trends along N10°E-S10°W and other trends along NW-SE was demarked in eastern part of the studied area. No contact metamorphic effect is observed along the periphery of the Sung intrusive. A total of 74 Bed Rock samples have been collected to assess REE mineralization from different litho units exposed in Sung valley complex. In order to achieve the

objective of the item, sampling at regular along the peripheral zone (P-3 block) of the complex was also done.

The Bed Rock samples collected from eleven different carbonatite bodies have indicated anomalous values of ΣLREE (ranging from 0.01% to 0.13 %) and ΣHREE (ranging from 0.001% to 0.019 %). Stream Sediment Samples indicate anomalous values of ∑LREE concentration being ranges between 64.153 ppm to 1380.16 ppm and ∑HREE conc. ranges between 9.49 ppm to 103.46 ppm. REE phases in carbonatite were identified through EPMA study that includes; Ancylite, Belovite, Bastnasite Britholite associated with magnetite. The ore microscopic studies have indicated presence of sulphide mineralisation such as pyrite, chalcopyrite and arsenopyrite.

Fluid Inclusion study indicates presence of primary and secondary mono-phase/bi-phase inclusions in the samples. The homogenisation temperature varies from 185°C to 362°C (average 258.95°C) which corresponds to a salinity range of 0.83 to 8.65 wt.% NaCl equivalent.

Isotope study shows that the δ^{13} C values and δ^{18} O values ranges from -3.28 to -2.25 $‰_{PDB}$ and 6.86 to 7.43 $‰_{PDB}$ of carbonatite sample. These values are indicative of the primary igneous nature of the carbonatite.

The item is codified under 334 of UNFC classification.

PRELIMINARY SEARCH FOR REE IN THE PERIPHERAL PART OF SUNG ULTRAMAFIC ALKALINE CARBONATITE EAST COMPLEX, KHASI HILLS DISTRICT & JAINTIA HILLS DISTRICT, MEGHALAYA

By
Ranjith, A., (Geologist)
and
Md. Sadiq (Geologist)

CHAPTER-I: INTRODUCTION

1.1 General

In pursuance of the Item No. ME/NER/SME/2010/018 & FSP proposal Id: 2010436, for the Field Season Programme 2010-2012, preliminary search for Rare Earth Elements (REE) in parts of Sung Valley Ultramafic-Alkaline-Carbonatite-Complex (SUACC), East Khasi Hills and Jaintia Hill Districts, Meghalaya (G4) was taken up.

1.2 Background Information

The Sung Ultramafic Complex Alkaline Carbonatite Complex (SUACC) consists of pyroxenite, uncompahrite serpentinized peridotite, melilitolite, ijolite, syenite, carbonatite and apatite-magnetite. Pyroxenite is the most dominant in the Complex and form a thick rim around the central serpentinite core. All the rock types are intrusive into the meta-sediments of the Shillong Group. Chattopadhaya et. al. (1981) during soil geochemical sampling in the Muskut carbonatite zone, lying to the southern peripheral part of the Complex reported enrichment of phosphate (0.07 to 21.50 % P_2O_5). A black carbonatite vein shows enrichment of rare earth content (>1000 ppm of Sr, Ni and 1000 ppm of La and Ce and 600 ppm of Ba) and indicated that some of the Nb rich pockets are highly radio-active. Drilling carried out during F.S. 1977-1978, analysed up to 800 ppm of Ni in some cores. South of the Muskut block, along NE-SW trending fault, effect of fennitisation is evident. Western part of the serpentinite body shows enrichment of Platinum Group of Elements (PGE) (Pt-135 ppm) and gold up to 0.2 ppm (Bora, 1992). In view of the litho association of apatite-magnetite rocks, it is likely that the hydrothermal solutions accompanying these rocks got channelised along weak zones in the country rocks around the periphery of the complex, especially in the receptive rocks such as schist and meta-argillite. These rocks are exposed in the north western part of the complex in the area around 5 kilometres northwest of Sung. Earlier workers have reported limonitisation in these rocks which needs a thorough evaluation for REE. The hydrothermal solutions accompanying the various mafic-ultramafic rocks of this complex are likely to be accommodated in these sheared and limonitised rock types. Earlier attempts to locate any significant mineralization were concentrated on the main body and these studies indicated Nb enrichment in magnetite + perovskite rich serpentinite-pyroxenite body with an anomalous 100-800 ppm Nb concentration in carbonatite vein and no attempt has been made so far to sample the peripheral zones. Hence, Large Scale Mapping (LSM) on 1: 12,500 scale and sampling are proposed in this area to identify zones rich in REE.

1.3 Location and Accessibility

Study area is located between the latitude of N25°30' 00" to N25°35'30" and longitude of 92°07'00" - 92°09'00" in Toposheet no. 83 C/2 (Figure - 1) in parts of East Khasi Hills and Jaintia Hills districts, Meghalaya. The intrusive body lies at about 22 km east of Shillong, capital of Meghalaya. The National Highway No. 44 connecting Shillong with Silchar via Jowai runs within a few kilometres southwest of the body between Mawryngkneng and Puriang. The central part of the complex which forms a wide valley is approachable from both Mawryngkneng and Puriang by fair weather jeepable tracts and rest of the part can be approached by foot tracks. Exposures are scanty and often covered with vegetation.

1.4 Physiography and Drainage

The area forms hilly and highly rugged terrain. The Sung Valley Complex forms a wide bowl like depression with elevation ranging from 890 m- 1000 m (above MSL.) in the valley floor to about 1050 m - 1365 m in the surrounding quartzite ridges. Numerous nalas, some of them perennial run into the valley from the surrounding high ridges and merge ultimately into the Um Khen river that flows towards northeast. A number of seasonal and perennial streams flowing towards the complex join flowing Sung nala. The NH-44 passes through the water divide where nalas towards north meet Um-Khen River and nalas flowing towards south join Um-Ngot River.

1.5 Climate and Rainfall

The climate of the area is moderate, subtropical and humid, attains an average annual rainfall of 241.5 cm and maximum temperature during summer (April to October) is 23°C and minimum 3°C during the winter (November to March). The climate of Jaintia Hills is subtropical with distinct alternate wet and dry seasons. The wet season extends from April to October, followed by a dry period from

November to March. During the wet season the monthly rainfall ranges from 152 to 756 mm, while in the dry period it is usually < 50 mm per month.

1.6 Vegetations

The central and southern parts of the Sung Valley Complex are very fertile and are extensively cultivated for paddy. Only the ridges of the complex are covered by jungle mainly of pine. The area is sparsely populated and is inhabited by Khasi and Jaintia tribes.

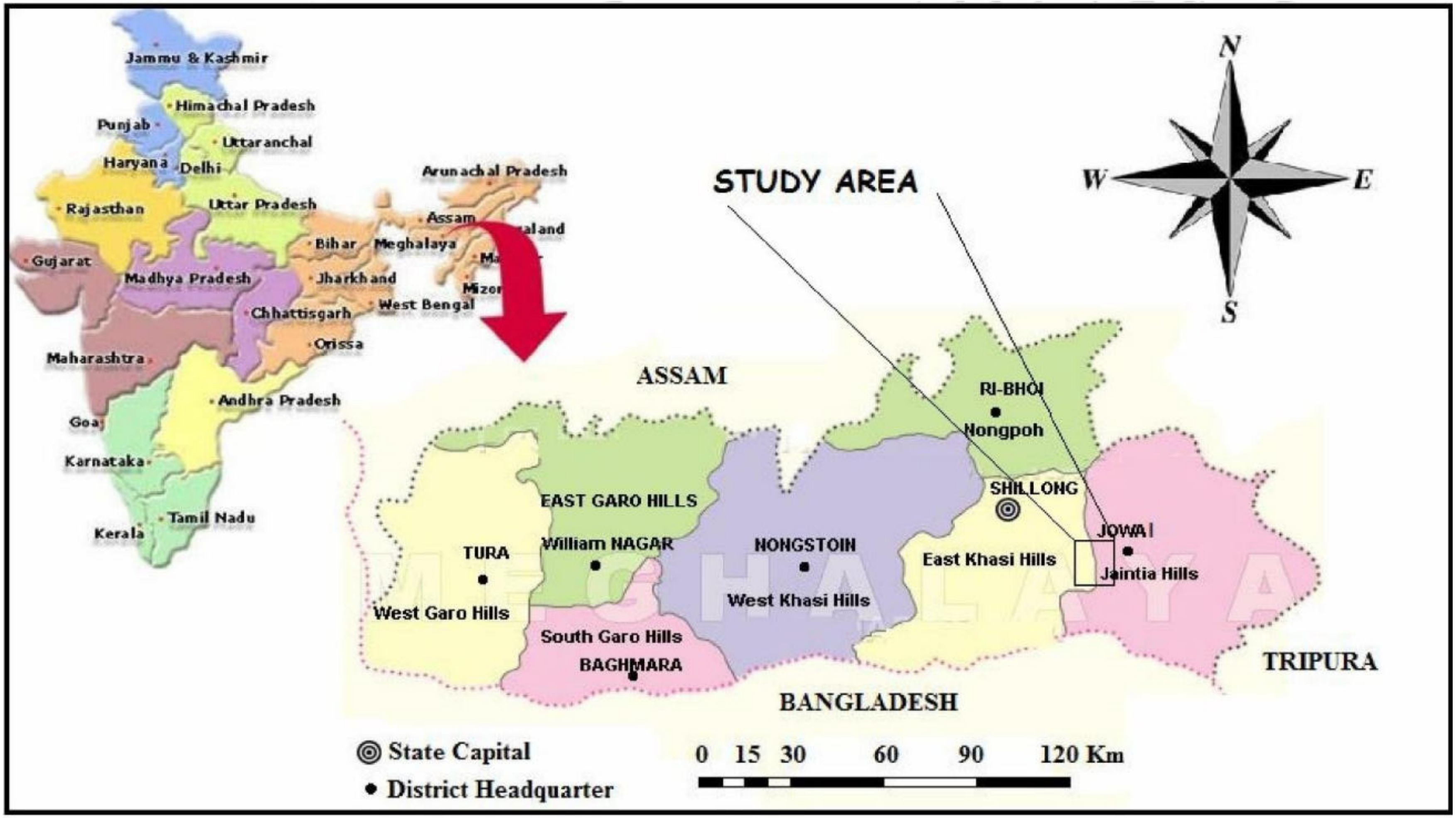


Figure 1.1: Location Map of the study area

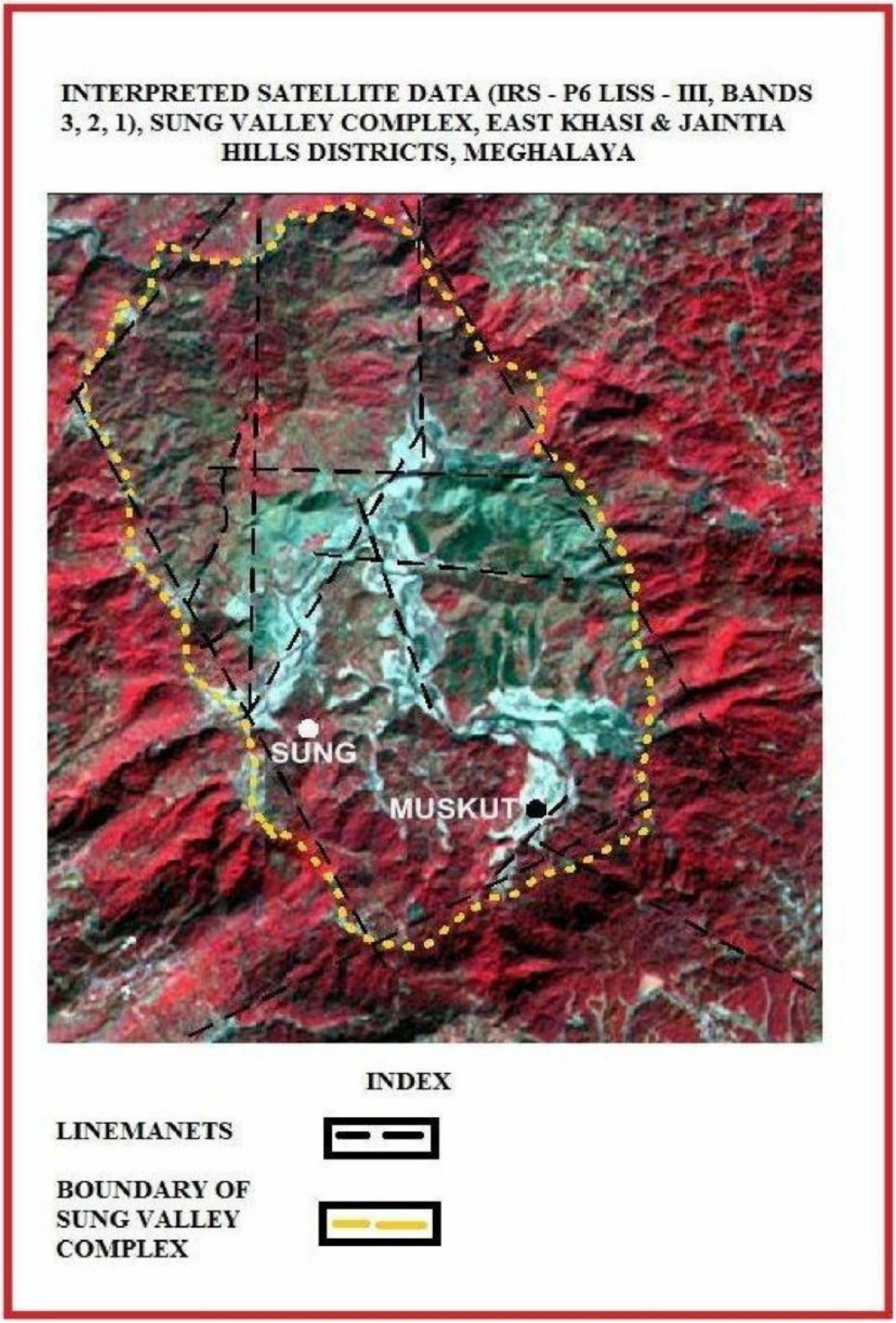


Figure 1.2: Geo-Coded imagery of field area FSP 2010-12

1.7 Previous Work

Regional geological map of the area on 1: 1,26,720 was prepared by Gogoi during F.S. 1972 -1973. N. Chattopadhyaya (1979) is the pioneer worker in Sung Valley Complex and did extensive work for P_2O_5. Subsequently different workers from GSI and other organization (AMD/Universities) worked in and around Sung Complex. During F.S 1976-77, Chottapadhyay (*Op.cit*), established that the Sung Valley intrusive as an ultramafic-alkaline-carbonatite complex and this opened up search for Nb, Ta, rare earths, P_2O_5 and associated elements within the complex. Yusuf and Saraswat (1977) and several other workers such as Chattopadhyaya and Hashmi (1984), Krishnamurthy (1985), Viladkar et al. (1994), Veena *et al* (1998), Ray *et. al*. (1999, 2000) and Sen (1999) have presented the geology and discussed the origin of the carbonatites and associated silicate rocks of Sung Valley complex. Studies on mineral compositions and petrogenetic evolution, petrological and genetic significance, emplacement age and isotope geochemistry of Sung Valley complex were carried out by Srivastava and Sinha *et al*. (2004, 2005 & 2010). The available age data on the Sung Valley complex, obtained by various methods on different materials ranges between 90 Ma and 150 Ma.

1.8 Prefield Studies

Before initiating field work, various unpublished report of GSI and AMD, miscellaneous publications, published papers in different journals, articles, old regional geological maps and satellite imagery, aero-geophysical data, exploration data, chemical data, drilling data and GIS analysis etc. were consulted to have a fair idea of the studied area as well as to achieve better understanding during the field work.

The data collected/used and the methodology adopted for the refinement of pre field map or preparation of integrated map for the identification of priority/target blocks for the search of REE mineralization in the Sung Valley complex are furnished below:

1. Survey of India Toposheet (83 C/2 on 1: 50,000 scales) IRS Data.
2. Indian Remote Sensing Satellite data (IRS ID LISS III FCC band 2 3 4; 83 C/2 on 1:50,000 scale)
3. High altitude aero-magnetic data (83 C/2 on 1: 250,000 scale)
4. Geological map of 83 C/2 on 1: 250,000 and 1: 50,000 scale.

5. Exploration data available from the GSI & AMD (Geological/drilling/known mineral occurrences) of Sung Valley.
6. Published/unpublished literatures of the study area.

The present study had been accomplished in the following steps viz:

1. Base map was prepared at 1: 12,500 scale from Toposheet (83 C/2 on 1: 50,000 scales) IRS Data.
2. Preparation of lineament map through visual interpretation of imagery.
3. Interpretation of magnetic data for anomalous zones (high, moderate &low) and magnetic breaks.
4. Compilation of exploration data (geochemical anomalous zones, high analytical values reported from the explored blocks/known mineral occurrence/drilling data etc.).
5. Preparation of integrated map showing priority/target blocks for the search of REE/other type of mineralization in GIS platform by superposing the thematic layers interpreted from aero-geophysical, remotely sensed and exploration data.
6. Field validation of target blocks for the search of REE/other type of mineralization.

Based on the above study three priority blocks were demarcated in the study area. (Figure-2) for the search of REE/other type of mineralization, viz;

1. **Priority block-I** Marked over the investigated blocks for phosphate, PGE and atomic minerals and on the basis of reported anomalous values of La, Ce &Y from carbonatite by GSI & AMD. Besides, the world's major REE sources are mainly from carbonatite, e.g. Mountain Pass, California, USA & Bayan Obo, Inner Mongolia, China.

2. **Priority block-II** Marked over the zones of lineament intersection, which are considered to be the structural locii for the emplacement of intrusive rocks hosting mineralization

3. **Priority block-III** Marked on the peripheral part of SUACC having intrusive contact with quartzite (Shillong Group). Search for REE mineralization in alteration zone (formed due to contact/thermal metamorphism) and also in oxidation zone, shear zone, silicified zone etc. is of importance in this block

1.9 Present Work

As per the field proposal the Field Item was to be carried out in E. Khasi Hills District. But due to objection of some local bodies/organisation and presence of carbonatite (main host of REE) bodies in Jaintia Hills District the work was carried out in both the Districts. Large Scale Mapping on 1: 12,500 scale was carried out with extensive field work and an area of 30 Km^2 was covered mainly in the eastern half of the SUACC and the Shillong Group of rocks. In order to identify/ classify and describe different lithologies, petrogenesis and to find out and to assess REE mineralization, a diverse types of samples were collected; 74 Bed Rock, 31 Stream Sediments, 23 Fluid Inclusion samples, 20 for Ore Microscopic studies, 13 for Petrological and 25 samples for whole rock analysis from carbonatite, pyroxenite, ijolite, serpentinite/peridotite, veins of carbonatite within pyroxenite/peridotite, apatite-magnetite rock (AMR) and amphibolites. 13 samples were also collected for EPMA study to ascertain the nature and type of REE phases present in the carbonatite.

Table-1 Nature Quantum and Time Schedule (NQT)

ITEM	TOTAL TARGETS ENVISAGED FOR FSP 2010-2012	ACHIEVEMENT
Preliminary Search for REE in the Peripheral Part of Sung Ultramafics-Alkaline-Carbonatite Complex, East Khasi Hills District, Meghalaya. (G4 Stage) FSP Code: ME/NER/SME/2010/18 Proposal ID: 2010436	Large Scale Mapping 1: 12500=30 sq. km	30 sq. km
	Bed Rock Sample= 50 Nos	74 Nos. & 2 Nos. for PGE
	Stream Sediment Sample= 30 Nos	31 Nos.
	Petrological Sample= 10Nos	10 Nos.
	Ore Microscopic Studies= 20Nos	20 Nos.
	Fluid Inclusion Studies= 20Nos	23 Nos.
ADDITIONAL SAMPLES COLLECTED		
	XRF Analysis sample= 25 Nos	
	Channel Sample= 14 Nos	
	EPMA Study= 13 Nos	
	C & O isotope studies= 06 Nos	

Table-2 Field stays of officers and supervisory officers

S. Nos	Officers/Supervisory Officers	Total Number of Field Days
1.	Shri J.C. Dutta, Director MMIP-I	4
2.	Dr. T. Kannadasan, Director MMIP-II. (Joined MMIP on 14-07-2011)	27
3.	Shri Ranjith. A, Geologist (Joined MMIP on 17-01-2011)	124
4.	Shri Mohd. Sadiq, Geologist (Joined MMIP on 08/7/11).	85
5.	Shri H.K. Sahoo, Senior Geologist (Transferred to NGCM in 07/2011)	23

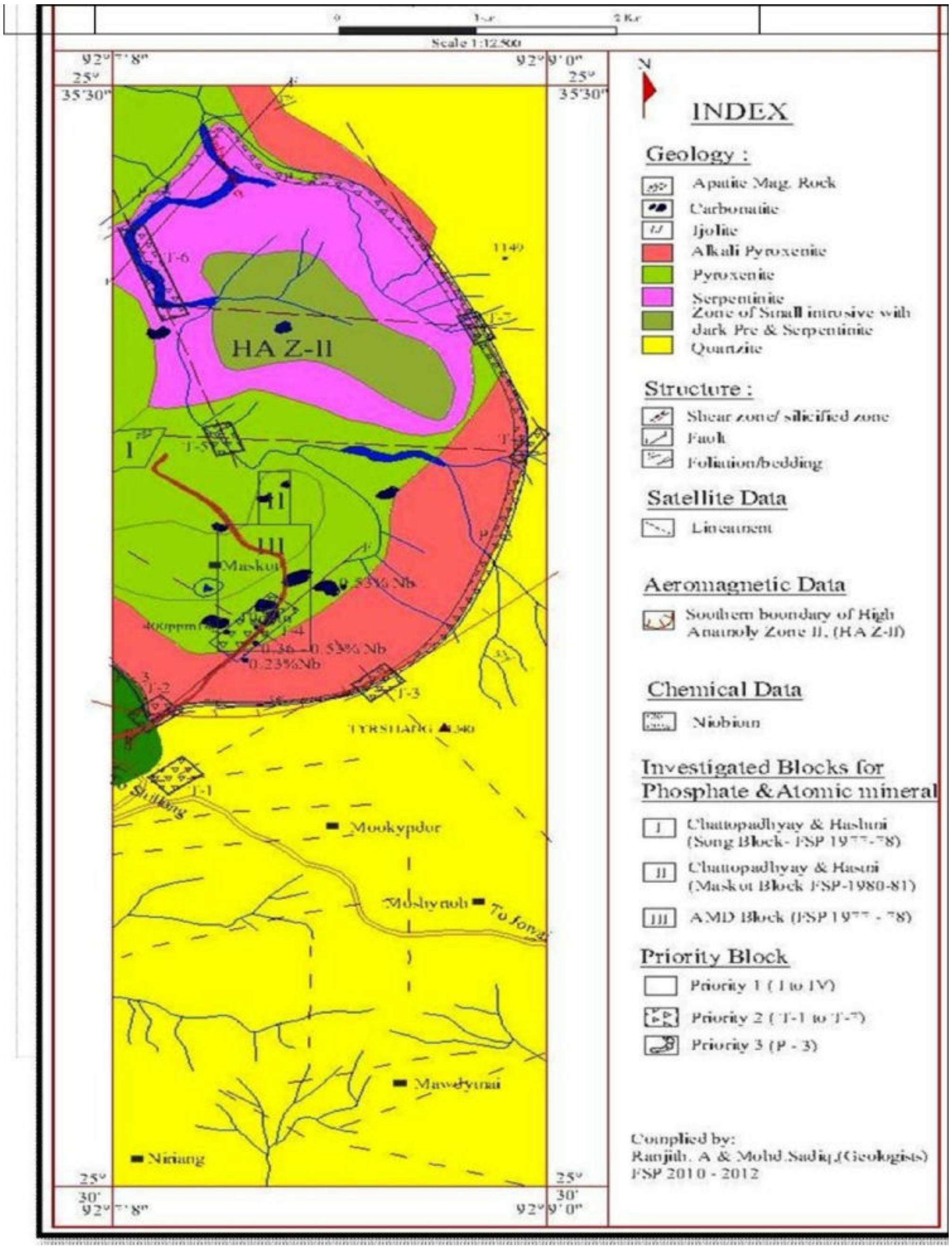


Figure 1.3: Integrated pre-field geological map of the study area (Based on Remote sensing, aeromagnetic, drilling and available chemical data) in parts of SOI Toposheet no 83 C/2.

1.10 Acknowledgement

The authors express their sincere thanks to Dr. T. Kannadasan, Director MMIP-I & RMH, GSI, NER and Shri J.C. Dutta, Director, MMIP-II, GSI, NER, Shillong for their constant guidance, support, keen interest, useful suggestions, critical review and also discussions and encouragement during the course of field work.

With due reverence, we are thankful to Shri U. K. Behara, DDG & HOD, GSI, NER, Shillong, and Shri P.B. Sarolkar, Director, PSS, GSI, NER, Shillong for providing various facilities to carry out the item successfully.

We would like to express my sincere gratitude to all Officers of MMIP, GSI, NER Shillong for their help and valuable timely suggestions on technical matters.

We particularly acknowledge our indebtedness to Shri M.A. Khongala, Ms Sougrapam Sujata & Ms. Imlishila Imchen, Geologists MGP-STM for discussion in the field and on the occurrence of carbonatite in Jaintia Hills District, Meghalaya.

Thanks are also due to the Directors of the associated laboratories viz; Petrology Division, Geodata Division and Chemical Division, GSI, NER, Shillong, Central Chemical Laboratory, GSI, Kolkata and PPOD Lab, GSI, SR, Bengaluru for providing assistance in completing this work on time.

We would like to acknowledge Atomic Mineral Department, NER, Shillong for technical consultation and guidance to complete the FSP successfully.

CHAPTER-II: REGIONAL GEOLOGY

2.1 General

The Shillong plateau is an uplifted horst-like feature covering an area of about 40000 km^2, bounded on all sides by major structural discontinuities (Figure. 4) viz. by the E–W trending Dauki and Brahmaputra fault systems in the south and the north, respectively. The west and the east sides are bordered by the N–S Jamuna fault system and the NW–SE trending Kopili fault. Other N–S trending structures that also traverse the Shillong Plateau are the Nongchram fault (Nambiar and Golani, 1985; Gupta and Sen, 1988; Golani, 1991) and Um Ngot lineaments (Gupta and Sen, 1988). On the basis of Landsat images and aerial photographs, Gupta and Sen (1988) observed that N–S trending Um Ngot lineament cuts across the general NE–SW trend of the Shillong Plateau. This lineament developed during the late Jurassic–early Cretaceous times. Gupta and Sen (1988) further stated that the Um Ngot lineament contains several alkaline intrusive bodies, including the Sung Valley complex, and is genetically related to the Ninety-East Ridge in the Indian Ocean. The plateau consists of rocks ranging from Archaean gneisses to Tertiary sediments. Several granite plutons (700–450 Ma) also intrude the gneissic basement as well as the Shillong Group of rocks. Small bodies of metamorphosed mafic igneous rocks are also reported (Mazumdar, 1976; Ghosh et. al., 1994). The Sylhet Trap, a part of the Rajmahal– Sylhet flood basalt province, are well exposed in the southern part of the plateau and are considered to be associated with the Kerguelen mantle plume (Storey et. al., 1992). The SUACC of the Shillong Plateau are also inferred to be associated with the Kerguelen Plume (Veena et. al., 1998; Ray et. al., 1999, 2000). The Sylhet Traps, a part of the Rajmahal-Sylhet flood basalt province, are well exposed in the southern part of Meghalaya.

2.2 Regional Geology

The state of Meghalaya is occupied by rocks belonging to (a) Archaean (?) – Proterozoic age (b) Khasi basic – ultrabasic intrusives of Proterozoic age (c) Shillong Group of metasediments of Meso-Proterozoic age (d) Granite Plutons viz. Kyrdem, Nongpoh and Mylliem Granite Plutons and South Khasi batholith of Neo-Proterozoic – Lower Proterozoic age (e) Lower Gondwana sedimentary rocks of Carboniferous – Permian age (f) Cretaceous volcanic rocks represented by Sylhet Trap and Cretaceous *SUACC* (g) Tertiary shelf sediments and (h) Pleistocene to recent fluvial sediments.

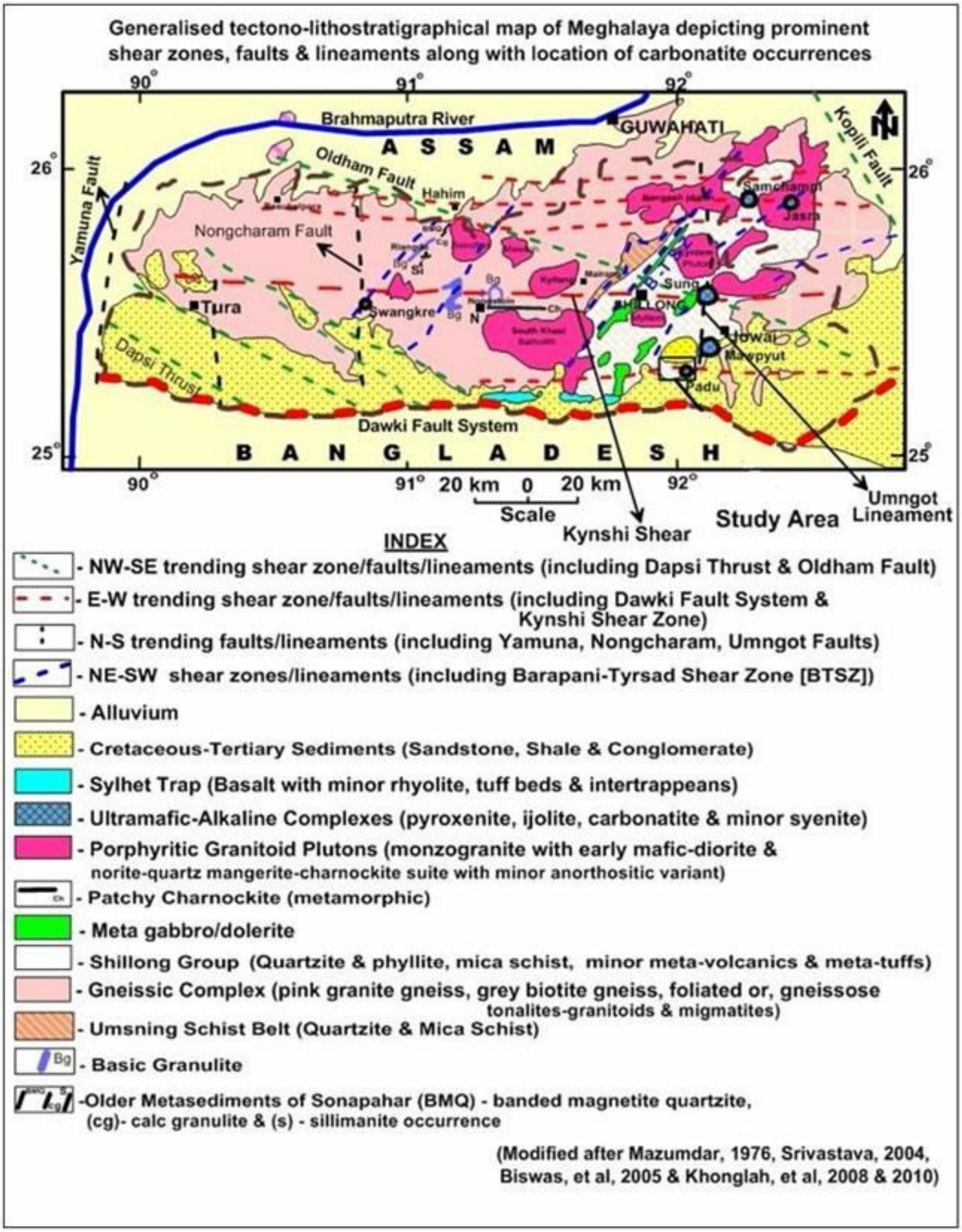


Figure 4: Generalised techno-lithostartigraphical map of Meghalaya

Table-3 : Generalized stratigraphic succession of Meghalaya

Age	Group	Formation	Lithology
Recent	Newer Alluvium	Unclassified	Sand, silt & clay
Pleistocene	Older Alluvium	Unclassified	Sand, clay, pebble & Boulder deposits
~~Unconformity~~~~~~~~~~~~~~~~~~~			
Mio-Pliocene		Dupli Tila (1050m)	Mottled clays, sandstone & conglomerate
~~Unconformity~~~~~~~~~~~~~~~~~~~			
Oligocene-Miocene	Garo Group	Chengapara (700m)	Coarse sandstone, siltstone, clay & marl
		Baghmara (530m)	Coarse feldspathic sandstone, conglomerate, clay, silty clay with a fossiliferous limestone horizon at the top.
		Simsang (1150m)	Siltstone & fine sandstone and alterations of siltstone-mudstone
Eocene - Oligocene	Barail Group	………………..	Coarse sandstone, shale, carbonaceous shale with streaks and minor lenses of coal
Paleocene-Eocene	Jaintia Group	Kopili (50m)	Shale, sandstone, marl & coal
		Shella (600m)	Alternations of sand - stone and limestone
		Langpar (100m)	Calc. shale, sandstone & Limestone.
Upper Cretaceous	Khasi Group	Mahadek (150m)	Arkosic sandstone (often glauconitic & uraniferous)
		Conglomerate (25m)	Conglomerate
		Jadukata (140m)	Conglomerate/sandstone
~~Unconformity~~~~~~~~~~~~~~~~~~~			
Cretaceous	Ultramafic-Alkaline-Carbonatite Complex of Sung	………………….	Pyroxenite- serpentinite, with abundant development of melilite pyroxene rock, ijolite, syenite & carbonatite
~~Unconformity~~~~~~~~~~~~~~~~~~~			
Cretaceous	Sylhet Traps		Basalt, alkali basalt, rhyolite & acidic tuffs
~~Unconformity~~~~~~~~~~~~~~~~~~~			
Carboniferous – Permian	Lower Gondwana	Karharbari	Very coarse to coarse grained sandstone with conglomerate lenses, siltstone, shale, carbonaceous shale & coal
		Talchir	Basal tillite with sand - stone bands, siltstone & shale
~~Unconformity~~~~~~~~~~~~~~~~~~~			
Neo Proterozoic –		Granite Plutons:	Porphyritic coarse granite, pegmatites, aplite/quartz veins traversed by epidiorite, dolerite and basalt dykes
		Kyrdem Granite Pluton (479± 26 Ma)	
		Nongpoh Granite (550± 15 Ma)	
		Mylliem Granite (607±13 Ma)	

Early Proterozoic		South Khasi Granite (690± 26 Ma)	
---Intrusive Contact--------------------------------------			
Proterozoic	Khasi Basic-ultrabasic intrusive	………………….	Epidiorite, dolerite amphibolites, pyroxenite dykes and sills
Palaeo-Meso-Proterozoic	Shillong Group	………………….	Quartzite, phyllite, Quartz sericite- schist, conglomerate
Archaean (?)-Proterozoic	Meghalaya Gneissic Complex		Bio, Hb, Granite gneisses, mica, sillimanite - quartz schist, biotite-granulite-amphibolite, pyroxene-granulite, gabbro & diorite

2.3 Sung Valley Complex (An Overview)

The Sung Valley Complex was emplaced within the Proterozoic Shillong Group of rocks, located within the Shillong Plateau (Figure. 4). Krishnamurthy, 1985; Viladkar et. al., 1994; Srivastava and Sinha, 2004 have described the geology of the SUACC, which consists of pyroxenite, serpentinized peridotite, melilitolite, ijolite, nepheline syenite and carbonatite (Figure. 5). Pyroxenite encloses serpentinized peridotite and represents the oldest rocks of the complex. Ijolite forms a ring structure. These three rock types form a major portion of complex, other rock units constitute less than 5%. Melilitolite occurs as small dykes and intrudes the peridotite and pyroxenite. Nepheline syenite occurs in the form of dykes and veins, which intrude ultramafic units as well as ijolites (cf. Krishnamurthy, 1985). Carbonatite is the youngest member of the complex as it intrudes all the units and occurs as small dykes, veins and oval shaped bodies. Here, it is important to mention that peridotites are severely affected by extensive alteration due to post-magmatic hydrothermal activity; so fresh exposures of peridotite and primary mineralogy are rarely preserved. SUACC shows a wide range of ages, between 90 and 150 Ma. The 106 ±11 Ma Rb–Sr and 107.2± 0.8 Ma 40Ar/39Ar dates reported by Ray et. al. (1999, 2000) are the most precise.

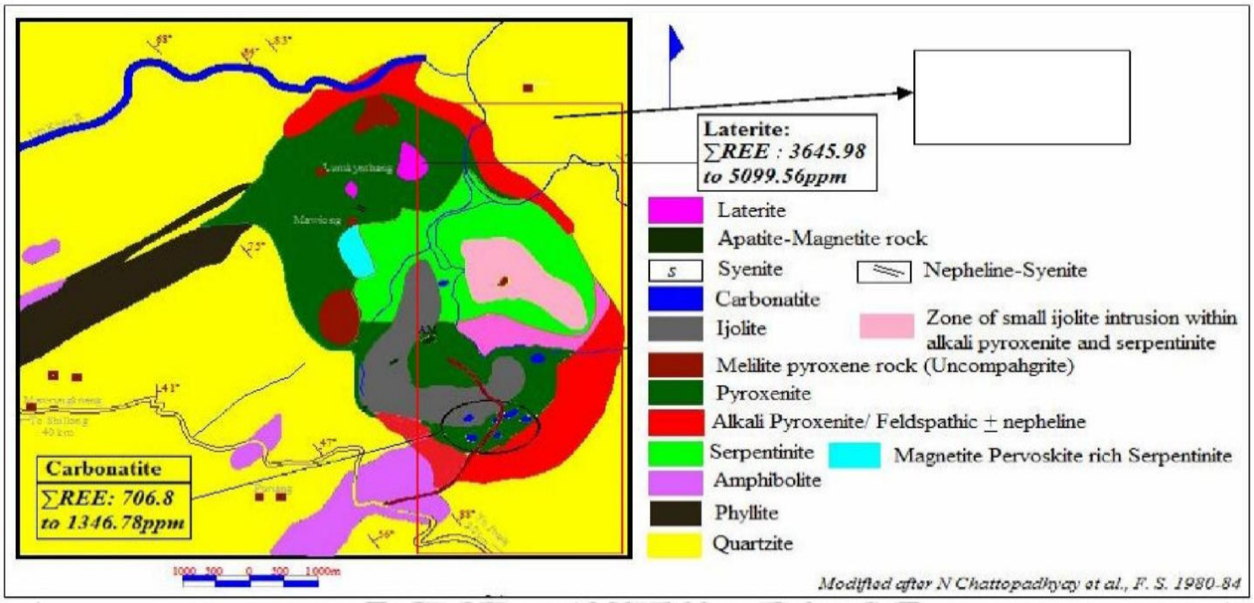


Figure 5: Sung Valley Ultramafic-Alkaline–Carbonatite Complex (SUACC), East Khasi and Jaintia Hills Districts, Meghalaya

CHAPTER-III: GEOLOGY OF THE AREA

3.1 Geology of the Study Area

During the FSP 2010-2012 an area of 30 Km^2 that was mapped on 1:12,500 scale is located in parts of SUACC and the Shillong Group of rocks (Figure.6) in East Khasi and Jaintia Hills Districts, Meghalaya. The objective of the work was to identify and classify different litho units, their contact relationship with adjacent lithologies and locating potential areas and zones that may host REEs. The area comprises mainly of Middle Proterozoic (?) Shillong Group of rocks, amphibolites (Older Intrusive) as well as rocks of Sung Intrusive Complex. General stratigraphic sequence of the area is as follows:

Table- 4: Stratigraphic sequence of the studied area (Modified after Gogoi, 1973)

Quaternary Tertiary	Jaintia Group	Alluvium Sylhet Sandstone
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~		
Cretaceous	Younger Intrusives	Sung Valley Alkaline- Ultramafic- Carbonatite Complex

	Older Intrusives/ Khasi metabasic	Granite, amphibolite/ epidiorite
Mid. Proterozic (?)	Shillong Group	Thick alternations of massive quartzite/ phyllitic quartzite with occasional thin bands of conglomerate (10 Cm to 1 m)
Archaean Basement		(Not Seen)

3.2 Lithological Ensemble

3.2.1 Shillong Group

In the area of investigation, the Shillong Group consists dominantly of quartzite, phyllite quartzite and thin horizons of intraformational conglomerate.

Quartzite

Quartzite is the dominant rock type, which comes in direct contact with the amphibolite and intrusive rocks of the SUACC. Quartzite generally shows variation in grain size, massive and with various degrees of recrystallisation in eastern and south eastern part. In northern part, it is very coarse grained to gritty with white to reddish white (due to iron stains) in colour and feebly recystallised. Compositionally, it is moderately to highly recrystallised quartz arenite with minor amount of alkali feldspar and occasional flakes of mica. Feldspar, magnetite and amphibole are commonly found in quartzite near the contact with amphibolite and with rare occurrence of pyroxenes (aegirine- augite?), when quartzite is in contact with pyroxenite, exhibiting a greenish appearance.

Phyllite Quartzite

In the eastern part of the area exposures of phyllite quartzite are observed. It is off white, light grey to grayish brown in colour, fine to medium grained, soft with well-developed foliation but at places it is crudely foliated. Along with the quartz, it is rich in micaceous minerals (muscovite and biotite).

Conglomerate

Thin bands of conglomerate are observed west of Moo Kyndoor village and in the northern part of the area. Near Moo Kyndoor, conglomerate consisting of sub-rounded to sub-angular, clasts of vein quartz and quartzite that vary in size from 2-5 cm across, embedded in siliceous matrix. However, near Byrthap village, thin bands of conglomerate are observed consisting mainly of quartz clasts, ranging in size from 1 cm to 4 cm across.

3.2.2 Older Intrusive

Granite

Toward the northern and north-eastern part of the complex, around Lyrnai, Sapoh, Nongkroh and Thadmassum upto Nartiang, very coarse grained, pink, porphyritic granite occur as intrusive within the Shillong Group of rocks.

Amphibolite

Large intrusive amphibolite body occupies the north-western part of Puriang. This amphibolite body varies widely in its physical characteristics and occurs dominantly conformably within the quartzite-phyllite of the Shillong Group but locally discordant relation is also observed (Chattopadhyay & Hashimi, 1977-78). Amphibolite bands show wide variation from being very little metamorphosed to foliated hornblende schist, but generally they are well foliated showing sub rounded clots of amphibole having a size of 4-6 mm across within a coarse-grained hornblende - feldspar matrix that is similar to augen structure. Quartz is abundant and biotite, apatite and opaques are the common accessory. At places amphibolite shows cumulate texture, completely made up of hornblende and may be called as hornblendite. A thin silicified zone is observed in the amphibolite with veins of epidote and secondary quartzo-feldspathic minerals.

3.2.3 Sung Valley Ultramafic-Alkaline–Carbonatite complex (SUACC)

Pyroxenite

Pyroxenite, the most dominant rock type of the Sung Valley Complex, generally occurs in the marginal part and comes in direct contact with the quartzite. It also occurs in the central part and is intruded by all the other rock types of the complex, except serpentinite and peridotite. Pyroxenite varies in grain size with the fine grained type in the marginal part to coarse grained type in the central part of the complex. In the central part pyroxenite is generally dark, greenish black to black in colour and massive consisting dominantly of diopsidic augite in cumulus pyroxenite with individual pyroxene grain measuring upto about two centimetres across. Hornblende and biotite occur as secondary, whereas sphene and magnetite as accessory minerals.

Under microscope, the rock is very coarse grained and almost monomineralic dominantly consisting of clinopyroxene with rare occurrence of orthopyroxene. Pyroxene grains are discrete, short, prismatic and euhedral with cumulate texture. They are pleochroic from light greenish yellow to dark green. The interstitial spaces are occupied by feldspar (?) which appears to have crystallized from residual liquid. Pyroxene also contains inclusion of euhedral apatite. Phlogopite is rare and is present along the border of hornblende grains. Sphene and carbonates occur as accessory and secondary minerals respectively in pyroxenite.

Peridotite

Peridotite is an important and rare member of the Sung Valley Complex and is exposed only in Sung nala and is traversed by numerous veins of pyroxenite and carbonatite. It is coarse grained with only olivine. Veins of serpentinite occur along cracks and cleavage planes with clinopyroxene, phlogopite and few opaque grains of which magnetite is most abundant.

Serpentinite

Serpentinite is one of the very common rock type of the complex and occurs in the central and eastern periphery of the SUACC. It contains veins of pyroxenite and is considered as an alteration product of peridotite. The rock consists dominantly of serpentine with magnetite and perovskite indicating an alkaline nature of the primary magma. Relict olivine is rare but relict clinopyroxene are present between grains of serpentinised olivine. Opaques are both large and small.

Ijolite

Ijolite is the third most abundant rock type developed within the Complex. It is medium to very coarse grained and shows wide variation of texture and granularity. Primarily it constitutes of nepheline, pyroxene with garnet and apatite with sphene as the main accessory. Nepheline occurs as coarse, pinkish, smoky black, subhedral to anhedral grains. Pyroxene is represented by aegirine - augite that are prismatic. These prismatic pyroxene grains and nepheline sometimes show "comb structure" which is again a characteristic feature of Ijolite within the Complex. In thin section, subhedral to anhedral nepheline and prismatic aegirine - augites are seen in almost equal amount. Calcite, apatite and magnetite are the common accessory minerals.

Carbonatite

Carbonatite though very minor in abundance, it is one of the important rock type of the Complex and occurs as dykes, lenses and veins. Such bodies are circular to semicircular in shape. Isolated carbonatite bodies (mainly trending NW-SE) were demarcated in and around Maskut & Sung villages in SUACC. The rock is milky white to off white in colour, coarse grained, consisting dominantly of calcite. Enclaves of pyroxenite within carbonatite are also observed (Plate-20). Calcite grains are subhedral and they often form mosaic. Some of the calcite grains are perfectly euhedral indicating primary crystallization. Carbonatites are mainly of "sovite" variety, coarse grained and consists of calcite, apatite, phlogopite, magnetite, olivine (fosterite), perovskite and pyrochlore with rare occurrence of pyroxenes. It exhibits an interlocking mosaic of coarse, anhedral calcite with nets and disseminations of prismatic needle shaped apatite and coarse magnetite grains. Magnetite veins upto 4-6 cm thick are seen in carbonate. Veins of carbonate are common in pyroxenite, serpentinized peridotite/peridotite.

Main mineral phases identified in carbonate sections by EPMA study include; calcite, dolomite, apatite, magnetite, pyrochlore, magnetite, phlogopite, olivine, haematite, pyrrhotite, barite, baddeleyite and very rare occurrence of monazite.

Apatite – magnetite rocks

Apatite - magnetite rock occurs as veins, lenses and fracture - fillings within the pyroxenites. It is coarse grained, consist mainly of calcite with significant quantity of apatite along with olivine, phlogopite, pervoskite, pyrochlore, with some spinels. Besides the above rock types, mellilolite and nepheline syenite was also reported in the complex by the earlier workers.

3.2.4 Tertiary Sandstone

Near Mookyndur, a small patch of Tertiary sandstone unconformably overlies the Shillong Group of rocks i.e. phyllitic quartzite. It is dark grey to off white in colour and medium grained.

3.3 Structures

3.3.1 Sedimentary Structure

Bedding is the only primary structure observed occasionally in the quartzite of the Shillong Group and in the Tertiary sandstone, defined by colour and compositional banding. The strike of the bedding is along NE - SW with a moderate dip towards northwest in quartzite and NW-SE trend with very gentle dip towards northeast in Tertiary sandstone. Towards the contact with the complex, the dip is very steep (near vertical) suggesting forceful intrusion of the Complex. Current bedding is observed in Tertiary Sandstone.

3.3.2 Foliation

Foliation is well developed in phyllitic quartzite, having NE-SW trend with moderate dip ranging from 28° to 40° towards northwest.

3.3.3 Angular unconformity

About 0.5 to 1m thick polymictic conglomerate band is exposed within quartzite about 2Km west and northwest of Puriang near Moo Kyndur. Pebbles are 2-4 cm across, sub- rounded and are made entirely of recrystallised quartzite with vein quartz material. The Tertiary sandstone forms sub-horizontal capping over phyllitic quartzite of the Shillong Group and transitional zone of schists, with a pronounced erosional unconformity near Mookyndur. Overlying Tertiary sandstone exhibits NW-SE trend with gentle dip (8°) towards northeast, whereas underlying quartzite shows NE-SW foliation plane with moderate dip (40°) towards NW (Plate-4).

3.3.4 Lineaments/faults

Two NE-SW faults/lineaments were marked by the earlier workers (Chattopadhyay and Hasimi et. al, 1977-78) one is along the Sung nala just to the north of Sung Block and another through the Maskut Block. But definite field evidence is not available for attributing these lineaments to any major dislocation.

Three sets of geomorphic lineaments were traced from the satellite imagery a) E-W b) NW-SE c) N-S to NE-SW. No penetrative structural element is recognisable in the area along the lineaments.

Irregular, closely spaced and randomly oriented fractures, filled by later anastomosing veins of carbonatite, apatite-magnetite rock and mica have been noticed in pyroxenite along Sung nala.

3.3.5 Secondary silicified zones/silicified zones/ shear zone

1) A N10°E-S10°W trending secondary silicified zone (about 20m long and 10-12m wide) mainly comprising of quartz veins (up to 6 cm thick) with parallel epidote veins with oriented amphibole needles, is exposed on the way to Byrthap village within amphibolite. Further north, near the contact of quartzite and pyroxenite (*N25°32'45.20"; E92°07'28.50")*, displacement in quartz

veins and oxidized pegmatitic material are observed that supports shearing in this part of the study area (Plate-6).

2) A NW-SE trending silicified zone/quartz vein (25x100m) is observed in the south eastern part of the area in the Shillong quartzite. No mineralization is observed.
3) A NE-SW trending silicified/brecciated zone, syenitic in composition marks the southwestern part of the Sung Intrusive Complex (Plate-12).

No significant mineralization is however observed with naked eye in these zones.

3.3.6 Volcanic/Relict Structure

Enclaves or caught up patches of pyroxenite in carbonatite and apatite magnetite rock were identified. Xenocryst/volcanic structure (pillow/lobes /bombs? or xenocryst) are observed in the carbonatite near Muskut area (Plate-22).

3.4 Metamorphism

No contact metamorphic effect is observed due to intrusion of the complex. However a narrow zone of fenite and a brecciated zone of mixed fenite and quartzite have developed at places, particularly along the peripheral part of SUACC.

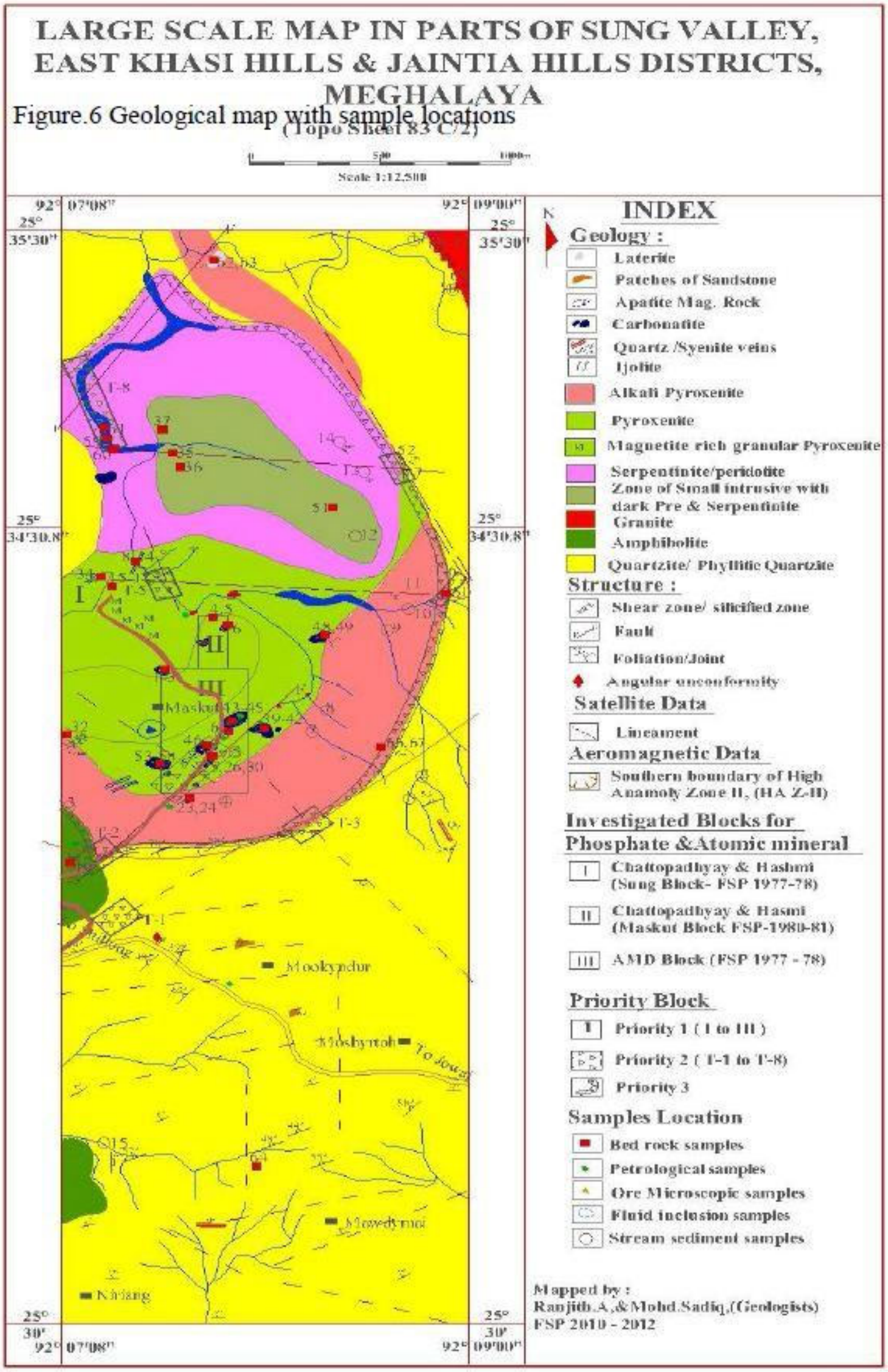


Figure 6: Geological map with sample locations

CHAPTER-IV: SAMPLING

4.1 Bed Rock Sampling (BRS)

In order to understand and assess the nature of REE mineralization a total of 74 Bed Rock Samples for REE analysis were collected from carbonatite, pyroxenite, ijolite, serpentinite/peridotite, veins of carbonatite within pyroxenite/peridotite, apatite-magnetite rock exposed in SUACC, older basic Intrusives, granite and the Shillong Group of Quartzite. Few samples were also collected from the laterite developed over the pyroxenite to test the potentiality of laterite as host of REE. BRS samples were also collected from kaolinite developed over ultramafic rocks, near Mawrenkyning village.

Rock samples were powdered, homogenised and prepared in duplicate after coning and quartering. One set of samples is submitted to chemical laboratory for analysis and one set is kept for preservation (Appendix-I). All the samples were analysed by ICP-MS in Central Chemical Laboratory, GSI, Kolkata (Annexure-II). Grab samples were collected from carbonatite that occurs as isolated bodies.

A total of 25 samples were collected for whole rock analysis to have a better understanding and in classifying the litho units, particularly carbonatite (Annexure- XIII & XIV).

For PGE analysis, 02 BRS were collected from the serpentinised peridotite/serpentinite and pyroxenite, falling in priority Block-III. Chemical results are awaited.

4.2 Channel Sampling

A total 14 Channel Samples were collected from two isolated carbonatite bodies (C2 & C4) to ensure the uniform quality of material over the entire body and to have representative sample for REE analysis (Appendix-IV & V). Across the strike of the carbonatite bodies channels of 10 X 2.5 X100 cm were made for collection of channel samples. Fixed width of 10cm along the sample line was first cleaned so that the surface undulations are removed as far as possible and for bringing the surface of sample to a uniform level. After cleaning the surface confined to this width, samples were collected at every meter across the strike of the body.

4.3 Stream Sediments Sampling (SSS)

A total 31 Sediment Samples were collected in such a way that the objective of the FSP can be fulfilled completely. Samples were collected from the streams originating from around the periphery of the complex (Priority-3 Block-III) and also from the streams coming/passing through the contacts of different rock types in the area so that the mineralization if any, along the contacts can be targeted. SSS were collected by wet sieving method from the first, second order streams and at confluence of two first order streams (Appendix – VII &VIII).

4.4 Fluid Inclusion (FI) Samples

A total of 23 (+4 resubmitted) Fluid Inclusion samples were collected from different carbonatite bodies and one sample from silicified zone/quartz vein occurring in amphibolite. However, wafers from all the rock samples could not be prepared due to the brittle nature of the rock and only five wafers were prepared and studied at PPOD Lab, Bengaluru. A total 51 inclusions were studied (Annexure-X).

4.5 Petrological Sample

A total 13 rock samples were collected for thin section study to identify and classify the different rock types as well as to search for favourable host minerals for REE (Annexure - X).

4.6 Ore Microscopic Sample

20 rock samples were collected from different rock types in the area to identify the type and nature of mineralization that is described in Chapter - IV (Annexure-XI).

4.7 EPMA Study

A total of 13 rock sample were collected from isolated carbonatite bodies falling mainly in Priority-1 Block-I, II &III and sent to PPOD Lab, Bengaluru for the preparation of sections. EPMA study was carried out to identify the REE phases in the carbonatite as well as to assess the nature and association of mineralization in the carbonatite (Annexure- XII).

4.8 Isotope Analysis

Six samples from carbonatite bodies were collected for Carbon and Oxygen isotopes analysis.

CHAPTER-V: MINERALIZATION

In order to decipher occurrence, type and nature of mineralization 20 polished sections pertaining to pyroxenite, ijolite, carbonatite, apatite-magnetite and amphibolite were studied with special reference to REE and other type of mineralization in the SUACC.

In most of the rock types under study, sulphides are occurring in disseminated and fracture filling/veins form. Apatite & pyrochlore are the main host for REE minerals identified in polished sections. However, main REE phases identified in carbonatite include ancylite, euxenite, britholite associated with calcite and apatite. Appreciable amount of REEs were also analysed in pyrochlore grains associated with magnetite in carbonatite sections. Mineralisation observed in different rock types by ore microscopic studies is summarised below.

5.1 Pyroxenite

In pyroxenite the observed opaques are very small and interstitial and are mostly represented by skeletal magnetite which has a tendency to develop equant outline. A few smaller laths like grains of ilmenite are also present. Numerous small, irregular sulphide grains are present which are represented by chalcopyrite showing intergrowth with pyrrhotite. Sulphides are all interstitial and possibly represent the last phase to crystallise. In coarse grained pyroxenite, subhedral, large and elongated perovoskite grains are observed.

5.2 Ijolite

In ijolite the dominant ore mineral is magnetite occurring as subhedral to anhedral in shape. Such grains are interstitial and are often poikilitic with respect to the silicate groundmass. Maghemitisation is common along irregular patches. Ilmenite grains are few, and are interstitial within silicate phase. The major sulphide phases identified include pyrite, pyrrhotite, chalcopyrite, arsenopyrite and bornite. Coloform banding is also observed in pyrite. Chalcopyrite grains are small rounded in shape and occupy the spaces within silicates.

5.3 Carbonatite

The main opaque mineral is magnetite which is subhedral to euhedral in shape. Few grains of ilmenite occurring as cluster are also observed. Opaques are mainly skeletal and are poikilitic with the carbonate phase. Intergrowth between magnetite and ilmanite is represented by few laths of ilmenite within magnetite. Clustering of apatite grains, occurring as cubic to sub rounded and elongated are also seen. Chalcopyrite, pyrrhotite, pyrite are common sulphide. Pervoskite and pyrochlore are the main host of REE minerals identified in polished section.

5.4 Apatite-Magnetite Rock

Magnetite is the main ore mineral in this rock. Pyrochlore grains are occurring with abundant inclusion of opaque oxide minerals (maghematites?). Smaller crystals of apatite occur close to pyrochlore. Carbonate constitutes the groundmass in the rock. Disseminated grains of pervoskite and bismuthinite in the rock are also noticed. As far as sulphides are concerned, specks and disseminations of pyrite and arsenopyrite are observed.

5.5 Amphibolite

One sample was collected from the silicified zone within amphibolite where magnetite and ilmenite are observed as main ore minerals. Ilmenite occurs as fracture filling / veins and pyrite, chalcopyrite are the common sulphide.

CHAPTER-VI: LABORATORY STUDY

6.1 Bed Rock

During the course of field work, 74 Bed Rock Samples (BRS) were collected from carbonatite, pyroxenite, Ijolite, veins of carbonatite in peridotite/serpentinised peridotite and pyroxenite and apatite-magnetite rock of Sung Valley complex.

All the samples were analysed chemically by ICP-MS in Central Chemical Laboratory, Kolkata. Chemical analysis of 27 BRS collected (Figure.7 & 8) from eleven different carbonatite bodies, falling in Priority-1 Block-I, yielded higher concentration of Σ LREE 660.00 ppm to 1264.85 ppm and Σ HREE 46.80 ppm to 81.92 ppm (Plot-4 &5) as compare to other rock types of the complex, and is followed by the apatite-carbonatite veins occurring in apatite-magnetite rock, pyroxenite (ΣLREE 681.47 to 1003.97ppm and Σ HREE 28.49 to 58.35ppm) and Ijolite (Σ LREE 424.35 to 906.09ppm and Σ HREE 58.19 to 190.80ppm) (Plots 3&4). Besides, three samples collected from apatite-carbonatite veins, NE of Maskut have indicated comparatively higher values of Sn (4.28 to 8.93 ppm), Ta (33.72 to 65.65ppm) W (0.95 to 2.12 ppm) and U (0.89 to 38.46 ppm). During regional traverse two samples were collected from the laterite cappings cappings developed over pyroxenite, Lumkynthang village shows the higher concentration of total rare earth elements viz; ***∑REE** ranges between* ***3645.98 to 5099.56ppm*** *(∑LREE ranges* between *3525. 85 to 4928.46ppm* and *∑HREE* ranges between *120.13 to 171.10ppm)***.**

The following inferences can be drawn from the chemical analysis:

1) Samples from carbonatite, ijolite & pyroxenite show enriched REE concentrations compared to the chondritic values (Evensen et. al., 1978) (Plot-1, 2 & 3).
2) Pyroxenite samples also display a small negative Eu anomaly (Plot-2).
3) The REE patterns for the carbonatite samples are strongly fractionated (Plot-1).
4) High values of total REE reflects the control minerals present in the carbonatites such as apatite, pyrochlore, bastnasite, ancylite etc. (Plot-1).

1) The Sung Valley rocks possibly indicating different origin or magma evolution processes to a first approximation that the REE patterns of pyroxenites, and ijolites could be explained by differentiation of a single magma.

2) Field observations clearly indicate that different magmas with distinct histories may be involved in the generation of the Sung Valley Complex. It seems likely that silicate and carbonatite members of the complex are derived from discrete magma batches.

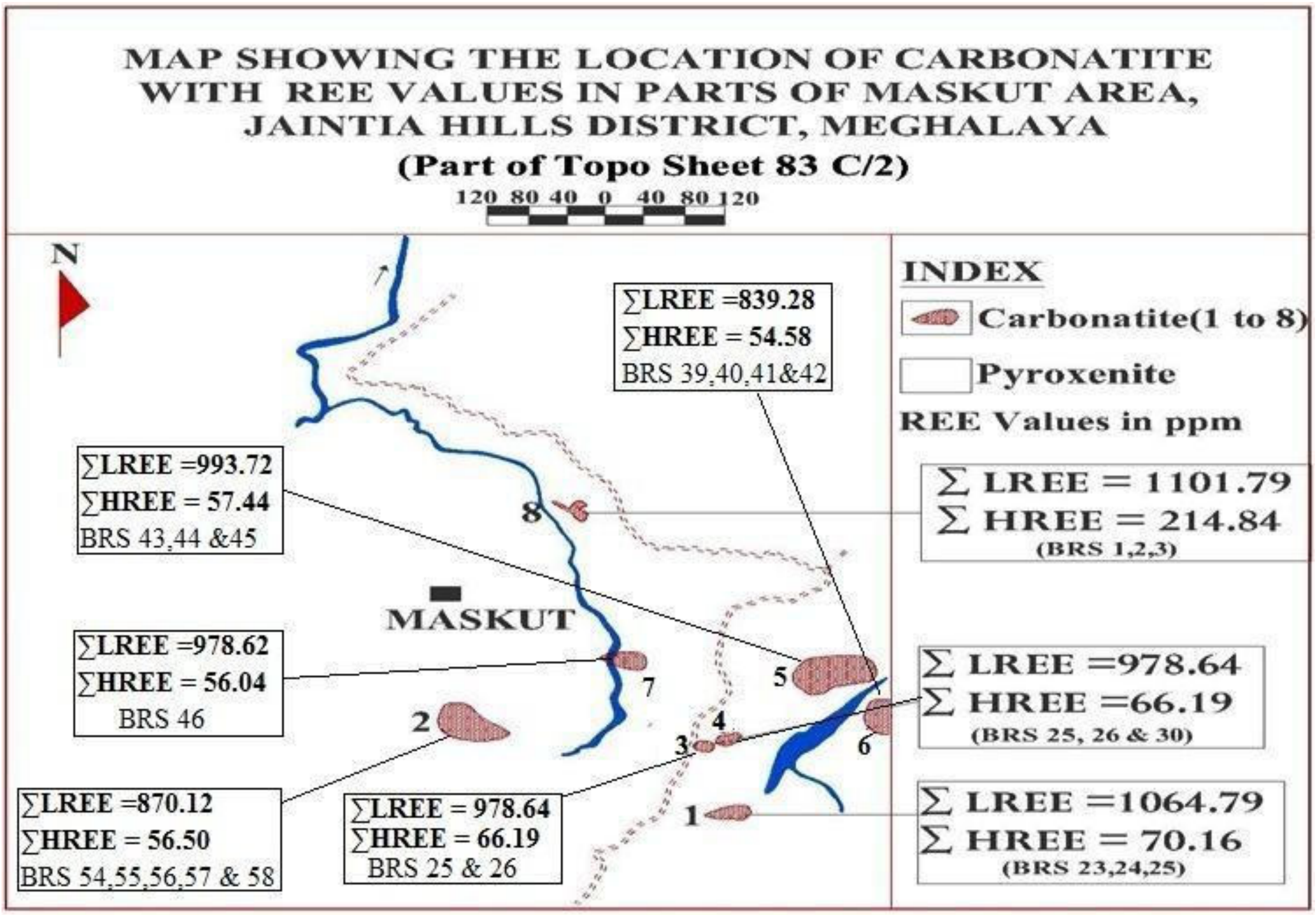


Figure 7: Locations of C1 to C8 carbonatite bodies with average REE concentrations

(Concentration shown in the map is the average concentration of the samples collected)

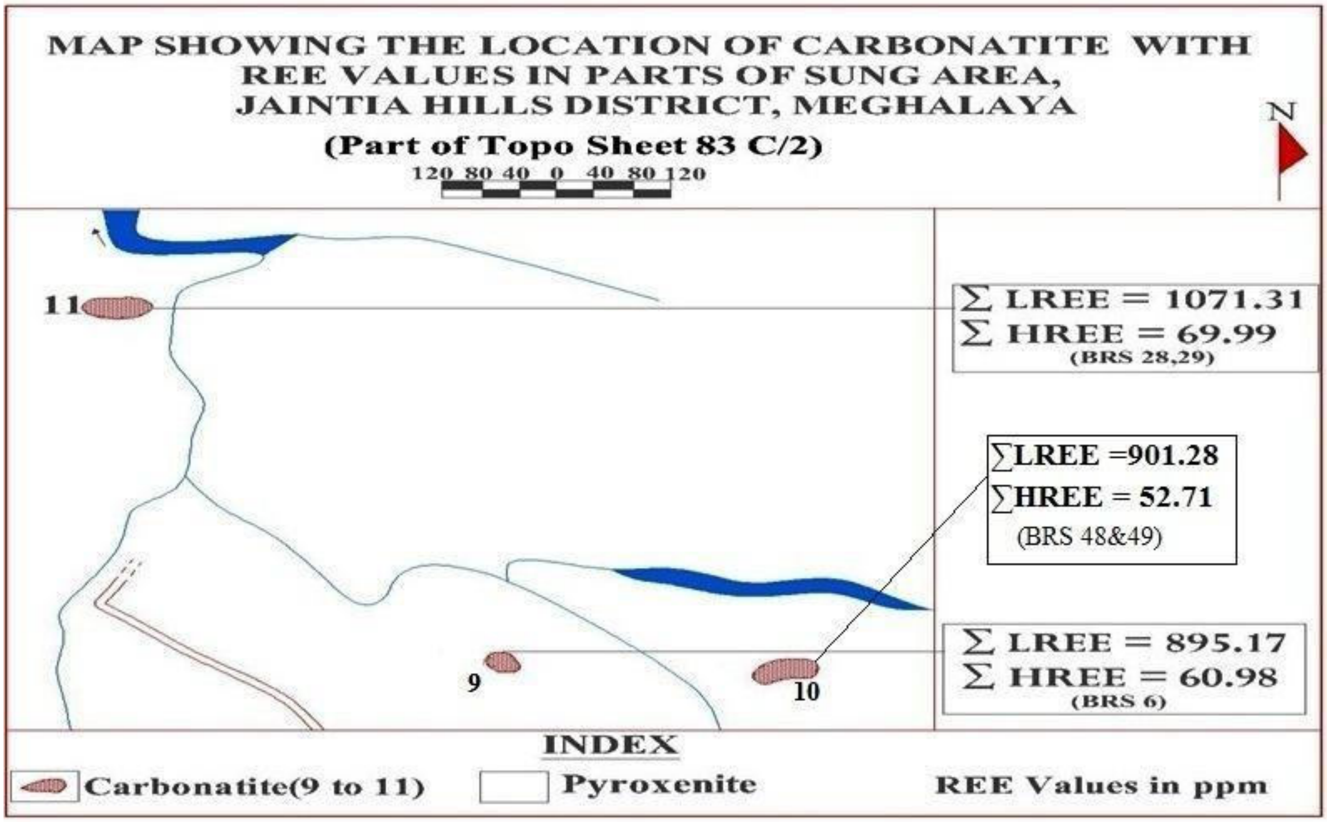
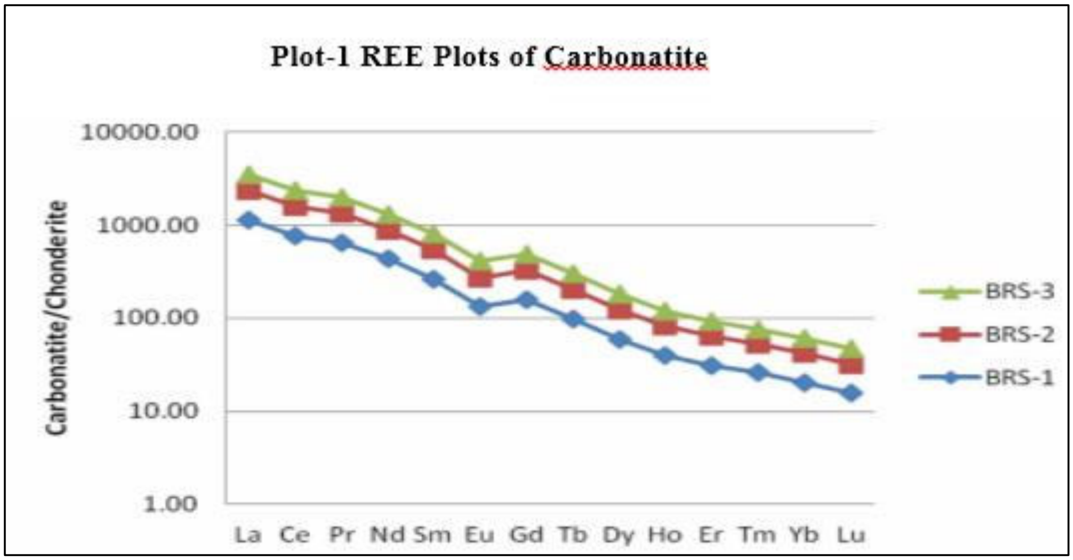
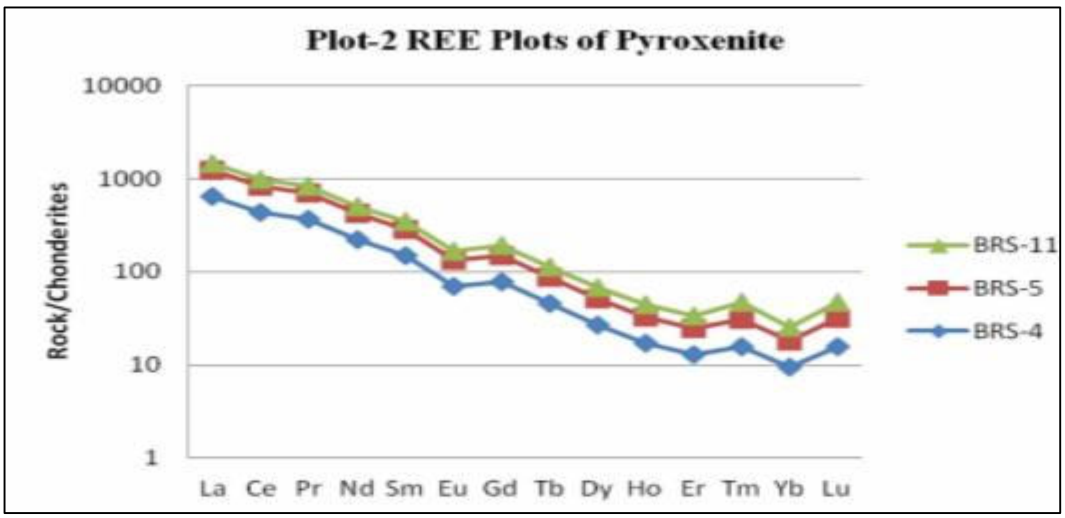
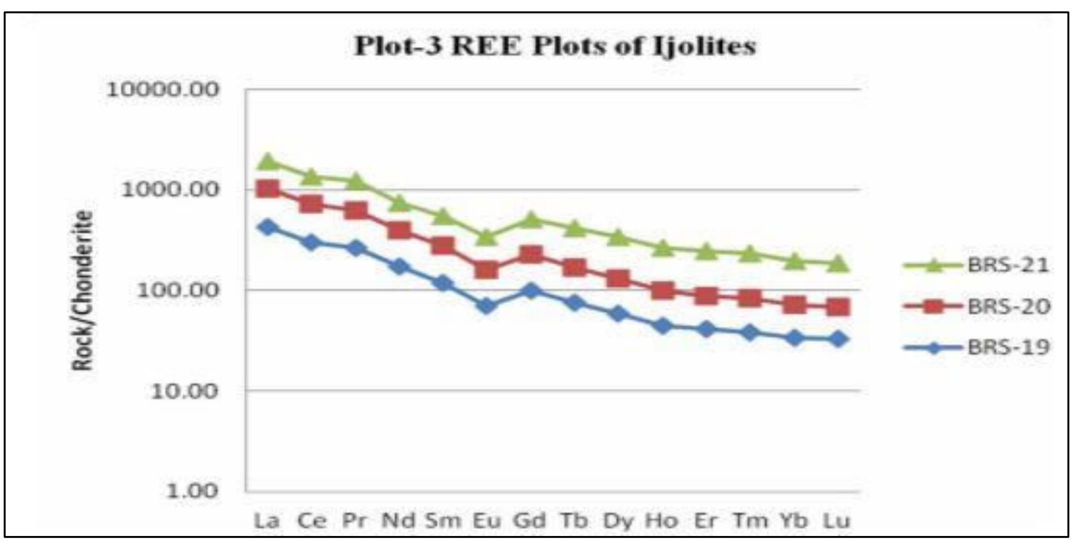


Figure 8: Locations of C9 to C11 carbonatite bodies with average REE concentrations

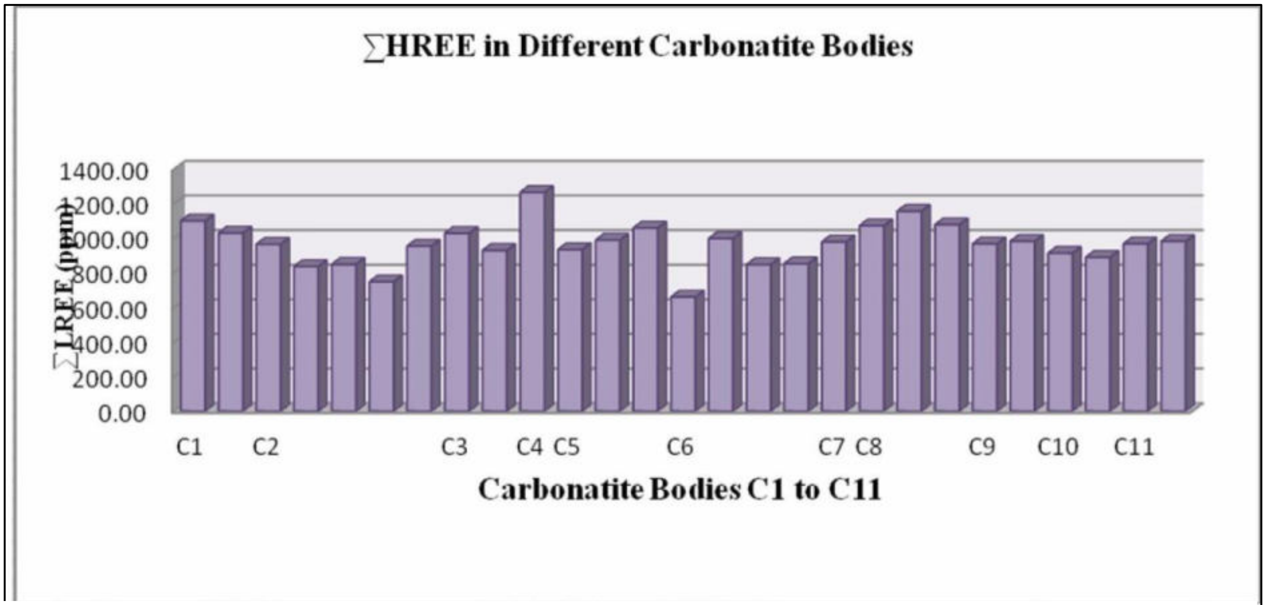
(Concentration shown in the map is the average concentration of the samples collected)


Plot-1 REE Plots of Carbonatite
10000.00
1000.00
100.00
10.00
1.00
Carbonatite/Chonderite
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
BRS-3
BRS-2
BRS-1

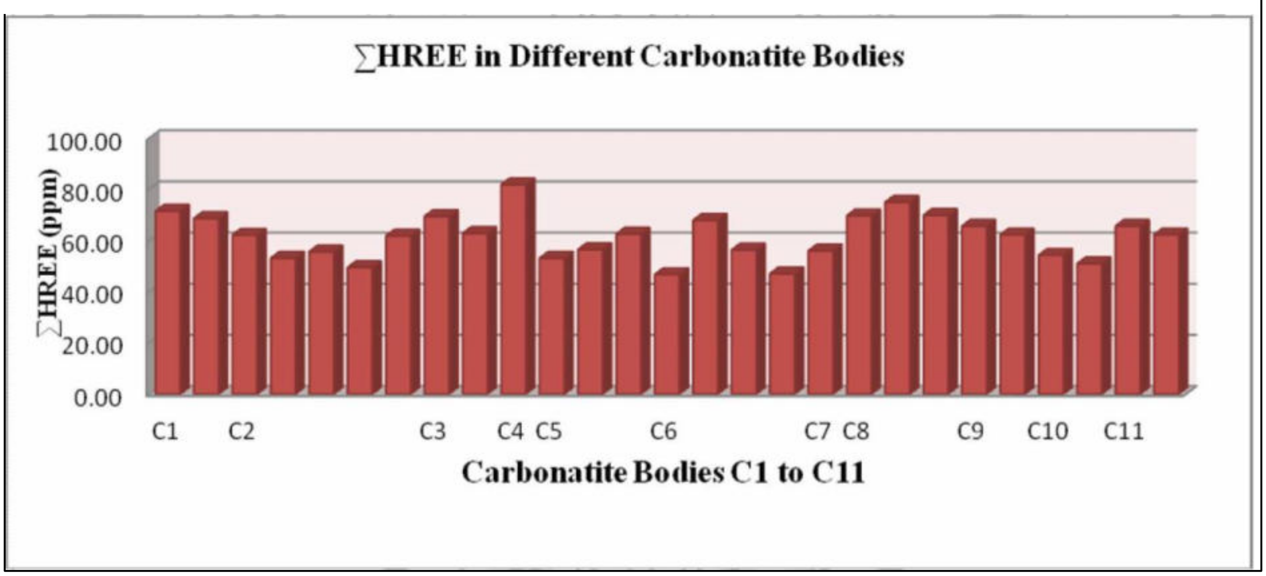

Plot-2 REE Plots of Pyroxenite
10000
1000
100
10
1
Rock/Chonderites
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
BRS-11
BRS-5
BRS-4


Plot-3 REE Plots of Ijolites
10000.00
1000.00
100.00
10.00
1.00
Rock/Chonderite
La Ce Pr Nd Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
BRS-21
BRS-20
BRS-19

Bar Diagram Showing Conc. of ∑LREE and ∑HREE in BRS collected from isolated Carbonatite bodies C1 to C10.

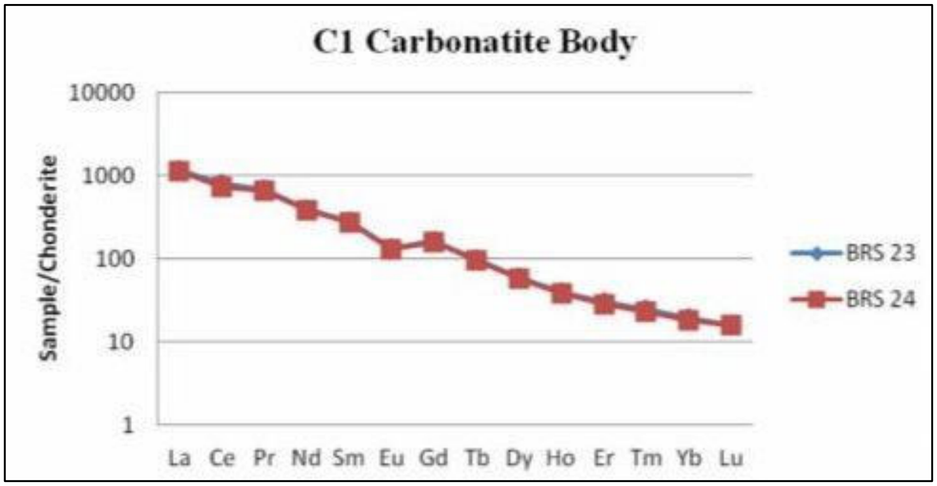


Plot-4 ΣLREE conc. in different isolated bodies ranges between 660 to 1264.85 ppm

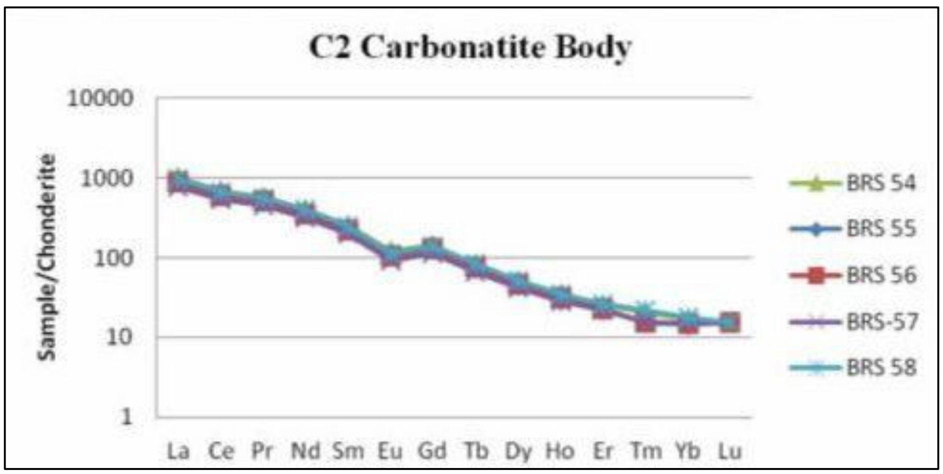


Plot-5 ΣHREE conc. in different isolated bodies ranges between 46.80 to 81.92 ppm

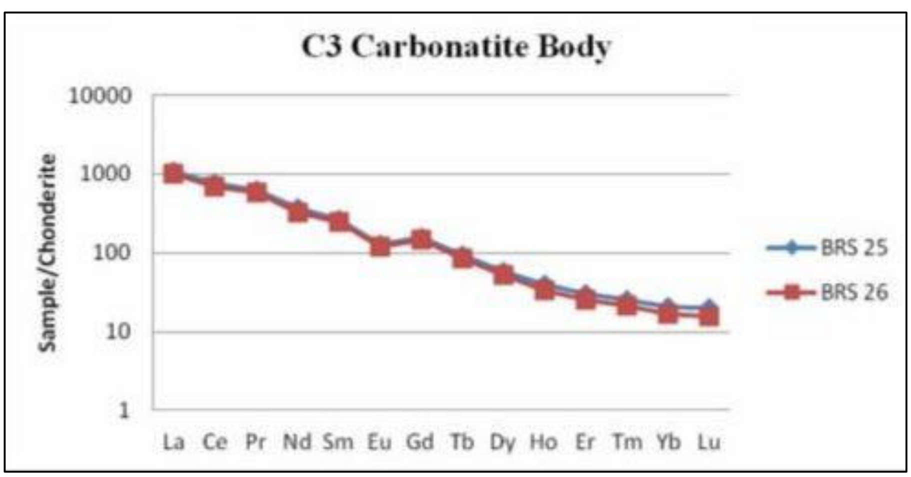
Plots 6 to 16-Sample/Chondrite plots of isolated carbonatite bodies (C1 to C11)



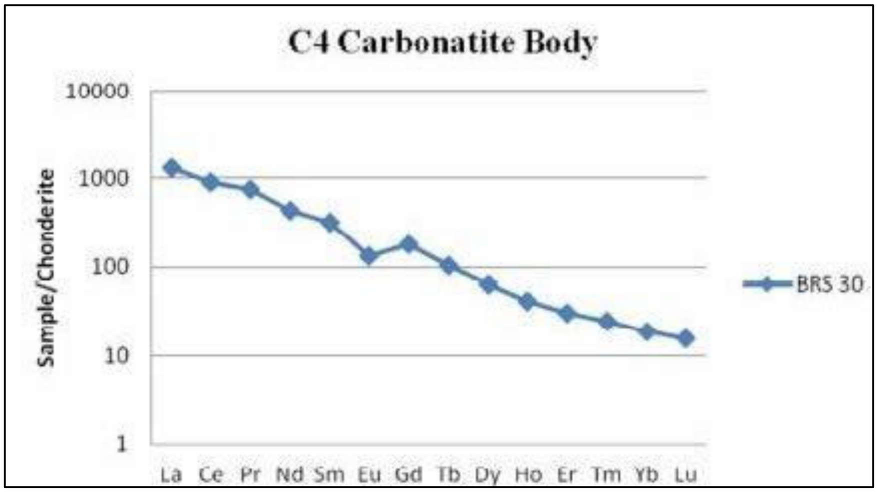
Plot -6



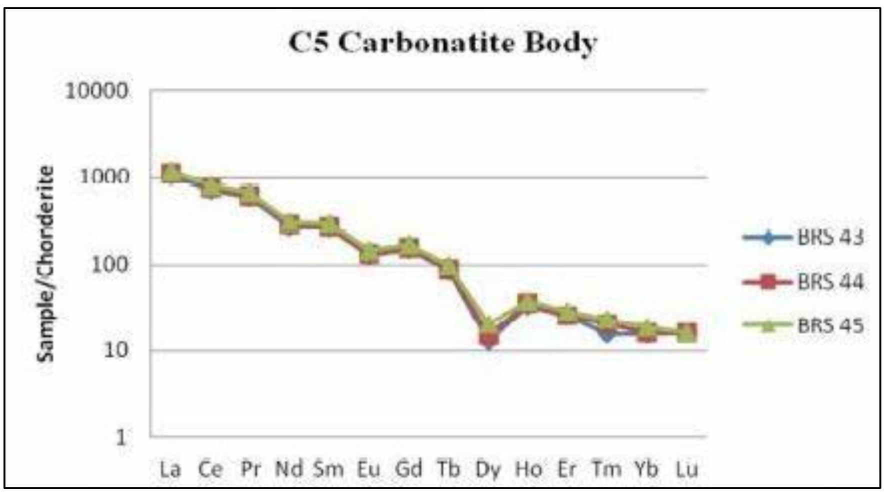
Plot7



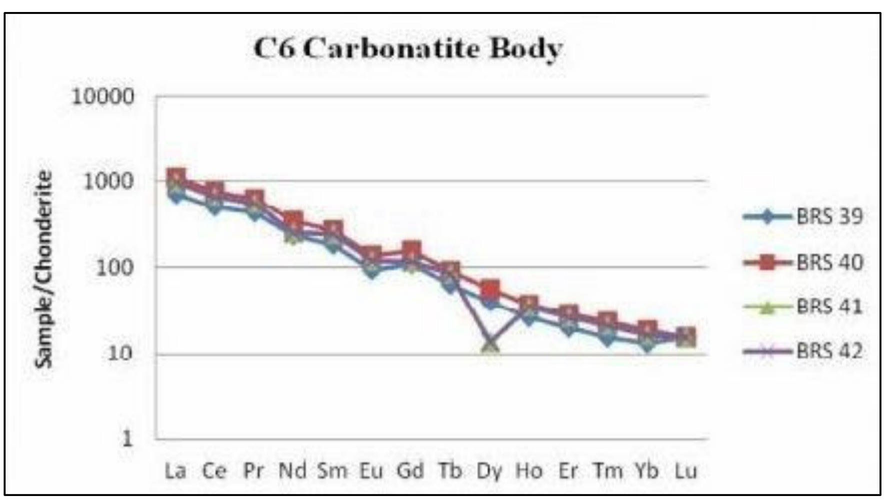
Plot-8



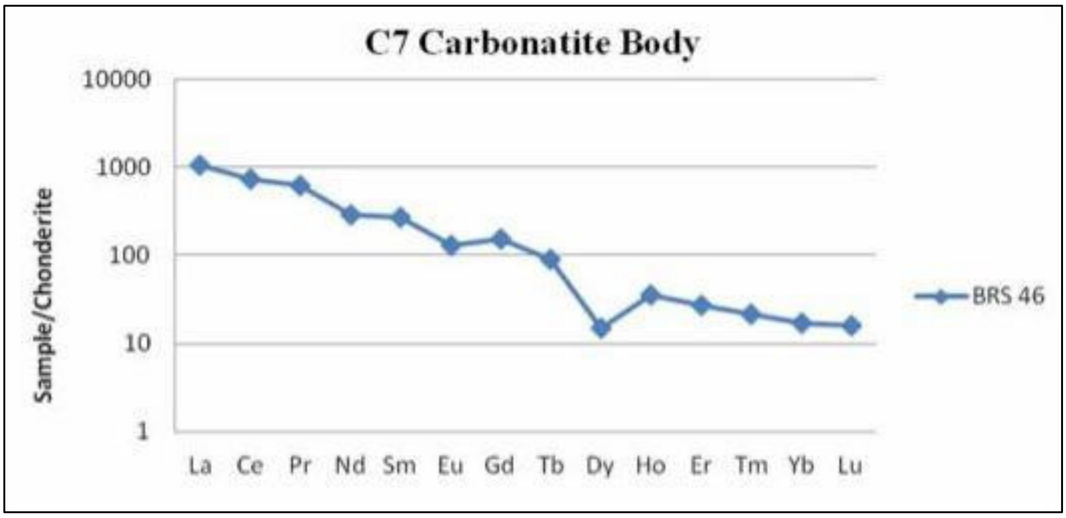
Plot-9



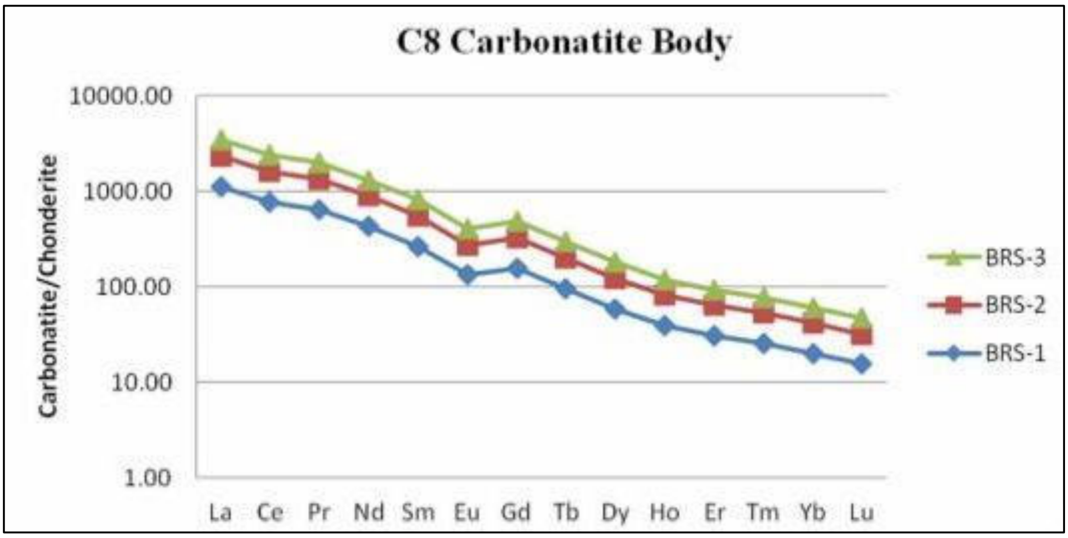
Plot-10



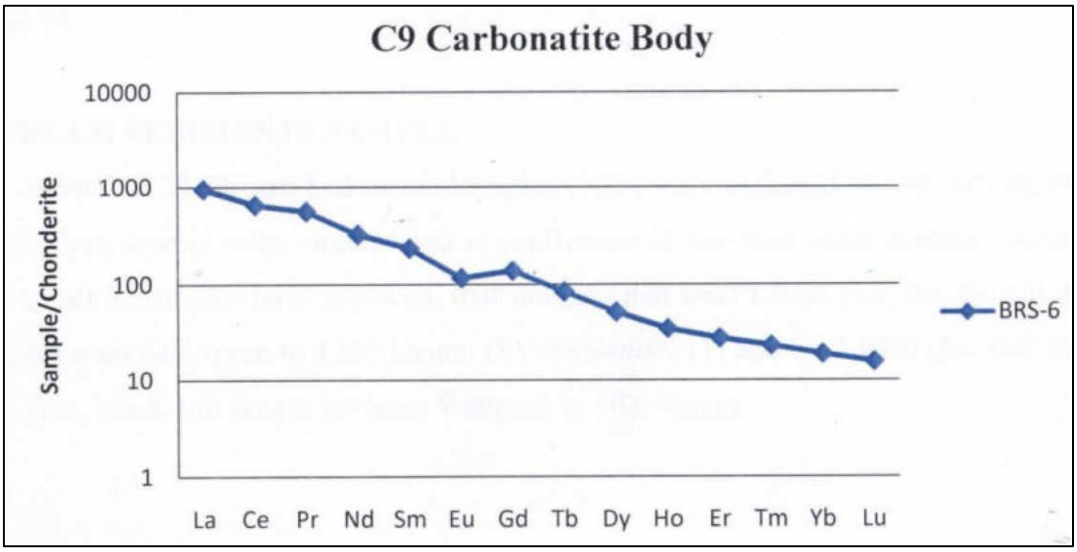
Plot-11



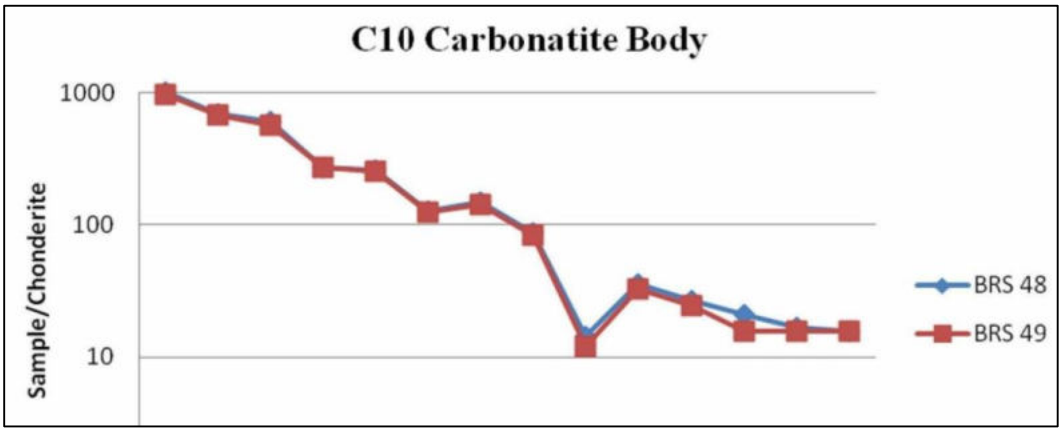
Plot-12



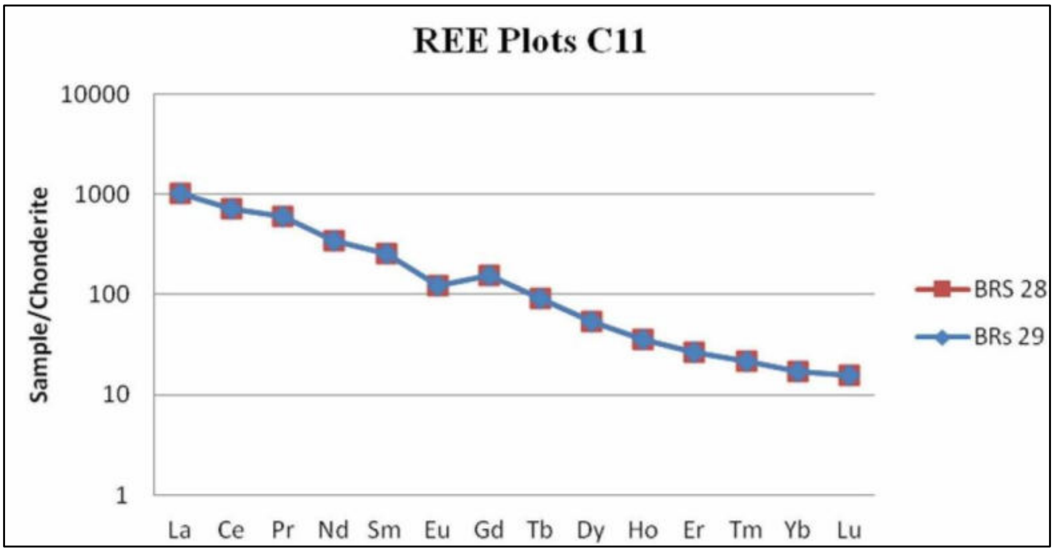
Plot-13



Plot-14



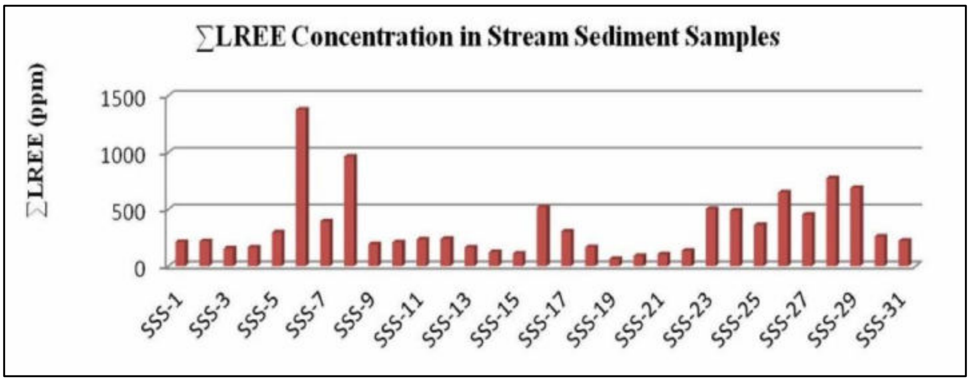
Plot-15



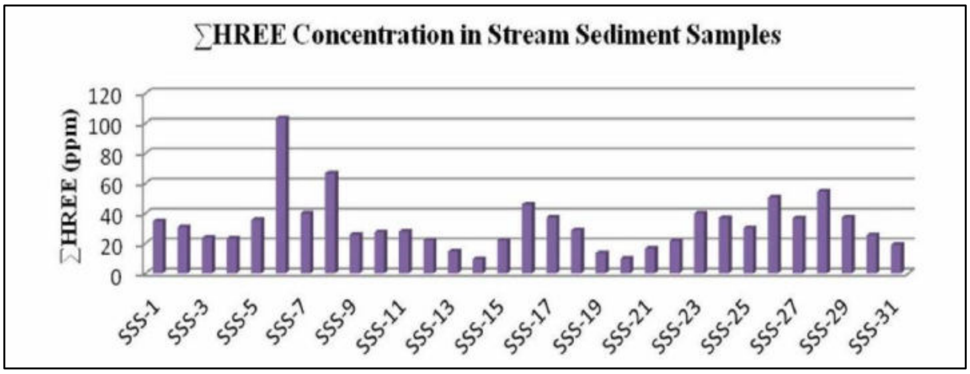
Plot-16

6.2 Stream Sediments

A total of 31 Stream Sediments Samples (SSS) were collected by wet sieving method from the first, second order streams and at confluence of two first order streams. Analytical results of all 31 samples have received, that indicate that total LREE (La, Ce, Pr, Nd & Sm) ranges between 64.14 ppm to 1380.16 ppm (SV/SSS-06/2011) and total REE (Eu, Gd, Td, Dy, Ho, Er, Tm, Yb & Lu) ranges between 9.49 ppm to 103.46 ppm.



Plot-17



Plot-18 Concentration of ΣHREE in SSS

6.3 Fluid Inclusion Studies

Entire studies of fluid inclusion were carried out in the PPOD Lab, Bengaluru.

6.3.1 Instrument and Methodology

The micro thermometric studies were carried out on a Linkam THMSG 600 heating/freezing stage fitted on an Olympus BX 50 transmitted light microscope. A silver block (THMSB) is used for heating. The unit operates in the temperature range of -195° to + 600°C. The stage is periodically calibrated by pure (demineralised water) (H_2O melting point=0°C) and pure CO_2 inclusions (synthetic CO_2 standard supplied by the stage manufacturer whose triple point = -56.6°C). Estimated accuracy is ±0.1°C at temperatures below 30°C and ±1.00°C at temperatures above 30°C. Reproducibility of the results of heating above 300°C has been tested and found to be ± 2 to 3°C.

Freezing experiments were performed first on all sections/wafers to avoid the decrepitation of inclusions followed by heating, following the procedure given by Roedder (1984). The measurements taken during melting include final melting temperature of ice (Tm_{ice}) to determine the salinity of aqueous phase. During the heating of the fluid inclusions, attempts were made to measure the homogenisation temperatures of the CO_2 ($ThCO_2$) to determine the density of CO_2 and the total homogenisation temperature (Th_{Total}).

Doubly polished thin wafers were prepared for fluid inclusions studies in the PPOD Division Bangalore. Fluid inclusion study (freezing and heating experiments) were carried out.

6.3.2 Fluid Inclusion Petrography

The petrographic study of wafers indicated the presence of primary and secondary mono-phase/bi-phase inclusions in the samples. The size of the vapour phase in the form of bubble ranging size from 0.12 to 9.40 μm. The characters of the bubble indicate heterogeneous nature of the parent fluid. The inclusions are generally irregular and facetted (Plate- 30, 40 & 41), and few are small and rounded (Plate. 39). The size of inclusions varies from 1.15 μm to 73.90 μm. Primary bi-phase inclusions are seen as isolated inclusions (Plate. 41) and their shapes are oval, spherical, rounded, irregular and facetted. Secondary inclusions are smaller and insignificant in their size which exhibit rounded, sub-rounded and faceted shapes are seen along healed fractures in linear fashion. Primary bi-phase CO_2 rich inclusions showing negative crystal shape are also noticed at places (Plate-42).

The petrographic study of wafers indicate that the area occupied by the CO_2-vapour phase ranges from 1.00 to 38% (average 19.5%). The area occupied by the aqueous phase varies from 62 to 99% (average 80.50%) suggesting that the inclusions studied are mainly aqueous in nature. Carbonic inclusions are also present in some the inclusions.

Suitable inclusions were selected for micro thermometric study. The inclusion size varies between 1.15μm to 73.90μm. The CO_2 vapour whenever presents is perfectly spherical, whereas the CO_2 liquid-aqueous-liquid interface varies from rounded to sub-rounded and oval in their shapes. Few of the CO_2 vapour bubble shows a dark rim in the periphery at room temperature which is due to the presence of a thin film of liquid CO_2 over vapour CO_2.

6.3.3 Micro Thermometry

Carbonic inclusion

The Mono-phase carbonic (CO_2) fluid inclusions are transparent to dark. Carbonic fluid inclusions are less abundant than aqueous fluid inclusions in these samples. The Carbonic inclusions are mainly dominated by CO_2 with some variable amounts of other gases such as CH_4, N_2 and H_2S (?). Carbonic fluid inclusions appear to have contain only one or two carbonic phases at room temperature (theoretically they must contain aqueous phase). This aqueous phase may occur as a thin film near the inclusion wall and may not be observable under microscope. Carbonic inclusions are commonly could not homogenize at the same temperature as the aqueous inclusions; they are most likely heterogeneously trapped inclusions and their homogenization temperature are unusable.

Primary carbonic fluid inclusions in these samples are typically in isolation and are mono-phase at room temperature. During cooling experiments, a vapour bubble nucleates and homogenizes in to the liquid phase. The melting temperature of CO_2 range from -57.1^0 C to - 58.0^0 C (Table-5) indicating that the fluid is dominated by CO_2 and the melting temperature of CO_2 range from -57.0^0 to -58.0 C (Table-5) indicating the fluid contains some amount of CH_4 in addition to CO_2. The homogenization temperatures of CO_2 range from 27^0 to 29^{0}C.

The isochores of carbonic inclusions is approximated by a CO_2 system; indicate the variation in fluid pressures (Plot-21). The fluid pressure varies from 900 to 1100 bars. The carbonic inclusions probably formed from homogeneous trapping of the vapour phase, but their temperature of total homogenization cannot be measured. The density of the CO_2 varies from 0.63 to 0.68 g/cm$^{3.}$

Aqueous Inclusion

The observed and calculated data like temperature of melting of ice (initial & final) temperature of homogenisation of CO_2 (Th CO_2) and total homogenisation temperature (Th_{Total}) of inclusions studied are tabulated in Table-5.

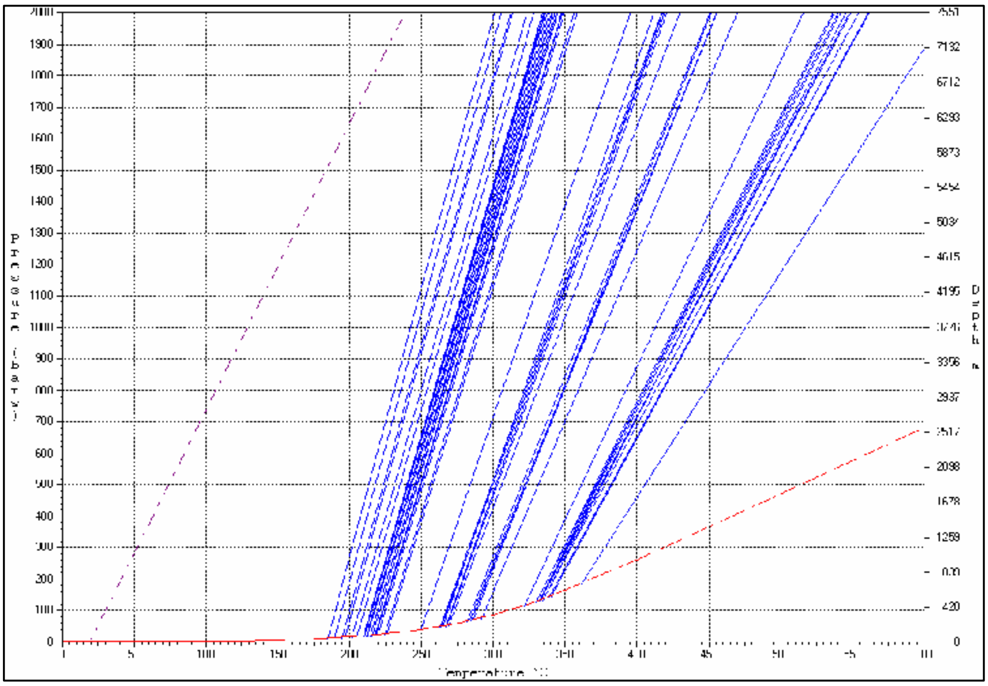
The observed range of homogenisation temperature varies from 185°C to 362°C (average 258.95°C) which corresponds to a salinity range of 0.83 to 8.65 wt.% NaCl equivalent (average 3.25 wt.% NaCl equivalent) as calculated using Linksys software (version 1.8) following the equations of state given by Bodnar (1983), Zhang and Frantz (1987) and Brown and Lamb (1988). The initial ice melting temperatures (T_{FM}) range from –44°C to –35°C with an average of –39.35 °C. This suggests that the major component in aqueous phase is NaCl in the fluid system. The maximum of first ice melting temperature of -44°C may indicate the presence of $CaCl_2$ with NaCl and H_2O (Shepered, Rankin and Aldertron, 1985) and also may indicate the presence of CH_4 in the CO_2 bearing inclusions. The final melting temperature of ice ranges from –5.6°C to – 0.5°C (average -1.99°C) corresponding with salinities of 0.83 to 8.65 wt.% NaCl equivalent. The present study indicates presence of vapour and liquid rich inclusions. The CO_2 density of inclusions studied varies from 0.92 to 0.62 gms/cm^3 with an average of 0.79 gms/cm^3.

The P-T plots and Th-Salinity plots using the PVTX modelling software for fluid inclusions (version 2.01) are given in Plot-19 & 20. The P-T estimates made from the total homogenisation of the aqueous-carbonic inclusions define a P-T path of evolution as shown in Plot-19. The intersecting isochores are designed for inclusions, which record the trapping of immiscible fluids (Shepherd, Rankin and Alderton, 1985) and in the present case the isochores for mixed H_2O-CO_2 fluids are considered. The P-T curve of the inclusions studied is presented in Plot-19. The isochores are representing individual fluid inclusions studied and are widely distributed from 185°C to 362°C of temperature of homogenisation (average 258.95°C).

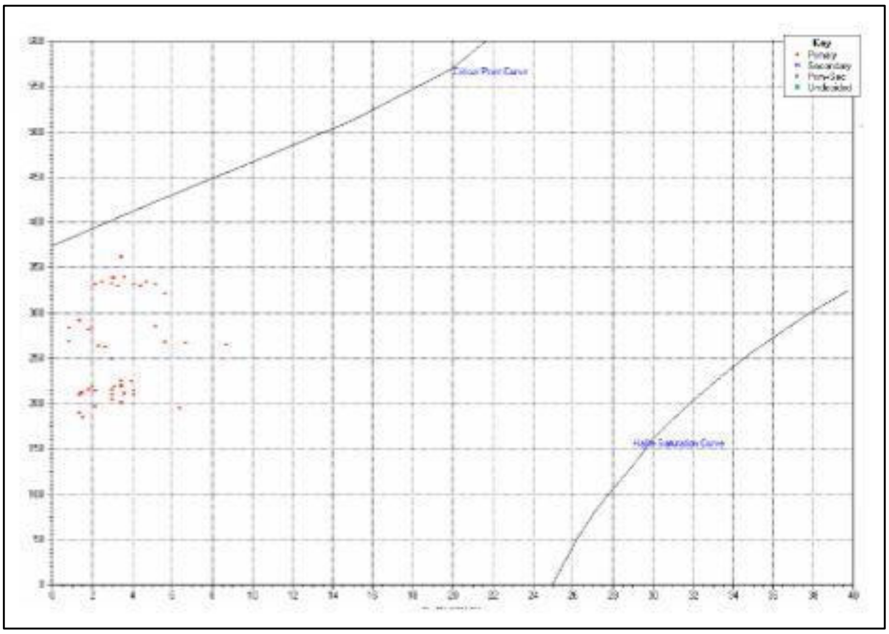
The co-existing aqueous and carbonic inclusions were also studied and the plot shows intersecting isochores. Three populations of isochors observed between 210°C - 225°C, 260°C - 270°C and 325°C - 340°C. The temperature of homogenisation - salinity plots for the inclusions studied are given in Plot-20. The most characteristic feature noticed is the clustering of plots near SE corner of the diagram indicating as follows. The trends of inclusion plots indicate the following possibilities: (after Shepherd, Rankin and Alderton, 85).

1. Isothermal mixing of fluids
2. Mixing with cooler less saline fluid

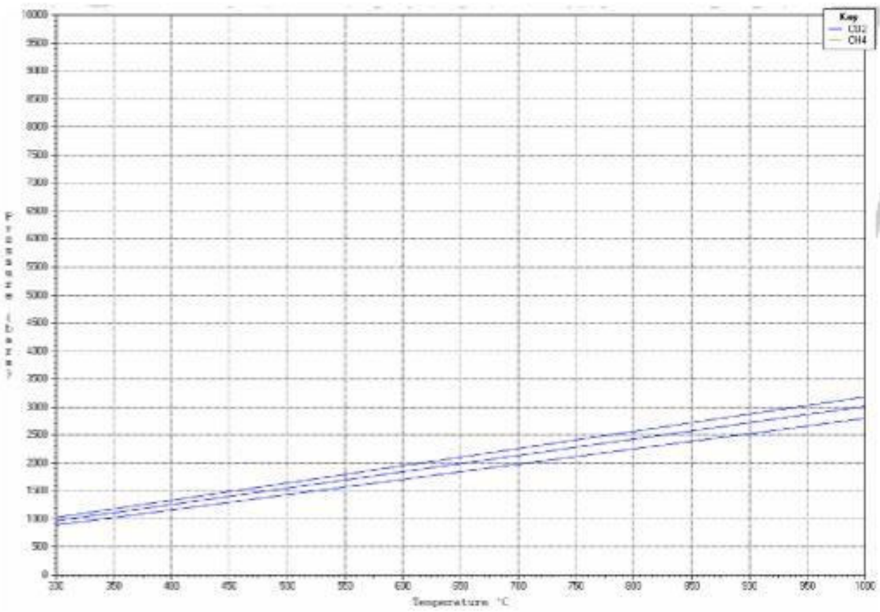
The trend line of temperature of homogenisation vs. salinity plot is shown in (Plot-22) indicates mixing of fluids with less salinity at moderate to higher temperature. (Giovami Ruggeri et. al., 1999). The temperature of homogenisation vs. CO_2 density plot is shown in (Plot-23) indicates that the CO_2 density increases with cooling. The temperature of homogenisation vs. temperature of final ice melting plots (Plot-24) shows fluid cooling at nearly constant salinity.



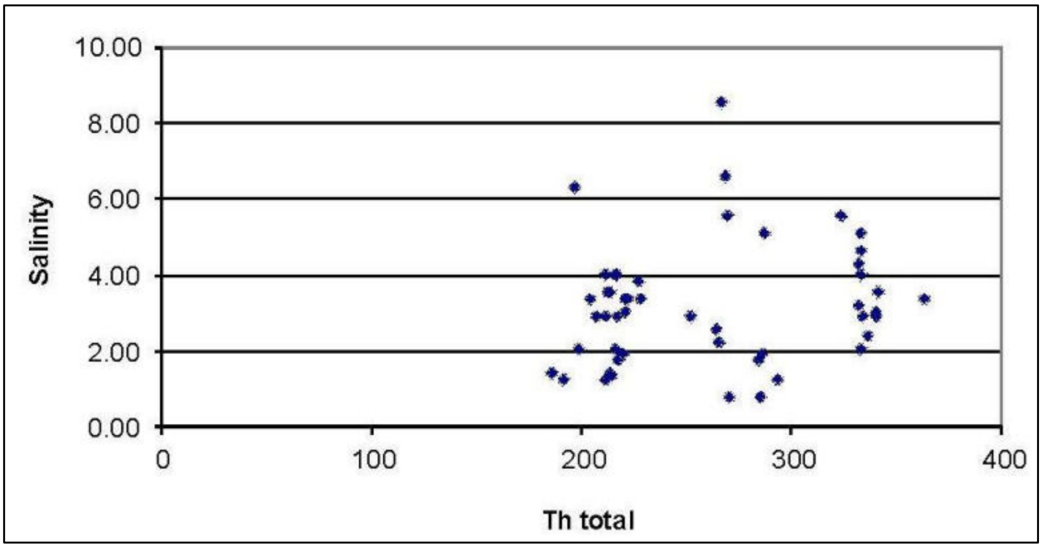
Plot-19 Isochores of acqueous fluid inclusions



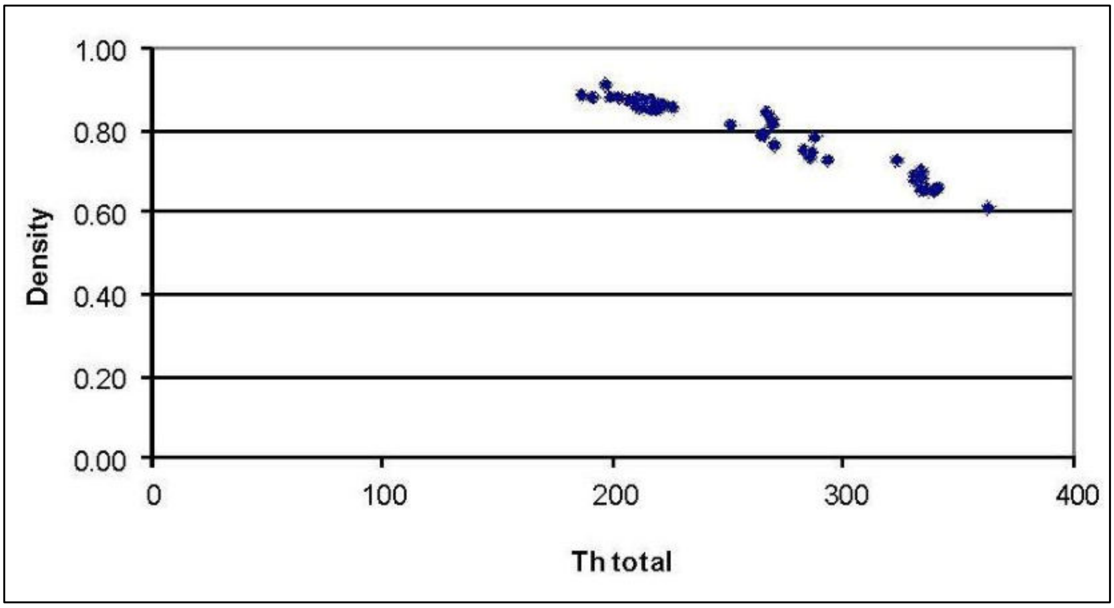
Plot-20



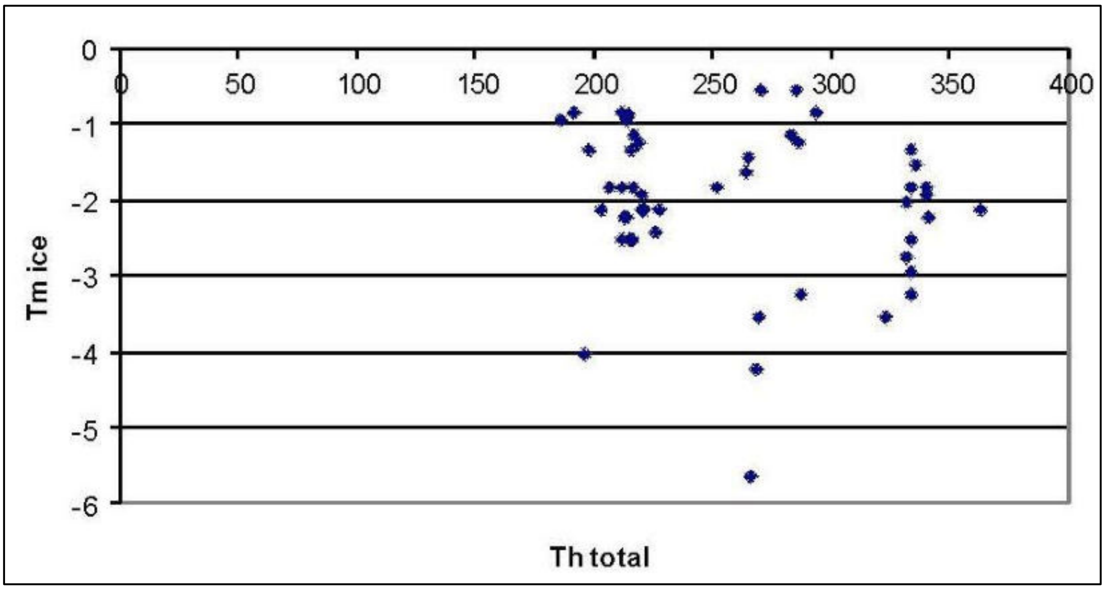
Plot-21



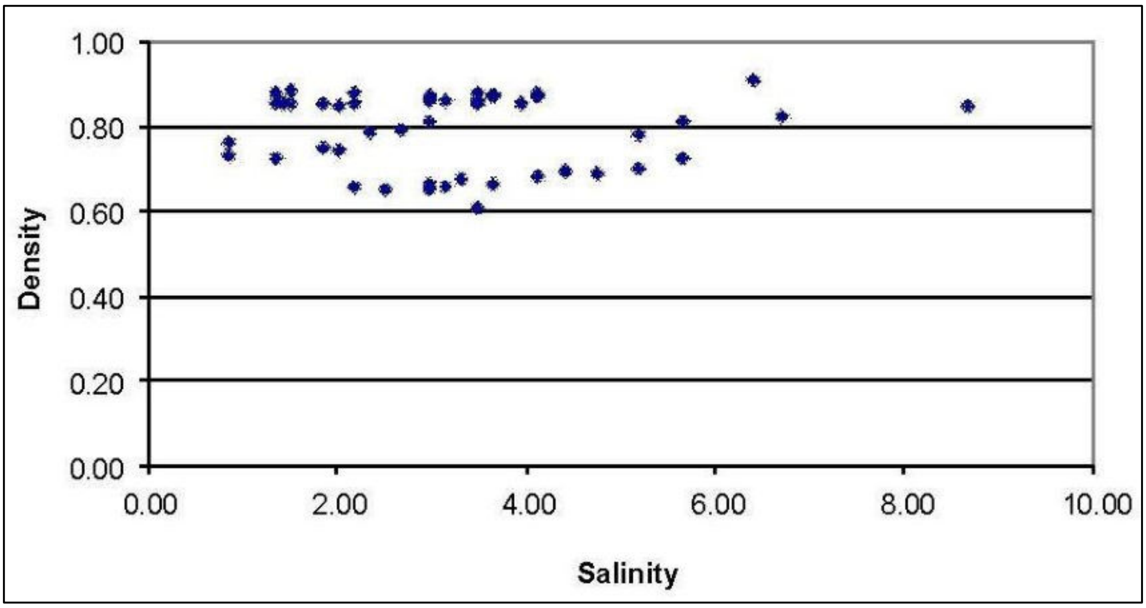
Plot 22 Plot showing Temperature of homogenization Vs Salinity



Plot-23 Plot showing Temperature of homogenisation Vs Density



Plot-24 Plots showing Temperature of homogenisation Vs Tm ice



Plot-25 Plots showing Temperature of Salinity Vs Density

Table 5 : Results of fluid inclusion samples

Inc Num	IncTy	Class	Shape	Size	Fill	Tm_ice	Tm_CO_2	Th_CO_2	Th_total	EqWt% NaCl	Density
1	V+L	Primary	Irregular	7.1744	0.907	-4	-54.9	22	195	6.37	0.92
2	V+L	Primary	Irregular	6.988	0.887	-3.5	-55.9	24	322	5.62	0.73
3	V+L	Primary	Irregular	5.28	0.9736	-3.2	-55	20	286	5.17	0.79
4	V+L	Primary	Irregular	17.808	0.871	-2.1	-56.2	18	362	3.44	0.62
5	V+L	Primary	Irregular	8.69	0.7535	-1.8	-56.1	20	333	2.96	0.67
6	V+L	Primary	Irregular	10.95	0.735	-2.7	-56.9	22	330	4.39	0.70
7	V+L	Primary	Faceted	23.3779	0.8518	-2.5	-57.2	19	332	4.07	0.69
8	V+L	Primary	Faceted	17.576	0.7	-1.2	-55.9	24	285	1.98	0.75
9	V+L	Primary	Irregular	72.1088	0.893	-1.8	-56.2	22	250	2.96	0.82
10	V+L	Primary	Irregular	7.6032	0.892	-0.8	-55.9	18	292	1.32	0.73
11	V+L	Primary	Irregular	8.816	0.892	-1.1	-56.2	21	282	1.82	0.76
12	V+L	Primary	Irregular	5.2668	0.806	-0.5	-56.9	23	283.7	0.83	0.74
13	V+L	Primary	Faceted	3.792	0.8322	-2.5	-56.9	19	210	4.07	0.89
14	V+L	Primary	Irregular	4.662	0.93	-1.8	-56.1	22	205	2.96	0.88
15	V+L	Primary	Irregular	4.1064	0.914	-1.3	-55.9	21	197	2.14	0.89
16	V+L	Primary	Irregular	6.732	0.929	-2.2	-55.8	18	211	3.60	0.88
17	V+L	Primary	Irregular	1.1519	0.8908	-2.5	-56.2	18	215	4.07	0.88
18	V+L	Primary	Irregular	5.9856	0.9201	-2.1	-56.1	15	220	3.44	0.87
19	V+L	Primary	Irregular	1.44	0.8949	-2.4	-55.5	17	225	3.92	0.86
20	V+L	Primary	Irregular	1.669	0.9129	-2.1	-56.3	21	202	3.44	0.89
21	V+L	Primary	Irregular	4.194	0.925	-1.8	-56.9	16.09	210	2.96	0.88
22	V+L	Primary	Irregular	5.0912	0.881	-2.5	-55.9	18	215	4.07	0.88
23	V+L	Primary	Faceted	3.13	0.933	-2.1	-55.9	19	219	3.44	0.87
24	V+L	Primary	Irregular	2.871	0.825	-1.9	-55.9	22	219	3.12	0.87
25	V+L	Primary	Irregular	4.5904	0.938	-2.2	-58	23	212	3.60	0.88
26	V+L	Primary	Rounded	73.9076	0.755	-2	-59	25	330	3.28	0.68
27	V+L	Primary	Rounded	37.3976	0.8456	-2.2	-58.8	24	340	3.60	0.67
28	V+L	Primary	Rounded	26.4242	0.799	-1.8	-59.2	-23	339	2.96	0.66
29	V+L	Primary	Rounded	7.548	0.687	-1.9	-59	24	339	3.12	0.66
30	V+L	Primary	Rounded	6.24	0.8741	-1.3	-58.5	18	332	2.14	0.66
30	V+L	Primary	Rounded	3.464	0.954	-1.5	-58.3	19	335	2.47	0.66
31	V+L	Primary	Rounded	20.4308	0.9025	-1.8	-57.5	21	215.9	2.96	0.87
32	V+L	Primary	Rounded	65.2638	0.8916	-0.9	-57.1	22	212	1.49	0.86
33	V+L	Primary	Faceted	26.56	0.8632	-0.8	-57	18	210	1.32	0.86
34	V+L	Primary	Rounded	15.0695	0.8853	-0.85	-56.9	21	213	1.40	0.86
35	V+L	Primary	Faceted	21.667	0.8956	-1.4	-58	22	264	2.31	0.79
36	V+L	Primary	Rounded	10.23	0.8839	-1.6	-58.1	21	263	2.63	0.80
37	L	Primary	Rounded	9.6625			-58	29			0.63
38	L	Primary	Rounded	16.621			-58	28			0.66
39	V+L	Primary	Rounded	40.1432	0.7657	-0.5	-57.1	25	269	0.83	0.77
40	V+L	Primary	Rounded	10.2367	0.9392	-0.8	-56.8	24	190	1.32	0.89
41	V+L	Primary	Rounded	9.1875	0.9759	-0.9	-56.2	25	185	1.49	0.90
42	V+L	Primary	Irregular	11.9989	0.9445	-5.6	-57.2	23	265	8.65	0.85
43	V+L	Primary	Faceted	16.389	0.6014	-4.2	-56.9	23	267	6.67	0.83
44	V+L	Primary	Faceted	58.696	0.9248	-3.5	-56.9	19	268	5.62	0.82
45	V+L	Primary	Faceted	33.2372	0.9884	-3.2	-56.8	18	332	5.17	0.71
46	V+L	Primary	Faceted	62.872	0.9595	-2.9	-56.9	19	332	4.70	0.70
47	V+L	Primary	Irregular	17.577	0.8352	-1.2	-56.7	19.1	218	1.98	0.86
48	V+L	Primary	Faceted	23.2809	0.8832	-1.3	-56.8	18.8	215	2.14	0.86
49	V+L	Primary	Irregular	1.84	0.9317	-1.1	-56.7	19	216	1.82	0.86
50	L	Primary	Rounded	45.3453			-57.1	27			0.68
51	V+L	Primary	Irregular	17.172	0.9226	-2.1	-56.7	23	226	3.438	0.86
Maximum						**-0.5**	**-54.9**	**29**	**362**	**8.65**	**0.92**
Minimum						**-5.6**	**-59.2**	**-23**	**185**	**0.83**	**0.62**
Average						**-1.99**	**-56.86**	**20.26**	**258.95**	**3.25**	**0.79**

6.4 Stable Isotope Analysis

6.4.1 Methodology

The powdered samples were analyzed for C and O isotopes in continuous flow (CFIRMS) mode of SerCon Geo 20-20 Isotope Ratio Mass Spectrometer (IRMS) using the Water Equilibration System (WES) peripheral. The following is the analytical procedure employed for the C and O isotope analysis:

1. About 1500 to 3000 µg (micrograms) of the sample was weighed and transferred into the Exetainer® reaction vials.
2. The vials were flushed with high purity Helium (He) using the GILSON autosampler of the WES unit of SerCon Geo20-20 IRMS to displace and remove air to avoid possible
3. About 2000 to 3000µl (microlitres) of 100% Orthoposphoric acid (H3 PO4) was added using a glass syringe through the rubber septa of the He flushed Extetainer vials.
4. The vials were kept in the WES unit at 70°C for 150 minutes for the following reaction to proceed:
   CaCO3 + H3 PO4 CaHPO4 + CO2 + H2O
5. The CO2 thus produced was extracted using Helium carrier gas to the mass spectrometer in continuous flow for C and O isotope analysis.

The data generated for the 6 carbonatite samples are tabulated below:

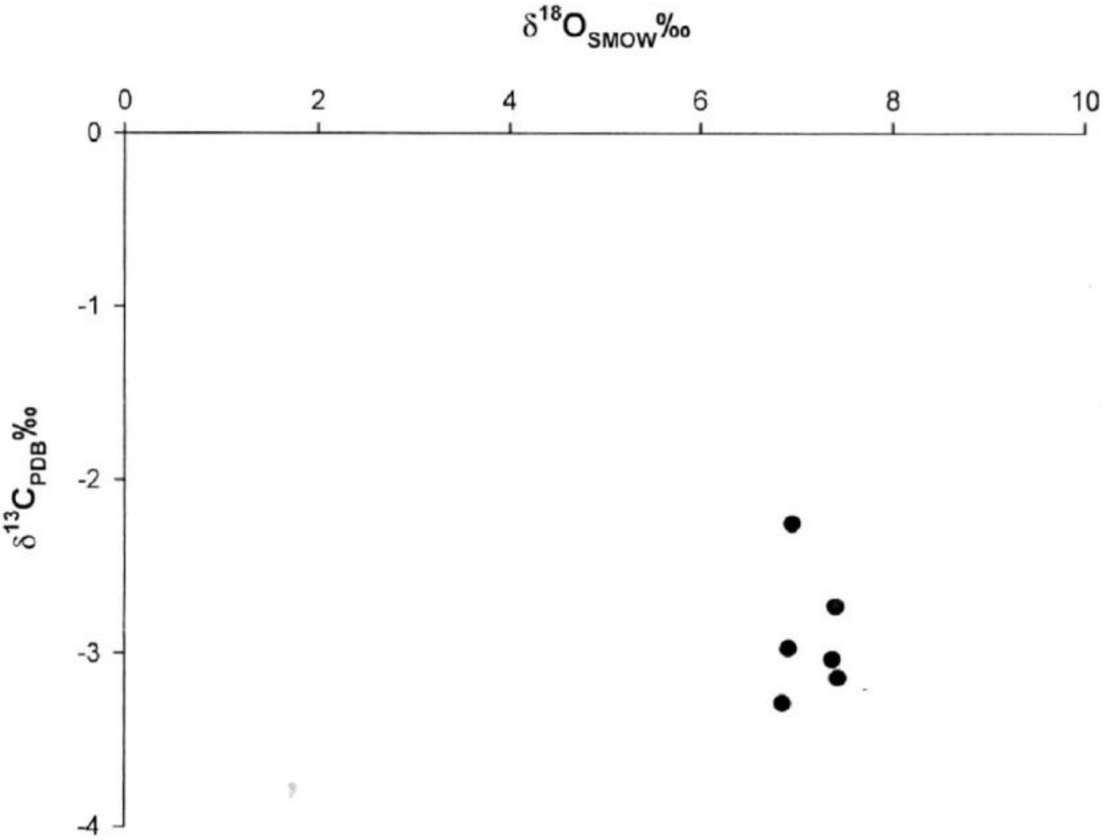
Table-6 Result of Isotope samples

SI. No	Sample Name	$\delta\ ^{13}C_{PDB}$%o	$\delta^{18}O_{PDB}$%o	$\delta\ ^{18}O_{SMOW}$%o
1	SV-1	-2.25	-23.19	6.95
2	SV-2	-2.73	-22.76	7.40
3	SV-3	-3.03	-22.79	7.37
4	SV-4	-2.97	-23.23	6.91
5	SV-5	-3.28	-23.29	6.86
6	SV-6	-3.14	-22.73	7.43

The standard NBS-18 and MAKMARB were analyzed to ensure and precision of the analysis. NB-18[1] gave $\delta^{13}C_{PDB}$ = -4.92± <0.1%o and $\delta^{18}O_{PDB}$ = -23.19 ± <0.1‰, while MAKMARB[2] gave $\delta\ ^{13}C_{PDB}$ = +3.65 ± 0.14 %o and $\delta\ ^{18}O_{PDB}$ = -10.83 ± 0.16 ‰.

[1]Reported values for NBS-18: 8 ^{13} C VPDB‰ =-5.014 %o and 8 $_{18}$ OPDB‰ = -23.2‰

[2]Reported values for MAKMARB: $\delta\ ^{13}C_{VPDB}$‰ = +3.7 ± 0.1%o and $\delta\ ^{18}O_{VPDB}$‰ = -10.8 ± 0.2‰



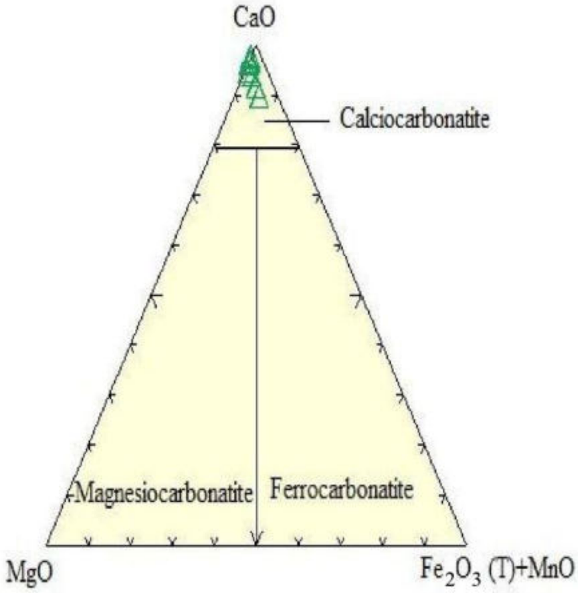
Plot-26 Scattered diagram (Isotope data results) for the Sung Valley carbonites

6.4.2 Interpretation

The $\delta^{13}C$ values of the 6 carbonatite samples collected from Sung valley, Meghalaya range from -3.28 to -2.25 ‰PDB. The $\delta^{18}O$ values of these samples range from 6.86 to 7.43 ‰PDB. These values are indicative of the primary igneous nature of the carbonatites. The primary igneous carbonatites have $\delta^{13}C$ values between -1 to -9 25 ‰PDB and $\delta^{18}O$ values between +5 to +12 ‰PDB (Deines, 1989 and Keller and Hoefs, 1995). The scatter diagram above plots the Sung valley carbonatites in the field of primary igneous Carbonatites defined by Taylor et al. (1967).

6.5 XRF Analysis

It was not a part of NQT but, in order to chemically classifying the lithounits particularly carbonatites, total 25 samples were collected for XRF analysis



Plot-27 Classification of SUACC carbonatites

14 samples were collected from different carbonatite bodies which correspond to calciocarbonatite on the chemical classification diagram (Plot-27) after *Wolly and Kempe, 1989.* Most carbonatite samples have negligible amounts of SiO_2 and TiO_2. Ijolite sample shows higher concentration of P_2O_5 (9.64%). As most of the peridotite samples are serpentinised and do not show a representative composition with varying amount of MgO (19.99 to37.68%).

6.6 EPMA Study of Carbonatite

EPMA study of carbonatite sections was carried out at PPOD lab Bengaluru. Minerals identified in carbonatite sections by EPMA study include; calcite, colomite, apatite, magnetite, pyrochlore, phlogopite, olivine and traces of barite, beddeleyite and very rare occurrence of monazite. Sulphides include pyrite, pyrrhotite and galena.

Main REE phases identified in carbonatite include *bastnasite, ancylite, belovite and britholite* associated with calcite and apatite. Appreciable amount of REE were also analysed in pyrochlore grains associated with magnetite in carbonatite sections.

6.6.1 Mineral Chemistry

CALCITE & DOLOMITE

Calcite and minor dolomite are present in the carbonatites (Table-7 & Table 8). Both phases contain appreciable amounts of Sr, higher in calcite than in coexisting dolomite (0.28–0.81

wt% SrO in calcite versus 0.09–0.33 wt% SrO in dolomite). Mn, Fe and Mg are invariably very low (Plate-43).

APATITE

Chemical analysis of apatite were obtained in section no. SV/EPMA-01&02/2011, SV/EPMA-05 & 06/2011 and SV/EPMA-08, 09 &10/2011 and is shown in Table-9. In apatite CaO ranges between 53.71 to 56.08%, P_2O_5 from 39.93 to 42.6% with low contents of ∑REO (0.17 to 0.49%), U & Th (Plate-43, 44, 45 & 49).

MONAZITE

Chemical dating of monazite in carbonatite sample no. SV/EPMA-02/2011 was attempted, but dates could not be obtained due to absence U, Th & Pb in monazite grains (Table-10). Total REO in monazite ranges from 64.4 to 67.44% and P_2O_5 ranges between 29.42 to 30.66%. (Plate-44).

OLIVINE

Olivine in the carbonatites was analysed in sample no. SV/EPMA-04 & 09/2012, has also a narrow range of compositions, but at markedly higher forsterite contents and with much lower CaO contents (Table-11) (Plot-28). This appears to be curious for a mineral in equilibrium with such Ca-rich rocks and minerals. Nevertheless, it is not unexpected, given the lack of monticellite–kirschsteinite solid solutions to buffer Ca contents in forsterite–fayalite solid solutions at their highest values (Sharp *et. al.* 1986). Olivine in the carbonatites (Plate-46) has a core slightly more Fe-rich than the rim, a feature much more evident in the coexisting phlogopite (Table-9).

PYROCHLORE

Pyrochlore was identified in carbonatite sample no SV/EPMA-01, 05, 07 & 08/2011 SV48, that shows 30.93 to 56.93% Nb_2O_5, 7.30 to 31.35% Ta_2O_5 ranges, 0.06 to 18.79% UO_2 and 0.8 to 12.32% total REO (Rare Earth Oxides) (Plate-45).

REE PHASES

REE phases identified in carbonatite sections include Bastnasite, Ancylite, Belovite, Britholite. (Source for mineral formulas: Mandarino 1999, with Ln = lanthanide elements.)

Bastnasite ($LnCO_3F$)

Bastnasite identified in section no. SV/EPMA-05/2012. Bastnasite in this section contain total REO% ranges from 58.25 to 74.23% (Table-14).

Britholite (Na, Ce, Ca)$_5$(OH) {(P, Si) O4}$_3$

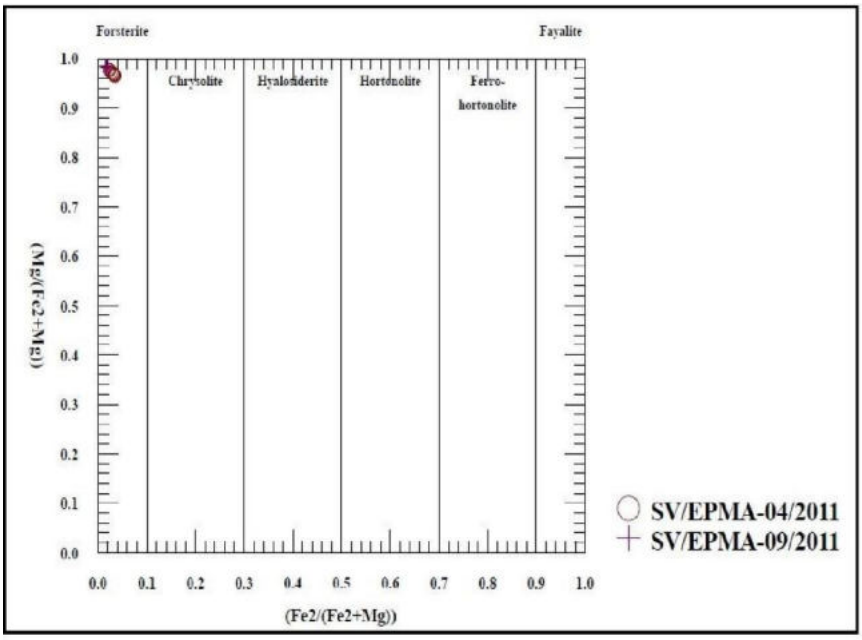
Britholite were analyzed in section no. SV/EPMA-07, 08 & 09/2011. Total REO% in this phase ranges between 43.71 to 54.06%. P_2O_5 ranges between 14.66 to 33.32 percent and CaO ranges from 1.27% to 13.77% (Table-15).

Ancylite (SrLn(CO$_3$)$_2$(OH)•H$_2$O)

Ancylite is the main phase and identified in carbonatite sections no. SV/EPMA-07 &08/2011 with total REO% ranges between 22.22 to 56.86%. SrO ranges between 9.01 to 23.42%. CaO is variable and ranges between 1.18 to 20.83% with minor amount of P_2O_5 and BaO (Table-16).

Belovite (Sr,Ce,Na,Ca)$_5$(PO4)$_3$(OH)

Belovite REE phase was identified in SV/EPMA/07,08,09 &10/201. Total REO% in this mineral ranges between 25.12 and 49.13%. CaO ranges from 4.32 to 11.25%, P_2O_5 from 3.34 to 21.31%, and SrO ranges between 8.17% to 42.27% with minor amount of MgO, BaO and SiO_2 (Table-17).



Plot-28 Classification of Olivine analysed in Carbonatite

Table-7 & 8: Representative composition of calcite & Dolomite

Table-7 Calcite

Point No.	CaO	MgO	MnO	FeO	SrO	Total	Sample No.
9 / 1.	61.96	1.23	0.29	0.02	0.81	64.31	EPMA-01
10 / 1.	59.48	0.27	0.18	0.13	0.27	60.33	
16 / 1.	63.11	0.13	0.09	0	0.43	63.76	
3 / 1.	63.72	0.08	0.15	0.11	0.18	64.24	EPMA-02
10 / 1.	62	0.16	0.18	0.03	0.49	62.86	
14 / 1.	61.67	0.18	0.1	0.01	0.54	62.5	
1 / 1.	56.66	0.14	0.11	0.04	0.28	57.5	EPMA-03
3 / 1.	60.01	0.48	0.12	0.45	0.57	61.63	
7 / 1.	52.67	2.21	0.09	0.32	0.44	55.73	
8 / 1.	53.23	2.22	0.02	0.13	0.46	56.06	
9 / 1.	50.61	2.14	0.09	0.49	0.53	53.86	
11 / 1.	59.82	0.51	0.19	0.05	0.53	61.1	EPMA-05
21 / 1.	51.93	0.35	0.14	0.07	0.34	52.83	
32 / 1.	59.07	0.83	0.12	0.07	0.4	60.49	EPMA-08
45 / 1.	59.29	0.97	0.13	0.05	0.57	61.01	

Table-8 Dolomite

1 / 1.	32.94	22.73	0.35	0.43	0.33	56.78	EPMA-01
6 / 1.	32.53	21.11	0.3	0.56	0.32	54.82	
21 / 1.	33.35	22.06	0.35	0.38	0.3	56.44	
22 / 1.	32.2	22.58	0.23	0.42	0.32	55.75	
1 / 1.	32.56	22.75	0.23	0.73	0.16	56.43	EPMA-02
2 / 1.	29.06	19.87	0.35	1.16	0.09	50.53	
13 / 1.	35.23	20.57	0.19	0.74	0.28	57.01	
10 / 1.	32.74	24.67	0.24	0.39	0.21	58.25	EPMA-05
31 / 1.	33.24	25.14	0.25	0.25	0.21	59.09	EPMA-07
46 / 1.	31.86	23.67	0.14	0.21	0.24	56.12	
10 / 1.	32.35	24.89	0.21	0.14	0.29	57.88	EPMA-09

Table-9 Representative composition of apatite

Sample. No.	Point No.	SiO_2	FeO	CaO	Na_2O	MgO	P_2O_5	SrO	La_2O_3	Ce_2O_3	ThO_2	UO_2	SO_2	Total
EPMA-01	5/1		0.47	53.71	0.16	0.10	41.24	0.42						96.10
	17/1	0.01	0.04	54.50	0.37	0.17	39.93	0.49						95.51
	24/1	0.03	0.02	54.38	0.20	0.06	40.99	0.43						96.11
	33/1	0.05		54.65	0.21	0.07	41.30	0.39						96.67
	34/1	0.04		55.21	0.22	0.12	41.40	0.53						97.52
	35/1	0.02	0.10	55.54	0.15	0.09	41.62	0.41						97.93
EPMA-02	6/1	0.11		55.59	0.20	0.09	41.86	0.24						98.09
	7/1	0.07	0.02	54.70	0.16	0.08	41.65	0.27						96.95
	11/1	0.04		55.78	0.15	0.40	41.67	0.30						97.98
	12/1	0.05	0.01	56.08	0.22	0.08	41.68	0.26						98.38
EPMA-05	5/1	0.05	0.05	55.64	0.22		41.83	0.20	0.02	0.05	0.01		0.03	98.10
	9/1	0.09	0.03	55.49	0.24	0.12	42.01	0.28	0.04	0.08			0.06	98.44
EPMA-06	9/1	0.19	0.09	54.78	0.28	0.16	40.46	0.25	0.01	0.07	0.01	0.03	0.09	96.42
EPMA-08	33/1	0.07	0.07	55.62	0.25	0.15	41.42	0.27	0.02	0.10			0.09	98.06
	44/1	0.02	0.03	55.62	0.19	0.08	41.80	0.31	0.02	0.12		0.03	0.05	98.27
EPMA-09	24/1	0.04	0.01	55.38	0.08	0.06	42.13	0.28	0.04	0.07		0.01	0.04	98.14
	25/1	0.03		54.75	0.12	0.09	42.60	0.37	0.09	0.17			0.07	98.29
EPMA-10	6/1	0.04	0.02	55.55	0.22	0.08	42.34	0.35	0.08	0.14		0.01	0.08	98.91

Table-10 Representative composition of Monazite in carbonatite

Point No.	CaO	SmO	PbO	Y_2O_3	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	Gd_2O_3	SiO_2	ThO_2	UO_2	P_2O_5	Total
1/1	0.48	0.61	-	-	18.56	34.01	3.13	8.85	2.89	0.06	0.01	0.01	30.66	99.25
2/1	0.63	0.51	-	-	20.64	33.44	2.89	7.42	2.82	0.04	0.01	-	30.61	99.02
3/1	0.57	1.09	-	0.03	16.33	32.94	3.39	10.64	3.03	0.03	-	-	30.67	98.72
4/1	0.33	1.58	-	0.11	14.23	32.35	3.67	12.47	3.27	0.05	-	-	30.41	98.49
5/1	0.80	1.17	-	0.02	14.84	32.79	3.60	11.77	3.04	0.04	0.01	-	29.96	98.03
6/1	0.75	1.23	-	0.03	15.30	32.54	3.59	11.67	3.07	0.07	0.01	-	29.90	98.18
7/1	1.18	0.56	-	-	18.31	33.98	3.07	8.27	2.90	0.02	-	-	29.58	97.86
8/1	1.65	1.71	-	0.03	11.83	31.68	3.89	13.94	3.06	0.06	0.03	0.03	29.42	97.35

Table-11 Representative composition of olivine

Formula	SiO_2	MgO	FeO	Na_2O	CaO	MnO	PbO	TiO_2	P_2O_5	Total	Smpl. No.
1/1.cr	38.87	55.67	1.78	0.01	0.02	0.31	0.13	0.26	0.02	97.07	EPMA-09
2/1.rm	38.83	56.60	1.46		0.02	0.28	0.13	0.15	0.07	97.54	
5/1.	42.48	54.46	3.26	0.02	0.04	0.35	0.02		0.05	100.68	EPMA-04
7/1.	42.04	53.78	3.23	0.04	0.06	0.45			0.04	99.64	
10/1.	41.80	54.11	3.00	0.03	0.08	0.31	0.02		0.06	99.41	
11/1.	41.97	54.73	2.84	0.01	0.07	0.41				100.03	
12/1.	42.13	54.21	3.23	0.01	0.06	0.39			0.04	100.07	
13/1.	38.41	50.02	2.03	0.02	0.05	0.26	0.02	0.03	0.06	90.90	
14/1.	40.31	53.49	2.33	0.02	0.06	0.30	0.09		0.10	96.70	
16/1.	39.35	52.28	2.22	0.03	0.05	0.37	0.01		0.06	94.37	
19/1.cr	41.77	54.35	3.52	0.01	0.08	0.45			0.19	100.37	
20/1.rm	41.91	53.69	3.41	0.03	0.13	0.44	0.02	0.03	0.14	99.80	

Table-12 Representative composition of mica

Spl No	Point No.	SiO_2	Al_2O_3	Na_2O	K_2O	MgO	CaO	MnO	FeO	BaO	TiO_2	Total
SV/EPMA-03/2011	1/1.cr	38.58	18.20	2.49	6.70	24.38	0.00		2.68	0.93	0.30	94.26
	2 1.rm	38.51	18.36	2.72	6.64	24.82	0.00	0.07	2.68	1.00	0.28	95.08
	3/1.cr	38.81	18.87	2.71	6.46	25.00	0.00	0.07	2.70	1.33	0.32	96.27
	4/1.rm	38.40	18.44	2.67	6.39	24.63	0.03		2.59	1.62	0.36	95.13
	5/1.cr	38.13	18.49	2.62	6.44	24.93	0.01		2.59	1.39	0.27	94.87
	6/1.rm	38.69	18.55	2.68	6.37	24.82	0.05	0.04	2.78	1.42	0.29	95.69
	7/1.cr	38.47	19.10	2.79	6.32	24.75	0.00	0.04	2.43	1.49	0.22	95.61
	8/1.rm	38.40	18.45	2.61	6.45	24.95	0.09	0.01	2.49	1.81	0.34	95.60
SV/EPMA-01/2011	9/1.cr	39.15	16.39	1.38	8.42	25.75	0.01	0.05	2.26	1.32	0.18	94.91
	10./ rm	39.59	15.82	1.27	8.74	25.84	0.03	0.03	2.05	0.85	0.27	94.49
	11/1. cr	39.49	15.95	0.86	9.02	26.02	0.05	0.03	1.93	0.57	0.19	94.11
	12/1 rm	39.89	15.58	1.23	8.86	25.82	0.04		1.81	0.72	0.20	94.15

	13/1.cr	38.50	17.29	1.46	8.19	25.08	0.00	0.04	2.21	1.94	0.16	94.87
	14/1 rm	39.24	15.97	1.32	8.56	25.66	0.07	0.04	2.05	1.21	0.16	94.28
	25/1.	38.74	15.99	1.22	8.54	25.84	0.04		1.95	1.23	0.18	93.73
	27/1.	38.56	15.82	1.29	8.30	25.82	0.03		2.23	1.32	0.19	93.56
	31/1.	38.93	15.76	1.37	8.27	25.83	0.04	0.08	2.02	1.27	0.20	93.77
SV/EPMA-10-2011	1/1.	38.23	18.86	2.98	5.49	26.13	0.08	0.03	1.85	3.45		97.10
	2/1.	31.83	22.84	2.76	3.26	23.63	0.05	0.05	1.47	10.66	0.04	96.59
	3/1.	38.74	18.59	2.63	5.71	26.18	0.04	0.05	1.83	2.88	0.03	96.68
	4/1.	32.67	22.22	2.45	3.92	23.80	0.04	0.03	1.47	9.77	0.02	96.39
	18/1.	37.62	18.59	2.51	5.46	25.94	0.02	0.02	1.64	3.83		95.63
	19/1.	34.34	20.39	2.25	4.64	24.64	0.10	0.02	1.44	8.24	0.03	96.09
	20/1.	31.40	23.08	2.74	2.91	23.51	0.13		1.38	10.98	0.01	96.14
	21/1.	32.39	21.99	2.47	3.65	23.91	0.19	0.02	1.50	9.62	0.02	95.76
	22/1.	39.44	17.91	1.95	6.11	26.73	0.13	0.04	1.70	2.87		96.88

Table-13 Representative composition of pyrochlore

Sample No.	Formula	Na_2O	MgO	CaO	MnO	FeO	BaO	PbO	La_2O_3	Ce_2O_3	Nd_2O_3	Tm_2O_3	TiO_2	ZrO_2	ThO_2	UO_2	Nb_2O_5	Ta_2O_5	Total
SV/EPMA-01/2011	1 / 1 .cr	0.61	0.72	11.89	0.5	1.83	2.18	0.09	0	0.74	0	0.25	1.03	0.66	2.13	15.04	48.04	9.29	95
	2 / 1 .rm	0.09	1.03	11.53	0.39	1.8	1.08	0.17	0.04	0.97	0.38	0.16	1.63	0.53	6.49	6.92	**56.93**	7.52	97.66
	3 / 1 . cr	0.09	0.76	10.5	0.28	3.76	1.41	0.08	0.16	1.07	0.24	0.37	1.48	0.52	5.83	8.75	54.99	7.43	97.72
	4 / 1 . rm	0.08	0.74	10.82	0.22	3.61	1.17	0	0.16	1.15	0.24	0.14	1.48	0.47	5.84	7.91	54.73	7.4	96.16
	5 / 1 . cr	1.21	0.51	10.94	0.58	2.24	1.01	0.45	0.09	0.73	0.24	0.29	1.33	0.57	4.23	11.7	53.17	8.16	97.45
	6 / 1 . rim	0.09	0.93	10.95	0.4	2.77	1.15	0.2	0.14	1.22	0.29	0.34	1.66	0.48	6.44	7.32	55.09	7.3	96.77
	7 / 1 . cr	0.14	0.7	8.94	0.45	2.63	2.02	0.1	0.28	1.86	0.4	0.23	1.68	0.74	4.29	11.26	51.6	7.62	94.94
	8 / 1 . rm	2.37	0.08	12.65	0.57	4.13	0.73	0.04	0.13	1.2	0.43	0.11	1.79	0.78	6.94	7.13	49.77	8.28	97.13
SV/EPMA-05/2011	1-Oct	2.36	0.05	10.45	0.43	3.2	2.07	0.09	0.35	2.65	0.66	0.07	3.16	0.33	7.3	0.98	40.17	12.88	87.2
	14 / 1	6.5	0.01	15.5	0.06	1.5	0.05	0	0.37	2.7	0.55	0.28	3.51	0	0	0	52.36	8.91	92.3
SV/EPMA-07/ 2011	13 / 1	6.97	0.02	14.72	0.06	3.8	0.02	0	0.15	1.1	0.07	0.45	0.73	-0.04	0.09	0.04	50.63	14.07	92.88
	16 / 1	4.48	0	5.72	0.23	3.4	4.69	0.25	0.02	1.36	0.09	0.4	0.8	1.12	5.02	10.51	36.26	18.71	93.06
	17 / 1	0.95	0.02	8.95	0.88	4.32	2.4	0.06	0.04	0.88	0	0.5	0.9	0.86	3.14	11.64	32.33	19.17	87.04

	18 / 1	4.89	0.13	14.38	0.22	5.27	-0.06	0.46	0.11	1.07	0.38	0.6	0.4	1.53	6.04	1.84	30.93	**31.35**	99.54
	26 / 1	3.91	0.03	13.96	0.08	1.02	0.22	0.04	0.77	8.75	2.5	0.3	10.01	-0.19	3.78	0.06	38.16	10.89	94.29
SV/EPMA-08/2011	16 / 1	4.78	0.43	7.62	0.35	1.39	0.99	0.68	0	0.48	0.17	0.17	0.52	1.7	3.67	**18.79**	46.3	11.76	99.8

Table-14 Composition of Bastnasite

Sample No.	Formula	MgO	CaO	SrO	BaO	SiO_2	PbO	Al_2O_3	Y_2O_3	TiO_2	ThO_2	UO2	P_2O_5	Ta_2O_5
EPMA-05	2 / 1.	0.03	1.51	0.49	0.11	0.23	0.05	0.01	0.3	0.03	0.02	0.03	0.06	
	3 / 1.	1.05	2.89	0.34	0.13	2.56			0.28	0.06	0.07	0.05	0.26	
	4 / 1.	1.54	3.88	0.98	0.12	0.71	0.15	0.04	0.05			0.04	1.85	0.09
	5 / 1.	1.05	3.23	0.43	0.18	0.21	0.12	0.03	0.38	0.08		0.01	0.5	

Sample No.	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	EuO	Gd_2O_3	Tb_2O_3	Dy_2O_3	Ho_2O_3	Er_2O_3	Tm_2O_3	Yb_2O_3	Lu_2O_3	Total	REO%
EPMA-05	23.01	34.13	3.3	10.09		2.86	0.16	0.25	0.1		0.19	0.14		71.1	74.23
	19.09	32.35	3.78	10.72		3.21		0.24			0.16	0.07	0.04	77.35	69.66
	17.67	27.03	2.55	8.27		2.54		0.19						67.7	58.25
	18.4	30.9	3.24	11.02		2.67		0.31	0.08		0.18	0.07	0.03	73.27	66.9

Table-15 Composition of Britholite

Sample No.		Na_2O	K_2O	MgO	CaO	MnO	FeO	SrO	SiO_2	SO_2	TiO_2	UO_2	P_2O_5	BaO	PbO	Al_2O_3
EPMA-08	27/1.	0.22	0.37	0.22	13.24			0.76	0.64	0.24	0.06	0.21	27.28	0.38	0.28	0.07
	30/1.	0.7	0.23	0.36	6.05	0.17	0.12	3.61	1.39	0.23	0.1	0.04	23.63	0.36	0.17	0.24
	32/1.	0.07	0.28	0.19	13.54	0.02	0.04	1.13	0.27	0.32	0.04	0.07	30.9	0.56	0.19	0.01
	33/1.	0.14	0.25	0.16	15.21	0.32		1.29	0.26	0.33	0.05	0.11	31.25	0.48	0.05	
	34/1.	0.11	0.13	0.11	13.77			1.29	12	0.25	0.03	0.07	33.32	0.47	0.14	
	37/1.	0.14	0.29	0.28	12.23	0.04	0.09	1.01	0.54	0.16	0.01	0.11	14.66	0.4	0.73	0.07
EPMA-09	23/1.		0.03	0.2	11.75	38		0.69	0.28	0.26	0.03	0.01	27.69	0.16	0.06	0.04
EPMA-07	27/1.		0.04	10.03	1.27	-0.05	3.15	0.57	14.51	0.04	0.04		20.21	0.14		0.24

Sample No.	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	EuO	Gd_2O_3	Tb_2O_3	Dy_2O_3	Ho_2O_3	Er_2O_3	Tm_2O_3	Yb_2O_3	Lu_2O_3	Total	REO%
EPMA-08	11.77	21.3	1.88	6.75		1.85			0.04		0.1	0.02		87.68	43.71
	12.21	25.83	2.92	9.09		2.39		0.07	0.15	0.06		0.06		90.18	52.78
	13.54	21.6	2.28	6.69		1.87		0.19	0.13	0.09	0.11	0.02	0.01	94.16	46.53
	13.54	24.17	2.14	8.08		2.23	0.05					0.05	0.23	97.85	47.95
	13.54	24.17	2.14	8.08		2.27		0.14	0.01		0.04	0.06	0.08	100.34	50.53
	12.09	21.17	1.9	7.29		1.84		0.14	0.05	0.05	0.03	-0.03		75.29	44.53
EPMA-09	15.02	25.32	3.08	7.9		2.24		0.36		0.06	0.01	0.07		95.64	54.06
EPMA-07	16.85	23.13	1.78	3.89		1.94		0.21					0.08	98.07	47.88

Table-16 Composition of Anclite

Sample No.	Formula	Na_2O	K_2O	MgO	CaO	SrO	BaO	SiO_2	TiO_2	ThO_2	UO_2	P_2O_5	Nb_2O_5	Ta_2O_5
EPMA-08	28/ 1				5.56	22.38	0.74	0.05	0.05			0.53	0.01	
	29 / 1	3.44	0.02	0.02	15.37	23.42	1.54	0.03	0.03				0.01	
	31 / 1	0.12	0.05	0.21	3.45	21.48	0.31	0.73			0.03	0.82		0.14
	39 / 1	0.11	0.03	0.13	4.11	18.37	0.14	0.2	0.09	0.01		1.85		0.07
	40 / 1				5.36	18.65	0.41	0.08					0.05	0.08
	42 / 1	0.77	0.03		14.76	17.84	0.78	0.03	0.03	0.01		0.08		0.05
	45 / 1	0	0.01	0.1	5.01	13.35	0.22	0.01		0.05		1.66		0.1
	47 / 1			0.01	1.8	21.17		0.06	0.01	0.03	0.04	1.14		
	48 / 1	2.74			20.83	13.16		0.02	0.02		0.06	0		0.06
	49 / 1			0.04	2.22	16.57	0.18	0.21	0.02		0.02	0.03		
	50 / 1	0.03		0.00	4.46	20.69	0.63	0.01	0.06	0.03		0.02	0.03	0.18
	51 / 1				4.38	21.22	0.77	0.04	0.03	0.03		0.04		
	52 / 1	3.47	0.01	0.01	17.89	9.01	0.74	0.05			0.09	0.01		0.04
	53/1 . 6636				7.98	17.6	0.1	0.03	0.04	0.01	0.03	0.03	0	
	54 / 1			0.02	4.57	19.41	0.62	0.1	0.04		0.04	0.15	0.03	
	55 / 1				2.79	19.97	0.49	0.03	0.1			0.01	0.11	0.2
	56 / 1			0.04	2.26	21.64	0.46	0.02	0.09			0.03	0.03	0.01
	57 / 1			0.02	4.28	16.77	0.28		0.06				0	
	58.00		0.02	0.02	5	18.88	0.26	0.03	0.03		0.05		0.01	
EPMA-05	1 / 1. 6633				1.18	18.94	0.21	0.17	0.02					0.18

	8/1	0.02		0.02	1.59	17.28	0.04	0.25	0.07			0.15		0.2
	13.00	0.06		0.01	2.38	19.29	0.07	0.17	0.03	0.01		1.05		
	1/1			0.07	1.67	19.23	0.05	0.36	0.09	0.09	0.03	0.03		
	7/1			0.04	7.96	16.08	0.14	0.07	0.03	0.06				
	9/1	7.00		0.08	2.97	18.03	0.19	0.11	0	0.01	0.03	0.01		0.01

Sample No.	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	EuO	Gd_2O_3	Tb_2O_3	Dy_2O_3	Ho_2O_3	Er_2O_3	Tm_2O_3	Yb_2O_3	Lu_2O_3	Total	REO%
EPMA-08	11.37	21.31	1.9	7.65	0.17	2.11		0.36			0.09	0.12		74.4	45.08
	4.95	10.62	1.16	4.06	0.02	1.12		0.12	0.03		0.12	0		66.08	22.2
	12.84	21.06	1.88	6.61		1.85			0.04		0.05	0.02		71.69	44.35
	14.13	23.2	1.79	6.26		2.39				0.1	0.24	0.01		73.23	48.12
	13.4	21.42	2.14	7.23		2.03						0.03		70.88	46.25
	9.42	15.26	1.36	4.83		1.5		0.09					0.04	66.88	32.5
	14.85	24.99	2.65	7.61		2.21	0.04				0.07	0.06		72.99	52.48
	11.78	21.86	2.58	9.44	0.34	2.21	0.1	0.13	0.17		0.07			72.94	48.68
	7.36	11.85	0.81	3.33		1.17		0.4					0.05	61.86	24.97
	14.81	24.84	2.48	7.59		2.12		0.2	0.14		0.09			71.56	52.27
	12.61	21.12	1.92	7.25		1.84		0.28			0.04	0.01	0.02	71.23	45.09
	13.65	20.7	1.9	5.47		1.97					0.1		0.04	70.34	43.83
	7.67	12.51	0.82	2.42		1.04	0.04	-0.05	0.05	3				55.85	24.53
	9.81	18.71	2.09	8.32	0.08	2.43	0.02	0.09	0.23		**0.08**			**67.68**	**41.86**
	12.7	20.55	1.92	7.06		2.03		0.19			0.01			69.44	44.46
	12.79	22.56	1.95	7.54		2.14	0.01	0.1				0 08	0.1	70.88	47.27
	12.74	21.98	1.83	7.27		2.13		0.08			0.13			70.74	46.16
	12.53	23.39	2.47	8.33		2.1	0.14	0.38	0.1	3	0.09	0.04		71.01	49.6
	12.64	22.58	2.2	7.57		2.26		0.06	0.05		0.25	0		71.91	47.61
EPMA-05	12.77	24.31	2.88	9.66		2.18		0.19	0.17		0.14			73	52.3
	16.12	27.05	2.63	8.34		2.35	0.01	0.26			0.05	0.01	0.04	76.48	56.86
	13.97	23.97	2.14	8.62		2	0.03	0.23			0.16	0.07	0.04	74.3	51.23
	16.94	27.49	2.85	7.59		2.32	0.05	0.12			0.04			79.02	57.4
	10.64	27.92	3.64	11.05	0.03	2.33	0.05	0.39	0.14		0.06	0.03		80.93	56.55
	11.52	26.2	3.46	10.66	0.16	2.11	0.07	0.18	0.05		0.04		0.17	76.13	54.62

Table-17 Composition of Belovite

Sample No.	Formula	Na_2O	MgO	CaO	SrO	BaO	SiO_2	TiO_2	ThO_2	UO_2	P_2O_5
EPMA-07	40/1.		1.91	6.17	16.78	0.01	1.69	0.04		0.01	3.74
EPMA-08	36/1.	0.05	0.05	5.53	12.71	0.80	0.22	-0.04	0.03	0.05	6.79
	38/1.	0.13	0.14	8.64	10.93	0.24	0.21	0.04			8.56
	41/1.	0.59	0.14	11.25	8.17	0.38	0.24	0.05			19.52
	35/1.	0.04	0.08	9.70	10.11	0.53	0.09	0.04	0.01	0.03	21.31
	44/1.		0.22	5.10	13.92	0.59	0.06		0.04		4.28
	43/1.	0.13	0.02	4.48	42.27	0.25	1.31	0.01	0.10	0.07	12.87
EPMA-09	15/1.		0.04	4.32	18.41	0.10	0.15	0.03	0.42		4.01
EPMA-10	17/1.	0.19	0.01	7.93	20.97	0.28	0.28	0.02	0.02	0.03	7.67

Sample No.	La_2O_3	Ce_2O_3	Pr_2O_3	Nd_2O_3	EuO	Gd_2O_3	Tb_2O_3	Dy_2O_3	Ho_2O_3	Er_2O_3	Tm_2O_3	Yb_2O_3	Lu_2O_3	Total	REO%
EMPA-07	11.34	15.66	1.08	4.69		1.29		0.34					0.04	64.88	34.44
EPMA-08	13.67	23.62	2.09	7.30		2.22		0.08	0.05		0.03	0.07		75.35	49.13
	10.61	23.97	2.37	8.07	0.01	2.26		0.24	0.07	0.01		0.11	0.03	76.64	47.75
	10.13	21.99	2.96	9.00	0.40	2.19		0.46	0.21	0.02	0.02			87.92	47.58
	15.94	22.62	2.07	5.34		2.07		0.50	0.01				0.16	90.74	48.71
	15.30	24.07	2.03	6.56		2.12	0.04	0.08		0.01				74.42	50.21
	8.08	10.99	1.20	3.31		1.02		0.26	0.10		0.07		0.09	86.63	25.12
EPMA-09	14.74	22.92	2.17	6.82		2.09		0.11	0.02		0.04			76.39	48.91
EPMA-10	12.04	17.95	1.82	5.03		1.88		0.17						76.21	38.89

CHAPTER-VII: CONCLUSION AND RECOMMENDATION

The SUACC is an oval shaped body occurring as intrusive within the Shillong Group of rocks. The study area falls in Toposheet no 83C/02 bounded by latitude N 25° 30' 00" to N 25° 35' 30" and Longitude E 92° 07' 00" to E 92° 09' 00". The altitude ranges from 890 to 1365 m.

The Shillong Group constitutes of quartzite, phyllitic quartzite and polymictic conglomerate. Granite and amphibolites, occur as intrusive near Thadmassum village and west of Moo Kyndur and in and around Niriang villages respectively. The predominant rock types of SUACC are pyroxenite in the periphery of the complex and the core is made up of serpentinite and ijolite. Carbonatite occurs as isolated patches within the complex and apatite- magnetite rock occurs as veins. Peridotite is an important and rare member of SUACC that is exposed at few places. Tertiary sandstone occurs as small cappings over Shillong group of quartzite. Laterite occurs as small cappings over pyroxenite of SUACC.

Bedding is the primary sedimentary structure observed in quartzite at few places. The trend of the bedding is along NW-SE with moderate dip towards NE. Foliation is developed in quartzite/phyllitic quartzite showing NE-SW trend, dipping 28° to 40° towards NW. An angular unconformity is a remarkable structure, exposed near Moo Kyndur village where Tertiary sandstone overlies phyllitic quartzite with a thin band of polymictic conglomerate in between. Three sets of geomorphic lineaments were marked from satellite imagery showing E-W, NW-SE and N-S trends. A secondary silicified zone was identified in amphibolites, trending of N10°E to S10°W, comprises of quartz and epidote veins. Another NW-SE trending silicified zone/quartz vein (25 X 100 m) was also seen north of Tyrshang. No contact metamorphic effect due to intrusion of SUACC has observed. However, along the periphery of SUACC incipient fennitisation is observed at some place.

74 bed rock samples were collected to assess REE mineralization from different litho units in Sung valley complex. Analytical results of 11 carbonatite bodies have indicated anomalous REE values and apatite-magnetite rock have indicated high values of Sn, W and U, which warrant systematic investigation to assess its potentiality. Samples collected from the laterite cappings developed over pyroxenite, near Lumkynthang village yielded higher concentration of total rare earth elements viz; ΣREE ranges between 3645.98 to 5099.56ppm (ΣREE ranges between 3525. 85 to 4928.46ppm and ΣHREE ranges between 120.13 to 171.10ppm). The ore microscopic studies have indicated presence of sulphide mineralization that of pyrite, chalcopyrite and arsenopyrite. Main REE phases identified by EPMA study in carbonatite include ancyclite, belovite, bastnasite, britholite associated with calcite and apatite. Appreciable amount of REE were also analysed in pyrochlore

grains associated with magnetite in carbonatite sections by probe analysis. XRF analysis of carbonatite indicate that carbonatite of SUACC correspond to calico carbonatite on the chemical classification diagram. The isotope data scatter diagram indicates that the Sung valley carbonatites plots in the field of primary igneous carbonatites. Fluid Inclusion study indicated the presence of primary and secondary mono-phase/bi-phase inclusions in the samples. Primary bi-phase inclusions are seen as isolated inclusions and their shapes are oval, spherical, rounded, irregular and faceted. Secondary inclusions are smaller and insignificant in their sizes which show rounded, sub-rounded and faceted shapes are seen along healed fractures in linear fashion. The homogenisation temperature varies from 185°C to 362°C (average 258.95°C) which corresponds to a salinity range of 0.83 to 8.65 wt.% NaCl equivalent (average 3.25 wt.% NaCl equivalent).

Recommendation

During FSP 2010-12 Bed rock samples collected from 11 carbonatite bodies have indicated anomalous values of REE, samples from apatite-magnetite rock have indicated high values of Sn, W and U values and few stream sediment samples also indicated encouraging values of REE. These anomalous values warrant detailed investigation (G3) to assess REE potentiality. Hence, it is recommended that in future the area may be covered by Detailed Mapping, systematic collection of samples by pitting and trenching (subsurface sampling) and one stratigraphic borehole to get the clear sub-surface picture of the target area. Moreover, in order to assess the potentiality of REE mineralisation in laterite, developed over pyroxenite of Sung Complex, Detail Sampling is highly recommended.

UNFC Classification Scheme

UNFC scheme provides information about stage of geological assessment, the stage of feasibility assessment and degree of economic viability. This investigation comes under the code of **334 of UNFC.**

REFERENCES

Acharya SK, Mitra ND & Nandy DR (1986) Regional geology and tectonic setting of northeast India and adjoining region. Geol. Surv. India 119: 6– 12

Bodnar RJ (1983) A method of calculating fluid-inclusion volumes based on vapor bubble diameters and P-V-T-X properties of inclusion fluids. Econ. Geol., 78: 535-542.

Borisenko AS (1977) Study of the salt compositions in gas liquid inclusions in minerals by the cryometric method. Soviet Geology & Geophysics. 18: 11-19.

Brown PE & Lamb WM (1988) P-V-T properties of fluids in the system H2O-CO2-NaCl: New graphical presentation and implications for fluid inclusion studies. Geochim Cosmochim. Acta, 53:1209- 21.

Chakraborty SK & Thapliyal AK (2000) Petrology and geochemistry of the sung valley alkaline-ultramafic-carbonatite complex, Meghalaya. GSI progress report (Unpublished)

Chattopadhyay N (1979) Report on the investigation of the Sung Valley Ultramafic-Carbonatite complex, Khasi and Jaitia Hills, Meghalaya. GSI progress report (Unpublished)

Chattopadhyay N, Hashimi S (1984) The Sung Valley alkaline–ultramafic–carbonatite complex, East Khasi and Jaintia Hills districts Meghalaya. Rec. Geol. Surv. India 113:24–33

Chattopadhyay N et. al., (1991) Final report on the investigation of phosphate in Sung Block, Sung Valley Complex, East Khasi and Jaitia Hills, Districts Meghalaya. Unpub. GSI report for F.S. 1980-1984

Deines P (1989) Stable isotopic variations in carbonatites. In: Bell K. (Ed), Carbonatite-Genesis and Evolution. Unwin Hyman

El-Ahmady IM (2010) Laterites-bearing REEs, Wadi Natash, Southeastern Desert, Egypt. Journal of Rare Earths, Vol. 28, No. 3, pp. 471

Geology and Mineral resources of Meghalaya, Geologica Survey of India, Miscll Publ. 30 (IV), vol. 2 (ii), 2009

Giovanni R, Michel C, Marie CB & Marigna C (1999) Boiling and fluid mixing in the chlorite zone of the Larderello geothermal system. Chemical Geology, vol.154, p.237-256.

Ghosh S, Chakrabarty S, Paul DK, Bhalla JK, Bishui PK, Gupta SN (1994) New Rb–Sr isotopic ages and geochemistry of granitoids from Meghalaya and their significance in middle to late Proterozoic crustal evolution. Indian Minerals 48: 33–44

Gogoi K (1972) Geological mapping in parts of Khasi and Jaintia Hills, Meghalaya. GSI progress report (Unpublished)

Golani PR (1991) Nangcharam fault: a major dislocation zone from western Meghalaya. J Geol. Soc. India 37: 31–38

Gupta RP & Sen AK (1988) Imprints of Ninety-East Ridge in the Shillong Plateau, Indian Shield. Tectonophysics 154: 335– 341

Hoefs J (2009) Stable Isotope Geochemistry, Springer, XII, 288p. Keller J & Hoefs J (1995) Stable isotope characteristics of recent natrocarbonatite form

Oldoiyno Lengai. In: Bell, K., Keller, J. (EDs.), Carbonatite Volcanism: Oldoinyo Lengai and Petrogenesis of Natrocarbonatite. Springer, Berlin, pp. 113- 123. London, pp. 301-359

Kelly & Turneaure (1970) Mineralogy, paragenesis and thermometry of ore deposition of the tin and tungsten deposits of the eastern Andes, Bolivia. Economic Geology 65:609-680.

Krishnamurthy P (1985) Petrology of the carbonatites and associated rocks of Sung Valley, Jainita Hills district, Meghalaya, India. J. Geol. Soc. India 26:361– 379

Le Bas MJ (1977) Carbonatite–Nephelinite Volcanism. Wiley, New York, N.Y. Majumdar SK (1976) A summary of the Precambrian geology of the Khasi Hills,

Meghalaya.Geol Surv. India Miscll Publ 23 (2): 311–334. Mandarino JA (1999) Fleischer's Glossary of Mineral Species1999. Tucson, AZ: The Mineralogical Record Inc.

Melluso L, Srivastava RK, Guarino V, Zanetti A and Sinha AK (2010) Mineral compositions and petrogenetic evolution of the ultramafic-alkaline-carbonatitic complex of Sung valley, northeastern india, The Canadian Mineralogist 48:205-229

Nambiar AR & Golani PR (1985) A new find of carbonatite from Meghalaya. Curr Sci. 54:281–282 Ray JS, Ramesh R & Pande K (1999) Carbon isotopes in Kerguelen plume-derived carbonatites: evidence for recycled inorganic carbon. Earth Planet. Sci. Lett. 170: 205–214.

Ray JS, Trivedi JR & Dayal AM (2000) Strontium isotope systematics of Amba Dongar and Sung Valley carbonatite–alkaline complexes, India: evidence for liquid immiscibility, crustal contamination and long-lived Rb/Sr enriched mantle source. J. Asian Earth Sci. 18:585– 594

Roedder E (1984) Fluid Inclusions. Reviews of mineralogy, vol.12, Min. Soc. America 644p.

Sen AK (1999) Origin of the Sung Valley carbonatite complex, Meghalaya, India: major element geochemistry constraints, J Geol Soc. India 53: 285-297

Sharp ZD, Essene EJ, Anovitz LM, Metz GW, Westrum EF, Jr Hemingway BS & Valley JW (1986) The heat capacity of monticellite and phase quilibria in the system CaO-MgO-SiO2-CO2. Geochim. Cosmochim. Acta 50:1475-1484.

Shepherd TJ, Rankin AH & Alderston DHM (1985) A Practical Guide to Fluid Inclusion studies, Blackie, Glassgow and London, 239p.

Srivastava RK, Hall RP (1995) Tectonic setting of Indian carbonatites. In: Srivastava RK, Chandra R (eds) Magmatism in relation to diverse tectonic setting. A.A. Balkema, Rotterdam, pp 134-154

Srivastava RK & Sinha AK (2004) The early Cretaceous Sung Valley untramafic-alkaline-carbonatite complex, Shillong Plateau, northeastern India: petrological and genetic significance. Mineral. Petrol. 80:241-263

Srivastava RK, Heaman LM, Sinha AK & Shihua S (2005) Emplacement age and isotope geochemistry of Sung Valley alkaline – carbonatite complex, Shillong Plateau, northeastern India: implications for primary carbonate melt and genesis of the associated silicate rocks. Lithos 81:33-54

Sukumaran PV (2012) The need to explore for rare earth minerals. Current Science, vol. 102, no. 6. Pp 839-841.

Storey M, Kent RW, Saunders AD, Hergt J, Salters VJM, Whitechurch H, Sevigny, JH, Thirlwall MF, Leat P, Ghose NC & Gifford M (1992) Lower cretaceous volcanic rocks on continental margins and their relationship to the Kerguelen Plateau. Proc. Ocean Drill. Program Sci. Result. 120:33-53

Taylor HP, Frechen J & Degens ET (1967) Oxygen and carbon isotopes studies of carbonatites from the Laacher Sea district, West Germany and the Alno district, Sweden. Geochim. Cosmochim. Acta 31:407-430

Veena K, Pandey BK, Krishnamurthy P & Gupta JN (1998) Pb, Sr and Nd isotopic systematics of the carbonatites of Sung Valley, Meghalaya, northeast India: implications for contemporary plume-related mantle source characteristics. J. Petrol. 39:1875-1884

Viladkar SG, Schleicher H & Pawaskar P (1994) Mineralogy and geochemistry of the Sung Valley carbonate complex, Shillong, Meghalaya, India. Neues Jahrb. Mineral., Monatsh H.11, 499-517

Wolley AR, Kempe DRC (1989) Carbonatite: Nomenclature, average chemical compositioned and element distribution. In: Bell K (ed) Carbonatite genesis and evolution. Unwin Hyman, London pp 1-37

Yusuf S & Sarasvat AC (1977) A preliminary note on carbonatite of Sung valley, Jaintia Hill district, Meghalaya Curr Sci 46:703-704

Zhang YG & Frantz JD (1987) Determination of the homogenisation temperatures and densities of superficial fluids in the system NaCl-KCl-CaCl2-H2O using synthetic fluids inclusions. Chem. Geol 64:335

LOCALITY INDEX

(Toposheet 83 C/02)

Name of the village	Latitude	Longitude	Toposheet no
Byrthap	25°32'60"	92°07'20"	83 C/02
Lumkynthang	25°35'20"	90°07'02"	
Maskut	25°34'09"	92°07'35"	
Mawdymai	25°30'25"	92°08'07"	
Mookyndur	25°32'00"	92°08'20"	
Nirang	25°31'10"	92°07'10"	
Sung	25°34'00"	92°06'40"	
Thadmassum	25°30'10"	90°09'20"	
Tyrshang	25°32'30"	92°08'55"	
Ummulong	25°31'00"	92°09'10"	

DATA REPORT FOR COSTING

1	Title of investigation	Preliminary Search for REE in the peripheral part of Sung Ultramafic-Alkaline-Carbonatite Complex, East Khasi Hills District, Meghalaya (G_4 Stage)
2	Item Code	ME/NER/SME/2010/018
3	Field Season	2010-2012
4	Toposheet no.	83 C/02
5	Area and co-ordinate	N25°30'00″: 25°35'30″ E92°07'00″ : 92°09'00″
6	Number of Geologist's associated	Two
7	Total number of Geologist's man days	263
8	Large Scale Mapping @ 1: 12500	30 Sq. Km
9	Number of Rock samples analyzed	74+02 (PGE)
10	Number of Rock samples analyzed by XRF	25 Nos.
9	Number of Rock samples analyzed (Channel Sample)	14 Nos.
9	Number of Stream Sediment Samples analyzed	31 Nos.
10	Number of Polished Sections Studied	20 Nos.
11	Number of Samples collected for fluid inclusion studies	23 Nos.
12	Petrological Sections	10+13 Nos. (EPMA Study)
13	C & O isotopes study	06 Nos.

Cost Estimate for Sung Valley Block, East Khasi and West Jaintia Hills Districts, Meghalaya state, (G-4 stage) of ion-adsorption and laterite hosted supergene enriched ree deposits under nmet

Name of the Exploration Agency - The Directorate of mineral resources, Govermemt of Meghalaya, Shillong

Total Area - 35 sqkm; Nos. of Borehole -12 ; Completion Time - 18 Months

S.N	Item of Work	Unit	Rates as per NMET SoC		Estimated Cost of the Proposal		Remark
			SoC-Item -Sl No.	Rates as per SoC	Qty.	Total Amount (Rs)	
A	**GEOLOGICAL WORK**						
1	**Geological mapping (1:5000) & sampling**						
a	Charges for one Geologist per day at HQ	one Geologist per day	1.3	9,000	70	6,30,000	
b	Charges for two Geologist per day at field (2 Nos)	one Geologist per day	1.3	11,000	140	15,40,000	
c	Labour (2Nos/ geologist)	per Labor day	5.7	494	280	1,38,320	Amount will be reimburse as per the notified rates by the Central Labour Commission or respective State Govt. - whichever is higher
e	Charges for one Sampler per day (1 Party)	one sampler per day	1.5.2	5,100	120	6,12,000	
f	Labour (4 Nos/ sampler)	per Labor day	5.7	494	240	1,18,560	Amount will be reimburse as per the notified rates by the Central Labour Commission or respective State Govt. - whichever is higher
2	**Trenching**						
a	Excavation of Trenches upto 2m depth	per cu m	2.1.3	5,330	160	8,52,800	
	Sub-Total -A					**38,91,680**	
B	**Petrological samples (Surface & Bh Core Samples)**						
i	Preparation of standard thin sections	Nos	4.3.1	2,353	50	1,17,650	
ii	Complete Petrographic/Ore microscopy Study/Mineragraphic	Nos	4.3.4	4,232	50	2,11,600	
iii	Preparation of unmounted polished section of rock	per sample	4.3.3	1,185	50	59250	
	Sub-Total -B					**3,88,500**	
C	**Digital Photograph of thin polished section**						
i	Digital Photographs	Nos	4.3.7	280	50	14,000	
	Sub-Total -C					**14,000**	
D	**LABORATORY STUDIES**						
1	**Chemical Analysis**						BH depth more than 100m has been considered for deviation.
a	Samples for REE and Trace using ICP-MS 48 radicals (40 BRS+ 200 Soil+ 25 Check + 75 Pit + 250 Borehole + 10 water sample = 600)	Nos	4.1.14	7,371	600	44,22,600	
b	Samples for Major Oxide by XRF (20 BRS+ 50 Soil + 5 Check + 25 Pit + 75 Borehole = 175)	Nos	14.1.15a	4,200	175	7,35,000	
c	Samples for Mineral identification using XRD (10 BRS+ 20 Soil + 3 Check + 17 Pit + 35 Borehole = 85)	per sample	4.5.1	4000	85	340000	
d	Samples for Mineral mapping using Qemscan (14 BRS+ 15 Soil + 1 Check + 10 Pit + 30 Borehole = 70)	per sample	--	20000	70	1400000	Given rates for EPMA is 8540 per hour and each sample ususally takes 2.5-3 hour in detailed study, In this prices Qemscan around 20000 per sample is better as it can study minerology of thin section with large area, fast mineral identification.
d	Samples for ion chromatography 10 water sample	per sample	4.1.8a	3680	10	36800	
	Sub-Total -D					**69,34,400**	
E	**Manpower**						
i	i) Project Associate	Nos	5.7	25,740	2	6,17,760	Minimum wages as per the order F. No. 1/5(2)/2023-LS-II Government of lndia, Ministry of Labour & Employment, Office of the Chief Labour Commissioner, New Delhi, dated 03/04/2023
	Sub-Total E					**6,17,760**	
F	**DRILLING (After Review)**						
i	Drilling up to 1560m (Hard Rock)	m	2.2.1.4a	11,500	1560	1,79,40,000	(12 BH, 130m Hole, Expploratory Diamond Core Drilling, Combination of Dry & Wet Drilling)
ii	Drilling Borewell for Groudnwater sample	m	nil	4,000	300	12,00,000	
iii	Drilling camp setting cost	per drill	2.2.9a	2,50,000	5	12,50,000	
iv	Drilling camp winding cost	per drill	2.2.9b	2,50,000	5	12,50,000	
v	Approach road making for rugged-Hilly terrain	per km	2.2.10b	32,000	60	19,20,000	Extreme hilly terrain, road will be made maintaining gradient for safe transportation
vi	Transportation of drill rig & truck associated per drill	per km	2.2.8	36	200	7,200	
vii	Monthly accomodation charges for drilling camp	Monthly basis	2.2.9	50,000	5	2,50,000	
viii	Drill core preservation	per m	5.3	1,560	1560	24,33,600	
ix	Land/crop compensation	per BH	5.6	50,000	12	6,00,000	

S.N	Item of Work	Unit	Rates as per NMET SoC		Estimated Cost of the Proposal		Remark
			SoC-Item -Sl No.	Rates as per SoC	Qty.	Total Amount (Rs)	
	Sub Total F					2,68,50,800	
	Total -(A to F)					3,86,97,140	
G	Contingency (F)	Nil	Nil	Nil	Nil	5,00,000	
G	Preparation of Exploration Proposal (5 Hard copies with a soft copy)	5 Hard copies with a soft copy	5.1	2% of the Cost subject to a maximum of Rs. 5 lakh		7,73,943	This amount will be reimburse after submission of the Hard Copies and the soft copy of the final proposal along with Maps and Plan as suggested by the TCC-NMET in its meeting while clearing the proposal.
H	Geological Report Preparation	5 Hard copies with a soft copy	5.2	For the projects having cost exceedingn Rs. 150 lakhs but less than Rs. 300 lakh - A minimum of Rs. 7.5 lakhs or 3% of the value of work whichever is more.		11,60,914	This amount will be reimburse after submission of the final Geological Report in Hard Copies (5 Nos) and the soft copy to NMET by the EA.
I	Peer review Charges		As per EC decision			30,000	
J	Total Estimated Cost without GST					4,11,61,997	
K	Provision for GST @ 18%					74,09,159	GST will be reimbursed as per actual and as per the applicable notified rate
L	Total Estimated Cost with GST					4,85,71,156	
					or Say in Lakhs (Rs.)	*485.71*	

Note:

1. If any part of the project is outsourced, the amount will be reimbursed as per the Paragraph 3 of NMET SoC and Item no. 6 of NMET SoC.

2. In case of execution of the project by EA on its own, a Certificate regarding non outsourcing of any component/project is required.

TIME SCHEDULE /ACTION PLAN FOR PROPOSAL FOR SUNG VALLEY BLOCK, EAST KHASI AND WEST JAINTIA HILLS DISTRICTS, MEGHALAYA STATE, FOR RECONNAISSANCE SURVEY (G4 STAGE) OF ION-ADSORPTION AND LATERITE HOSTED SUPERGENE ENRICHED REE DEPOSITS UNDER NMET

Sl. No.	Activities	Unit	MONTHS									Total
			01-02	03-04	05-06	07-09	Review	10-12	13-14	15-16	17-18	
1	Geologist Party days (1 Party)	day		45			Review	25				70
2	Sampling Party days (1 party)	day		30			Review	30	10			70
7	Laboratory Studies	Nos.		30	30	30	Review	30	30	30		180
8	Geologist Party days (1 Party), HQ	day	15			30	Review				30	75
4	Core Drilling (12 rigs)	m.					Review	1560				1560
5	Camp Setting	day					Review	15				15
6	Camp Winding	day					Review	15				15
9	Report Writing	day					Review				60	60

NOTE

1	**Commencement of project may be reckoned from the day the exploration acreage is available along with all statutory clearances.**
2	**Time loss on account of monsoon/agricultural activity/forest clearance / local law & order problem/ lockdown etc will be additional to above time line.**