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Geochemistry study of the Lohit Granitoide Complex (LGC): Implication of tectonic setting of the LGC in Trans Himalayan Belt, Arunachal Pradesh, India

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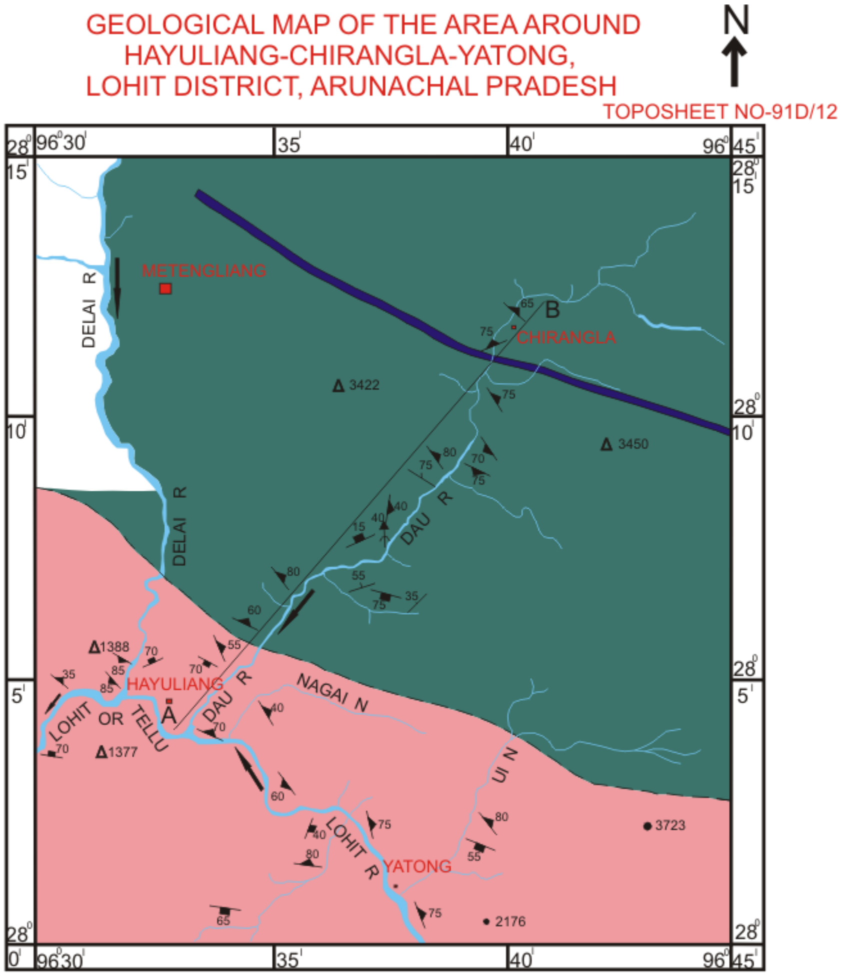
Abstract:
The study area situated in the eastern Arunachal Pradesh forms a part of the Trans-Himalayan belt which is also known as the Lohit Himalaya. The main stratigraphic units of the area are Lohit Granitoid Complex and Etalin Formation, and their contact is intrusive in nature. The Lohit Granitoid Complex forms the most conspicuous unit in the eastern Arunachal Pradesh. It consists of multi variant plutonic rocks of multiphase character with several restites of high grade metasediments. The granitoids include diorite, granodiorite, tonalite, hornblende-biotite granite and leucogranite. The high grade restites are designated as Etalin Formation. The overall bulk composition of the Lohit Granitoid is dioritic to quartz dioritic. After analysing the geochemical data, it has been deciphered that Lohit granitoid is I-type, calc alkaline and metaluminous in nature. This granitoid represents the Andean type magmatism due to melting of the north dipping Tethyan oceanic crust below an island arc situated along the southern margin of Eurasia.

Keyword: Lohit Granitoid Complex, Geochemistry, Lohit Himalaya

Introduction:
The Arunachal Himalaya occupies the easternmost part of the great Himalayan mountainrange. The studied area belongs to the part of eastern Arunachal Pradesh also known as the Lohit Himalaya. This part shows some peculiarities in comparison to rest of the Himalaya. The major tectonic unit shows bend in their regional strike from NE-SW to NW-SE and this bend is known as Eastern Himalayan Syntaxis (EHS), which represents a major antiformal structure known as Siang antiform(Singh, 1993) or the Siang Window. The present area of study is part of eastern limb of the EHS (Fig:1). The region is considered to be the part of central Burmese plate which abuts against the Indian plate along the Tiding suture (Nandy, 1980). From south to north the Himalayan mountain belts is characterised by the Siwaliks, theLesser Himalaya, the Higher Himalaya, the Tethyan Himalaya, the Indus-Tsangpo Suture zone and the Trans–Himalaya. They are defined by linear and major tectonic boundaries like the Himalayan Frontal Fault (HFF) i.ethe boundary between the Ganges/ Brahmaputra alluvial plain and the Siwalik created between 10-0Ma, the Main Boundary Thrust(MBT), boundary between the Siwaliks and the Lesser Himalaya and Gondwana created between 20-10Ma, the Main Central Thrust (MCT) between the Lesser Himalaya and the Higher Himalayan Crystallines created between 40-20Ma (Johnson, 2002, Lyon-caen and Molnar,1983) and the South Tibetan

Detachment System (STDS) separating the Indian and the Tibetan Himalaya which is not exposed in the Arunachal Pradesh (Kumar, 1997). However the EHS has developed much later than the other Himalayan major tectonic events i.e. about 4 Ma ago (Burg *et al.*, 1997). Therefore on the basis of structural-tectonic setup the Arunachal Himalaya is divided into two main domain, the western and the eastern part, separated by the Siang windows directly south of the EHS. The Lohit Himalaya also called as Mishmi Hills is characterised by three distinct features. First, NW-SE regional trend as compared to NE-SW in the Himalayan part to the west.Second, absence of Gondwana and Siwalik sequences. Third the presence of ultrabasic and granodiorite complex associated with metasediments showing varying degree of metamorphism. In general the geology of Lohit Himalaya is represented by 4-lithotectonic units from SW to NE which are: the rocks of the Lesser Himalaya, the Mishmi Crystallines/Higher Himalayan crystallines, the tidding Suture zone and the Lohit Plutonic complex (Gururajan and Choudhary, 2003). The foot hill is represented by Brahmaputra alluvium and Tipams of Assam. The Siwaliks and Gondwana group of rocks do not extend to the eastern limb of the syntaxis, where they are probably overlapped or cut-off by the Mishmi thrust. The Lesser Himalayan rocks consist of non-metamorphic to low grade chlorite facies of sedimentary sequences. The rocks of the HigherHimalayan crystallines exhibit inverted metamorphism and are divided into two units: the lower Bomdila Group and the upper Sela Group (Verma and Tandon, 1976). Of these two, only the Bomdila Group extends into the eastern limb of the syntaxis(Kumar, 1997), where they are known as the Mishmi crystallines(Thakur and Jain, 1975). According to them the rocks of the Tidding Suture zone represent an ophiolitic melange which thrust over the Mishmi crysatllines and in turn are thrusted over by the Lohit Plutonic Complex along the Lohit Thrust(?).



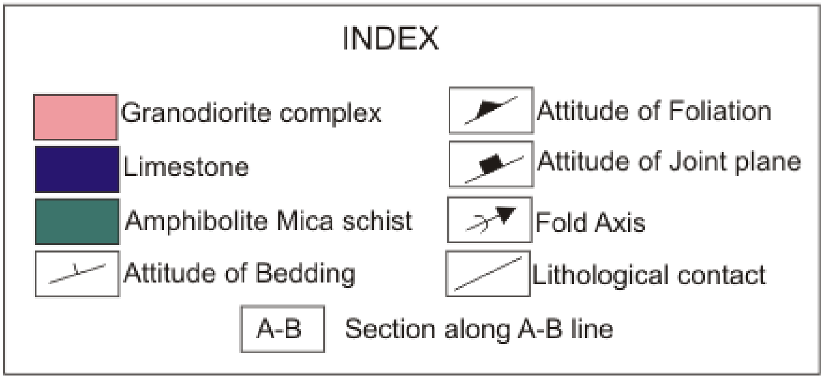


Fig 1: Geological map of the study area

Geology of study area:

Due to extreme remoteness, inaccessibility, hostile terrain and dense vegetation most of the area still remains out of reach for detailed geological study and overall the geological data on this crucial segment still remains limited. Foliations were very rare to get in this area and are developed in quartzites and in schistose rocks. The parallel alternate arrangement of biotite, chlorite, hornblende and quartz and feldspar wherever are rich in silica grains impart a diffused layered look (compositional colour banding) which may also be transposed foliation(Fig 2&3). The general trend of the rock is NW-SE with moderate to steep dip towards NE. The area has undergone 3 generation of folding. The F2 folds are the most dominant fold pattern observed in the area and are co-axial with F1 folds. The first generation of folding is represented by very tight to isoclinals folds. The intensity of deformation was very high as the imprints of F1 folding is also observed in Lohit granitoids as well as the second generation of folding which is dominant over the area. The second generation folding is manifested by M-Z type, S type, Hook shaped folds and other types of fold. The second generation fold (F2) becomes co-axial with F1 folds with progressive deformation and forms the dominant foliation pattern in the area which is NW-SE with moderate to steep dip towards NE. The coaxial F1 and F2 folding pattern gives a layer of alternate light colour silica rich and mafic rich layers. The third generation of fold is observed in the form of broad warps and open fold trends NE-SW with moderate dip towards NW and SE. Other deformational features observed in the area are boudins, related with folds of flexure slip where the stretching of outer layer in the hinge zone is accommodated by pull apart of beds and formation of boudins.

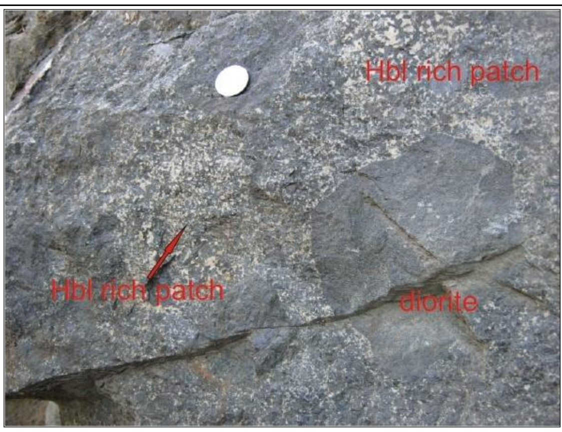


Fig 2: Segregation of hornblende rich patches in the diorite. Loc: In between Kholiang and Yatong village.

Fig 3: Undigested patch of hornblende chlorite schist within the diorite. Loc: In between Kholiang and Yatong village.

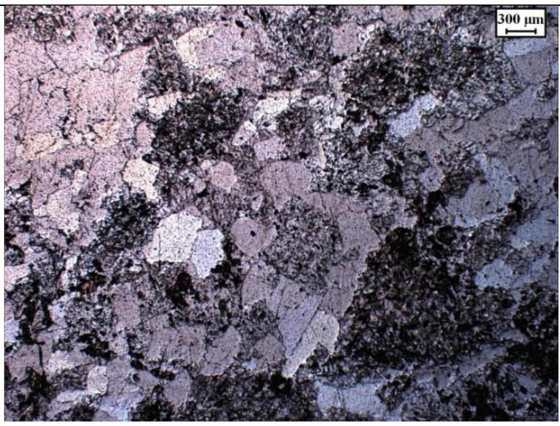


Fig 4: Photomicrograph showing subhedral grains of quartz and saussuritised feldspar with inequigranular and interlocking texture.

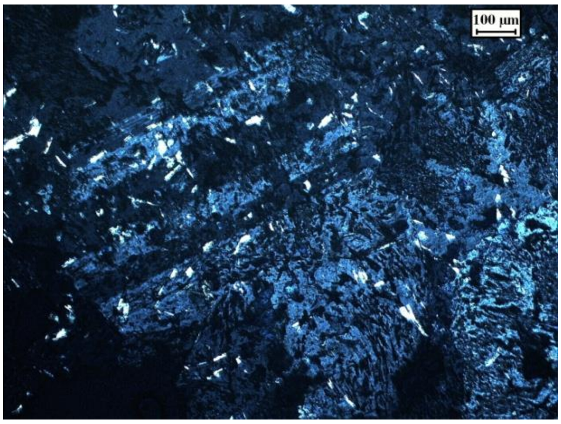


Fig 5: Saussuritised feldspar grain showing relict lamellar twinning.

Petrography study of LGC :

This complex exhibits a wide variation in its mineralogical composition and texture and is exposed around Hayuliang-Chipru, Hayuliang- Khupa and Hayuliang-Yatong road sections and occupies the major part of the mapped area. This suite of rock is a heterogeneous in composition varies from quartz diorite to granodiorite to tonalite. It is greenish grey in colour, medium to coarse grained, hard and compact comprising feldspar mainly plagioclase, quartz, muscovite and mafic accessories includes amphiboles, chlorites and pyroxene in minor proportion. Concentration of major oxides (in wt%) such as SiO_2, Al_2O_3, Fe_2O_3(T), Na_2O, K_2O, P_2O_5, MnO and MgO varies from 48.29 to 69.58, 5.73 to 19.6, 0.7-11.32, 0.41-6.32, 0.02-4.08, 0.03-0.73, 0.01-0.19 and 0.47-12.03, respectively. At places it is foliated showing NW-SE trend with moderate dip towards NE. A leucocratic variety of granodiorite is present which is more quartz rich and gives an appearance of leucogranite. Near Teapani village in Hayuliang-Metengliang road diorite is cross-cut by the veins of leucocratic granodiorite where chilled margin is also observed. This suggests that there exist at least two phases of magmatism. A lath of hornblende has formed with random orientation wherever there is an intrusion of leucocratic granodiorite vein. It can be inferred that this is a product of contact metamorphism and is related to later stage intrusion event. At places it shows some compositional segregation which is hornblende rich. These pure hornblende rich patches might be representing the meta somatically segregated masses or the undigested patches of the country rock (hbl-chl-schist) or it may also be a feature of magma mixing and mingling which is not prevalent throughout. Whole area represented by this rock shows an anatomizing pattern of joints. It is intruded by a number of norite dykes and amphibolites bands. The Granodiorite-diorite complex contains xenoliths of hornblende chlorite schist of Etalin Formation as well as the occurrences of granodiorite-diorite as tongues and apophyses within Etalin Formation points to its intrusive nature. So, its contact with the Etalin Formation is established as intrusive. At some places (near Goiliang village), migmatites have also been observed near the contact/intrusion**.** It is also noticeable that no thermal effect like chilled margins is found neither at contact of dioritic mass with the schists of Etalin Formation nor at the contact of noritre dyke or amphibolites with the granodiorite-diorite mass.

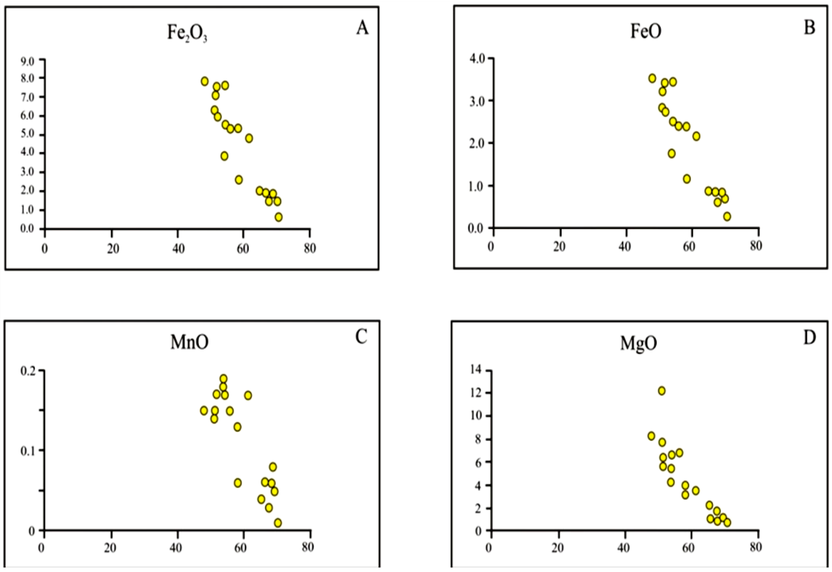
Microscopically, the rock is coarse grained and composed of plagioclase, quartz, biotite, muscovite, hornblende, chlorite and epidote(Fig 4&5). Quartz and plagioclase is the dominant mineral phases present in the rock. Quartz grains are euhedral in shape with serrated grain boundaries with plagioclase. Quartz grains are polycrystalline in nature and shows wavy extinction. Stretched quartz grains are noticed along some weak plane. Grain size reduction has been seen due to shearing, which is much localised. Feldspar grains are lath shaped, subhedraland medium to high relief with dusty appearance. Plagioclase feldspars are mostly saussuritised and altered to muscovite, chlorite and apatite with relict lamellar twinning. Potassium feldspar showing cross hatch twinning and are not altered. Among ferromagnesian minerals hornblende is the major constituent and it occurred as primary as well as secondary hornblende. Primary hornblendes have interlocking/serrated grain boundaries with plagioclase and quartz whereas secondary hornblendes are altered to chlorite due to retrogressed metamorphism. Twinning in hornblende is also seen. The rock is coarse grained, subhedral to euhedral grain boundaries and minerals can be seen by naked eyes, representing phanerocrystalline-hypidiomorphic texture. Moreover the grain boundaries are serrated and interlocking, which represents the rock is having interlocking texture. The rock shows continuous size ranges of principle crystals, i.e. quartz and plagioclase, representing seriate texture. The rock is completely composed of crystals and devoid of any glassy material which indicate that the rock is holocrystalline. So, texturally the rock can be named as hypidiomorphicinequigranularholocrystalline rock.

Norite is well exposed on Hayuliang-Yatong road section and starts to occur only after village Kholiang and occurs beyond Yatong. It is fine to medium grained, purple colour rock occurring as tongues and apophyses of variable thickness within the crystallines. The trend is variable and scanty exposure restricts to know its structural setup. Microscopically, it is composed of orthopyroxene, plagioclase and clinopyroxene with biotite, hornblende and chlorite. Alteration along the orthopyroxene grain boundary is also seen. Orthopyroxene altered to hornblende along the grain boundaries, which is known as uralitisation. Feldspars are unaltered showing lamellar twinning with bend lamellas, indicating signature of deformation. The rock is coarse grained with well-defined crystal boundaries i.e. euhedral grain boundaries. The rock is almost equigranular. So texturally the rock is holocrystalline idiomorphic equigranular rock.

Modal analysis has been carried out of 15 numbers of petrographic thin sections by using Leica image analyser software in GSI, CHQ, Central Petrological Laboratory, Kolkata. More than 500 grains have been calculated per slide and were plotted in the QAP diagram (Streckeisen, 1976) to classify the granitoid rocks. The rocks mainly fall under granodiorite and diorite field. It is evident that the LohitGranitoid Complex represents heterogeneity in composition and it varies from granodiorite to quartz diorite to diorite.

Geochemistry and Tectonic Environment

The Lohit Granitoid represents the Andean type magmatism (Annexture:1) due to melting of the north dipping Tethyan oceanic crust (Scharer*et al.* 1984) below an island arc situated along the southern margin of Eurasia (Raz and Honegger 1989). The overall bulk (Fig:6) composition of the Lohit Granitoid for general comparision were ploted on Middlemost, 1985 (Fig:7) which comes under mainly diorite to gabbro-diorite field and few comes under granodiorite and granite field. Modal analyses of the samples, that comes under granite field, were carried out and it has found that there is no *sensustricto*granite present in the study area and all those samples were compositionally comes under granodiorite field (QAPF diagram, Streckeisen, 1976). The samples were also analysed on total alkali versus silica plot (Fig:8) (Middilemost, 1994) and the distribution displays Quartz- Diorite to Granodiorite character of Lohit Granitoid Complex (LGC), which is similar to field observation based on megascopic character. The samples of LGC cannot be plotted and classified according to De la Roche *et al.*, 1980 as it is less suitable for granitic rocks because Kfeldspar and albite plot at the same point (Frost *et al.*, 2001). The distribution of LohitGranitoid, when plotted on AFM diagram (Fig:9) and SiO_2vs K_2O distribution diagram after Peccarillo and Taylor (Fig:10), 1976, shows that the magma is dominantly calc-alkaline and in nature. Frost *et al.,* 2001(Fig:11&12) introduced a new classification scheme of granitic rocks using modified alkali lime index (MALI), which is based upon alkali lime index classification. The Lohit Granitoid shows calc-alkalic to calcic in nature with Na_2O+K_2O+CaO value ranges from 8.09 to 5.8, when plotted in SiO_2vs Na_2O+K_2O-CaO plot. These plutonic rocks are having <70 wt% SiO_2 with Fe no. [FeO/(FeO+MgO)] <0.6 (ranges from 0.21 to 0.47), which are of magnesian character with having closer affinity to Cordilleran granites when plotted in SiO_2vsFeO/(FeO+MgO) plot described after Frost *et al*., 2001. The distribution of Lohit Granitoid on Batchelor and Bowden, 1985 plot(Fig:13) shows that the magma for Lohit Granitoids is a factor of mantle fraction and syn to pre plate collision. Lohit Granitoid Complex. According to Shand's Index 1943,(Fig:14) the composition of Lohit Granitoid is dominantly metaluminous to weakly peraluminous having A/NK value (molar) ranges from 1.2 to 6.8 and A/CNK value (molar) ranges from 0.2 to 1.3. Results of REE data of Lohit Granitoid Complex are presented. The REE data were normalised to Primitive mantle values after McDonough *et al*., 1991(Fig:15) and were presented on a concentration vs atomic number diagram using Microsoft Excel Program. The REE pattern shows enriched LREE pattern with a decreasing trend from La-Nd with a moderate to feeble Eu anomaly whereas the HREE (Er to Lu) shows almost a linear trend. In few samples HREE shows fractionated patterns. Distribution pattern of REE varies slightly in granodiorite and diorite. Granodiorites exhibits low to slightly enriched REE pattern with (La/Yb)N ratio 0.16 to 2.38, slightly enriched LREE pattern with (La/Sm)N ratio 1.77 to 2.86 and very low to almost flat HREE pattern with (Tb/Yb)N ratio 0.56 to 0.93. Whereas diorite shows medium enriched fractionated pattern with (La/Yb)N ratio 3.36 to 8.2, moderately enriched LREE pattern with (La/Sm)N ratio 3.06 to 4.89 and almost flat HREE pattern with (Tb/Yb)N ratio 1.06 to 1.39. The total average REE content of granodiorite is 83.02 and diorite is 85.30. Granodiorite exhibits very small Eu anomaly with Eu/Eu* value ranges from 0.75 to 0.85. Similarly diorite also exhibits weak Eu anomaly with Eu/Eu* value ranges from 0.64 to 0.79. Europium occurs in +2 valence state and can readily substitute for Sr+2 to Ca+2 in plagioclase. So, when a plagioclase bearing rock is melted to produce magma and plagioclase remains as a residual solid phase, then the resulted magma will be Eu depleted. This indicates the presence of plagioclase in the parent rock. Under pressure, plagioclase converts to spinel at a depth of 20-30 km. Hence if the rare earth shows negative Eu anomaly then it can be said that the magma has generated at a depth less than 30 km that means from the crust. In this case the Eu anomaly is expected to be much steeper but the Eu anomaly is moderate to shallow, which may be attributed to the involvement of mantle material within it. So, it can be said that either the magma has a mixed origin involving both crustal as well as mantle material or magma has been generated at a depth near to the mantle. Negligible Eu anomaliesmay also results by the presence of equal amount of clinopyroxenes and plagioclase or twice as much plagioclase as hornblende in the residue (Hanson, G. 1978). Whereas depletion in MREE (Middle REE) and HREE (High REE) may be attributed to the presence of hornblende and clinopyroxenes in the parent rock. It can be said that granitic rocks have generated either by partial melting of mantle or by melting of rocks of intermediate composition like basaltic rocks. Trace element discrimination diagrams have been used to fingerprint the tectonic setup of plutonic rocks by many workers (e.g. Pearce *et al.,* 1984)(Fig:17). Sometimes however the complicated petrogenetic history of granites makes their chemical composition difficult to interpret. All the trace elements are normalized using Upper Continental Crust values (Taylor and McLennan, 1985) (Fig:16) and are plotted in multi elemental diagram. Granitoid shows significant depletion in Rb, Ba, U, &Hf and high content of Th, and Sr with respect to UCC The samples of LohitGranitoids were plotted on multi elemental plot normalized by ocean ridge granites after Pearce et al 1984, the granitoids are characterized by enrichment in Th and Ce relative to Rb, Ta and Hf. Further Hf has very low value relative to normalizing composition. The pattern is indicative of similarity with Volcanic Arc Granite (VAG) of Pearce *et al.*, 1984(Fig:18). Selective enrichment like Th relative to Ta and Ce relative to adjacent elements can be attributed to crustal involvement. Concentration of Sr increases from granodiorite (Sr: 81-221 ppm) to diorite (Sr: 118-1697 ppm) and concentration of Zr in granodiorite ranges from 133-187 ppm and in diorite it ranges from 15-223 ppm. In contrast, Rb and Rb/Sr ratio decreases from granodiorite to diorite. Rb/Sr ratio in granodiorite is 0.04-0.14 and in diorite it is 0.002-0.008. Rb has larger radius than K. Consequently, Rubidium is always admitted in to potassium minerals such is biotite and potassium minerals. Since potassium is the only major element Rubidium can replace, Rubidium concentration in the melt increases with differentiation. Strontium, on the other hand, can replace two major elements: calcium and potassium. According to Bowen's reaction series Ca bearing minerals crystallizes earlier with progressive crystallisation, so admittance of Sr in place of Ca is the dominant process of removal of strontium from the magma. Hence, with progressive crystallisation Sr systematically decreases in the melt. This is why, Sr value decreases from diorite (Sr: 118-524 ppm) to granodiorite (Sr: 81-233 ppm). Ba has the larger ionic radius and can be comparable with the ionic size of potassium, so barium is captured by potassium compounds. It therefore appears in biotite and potash feldspar. Thus crystallisation of these minerals contributes to reduction of Ba in the melt. Low value of Co, Ni and Cr role out the possibility of a peridotite parental source since higher value of Ni, Co and Cr are good indicators of parental magma from a peridotite mantle source.Rb value ranges from 3 to 35 ppm and Y+Nb value ranges from 8 to 48 ppm. These two components were widely used to determine the tectonic setting of the granitoid rock introduced by Pearce *et al.,* 1984. Geochemical characteristics of Lohitgranitoid complex, on Rb versus (Yb+Nb) plot after Pearce *et al.,* 1984, represent the tectonic setting of volcanic arc granitoids. On combining and correlating the results of all geochemical plots, it can be said that the LohitGranitoid is dominantly quartz-dioritic in composition having Calc-alkaline nature of magma which is metaluminous. The magma has mixed origin involving both crustal component as well as mantle material forming in a subduction zone environment. So based on analogy the LohitGranitoid can be said as I-type granite of Chappel and White, 1974, VAG granites of Pearce *et al.*, 1984, and magnesiangranitoid type of cordilleran Batholiths of Frost *et al.,* 2001.



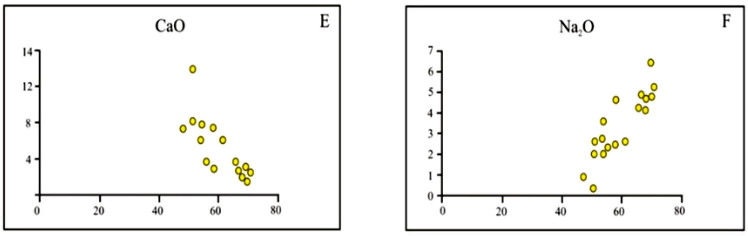


Fig:6 Harkar diagram showing distribution of oxide percentages with increase in SiO_2 percentage in Lohit Granitoid Complex.

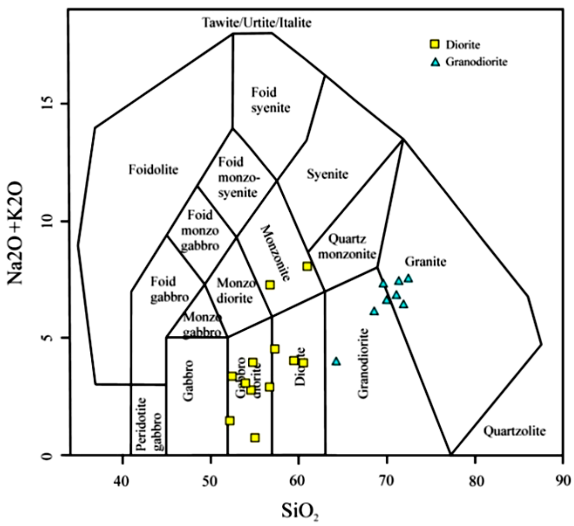


Fig 7:Discrimination diagram of LGC after Middlemost, 1985

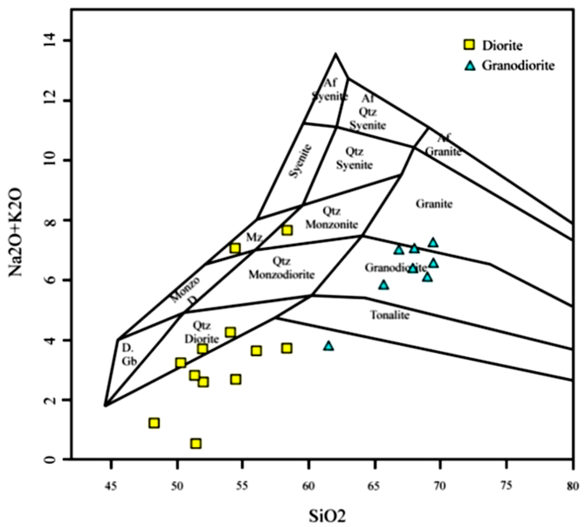


Fig 8:TAS diagram showing composition of LGC after Middlemost, 1994.

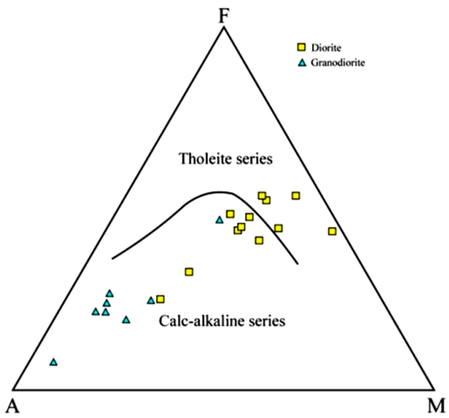


Fig 9:AFM diagram showing calc alkaline nature of LGC.Irvine Barager, 1971

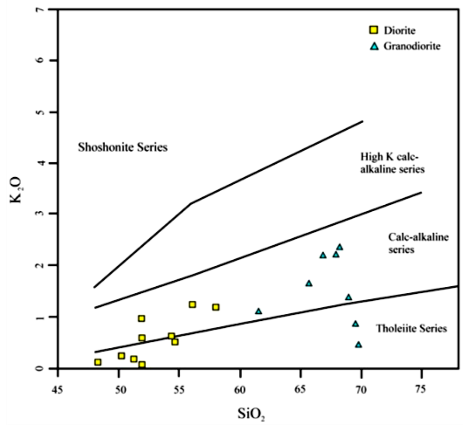


Fig 10: Diagram showing clac-alkaline to tholeiite nature of LohitGranitoids, after Peccarillo and Taylor, 1976.

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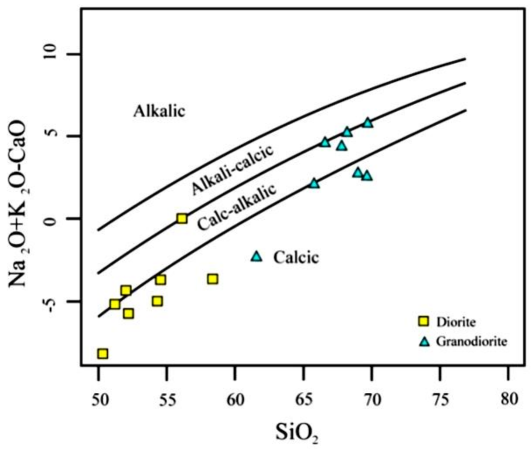


Fig 11: Diagram showing calc-alkalic to calcic nature of LGC after Frost *et al.*, 2001

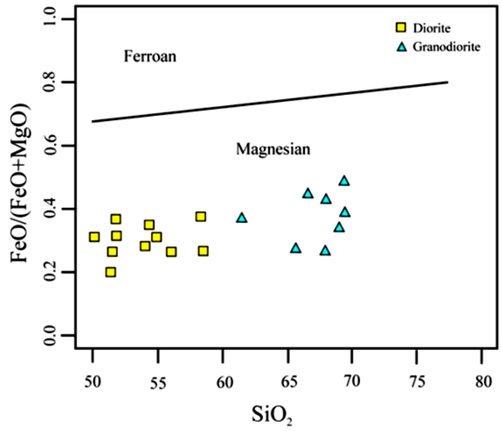


Fig 12:Diagram showing magnesium nature of LGC after Frost *et al.*, 2001.

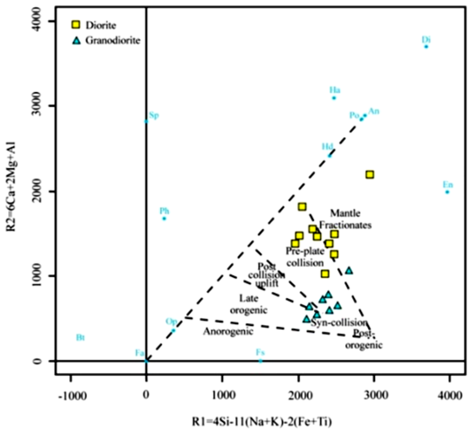


Fig 13: R1-R2 diagrams indicating mantle fractionate and pre plate collision character of LGC after Batchelor and Bowden, 1985

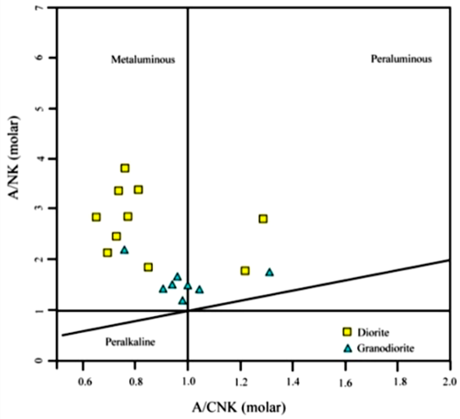


Fig 14: Diagram showing meta aluminous nature of LGC after Shand, 1943 showing meta aluminous nature of LGC.

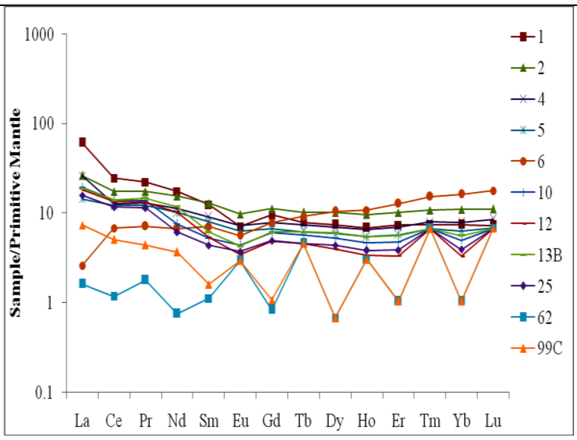


Fig 15: Rare earth element abundances of Lohit Granitoid Complex normalized to Primitive Mantle values after McDonough *et al.*, 1991

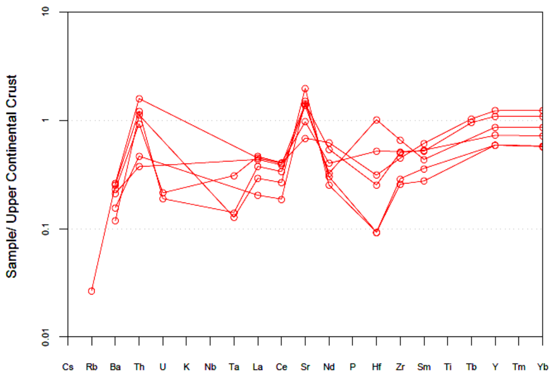


Fig 16: UCC normalized spider diagram for LGC after Taylor & McLennan, 1985

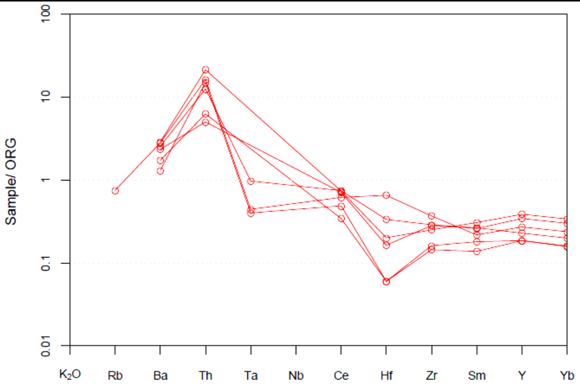


Fig 17:ORG normalized spider diagram for LGC after Pearce *et al.*, 1984.

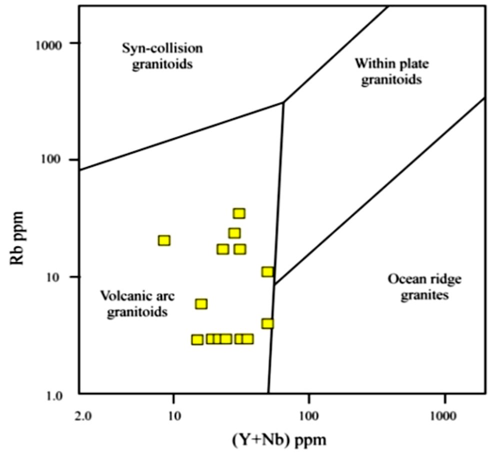


Fig 18: VAG diagram (Pearce, et. al. 1984).

Annexure-1 :Chemical Analysis of major oxides of LGC								
Sample No	AJ/13-14/HG/1	AJ/13-14/HG/2	AJ/13-14/HG/4	AJ/13-14/HG/5	AJ/13-14/HG/6	AJ/12-13/HY/10	AJ/12-	AJ/12-
							13/HY/12	13/HY/13B
Lithology	Diorite	Granodiorite	Granodiorite	Granodiorite	Granodiorite	Diorite	Diorite	Diorite
Latitude	28^0 05' 12.6"	28^0 05' 18.5"	28^0 05' 3.9"	28^0 04' 59.4"	28^0 04' 35.1"	28^0 02' 39.7"	28^0 02' 36.3"	28^0 02' 39.7"
Longitude	96^0 34' 24.3"	96^0 34' 23.2"	96^0 34' 3.1"	96^0 33' 57.6"	96^0 33' 34.7"	96^0 36' 06.0"	96^0 36' 22.0"	96^0 36' 06.0"
SiO_2	48.29	69	66.9	68.14	69.53	51.88	54.52	54.41
TiO_2	0.65	0.32	0.25	0.24	0.26	0.86	0.62	0.98
Al_2O_3	15.19	13.43	15.13	14.39	13.68	13.91	14.45	11.89
Fe_2O_3 T	11.32	2.64	2.66	2.26	2.36	10.86	7.99	10.99
FeO	3.51	0.82	0.83	0.70	0.73	3.37	2.48	3.41
Fe_2O_3	7.81	1.82	1.83	1.56	1.63	7.49	5.51	7.58
MnO	0.15	0.08	0.06	0.06	0.05	0.17	0.17	0.19
MgO	8.16	0.91	1.07	0.89	1.18	6.33	5.39	6.53
CaO	7.25	3.01	2.64	1.92	1.4	8.11	7.76	7.73
Na_2O	1.09	4.74	4.8	4.69	6.32	2.11	3.68	2.13
K_2O	0.12	1.37	2.2	2.35	0.88	0.6	0.56	0.61

P_2O_5	0.1	0.12	0.09	0.07	0.04	0.31	0.23	0.31
Ba	31	121	204	162	28	127	117	144
Co	42	<1	<1	<1	<1	40	29	46
Cr	52	<15	<15	<15	<15	26	21	37
Cu	267	21	9	10	17	113	52	164
Ga	23	22	20	28	28	16	24	25
Nb	<5	<5	<5	<5	<5	<5	<5	<5
Ni	18	<2	<2	<2	<2	12	20	22
Pb	<2	<2	<2	<2	<2	<2	13	<2
Rb	<3	11	18	24	4	<3	<3	<3
Sc	27	11	6	10	5	36	25	48
Sr	409	221	233	170	81	340	499	240
Th	14	12	9	11	8	10	4	17
V	536	27	40	32	24	430	262	560
Y	12	43	24	22	43	24	16	27
Zn	113	30	36	32	33	113	123	151
Zr	48	187	160	133	147	98	96	85
L.O.I. (%)	5.62	2.14	2.4	2.23	2.06	2.61	1.94	1.71

EPMA analysis:

The chemical composition of coexisting mineral phases in Rocks of Lohit Granitoid complex was determined at the Northern Region, Petrological laboratory of G.S.I., Faridabad using CAMECA SX-100 microprobe. The operating conditions were 1micron beam diameters, 15 KV accelerating voltage and 12 nA beam current. The PAP matrix corrections were applied for analysing and natural silicate standards were used to quantify.

Rocks of Lohit Granitoid complex mainly composed of amphibole, feldspar, quartz, chlorite and mica (Fig: 19 to 22). Analysis has been done for all the minerals to study the composition of the minerals. Amphiboles (Annexure-2) of Lohit Granitoid Complex also shows a range of composition [CaO: 10.06-12.3 wt%, MgO: 9.79-18.67 wt%, FeO: 7.91-6.8 wt%]. Amphiboles are classified as Fe-Mg-Mn-Li group [(Ca+Na)B<1.0, Σ(Fe,Mg,Mn,Li)>1.0] and calcic group [(Ca+Na)B>1.0 and NaB<0.5] (Fig:23 &24), according to the classification scheme of Leake*et al.*, 1997. (Ca+Na)B value (Fig:25) in Fe-Mg-Mn-Li group and calcic group ranges from 0.008 to 0.801 and 1.12 to 1.90, respectively, with Σ(Fe,Mg,Mn,Li) value ranges from 1.16 to 1.99 and 0.09 to 0.91, respectively. TSi value ranges from 6.39 to 8.9 atoms per formula unit (a. p. f. u) whereas AlTot value ranges from 0.18 to 2.65 a. p. f. u. XMg [where XMg= (Mg/Mg+Fe)] value of Fe-Mg-Mn-Li group and calcic group ranges from 0.54 to 0.67 and 0.53 to 0.80, respectively. The amphiboles of Fe-Mg-Mn-Li group are further classified as orthorhombicamphibole. Orthorhombic amphibole of Lohit Granitoid complex shows a composition of anthophyllite [TSi 6.9-7.69 and XMg 0.54-0.67 and AlTot 1.75-2.51]. Composition of amphiboles from core to rim varies from anthophyllite to edenite, edenite to anthophyllite and pargasite to anthophyllite. Calcic amphiboles are all monoclinic amphibole and their classification parameters according to Leake et al 1997 are i) CaB≥1.5; (Na+K)A<0.5 with CaA<0.5 and CaA≥0.5 and ii) CaB≥1.5; (Na+K)A≥0.5 with Ti <0.5 and Ti≥0.5. Calcic amphiboles, according to former classification, ranges from magnesiohornblende to actinolite [TSi 6.73 to 8.05; XMg 0.67-0.80 and AlTot

0.45 to 1.98] (Fig. 4.33) and according to latter one, amphiboles are edenite to pargasite [TSi 6.3 to 7.1; XMg 0.53-0.68 and AlTot 1.8 to 2.6] (Fig. 4.34). Pargasite have VIAl>Fe3+ whereas magnesiohastingsiteVIAl<Fe3+. According to these criteria, pargasite has been distinguished from magnesiohastingsite. In some part core to rim composition varies from magnesiohornblende-edenite and in some part, composition varies from edenite to actinolite, from core to rim. In these samples composition from core to rim also shows uniformity. Overall the amphibole shows heterogeneity in composition which points towards inequilibrium during crystal growth. The sample which shows heterogeneity in composition belongs to the dykes of granodiorite and diorite within Etalin Formation. So, the fluid injection from the dyke may be one of the reasons for compositional heterogeneity.

Feldspars (Annexture-3) has also been recalculated and classified (Fig:26) on the basis of 8 oxygen atoms and were plotted in Or-Ab- An ternary diagram. Feldspars are rich in Na content that varies from 0.693 to 0.958. Feldspar of Lohit Granitoid Complex varies in between albite to andesine in composition. Biotites have been recalculated and classified on the basis of 24 oxygen atoms. It has been observed that biotites (Annexture:4) are mostly of intermediate composition between phologopite and annite . Fe content varies from 2.681 to 3.066 whereas Mg content varies from 2.35 to 2.65. Mostly these amphiboles are Fe rich and compositionally these are annite.

EPMA data indicate that anthophyllite, cummingtonite and gedrites are uncommon in igneous rocks. These amphiboles occur at the vicinity of diorite-granodiorite dykes. It was observed in the field that laths of hornblende with random orientation developed due to contact metamorphism. Edenite and pargasites are hornblendes and are characteristics minerals of intermediate plutonic rock. In diorite granodiorite complex these amphiboles have Mg:Fe ratio almost 1:1 with moderate Al content 1.6 to 2.2. Feldspars composition varies from albite to andesine and belongs to plagioclase solid solution series. Plagioclase with compostion An1 to An 6.8 is very common in intermediate plutionicrocks, in this case it is diorite-granodiorite. These plagioclase feldspars are almost homogeneous in composition having similar composition at the core and rim, An 6.8 and An 10.9, respectively. These feldspars are formed during the progressive cooling of magma.

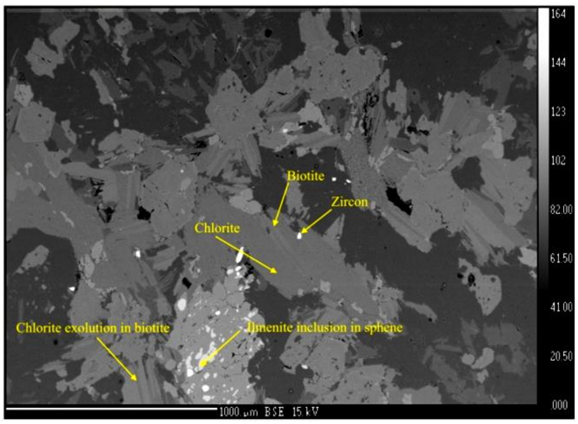


Fig:19 BSE image of granodiorite showing chlorite exolution in biotite and rutile inclusion in sphene.

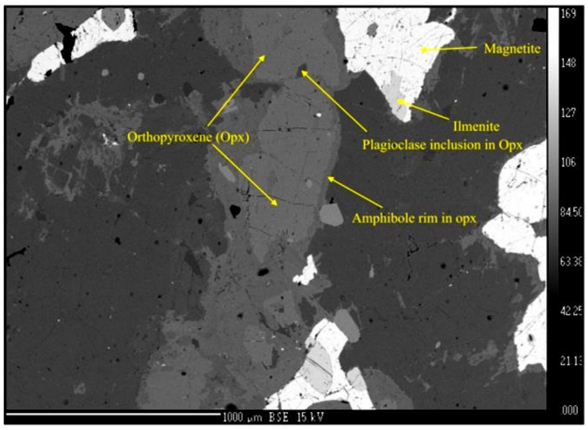


Fig:20 BSE image of norite showing orthopyroxene, amphibole rim and plagioclase inclusion within orthopyroxene.

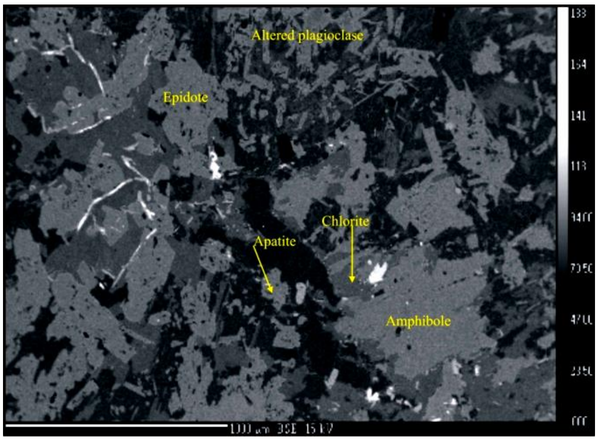


Fig:21 BSE image of sample of a highly altered diorite showing randomly oriented grains of epidote, amphibole and saussuritised plagioclase.

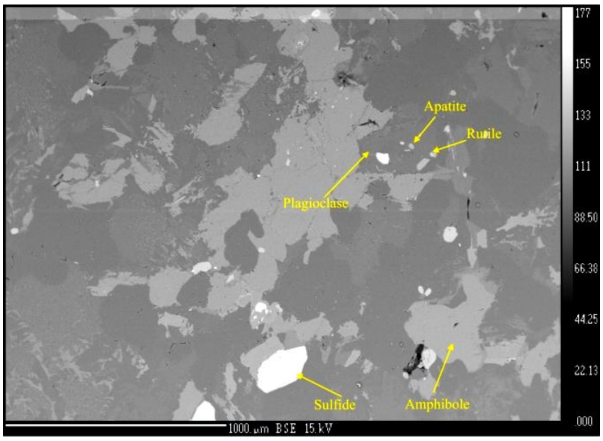


Fig:22 BSE image of sample of granodiorite dyke within Etalin Formation showing mineral phases like plagioclase, apatite, rutile, amphibole and sulphides.

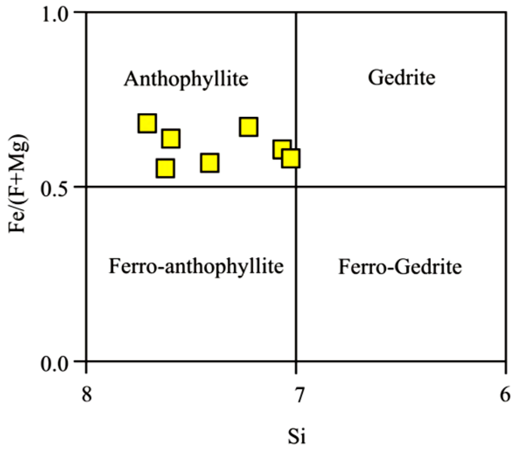


Fig:23 Diagram showing classification of Fe-Mg-Mn amphibole (orthorhombic) of Lohit Granitroid complex after Leake *et al.*, 1991.

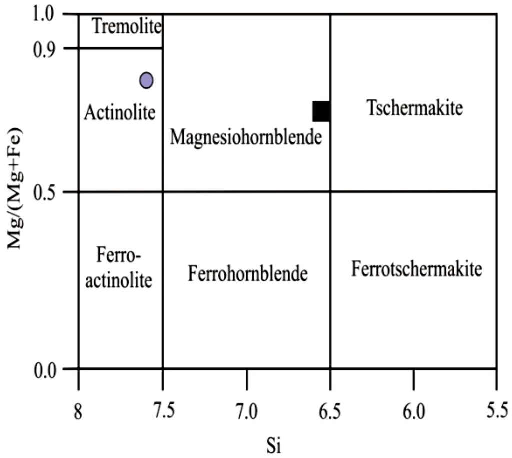
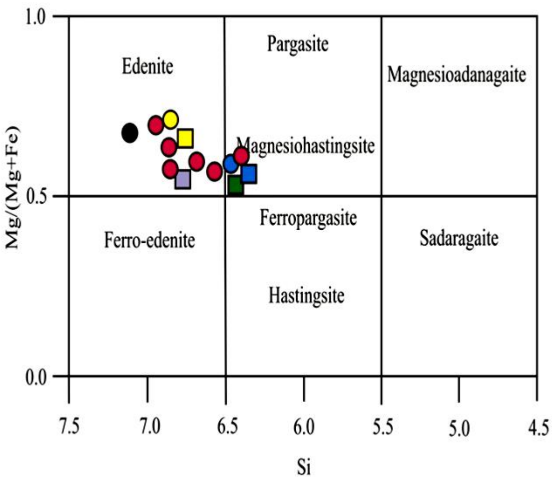


Fig:24 Diagram showing classification of calcic amphiboles of Lohit Granitoid complex according to the parameter $Ca_B \geq 1.5$; $(Na+K)_A < 0.5$ with $Ca_A < 0.5$ and $Ca_A \geq 0.5$.



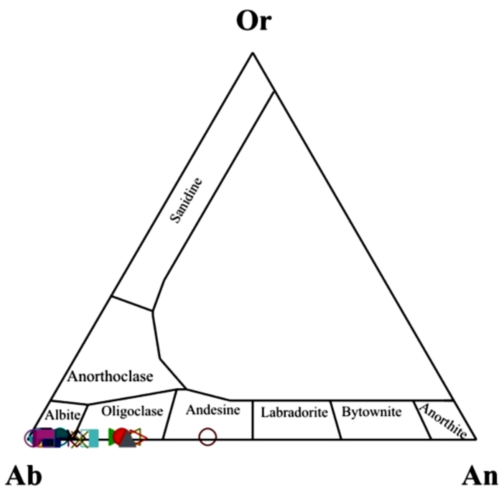


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Fig:25 Diagram showing classification of calcic amphiboles of Lohit Granitiod Complex according to the parameter $Ca_B \geq 1.5$; $(Na+K)_A \geq 0.5$ with Ti <0.5	Fig:26 Plot of feldspar of Lohit Granitoid Complex on the basis of 8 oxygen.

Annexure -2 :EPMA data of amphiboles of Lohit Granitoid Complex and cations								
recalculated on the basis of 23 oxygen atoms								
Sample	10	10	25	99A	99A	99A	99A	99A
Points	10-1/1.	10-6/1.	15-14/1.	99A-1/1.	99A-2/1.	99A-20/1.	99A-21/1.	99A-3/1.
SiO2	55.849	42.738	44.546	45.933	46.076	46.383	46.962	46.186
TiO2	0.001	0	1.471	0.62	0.933	0.469	0.654	0.632
Al2O3	0.982	14.988	9.359	11.472	11.385	11.087	11.141	11.27
FeO	11.322	15.334	16.8	11.391	11.411	11.757	11.285	11.589
MnO	0.362	0.468	0.231	0.14	0.143	0.154	0.152	0.152
MgO	16.863	9.799	11.197	13.514	13.692	13.678	13.753	13.594
CaO	12.317	11.789	11.081	11.35	11.396	11.293	11.923	11.598
Na2O	0.256	1.304	1.585	1.72	1.616	1.858	1.948	1.846
K2O	0	1.057	0.982	0.42	0.421	0.359	0.399	0.35
BaO	0	0.195	0.073	0	0	0.032	0.034	0.078
P2O5	0.046	0.041	0	0.048	0	0.061	0	0.007
Cr2O3	0	0.087	0	0.002	0	0.023	0.021	0
ZnO	0.108	0.029	0					
ZrO2	0	0	0.018	0	0.046	0.154	0	0
HfO2	0	0	0.007					
F	0.259	0.009	0.175	0	0.151	0	0.014	0.323
Cl	0.054	0.017	0.14	0.001	0	0.013	0.005	0.022
Total	98.42	97.856	97.664	96.611	97.27	97.323	98.29	97.646
TSi	8.927	6.426	7.607	6.733	7.102	7.207	6.835	6.802
TAl	0	1.574	0.393	1.267	0.898	0.793	1.165	1.198
TFe3	0	0	0	0	0	0	0	0
TTi	0	0	0	0	0	0	0	0
Sum_T	8.927	8	8	8	8	8	8	8
CAl	0.185	1.08	1.489	0.713	1.169	1.392	1.124	0.717
CCr	0	0.01	0	0	0	0.002	0	0.003
CFe3	0	0	0	0	0	0	0	0
CTi	0	0	0.189	0.068	0.108	0.092	0.075	0.052
CMg	4.018	2.196	2.85	2.953	3.146	3.153	2.909	2.99
CFe2	0.797	1.714	0.472	1.266	0.577	0.361	0.893	1.238

Sum_C	5	5	5	5	5	5	5	5
BMg	0	0	0	0	0	0	0	0
BFe2	0.716	0.214	1.927	0.131	0.894	1.203	0.614	0.204
BMn	0.049	0.06	0.033	0.017	0.019	0.011	0.029	0.019
BCa	1.235	1.726	0.039	1.782	1.087	0.786	1.358	1.774
BNa	0	0	0	0.069	0	0	0	0.002
Sum_B	2	2	2	2	2	2	2	2
ACa	0.875	0.173	1.988	0	0.795	1.179	0.499	0
ANa	0.08	0.38	0.525	0.419	0.483	0.568	0.544	0.526
AK	0	0.203	0.214	0.079	0.083	0.082	0.098	0.067
Sum_A	0.954	0.756	2.727	0.498	1.361	1.829	1.141	0.593
Sum_cat	16.881	15.756	17.727	15.498	16.361	16.829	16.141	15.593
CCl	0.015	0.004	0.041	0	0	0.005	0.008	0.003
CF	0.131	0.004	0.095	0	0.074	0.096	0.033	0

Annexture:3 EPMA data of feldspar of LohitGranitoid Complex and cations recalculated on the basis of 8 oxygen atoms										
Sample	99A	99A	99A	99B	99B	99B	99C	99C	99C	99C
Points	99A-15/1	99A-18/1.	99A-19/1.	99B-22/1.	99B-23/1.	99B-14/1.	99C-13/1.	99C-14/1.	99C-18/1.	99C-19/1.
SiO2	68.58	69.17	70.00	67.90	66.46	77.47	63.47	62.69	64.084	63.469
TiO2	0.03	0.05	0.03	0.16	0.00	0.00	0.00	0.00	0.017	0.045
Al2O3	20.33	20.63	19.91	20.78	21.39	13.74	23.68	23.79	23.084	23.063
FeO	0.03	0.05	0.17	0.12	0.06	0.27	0.08	0.00	0.057	0
MnO	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0	0
MgO	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.012	0
CaO	0.85	1.09	0.22	1.43	2.28	0.85	4.75	5.00	4.19	4.362
Na2O	11.11	11.07	11.37	10.74	10.27	8.40	8.77	8.46	9.367	9.045
K2O	0.04	0.06	0.06	0.11	0.01	0.03	0.10	0.02	0.09	0.094
BaO	0.00	0.11	0.00	0.07	0.02	0.00	0.11	0.03	0	0
P2O5	0.00	0.00	0.03	0.07	0.00	0.00	0.07	0.07	0	0.009
Cr2O3	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.03	0	0
ZnO										
ZrO2	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0	0.006
HfO2										
F	0.00	0.00	0.00	0.00	0.21	0.10	0.08	0.01	0.067	0.197
Cl	0.00	0.04	0.00	0.00	0.01	0.02	0.01	0.00	0.027	0
Total	101.00	102.26	101.81	101.38	100.73	100.87	101.15	100.10	100.995	100.291

Si	2.967	2.961	2.998	2.935	2.902	3.299	2.778	2.768	2.806	2.8
Al	1.036	1.04	1.004	1.058	1.1	0.671	1.221	1.237	1.19	1.198
Fe3										
Ti	0.001	0.001	0.001	0.005	0	0	0	0	0.001	0.001
Fe2	0.001	0.002	0.006	0.004	0.002	0.01	0.003	0	0.002	0
Mn	0.001	0	0	0	0	0	0	0	0	0
Mg	0	0	0	0	0.002	0	0	0	0.001	0
Ba	0	0.002	0	0.001	0	0	0.002	0.001	0	0
Ca	0.039	0.05	0.01	0.066	0.106	0.039	0.223	0.236	0.197	0.206
Na	0.932	0.919	0.944	0.9	0.869	0.693	0.744	0.724	0.795	0.774
K	0.002	0.003	0.003	0.006	0.001	0.002	0.005	0.001	0.005	0.005
Z	0.975	0.976	0.963	0.977	0.98	0.744	0.977	0.962	1	0.985
Ab	95.8	94.5	98.6	92.6	89	94.4	76.5	75.3	79.7	78.6
An	4	5.1	1	6.8	10.9	5.3	22.9	24.6	19.8	20.9
Or	0.2	0.3	0.3	0.6	0.1	0.3	0.5	0.1	0.5	0.5

Annexture:4 EPMA data of biotite of LohitGranitoid Complex and cations						
recalculated on the basis of 24 oxygen atoms						
Sample No	10	10	5	5	5	
Poitns	10-15/1.	10-16/1.	5-2/1.	5-9/1.	5-10/1.	
SiO2	36.467	36.027	36.968	37.04	36.43	
TiO2	2.864	2.837	1.311	1.087	1.829	
Al2O3	14.763	14.362	15.43	15.98	15.226	
FeO	22.827	22.242	20.53	20.065	21.646	
MnO	0.157	0.118	0.478	0.508	0.624	
MgO	9.849	9.89	10.552	11.135	10.329	
CaO	0	0.055	0.192	0.118	0.054	
Na2O	0.049	0.107	0.076	0.032	0.06	
K2O	9.117	8.983	7.953	9.108	9.39	
BaO	0.126	0.073	0	0.31	0.07	
P2O5	0	0	0	0.016	0.01	
Cr2O3	0	0	0.009	0.039	0	
ZnO	0.045	0				
ZrO2	0	0	0.012	0	0.091	
HfO2	0	0				
F	0.17	0.249	0.366	0.653	0.569	
Cl	0.271	0.291	0.029	0.04	0.016	
Total	96.706	95.233	93.908	96.131	96.344	

Si	5.857	5.873	5.993	5.918	5.867	
AlIV	2.143	2.127	2.007	2.082	2.133	
AlVI	0.649	0.63	0.939	0.925	0.755	
Ti	0.346	0.348	0.16	0.131	0.222	
Fe2	3.066	3.032	2.783	2.681	2.916	
Cr	0	0	0.001	0.005	0	
Mn	0.021	0.016	0.066	0.069	0.085	
Mg	2.358	2.404	2.55	2.652	2.48	
Ba	0.008	0.005	0	0.019	0.004	
Ca	0	0.01	0.033	0.02	0.009	
Na	0.015	0.034	0.024	0.01	0.019	
K	1.868	1.868	1.645	1.857	1.929	
CF	0.173	0.257	0.375	0.66	0.58	
CCl	0.148	0.161	0.016	0.022	0.009	
Fe_FeMg	0.57	0.56	0.52	0.5	0.54	
Mg_FeMg	0.43	0.44	0.48	0.5	0.46	

Conclusion:

The Lohit Granitoid Complex forms the most conspicuous unit in the eastern Arunachal Pradesh. It consists of multi variant plutonic rocks which includes diorite, granodiorite, tonalite, hornblende-biotite granite and leucogranite. The distribution of Lohit Granitoid, when plotted on AFM diagram and SiO_2vs K_2O distribution diagram, shows that the magma is dominantly calc-alkaline in nature with Na_2O+K_2O+CaO value ranges from 8.09 to 5.8. The differentiated units of Lohit Granitoid Complex shows signature of mantle fraction and syn to pre plate collision. The lithounits of Lohit Granitoid Complex is dominantly metaluminous to weakly peraluminous in nature. The REE pattern shows enriched in LREE with a decreasing trend from La-Nd with a moderate to feeble Eu anomaly, whereas the HREE (Er to Lu) shows almost a linear trend. Distribution pattern of REE varies slightly from granodiorite to diorite. Granodiorites exhibits slightly enriched REE pattern with (La/Yb) and LREE pattern with (La/Sm), very low to almost flat HREE pattern with (Tb/Yb). Whereas diorite shows moderately enriched fractionated pattern with (La/Yb), moderately enriched LREE pattern with (La/Sm) and almost flat HREE pattern with (Tb/Yb).Granodiorite exhibits very little Eu anomaly, similar to diorite which also exhibits weak Eu anomaly. This indicates the presence of plagioclase in the parent rock. Hence if the rare earth shows negative Eu anomaly then it can be said that the magma has generated at a depth less than 30 km that means from the crustal level. In this case the Eu anomaly is expected to be much steeper but the Eu anomaly is moderate to shallow, which may be attributed to the involvement of mantle material within it. So, it can be said that either the magma has a mixed origin involving both crustal as well as mantle material or magma has been generated at a depth near to the mantle. Negligible Eu anomalies, depletion in MREE (Middle REE) and HREE (High REE) indicates equal amount of clinopyroxenes and plagioclase or twice as much plagioclase as hornblende in the residual melt. Microscopically the rock is coarse grained and composed of plagioclase, quartz, biotite, muscovite, hornblende, chlorite and epidote. Quartz and plagioclase are the dominant mineral phases present in the rock. The geochemical character indicates that the granitoids have generated either by partial melting of mantle or by melting of rocks of intermediate composition like basaltic rocks. According to trace element discrimination diagrams, thegranitoids shows significant depletion in Rb, Ba, U, &Hf and high content of

Th and Sr with respect to UCC. The samples of LohitGranitoids are enriched in Th and Ce relative to Rb, Ta and Hf. Further Hf has very low value relative to normalizing composition. The pattern is indicative of similarity with Volcanic Arc Granite (VAG). Low value of Co, Ni and Cr role out the possibility of a peridotite parental source since higher value of Ni, Co and Cr are good indicators of parental magma from a peridotite mantle source. On combining and correlating all the geochemical parameters, the magma has mixed origin involving both crustal component as well as mantle material forming in a subduction zone environment.

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