

T.C.
AKDENİZ ÜNİVERSİTESİ



**TRANS-HİMALAYA (HİNDİSTAN), LEH (LADAKH BATOLİTİ) BÖLGESİNDE
YERALAN İNTRÜZİF KAYAÇLARIN PETROGRAFİSİ, JEOKİMYASI VE
PETROJENEZİ**

Azimuddin MİRZA

FEN BİLİMLERİ ENSTİTÜSÜ

JEOLojİ MÜHENDİSLİĞİ

ANABİLİM DALI

DOKTORA TEZİ

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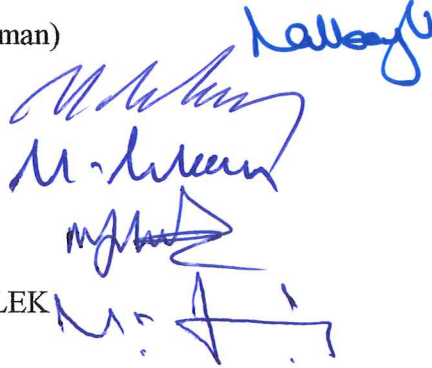
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ÖZET

TRANS-HİMALAYA (HİNDİSTAN), LEH (LADAKH BATOLİTİ) BÖLGESİNDE YERALAN İNTRÜZİF KAYAÇLARIN PETROGRAFİSİ, JEOKİMYASI VE PETROJENEZİ

Azimuddin MİRZA

Doktora Tezi, Jeoloji Mühendisliği Anabilim Dalı

Danışman: Doç. Dr. Nurdane İLBEYLİ

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Trans-Himalaya Plutonik Kuşağı içerisinde, Jammu ve Keşmir (Hindistan) bölgesinde bulunan Ladakh Batoliti, dalma-batmaya bağlı And-tipi magmatizma ve bir ada yayını temsil eden, genellikle I-tipi karakterli, bir kaç intrüzif kütlede oluşmaktadır. Bu batolit BKB-DGD yönelimli, ~600 km uzunluğunda, 30-80 km genişliğinde, 3 km kalınlığında olup; kuzeyde Shyok ve güneyde ise İndus kenet kuşağı sınırlanmıştır.

Ladakh Batolitinin Basgo, Nimu, Umla ve Taru bölgesi ve civarının intrüzif kayaçları orta-iri taneli genellikle grimsi renkli monzodiyoritden-granite kadar farklı bileşimler sunmaktadırlar. Bu kayaçlar içerisinde mafik magmatik anklavlar yaygındır ve bu kayaçları farklı doğrultularda kesen dayklar bulunmaktadır.

Basgo, Nimu, Umla ve Taru bölgesi intrüzif kayaçlarında genellikle orta-iri taneli holokristalen taneli ve hipidiyomorfik doku yaygındır. Bu kayaçların ana minerallerini K-feldispat, plajiyoklas, kuvars, biyotit, hornblend oluştururken; sfen, apatit, zirkon, Fe-Ti oksit ise aksesör mineralleri oluşturmaktadır.

Bu intrüzif kayaçların plajiyoklas içerikleri An_{55-99} arasında değişirken K-feldispat içerikleri de Or_{85-99} aralığındadır. Amfibollerin bileşimleri esas olarak edenit, magnesio-hornblend ve hastingsitdir. Al-Mg-Fe(t) içeriğine göre annit bileşiminde gözlenen biyotitler, Mg'den daha fazla Fe içeriklerine sahiptir. İntrüzif kayaçların jeotermobarometre sonuçları, 452-628°C arasında değişen kristalleşme sıcaklıkları, 2.3-3.9 kbar aralığında değişen basınç değerleri sunmaktadır. Al-Hornblende barometri kristallenme derinliğini diyorit için 12.8 km ve granodiyorit için 8.3 km civarında olduğunu gösterir.

Monzodiyoritten granite kadar bileşimsel farklılık sunan intrüzif kayaçların 0.87 ile 1.31 olan A/CNK oranları, pek çok örnek için I-tipi graniti işaret etmektedir. Bazı örneklerin değerleri ise I- ile S-tipi granitoyitler arasında geçişi işaret etmektedir. Ladakh Batolitine ait örneklerin SiO_2 değerleri %51.8 ile 75.8 arasında değişim sergilemektedir. Artan silika değerlerine karşı çizilen Al_2O_3 , TiO_2 , Fe_2O_3 , MgO , CaO , Na_2O , P_2O_5 Harker ikili diyagramları güçlü negatif korelasyon göstermekte iken; ve K_2O değerlerinde ise güçlü pozitif korelasyon vardır.

İntrüzif kayaç örneklerinin kondrite göre normalize REE desenleri, LREE açısından zenginleşme gösterirken HREE açısından tüketilmeye işaret etmektedir. İntrüzif kayaç örneklerinin toplam REE içerikleri 20-181 ppm arasında değişim sunarken, $(La/Yb)_N=3.75-45.95$ aralığında değişen oranları ile LREE açısından orta-yüksek zenginleşme göstermektedir. Negatif Eu anomalileri $(Eu/Eu^*=0.35-4.97)$ ve $(Gd/Yb)_N=0.83-4.40$ oranları orta HREE ayırtılmasını göstermektedir.

Ladakh Batoliti örneklerin Sr ve Nd izotopik analiz değerleri $^{87}Sr/^{86}Sr_{(i)}$ (0.70414-0.70544) ve $^{143}Nd/^{144}Nd_{(i)}$ (0.512647- 0.512695) aralıklarında değerler sunmaktadır. Sr_i - Nd_i diyagramında örnekler düşük Sr ve yüksek Nd alanında yer alırken, bazı granodiyorit bileşimli örnekler ise yüksek Sr ve yüksek Nd kadranı temsil eden alanda yer almaktadır. 1.68 ile 2.62 aralığında değişen $\epsilon Nd_{(i)}$ değerlere sahiptir.

Petrografi, kayaç ve izotop jeokimyası göstermektedir ki, Ladakh intrüzif kayaçlarının oluşumunda fraksiyonel kristalleşme ve magma mixing/mingling süreçleri etkilidir.

ANAHTAR KELİMELEER: Jammu ve Keşmir, Hindistan, Trans-Himalaya, Ladakh Batoliti, İntrüzif Kayaç, Mineral Kimyası, Jeokimya, Radyojenik İzotop Jeokimyası, Petrojenez, Fraksiyonel Kristallenme, Magma Mixing/Mingling

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ABSTRACT

PETROGRAPHY, GEOCHEMISTRY AND PETROGENESIS OF THE INTRUSIVE ROCKS IN THE LEH (LADAKH BATHOLITH) REGION, TRANS- HIMALAYA (INDIA)

Azimuddin MIRZA

PhD Thesis in Geological Engineering

Supervisor: Assoc. Prof. Dr. Nurdane İLBEYLİ

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The Ladakh Batholith is a part of the Trans-Himalayan Plutonic Belt located in Jammu & Kashmir (India), which represents subduction-related And-type magmatism, intruding an island arc setting. The Shyok tectonic zone lies to the north and Indus suture zone to the south of the Ladakh batholith that extends with WNW-ESE direction having ~600 km in length, 30-80 km in width and 3 km in thickness.

The intrusive rocks of the Basgo, Nimu, Umla, and Taru regions of the Ladakh batholith and its surroundings show different compositions ranging from medium-coarse-grained to generally grayish colored monzodiorite to granitic rocks. These rocks are having common mafic magmatic enclaves and dykes that cut these rocks in different directions.

The intrusive rocks of Basgo, Nimu, Umla and Taru region are medium to coarse grained with having common holocrystalline and hypidiomorphic granular texture. The main minerals of these rocks are K-feldspar, plagioclase, quartz, biotite, hornblende; sphene, apatite, zircon, Fe-Ti oxide forms accessory minerals.

Petrographically, they are fine to medium grained monzonite, monzodiorite, diorite, granodiorite and granite rocks. They consist of plagioclase (An_{55-99}), K-feldspar (Or_{85-99}). Amphiboles are mainly Edenite, Magnesio-Hornblende and Hastingsite in composition. In terms of Al-Mg-Fe(t) content, all samples are plotted in field of annite have relatively more Fe content than Mg. Biotites from all granitoids were accompanied with amphibole group of minerals, which is a typical characteristic of calc-alkaline subduction related metaluminous (I-type) granitoids. Fe-Ti oxide with poikilitic, perthitic, myrmekitic textures and graphic textures. The geothermobarometry results of intrusive rocks have crystallization temperatures ranging from 452 to 628°C and pressures ranging from 2.3 to 3.9 kbar. Al-in-hornblende barometry indicates the depth of crystallization for the diorite to be 12.8 km and granodiorite to be around 8.3 km.

The calc-alkaline rocks are metaluminous/peraluminous I-to S-type of pluton ranging from monzodiorite to granite. A/CNK (0.87-1.31) indicating I-type parental magma

for most of the samples, whereas some samples shows transition between I & S- type granitoids. SiO₂ values of Ladakh Batholith samples are vary between 51.8% and 75.8%. Binary Harker diagrams show a strong negative correlation when Al₂O₃, TiO₂, Fe₂O₃, MgO, CaO, Na₂O, P₂O₅ are plotted against the increasing amount of silica, while K₂O values have strong positive correlation.

Chondrite-normalized REE patterns of intrusive rocks shows enrichment in LREE pattern whereas depletion in HREE pattern. They have total REE content of 20–181 ppm, and are moderately to highly LREE enrichment, with (La/Yb)_N = 3.75–45.95. These granites show prominently negative Eu anomalies (Eu/Eu* = 0.35–4.97) and moderately HREE fractionation with (Gd/Yb)_N = 0.83–4.40.

Sr-Nd isotope analyses of the Ladakh intrusive rocks fall within a narrow range for initial ⁸⁷Sr/⁸⁶Sr_i (0.70414 to 0.70544) and ¹⁴³Nd/¹⁴⁴Nd_i (0.512647 to 0.512695) ratios with slightly positive εNd_i values (+1.68 to +2.62), similar to I-type granites generated in an arc setting. In the Sr_i-Nd_i diagram, samples are located in the low Sr and high Nd area, while some granodiorite composition samples are located in the area representing the high Sr and high Nd area.

Petrography, rock and isotope geochemistry shows the fractional crystallization and magma mixing / mingling processes are effective in the formation of Ladakh intrusive rocks.

KEYWORDS: Jammu and Kashmir, India, Trans-Himalaya, Ladakh Batholith, Intrusive Rock, Mineral Chemistry, Geochemistry, Radiogenic Isotope Geochemistry, Petrogenesis, Fractional Crystallization, Magma Mixing/Mingling

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ÖNSÖZ

Trans-Himalaya bölgesi, Ladakh Batoliti, intrüzif kayaların mineralojisi, petrografisi, kayaç-izotop jeokimyası ve petrojenez özelliklerinin belirlenmesi amacıyla yapılan bu çalışma Akdeniz Üniversitesi Fen Bilimleri Enstitüsü, Jeoloji Mühendisliği Anabilim Dalı'nda Doktora tezi olarak hazırlanmıştır.

Doktora tezimin konu tespitinde, arazi, laboratuvar ve analiz kısımların değerlendirilmesinde yardım, katkı ve önerileriyle her zaman yanımda olan danışmanım Sayın Doç. Dr. Nurdane İLBEYLİ'ye çok teşekkür ederim.

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AKADEMİK BEYAN

Doktora Tezi olarak sunduğum “Trans-Himalaya (Hindistan), Leh (Ladakh Batoliti) Bölgesinde Yeralan İntüzif Kayaçların Petrografisi, Jeokimyası ve Petrojenezi” adlı bu çalışmanın, akademik kurallar ve etik değerlere uygun olarak yazıldığını belirtir, bu tez çalışmasında bana ait olmayan tüm bilgilerin kaynağını gösterdiğimi beyan ederim.

12/07/2019

Azimuddin MİRZA



SİMGELER VE KISALTMALAR

Simgeler

Al_2O_3	: Alüminyum Oksit
Ba	: Baryum
CaO	: Kalsiyum Oksit
Ce	: Seryum
Co	: Kobalt
CO_2	: Karbon Dioksit
Cr_2O_3	: Krom (III) Oksit
Cu	: Bakır
Dy	: Disporsiyum
Eu	: Evropiyum
Er	: Erbiyum
Fe_2O_3	: Demir (III) Oksit
Ga	: Galyum
Gd	: Gadolinyum
Hf	: Hafniyum
Ho	: Holmiyum
Km	: Kilometre
K_2O	: Potasyum Oksit
La	: Lantan
Lu	: Lütesyum
M	: Metre
MgO	: Magnezyum Oksit
Mm	: Milimetre

MnO	: Mangan Oksit
My	: Milyon yıl
Na ₂ O	: Sodyum Oksit
Nb	: Niobyum
Nd	: Neodiyum
Ni	: Nikel
P ₂ O ₅	: Difosfor Pentaoksit
Pb	: Kurşun
Pr	: Praseodim
Rb	: Rubidyum
SiO ₂	: Silisyum Dioksit
Sm	: Samaryum
Sr	: Stronsiyum
Ta	: Tantal
Tb	: Terbiyum
Th	: Toryum
TiO ₂	: Titanyum Dioksit
Tm	: Tulyum
U	: Uranyum
V	: Vanadyum
Y	: İtiryum
Yb	: İterbiyum
Zn	: Çinko
Zr	: Zirkon

Kısaltmalar

BS	: Bangong Süturu
DP	: Deosai Plato
IC	: Indus Kavşağı
ISZ	: Indus Sütur Zonu
JS	: Jinsha Sütur
KG	Kaghan
ATF	: Altyn Tagh Fayı
HFF	: Himalaya Ön Fayı
BNS	: Banggong Nujiang Süturu
KF	: Kunlun Fayı
NBT	: Kuzey Sınır Bindirmesi
MBT	: Sınır Bindirme Fayı
MCT	: Merkez Bindirme Fayı
THSZ	: Trans Himadri Makaslanma Zonu
STDZ	: Güney Tibet Sıyrılma Zonu
SS	: Shyok Sütur Zonu
TD	: Güney Tibet Fayı
WP	: Batı Pakistan
ZP	: Zhepure Shan
ZS	: Zanskar Makaslama Zonu
B	: Batı
D	: Doğu
G	: Güney

GB	: Güneybatı
GD	: Güneydoğu
HFSE	: Yüksek Çekim Alanlı Elementler
HREE	: Ağır Nadir Toprak Elementleri
K	: Kuzey
KB	: Kuzeybatı
LILE	: Büyük İyon Yarıçaplı Elementler
LREE	: Hafif Nadir Toprak Elementleri
Plj	: Plajiyoklas
Qtz	: Kuvars
ppm	: Milyonda Bir Birim
REE	: Nadir Toprak Elementleri
Op	: Opak mineraller
Bt	: Biyotit
Ser	: Serisit
Ap	: Apatit
Zrn	: Zirkon
Mnz	: Monazit
Or	: Ortoklas
Myrm	: Mirmekitik Doku
Grp	: Grafik Doku
Pert	: Pertitik Doku
Kfs	: K-feldispat
Mc	: Mikroklin

Spn	: Sfen
Hbl	: Hornblend
Saus	: Sossoritleşme
Alt	: Alterasyon
Ep	: Epidot
MORB	: Okyanus Ortası Sırtı Bazaltlar
DM	: Tüketilmiş Manto
OIB	: Okyanus Ada Bazaltları
IAB	: Ada Yayısı Bazaltları
AFC	: Asimilasyon-Fraksiyonel Kristallenme

Bu tezin yazımında ondalık ayırıcı olarak "." kullanılmıştır.

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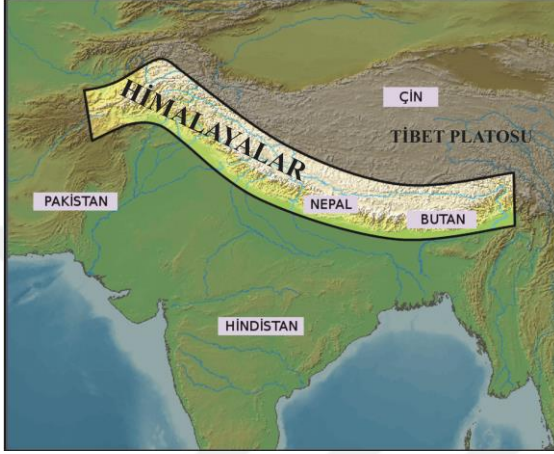
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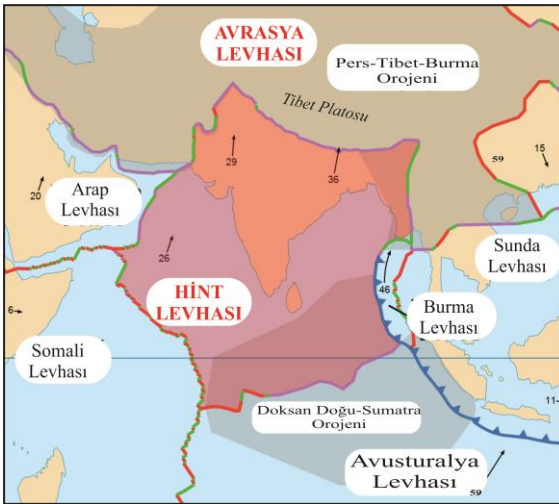
1. GİRİŞ

Himalayalar, tektonik ve magmatik süreçler açısından karmaşık bir jeolojik yapı sunan dağ silsilesinden oluşmuştur. Bu dağ silsilesi, jeolojik açıdan bölgenin oluşumunu ve oluşum mekanizmalarını açıklamayı daha da zorlaştırmaktadır (Şekil 1.1).



Şekil 1.1. Himalayaların genel konumu (ölçeksiz) (Anonim 1)

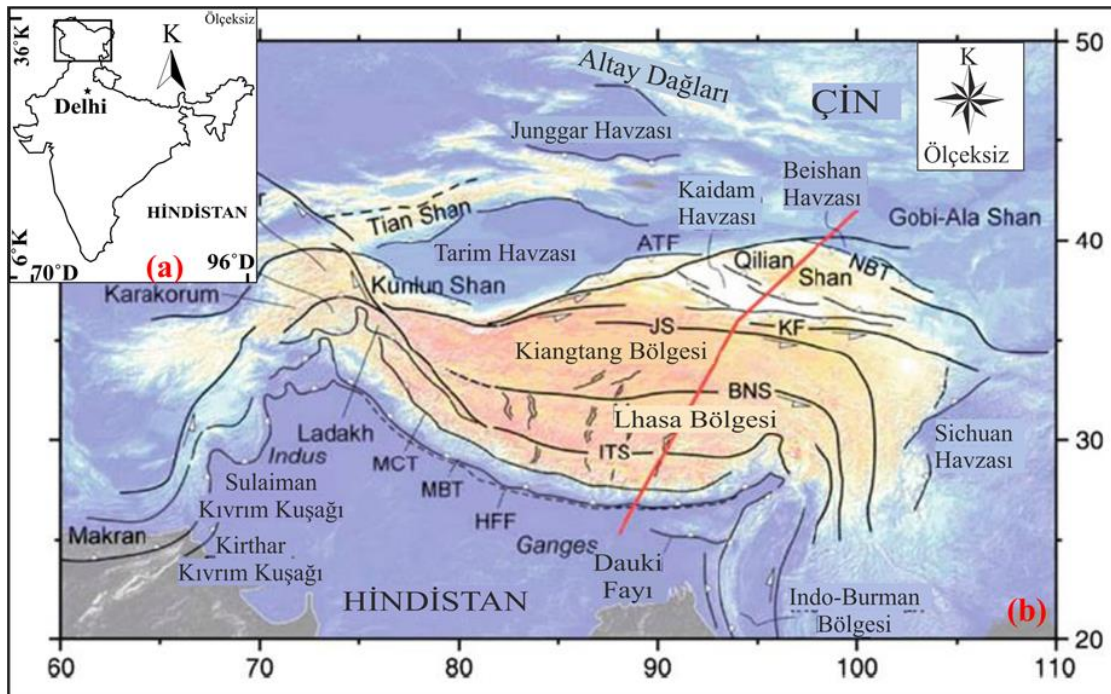
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Şekil 1.2. Hint levhası ve etrafında bulunan diğer levhalar (ölçeksiz) (Anonim 2)



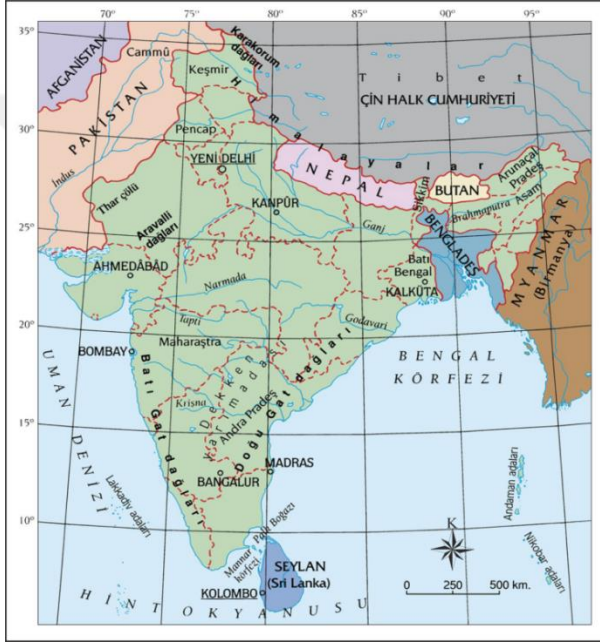
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(Anonim 3)



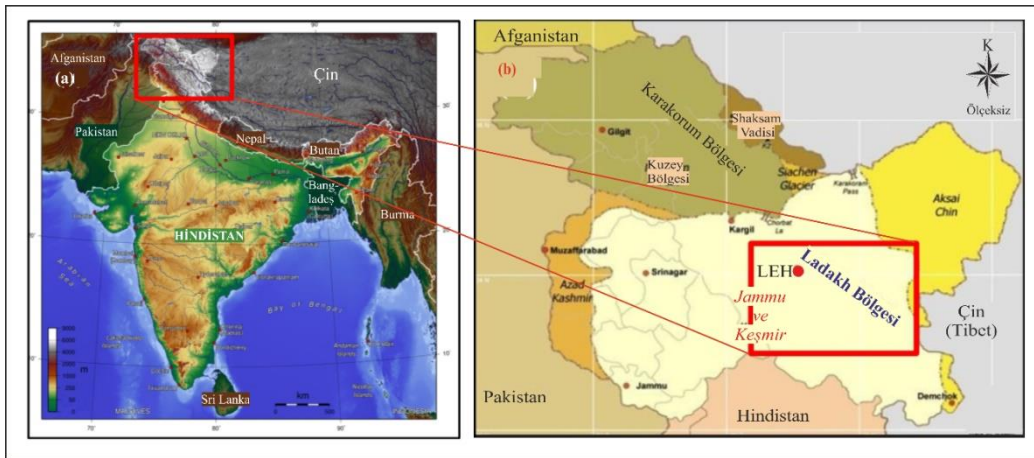
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göstermektedir. Kırmızı renkli çizgi-kısaltmalar ile belirtilen alanları sınırlamaktadır: ATF- Altın Tagh Fayı, HFF- Himalaya Ön Fayı, MBT- Himalaya Esas Sınır Bindirmesi, MCT- Ana Merkez Bindirmesi, ITS- Indus-Tsangpo Süturu, BNS- Banggong-Nujang Süturu, JS- Jinshan Süturu, KF- Kunlun Fayı, NBT- Kuzey Sınır Bindirmesi

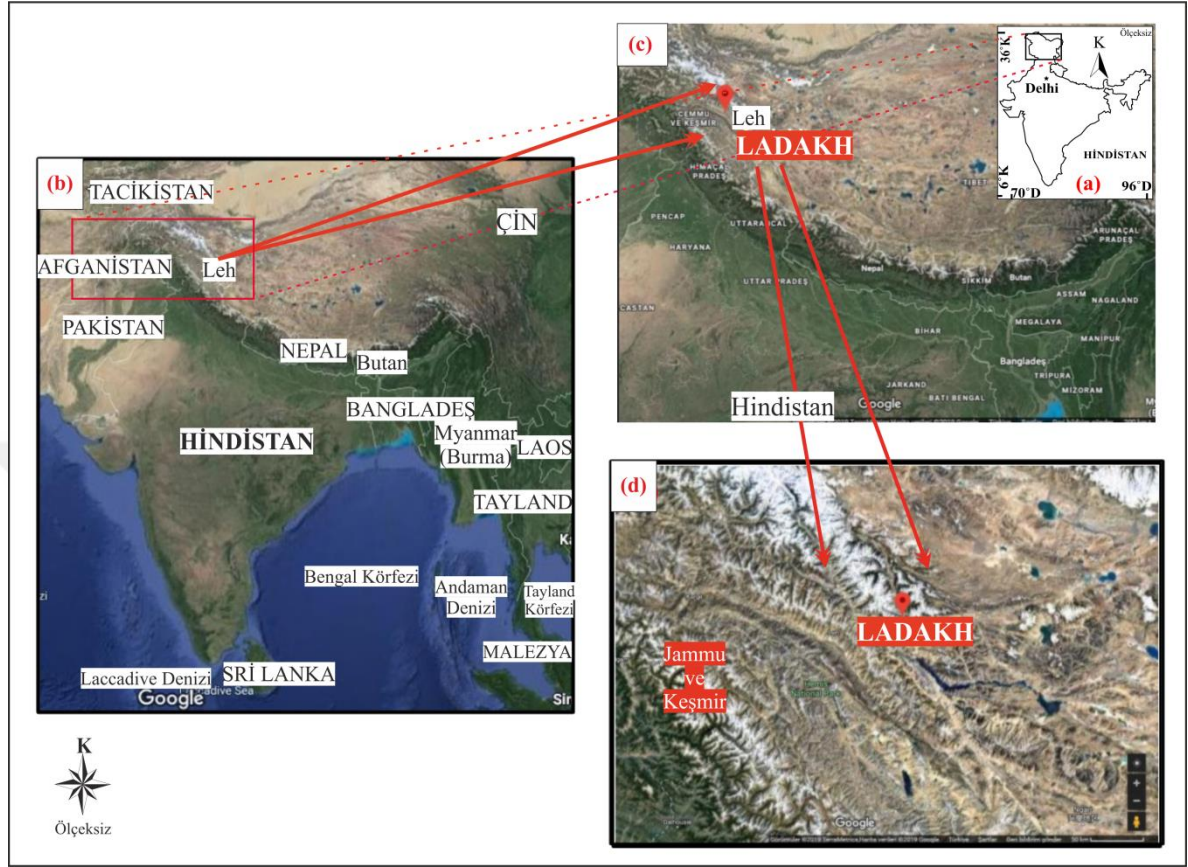
Himalaya dağ zincirinin önemli bir bölümünü Trans-Himalaya Magmatik Yayı (Trans-Himalaya Batoliti) kapsamaktadır. Bu yay içerisinde yer alan ve Hindistan'ın Jammu ve Keşmir eyaletinde bulunan, KB-GD yönelimli Ladakh Batoliti (Harris vd. 1988) (Leh ve civarı) bu doktora tez çalışması için tercih edilmiştir (Şekil 1.5-1.7).



Şekil 1.5. Hindistan ve komşu ülke sınırlarını gösteren siyasi harita (Anonim 4)

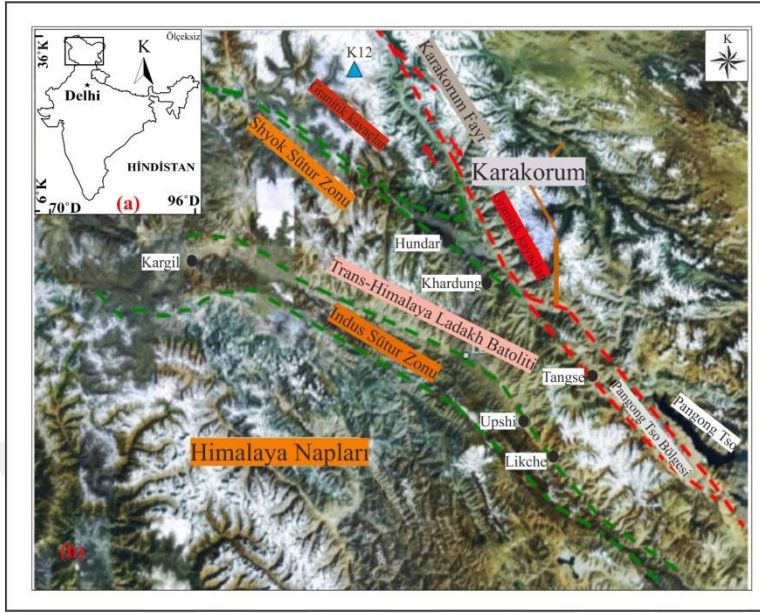


Şekil 1.6. a) Ladakh bölgesi ve çevresini gösteren Google Earth görüntüleri (Anonim 5), b) Ladakh bölgesinde Hindistan'ın Jammu ve Keşmir eyaletini gösteren harita (Anonim 6)

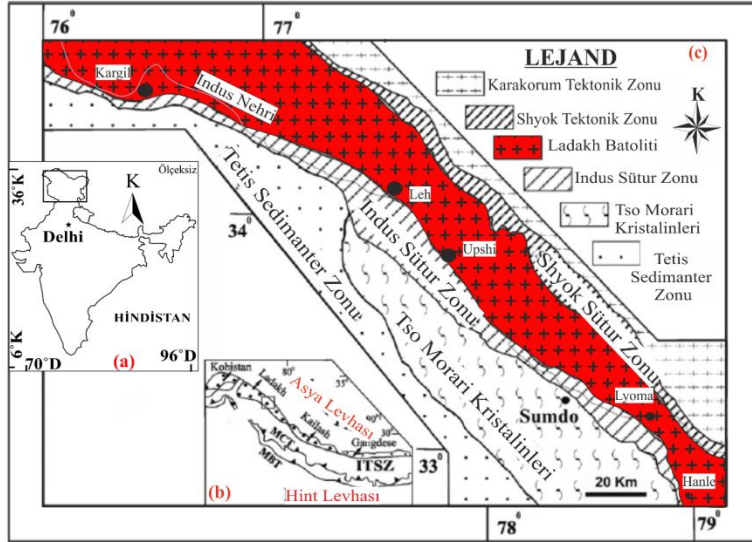


Şekil 1.7. a-d) Hindistan, Jammu ve Keşmir eyaleti (Valdiya 1988) ile Leh ve Ladakh bölgelerini gösteren Google Earth görüntüleri (ölçeksiz)

Bu Ladakh Batoliti güneyde Indus Tsangpo Suture Zonu (ITSZ) ve kuzeyde ise Shyok Suture Zonu (SSZ) ile sınırlanmış olup (Shah vd. 1976; Shanker vd. 1976; Gansser 1977; Franket vd. 1977; Sharma ve Kumar 1978; Thakur 1981; Beck vd. 1995) (Şekil 1.8, 1.9); bu magmatik yay 102 ± 2 My'dan (Honegger vd. 1982) 50 ± 1 My'a kadar (Weinberg ve Dunlop 2000) yoğun magmatizma süreçleri sonucunda (Scharer vd. 1984; Singh vd. 2007; Upadhyay vd. 2008) oluşmuştur.

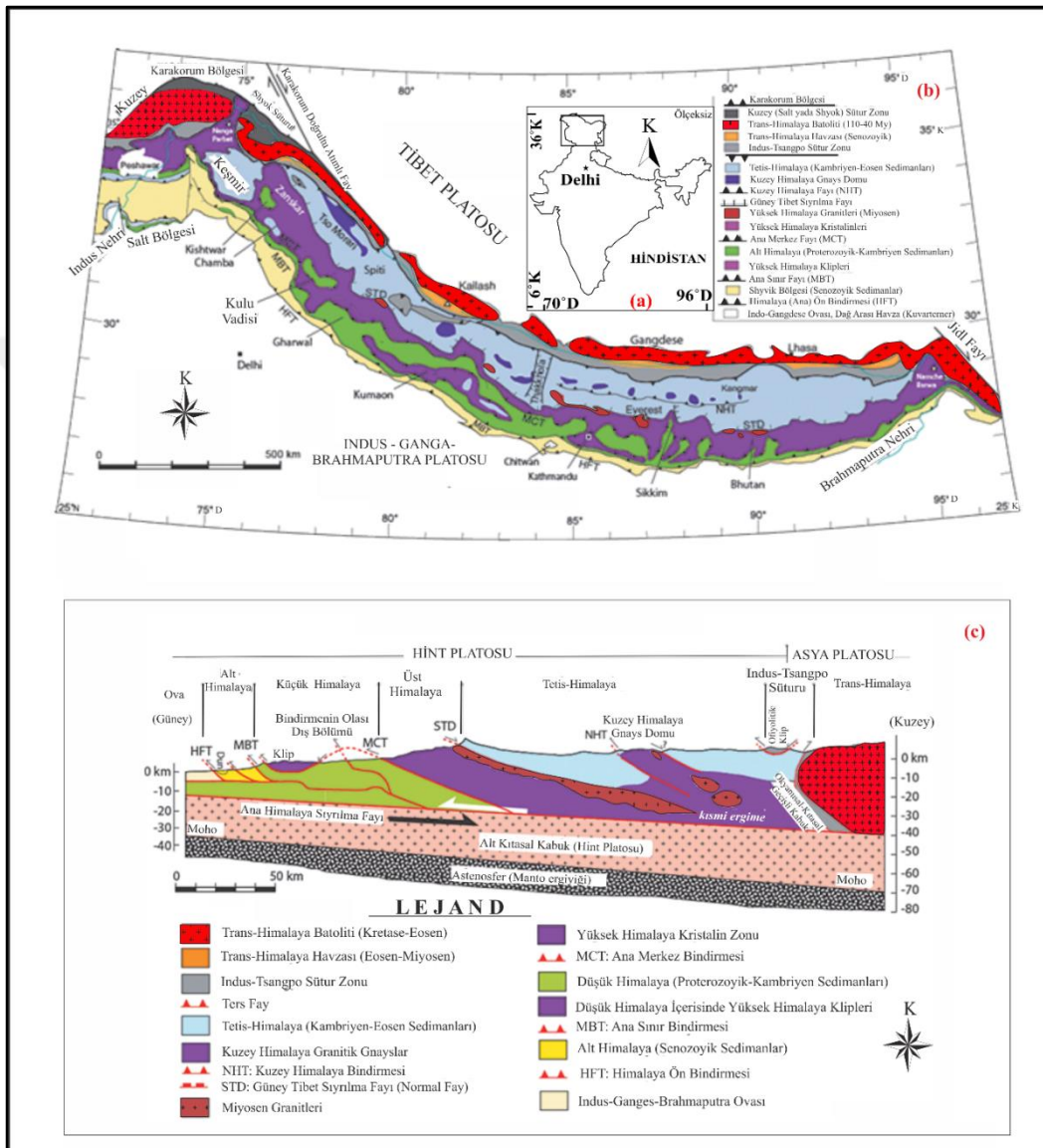


Şekil 1.8. a) Ladakh Batolitinide içerisine alan Jammu ve Keşmir (Hindistan) eyaletini gösteren alan (Valdiya 1988), **b)** Leh bölgesinde yer alan Trans-Himalaya Ladakh Batoliti ve bu batoliti sınırlayan suture zonlarını gösteren Google Earth görüntüsü (ölçeksiz)



Şekil 1.9. a) Hindistan'ın kuzeyinde yer alan Ladakh Batolitinin bulunduğu çalışma alanı (Valdiya 1988), **b)** Indus-Tsangpo Suture Zonu boyunca Avrasya Levhası'nın altına dalan Hint Levhası'nın içerisinde yer alan Kohistan, Ladakh, Kailash ve Gangdese Trans-Himalaya kalk-alkalen batolitlerinin basitleştirilmiş tektonik haritası (Singh 2007), **c)** Kuzeyde Shyok Suture Zonu ve güneyde Tsangpo Suture Zonu ile sınırlanmış Ladakh Batolitinin jeolojik haritası (Singh 2007). Yüksek basınç metamorfizmasına maruz kalmış Hint lehvası, Tetis Sedimanter Zonu ile örtülmüş Tso Morari Kristalinleri olarak gösterilmiştir

ITSZ (Indus-Tsangpo Suture Zonu) genellikle filiş, molas, olistolitik kireçtaşı, Dras volkanikleri ve ofiyolitik melanjlardan oluşmaktadır (Şekil 1.8-1.10).



Şekil 1.10. a) Hindistan’ın kuzeyinde yer alan Ladakh Batolitinin çalışma alanı (Valdiya 1988), **b)** Himalayaların genel jeoloji haritası (Anonim 7), **c)** Güney-kuzey yönlü Himalayalar enine kesit (Anonim 8)

Bu birimler Hint Levhasının kuzey yönlü hareketi ile Neo-Tetis Okyanusu'nun kapanması sırasında ve üzerlenme süreçleri ile gelişmiştir (Gansser 1964; Sharma ve Kumar 1978; Honegger vd. 1982; Thakur 1992; Rowley 1996; Jain vd. 2003; Leech vd. 2005; Jain vd. 2008; Jain 2014). Bu geniş zon genellikle, masif-porfirik andesit, dasit, riyolit, tüf, çört, sleyt, kuvarsit, kumtaşı, kireçtaşı, mermer, molas ve ofiyolitik melanj içeren Shyok Formasyonundan oluşmaktadır (Rai 1982). Bu formasyon, Shyok-Nubra

vadisinde gözlenen, Kretase-Alt Eosen yaşlı Nubra Formasyonuna benzer litolojik özellikler sunmaktadır (Rai 1982). Shyok-Nubra kesişim alanında yer alan Ladakh, Saltoro ve Karakorum tektonik sıradağları, güneyden kuzeye doğru üçlü kavşak oluşturmaktadır (Weinberg vd. 2000) (Şekil 1.9c). Ladakh bölgesinin kuzey kısımları, Khardung ve Shyok Formasyonu litolojik birimlerinden oluşmaktadır. Bölgenin KD sınırı, Ladakh bölgesinden Khalsar bindirmesi (KT) boyunca Saltoro bölgesinden ayrılmaktadır (Şekil 1.9c). Thakur vd. (1981), Khardung Formasyonu'nda yer alan litolojik birimlerin Shyok Formasyonu birimlerine eşdeğer olduğunu öne sürmüştür. Saltoro bölgesi, kuzeyde Nubra Formasyonu ve güneyde Shyok Formasyonu ile sınırlanmaktadır ve bu formasyon genellikle orta-iri taneli mesokratik kalk-alkalen granitoyitlerden oluşmaktadır (Thakur ve Mishra 1984; Upadhyay ve Sinha 1998). Kuzeye doğru gidildikçe, Nubra Formasyonunu oluşturan litolojik birimler doğrultu atımlı Karakorum Fayı (KF) boyunca Karakorum bölgesinde yeralan litolojik birimler ile dokanak oluşturmaktadır. Bu bölgede yeralan intrüzif kayalar, genellikle çarpışma sonrası tektonik ortamlarda oluşan lökograditlerden meydana gelmektedir (20-25 My, Parrish ve Tirrul 1989, Schärer vd. 1990; 12-18 My, Searle vd. 1998, Weinberg vd. 2000).

Ladakh bölgesinde yeralan litolojik birimler, Himalaya'nın kuzeybatısındaki ISZ (Indus Sütur Zonu) ve SSZ (Shyok Sütur Zonu) boyunca yer almaktadır. SSZ, güneydeki Kohistan-Dras ada yayı ile kuzeydeki Karakorum-Tibet bölgesini birbirinden ayırmaktadır (Şekil 1.9, 1.10). SSZ, kabuksal anlamda kısalmış yay gerisi havzasının tektonik kalıntıları işaret etmektedir (Rai 1982; Srimal 1986). Sıkışmaya maruz kalmış yay gerisi havza çoğunlukla kıvrımlanmış ve faylanmış metasedimanlar ve metavolkaniklerden meydana gelmiştir (Weinberg vd. 2000; Dunlap ve Wysoczanski 2002; Rehman vd. 2011). Metavolkanikler, Kretase yaşlı eski süturları işaret ettiği düşünülen Shyok Formasyonu'nun büyük bir bölümünü oluşturmaktadır (Weinberg vd. 2000; Dunlap ve Wysoczanski 2002; Rehman vd. 2011) (Şekil 1.9, 1.10).

Himalayalarda yeralan intrüzif kayalar coğrafik dağılımlarına göre Le Fort (1988) tarafından sınıflandırılmış ve kuzeyden-güneye doğru beş kuşak ayırt edilmiştir (Şekil 1.9, 1.10):

- ✓ Karakorum Eksen Batoliti
- ✓ **Trans-Himalaya Batoliti**
- ✓ Kuzey Himalaya Granit Kuşağı
- ✓ Yüksek/Yukarı Himalaya Kristalin (HHC) Kuşağı
- ✓ Alçak/Aşağı Himalaya Granit Kuşağı.

Trans-Himalaya Batoliti, Lhasa bloğu/Avrasya kıtasının güney kenarında gelişmiş olup, coğrafik olarak üç bölüme ayrılmış ve adlandırılmıştır (Honegger vd. 1982; Debon vd. 1986; Harris vd. 1988; Ahmad vd. 1998) (Şekil 1.9, 1.10):

- ✓ Pakistan'da Kohistan Batoliti
- ✓ **Hindistan'da Ladakh Batoliti** / Plütonik Kompleksi
- ✓ Tibet'te Gangdese/Kangdese Batoliti

Ayrıca Trans-Himalaya kuşağında yer alan plütonların batı kısımları Kohistan (doğu)-Ladakh (batı) (Şekil 1.9, 1.10) olarak adlandırılmıştır. Doğu kısımları ise Kuzey Kohistan'dan Ladakh ve Lhasa'ya kadar uzanan 3000 km'lik (Harris vd. 1988) mesafelere kadar uzanmaktadır. Bu uzanım düzensiz gövdeler şeklinde gözlenen Gangdese magmatik kuşağı ile kaplanmıştır (Harris vd. 1988) (Şekil 1.9, 1.10).

Trans-Himalaya kuşağında bulunan Ladakh Batoliti ise Indus-Tsangpo Süturu'nun kuzeyine doğru uzanmakta ve tonalit-diyorit-granodiyorit-granit bileşiminde ve farklı dokulara sahip intrüzif kütlelerden oluşan doğrusal bir kuşak oluşturmaktadır (Sharma 1990; Ahmad vd. 1998) (Şekil 1.9, 1.10). Ladakh magmatik yayının kıtasal yamaçtan gelen hendek birimleri ve volkano-sedimanter bileşenleri ile Hint Levhasının kuzey kesimlerinden gelen şelf sedimanları, önemli bir bindirme zonu olarak kabul edilen Indus Sütur Zonu (ISZ) ile birbirinden ayrılmaktadır (Sharma 1991; Thakur 1992) (Şekil 1.9b,c, 1.10).

Bazı yazarlara göre (Tahirkheli 1979; Honegger vd. 1982; Maluski vd. 1982; Bard 1983; Scharer vd. 1984; Petterson ve Windley 1985; Debon vd. 1986, 1987; Harris vd. 1988; Khan vd. 1989; Sharma 1990; Ahmad vd. 1998; Rolland vd. 2000; Weinberg ve Dunlap 2000) Erken Kretase-Alt Eosen döneminde Neo-Tetis Okyanusunun kuzeye doğru Avrasya Levhası'nın güneyindeki aktif kısmının altına dalması ve daha sonraki jeolojik süreçler Trans-Himalaya magmatik kuşağının oluşmasını sağlamıştır.

Searle (1983) Batı Himalayalar'da üç ana tektonik evre tanımlamıştır: (i) 75-60 My arasında çarpışma öncesi ofiyolit üzerleme aşaması, (ii) 45-25 My arasında kıtasal çarpışma aşaması ve (iii) sonrası ile 15 My arasında çarpışma sonrası evre. Searle vd. (1999) 60-50 My önce Ladakh Batoliti boyunca And-tipi magmatik yay yerleşiminin (gabro-diyorit-granodiyorit-granit), Hint-Avrasya çarpışması sırasında sona erdiğini öne sürmüştür (Şekil 1.9c). Magmatizmanın evrimi çarpışma öncesi dalma-batma süreci ile başlayıp, daha sonraki çarpışma sonrası ile ilişkilendirilmektedir (Debon vd. 1987; Searle vd. 1988). St-Onge vd. (2010) tarafından Chumatang yakınından alınan lökokratik dayk ve hornblend granodiyorit örneklerinde yapılan U/Pb (ID-TIMS) yaş analizi sonucunda: intrüzif kayaçların yaşlarının ~57.7 ile ~47 My arasında olduğu ve bu kayaçların Hint ve Avrasya levhalarının çarpışmasının bir ürünü olarak tanımlanmıştır.

Dalma-batma ile ilişkili tektonik ortamlar, Peru kıyılarında yer alan Pasifik kuşağında yer alan Kordilleran Batolitleri (Pitcher 1978) ve Trans-Himalaya Ladakh Batolitinde (Hindistan; Sharma 1991) de görülmektedir. Her iki bölgede gözlenen kayaçlar genellikle kalk-alkalen bileşimli granitlerden oluşmaktadır. Ladakh Batolitinin jeokimyasal özellikleri, Peru'da yer alan I-tipi Kordilleran Batolitleri ile birçok açıdan uyum sağlamaktadır (Honegger vd. 1982). Ladakh Batolitini oluşturan kayaçların bileşimleri olivin noritten-lökogranitlere kadar değişim sunmakta ve genellikle granodiyorit bileşimi sergilemektedir (Thakur 1981; Honegger vd. 1982). Magmatizmanın son evresi, Pakistan'da Gilgit-Indus Nehirleri çevresi ve Ladakh Chumathang'da lökogranit dayklar ile kesilmesi şeklinde gözlenmektedir (Petterson ve Windley 1985). Daha felsik magmaların gelişimi ile birlikte kabuk büyümesi ve zamansal evrim süreci hakkında yapılan gözlemsel

çalışmalar, yalnızca Ladakh Batolitinde değil (Pettersson ve Windley 1985; Raz ve Honegger 1989) ayrıca Sierra Nevada (Bateman 1983) ve Andlar bölgesinde de yapılmıştır (Pitcher 1993).

Hint-Avrasya jeodinamik çerçevesinde günümüz çalışmalarında, Leh ve çevresindeki plütonik kayaçların oluşumunun anlaşılması adına Indus ve Shyok suture zonları arasındaki Ladakh Batolitinde yeralan plütonlar ile ilgili çalışmalar son derece sınırlıdır. Bu sebeple doktora çalışmasının konusunu oluşturan Leh ve civarında yeralan Ladakh Batoliti intrüzif kayaçları, petrolojik, jeokimyasal ve petrojenetik çalışmalar açısından daha detaylı çalışılması amaç edinilerek tercih edilmiştir. Bu çalışma ile birlikte magmatizmanın türü, magma yerleşim derinliği, sıcaklığı, basıncı, kaynak kaya(ları)nın türü, bunların oluşum ortamları ve mekanizmalarının tespit edilmesine çalışılacaktır.

1.1. Kapsam ve Amaç

Ladakh Batoliti, Trans-Himalaya kuşağının önemli bir kısmını kapsamaktadır. Çalışma kapsamında batolitin KB kısmında, Leh bölgesinin 50-60 km batısında yeralan Basgo, Nimmu, Umla ve Taru bölgelerinde bulunan intrüzif kayaçlar çalışılmıştır. Bu doktora çalışması, Kohistan-Ladakh Batoliti boyunca And-tipi magmatik yay içinde oluşan granitoyitik kayaçların arazi, petrografik, mineralojik, jeokimyasal ve izotopik çalışmalarını içermektedir.

Leh civarındaki çalışmalar ağırlıklı olarak genel jeoloji ve jeokronolojiyi kapsamakta olup (Gansser vd. 1977; Vadlamani vd. 2009), bu bölgede yeralan intrüzif kayaçlar ile ilgili petrolojik, jeokimyasal ve petrojenetik çalışmalar oldukça kısıtlıdır.

Çalışma kapsamında, Ladakh Batolitine ait Leh bölgesi ve civarında yeralan intrüzif kayaçların (Basgo, Nimu, Umla, Taru) petrografisi, mineralojisi, kayaç/mineral jeokimyası ve izotop jeokimyası çalışmaları yapılarak; kayaçların petrolojisi, kökeni ve petrojenezi bir bütün olarak değerlendirilmiştir.

Tez çalışması aşağıda belirtilen aşamalarda gerçekleştirilmiştir:

- ✓ İntrüzif kayaçların jeolojik evriminde rol alan faktörler,
- ✓ Kısmi ergime, kabuksal asimilasyon, magma mixing/mingling gibi magmatik süreçlerin bu kayaçların oluşumlarındaki etkileri,
- ✓ Kaynak kaya(lar)ın kökenleri,
- ✓ Kaynak kaya(lar)ın oluşum ortamları,
- ✓ Kaynak kaya(lar)ın oluşum mekanizmaları.

1.2. Çalışmanın Tanım ve Organizasyonu: Verilerin Sunumu

Bu doktora tez çalışması 7 (yedi) bölümden oluşmaktadır:

1. Bölüm 1: Himalaya, Trans-Himalaya ve Ladakh (Leh bölgesi civarı)nın jeolojisi ile ilgili genel bilgilendirmelerin yapılması.

2. Bölüm 2: Ladakh Batoliti ve Leh civarında yeralan intrüzif kayaçlar ile ilgili kaynak taraması.
3. Bölüm 3: Materyal ve metotların tanımlaması.
4. Bölüm 4: Bulgular ve tartışma içeriğinin aşağıdaki gibi alt konulara bölünerek verilerin tartışılması:
 - 4.1. Bölge jeolojisi
 - 4.2. Yerel jeoloji
 - Arazi çalışması
 - 4.3. Petrografi
 - 4.4. Mineral kimyası
 - 4.5. Tüm kaya jeokimyası
 - 4.6. İzotop jeokimyası
 - 4.7. Petrojenez
5. Bölüm 5: Çalışma kapsamında elde edilen verilerin değerlendirilmesi ve sonuçlarının tartışılması.
6. Bölüm 6: Tez kapsamında kullanılan kaynaklar belirtilmesi.
7. Ekler: Öğrencinin özgeçmişi ve tezin ingilizce çevirisinin yer aldığı ekler kısmının sunulması.

EK-1'de çalışma kapsamında numune hazırlama metotları ve analitik teknikler tanımlanmaktadır. Mineral kimyası veritabanı **EK-2**, tüm kaya jeokimyası veritabanı **EK-3**, izotop jeokimyası veritabanı **EK-4**'de verilmiştir. Tezin ingilizce metni ise **EK-5**'de yer almaktadır.

2. KAYNAK TARAMASI

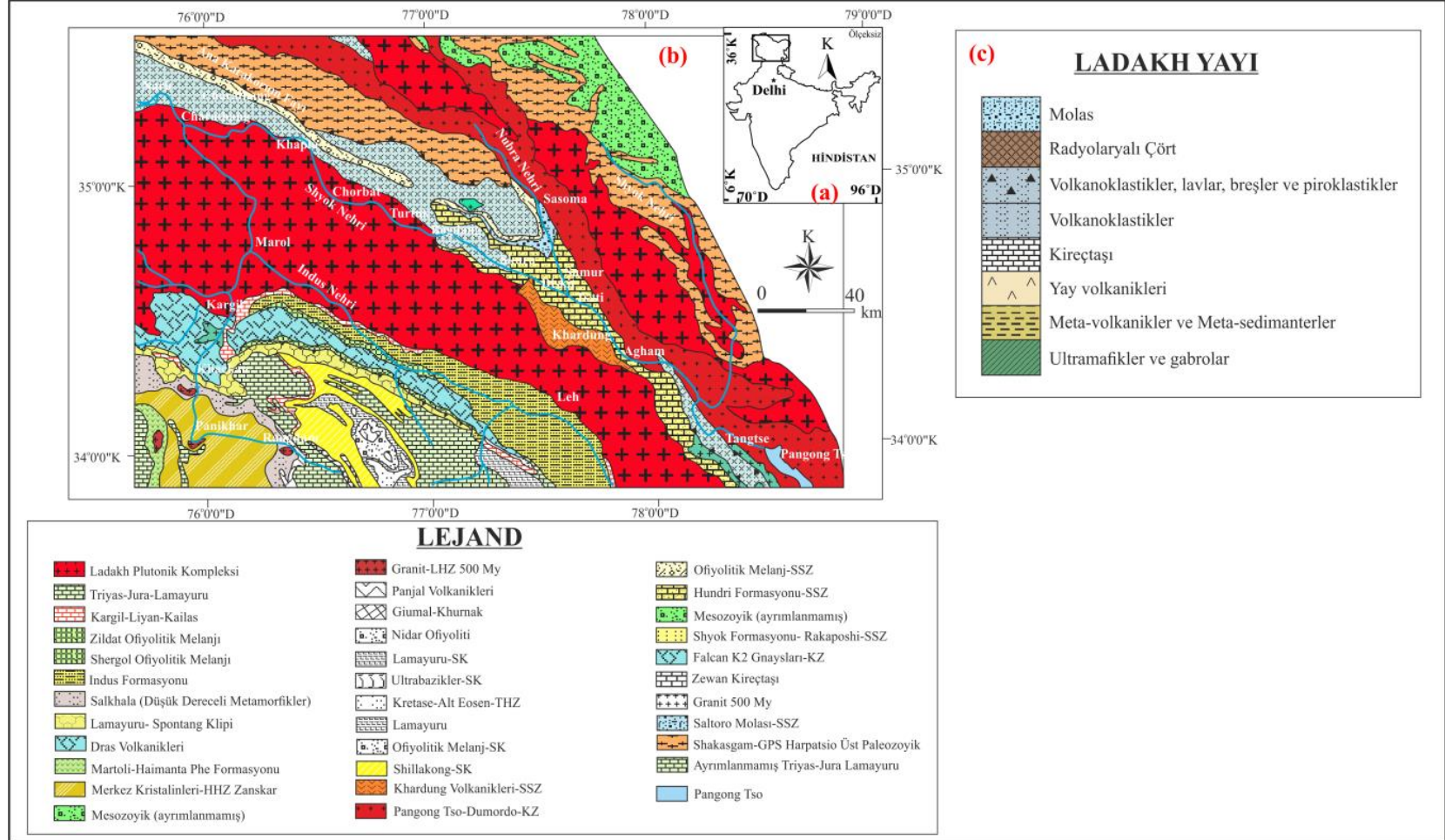
2.1. Ladakh Batoliti ve Çevresinin Jeolojisi

Ladakh Batoliti, Avrasya Levhasının güney kısmında 2500 km'den fazla mesafe boyunca yayılım sunan Trans-Himalaya Batolitinin bir bölümünü temsil etmektedir. Ayrıca Ladakh bölgesi, barındırdığı daha genç kayalık birimleriyle Avrasya levhasını Hint levhasından ayırmaktadır (Searle vd. 1997; Steck 2003). Bu litotektonik birlik 3 (üç) ana zon şeklinde tanımlanmıştır (Searle vd. 1997; Steck 2003):

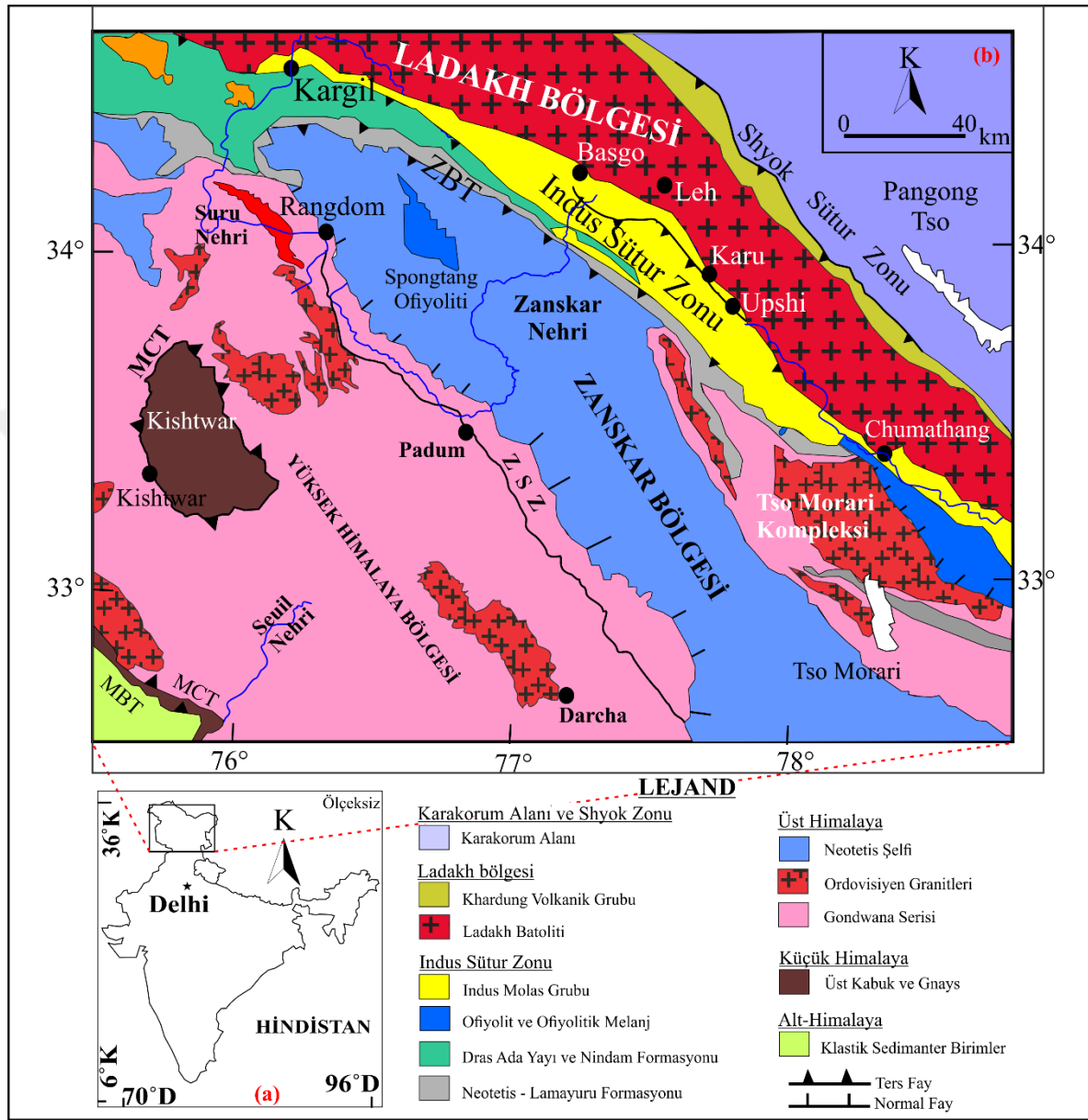
- ✓ Indus nehir vadisi boyunca yayılan Indus Sütur Zonu
- ✓ Shyok nehri boyunca yayılan Shyok Ofiyolitik Melanjı veya Shyok Sütur Zonu
- ✓ Indus ile Shyok vadileri arasında bariyer görevi gören Ladakh Batoliti veya Ladakh Magmatik Yay

Ladakh ve Zaskar bölgeleri, Indus Sütur Zonu, Kuzey Hint kıta kenarları ve Avrasya levhasının güney kesimlerinin kayalarından oluşmaktadır (Searle vd. 1997; Steck 2003) (Şekil 2.1, 2.2). Indus Sütur Zonu, Hint ile Avrasya levhaları arasındaki çarpışmanın gerçekleştiği asıl bölgeyi işaret etmektedir. Sütur zonunun güney sınırı, güney-güneybatı dalımlı bindirme hattı boyunca sütur zonu üzerinde kuzey yönlü Alt Mesozoyik şelf karbonatlarının bölgeye yapı olarak yerleşmesini sağlayan Ana Zaskar Bindirmesiyle temsil edilmektedir (Searle vd. 1997; Corfield ve Searle 2000) (Şekil 2.1, 2.2). Kuzey sınırı ise Ladakh Batolitine karşılık gelmektedir.

Himalayalarda, Karakorum bloğu ve Kohistan-Ladakh ada yayı, eski çarpışma sınırını temsil etmektedir. Hint ve Avrasya levhaları arasındaki diğer zon ise ana sınır zonu olarak tanımlanmıştır (Gansser 1977). Genellikle kalınlığı en az 2 km olan kıtasal sedimanlardan oluşan Indus Grubu, Ladakh Batoliti ile Indus Sütur zonu arasında sınır oluşturan yay önü ve dağ içi havza gelişimine işaret etmektedir (Garzanti ve Van Hayer 1988; Sinclair ve Jaffey 2001; Kirstein vd. 2006). Batolit, Tibet Platosu'nun güneybatı kısmını sınırlayan ve Miyosenden günümüze kadar aktif olan doğrultu atımlı Karakorum fayı etkisiyle genişlemektedir (Searle vd. 1992; Searle 1996). Ladakh Batoliti, deformasyona maruz kalmamış ve büyük oranda kırılğan deformasyon etkisi de göstermemektedir (Weinberg ve Dunlap 2000). Ancak, KKB-yönlü Thanglasgo Makaslanma Zonu'nda yoğun sünümlü makaslanma dokuları, Leh'in kuzeyinde ise difüze deformasyon zonu gözlenmiştir (Weinberg ve Dunlap 2000). Kuzeyde Büyük Karakorum Dağları (Saser Muztagh), ortada yer alan Ladakh bölgesi ve Jasker Dağı'nın küçük bir kısmı güneybatıda belirgin bir şekilde gözlenmektedir (Şekil 2.1, 2.2). Ladakh vadilerini en iyi yansıtan, güneyde Indus vadisi ve Leh'in kuzeyinde Shyok-Nubra vadisidir. Bölgenin kuzey ve kuzeydoğusunda yeralan bazı bölümleri buzul ile kaplıdır. Ortalama yükseklikler 2995 m (34° 46'; 77° 15') ile 7672 m (34° 51'; 77° 45') arasında değişmektedir. Bölge, neredeyse birbirine paralel kuzeybatı-güneydoğu yönünü takip eden Shyok ve Indus Nehirleri ile beslenmekte ve güneydoğu yönlü Numbra Nehri, Shyok Nehri (Diskit yakınında) ile birleşmektedir (Şekil 2.1). Zaskar sedimanter kuşağı, ayrımlanmamış Kuling-Lilang ve Lilang kayalık gruplarından oluşmaktadır (Şekil 2.2).



Şekil 2.1. a) Hindistan'ın kuzeyinde yer alan Ladakh Batolitinin bulunduğu çalışma alanı (Valdiya 1988), **b)** Ladakh bölgesinde yer alan Shyok, Nubra, Leh ve Zaskar bölgelerinin jeoloji haritası (Thakur 1992'den değiştirilerek alınmıştır), **c)** Ladakh bölgesinin kolon kesiti (Robertson vd. 2002'den değiştirilerek alınmıştır)



Şekil 2.2. a) Hindistan'ın kuzeyinde yer alan Ladakh Batolitinin bulunduğu çalışma alanı (Valdiya 1988), **b)** Kuzey Ladakh-Zaskar bölgesinin basitleştirilmiş jeolojik haritası (Thakur 1981; Thakur ve Misra 1983, 1984; Steck 2003; Epard ve Steck 2008; kaynaklardan değiştirilerek alıntı yapılmıştır). MBT-Ana Sınır Bindirmesi; MCT-Ana Merkez Bindirmesi; ZBT-Ana Zaskar Bindirmesi; ZSZ-Zaskar Makaslanma Zonu

Indus Tektonik Kuşağı, Indus Grubu volkano-sedimanter dizisi ve ofiyolit Sangleuma Grubu kayalar ile Ladakh Batolitinden oluşmaktadır. Shyok-Nubra volkano-sedimanter kuşağı ise granitoidik birimlerde içermektedir. Karakorum Granitoid Kuşağı, Karakorum sedimanterleri ve daha yaşlı metamorfik kayalardan oluşmaktadır.

Ayrımlanmamış Permiyen-Jura yaşlı Kuling-Lilang Grubu, bölgenin güneybatı kesimlerinde bindirmenin açığa çıktığı her iki alanla sınırlanmıştır. Siyah, gri, yeşil ve mor şeyl litolojilerinden ve grimsi kireçtaşı bantlarından oluşmaktadır.

Triyas-Jura yaşlı ayrımlanmamış Lilang Grubu kayalar, kireçtaşı, dolomit ve kuvarsitten oluşmaktadır. Geç Kretase-Erken Miyosen yaşlı Indus Tektonik Kuşağı kayaları, kuzeyde Ladakh Batoliti ve güneyde Spiti-Zasker Fanerozoik sedimanter kuşağı ile sınırlanmıştır. Bu zon iki farklı paralel kuşak olan Indus Grubu ve Sangeluma Grubu'ndan oluşmaktadır. Ancak, doğu Ladakh'taki Shyok sutureunun tam yeri araziye sınırlı ulaşım nedeniyle henüz belirlenmemiştir (Rolland vd. 2000; Rolland ve Pecher 2001; Weinberg ve Dunlap 2001) (Şekil 2.2). Ladakh Batoliti (Güneyde molasin Ladakh Batolitini üzerlediği yerler hariç), Indus Molaslarının deforme sedimanter birimlerin yerini alarak batoliti birbirinden ayıran ISZ ile sınırlanmıştır (Frank vd. 1977).

Indus Molasları, Eosen'den Miyosen'e kadar yaş aralığı sunan silttaşı, kireçtaşı ve konglomera içeren sedimanlardan oluşmaktadır (Searle vd. 1990). Batolit, Shyok tektonik kuşağının Paleozoik-Eosen yaşlı metasedimanter, volkanik ve metamorfik kayalardan oluşan BKB atımlı bindirmeli güney sınırını meydana getirmektedir (Srimal vd. 1987). Kretase-Tersiyer yaşlı Ladakh Batoliti, farklı doğrultularda lökokratik granit ve porfiritik granit, biyotit-hornblend granit, granodiyorit, kuvars monzodiyorit, diyorit, tonalit ve lamprofir daykaları tarafından kesilmektedir (Srimal vd. 1987). Batolit içerisinde ince bantlı yapılar şeklinde gözlenen daha yaşlı metasedimanter kayalar sleyt, kuvarsit, şist ve gnays bileşimindedir (Srimal vd. 1987). İri taneli granit ve granodiyorit bileşimli intrüzifler içeren Ladakh Batoliti, kenarlarında yoğun ancak merkeze doğru neredeyse varlığı az olan diyoritik bileşimli anklavlar içermektedir (Srimal vd. 1987).

2.2. Önceki Çalışmalar

Ladakh bölgesinin jeolojisi hakkında ilk çalışmalar Stoliczka (1866) ve Drew (1875) tarafından gerçekleştirilmiştir. Sonra yapılan çalışmalar ise Wadia (1937), Norin (1946), Tewari (1964), Shankar vd. (1976), Shah vd. (1976); Frank vd. (1977), Fuchs (1977), Sharma ve Kumar (1978), Thakur (1981), Brookfield ve Andrew (1984)'e aittir.

Ladakh bölgesinde bazı bilim insanları, Indus ve Shyok Suture Zonu olmak üzere iki sutureun yer aldığını öne sürmüşlerdir (Gansser 1980; Honegger vd. 1982). Shyok Sutureu, Indus Suture Zonu'ndan farklı olarak bir paleo-suture olarak tanımlanmıştır (Gansser 1980; Honegger vd. 1982). Karşıt görüş olarak ise Shyok Suture Zonu boyunca oluşan paleo-dalma-batmanın varlığı Rai (1982) tarafından arazi verileri kullanılarak öne sürülmüştür.

Himalayaların oluşumunda oynadığı jeotektonik rol ve karakteristik kayac birliğinden dolayı, Ladakh bölgesi içerisinde yer alan Indus Suture Zonu, yaygın çalışma alanlarından biridir. Bu zonun önemi ilk olarak Gansser (1964) tarafından ortaya konulmuş ve ilk defa yazar tarafından Indus Suture Zonu (ISZ) ismiyle adlandırılmıştır. Indus Suture Zonu'nun bir bölümü batıda Çin'e ve doğuda ise Pakistan'a kadar uzanmaktadır (Gupta vd. 1970; Gansser 1974, 1977; Shanker vd. 1976; Kaila ve Narain 1976; Frank vd. 1977; Fuchs

1977; Gansser 1977; Thakur ve Viridi 1979; Sharma ve Gupta 1978; Tahirkheli vd. 1979; Klootwijk ve Conaghan 1979; Powell 1979; Srikantia ve Razdan 1980; Rai 1980, 1982; Thakur 1981, 1983; Honegger vd. 1982; Searle 1983; Windley 1983; Allegre vd. 1984; Thakur ve Mishra 1984). Indus-Tsangpo Sütur Zonu, Hint levhası ile Avrasya levhasının Karakorum-Tibet bloğu arasında kesişim noktasıdır. Batıdan doğuya Himalayaların kuzeyine doğru 2500 km kadar uzanmakta ve bu zon ofiyolit, ofiyolitik melanjlara, plütonik-vulkanik kayalar ve molas sedimanlar ile karakterize edilmektedir (Gansser 1977; Sharma ve Kumar 1978) (Şekil 2.1).

Kaila ve Narain (1976), Himalaya boyunca DSS (Derin Sismik Sondaj) profillemesinin temelinde, Hint levhasının kuzey sınırı Indus Sütur Çizgisi ile karşılaşmamakta fakat Çin'deki Tien-Shan'ın güney kesiminin kuzeylerine kadar uzanmasının yattığını öne sürmüştür.

Indus Sütur Zonu iki ana volkanik aktivite (Dras ve Sumdo volkanikleri) ile ilişkilidir: Bu volkaniklerden bir tanesi güney zonda bulunurken ve daha genç olan Khardung volkanikleri ise kuzeyde bulunmaktadır (Şekil 2.1).

Dras volkanikleri genellikle bazalt ve volkano-sedimanlardan oluşmaktadır. K/Ar metodu ile bu volkanik kayaların yaşlarının 77.5 ± 1 My olduğunu göstermiştir (Sharma vd. 1978). Jeokimyasal olarak volkanik kayalar kalk-alkalen karakterli yay toleyitikleridir (Gergan 1978). Shyok-Kardung'da bulunan ikinci volkanik kuşak, Sharma ve Gupta (1978) tarafından belirlenmiştir. Bölgedeki Panjal volkaniklere eşdeğer sayılabilen volkanikler hakkında bilgiler Lydekker (1883) ve Norin (1946) tarafından ileri sürülmüştür. Sharma vd. (1978)'nin, Khardung volkaniklerinde gerçekleştirdiği ilk radyometrik yaş verilerinde 38 ± 2 (K/Ar) My tespit etmişlerdir. Ayrıca Khardung bölgesi ve Shyok vadisindeki bu volkanik aktiviteler Indus Vadisi'ndekilerden (Dras Volkanikleri) çok daha gençtir. Khardung volkaniklerini, ortaçağ ve asidik karakterli volkano-klastikler ve volkano-sedimanlar oluşturmaktadır.

Indus Filiş ve Indus Molas'ın iki farklı doğrusal kuşak oluşturduğu fikri kabul edilmektedir (Sharma ve Kumar 1978). Indus Filişleri Alt Kretase-Eosen yaşlı iken Indus Molaları ise Geç Orta Miyosen yaşlıdır (Sharma ve Kumar 1978).

Shanker vd. (1976)'ne göre Ladakh granitleri farklı magmatik aktivite fazları göstermektedir. Granitler mineral bileşimine göre; biyotit granit, hornblend granit ve turmalin granit olarak sınıflandırılmışlardır (Shanker vd. 1976). Sharma ve Kumar (1978)'e göre Ladakh Batoliti zonlu ve merkeze doğru daha asidik özelliktedir. Sharma ve Kumar (1978) tarafından bu batolitte üç adet zon tanımlanmıştır (hale zonu, sınır zonu, merkez zonu). Ladakh'taki granitoid kayaların jeokimyası, birçok bilim insanı tarafından tartışılmaktadır (Varadarajan vd. 1980; Honegger vd. 1982; Sharma ve Choubey 1983). Bu çalışmalar Ladakh granitoidlerinin köken magmasının kalk-alkalen karakterli olduğunu göstermektedir (Varadarajan vd. 1980; Honegger vd. 1982; Sharma ve Choubey 1983).

Hint levhasının kuzeye doğru dalması sırasında, Tetis okyanusal litosferi, Avrasya'nın, aktif And-tipi, güney kenarının altına dalma-batmasıyla, 2500 km'lik çarpışma zonu boyunca Trans-Himalayan kalk-alkalen batolitin sokulum yapmasını sağlamıştır (Patterson ve Windley 1985). Batolitin ana bileşimi genellikle granodiyorit bileşimli olmasına karşın, norit, gabro, granit ve tonalit bileşimlerinde sahiptir. Ladakh'taki Chumathang bölgesinde ve Pakistan'da yer alan Gilgit-Indus Nehirleri etrafında gözlenen magmatik fazın son ürünleri ise lökokratik granit dayklardır (Patterson ve Windley 1985). Batolitin Sm-Nd izotop verileri ve ilksel Sr oranlarının kondrite yakın değerlerde olması ve ihmal edilebilir, kabuk etkisiyle birlikte manto kökenli olduğunu işaret etmektedir (Honegger vd. 1982; Scharer vd. 1984; Petterson vd. 1985).

Ladakh Batoliti ile ilgili önceki çalışmalar aşağıda sunulmuştur:

Searle vd. (1990), Ladakh Himalaya (Hindistan) dağ içi Indus Molass havzası gelişimi ve yeniden yapılanması ile ilgili araştırma çalışmalarını yayınlamışlardır. Yapılan çalışmalarda D-B yönlü paleo-akıntılar, eksene paralel, ikincil yanal girişleri olan sediman taşınmasına işaret etmektedir. Indus molass baseni, tüm stratigrafiyi kesen çeşitli Eosen sonrası ve Tersiyer zamanlarında da aktif olan K yönlü bindirmeler ile deforme olmuştur.

Singh (1993), Ladakh Batoliti'nin bir bölümünün jeolojik gelişimi üzerine çalışma yapmıştır.

Rolland vd. (2000), Rolland ve Pecher (2001) ve Weinberg ve Dunlap (2001) çalışmalarını Orta Kretase yaşlı yay gerisi oluşumu ve Avrasya kenarı boyunca oluşan yayın (Kuzey Ladakh Shyok Sütur Zonu, KB Himalaya) gelişimi üzerine yapmışlardır. Bu yayında her iki bölgesinden elde edilen veriler, Kuzey Ladakh'da yay gerisinden-yay önüne doğru kuzeybatıdan-güneydoğuya evrimini açıklamaktadır. Bu yay gerisi havzanın açılması, Ladakh Yayının kuzeybatı tarafında meydana gelmiştir. Yay gerisi ise devamlı olarak doğu yönlü olarak kapanmıştır. Yayın kendisi, doğuda daha olgun, güney Tibet kıta yayına benzemektedir olup; daha fazla kıtasal sedimantasyon ile karakterize edilmektedir (Rolland vd. 2000, Rolland ve Pecher 2001 ve Weinberg ve Dunlap 2001).

Jamieson vd. (2003), Himalaya'daki dikey vadilerin tektonik hareketleri üzerine çalışma (Kuzey Hindistan, Ladakh Batoliti'nin Morfolojik Analizi) yapmışlardır. Bu çalışma, Ladakh Batoliti'ni Indus ve Shyok nehirlerine boşaltan, enine havzalardaki jeomorfolojik farklılıkları araştırmaktadır. Batolitin kuzeydoğu ve güneybatı sınırlarının değişken yapısal özellikleri göz önüne alınarak üç farklı bölgeye ayrılmıştır. Indus ve Shyok vadilerine boşaltan 62 havzanın morfometrik analizi, üç adet dijital veri seti kullanılarak saha gözlemiyle desteklenerek gerçekleştirilmiştir. Morfometrik asimetri, Shyok vadisinin tektonik olarak pasif olduğu düşünülen merkez bölgesinde daha çok belirgindir. Ancak Indus Vadisi, batolit ve kuzeydoğu yönünde bindirme yapan Indus Molass ile sınırlanmıştır. Indus Molass bindirme cephesi, son 20 My'da Ladakh Batoliti'ne en az 36 km kadar ilerlemiştir. Bu nedenle, uzun süreli asimetric deformasyon ve yüzeylenme/yükselme, Indus dikey vadisinin yanal olarak Ladakh Batoliti'ne doğru hareket

etmesine ve böylece enine havzaların morfometrik asimetrisine neden olduğu ileri sürülmüştür.

Ravikant (2005), Doğu Karakorum, Ladakh ve Hindistan'daki Miyosen ve Kretase'de gerçekleşen jeolojik olayları tespit etmek için Rb-Sr jeokronolojisini kullanmıştır.

Singh vd. (2007) tarafından yapılan çalışmada, Shyok Sütur Zonuna yakın bölgede kuzey sınırından alınan granodiyorit örneğinde SHRIMP-II U-Pb zirkon yaşlandırma tekniği kullanılarak 60.1 ± 0.9 My yaş tespit edilmiştir. Ayrıca Indus-Tsangpo Sütur Zonuna yakın güney sınırından alınan diyorit numunesi üzerinde aynı yaşlandırma tekniği ile 58.4 ± 1.0 My değeri elde edilmiştir. Bu çalışma ile kristallenme sonrası verileri ve yerleşme derinliği verileri, Ladakh Batoliti'nin kuzeye doğru eğimlendiğini göstermektedir.

Vadlamani vd. (2009), doğu Karakorum ve Ladakh'ta yer alan Kretase-Tersiyer granitlerinin petrojenezi üzerine yaptıkları çalışmada zirkon U-Pb ve Hf izotop tekniklerini kullanmışlardır. Ladakh Batolitinden alınan granodiyorit örneğinde, zirkon U-Pb yaşlandırma verilerine göre 68 ve 64 My ve $+6.4$ ve $+10.3$ $\epsilon\text{Hf}(t)$ değerleri; Leh ve Darbuk yakınlarından alınan üç diyorit örneğinde ise aynı teknikler ile 50.4 ve 51.0 My, $+7.4$ ve $+8.9$ $\epsilon\text{Hf}(t)$ değerleri elde edilmiştir. Bu veriler granitik magmatizma için en önemli zaman aralığının Paleosen-Eosen olduğunu göstermektedir. Karakorum ve Ladakh Batolitindeki granitlerden elde edilen magmatik zirkonların çözünmüş Hf izotopik bileşimleri, en azından Orta Kretase'den beri aktif kıta kenarında, hem eski hem de genç kıtasal kabuğun bu kayaçların oluşumunda etkili olduğunu göstermektedir.

Kumar (2010), Ladakh Batoliti (Kuzey Himalaya)'nde yer alan mafik mikrogranüler anklavlar üzerinde çalışmıştır. Yazara göre, arazi ve mikroyapısal kanıtlar, Ladakh granitoid ve anklavlarının, dalma-batma zonunda magma odası(açık) içerisinde felsik ve mafik magmanın fraksiyonel farklılaşması ile meydana gelen çoklu evreli magma mixing ve mingling ürünleri olduğu şeklinde yorumlanmıştır.

Marc vd. (2010), Chumathang bölgesinde Ladakh Batolit'i zirkon yaş tanımlaması üzerinde çalışmışlardır. Hornblend granodiyorit (57.7 ± 0.2 My; U-Pb ID-TIMS) ve onu kesen lökokratik dayk örneklerinden (47.1 ± 0.1 My; U-Pb ID-TIMS) yeni zirkon yaş verileri elde etmişlerdir. Buna göre Doğu Ladakh'da meydana gelen dalma-batma ilişkili granodiyoritik magmatizmanın, çoğunlukla Paleosen-Erken Eosen yaşlı olduğu şeklinde yorumlanmıştır.

White vd. (2011), Ladakh Batoliti zirkonlarında U-Pb SHRIMP yöntemiyle yapılan analizler sonucunda 66-46 My yaş aralığı tespit etmişlerdir.

Kumar vd. (2011), Kuzeybatı Himalaya yükseklerindeki Ladakh Batoliti'nden alınan granitoidler ve anklavlar üzerinde Hf izotop, zirkon U-Pb jeokronoloji ve jeokimya çalışmaları yapmışlardır.

Heri vd. (2015), çalışmalarını Ladakh Batolitini kesen Eosen dayklarının izotop jeokimyası ve jeokronolojisi üzerine gerçekleştirmişlerdir. Yazarlar tarafından, kuvars ksenokristallerinin yer aldığı aşınmış doğu dayklarının negatif $\epsilon_0(\text{Nd})$ ve pozitif $\epsilon_0(\text{Sr})$ değerleri tespit edilirken, batı dayklarında ise kuvars ksenokristallerinin gözlenmediği ve pozitif $\epsilon_0(\text{Nd})$ ve sıfıra yakın $\epsilon_0(\text{Sr})$ değerleri tespit edilmiştir. Sr-Nd izotoplarındaki ($\epsilon_0(\text{Nd}) = +3.6 - (-)9.6$, $\epsilon_0(\text{Sr}) = +0.4 - +143$) farklılığı, kuvars ksenokristallerinin varlığına ve daykların ana magmasının kabuksal asimilasyonu (farklı derecelerde) ile açıklamışlardır. Dayk örneğinden seperasyonla elde edilen minerallerden ^{40}Ar - ^{39}Ar yaş verileri elde edilmiştir. Amfibol mineralinden elde edilen yaşlar 50-54 My arasında iken, tek biyotit mineralinden elde edilen (hem Rb-Sr ve hemde ^{40}Ar - ^{39}Ar teknikleri ile tespit edilen) yaş ise 45 My olarak tespit edilmiştir. Psödotakilit numunesi ise yaklaşık 54 My yaş değerini vermiş olup; bu durum batolitin bir bölümünün bu yaş civarında kırılga olduğunu ve hızlı bir yükselmeye maruz kaldığını göstermiştir.

Ladakh Batoliti ile ilgili jeolojik anlamda çok sayıda araştırma yapılmasına rağmen, bu batolite ait kayaçların mineral kimyası, tüm kaya jeokimyası (ana-iz-REE) ve izotop jeokimyası çalışmaları ise son derece sınırlıdır.

3. MATERYAL VE METOT

Bu doktora tez çalışması arazi, mikroskop ve laboratuvar çalışmalarının entegrasyonu şeklinde tasarlanmıştır (Çizelge 3.1).

- ✓ Hindistan Jeoloji Araştırma Kurumu (Geological Survey of India, Kolkata) tarafından yayınlanan Ladakh bölgesinin 1:250.000 jeolojik haritası kullanılmıştır. Ayrıca Toposheet, LandSAT ve Google Earth görüntüleri çalışma alanından örnek toplama aşamasında faydalanılmıştır.
- ✓ Saha çalışması Leh (Ladakh, Hindistan) bölgesinde örnek alımı şeklinde yapılmıştır.
- ✓ Mineraloji-petrografi çalışmaları için araziden alınan tüm numunelerden ince kesitler yaptırılmıştır. Bu çalışmalar Nikon-polarize mikroskobu kullanılarak gerçekleştirilmiştir.
- ✓ Minerallerin bileşimlerinin tespiti ve jeotermobarometre tayini için EMPA (Elektron Mikroprob) kullanılarak gerçekleştirilmiştir.
- ✓ Kayaçlarda ana ve iz element (REE dahil) jeokimya verileri XRF + ICP-MS teknikleri kullanılarak elde edilmiştir.
- ✓ Radyojenik izotop jeokimyası (tüm kaya Rb-Sr, Sm-Nd) ise TIMS kullanılarak gerçekleştirilmiştir.

Çizelge 3.1. Ladakh Batoliti örneklerinde kullanılan yöntem ve analitik teknikler

ANALİTİK TEKNİKLER	ÖRNEK SAYISI	OKSİTLER/ ELEMENTLER/ İZOTOP	LABORATUVAR
ELEKTRON MİKROPROB (EPMA) (mineral)	12	Ana oksitler	Indian Institute of Technology Bombay (IIT Bombay) Department of Earth Sciences
XRF (tüm kaya)	41	Ana oksitler İz elementler (Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Nd, Pb, Th, U)	Bureau Veritas Mineral Laboratories, Vancouver, Canada
ICP-MS (tüm kaya)	41	İz elementler (Sc, V, Cr, Ni, Co, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Cs, Ba, Hf, Ta, Pb, Th, U) Nadir toprak elementleri (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu)	Bureau Veritas Mineral Laboratories, Vancouver, Canada
KÜTLE SPEKTROMETRİSİ (TIMS) (tüm kaya)	16	$^{87}\text{Sr}/^{86}\text{Sr}$ $^{143}\text{Nd}/^{144}\text{Nd}$	Orta Doğu Teknik Üniversitesi (ODTÜ) Jeoloji Bölümü, Ankara

3.1. Arazi Çalışması ve Numune Alımı

Temmuz 2015'te yapılan saha çalışması sırasında, Ladakh-Leh bölgesinin (Şekil 3.1) batısına doğru (Basgo, Nimmu, Umla ve Taru civarları) 50 ile 60 km'den örnekler toplanmıştır. Her biri ~1 kg ağırlığındaki örnekler numaralandırılarak bez torbalara konulmuştur.



Şekil 3.1. Arazi çalışma bölgesine (Ladakh) girişi gösteren fotoğraf (arka tepelerde Ladakh intrüzif kayalar yer almaktadır)

- ✓ Ancak, bazı bölgelerden alınması öngörülen örnekler, Hindistan yasalarının kısıtlamaları nedeniyle alınamamıştır.
- ✓ Bazende arazi koşullarının zorlukları nedeniyle numuneler alınamamıştır. Ladakh ve civarı Jammu ve Keşmir eyaletinin en yüksek platosu olup; yaklaşık olarak 3000 m yüksekliktedir. Yüksek irtifada oksijen azlığı nedeniyle, aralıklarla oksijen takviyesi gerekmektedir (Şekil 3.2); bu da son derece meşakketli ve zaman alan bir işlemdir.
- ✓ Bazende iklim koşulları nedeniyle numuneler alınamamıştır. Çünkü Ladakh bölgesi soğuk çöl iklim özelliklerine sahiptir.



Şekil 3.2. Leh merkezinde yeralan devlet hastanesinde araziye çıkmadan önce oksijen takviyesi

3.2. İnce Kesit Hazırlama ve Petrografik Çalışmalar

Araziden alınan numuneler elmas bıçaklı su testeresiyle iki eşit parça olacak biçimde kesilmiştir. İki eşit parçadan bir tanesi şahit numune olarak arşivlenmiş diğer yarısından altere olmuş bölümleri ayrılarak taze kısımları ince kesit örnekleri için uygun boyutlarda harırlanmıştır. Kırk bir örnek ince kesitlerin hazırlanması için Ankara’da bulunan MG Grup Laboratuvarlarına gönderilmiştir. Petrografik analizler, Akdeniz Üniversitesi Jeoloji Mühendisliği Bölümü Optik Mineraloji laboratuvarında, 50ipol Nikon ve 100ipol polarizan mikroskopları ile gerçekleştirilmiştir. Fotoğraf çekimleri ise mikroskoba entegre Clemex 6.0 programı kullanılarak gerçekleştirilmiştir (Şekil 3.3).



Şekil 3.3. Akdeniz Üniversitesi, Jeoloji Mühendisliği Bölümü Optik Mineraloji Laboratuvarında gerçekleştirilen, petrografik çalışmalarından bir görünüm

3.3. Mineral Kimyası Çalışmaları

Kayaçlarda bulunan minerallerin türleri, kimyasal bileşimleri, yerleşim sıcaklığı ve basınç değerlerinin tespit edilmesi amacıyla mineral kimyası EPMA ile gerçekleştirilmiştir. Bu çalışmalar Indian Institute of Technology Bombay (IIT Bombay), Department of Earth Sciences’da bulunan Cameca-SX Five elektron mikroprobu kullanılarak tarafımdan gerçekleştirilmiştir (Şekil 3.4).



Şekil 3.4. Hindistan Teknoloji Enstitüsü (Bombay)’nde, EPMA tekniği ile gerçekleştirilen mineral kimyası çalışmasından bir görünüm

3.4. Kimyasal Analiz ve İzotop Jeokimyası

Bu çalışma kapsamında ilgili analitik teknikler aşağıdaki gibidir:

- ✓ XRF ve ICP-MS kullanılarak ana ve iz element analizlerinin tespiti.
- ✓ TIMS kullanılarak radyojenik izotop (Sr, Nd) analizlerinin gerçekleştirilmesi.

4. BULGULAR VE TARTIŞMA

4.1. Bölge Jeolojisi

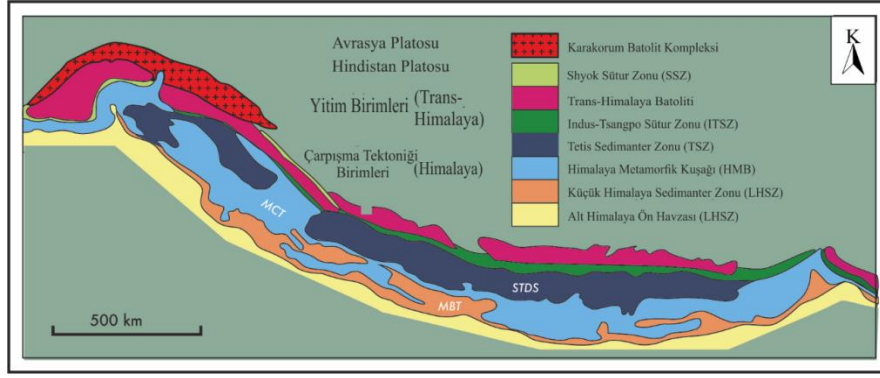
Himalayalar, dünyadaki en genç dağ sıralarından biridir ve genellikle yükselmiş metamorfik, magmatik ve sedimanter kayalardan oluşmaktadır. Himalayaların jeodinamik evrim 5 farklı evre ile açıklanmaktadır (Jain vd. 2002; Singh ve Jain 2002):

- ✓ Geç Mesozoyik döneminde dalma-batma ve büyüme
- ✓ Senozoyik döneminde çarpışma
- ✓ Çarpışmanın son evresinde genişleme tektoniği
- ✓ Çarpışma sonrası ön çukurlarda sedimantasyon
- ✓ Günümüz jeodinamiği

Himalayalar, Proterozoyik ile Günümüz yaş aralığında oluşan, farklı bileşimli intrüzif kayalar içermektedir (Coward vd. 1982; Honegger vd. 1982; Dietrich vd. 1983; Khan vd. 1989; Rolland vd. 2000). Kohistan, Ladakh ve Karakorum batolitleri olarak da adlandırılan Trans-Himalaya Plütonları ve Gangdese Magmatik Kuşağı, Hint-Avrasya Levhalarının karşılaşması sonucu oluşan magmatik ürünlerdir (Coward vd. 1982; Honegger vd. 1982; Dietrich vd. 1983; Khan vd. 1989; Rolland vd. 2000). Trans-Himalaya plütonları, Peru'daki I-tipi Kordilleran kayaları ile benzer özelliklere sahiptir. Gangdese ve Ladakh Batolitlerinin ilksel Sr, Nd ve Pb izotopik değerleri, bu batolitlerin mantodan türemiş bileşenlere sahip olduğunu göstermektedir (Coward vd. 1982; Honegger vd. 1982; Dietrich vd. 1983; Khan vd. 1989; Rolland vd. 2000). Trans-Himalaya plütonları için U-Pb yaş verileri 105-45 My arasında değişmektedir (Coward vd. 1982; Honegger vd. 1982; Dietrich vd. 1983; Khan vd. 1989; Rolland vd. 2000). Batolitlere ait yaş ve jeokimyasal veriler, bunların oluşumunda kabuk kirlenmesinin düşük oranda etkili olduğunu işaret etmektedir (Coward vd. 1982; Honegger vd. 1982; Dietrich vd. 1983; Khan vd. 1989; Rolland vd. 2000).

Tetis Okyanusu'nun kapanması genellikle, Indus-Tsangpo Suture Zonu (ITSZ) ve Kohistan Yayı arasında sınırlanmıştır. Yüksek Himalayalar'da yer alan Hint Levhasının kuzey kesimleri, Yüksek Himalaya Kristaleni (HHC) içerisinde ve Proterozoyik yaşlı sedimanter örtüsü tarafından kuşatılmıştır. Bu kayalar, Tetis Sedimanter Zonu'nun Paleo-Mesozoyik platform dizisi ile örtülmüştür. Kıta-kıta Çarpışması sırasında Hint Levhası'nın kabuksal olarak kısılması, Yüksek Himalayaların temelindeki metamorfik kayaları önemli ölçüde deforme etmiştir.

Himalaya granitoidleri, Himalaya orojenezi ile ilişkili iki ana gruba ayrılmıştır (Pande 1999; Jain vd. 2000; Hodges 2000; Singh 2001): (i) granit/gnays bileşimli çıkan çarpışma öncesi oluşan intrüzif kütleler ve (ii) çarpışma ile eşyaşı - çarpışma sonrası oluşan lökokratik intrüzif kütleler. Himalaya granitoidleri, Himalaya orojenindeki doğrusal kuşaklar şeklinde görülen çeşitli stratigrafik ve tektonik dizilimlerin coğrafik dağılımına göre sınıflandırılabilir (Şekil 4.1; Singh ve Jain 2002). Küçük Himalayalar hariç diğer tüm tektonik birimlerin hemen hemen her birinde farklı boyutlarda intrüzif kütleler bulunmaktadır.



Şekil 4.1. Himalaya bölgesinin jeolojisini gösteren harita (Kısaltmalar: SSZ-Shyok Suture Zonu, ITSZ-Indus Tsangpo Suture Zonu, THSZ/STDZ-Trans-Himadri Makaslanma Zonu/Güney Tibet Sıyrılma Zonu, MCT-Ana Merkez Bindirmesi, MBT-Ana Sınır Bindirmesi (Singh ve Jain 2002’den değiştirilerek alınmıştır)

4.1.1. Tektonik zonlar

Himalaya Sıradağları (Şekil 1.1), batıda Nanga Parbat tepesinden (8125 m), doğuda Namche Barva tepesine (7782 m) kadar 2500 km’lik alanı kapsamaktadır (Valdiya 1980; Hodges 2000) (Şekil 1.5). Kuzeyde Trans-Himalaya zonundan güneyde Ganj düzlüklerine kadar uzanan bu sıradağlar 200-250 km genişliktedir (Le Fort 1975). Merkez Himalayalar ise bu dağların en dar bölümlerine sahip olup, 100-120 km genişliktedirler. Güneyde Indo-Ganj düzlüklerinden-kuzeyde Tibet Platosu’na kadar etkili geçişe sahiptirler (Hodges 2000). Himalaya evriminde rol oynayan tektonik olayların bir sonucu olarak, tektonik zonlar açısından Himalaya Sıradağları’nın tanımlanması ilk olarak Gansser (1964) tarafından beş zona ayrılarak yapılmıştır. Her bir zonun sınırları bölgeden geçen beş ana fay ile sınırlanmıştır. Bu zonlar kuzeyden itibaren 1) Indus-Tsangpo Suture Zonu (ITSZ), 2) Tethyan Sedimentary Zonu (TSZ), 3) Büyük Himalaya Zonu (HH), 4) Küçük Himalaya Zonu (LH) ve 5) Yarı-Himalaya Zonu (SHZ)’dur.

Bu zonlar birçok kaynakta farklı isimlerle anılmaktadır: ITSZ genellikle Indus Suture Zonu veya Trans-Himalaya Zonu olarak isimlendirilmektedir. TSZ ise Tibet-Tethyan Himalaya Zonu, Tethyan Himalayaları, Tethyan Sedimentary Serisi veya Yüksek Himalaya Sedimentary Zonu olarak adlandırılmaktadır. HH genellikle Yüksek Himalaya Kristalin Zonu veya Yüksek Himalayalar olarak isimlendirilmiştir. SHZ çoğunlukla bazı yazarlar tarafından, tamamen ayrı şekilde, Siwalik Tepeleri olarak isimlendirilmiştir (Kothiyari vd. 2010).

Le Fort (1975), TSZ (Tibet-Tethyan Himalaya Zonu)’nin HH (Büyük Himalaya Zonu) zonu ile birleştirilebileceğini öne sürerek Gansser (1964)’in yayınındaki zonların farklı bölünlendirilmesi ile ilgili tartışmaya dikkat çekmiştir. Valdiya (1980), Kumaun Küçük Himalayalar’ın Jeolojisi isimli yayınında Küçük Himalayaları daha detaylı bir şekilde incelemiştir. Valdiya (1980) tarafından yapılan bu araştırma daha sonra birçok yazar tarafından detaylı incelenerek her bir sistem tektonik özelliklerine yeniden isimlendirilmiştir. Himalaya’yı tanımlayıp anlamak adına, eklenen bu yeni bilgiler, araştırmacılar arasında anlaşmazlıklara yol açarak, Himalaya’nın tanımlanmasını daha da karmaşık bir hale getirmiştir. Ancak, Gansser (1993), Le Fort (1989)’un ve kendi

önceki çalışmalarını derleyerek Himalaya Sıradağları'nın en eksiksiz bölgesel tanımını hazırlamıştır. 1993 yılından bu yana Gansser (1964), Le Fort (1975) ve Valdiya (1980)'nin çalışmaları ile birlikte bölge hakkında birçok çalışma yapılmış olup çok sayıda makale yayınlanmıştır.

4.1.1.1. Indus-Tsangpo suture zone (ITSZ)

Hindistan'ın kuzey uzantısı, Indus-Tsangpo Suture Zonu'ndan (ITSZ) oluşmaktadır (Şekil 1.9, 1.10). Bu zonun eski çarpışma olaylarıyla ilgili verilere sahip olduğu birçok yazar tarafından kabul edilmektedir. Bu zonda yer alan okyanusal kabuk parçaları, bir zamanlar Neo-Tetis Okyanusu'nun bir bölümünü oluşturduğunu ve bölgenin jeolojik evriminin çarpışmayla sonuçlandığını göstermektedir (Kravchenko 1979; Valdiya 1984; Bickle vd. 2001; Najman vd. 2004). Buna ek olarak, Xizang ve Ladakh'ın güney-merkezlerinde bulunan ofiyolitler (Hodges 2000), Neo-Tetis Okyanusunu işaret etmekte ve kıtasal çarpışma öncesinde bir okyanusun varlığını kanıtlamaktadır. Trans-Himalaya ve Hint Levhası türbiditik kayalar suture zone boyunca ofiyolitleri çevrelemektedir. Bu türbiditlerin yaş aralığı Trans-Himalayalar'da Jura-Kretase, Hint levhasında ise Triyas-Kretase arasında değişmektedir (Hodges 2000). Hodges (2000)'e göre, çarpışma aktiviteleri, daha önce Gangdese kıtasal yayında yer alan türbiditlerin suture zonuna girmesini sağlamıştır. Kuzey Hint shelfinde gözlenen kireçtaşları ve shelf yamaçları Hint Levhasının kalıntılarını temsil etmektedir (Hodges 2000).

Himalaya (Hint levhası) ve Tibet Platosu (Lhasa bölgesi) arasındaki kuzey tektonik sınır, Indus-Tsangpo veya Yarlung Zangbo Suture Zonu ile sınırlanmıştır. Indus-Tsangpo suture zone okyanusal kayalardan oluşan ve Tetis Denizi'nin üzerlenmiş kalıntılarını temsil eden daha dar (15 km'den daha az) bir kuşaktır (Ding vd. 2005). Suture zone deforme ve yer değiştirmiş olan, neredeyse dik tektonik dilimlerden oluşmaktadır (Diener 1895, 1898; von Krafft 1902; Heim ve Gansser 1939). Suturelar, Permian kireçtaşı, Erken Triyas pelajik kireçtaşı, serpantinit mercekleri, Geç Kretase kalkışist, yastık lavları ve masif alkali bazaltik lav blokları içeren devamsız filiz zonlarından oluşmaktadır. Bu bölge aynı zamanda, sıcaklığı yaklaşık 350-450 °C ve basıncı 1 GPa olan ince tabakalı ve üzerlenmiş kütleler halindeki ofiyolit, bazik lavlı radyolaritler ve mavişistlerden oluşmaktadır (Mascle vd. 2012). Sutureun orta kısmı boyunca, Tetis Himalaya'nın Mesozoyik yaşlı sedimanları metamorfizmaya uğramıştır. Sutureun güney kısımlarında ise metamorfizma sonrası granitik intrüzyonlar gözlenmektedir (Gansser 1977). Kailas Vadisi'nin doğusunda ise filiz, büyük bindirme boyunca metamorfik olmayan ve neredeyse yatay konumlu Kailas Konglomeraları'nı üzerlemektedir (Heim ve Gansser 1939). Indus-Tsangpo suture zonunun karmaşık geometrisi, 3 olay dizisinden kaynaklanmaktadır: (1) nap hareketleri, (2) kısalma ve izoklinal kıvrım ve (3) ters kıvrım (Burg 1992).

4.1.1.2. Tetis sedimenter zone (TSZ)

Tetis Sedimenter Zonu, ITSZ (Indus-Tsangpo Suture Zonu)'nin güneyinde yer almaktadır (Şekil 1.9). Bu zon Güney Tibet Sıyrılma Zonu'na (STDZ) doğru devam etmektedir. Geç Prekambriyen-Eosen yaşlı çok düşük-düşük dereceli metasedimenter kayalar, çeşitli kıvrım ve bindirme yapıları bu zonun oluşturmaktadır (Webb vd. 2007; Searle vd. 2010). Sedimenter kayalar, Yüksek Himalayalar zonunda olduğu gibi aynı

zamanda kristalin kütleyi kaplamaktadır. Kristalin gövde, amfibolit, migmatit, gnays ve şistlerden oluşmaktadır (Srikantia 1987). Ek olarak, eklojitler içerisinde koesitin varlığı, yüksek basınç metamorfizmasını işaret etmektedir (Ahmad 2011).

4.1.1.3. Yüksek Himalayalar (HH)

Yüksek Himalayalar (HH), Güney Tibet Sıyrılma Zonu'ndan (STDZ) itibaren başlamaktadır (Singh 2010). Bu zon, batıda Zanskar'dan Butan'a ve doğuda Arunachal Pradesh'e kadar yaklaşık 2200 km boyunca uzanmaktadır (Searle vd. 2008, 2010). Güneyde, Ana Merkez Bindirmesi (MCT) bu zonun Küçük Himalayalar'dan ayırmaktadır. Bu kristalin zon, 1200-7800 m arasında değişen (ortalama 4700 m) kotlara ve dik yamaçlara sahiptir (Singh, 2010). Ana Merkez Bindirmesi'nin (MCT) bölgedeki yüksek dağların oluşmasından sorumludur (Singh ve Hasnain 1998; Bickle vd. 2001; Searle vd. 2008). Gnasser (1993)'e göre, bu bindirmenin, 15 km'lik alanı kapsayan kristalin kayaçları örterek; güneye doğru Küçük Himalayaları (LH) kaplayan (100-150 km) Tetis sedimanlarının yaklaşık 12 km'sini oluşturmaktadır.

Searle vd. (2008)'ne göre MCT sınırlı makaslama zonu olup; bu zon HH metamorfik kayaçlarının, LH metamorfik olmayan kayaçların üzerine üzerlediği bölgede yer almaktadır. Singh ve Hasnain (1998) ve Singh (2010)'a göre HH kayaçları, Proterozoyik'te orta-derin kıtasal kabuk metasedimanlardır. Bölgede ayrıca biyotit-muskovit granitler ile birlikte yaşları Kambro-Ordovisiyen arası değişen bazı karbonat ve kalsitik kayaçlar gözlenmektedir (Singh 2010). Searle vd. (2010), bu granitlerin kıtasal kabuğun orta kısımlarında migmatit zonunun kısmi ergimesi ile oluştuğunu öne sürmüştür. Erken Miyosen veya Pliyosen'deki turmalin, biyotit, muskovit ve granat içeren lökokratik intrüzifler, Yüksek Himalaya Kristalin Zonu'nun kuzey kesimleri içerisinde yer almaktadır (Searle vd. 2010; Singh 2010). Singh ve Hasnain (1998) ve Singh (2010)'a göre, 500-20 My aralığında gerçekleşen metamorfizma ve deformasyon süreçleri, bölgedeki kayaç çeşitliliğine sebep olmuştur.

4.1.1.4. Küçük Himalayalar (LH)

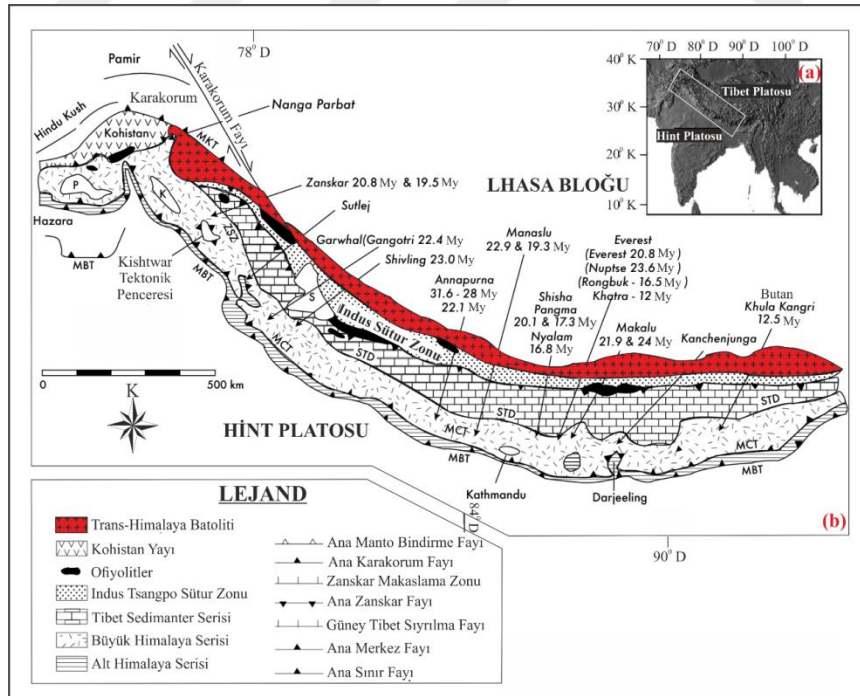
Ana Merkez Bindirmesi (MCT)'nin güneyi ve Ana Sınır Bindirmesi (MBT)'nin kuzeyinde yer alan bölge Küçük Himalayalar (LH) olarak tanımlanmaktadır. Bu bölge, yüksekliği ortalama 2500 m olan düşük rölyefli Prekambriyen-Paleozoyik kayaçlarından oluşmaktadır (Singh 2010). LH'nin kalınlığı 8 ile 10 km arasında değişmektedir (Hodges 2000; Singh 2010). Lave ve Avouac (2001) bu zonun düşük dereceli metasedimanlar ile yeşilşist ve amfibolit kayaçlarından oluştuğunu belirtmektedir. Kuvarsit ve mermer, fillit, şist, metamorfik mafik kayaçlar ve gözlü gnaysların varlığı, düşük seviyeden yüksek seviyeye doğru bir metamorfizma artışını işaret etmektedir (Hodges 2000). Hodges (2000)'in LH'yi ve özelliklerini anlatan çalışmasında, burada yer alan alt tabakaların stratigrafisi, yaş ve korelasyonunun tartışmalı ve belirsiz olduğunu belirtmiştir.

Bölgenin alt zonları, önceki araştırmacılar tarafından, allokon ve otokon olarak ikiye ayrılmıştır Hodges (2000). Hodge (2000) ve Fuchs (2011) kayaç tipleri konusunda birbirlerinden farklı düşüncelere sahiptir. Fuchs (2011) korelasyonları konusunda ısrarcıyken, Hodges (2000) bölgedeki kristalin dizinin HH ile stratigrafik olarak ilişkili olmadığını savunmaktadır. Ayrıca Kohn (2010), LH'nin alt bölgelerinde bulunan ve

Hint levhasının temeli ile kökensel ilişkisi olmayan veya Paleoproterozoyik zamanındaki çarpışmanın sonucu oluşan gnaysların kökeni konusunda bilgiler vermiştir. MBT'nin önemi, Yarı-Himalayalar Zonu'ndan gelen havza sedimanlarının bindirme hareketleri açısından çok belirgindir (Singh ve Hasnain, 1998; Bickle vd., 2001). MBT boyunca oluşan kolüvyal yelpazeler, daha sonra hızlı erozyon ile sonuçlanan normal fayların yükselmeleri hakkında önemli kanıtlar sunmaktadır (Kothyari vd. 2010).

4.1.1.5. Yarı-Himalayalar zonu (SHZ)

Himalaya Sıradağları'nın uzantısı takip edildiğinde Alt Himalayalar Zonu'nu üzerlediği görülmektedir. SHZ, Ana Sınır Bindirmesi (MBT) ile kuzeyde ve Ana Ön Bindirme (MFT) ile güneyde sınırlanmıştır. Hodges (2000)'e göre, batıdan doğuya yer alan sedimanlar hakkında çok sayıda araştırmalara, bölge jeolojisinin açıklanmasına katkı sağlamıştır. Batıda iki grup kayaç bulunmaktadır (Hodges 2000): (i) Üst Paleozoyik-Alt Miyosen Rawalpindi Grubu silttaşları ve kumtaşları, (ii) Alt Miyosen-Pliyosen Siwalik Grubu nehir molaslı sedimanter kayaçlar (kumtaşları). Doğuda ise bölgede Siwalik grubu kayaçlar baskındır (Hodges 2000). MBT'de 1500 km boyunca, Yarı-Himalayalar Zonu'ndaki metamorfik kayaçlar, metamorfizmaya uğramamış SHZ'ye bindirme yapmıştır (Singh ve Hasnain 1998; Kothyari vd. 2010). 500-1000 m arasında yükseklik sunan Siwalik Tepeleri (Lave ve Avouac 2001), bindirmelerden oluşmaktadır (DeCelles vd., 2001). Siwalik Grubu kayaçları Neojen yaşlı (Kothyari vd. 2010) kumtaşı, konglomera, silttaşı ve çamurtaşlarından (Hodges 2000) oluşmakta ve zondaki boyutları 10-25 km arasında değişmektedir (DeCelles vd. 2001). Kothyari vd. (2010)'a göre, bölgede iki farklı sediman depolanma dönemi mevcuttur: (i) 6.5 ile 8 My, (ii) 9 ile 10 My arası.



Şekil 4.2. a) Hint ve Tibet Platosu'nu gösteren harita (Godin vd. 2006), **b)** Himalaya'nın jeoloji haritası (Godin vd. 2006 değiştirilerek alınmıştır)

4.1.1.6. Indus suture zone (ISZ)

Hint ile Avrasya (Karakorum-Lhasa Bloklarının) levhalarının çarpışma bölgesini (Gansser 1964, 1977; Allegre vd. 1984; Searle vd. 1987) temsil eden Indus Suture Zonu (ISZ), güney Tibet'in doğu kısımlarındaki Kohistan ve Ladakh'tan Hindistan-Burma'nın KD kısımlarına kadar olan 2000 km'lik alanda izlenmektedir. Bu zon Tibet'te genellikle Yarlung-Tsangpo Suturesu, batı Himalayalar'da ise Indus Suture Zonu olarak adlandırılmaktadır (Gansser 1964, 1977; Allegre vd. 1984; Searle vd. 1987). ISZ; Ladakh'ın batısında büyük Nanga Parbat civarında kıvrımlanmış, Merkez Kristalin Karmaşığı ve merkezinde gnaylara sahip olan dik antiklinallere sahiptir (Şekil 4.3). ISZ, geç Tersiyer'de Nanga Parbat zirvesi ile dengelenmiş ve Rakhiot Fay zone boyunca Nanga Parbat'ın batısında faylanmıştır. ITS, güneyde Zaskar Süpergrubu ve Tso Moriri kristalin kompleksinin şelf sedimanları, kuzeyde ise Ladakh Batoliti ile sınırlıdır. Gupta ve Kumar (1975), Shah vd. (1976), Frank vd. (1977), Fuchs (1977, 1979), Bassoullet vd. (1978, 1981), Andrieux vd. (1981), Thakur (1981, 1987), Baud vd. (1982), Searle vd. (1983, 1986), Brookfield ve Andrews-Speed (1984a, b) tarafından ISZ'nin jeolojisi tanımlanmıştır. Ladakh'taki Indus Suture Zonu, Lamayuru Karmaşığı, Nindam-Dras Volkanik Grubu ve Indus Grubu molasları olarak üç ana doğrusal bindirme kuşağından oluşmaktadır: Indus Suture Zonu (ISZ) içinde gözlenen, Eosen öncesi kayaç stratigrafisine sahip Neo-Tetis havzasının paleocoğrafik yapısı ana fay zonları veya ofiyolitik melanj kuşakları tarafından bölünmüştür (Robertson 2000).

Indus Grubu Molasları

Molas terimi, yükselen dağ zincirlerinde karasal veya sığ denizel olarak depolanan kumtaşı, şeyl ve konglomeralar için kullanılan bir tanımlamadır. Indus Grubu, 2000 m kalınlıktaki klastik dizi, alüvyal yelpaze, örgülü akıntı ve flüvyo-göl sedimanlarından oluşmaktadır (Brookfield ve Andrews-Speed 1984a, b; Van Haver 1984). Konglomeralarda yer alan klastlar çoğunlukla kuzeyde yükselmiş ve erozyona uğramış Ladakh Batoliti ve suture zonundan (çört, kireçtaşı ve serpantinleşmiş peridotitler) ve güneyde Zaskar şelf karbonatlarından türemiştir. Paleo-akışlar, doğudan batıya havza eksenine paralel sediman taşınma yönlerinde baskın bir şekilde gözlenmektedir (Pickering vd. 1987). Indus molasları Kargil yakınında, ISZ'nin kuzey kısımları boyunca yer alan Ladakh granitoidlerini uyumsuz olarak örtmektedir. Hindistan ile Karakorum ve Lhasa Bloklarının çarpışması ve Tetis'in 50 My önce kapanması, Indus Grubu molas depolanmasının başlangıcına işaret etmektedir (Searle vd. 1987). Molaların tabanında bulunan Chodgo Formasyonu stratigrafik olarak geç Paleosen yaşlıdır.

4.1.2. Himalayaların evrimi

Hint ve Avrasya levhalarının 100 My'dan fazla süren kıtasal çarpışması sonucunda Himalaya Dağları oluşmuştur. Hindistan ve Avrasya'yı 2000 km kadar ayıran Neo-Tetis Okyanusu, Paleosen (~58 My) sonunda kapanmıştır (Le Fort 1996; Clift vd. 2008). Kapanmanın kanıtları, Himalaya Dağları'nın bazı bölgelerinde okyanusal kabuk kalıntıları şeklinde görülmektedir (van Hinsbergen vd. 2012). Bindirme, fay ve kıvrımları da içeren tektonik aktiviteler, kıtasal çarpışma sırasında

bölgede etkisini göstermiştir. Kıta çarpışması süresince Himalaya boyunca bindirmeler meydana gelmiş ve kayaç tipi serileri veya zonları oluşmuştur. Bu zonlar veya kayaç tipleri sıradağlar boyunca çeşitli bindirme katmanlarıyla sınırlanmıştır. Daha yoğun olan bindirme fayı bölgeyi, belirgin olarak Ana Merkez Bindirmesi (MCT), Ana Sınır Bindirmesi (MBT) ve halen aktif olan Ana Ön Bindirmesi (MFT) şeklinde bölmüştür. Bu bindirmeler, Büyük Himalayalar (HH), Küçük Himalayalar (LH) ve Yarı-Himalayalar Zonu (SHZ) olmak üzere üç zondan oluşmaktadır.

Kayaç zonlarının oluşumuna ek olarak, kıtasal çarpışma 20-22 My bir süreç boyunca Büyük Himalayaların'ın yükselmesine neden olmuştur (Valdiya 2002). Himalayalar çok yüksek boyutlara ulaştıkça mevsimsel musonlar gelişmiş ve böylece bölgedeki iklim ve bitki örtüsünün değişiminde etkin rol oynamıştır. Himalayalar'ın yüksek boyutlara ulaşmasının bir diğer sonucu ise, drenaj desenlerindeki değişimdir. Prekambriyen'den bu yana Hindistan nehirleri kuzeye akışlarını sürdürmüşlerdir. Fakat Oligosen'de bu nehirler güney yönlü akmaya başlamıştır (Valdiya 2002). Nehirlerin beraberinde çok miktarda Himalaya sedimanı taşınması depolandığı Gangetic bölgesini eğimli hale getirmiştir. Günümüzde halen çok miktarda sediman bu sıradağ bölgesinden nehirlerle taşınarak yüksek dağ bölgelerinde çeşitli erozyon ve bozunmalara sebep olmaktadır.

İki tektonik levhanın çarpışması ile yılda yaklaşık 0.92 cm kabuksal kısalma günümüzde halen sürmektedir (Kothiyari vd. 2010). Himalayalar, milyonlarca yıl öncesinden-günümüze kadar birçok büyük tektonik olay ile gelişimine devam ederken, bölgenin şekillenmesinde aktif rol oynayan sıradağlar arasında en aktif olanıdır. Ana tektonik olayların zaman çizelgesini göstermektedir (Valdiya 2002).

Hint Levhası ve Avrasya'nın mikro-kıtasal levhaları arasında gelişen çarpışmanın yaklaşık 50-45 My (Orta-Geç Eosen) sırasında geliştiği tezi, günümüzde halen yaygın olarak kabul edilmektedir (Alleigre vd. 1984; Searle vd. 1987). İki levhanın son çarpışma zamanı (i) Indus Sütur Zonu'ndaki (ISZ) denizel sedimentasyonun bitişi, (ii) sütur zonu boyunca kıtasal molas çökeliiminin başlaması, (iii) Trans-Himalaya (Ladakh-Kohistan-Gangdese) Batoliti boyunca gelişen And-tipi kalk-alkalen magmatizmasının bitişi ve (iv) Himalaya Sıradağlarındaki çarpışma ve bindirme sistemlerinin başlaması verilerinden yararlanılarak elde edilmiştir (Aitchison vd. 2007).

Paleo-magnetik veriler, 55 My önce Neo-Tetis'in yaklaşık 2000-2500 km'den fazla ayrıldığı (Klootwijk 1979) ve son çarpışmanın 40 My önce gerçekleştiğine işaret etmektedir (Molnar ve Tapponnier 1975; Klootwijk ve Radhakrishnamurthy 1981) (Şekil 4.3).

Güney yönlü bindirme, Orta Eosen yaşlı çarpışma ve kapanma döneminden bu yana Himalayalar'da gözlenmektedir (Molnar, 1984; Mattauer, 1986; Searle vd., 1987). Orta Tersiyer'de Yüksek Himalayalar ve Zaskar Sıradağları'nda, Ana Merkez Bindirme (MCT) sisteminden Küçük Himalayalar'a ve daha sonra Tersiyer Ana Sınır Bindirme (MBT) sistemine doğru güney yönlü hareket eden bindirmeler ile birlikte kıtasal kısalma ve bindirmeler gözlenmiştir (Şekil 4.2). En genç bindirmeler Himalayalar'ın güney sınırları boyunca, Ana Ön Bindirme'nin (MFT), Indo-Gangetic

bölgenin altında sona erdiğinin kanıtları, Hint ön havzası Siwalik molas yataklarında görülmektedir.

Ladakh-Zaskar Himalayalar'ı dört ana tektonik zondan oluşturmaktadır: Bunlar kuzeyden güneye, Ladakh (Trans-Himalaya) Batoliti, Indus Sütur Zonu, Tibet-Tetis (Zaskar Şelfi) Zonu ve Yüksek Himalayalar olarak tanımlanmaktadır (Şekil4.2).

4.1.3. Himalayaların tektonik evrimi

İnanılmaz yükseltiye sunan Himalayalar birçok orojenik hareket sonrası oluşan sıradağlar silsilesidir. Himalayalar'ın tektonik tarihçesi çok fazla tartışılan bir konudur (Jain vd. 2016). Bazı araştırmacılar küçük ölçekli kısalma yapılarında beş farklı deformasyon fazı olduğunu tespit etmiştir. Diğerleri ise dört farklı ana tektonik hareket varlığına işaret ederek, en erken olanların Prekambriyen veya alt Paleozoyik yaşlı diğer üç tanesi ise Permiyen sonrası şeklinde olduğunu savunmuştur. Birkaç araştırmacı ise Kretase sonrası gelişen yalnızca üç adet farklı orojenik aktivite tespit etmiştir.

Himalaya orojenez olaylarının ilk evresinde (Prekambriyen veya alt Paleozoyik), oluşan asidik ve bazik intrüzyonlar, orta dereceli metamorfizmaya maruz kalmışlardır. Ladakh evresi olarak bilinen ikinci orojenez aşaması, Himalayaların yükselmesinden sorumlu olan hareketin başlangıcını içermektedir. Hint-Avrasya levhalarının çarpışma süreçleri yine bu evrede gerçekleşmiştir. Bu çarpışma ile denizlerin kapanması ile birlikte Indus Sütur Zonu boyunca ofiyolitlerin yerleşmesi, granitik intrüzyonlar, palinjenez ve granitleşme olayları gerçekleşmiştir. Himalaya orojenezinin bu evresi Geç Kretase'den Erken Eosen'e kadar aktiftir.

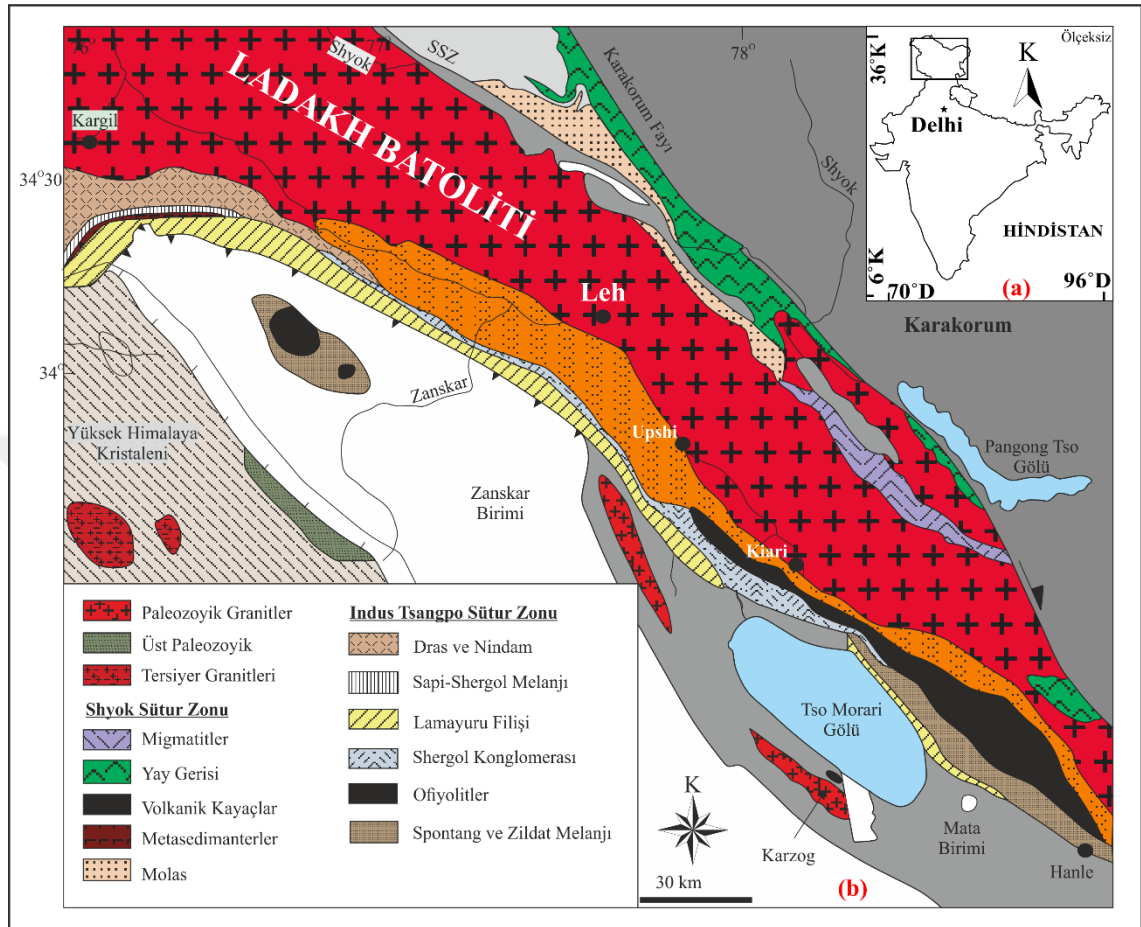
Üçüncü ve en etkili orojenik hareket, Dharamsala evresi olarak bilinmekte olup; Orta Miyosen'de gerçekleşmiştir. Hint levhasının Tibet (Avrasya) levhasının altına doğru dalma-batması sonucu oluşan sıkışma, bölgede büyük ölçekli izoklinal yapıların oluşmasına ve Prekambriyen kristalin kayaçların kıvrımlanmasına neden olmuştur. Bu durum, büyük bloklu kayaçların güney yönlü bindirme hareketine ve genç sedimanter birimlerinin üzerlemesine neden olmuştur. Küçük Himalayalar'ın bindirme tabakalarının çoğu, geniş ölçekli bölgesel metamorfizma ve asidik volkanik aktiviteler ile ilişkilidir. Büyük yükselme nedeniyle, yükselen Himalayalar'ın ön kısımlarında Siwalik molas sedimanlarının depolandığı ön çukurlar oluşmuştur.

Geç Pliyosen'den Orta Pleyistosen'e kadar aktif bir evre durumunda olan Himalaya orojenezinin dördüncü evresi Siwalik evresidir. Himalayalar'ın günümüzde halen görülmekte olan yapılarının çoğu bu evrede oluşmuştur. Ayrıca bu evrede Siwalik sedimanlarında yükseldiği görülmektedir. Himalaya bindirme faylarının bazıları boyunca oluşan tektonik hareketlilik, Üst Siwalik kayaçlarının çakıl yataklarına taşınması ve bölgedeki depremsellik bu evrenin henüz tamamlanmadığına işaret etmektedir.

4.2. Ladakh Batoliti ve Yerel Jeoloji

Ladakh Batoliti, Indus Sütur Zonu'nun kuzeyinde gözlenen, Avrasya kıtasının güney kesimleri boyunca 2500 km uzanan, Trans-Himalaya Plütonik Kuşağı'nın (Kretase-Paleosen And-tipi magmatik yay) bir parçasıdır (Şekil 1.9, 1.10, 2.1, 2.2, 4.1-

4.3). Ladakh Batoliti 600 km uzunluğunda, 30-80 km genişliğinde ve BKB-DGD uzanımlıdır (Singh vd. 2007). Norit, gabro, granodiyorit ve granit bileşimi sunan batolit 110-40 My aralığında yaş verileri sunmaktadır (Honegger vd. 1982).



Şekil 4.3. a) Hindistan'ın kuzeyinde yer alan Ladakh Batolitinin bulunduğu çalışma alanı, **b)** Ladakh-Zaskar bölgesinin jeoloji haritası (Mahe' o vd. 2000'den değiştirilerek alınmıştır)

Ladakh Batoliti, güneyde Indus Sütür Zonu, kuzeyde Shyok Sütür Zonu ve doğuda ise Karakorum fayı ile sınırlanmıştır (Şekil 1.9, 1.10, 2.1, 2.2, 4.1-4.3). Ancak, Shyok sutureunun doğu Ladakh'daki tam yeri araziye sınırlı ulaşım sebebiyle kesinleştirilememiştir (Rolland vd 2000; Rolland ve Pecher 2001; Weinberg ve Dunlap 2001).

Ladakh Batoliti güneyde, molasin batoliti üzerlediği yer hariç genellikle batoliti deforme sedimanter Indus Molası oluşumlarından ayıran ISZ ile sınırlanmıştır (Frank vd.1977). Indus Molası litolojik birimleri silttaş, kireçtaş ve konglomera içeren Eosen-Miyosen sedimanlarından oluşmaktadır (Searle vd. 1990). Batolit, Shyok tektonik kuşağının güney sınırını oluşturmaktadır. Bu sınır Paleozoyik-Eosen metasedimanter, volkanik ve metamorfik kayalardan oluşan ve BKB yönlü bindirmeler ile sınırlıdır (Srimal vd. 1987).

Ladakh Batoliti, lökokratik granit ve porfiritik granit, biyotit-hornblend granit, granodiyorit, kuvars, monzodiyorit, diyorit, tonalit ve lamprofir daykları içermektedir.

Daha yaşlı metasedimanter kayaçlar ise, Ladakh Batoliti'nda sleyt, kuvarsit, şist ve gnaystan oluşan ince bantlar şeklinde gözlenmektedir.

Ladakh Batoliti, kenar bölgelerinden merkeze doğru gidildikçe azalan iri taneli granit ve bol miktarda mafik magmatik anklavları içeren granodiyoritler ile karakterize edilmektedir (Kumar ve Singh 2008). Batolitinin merkezinde, mineralojik olarak porfirik K-feldispat mineralleri hakimdir. Ladakh Batoliti'nin ana kısımları, güney ve kuzey bölümlerinde sırasıyla Indus Grubu ve Shyok Sütur Zonu ile sınırlanmış Geç Kretase-Eosen (102-50 My) yaşlı granitoidlerden oluşmaktadır.

Batolitler çoğunlukla granit, kuvars monzonit veya diyorit gibi felsik veya ortaç kayaç türlerinden meydana gelmektedir. 2000 km'lik Trans-Himalaya Batolitinin bir kısmını oluşturan Ladakh Batoliti, ISZ'nin (Indus Sütur Zonu) kuzeyi ve Ladakh Sıradağları içerisinde yer almaktadır (Şekil 4.3). Trans-Himalaya kuşağı, Kohistan Batolitini (Kuzey Pakistan; Patterson ve Windley 1985) ve Gangdese (Güney Tibet) Batolitini (Tapponnier vd. 1982; Alleigre vd. 1984) içine alan geniş bir bölgeyi kapsamaktadır. Ladakh Batoliti, olivin noritden granodiyorite lökogramitlere kadar bileşimsel değişim göstermektedir (Thakur 1981; Honegger vd. 1982). Ladakh Sıradağları'nda granitik gnays ve metasedimanter dizinin varlığı kıtasal kabuğa işaret etmektedir (Honegger ve Raz 1985).

İki farklı araştırmacıdan alınan ilksel $^{87}\text{Sr}/^{86}\text{Sr}$ 0.705 (Honegger vd. 1982) ve $^{87}\text{Sr}/^{86}\text{Sr}$ 0.705 (Schärer vd. 1984) izotop değerleri magmaların türevi olan birincil mantoya işaret etmektedir. Jeokronolojik tespitler, Ladakh Batolitinin karmaşık bir yapı sunması, çarpışma öncesi magmatik olayların kökeninde etkili olduğunu göstermektedir. Kargil yakınlarından alınan örneklerden elde edilen yaş verileri (103 ± 3 ve 101 ± 2 My; U-Pb zirkon) Orta Kretase magmatizmasını işaret etmektedir. Leh yakınındaki biotit granit (monazit/allanit) örneklerden yapılan yaş değerleri (60.7 ± 4 My; U-Pb, 73 ± 2.4 My; Rb-Sr izokron; Schärer vd. 1984), (82 ± 6 ; $^{39}\text{Ar}/^{40}\text{Ar}$ My; Schärer ve Allegre 1982) kıta-kıta çarpışması ile sonuçlanan 40 My önceki magmatic aktivitelerin devamına işaret etmektedir (Şekil 4.3). Benzer şekilde, K-Ar mineral yaşlarının 50-40 My aralığında yaş verileri, yükselme ile ilişkili bir soğuma sürecine işaret etmektedir (Ngo vd. 2010).

Ladakh Batolitinde granitik magmatizmanın sonlanması Neotetis'in ISZ boyunca kapanması ile aynı zamanda ve denizel sedimantasyondan kıtasal sedimantasyon süreçlerine dönüşmesiyle oluşmuştur (Srimal vd. 1987). Granit, andezit ve riyolit klastları, Indus Grubu molasların Chogdo, Nurla ve Hermis Formasyonları'nda bulunan ve batolitleri üzerleyen konglomeralarda oldukça yaygındır. Ladakh Batolitini üzerleyen volkanik kayaçlar andezit ve riyolit bileşimlidir (Srimal vd. 1987). ISZ boyunca granitleri farklı doğrultu ve eğimlerde kesen lökogramitik daykları 50 My'lik çarpışma sonrasında kabuk içi erimenin son aşamasını yansıtmaktadır. Ladakh Batoliti granitoidleri, Dras ada yayı volkanikleri ve Kargil civarı sütur zonu kayaçlarına intrüzyon yapmaktadır. Bu durum Dras ada yaylarının Orta Kretase'de Karakorum-Lhasa Bloklarına katıldığını ve Ladakh ve Karakorum arasındaki Shyok (Kuzey) Süturu'nun Geç Tersiyer'de (Thakur 1981, 1987) değil Orta Kretase'de (Coward vd. 1986; Pudsey 1986; Searle vd. 1988) kapandığını göstermektedir.

4.2.1. Ladakh ve civarının arazi özellikleri

Ladakh 30°-36° D enlemi ve 76°-79° K boylamları arasında bulunmaktadır. Jammu ve Keşmir eyaletinin 96.701 km²'lik alanını kapsamakta ve 200.000 nüfusa sahip bir yerleşim yeridir. Ladakh kuzeyde Karakorum Dağları ve Tibet Platosu'nun doğu kısımları tarafından sınırlanmıştır. Ladakh Keşmir Vadisi karşısında ve meşhur Zoji geçidi (Zozi La geçidi) arasında uzanmaktadır. Dondurucu rüzgarların ve kavuran güneş ışınlarının eksik olmadığı Ladakh Bölgesi, Büyük Himalayalar ve diğer küçük sıradağların gölgesinde yatan soğuk bir çöldür. Ladakh Bölgesi, Afganistan, Pakistan, Çin, Keşmir Vadisi (Hindistan) ve Himachal Pradesh (Hindistan) ile sınırları olan bir coğrafik yapıya sahiptir.

Ladakh'ın ortalama yüksekliği 2700 m'den 4200 m'lere ulaşmaktadır. Güneyde uzanan Büyük Himalaya Dağları bölgede muson için bir bariyer oluşturmaktadır. Ladakh'ın en önemli fiziksel özelliği, sıradağlarına olan paralelliklerinden gelmektedir. Aşırı kurak olan bu bölgeye yıllık ortalama 10 cm³ yağış düşmektedir. Ladakh'ın uzak bölgelerinde de birçok mineralli su özelliği gösteren nehirler (Panamic (Nobra), Chumathang ve Puga sülfür nehirleri) bulunmaktadır. Bölgenin insanları bu nehirlerden alınan suları birçok hastalığı iyileştirmek ve hastalıklardan korunmak amacıyla kullanmaktadır. Ladakh'ta bulunan büyük nehirler ve bu nehirlerin kolları, dik tepelerin çok altında derin geçitler açmıştır. Ancak, bu bölgeki sular yüzeydeki yüksek bölgelerde bulunanlar kadar kullanışlı değildir. Ladakh bölgesi her yıl Kasım-Haziran ayları arasında, Ladakh'ı ülkenin diğer bölgeleriyle bağlayan Srinagar-Ladakh ve Ladakh-Manali karayolları, kar ve sert kış nedeniyle kapalı kalmaktadır. Ladakh'ın izole soğuk çöl bölgesi olması Leh'de kuru bitki örtüsü olan kavak ve söğüt ağaçlarının yetişmesine olanak vermektedir.

Kuzeydoğuda Büyük Karakorum Dağları (Saser Muztagh), ortada Ladakh sıradağları ve güneybatıda ise Jasker Dağları'nın küçük bir kısmı yer almaktadır (Şekil 4.2). Ladakh vadilerinin en çok resmedilmeye değer kısımları güneyde Indus Vadisi ve Leh'in kuzeyinde Shyok-Nubra Vadisi'dir. Bölgenin kuzey ve kuzeydoğu bölgelerinde yer alan yükseltilerinde birçok buzul bulunmaktadır (2995 m; 34° 46'; 770 15,7672 m; 34° 51'; 770 45'). Bölge Shyok ve Indus Nehirleri tarafından beslenmektedir. Kuzeybatı-güneydoğu yönünde paralellik sunan bu nehirler güneydoğuda akan Nubra Nehri, Shyok Nehri (Diskit yakınında) ile birleşmektedir.

4.2.2. Arazi çalışması

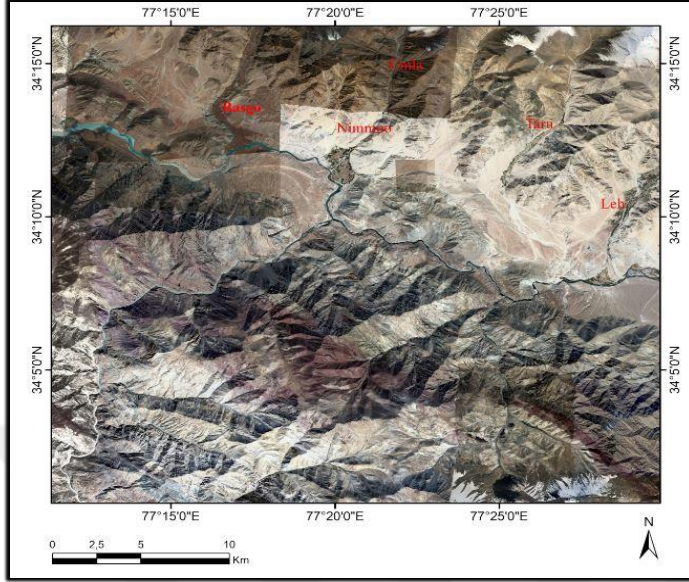
Ladakh bölgesi, Jammu ve Keşmir eyaletindeki 3000 m'yi geçen en yüksek platoya (32-36° kuzey enlemi ve 75-80° doğu boylamı arasında) sahiptir. Toplamda 45110 km² alan ile Ladakh, Hindistan'ın en büyük bölgesidir. Ladakh, Kargil ve Leh bölgeleri olarak ikiye ayrılmıştır. Kargil 2750 m yüksekliğinde iken, Leh 3505 m yüksekliğe sahiptir. Leh şehri yüzölçümü bakımından Ladakh bölgesindeki en büyük şehir statüsündedir. Ladakh yüksek rakımlı dağları ve kültürü açısından çok tanınmış bir bölgedir. Batolit, Büyük Himalaya ve Karakorum sıradağlarına ve Indus Nehir Vadisine kadar uzanmaktadır.

Basgo, Nimu, Umla ve Taru intrüzif kayaçlarında (Şekil 4.4) gerçekleştirilen arazi çalışmaları ile ilgili bilgiler detaylı olarak aşağıda verilmiştir.



Şekil 4.4. Ladakh bölgesinde yeralan plütonik kayaçların genel arazi görünüşleri

Saha çalışmaları için belirlenen araştırma alanı Leh'in 50-60 km batısında; Basgo, Nimu, Umla ve Taru civarında yeralan plütonik kayalar (Şekil 4.5) içermekte olup; toplamda kırk bir adet sistematik olarak numune alımı gerçekleştirilmiştir.



Şekil 4.5. Leh-Ladakh bölgesinde yeralan Basgo, Nimu, Umla ve Taru plütonik kayalarının Google Earth haritası

Basgo plütonik kayaları

Basgo (veya Bazgo) deniz seviyesinden 3292 m yükseklikte ve Ladakh bölgesinde Indus Nehri'nin yakınında bulunmaktadır (Şekil 4.6, 4.7).



Şekil 4.6. Leh-Ladakh bölgesinde yeralan Basgo kasabasına giriş (arka tepelerde gözlenen intrüzif kayalar) (Anonim 9)



Şekil 4.7. Basgo kasabasına giriş (arka tepede Indus molas kayaçları)

Basgo Plütonu, biyotit granodiyorit-biyotit granit bileşimlidir. Bu her iki kayaç türü birbirine benzer özellikler gösterse de: biyotit granodiyorit, biyotit granitten daha fazla oranda kuvars içermektedir. Ayrıca, biyotit granodiyorit K-feldispat megakristallerini içerirken, biyotit granit ise playioklas fenokristalleri içermektedir (Şekil 4.8).



Şekil 4.8. Orta-iri taneli feldispat (açık pembemsi renkli K-feldispat, beyaz renkli plajiyoklas) mineralleri içeren kayaçların genel ve yakın görünümü

Biyotit granodiyorit gri ve koyu gri renklidir. Prizmatik, açık pembe renkli feldispat içeriğiyle biyotit granodiyorit diğer granitoidlerden ayrılmaktadır. Biyotit granit kayaçları ise biyotit granodiyorit bileşimli kayaçlara benzer arazi karakteristikleri göstermektedir. Fakat bu birim biyotit granodiyoritten farklı olarak daha prizmatik, açık pembemsi renkli K-feldispat megakristallerinden oluşmaktadır (Şekil 4.9).



Şekil 4.9. Basgo plütonik kayaçlarının arazi görünümü

Nimu plütonik kayaçları

Nimu (veya Nimmoo, Nimmu) Jammu-Keşmir eyaletinde Leh'ten 35 km uzakta Ladakh Bölgesinin güneydoğusunda yer almaktadır (Şekil 4.10). Nimu'nun sert vadileri Ladakh bölgesinin güneybatı kesimlerinde yer almaktadır. Yükseltisi 3000 m'yi bulan Nimu'nun yakınında Indus Nehri akmaktadır (Şekil 4.11). Kasabada sıcaklık yazın $+40^{\circ}\text{C}$ 'ye, kışın ise -29°C 'lere ulaşmaktadır.



Şekil 4.10. Nimu kasabasına giriş



Şekil 4.11. Indus nehri civarından bir görünüm (arkada yeralan birimler Indus molas birimleri)

Nimu plütonik kayaları biyotit hornblend granodiyorit, biyotit granodiyorit ve biyotit granit bileşimlidir (Şekil 4.12). Bu kayaç türleri benzer arazi karakteristikleri sunarken biyotit granodiyorit bileşimli kayaçlar, diğer kayaçlara göre fazla oranda kuvars içeriğine sahiptir.



Şekil 4.12. Orta-iri taneli biyotit granodiyorit in mostra görünümü

Granit ve granodiyorit bileşimli numunelerinin renkleri içerdikleri biyotit ve hornblend minerallerinden dolayı açık griden-koyu gri renk tonları doğru değişim göstermektedir (Şekil 4.13).

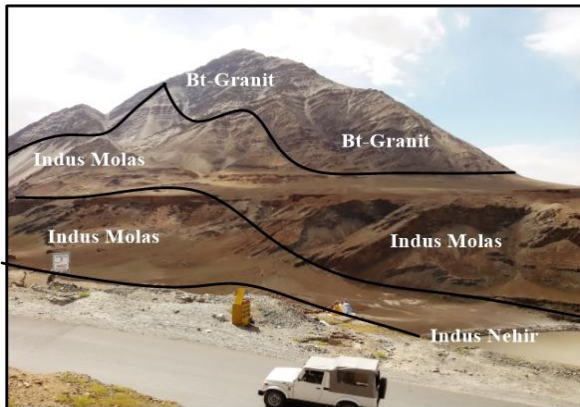


Şekil 4.13. Levha şekilli feldispat taneleri içeren orta-iri taneli biyotit-granodiyoritın mostra görünümü

Nimu'nun 2 km uzağında gözlenen Ladakh intrüzif kayaçlarının Indus Molaları ile durumu ve Zaskar nehrinin Indus nehrine Nimu Gyasho boyunca karıştığı gözlenmektedir (Şekil 4.14, 4.15).



Şekil 4.14. Leh'ten Nimu istikametine giden yol civarında biyotit ve hornblend granit kayaçlarının ve ayrıca Indus Molasının görünümü (Fotoğraf, Leh yönünde hareket ederken, yolun sağından çekilmiştir)



Şekil 4.15. Ladakh Batoliti ve Indus Molalarının görünümü ve her iki litolojiyi katederek geçen Indus Nehri'nin görünümü. Kırmızı ve kahverengi ile kaplanmış kum ve siltli arazi, Indus molalarını göstermektedir (Bt-biyotit)

Nimu civarında yeralan magnetik alanları ile ünlü Magnetik Tepe koyu renkli ferromagnezyen içerikli ağır minerallerin konsantrasyonunu göstermektedir (Şekil 4.16).



Şekil 4.16. Nimu yakınında yer alan Magnetik Tepe olarak isimlendirilen bölgenin görünümü

Umla plutonik kayaçları

Umla kasabası Leh'in 25 km batısında yer almaktadır (Şekil 4.17).



Şekil 4.17. Umla köyü civarında intrüzif kayaçlar (Anonim 10)

Çalışma alanında geniş yüzlekler veren Umla plutonik kayaçları; granit, kuvars granodiyorit ve biyotit granit bileşimlidir. Granit bileşimi sunan intrüzif kütleler orta-iri taneli ve değişen oranlarda plajiyoklas, K-feldispat, kuvars, hornblend ve biyotit mineralleri içermektedir. Mafik mineral içeriği ise büyük oranda biyotit mineralinden oluşmaktadır. Granitin renk içerikleri kayaç bünyesinde farklı oranlarda gözlenen

biyotit ve hornblend minerallerinden dolayı açık-koyu gri renk tonlarında değişmektedir (Şekil 4.18).



Şekil 4.18. Umla intrüzif kayaçlarının genel arazi görünümü

Taru plutonik kayaçları

Taru (veya Taroo), Jammu ve Keşmir Eyaleti'nin Leh-Ladakh Bölgesi'nde bir kasabadır. Taru plütonik kayaçları; kuvars granodiyorit, monzodiyorit, biyotit hornblend granodiyorit ve granit bileşimlidir Her bir intrüzif kütle benzer arazi özellikleri gösterse de içerdikleri farklı oranlardaki açık renkli mineral (kuvars, plajiyoklas ve K-feldispat) ve megakristal türlerinde den dolayı farklı dokusal özellik sunmaktadır (Şekil 4.19 ve 4.20).



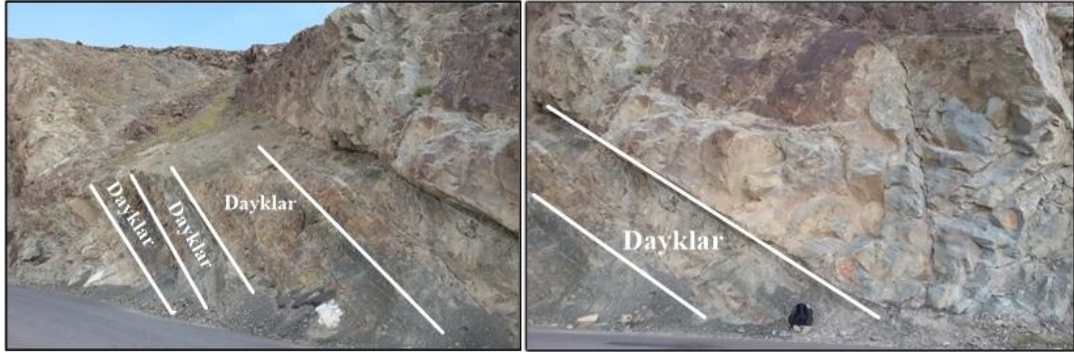
Şekil 4.19. Taru ve civarında yeralan plutoik kayaçların genel görünümü (sağ taraftaki, koyu renkli olan kayaçlar biyotit granit; sol taraftaki, açık renkli olanlar ise lökogradit)



Şekil 4.20. Taru kasabası (Leh) yakınındaki kuvars granodiyorit in mostra görünümü

Dayklar

Intrüzif kayaçları kesen pegmatit ve aplit dayklarına rastlanmakla birlikte; özellikle Leh-Nimu yolu üzerinde, Taru yakınlarında farklı doğrultu ve eğimlerde mafik dayklara rastlanılmıştır. Bu dayklar yoğun alterasyona maruz kalmış mafik dayklardır (Şekil 4.21).



Şekil 4.21. a) Leh-Ladakh bölgesindeki Ladakh Batolitini farklı doğrultu ve eğimlerde kesen mafik dayklardan bir görünüm (Resim Leh-Nimu yolu üzerindeki yol kenarından çekilmiştir) ve **b)** mafik daykın yakın görünümü

Anklavlar

Çalışma alanında iki tür anklav tanımlanmıştır: ksenolit ve mafik mikrogranüler anklavlar. Ksenolitler, Indus-Shyok vadisinde yeralan intrüzif kayaçlarında gözlenmiştir. İnce taneli, farklı boyut ve şekillerdeki mafik mikrogranüler anklavlar kayaçlar içerisinde yaygın olarak gözlenmektedir (Şekil 4.22).

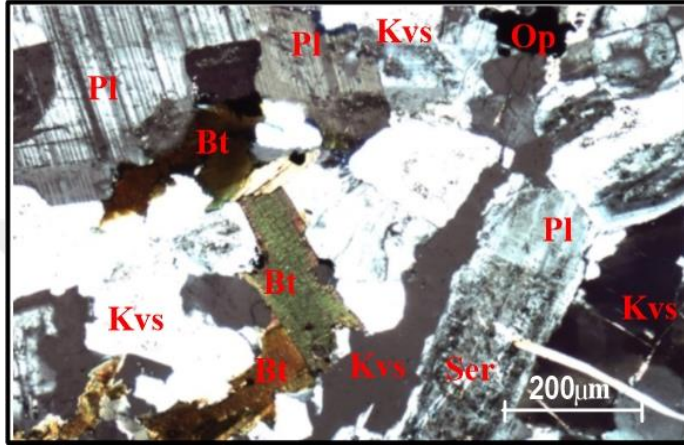


Şekil 4.22. İntrüzif kayaçlar içerisinde bulunan mafik magmatik anklavların genel görünümü

4.3. Petrografik Çalışmalar

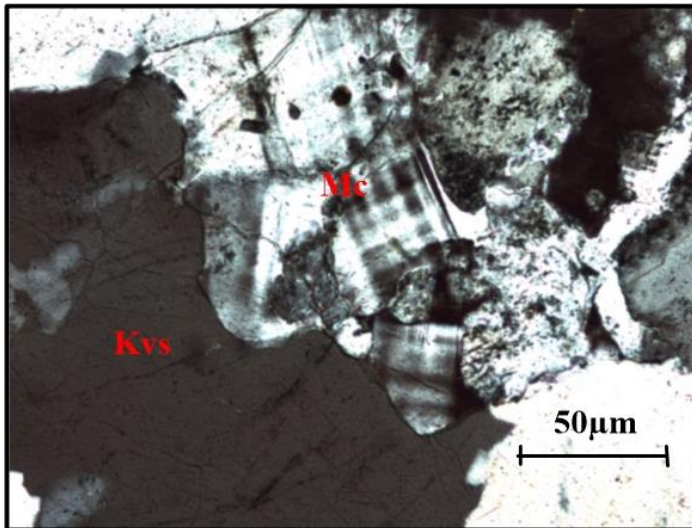
4.3.1. Basgo plutonik kayaları

Biyotit granodiyorit ve biyotit granit bileşimli kayalar genellikle orta-iri taneli, tanesal dokuludur. Modal değerleri genel olarak; %35-40 plajiyoklas ve K-feldispat, %30-35 kuvars, %5-10 biyotit ve %3-5 hornblenddir (Şekil 4.23). Daha az oranda apatit, sfen, zirkon, rutil, monazit ve opak mineraller bulunmaktadır. Kayalarda bulunan ikincil mineraller ise serisit, muskovit, klorit ve epidotdur.

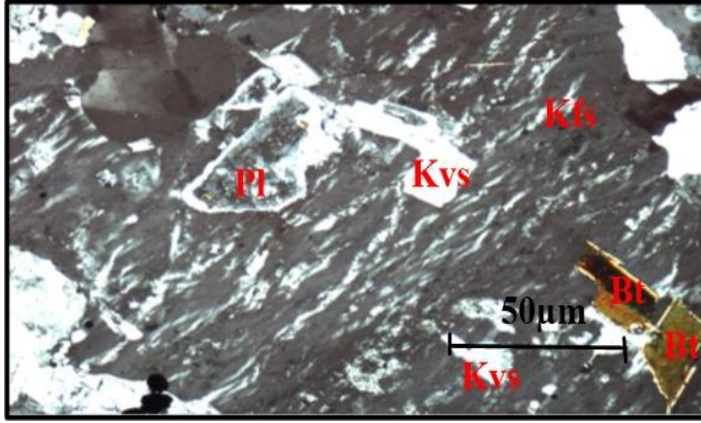


Şekil 4.23. Basgo intrüzif kayalarının mikroskop altındaki genel görünümü (Ç.N; Kvs-Kuvars, Pl-Plajiyoklas, Bt-Biyotit, Op-Opak mineral, Ser-Serisit; Numune AM 2)

Her iki kayaç türün de, K-feldispat genellikle ortoklas bileşimli olup ve mikrokline de rastlanılmaktadır (Şekil 4.23). Yarı özşekilli, basit ikizlenmeli, K-feldispat kristalleri, biyotit ve plajiyoklas minerallerini kapanım olarak içermektedir. Pertitik, mirmekitik ve grafik doku yaygındır (Şekil 4.24).

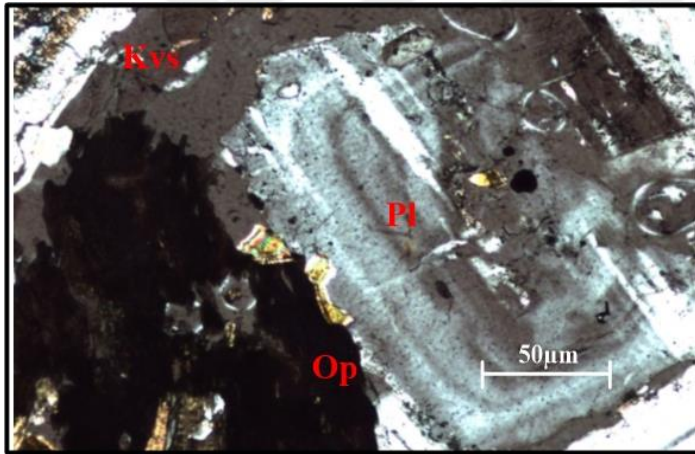


Şekil 4.24. Kafes ikizlenmeli mikroklin (Ç.N; Kvs-Kuvars, Mc-Mikroklin; Numune AM 4)



Şekil 4.25. K-feldispat megakristallerinde gözlenen pertitik doku (Ç.N; Kvs-Kuvars, Pl-Plajiyoklas, Kfs-K-feldispat, Bt-Biyotit; Numune AM 3)

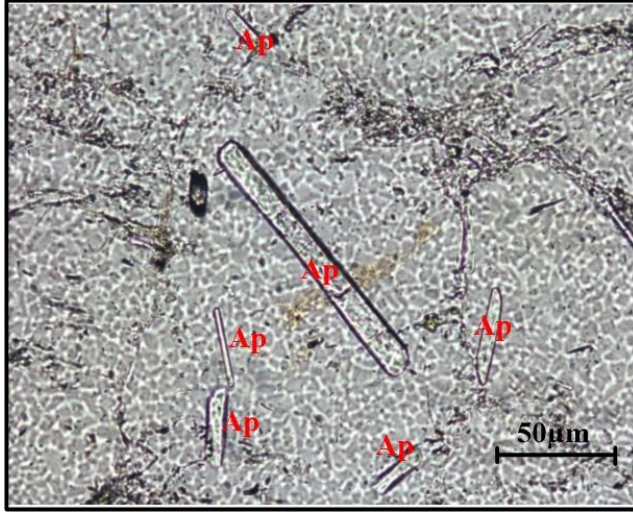
Yarı özşekilli, levhamsı (yassı prizmatik) şekilli plajiyoklas megakristalleri zonlu doku göstermektedir (Şekil 4.26). Yarı özşekilli plajiyoklas mineralleri polisentetik (çoklu) ikizlenme göstermektedir (Şekil 4.23, 4.26). Plajiyoklasların ikizlenme yüzeyleri boyunca ve özellikle bu kristalin merkez bölümlerinde alterasyon (serisitleşme) gelişmiştir (Şekil 4.23).



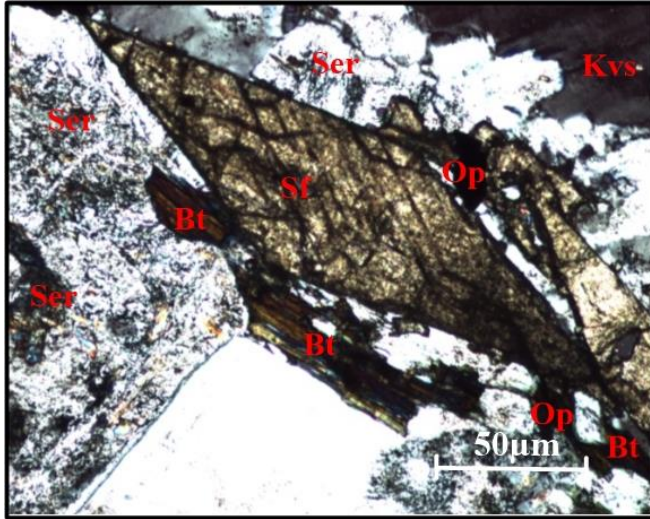
Şekil 4.26. Plajiyoklas megakristalinde gözlenen zonlanma (Ç.N; Kvs-Kuvars, Pl-Plajiyoklas, Op-Opak mineral; Numune AM 1)

Özşekilsiz kuvars mineralleri ise diğer minerallerin arasını doldurur şekilde ve dalgalı sönme göstermektedir (Şekil 4.23). Yarı özşekilli biyotit mineralleri en yaygın mafik mineraldir (Şekil 4.23). Ayrıca bu minerallerde kenarları ve dilinimleri boyunca kloritleşmeler gelişmiştir. Özşekilli, yarı özşekilli hornblend minerallerine ise biyotite göre daha az rastlanmaktadır.

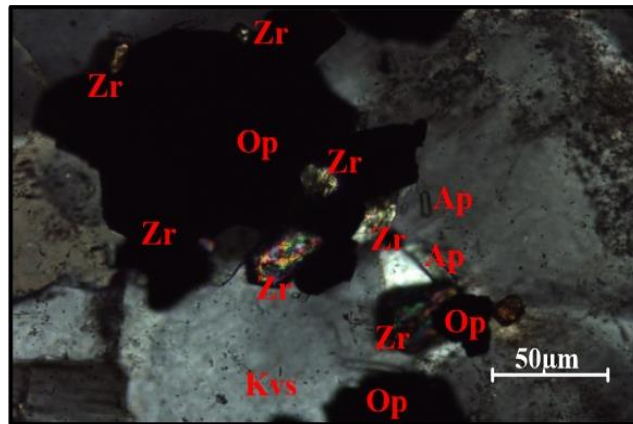
Biyotit minerali içinde gözlenen kapanım olarak gözlenen apatit mineralleri, yer yer uzun prizmatik ve özşekillidir (Şekil 4.27). Sarımsı-kahverengimsi renkli, özşekilli taneler olarak gözlenen sfen mineralleri, genellikle opak minerallerin hakim olduğu alanlarda gözlenmektedir (Şekil 4.28). Özşekilli zirkon mineralleri, opak, biyotit ve hornblend mineralleri içinde kapanım haline rastlanılmaktadır (Şekil 4.29). Diğer bir aksesör mineral ise yarı özşekilli monazitdir (Şekil 4.30).



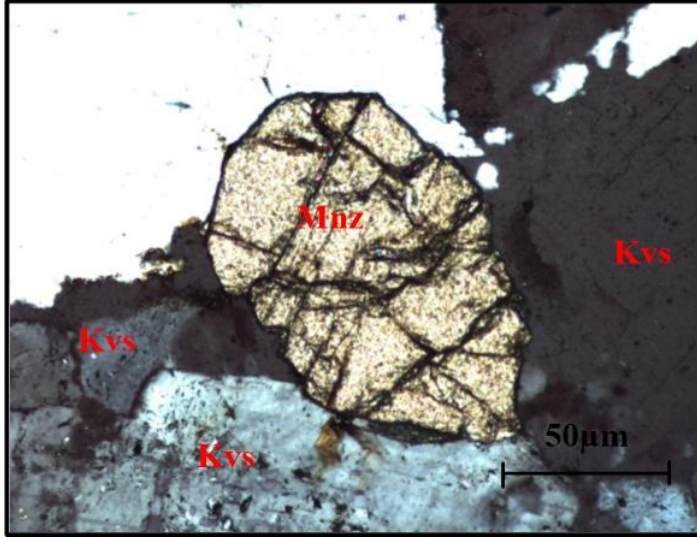
Şekil 4.27. Özşekilli, uzun prizmatik apatit mineralleri (T.N; Ap-Apatit; Numune AM 2)



Şekil 4.28. Yüksek rölyef ve çiftkırmaoya sahip, özşekilli sfen mineralleri (Ç.N; Kvs-Kuars, Bt-Biyotit, Ap-Apatit, Op-Opak mineral, Spn-Sfen, Ser-Serisit; Numune AM 2)



Şekil 4.29. Özşekilli, çiftkırması yüksek zirkon minerallerinin opak mineraller içindeki görünümü (Ç.N; Zrn-Zirkon, Op-Opak Mineral, Ap-Apatit; Numune AM 3)

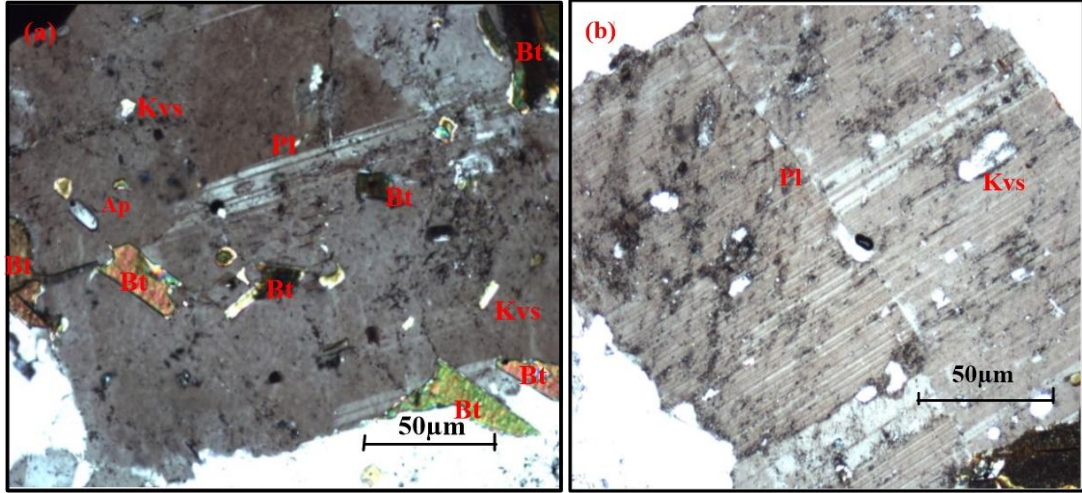


Şekil 4.30. Yarı özşekilli monazit mineralinin görünümü (Ç.N; Kvs-Kuvars, Mnz-Monazit; Numune AM 3)

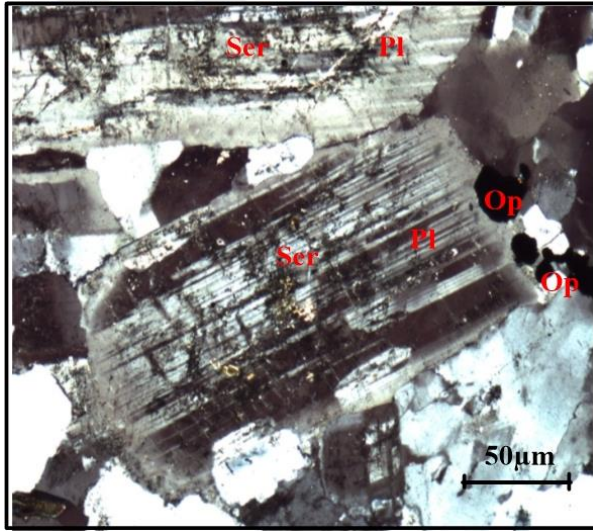
4.3.2. Nimu plutonik kayaçları

Nimu intrüzif kayaçları, biyotit hornblend granodiyorit, biyotit granodiyorit ve biyotit granit bileşimlerinden oluşmaktadır. Bu kayaç türleri benzer özellikler sunarken, biyotit granodiyorit bileşimindeki kayaçta kuvars oranı diğer kayaçlara göre daha fazladır. Biyotit hornblend granodiyorit, biyotit granodiyorit ve biyotit granit bileşimindeki plütonik kayaçların modal bileşimleri, %35-45 plajiyoklas ve K-feldispat, %35-40 kuvars, %10-15 biyotit ve %5-10 hornblend içermektedir. Tüm bu kayaç örnekleri genellikle orta-iri taneli ve taneseli dokuludur. Aksesorik mineraller sfen, apatit, zirkon ve opak minerallerdir. İkincil mineraller ise serisit, klorit, epidot ve muskovitdir.

Yarı özşekilli, iri taneli, polisentetik ikizlenmeli, plajiyoklas kristallerinde yer yer zonlu dokuya rastlanılmakta olup; genellikle diğer mineralleri, özellikle biyotit, kapanım olarak içermektedir (Şekil 4.31). Plajiyoklaslarda alterasyon türü olarak serisitleşmeler yaygındır (Şekil 4.32).

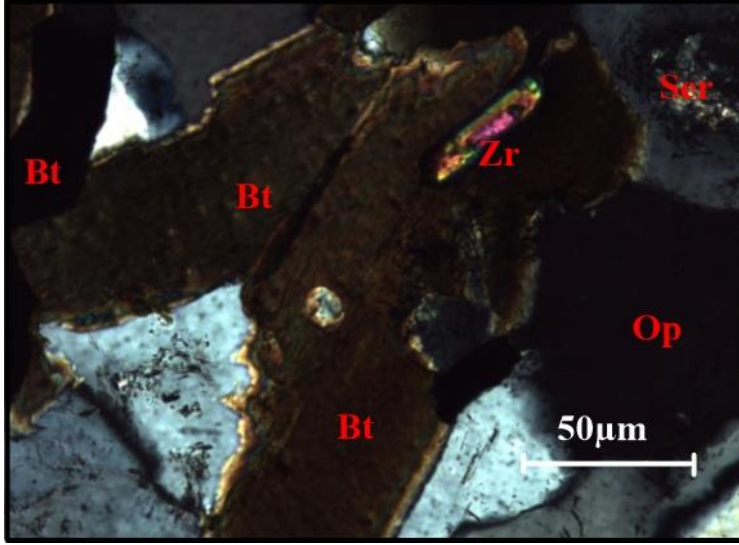


Şekil 4.31. a) Plajiyoklas içinde kapanımlar şeklinde gözlenen apatit ve biyotit kristalleri, **(b)** Plajiyoklas mineralinde gözlenen polisentetik ikizlenme (Ç.N; Kvs-Kuvars, Bt-Biyotit, Pl-Plajiyoklas, Ap-Apatit; Numune AM 17)

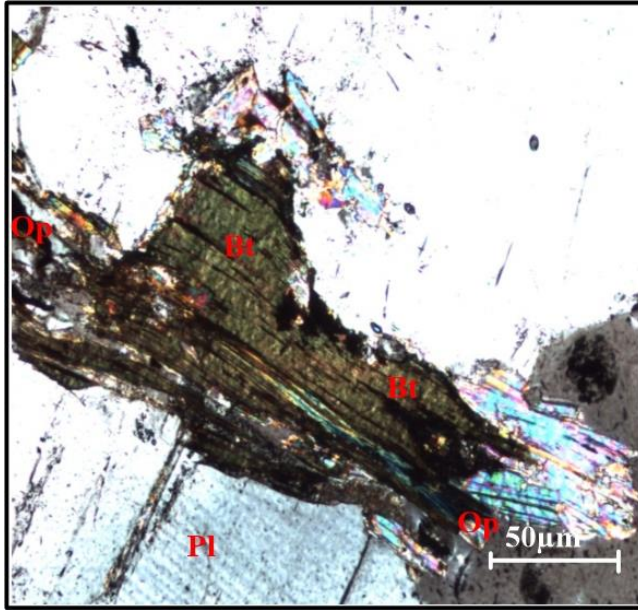


Şekil 4.32. İkizlenme düzlemleri boyunca ve ayrıca mineral merkezinde gözlenen serisitleşme (Ç.N; Pl-Plajiyoklas, Ser-Serisit, Op-Opak mineral, Or-Ortoklas, Pert-Pertitik doku, Spn-Sfen, Bt-Biyotit; Numune AM 20)

İri taneli K-feldispat, genellikle Karlsbad ikizlenmeli ve mikropertitik yapıdadır. Kafes ikizlenmeli mikroklin mineraline de yer yer rastlanılmaktadır. Dalgali sönme gösteren kuvars, plajiyoklas ve K-feldispatı göre daha az oranda ve küçük taneler halinde ve diğer minerallerin arasında doldurur özelliktedir. Biyotit, genellikle yarı öz şekilli kristaller halinde olup (Şekil 4.33), kenarlarından ve dilinimlerinde itibaren kloritlemiştir (Şekil 4.34).

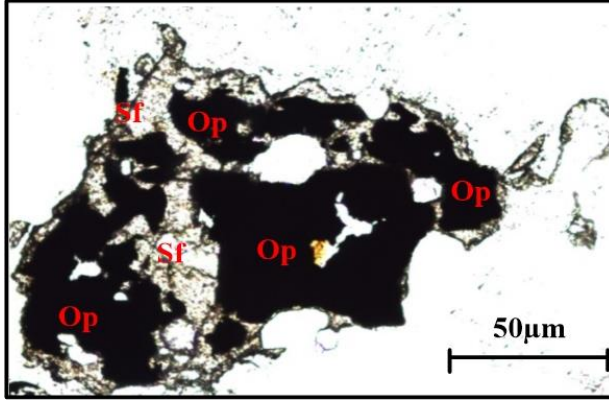


Şekil 4.33. Biotit minerali içinde inklüzyonlar şeklinde gözlenen prizmatik şekilli zirkon mineralinin görünümü (Ç.N; Bt-Biyotit, Zrn-Zirkon, Ser-Serisit, Op-Opak mineral; Numune AM 20)



Şekil 4.34. Biotit mineralinde ikincil klorit ve plajiyoklas mineralinde ikincil muskovit oluşumları (Ç.N; Bt-Biyotit, Kvs-Kuvars, Op-Opak mineral; Numune AM 19)

Sfen mineralleri genellikle opak minerallerin bulunduğu alanlarda yoğunlaşmışlardır (Şekil 4.35).

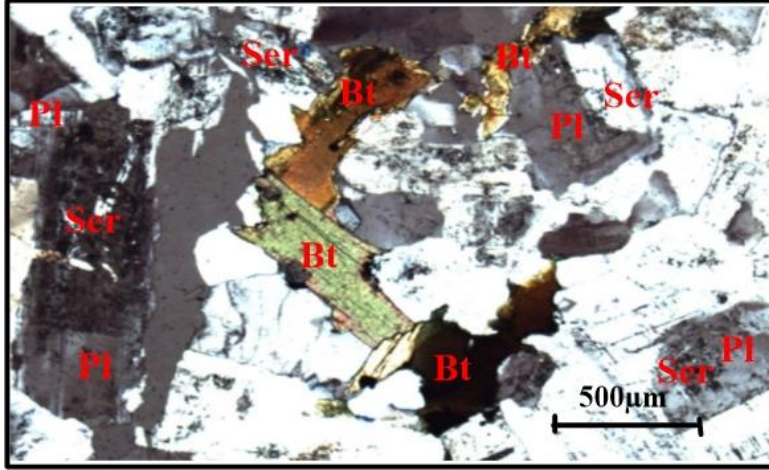


Şekil 4.35. Birarada bulunan opak ve sfen mineralleri (T.N; Spn-Sfen, Op-Opak mineral; Numune AM 18)

4.3.3. Umla plutonik kayaçları

Umla intrüzif kayaçları granit, kuvars granodiyorit ve biyotit granit bileşimlidir. Her bir kayaç türünün petrografik özellikleri benzer olmasına rağmen, kuvars granodiyoriteki kuvars oranı diğer kayaç türlerine göre daha fazladır.

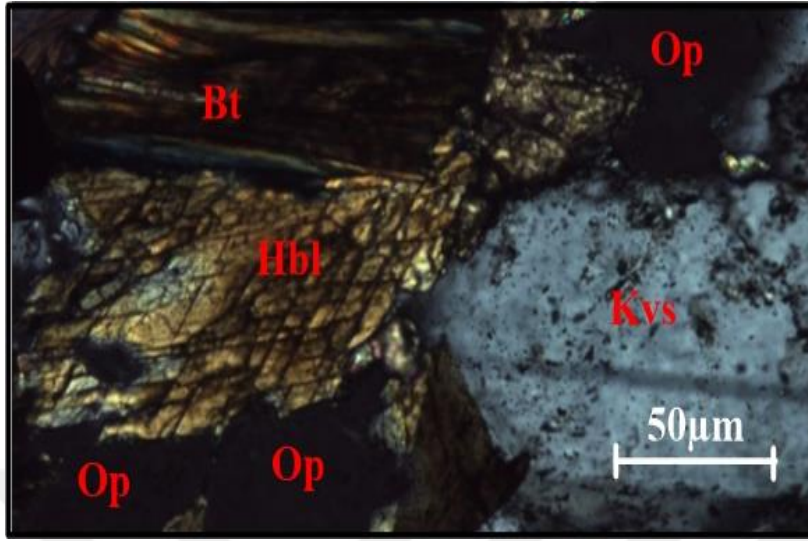
Orta-iri taneli, taneseli dokulu tüm kayaç türlerindeki modal bileşim %35-38 plajiyoklas ve K-feldispat, %35-40 kuvars, %10-15 biyotit ve %5-10 hornblend şeklindedir (Şekil 4.36). Aksesuar mineraller sfen, apatit, zirkon ve Fe-Ti oksitidir. Kayaçlarda bulunan en yaygın alterasyon türleri serisitileşme ve kloritleşmedir.



Şekil 4.36. Biyotit granitin mikroskop altındaki genel görünümü. Alterasyon türü olarak plajiyoklaslarda serisitileşme ve biyotitlerde kloritleşme gözlenmektedir (Ç.N; Op-Opak mineral, Kvs-Kuvars, Bt-Biyotit; Numune AM 21)

Plajiyoklaslar, K-feldispat minerallerine nazaran daha iri taneli, özşekilli-yarı özşekilli ve polisentetik ikizlenmelidir. Ayrıca plajiyoklaslarda zonlanma yaygındır ve zonlanma boyunca serizitleşmeler gelişmiştir. Orta-iri taneli K-feldispat minerallerinde pertitleşme yaygındır. İrili ufaklı ve dalgalı sönme gösteren kuvars, öz şekilsiz kristaller şeklinde diğer minerallerin arasını doldurmaktadır. Biyotit mineralleri kahverengiden yeşile doğru değişen pleokroyizmaya sahiptir. Yarı özşekilli latalar şeklinde olan

biyotitlerde kloritleşmeler yaygındır (Şekil 4.37). Hornblend mineralleri özşekli-yarı özşekli ve çift ve/veya tek yönde dilinime sahiptirler (Şekil 4.37).

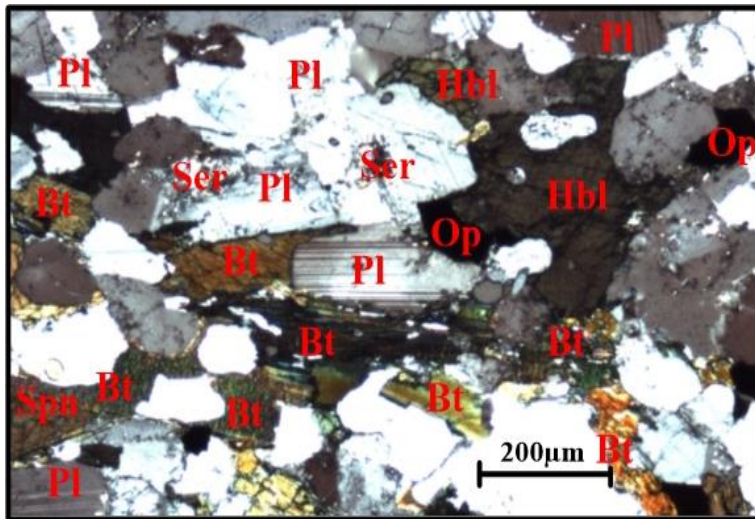


Şekil 4.37. Özşekli-yarı özşekli, çift yönde dilinimli hornblend ve biyotit mineralinde gözlenen kloritleşme (Ç.N; Hbl-Hornblend, Bt-Biyotit, Op-Opak mineral, Kvs-Kuars; Numune AM 22)

4.3.4. Taru plutonik kayaçları

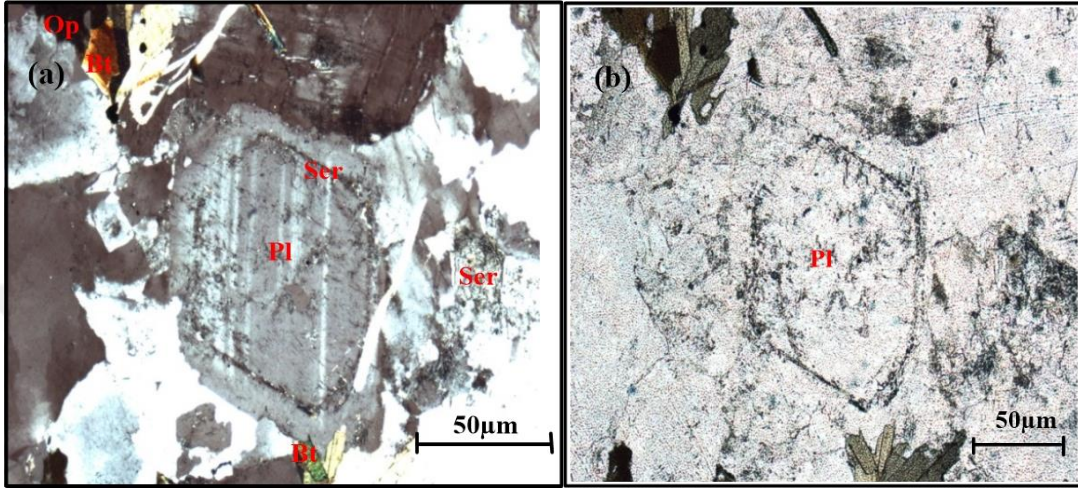
Taru plutonik kayaçları granodiyorit, monzodiyorit, biyotit hornblend granodiyorit ve granit bileşimlidir.

Orta-iri taneli, taneler dokuya sahip bu kayaç türlerinde ana mineral yüzde içerikleri, 30-35 plajiyoklas ve K-feldispat, 40-45 kuvars, 10-15 biyotit ve 5-10 hornblend şeklindedir (Şekil 4.38).

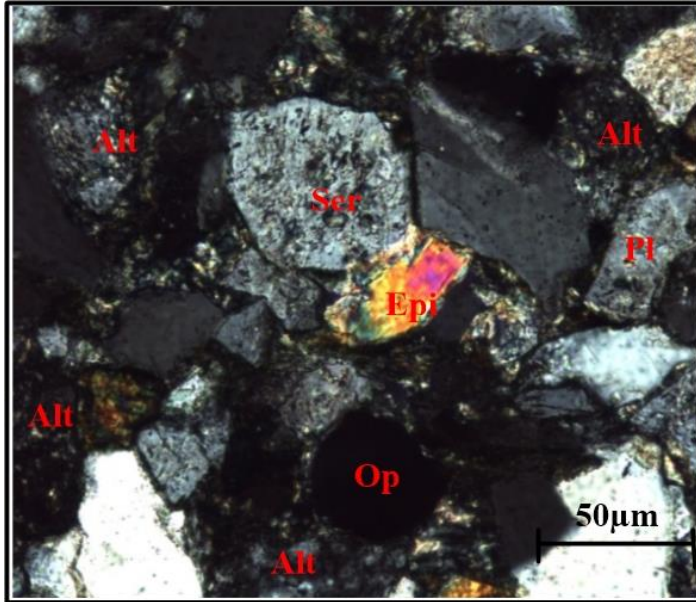


Şekil 4.38. Taru granitik kayaçlarının genel görünümü (Ç.N; Pl-Plajiyoklas, Op-Opak mineral, Bt-Biyotit, Hbl-Hornblend, Spn-Sfen, Ser-Serisit; Numune AM 32)

Plajiyoklas, özşekli-yarı özşekli ve polisentetik ikizlenme göstermektedir. Düşük sönme açılı plajiyoklas mineralleri albit bileşimli olup, kayacın yaklaşık %30'unu oluşturmaktadır (Şekil 4.39). Plajiyoklas kristalleri kısmen veya tamamen serisitleşmiştir. Yer yer bu serisitleşmeler plajiyoklas kristallerinin zonları boyunca gelişmiştir (Şekil 4.39). Ayrıca bazı kesitlerde plajiyokların alterasyonu ile ikincil epidot mineralleri gelişmiştir (Şekil 4.40). Orta-iri taneli K-feldispat minerallerinde de serisitik alterasyona rastgelinmiştir.

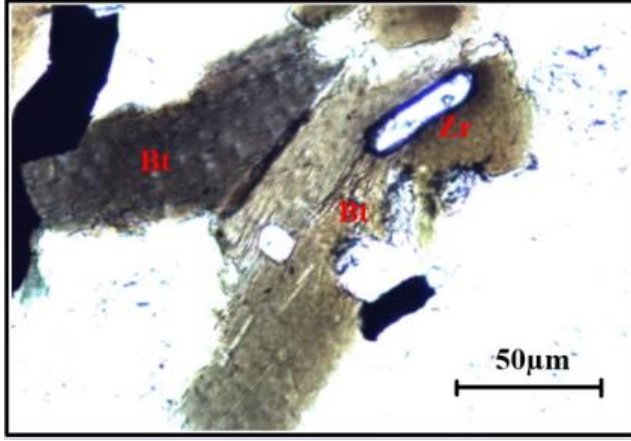


Şekil 4.39. a, b). Plajiyoklas mineralinde gözlenen zonlanma (Ç.N ve T.N; Pl-Plajiyoklas, Ser-Serisit, Op-Opak mineral, Bt-Biyotit; Numune AM 33)



Şekil 4.40. İkincil epidot mineralleri (Ç.N; Pl-Plajiyoklas, Epi-Epidot, Op-Opak mineral, Alt-Alterasyon (klorit ve serisit); Numune 40)

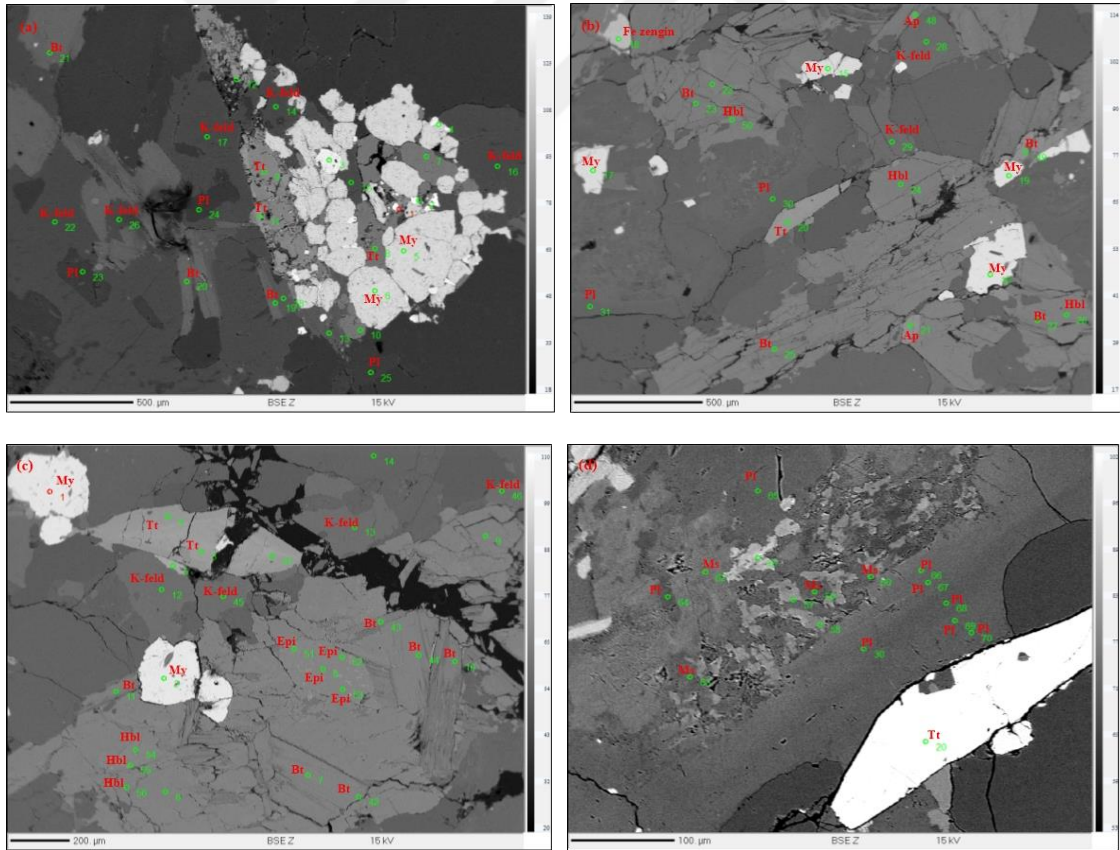
Özşekilsiz kuvars mineralleri dalgali sönme göstermektedir. Biyotit ve hornblend genellikle yarı özşekli-özşekilsizdir. Biyotit minerallerinde kloritleşmeler yaygındır. Sfen, apatit, zirkon gibi aksesori mineraller diğer minerallerin içinde kapanımlar halindedir (Şekil 4.41).



Şekil 4.41. Biotit mineralinde gözlenen kapanımlar (apatit ve zirkon) (T.N; Op-Opak mineral, Zr-Zirkon, Ap-Apatit, Bt-Biyotit; Numune AM 33)

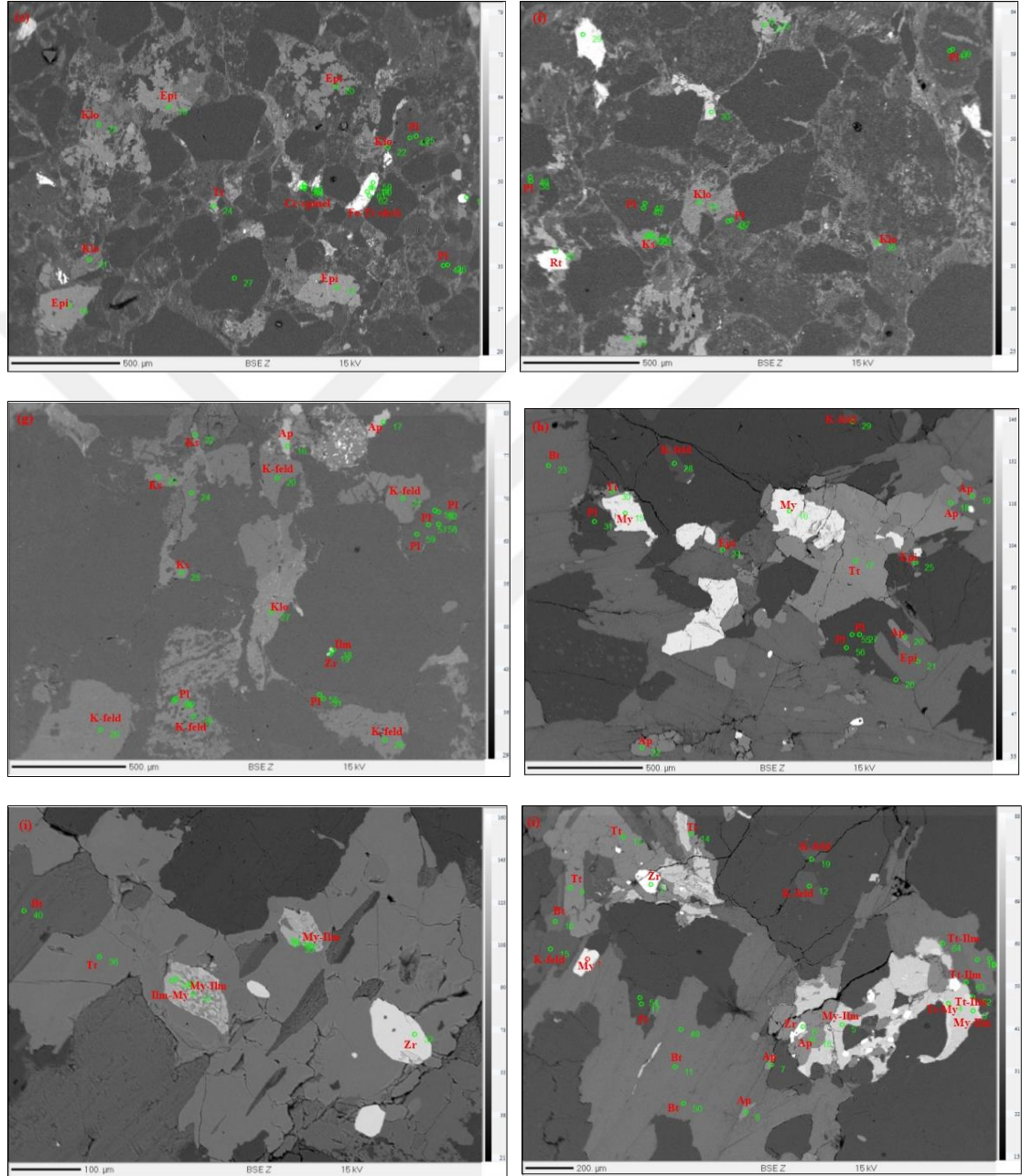
4.4. Mineral Kimyası

Basgo, Nimu, Umla ve Taru intrüzif kayaçlarından 12 temsili örnek üzerinde toplam 712 nokta analizi yapılmış olup (Şekil 4.42); tüm elektron mikroprob sonuçları EK-2’de verilmiştir.

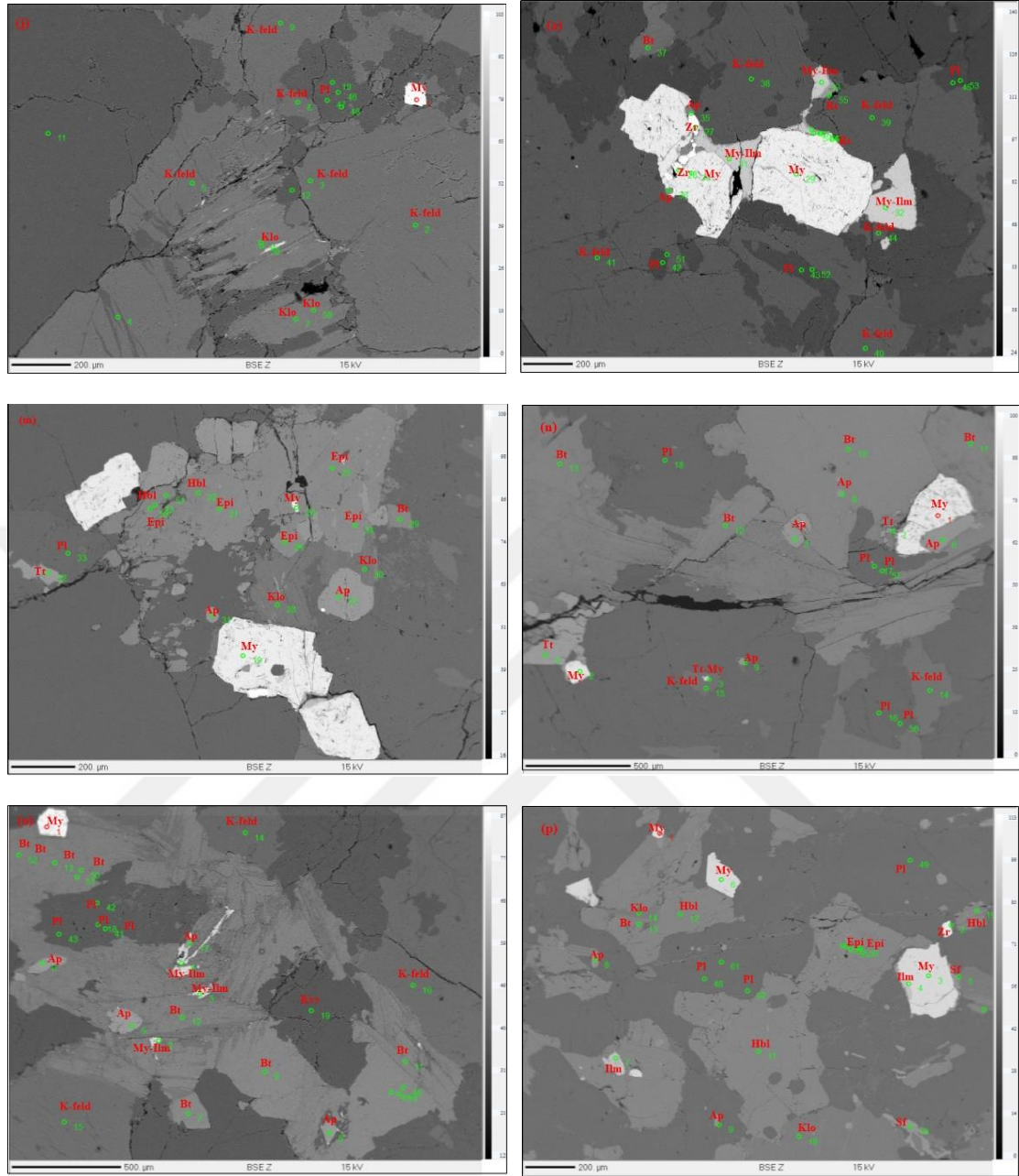


Şekil 4.42. Basgo, Nimu, Umla ve Taru intrüzif kayaçlarından 12 temsili örnekler üzerinde çalışılan alanları gösteren geri-saçılmış elektron (BSE) görüntüleri (a), (e) ve (f) Basgo Granit AM-1 ve AM-5, (b), (c) ve (d) Basgo Granodiyorit AM-3, (g) Nimu Granit AM-15, (h) ve (i)

Nimu Granodiyorit AM 17, **(j)** Umla Granodiyorit AM-21, **(k)** ve **(l)** Umla Granit AM-22, **(m)** ve **(n)** Taru Granodiyorit AM-37, **(o)** Taru Granit AM-38, **(p)** Taru Granodiyorit AM-4, (K-feld-Feldspar, Bt-Biyotit, Pl-Plajiyoklas, Ap-Apatit, Kvs- Kuvars, Epi-Epidot, My- Manyetit, İlm-İlmenit, My-İlm-Manyetit-İlmenit, Ms-Muskovit, Ks-Kalsit, Hbl-Hornblend, Klo-Klorit, Sf-Sfen, Mc-Mikroklin, Zr-Zirkon. Yeşil renk noktalar mikroprob nokta analizlerinin konumlarını göstermektedir)



Şekil 4.42'in devamı



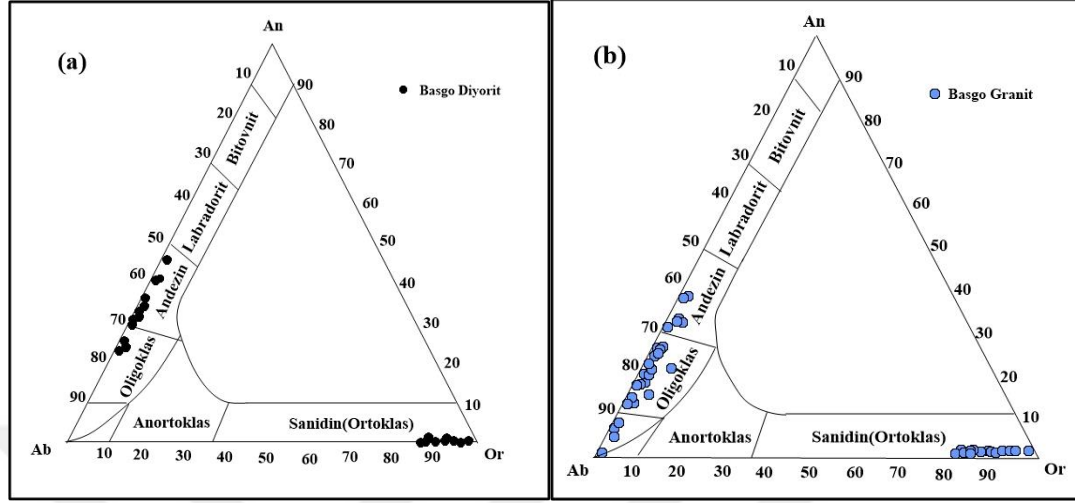
Şekil 4.42'in devamı

4.4.1. Mineral fazları

4.4.1.1. Feldispat

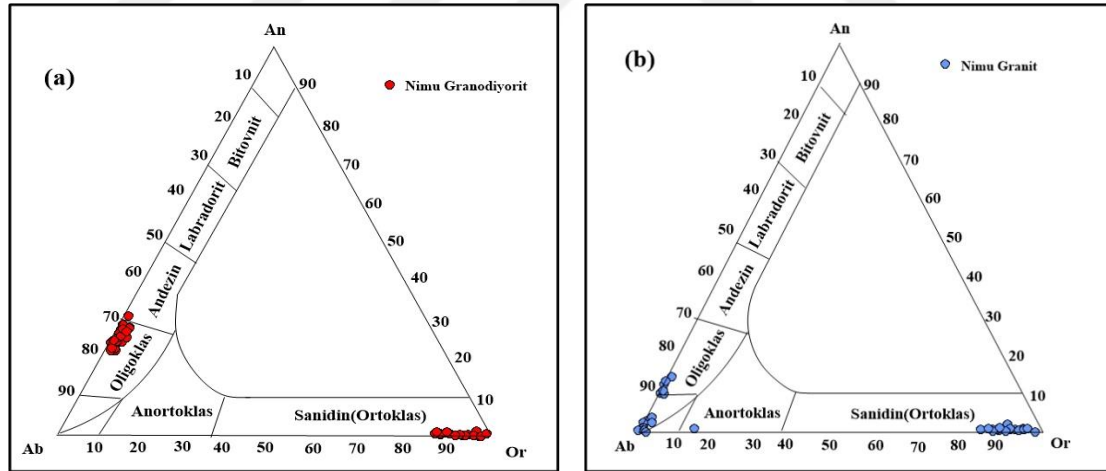
Feldispat (plajiyoklas ve K-feldispat) Basgo, Nimu, Umla ve Taru intrüzif kayaçlarında en çok bulunan mineral fazıdır. Tüm örneklerde analiz yapılan feldispat kristallerinde alterasyon etkileri yok denecek kadar azdır. Feldispat kristalleri üzerinde 228 adet prob analizi yapılmıştır. Elde edilen analiz sonuçlarına göre, bu kayaçlardaki plajiyoklaslar albit-oligoklas-andezin (An_{01-45}) bileşiminde, K-feldispat ise ortoklas (Or_{82-99}) bileşimlidir (Şekil 4.43-4.45).

Basgo intrüzif kayaçlarında bulunan plajiyoklaslar; granodiyoritte genellikle andezin (An_{30-45}), granitde ise oligoklas (An_{10-28}) daha az oranda ise albit-andezin (An_{01-08}) bileşimlidir (Şekil 4.42).



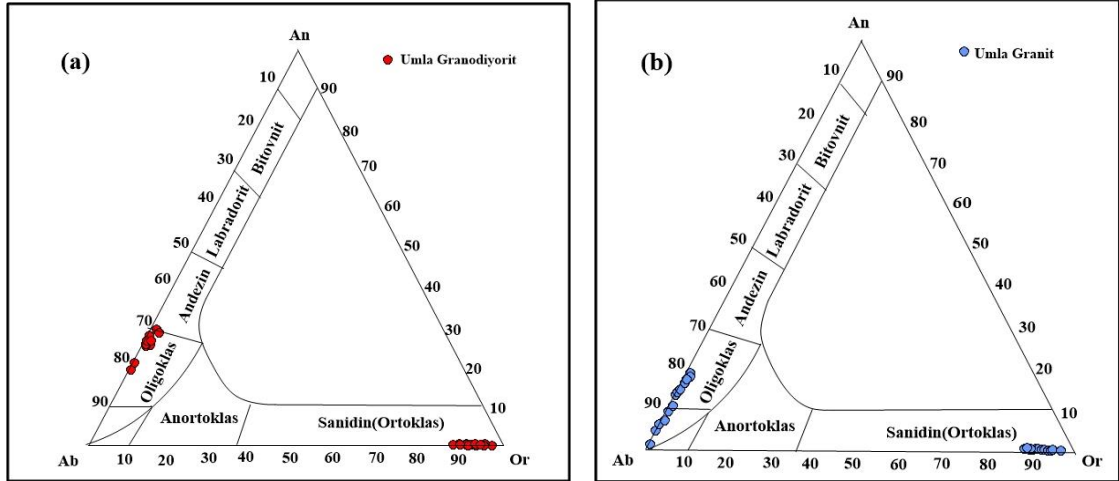
Şekil 4.43. a, b) Ab(albit)-An(anortit)-Or(ortoklas) üçgen diyagramında Basgo diyorit ve granit kayaçlarındaki feldispat bileşimleri

Nimu plutonik kayaçlarında bulunan plajiyoklaslar; granodiyoritte oligoklas (An_{21-31}), granitde ise albit ve oligoklas (An_{02-15}) bileşimlidir (Şekil 4.44).



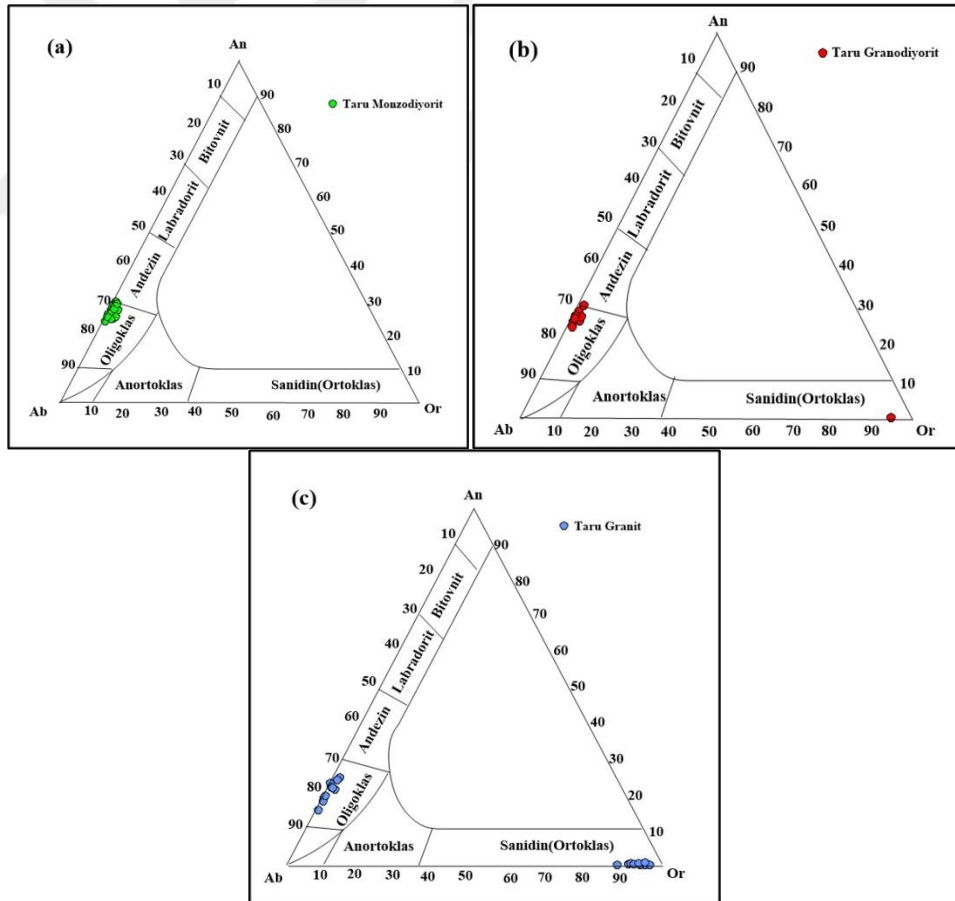
Şekil 4.44. a, b) Ab(albit)-An(anortit)-Or(ortoklas) üçgen diyagramında Nimu granodiyorit ve granit kayaçlarındaki feldispat bileşimleri

Umla intrüzif kayaçlarında bulunan plajiyoklaslar; hem granodiyorit ve hemde granitde oligoklas (An_{01-30}) bileşimlidir (Şekil 4.45).



Şekil 4.45. a, b) Ab(albit)-An(anortit)-Or(ortoklas) üçgen diyagramında Umla granodiyorit ve granit kayaçlarındaki feldispat bileşimleri

Taru intrüzif kayaçlarında bulunan plajiyoklaslar; monzodiyorit, granodiyorit ve granitde oligoklas (An_{15-30}) bileşimlidir (Şekil 4.46).

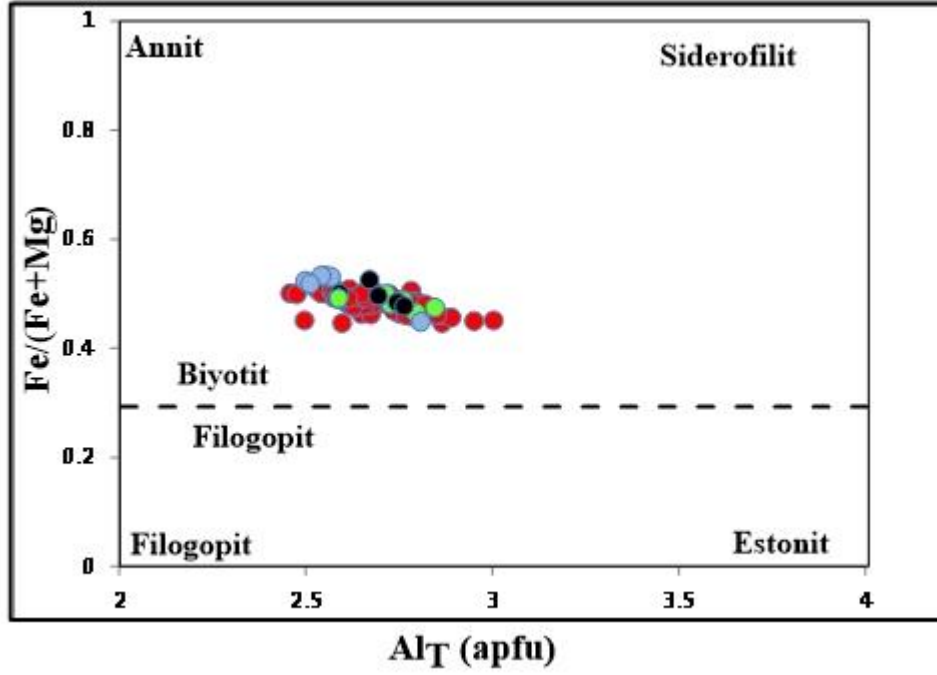


Şekil 4.46. a, b, c) Ab(albit)-An(anortit)-Or(ortoklas) üçgen diyagramında Taru monzodiyorit, granodiyorit ve granit kayaçlarındaki feldispat bileşimleri

4.4.1.2. Biyotit

Basgo, Nimu, Umla ve Taru intrüzif kayaçlarında yaygın olarak bulunan koyu renkli mineral, biyotittir. Biyotit kristalleri üzerinde 108 adet prob analizi yapılmıştır.

$Al_T - Fe/(Fe+Mg)$ diyagramı (Deer vd. 1992) (Şekil 4.47) ile de bu minerallerin biyotit bileşimli olduğu desteklenmektedir. Biyotit kristallerinin yapılarındaki Al_T (~2.5-3.0) ve ayrıca $Fe/(Fe+Mg)$ (~0.40-0.57) oranları sınırlı değerlere sahiptir (Şekil 4.47).

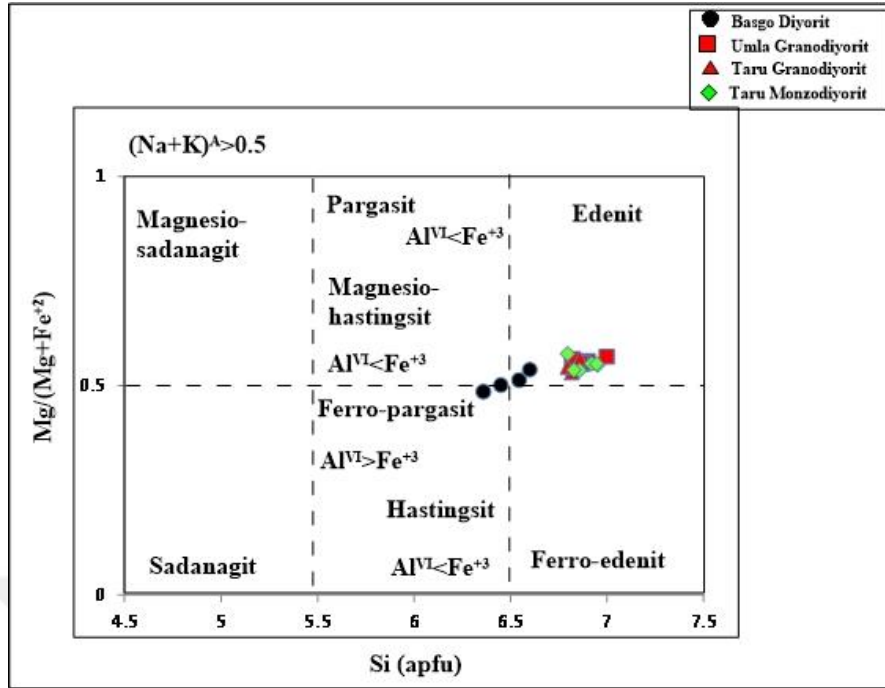


Şekil 4.47. Toplam Al - Fe/(Fe+Mg) değerlerine göre (Deer vd. 1992), Basgo, Nimu, Umla ve Taru intrüzif kayaçlarında bulunan biyotitlerin bileşimleri

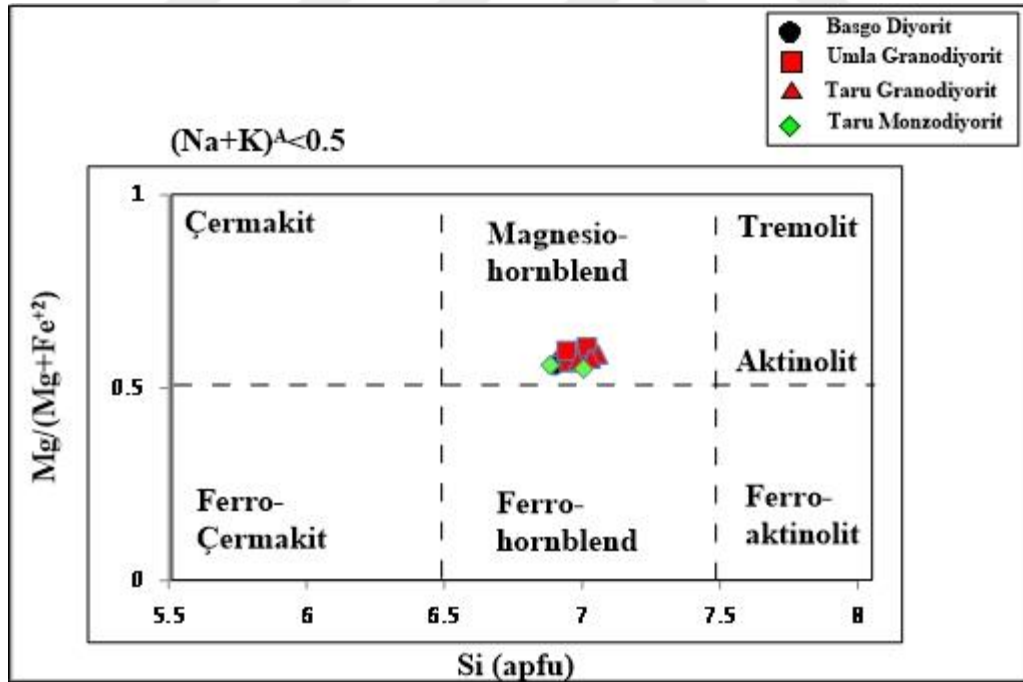
4.4.1.3. Amfibol

Basgo, Nimu, Umla ve Taru plutonik kayaçlarında bulunan amfibol kristalleri üzerinde toplam 132 noktada elektron mikroprob analizi yapılmıştır.

Si - $Mg/(Mg+Fe^{+2})$ diyagramı (Leake vd. 1991) (Şekil 4.48, 4.49) kullanılarak, bu kayaçlardaki amfibollerin Edenit, Hastingsit ve Magnesio-Hornblend bileşimli olduğu tespit edilmiştir.



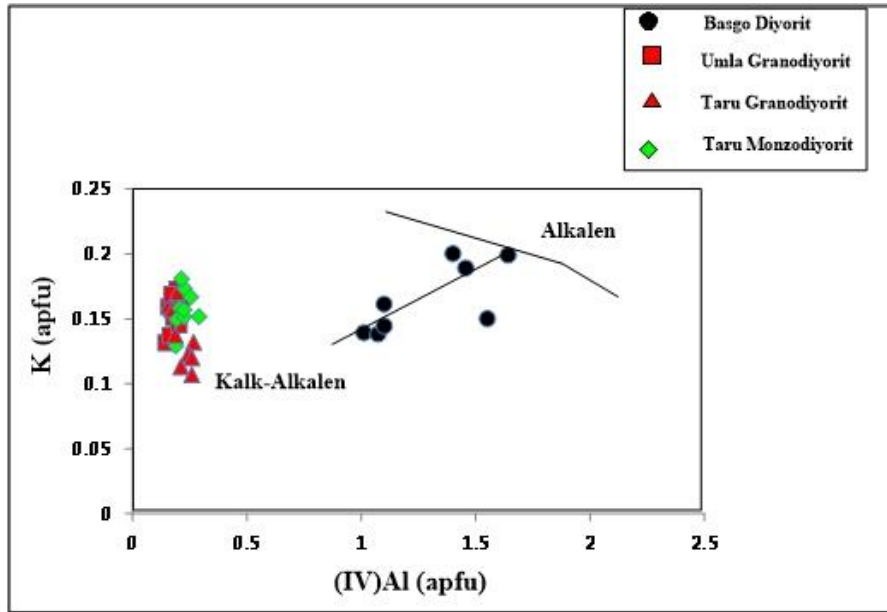
Şekil 4.48. Basgo, Nimu, Umla ve Taru intrüzif kayaçlarında bulunan amfibollerin sınıflandırılması ($(Na+K)^4 > 0.5$; Leake vd. 1991)



Şekil 4.49. Basgo, Nimu, Umla ve Taru intrüzif kayaçlarında bulunan $(Na+K)^4 < 0.5$; Leake vd. 1991)

Al (apfu) - K (apfu) diyagramında (Şekil 4.50) ise intrüzif kayaçlardaki amfiboller kalk-alkalen bölgede yer almakta olup; bu kayaçların dalma-batma zonunda oluştuğunu işaret etmektedir. Ayrıca Basgo granodiyoritik kayaçlarında bulunan

amfibol kristallerinde bulunan $(IV)Al$ artışı ile birlikte K artışı gözlenmektedir (Şekil 4.50)



Şekil 4.50. K (apfu) - $(IV)Al$ (apfu) diyagramı (sınır çizgileri; Ridolfi ve Renzulli 2012'den alınmıştır)

4.4.1.4. Fe-Ti oksit

Basgo, Nimu, Umla ve Taru plutonik kayalarda bulunan Fe-Ti oksitler üzerinde toplam 143 noktada prob analizi yapılmıştır. Bu analizler sonucunda kayaç türlerinde genel olarak tespit edilen opak mineraller, manyetit ve ilmenit bileşimindedir.

Takasashi vd. (1980) ve Ishahara (1977) granitleri manyetit- ve ilmenit-serisi olarak adlandırmışlardır. Chappell ve White'ın (1974) I- ve S-tipi granit sınıflamaları ile karşılaştırmışlardır. Buna göre I-tipi granitleri manyetit-serisi ile S-tipi granitleri de ilmenit-serisi ile eşleştirmişlerdir. Manyetitin yokluğu ve ilmenitin varlığı, sedimanter kökenli kaynağın C (grafit) içeriği nedeniyle, genellikle S-tipi granitler ile ilişkilidir.

4.4.2. Jeotermobarometre

Granitik kayaların mineral bileşimleri, bu kayaların köken magma(lar)nın termometre ve barometre koşullarının, hesaplamalarla tespit edilmesini mümkün kılmaktadır. Oksijen fugasitesi (f_{O_2}) ve su fugasitesi (f_{H_2O}) magmanın kristalleşme koşullarını kontrol eden faktörlendendir. Fakat bu değişkenlerin magmatik koşullarda belirlenmesi, subsolidus aşamasında yeniden dengelemenin neden olduğu faz ve bileşimsel değişiklikler nedeniyle, zordur (Czamanske ve Wones 1973; Wones 1981).

Bununla birlikte, Basgo, Nimu, Umla ve Taru plutonik kayaların kaynak kayalarının yerleşmesi sırasındaki basınç, sıcaklık ve oksijen fugasitesini tespit etmenin birkaç yolu vardır:

- ✓ Al-hornblend jeobarometre ve Amfibol-plajiyoklas jeotermometresi

- ✓ Oksijen fugasitesi (Wones 1989)

4.4.2.1. Amfibol-plajiyoklas jeobarometre ve jeotermometresi

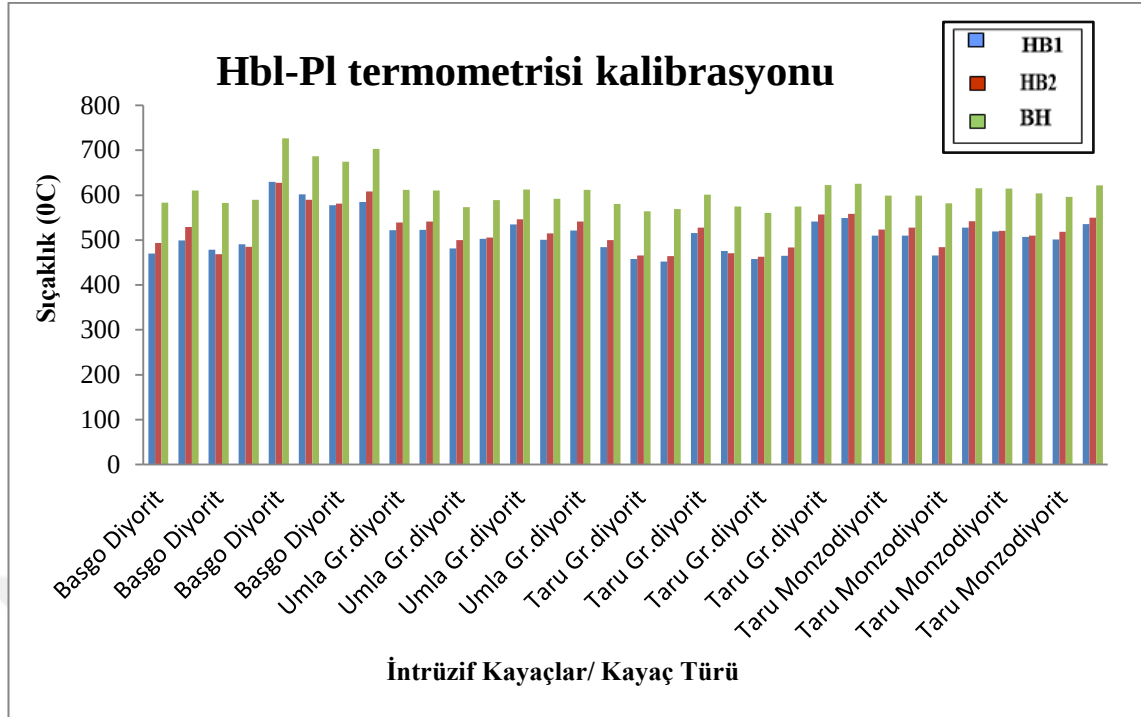
Al-hornblend barometre (Schmidt 1992; Anderson vd. 1995) hesaplamaları Basgo, Umla ve Taru granodiyorit ve monzodiyorit örneklerinde gerçekleştirilmiştir. Nimu'dan alınan intrüzif kayaç örnekleri hariç tutulmuştur, çünkü bu kayaç örneklerindeki amfiboller $Fe/(Fe+Mg) > 0.65$ oranlarına sahiptir. Bu nedenle jeobarometre hesaplamaları 12 örnekten 4'ünde ve sadece 35 noktada belirlenmiştir. Sonuçlar, Çizelge 4.1 ve EK-2'de verilmiştir.

Basgo granodiyoritten elde edilen basınç değerleri, diğer kayaç birimlerine göre yüksektir (2.88-23.84 kbar). Çizelge 4.1'de görüldüğü üzere intrüzif kayaçların çoğu 2-3 kbar basınç değerlerine sahiptir. Bu değerler de bu kayaçların kaynak kayalarının sığ yerleşime (<10 km) sahip olduğunu göstermektedir. Bu değerler aynı zamanda petrografik incelemelerle de doğrulanmıştır (ör: mikrografik, granofirik dokular).

Çizelge 4.1. Basgo, Umla ve Taru plutonik kayaçları basınç ve derinlik değerleri

İNRÜZİF KAYAÇLAR/ KAYAÇ TÜRÜ	BASINÇ (kbar) (± 0.6)		DERİNLİK (km)	
	Al-hornblend barometresi (Schmidt 1992)	Al- hornblend barometresi (Anderson vd. 1995)	Al-hornblend barometresi (Schmidt 1992)	Al- hornblend barometresi (Anderson vd. 1995)
Basgo İntrüzif Kayaçlar/ Granodiyorit	2.88-23.84	2.32-28.08	13.7	12.8
Umla İntrüzif Kayaçlar/ Granodiyorit	2.73-3.43	2.13-3.00	9.9	8.1
Taru İntrüzif Kayaçlar/ Granodiyorit	2.74-3.55	1.83-3.15	10	8.3
Taru İntrüzif Kayaçlar/ Monzodiyorit	2.90-3.94	2.35-3.62	11	9.5

Blundy ve Holland (1990) (BH1), Holland ve Blundy (1994) (HB1) ve Holland ve Blundy (1994) (HB2) hornblend-plajiyoklas jeotermometre kalibrasyonları kullanılarak Ladakh batolitinde incelenen granitoidler için elde edilen sıcaklıklar 561-727 °C (BH1), 452-629 °C (HB1) ve 463-628 °C (HB2) aralığındadır (Şekil 4.51).



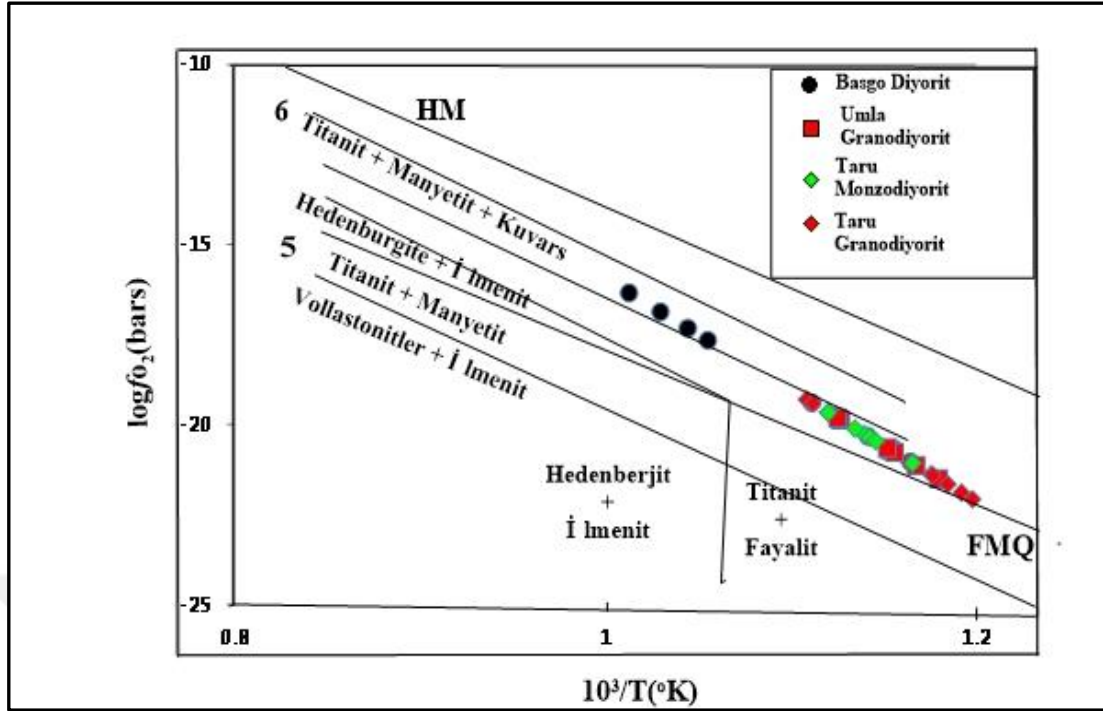
Şekil 4.51. Ladakh batolitinde incelenen plutonik kayaçlar için kristalleşme sıcaklıklarının dağılımını gösteren histogram. Kısaltmalar: BH (Blundy ve Holland 1990, HB1 (Holland ve Blundy 1994) ve HB2 (Holland ve Blundy 1994)

4.4.2.2. Oksijen fugasitesi

Oksijen fugasitesi (f_{O_2}), magmatik kayaçların kristallenme süreçlerinde kayacı oluşturan ergiyeğin, sıcaklık, basınç ilişkisini kontrol ettiği gibi, kayaçları oluşturan minerallerin duraylılık alanlarını da etkiler (Karlı vd. 2000). Oksijen fugasitesi değerleri için silikat ve oksit faz bileşimleri kullanılmıştır. Örneğin granitik kayaçlarda "titanit (sfen) + manyetit + kuvars" mineral birliği oksijen fugasitesinin tahminini sağlar.

Basgo, Nimu, Umla ve Taru intrüzif kayaçları için oksijen fugasitesi hesaplamalarında Wones (1981)'in eşitliği kullanılmış olup; $\log f_{O_2}$ (-16.34) - $\log f_{O_2}$ (-22.08) arasında değerler elde edilmiştir (Şekil 4.52). Şekil 4.52'dan görülebileceği gibi intrüzif kayaç örnekleri Fayalit-Manyetit-Kuvars çizgisinde yer almaktadır.

Fugasite değerlerinin düşük olması ise kristallenmenin düşük sıcaklıkta gerçekleştiğini işaret etmektedir. Düşük sıcaklık değerleri hornblend-plajiyoklas jeotermometresinden elde edilen sonuçlar ile de desteklenmektedir.



Şekil 4.52. Basgo, Nimu, Umla ve Taru intrüzif kayaçları için f_{O_2} - sıcaklık $10^3 T$ ($^{\circ}K$) log-log diyagramı (Wones 1981). Kısaltmalar: HM = Hematit-Manyetit, FMQ = Fayalit-Manyetit-Kuvars

4.5. Ana Oksit ve İz Element Jeokimyası

Tüm kayaç ana oksit ve iz element analitik verileri, Trans-Himalaya kuşağında yer alan Ladakh Batoliti Leh bölgesinin batı kısımlarından alınan 41 adet numuneden elde edilmiştir. Bu kayaçlara ait tüm kaya jeokimya sonuçları EK-3’de verilmiştir.

Bu bölüm, iki alt bölümde incelenecektir:

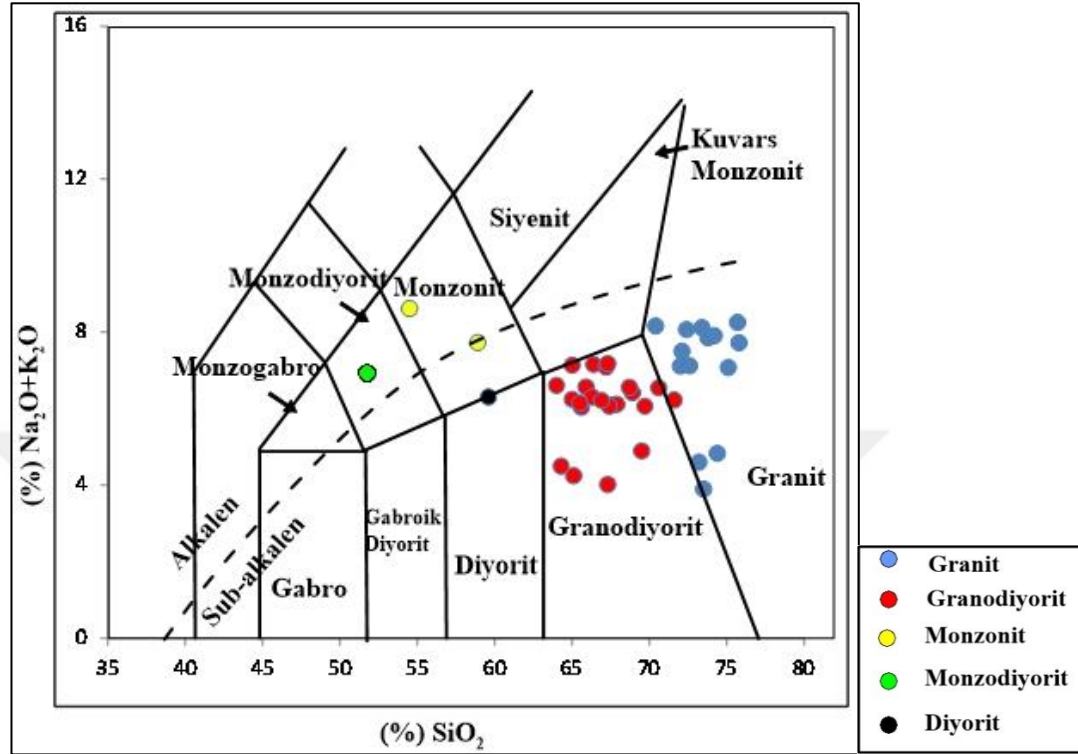
- ✓ Birinci bölüm; tüm kayaç ana oksit kimyası kullanılarak kayaçların sınıflandırılması
- ✓ İkinci bölüm; tüm kayaç ana ve iz element Harker, çoklu element, REE, iz-iz element ve tektonik sınıflandırma diyagramları.

4.5.1. Ana oksitler

4.5.1.1. Ana oksit jeokimyası kullanılarak kayaçların sınıflandırılması

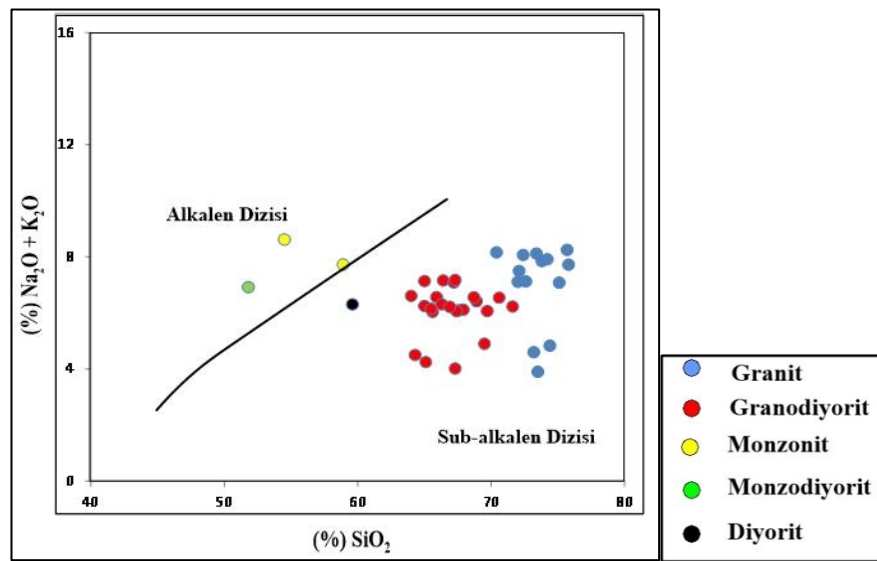
Ladakh Batoliti kayaçları monzodiyoritden, kuvars granodiyorite ve biyotit granite kadar farklı bileşimlere sahiptir. Bu kayaçların jeokimyasal olarak sınıflandırılması arazi ve petrografik özelliklerine de benzerlikler sunmaktadır (Şekil 4.53) (Bkz. Bölüm 4.2, 4.3). Toplam alkali (Na_2O+K_2O) - SiO_2 diyagramında kayaç örnekleri %53-78 arasında değişen SiO_2 değerlerine sahip olup, genellikle granodiyorit ve granit alanında yer almaktadır (Şekil 4.53).

Bu bölümden ve sonraki bölümlerde ve bunların çizelge ve diyagramlarında Ladakh Batoliti Basgo, Nimmu, Umla ve Taru kayaç örnekleri, diyorit, monzodiyorit, monzonit, granodiyorit ve granit olarak adlandırılacaktır.



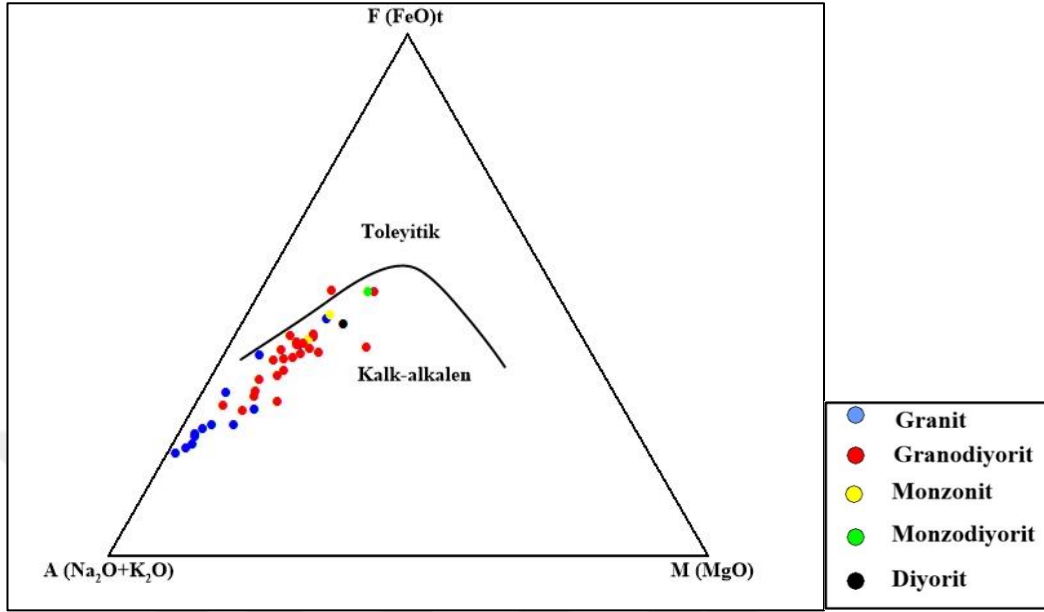
Şekil 4.53. Ladakh intrüzif kayaçlarının toplam alkali ($\text{Na}_2\text{O}+\text{K}_2\text{O}$) - SiO_2 diyagramı (Middlemost 1994) üzerindeki izdüşümleri

Ayrıca toplam alkali - SiO_2 diyagramında (Irvine ve Baragar 1971) genellikle birkaç örnek hariç, numuneler subalkalen alanında yer almaktadır (Şekil 4.54).



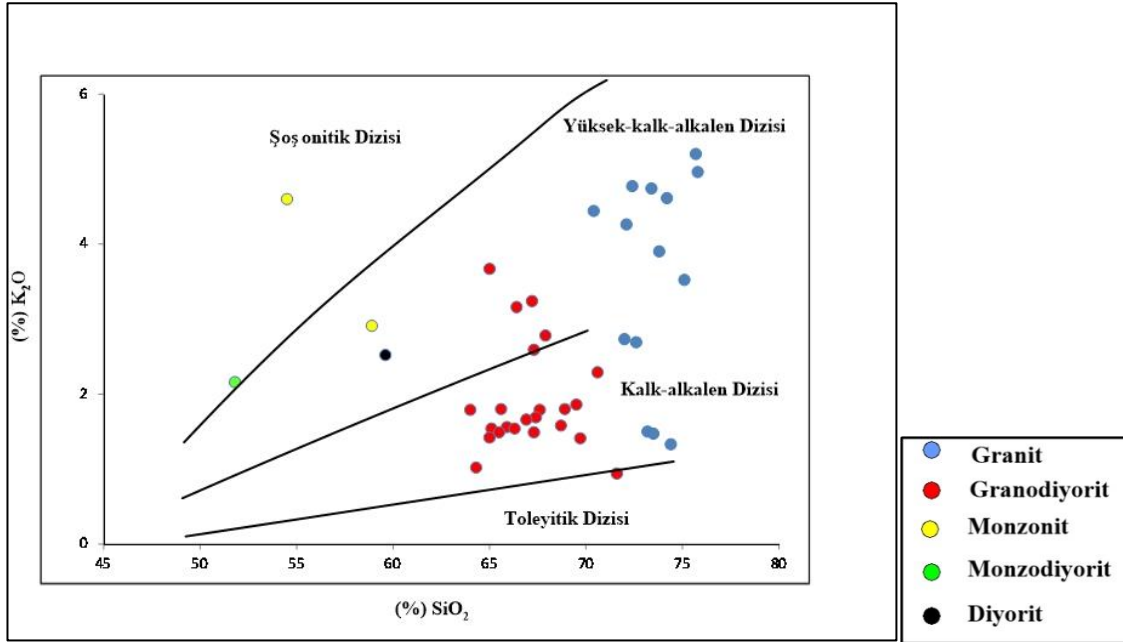
Şekil 4.54. Ladakh intrüzif kayaçlarının toplam alkali - SiO_2 diyagramı (Irvine ve Baragar 1971) üzerindeki izdüşümleri

Ladakh Batoliti kayaçları AFM diyagramında (Peacock 1931) kalk-alkalen alanda yer almakta ve F köşesinden (FeO)_t - A (Na₂O+K₂O) köşesine doğru alkalice zenginleşen bir yönelim göstermektedir (Şekil 4.55).



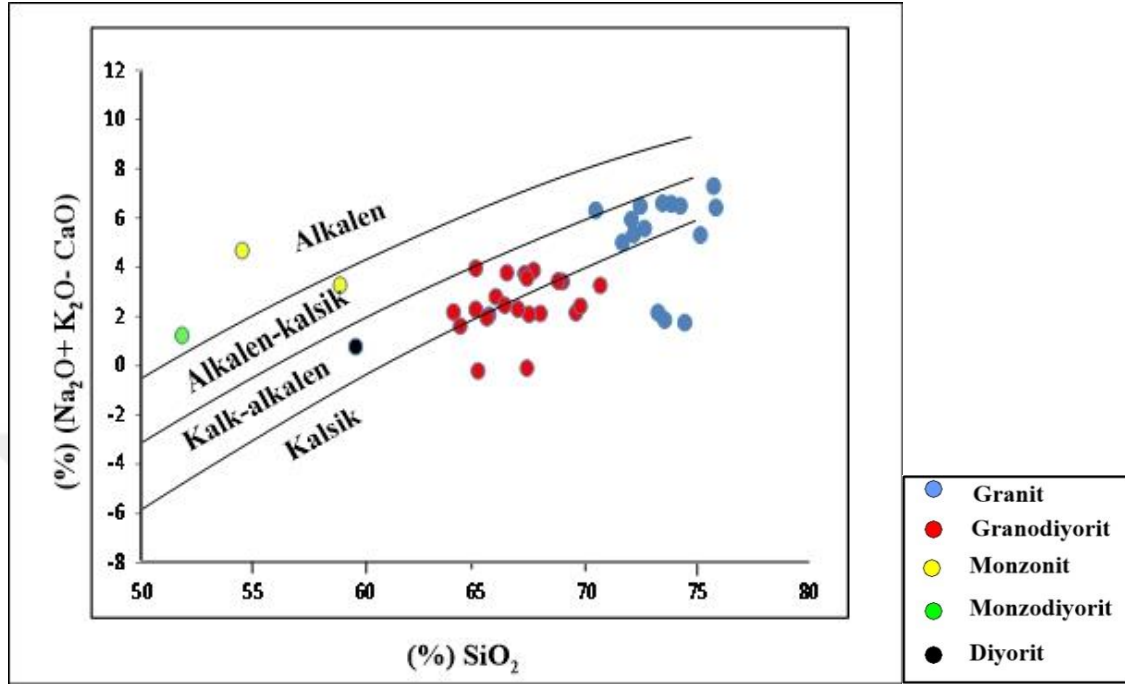
Şekil 4.55. Ladakh intrüzif kayaçların AFM üçgen diyagramı (Peacock 1931) üzerindeki izdüşümleri

Bu kayaçların AFM diyagramındaki kalk-alkalen özelliği, K₂O - SiO₂ diyagramı (Peccherillo ve Taylor 1976) ile desteklenmekte olup; Ladakh Batoliti kayaçları genellikle orta- ve yüksek-K kalk-alkalen alanlarında yer almaktadır (Şekil 4.56).



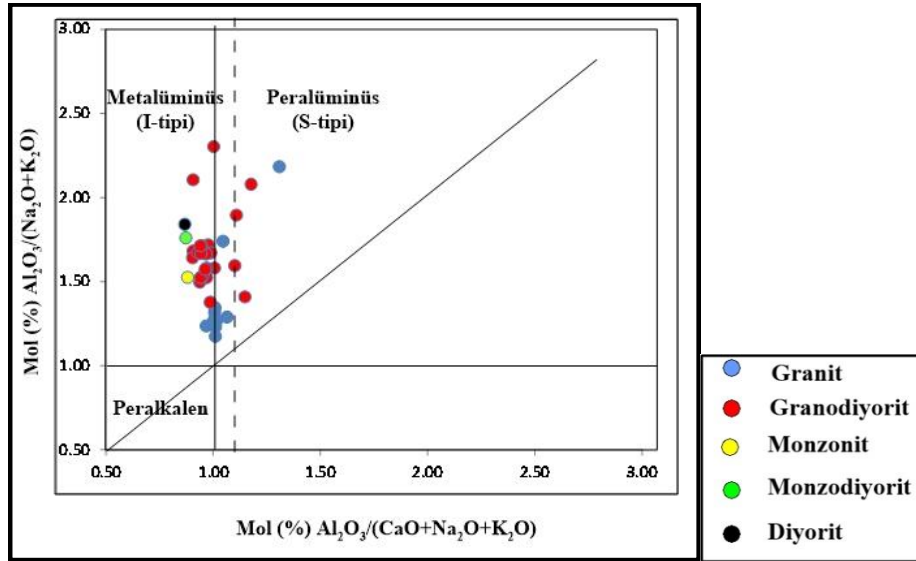
Şekil 4.56. Ladakh intrüzif kayaçların K₂O - SiO₂ diyagramı (Peccherillo ve Taylor 1976) üzerindeki izdüşümleri

($\text{Na}_2\text{O}+\text{K}_2\text{O}$)- CaO - SiO_2 diyagramı (Frost vd. 2001) ile desteklenmekte olup; Ladakh Batoliti kayaçları hem kalk-alkalen hemde kalsik alanlarda yer almaktadır (Şekil 4.57).



Şekil 4.57. Ladakh plutonik kayaçların $(\text{Na}_2\text{O}+\text{K}_2\text{O})$ - CaO - SiO_2 diyagramı (Frost vd. 2001) üzerindeki izdüşümleri

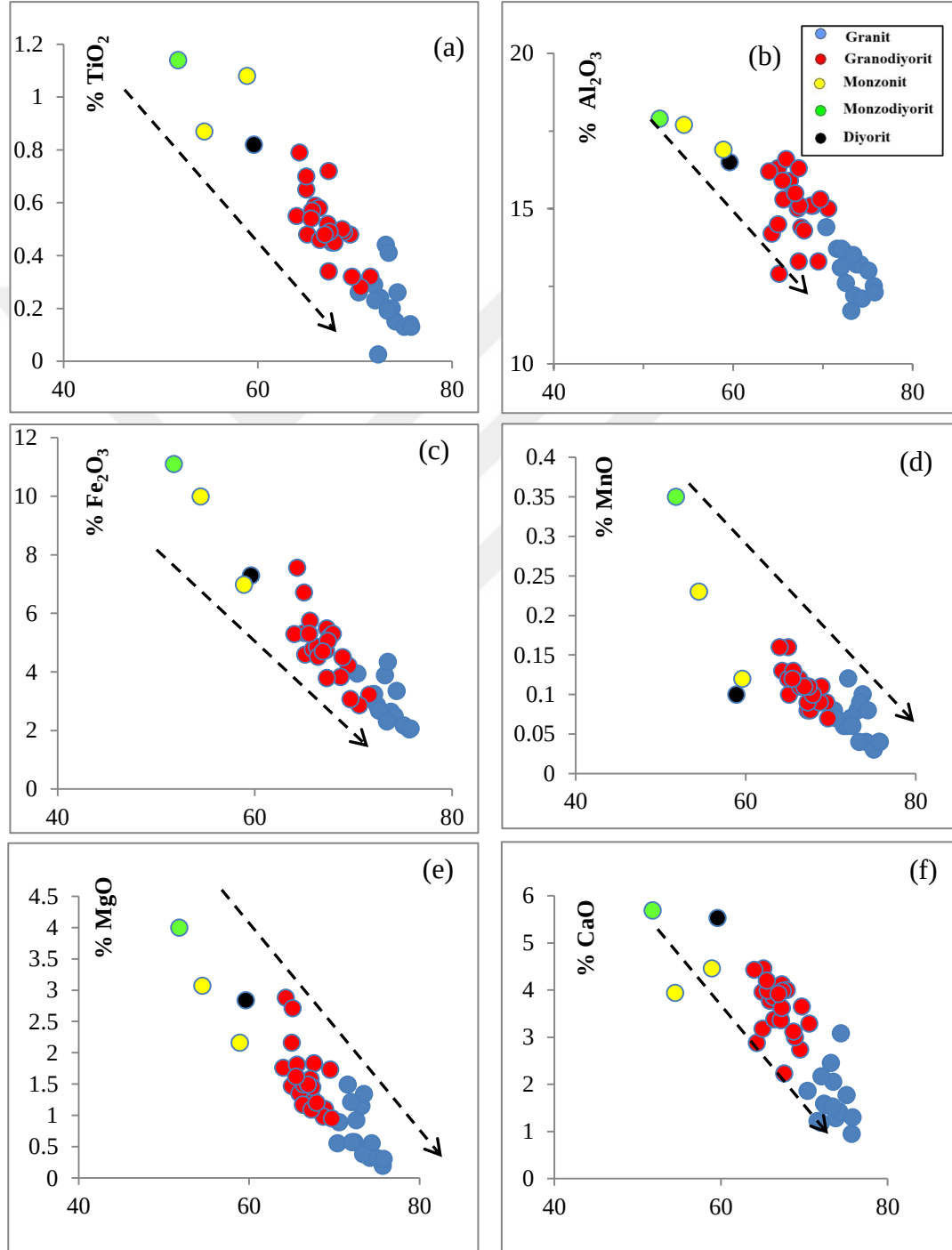
Shand (1951) alümina doygunluk diyagramında (Şekil 4.58), Ladakh Batoliti plutonik kayaçları, genellikle metalüminus alanında yer almakta olup; bu kayaçlar için I-tipi kaynağa işaret etmektedir (Şekil 4.58).



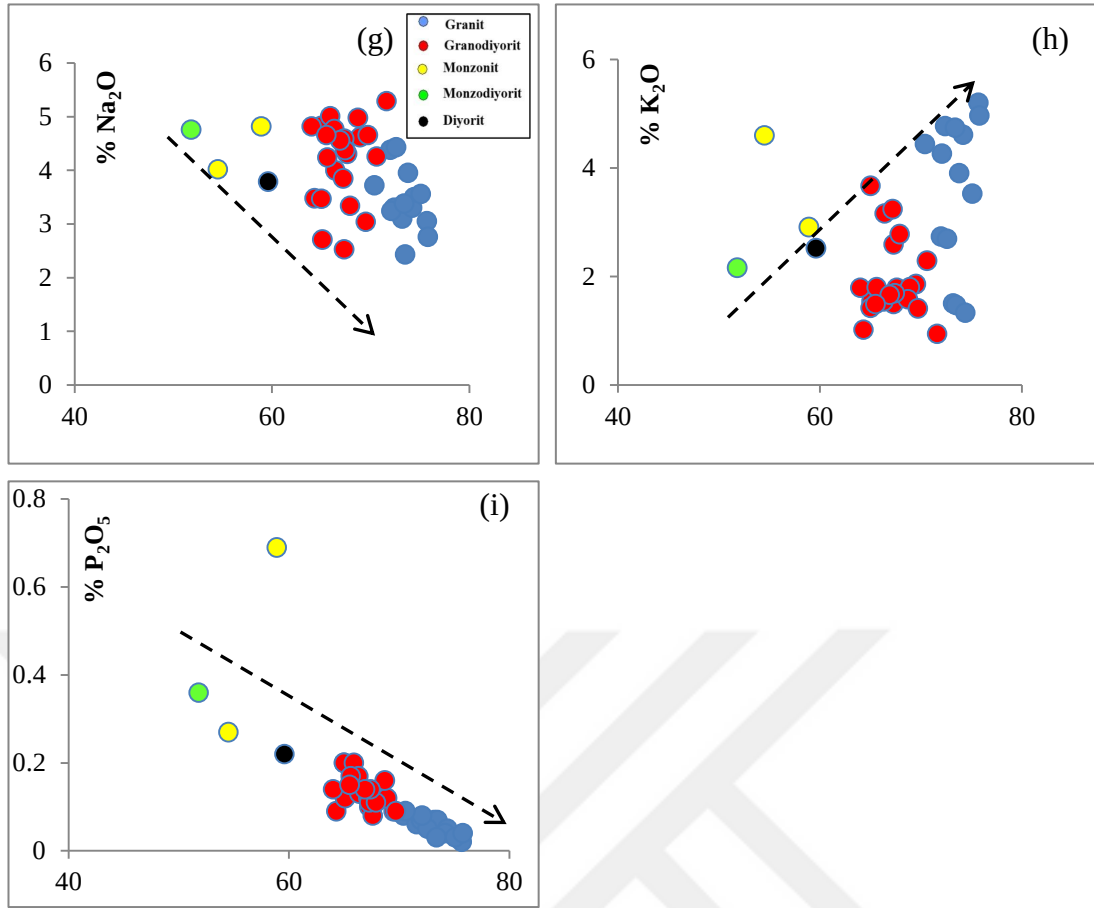
Şekil 4.58. Ladakh intrüzif kayaçların Shand (1951) alümina doygunluk diyagramında gösterimi

4.5.1.2. Ana oksit Harker diyagramları

Ana oksitlerin SiO_2 'e karşı izdüşürüldüğü Harker (1909) diyagramlarında (Şekil 4.99); inceleme alanındaki plutonik kayalarda SiO_2 artışı ile birlikte TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , CaO , Na_2O , P_2O_5 değerlerinin azaldığı (Şekil 4.59a-i) ve K_2O değerinin (Şekil 4.59h) ise arttığı gözlenmektedir.



Şekil 4.59. Ladakh Batoliti intrüzif kayaların ana oksit Harker varyasyon diyagramlarında gösterimi

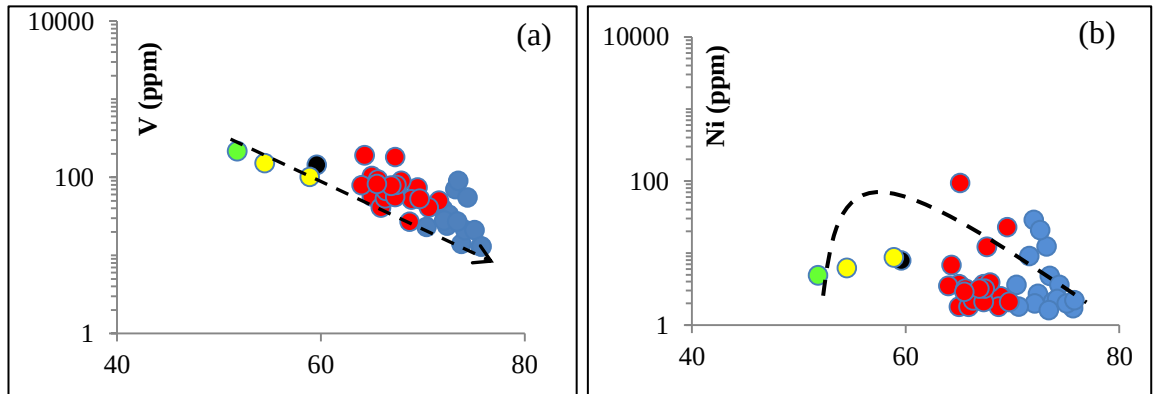


Şekil 4.59'in devamı

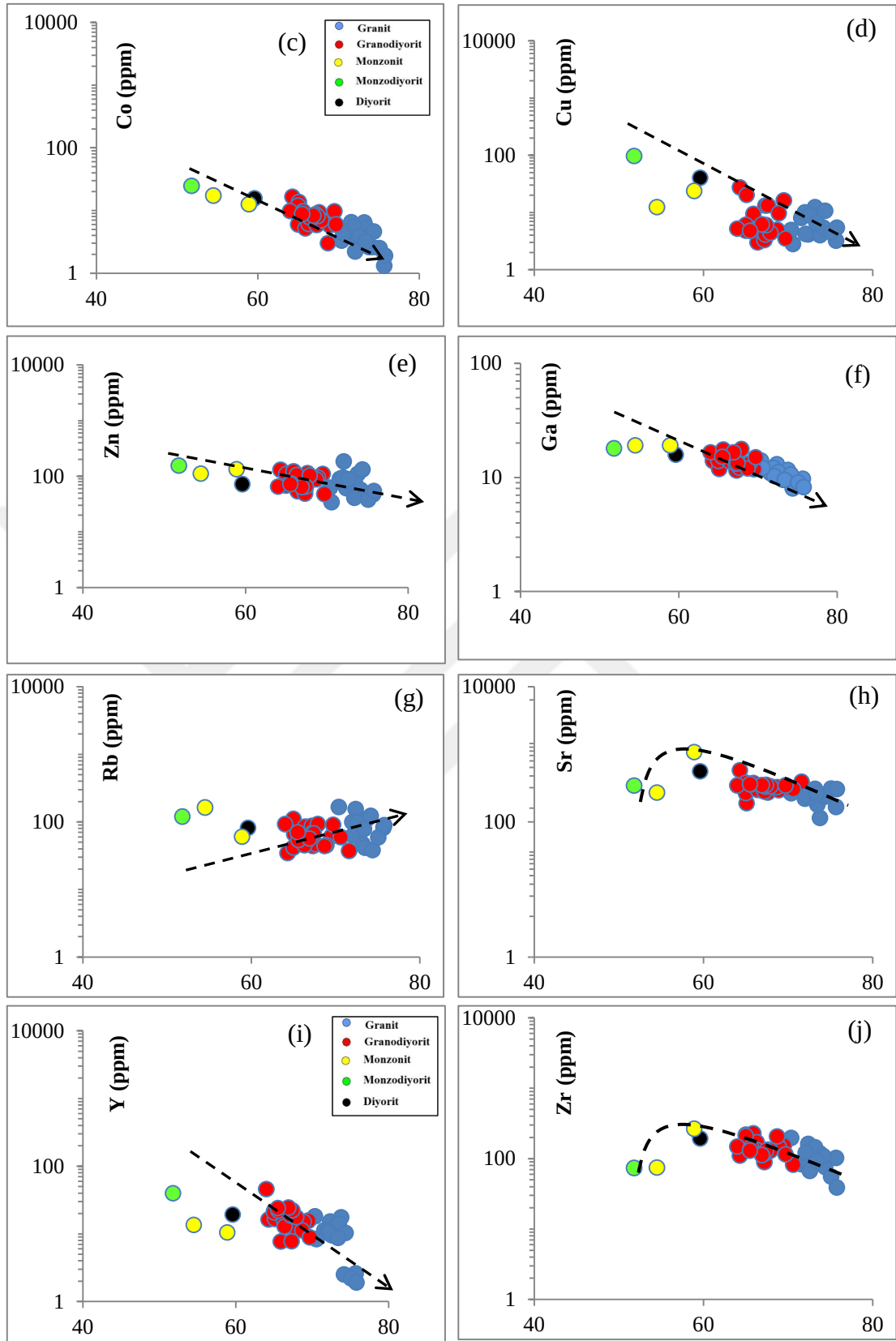
4.5.2. İz elementler

4.5.2.1. İz Element Harker diyagramları

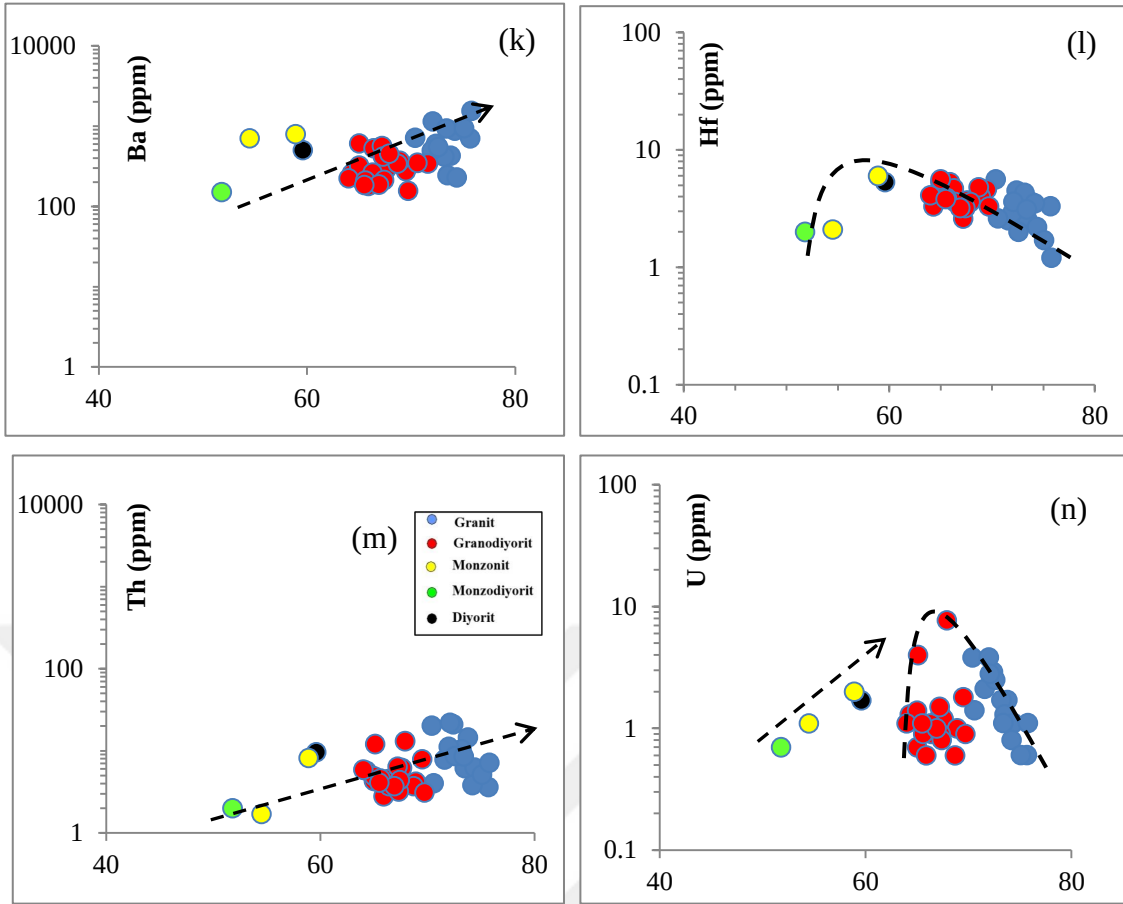
Silikaya karşı iz elementlerin kullanıldığı Harker diyagramlarında (Şekil 4.60) ise artan SiO₂'ye karşı V, Ni, Co, Cu, Zn, Ga, Y değerlerinde azalma; Rb, Ba, Th değerlerinde artış ve Ni, Sr, Zr, Hf ve U değerlerinde %60 silikaya kadar artış, bu değerden sonra ise azalma gözlenmektedir.



Şekil 4.60. Ladakh Batoliti intrüzif kayaçlarının iz element Harker diyagramları



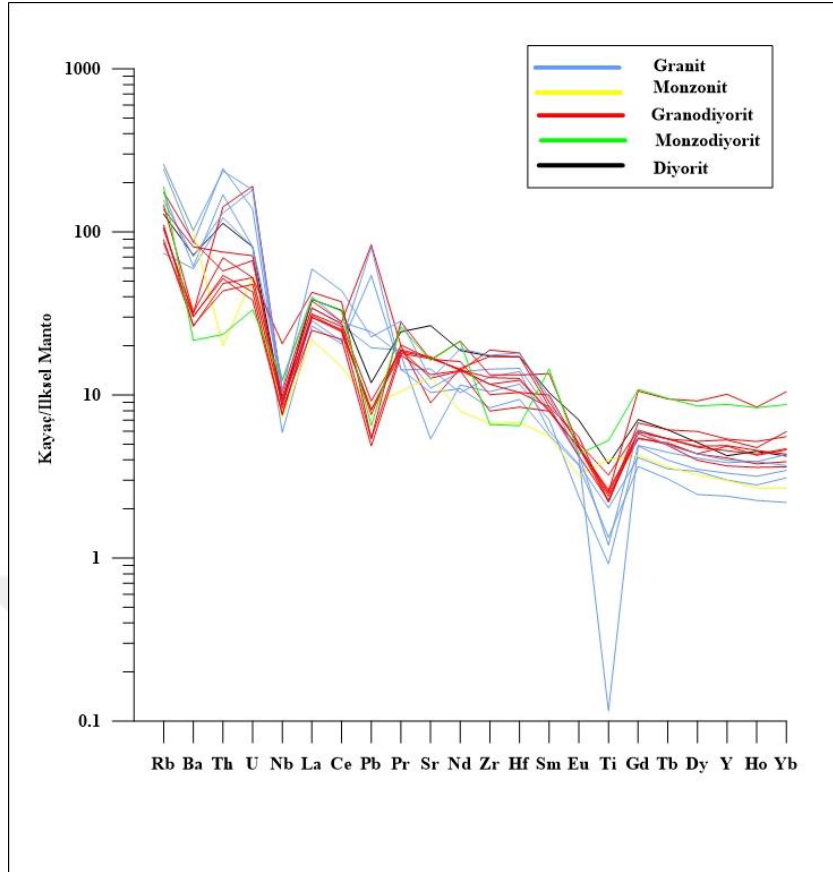
Şekil 4.60'in devamı



Şekil 4.60'in devamı

4.5.2.2. Çoklu element diyagramı

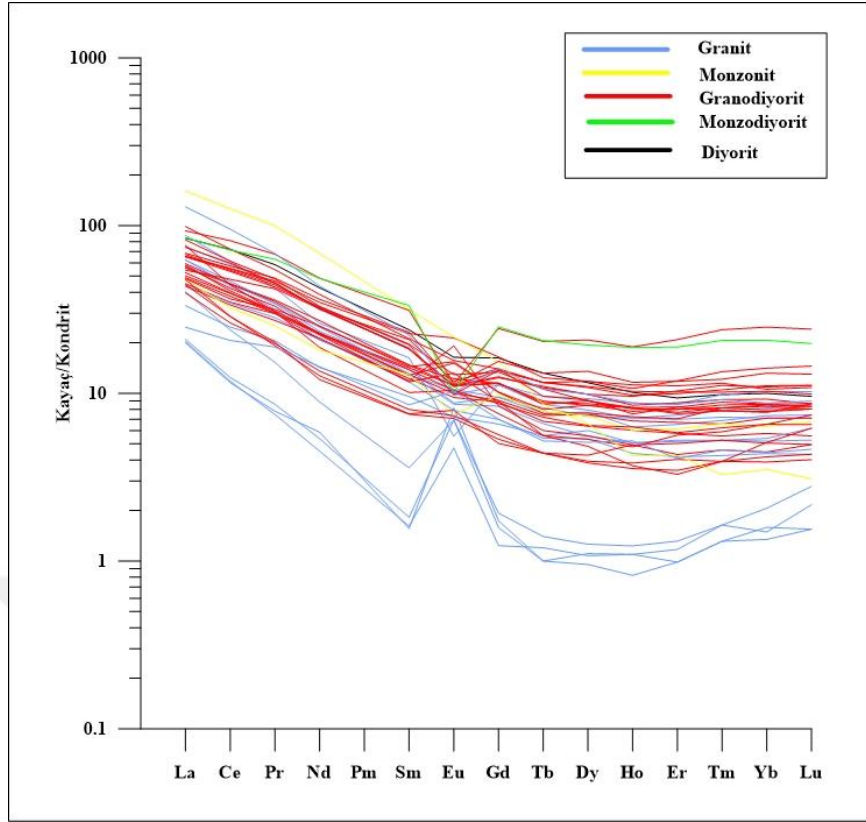
Ladakh intrüzif kayaç örnekleri ilksel mantoya göre normalize edilerek çoklu element diyagramları hazırlanmıştır (Şekil 4.61). Bu kayaçlar ilksel mantoya göre LILE'ce daha zengin bir karakteristik sunmaktadır (Şekil 4.101). Ancak, Nb ve Ti'de dahil olmak üzere HFSE açısından tüketilme gözlenmektedir. Bunun gibi iz element karakteristikleri genellikle dalma-batma kökenli magmatizmalarda gözlenmektedir (Sun McDonough 1989).



Şekil 4.61. Ladakh intrüzif kayaç örneklerinin ilksel mantoya göre normalize edilmiş çoklu element diyagramı (normalize değerleri Sun ve McDonough 1989'dan alınmıştır)

4.5.2.3. Nadir toprak elementleri

Ladakh intrüzif kayaç örneklerinde, nadir toprak elementleri kondrite göre normalize edilerek diyagramlar oluşturulmuştur (Şekil 4.62). Tüm numuneler hemen hemen benzer desenler göstermektedir. Toplam REE içeriği 20-181 ppm ve LREE/HREE değerleri $(La/Yb)_N = 3.75-45.95$ arasında olup; LREE'lerin HREE'lerden daha fazla zenginleştiğini göstermektedir. Ayrıca MREE/HREE $(Gd/Yb)_N = 0.83-4.40$ arasındadır. Tüm kayaç kondrit normalize REE desenleri, LREE'ce (La-Nd) zenginleşme MREE (Sm-Gd)'lerinde ise LREE'lere göre tüketilme ve HREE'lerde ise tüketilme (Tb-Lu) gözlenmektedir. Ayrıca kayaçlarda genellikle Eu negatif anomali ($Eu/Eu^* = 0.35-0.95$) ve granitik kayaçlarda ise Eu pozitif anomalinin ($Eu/Eu^* = 1.07-4.97$) varlığı gözlenmektedir (Şekil 4.62).



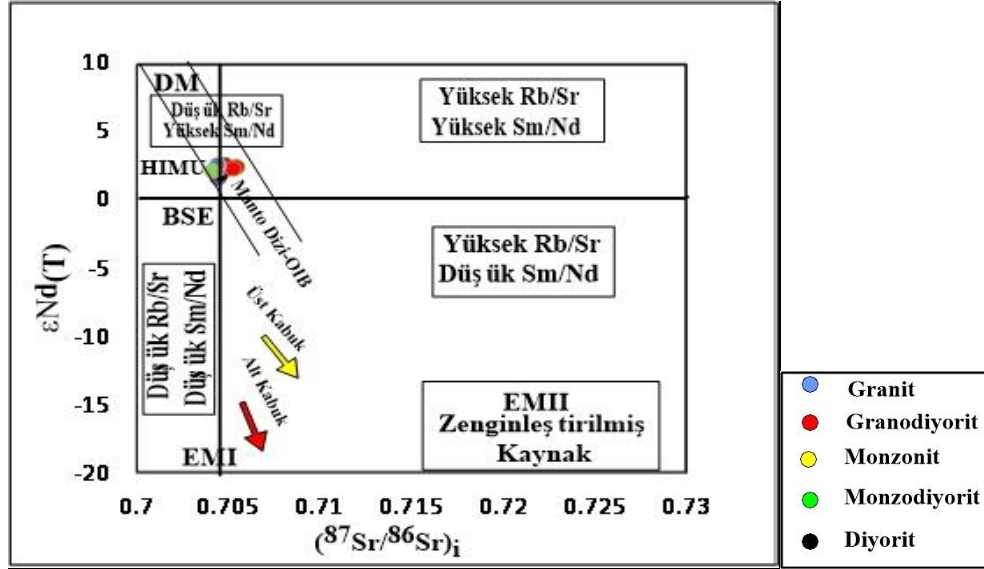
Şekil 4.62. Çalışılan intrüzif kayaçlar için kondrit-normalize REE desenlerini göstermektedir (normalize değerleri Boynton 1984'dan alınmıştır)

4.5.3. İzotop jeokimyası

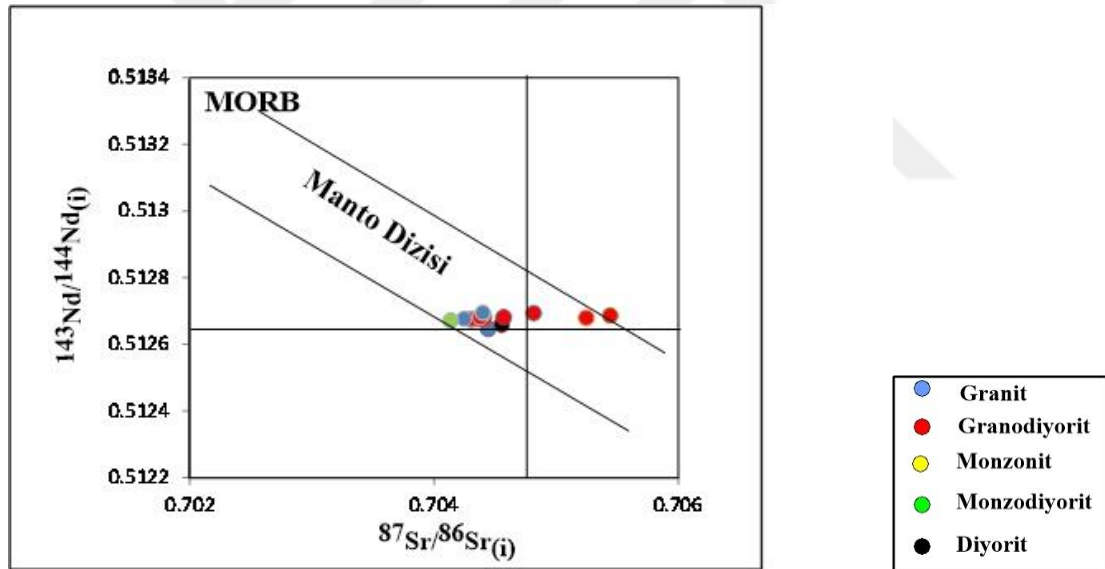
Ladakh intrüzif kayaçlarının Sr ve Nd izotop oranları için ölçülen ilksel değerleri ve Rb, Sr, Sm ve Nd konsantrasyonları EK 4'te verilmiştir.

Rb-Sr ve Sm-Nd izotopik değerleri kullanılarak hazırlanan diyagram ise Şekil 4.63, 4.64'de verilmiştir. Bu diyagramlarda plütonik kayaçlar yüksek $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$ ve düşük $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ oranlarına sahiptir. Ladakh kayaçları ilksel $^{87}\text{Sr}/^{86}\text{Sr}$ (0.70414 – 0.70544) ve ilksel $^{143}\text{Nd}/^{144}\text{Nd}$ (0.512647 – 0.512695) oranları gibi kısıtlı bir alana düşmektedir (Şekil 4.63, 4.64).

Bu diyagramlarda intrüzif kayaçlar genellikle düşük $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$ ve yüksek $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ kadranına düşmüş olup bazı granitoid örnekleri ise yüksek ilksel $^{87}\text{Sr}/^{86}\text{Sr}$ ve düşük ilksel $^{143}\text{Nd}/^{144}\text{Nd}$ kadranına düşmüştür. Bu değerler ise kıtasal kabul veya zenginleşmiş manto kaynaklı karakteristik özelliklerine işaret etmektedir.



Şekil 4.63. Ladakh intrüzif kayaçların $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$ - $\epsilon\text{Nd}_{(T)}$ diyagramındaki izdüşümleri (manto dizisi Faure 1986'dan alınmıştır). DM: Tüketilmiş Manto; HIMU: Yüksek μ Değerine Sahip Manto; BSE: Toplam Yerküre Bileşimi; OIB: Okyanus Adası Bazalt; EMI: Zenginleştirilmiş Manto I; EMII: Zenginleştirilmiş Manto II



Şekil 4.64. Ladakh intrüzif kayaçların ilksel $^{143}\text{Nd}/^{144}\text{Nd}$ - ilksel $^{87}\text{Sr}/^{86}\text{Sr}$ diyagramındaki izdüşümleri (MORB: Okyanus Ortası Sırt Bazaltlar; manto dizisi DePaolo 1988'den alınmıştır)

4.6. Petrojenez

Ladakh Batoliti intrüzif kayaçlarının (Basgo, Nimu, Umla ve Taru) tüm kayaç iz element diyagramlarında göstermiş oldukları Nb, Ti gibi HFSE'ce tüketilme, Rb, Ba, Th, Pb gibi LILE'ce zenginleşme (Şekil 4.61); tipik olarak dalma-batma zonu plutonik kayaçları özelliği sunarlar (Ewart 1982; Pearce 1982, 1983; Thompson vd. 1984; Hawkesworth vd. 2000; Elburg vd. 2002). Bazı araştırmacalara göre (Gill 1981; Hawkesworth vd. 1991; McDermott vd. 1993) LILE'ce zenginleşme; dalan okyanusal

litosferden ve/veya bu dalan litosfer üzerindeki sedimanlardan açığa çıkan akışkanlar aracılığı ile zenginleştirilmiş olan kaynak alandan ana magmanın türeyebileceğini göstermektedir.

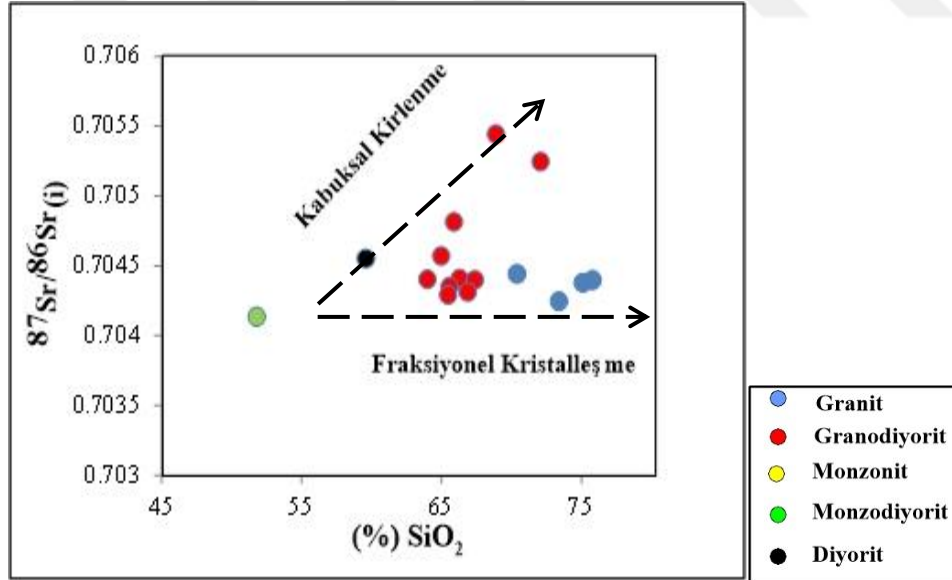
4.6.1. Magmatik farklılaşma süreçleri

Harker diyagramlarında (Şekil 4.59, 4.60); SiO_2 artışı ile birlikte, K_2O hariç diğer tüm ana oksit (TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , CaO , Na_2O , P_2O_5); ve Rb, Ba, Th hariç diğer tüm iz element değerlerinde (V, Co, Cu, Zn, Ga, Y) negatif trendler gözlenmektedir. Bu varyasyonlar kayalar oluşturulan magma(lar)ın amfibol, Fe-Ti oksit, plajiyoklas, K-feldispat ve biyotit minerallerinin fraksiyonel kristallenmesini işaret etmektedir. Kayaların çoklu element ve REE diyagramlarındaki (Şekil 4.61, 4.62):

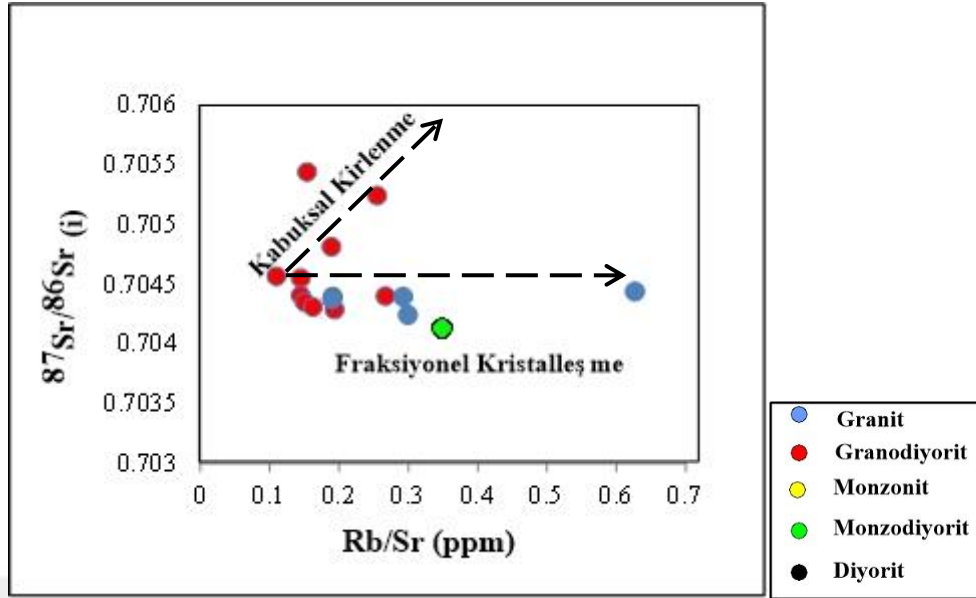
- ✓ Ti negatif anomalisi; Fe-Ti oksit
- ✓ Rb, Ba negatif anomalileri; biyotit ve K-feldispat
- ✓ Sr ve Eu negatif anomalileri; plajiyoklas minerallerinin kristallenmelerini destekler durumdadır.

Ancak bu anomaliler kabuksal kirlenme ve/veya AFC (kabuksal kirlenme+kristallenme) ile de oluşabilmektedir.

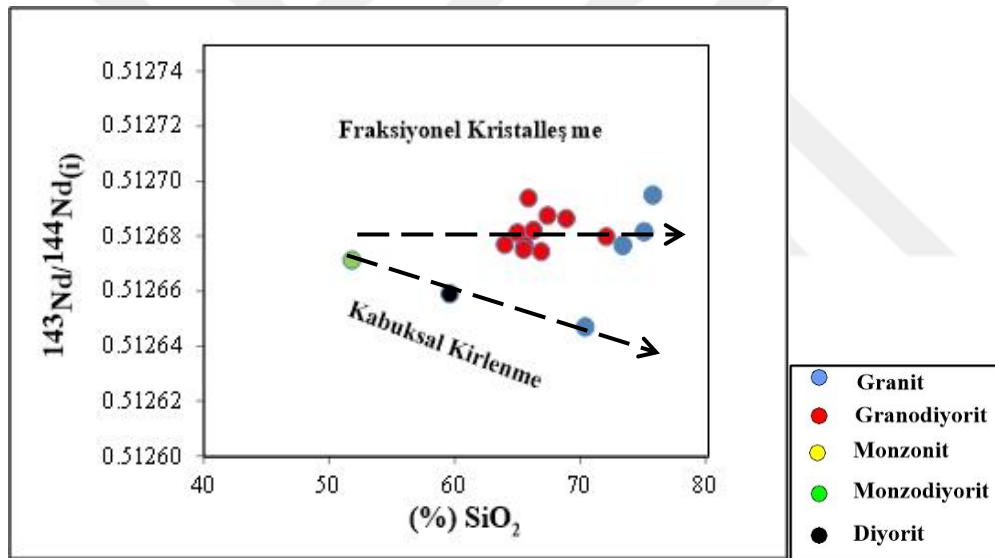
Ladakh Batoliti kayaç örneklerinde gözlenen bu anomalilerin kökenini (kristallenme ve/veya kabuksal kirlenme) tespit etmek amacıyla $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$, $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ izotop oranları, SiO_2 , Rb/Sr ve Sm/Nd oranlarından faydalanılmıştır (Şekil 4.65-4.68).



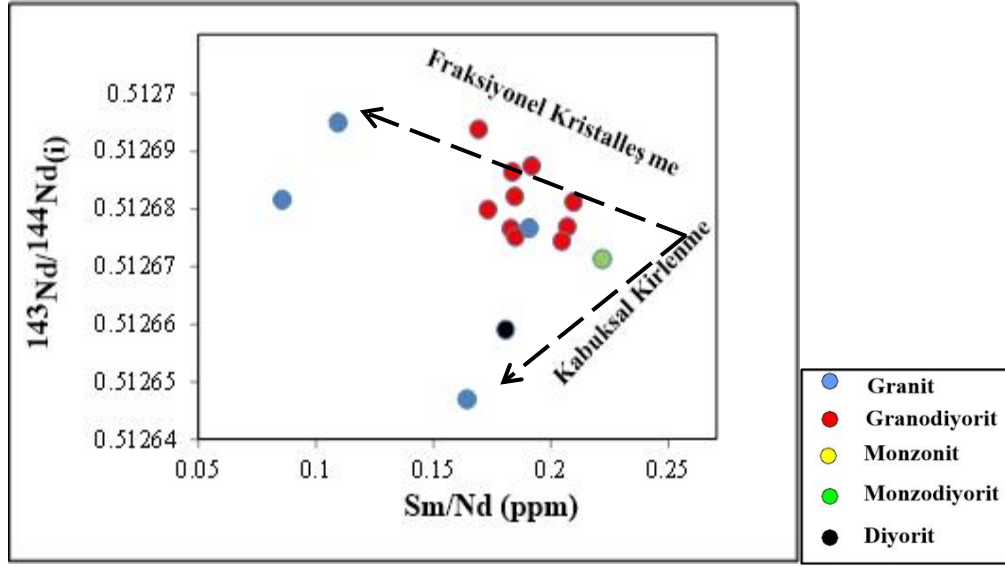
Şekil 4.65. Ladakh intrüzif kayaç örneklerinin $^{87}\text{Sr}/^{86}\text{Sr}_i$ - SiO_2 diyagramındaki izdüşümleri



Şekil 4.66. Ladakh plutonik kayaç örneklerinin $^{87}\text{Sr}/^{86}\text{Sr}(i)$ - Rb/Sr diyagramındaki izdüşümleri



Şekil 4.67. Ladakh intrüzif kayaç örneklerinin $^{143}\text{Nd}/^{144}\text{Nd}(i)$ - SiO_2 diyagramındaki izdüşümleri



Şekil 4.68. Ladakh intrüzif kayaç örneklerinin $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ - Sm/Nd diyagramındaki izdüşümleri

$^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$ - SiO_2 , $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ - SiO_2 , $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$ - Rb/Sr ve $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ - Sm/Nd diyagramları (Şekil 4.65-4.68), ana oksit ve iz element diyagramlarını da desteklemekte olup (Şekil 4.59-4.62); bu kayaçların ana magmasının evriminde fraksiyonel kristallenmenin etkin olduğunu göstermektedir.

Çalışma alanında gözlenen farklı boyut ve şekillerde mafik magmatik anklavlar; Ladakh intrüzif kayaçlarının ana magmasının evriminde fraksiyonel kristallenmenin yanı sıra magma mixing/mingling süreçlerinin de etkili olduğunu göstermektedir.

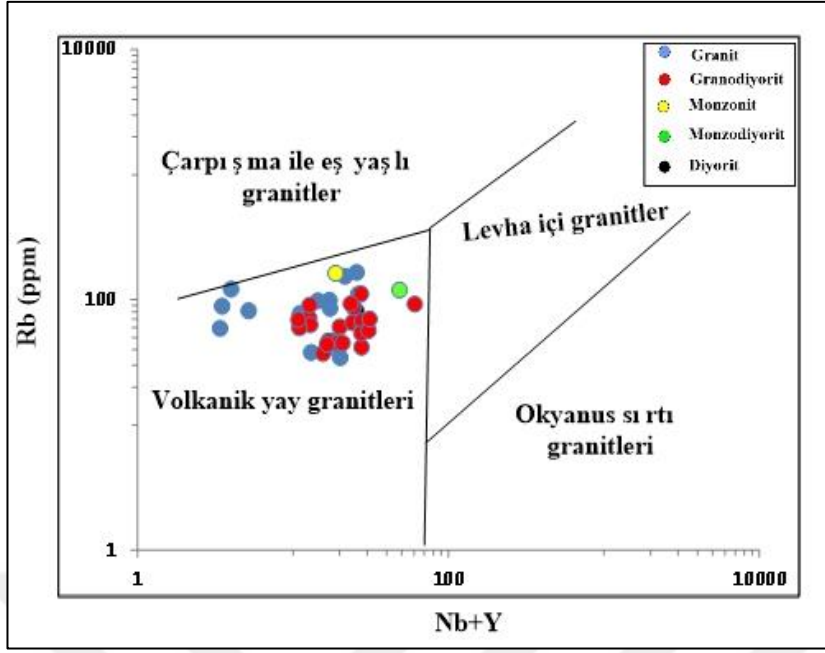
Ayrıca kayaç örneklerinde mikroskop altında incelenmesi sonucunda gözlenen dengesizlik dokuları (plajiyoklas-zonlu doku, iri taneli plajiyoklas-daha ince taneli plajiyoklas içermesi, biyotit-bıçağımsı; apatit-çok ince taneli, prizmatik) magma mixing/mingling'in etkili olduğunu desteklemektedir.

Jeokimyasal olarak, bazı ana oksit ve iz elementler ile SiO_2 arasında gözlenen doğrusal yönelimler (Şekil 4.59, 4.60) magma mixing/minglingi destekleyen verileridir (Perugini ve Poli 2004).

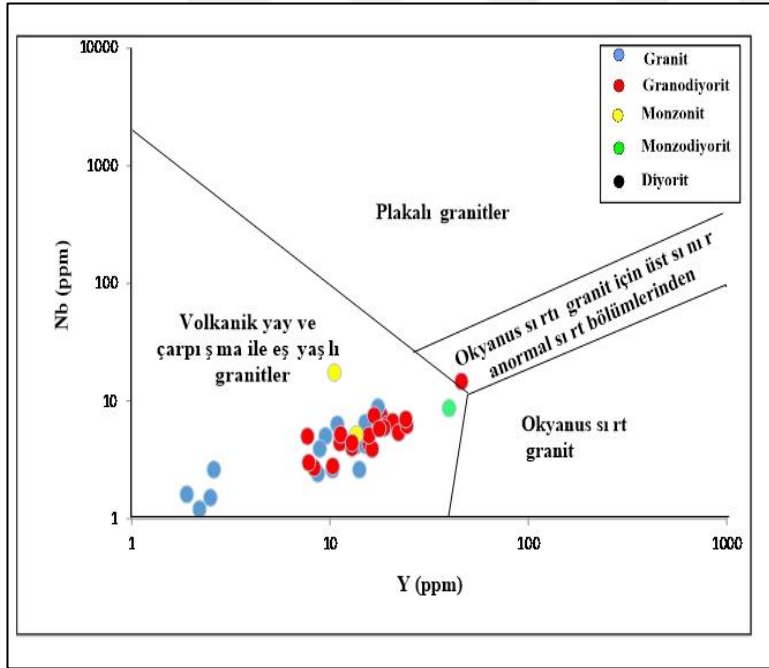
4.6.2. Tektonik ayırım diyagramları

Pearce vd. (1984) tarafından geliştirilen ve granitik kayaların oluştuğu jeotektonik ortamları tespit etmeye yardımcı olan iz - iz element diyagramları Şekil 4.69-4.71'de sunulmaktadır.

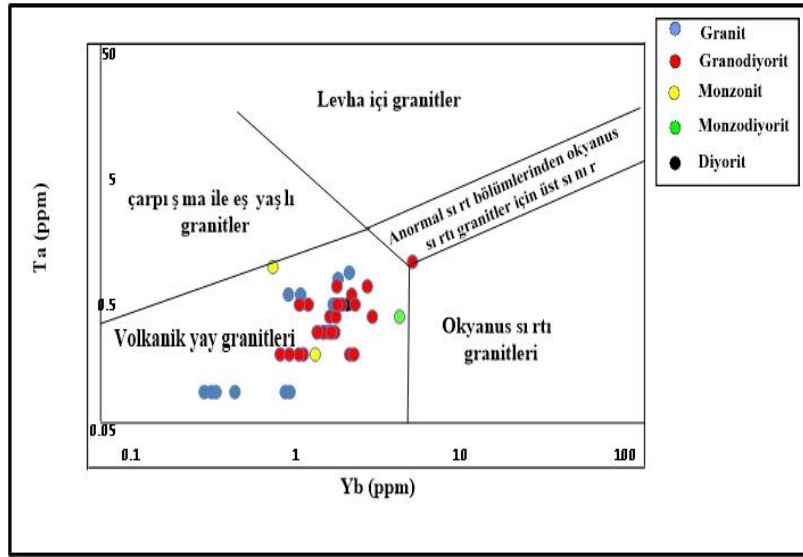
Rb-(Nb+Y), Nb-Y, Ta-Yb diyagramlarında volkanik yay, çarpışma ile eş yaşlı, levha içi, okyanus ortası sırtı granitleri birbirinden ayrılabilir (Şekil 4.69-4.71). Tüm bu diyagramlarda hemen hemen tüm kayaç örnekleri volkanik yay, volkanik yay ve çarpışma ile eş yaşlı granit alanlarına düşmektedir.



Şekil 4.69. Ladakh intrüzif kayaç örneklerinin Rb – (Nb+Y) (Pearce vd. 1984) diyagramındaki izdüşümleri



Şekil 4.70. Ladakh intrüzif kayaç örneklerinin Nb – Y (Pearce vd. 1984) diyagramındaki izdüşümleri



Şekil 4.71. Ladakh intrüzif kayaç örneklerinin Ta – Yb (Pearce vd. 1984) diyagramındaki izdüşümleri

5. SONUÇLAR

Leh bölgesinin KB kısmında yer alan Ladakh Batoliti kayaçlarının arazi, mineraloji-petrografi, tüm kaya, mineral ve izotop jeokimyası verilerini kapsayan bu tez ile aşağıdaki sonuçlar elde edilmiştir:

- ✓ Ladakh Batolitinin Leh (Jammu ve Keşmir, Hindistan) civarında dört farklı alanda Basgo, Nimu, Umla ve Taru intrüzif kayaçları çalışma alanı/konusu olarak belirlenmiştir. Batolit güneyde Indus-Tsangpo Sütur Zonu kuzeyde ise Shyok Sütur Zonu ile sınırlandırılmıştır.
- ✓ Bu kayaçlar orta-iri taneli monzodiyorit, monzonit, granodiyorit ve granit bileşimlidir. Bu kayaçların ana mineralleri plajiyoklas, K-feldispat, kuvars, biyotit ve amfiboldür. Aksesuar mineraller ise sfen, apatit, zirkon, monazit ve opak minerallerdir. Serisitleşme, killeşme, kloritleşme, sossuritleşme ise alterasyon türleridir.
- ✓ Bu intrüzif kayaçların plajiyoklas içerikleri $An_{(55-99)}$ arasında değişirken, K-feldispat içerikleri $Or_{(85-99)}$ aralığında değişmektedir. Biyotitler ise annit bileşimlidir. Amfiboller ise edenit, magnesio-hornblend ve hastingsit bileşimlidir.
- ✓ İntrüzif kayaçların jeotermobarometre sonuçları, 452 ile 628 °C arasında değişen kristalleşme sıcaklıkları sunarken, 2.3-3.9 kbar aralığında değişen basınç değerlerine sahiptir. Batolitte güneydeki sütur zondan (Indus-Tsangpo Sütur Zonu) kuzeydeki sütur zonuna (Shyok Sütur Zonu) ilerledikçe sıcaklık-basınç-derinlik (güneyde:13.7-12.8 km; kuzeyde: 9.9-8.1 km) değerlerinde bir azalma tespit edilmiştir.
- ✓ Monzodiyoritten granite kadar bileşimsel değişim sunan intrüzif kütlelerin toplam alkali % (Na_2O+K_2O) değerleri %3.9-%8.65 arasında değişim gösterirken SiO_2 değerleri %54.5 ile %75.8 arasındadır. A/CNK (0.87 ile 1.31) oranları, çoğu örnek için I-tipi kaynağa işaret etmektedir. Bazı örneklerin değerleri ise I- ile S-tipi granitoidler arasında geçişi işaret etmektedir.
- ✓ Harker varyasyon diyagramlarında, K_2O ile Rb, silika karşısında pozitif korelasyon gösterirken, TiO_2 , Al_2O_3 , Fe_2O_3 , MgO ve CaO, silikanın artışı ile negatif korelasyon göstermektedir. K_2O ve SiO_2 arasında görülen pozitif korelasyon, K-feldispat ve biyotit içerisinde bulunan K_2O içeriğine işaret etmektedir.
- ✓ Harker varyasyon diyagramlarında, K_2O ile Rb, silika karşısında pozitif korelasyon gösterirken, TiO_2 , Al_2O_3 , Fe_2O_3 , MgO ve CaO, silikanın artışı ile negatif korelasyon

göstermektedir. K_2O ve SiO_2 arasında görülen pozitif korelasyon, K-feldispat ve biyotit içerisinde bulunan K_2O içeriğine işaret etmektedir.

- ✓ İz element harker diyagramlarında ise artan SiO_2 'ye karşı V, Ni, Co, Cu, Zn, Ga, Y değerlerinde azalma; Rb, Ba, Th değerlerinde artış görülmektedir.
- ✓ İlksel mantoya göre oluşturulan çoklu element diyagramlarında, LIL elementlerince zenginleşme göstermektedir. Ancak, Nb ve Ti'de dahil olmak üzere HFSE açısından tüketilme gözlenmektedir. Bunun gibi iz element karakteristikleri genellikle dalma-batma kökenli magmatizmalarda gözlenmektedir.
- ✓ Ladakh intrüzif kayaçların toplam REE içerikleri 20-181 ppm arasında değişim sunarken, $(La/Yb)_N=3.75-45.95$ aralığında değişen oranları ile LREE açısından orta-yüksek zenginleşme göstermektedir. Negatif Eu anomalileri ($Eu/Eu^*=0.35-4.97$) ve $(Gd/Yb)_N=0.83-4.40$ oranları orta HREE ayrımlaşmasını göstermektedir. Bunun yanında tüm kayaç-kondrite göre normalize REE desenleri, LREE açısından zenginleşme gösterirken HREE açısından tüketilmeye işaret etmektedir.
- ✓ Ladakh Batoliti örneklerin Sr ve Nd izotopik analiz değerleri $^{87}Sr/^{86}Sr_{(i)}$ (0.70414-0.70544) ve $^{143}Nd/^{144}Nd_{(i)}$ (0.512647- 0.512695) aralıklarında değerler sunmaktadır. $Sr_{(i)}$ - $Nd_{(i)}$ diyagramında örnekler düşük Sr ve yüksek Nd alanında yer alırken, bazı granodiyorit bileşimli örnekler ise yüksek Sr ve yüksek Nd kadranı temsil eden alanda yer almaktadır. 1.68 ile 2.62 aralığında değişen $\epsilon Nd(t)$ değerlere sahiptir.
- ✓ Ladakh intrüzif kayaçları, tektonik ayrım diyagramlarında genellikle volkanik yay alanında yer almaktadır.
- ✓ Arazi, mineraloji-petrografi, mineral-kayaç ve izotop jeokimyası göstermektedir ki, Ladakh intrüzif kayaçlarının oluşumu ve gelişiminde fraksiyonel kristalleşme ve magma mixing/mingling süreçleri etkilidir.

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7. EKLER

EK-1. X-IŞINI FLORESANSI (XRF) KULLANARAK ANA OKSİT VE İZ ELEMENT ANALİZİ

Örnek hazırlama

Örnekler, Akdeniz Üniversitesi Mühendislik Fakültesi Jeoloji Mühendisliği Bölümü Laboratuvarlarında yeralan çeneli kırıcı kullanılarak ufalanmıştır. Ezilmiş numuneler dikkatlice tasnif edildi, toz parçacıklarını uzaklaştırmak için yıkandı ve 110°C'de kurutulmuştur. Ezilmiş numunelerin ebadı, kontaminasyonu önlemek için her numuneden sonra iyice temizlenmiş olan rulo kırıcı ile daha da azaltılmıştır. Öğütülmüş malzeme, her kaya tipinin temsili örneğini almak için örnek ayırıcıdan geçirilmiştir. Her numuneden yaklaşık 200 g, TEMA tungsten karbid öğütme değirmeninde toz haline getirildi ve daha ileri laboratuvar analizleri için hava geçirmez plastik şişelerde saklanmıştır. Petrografik çalışmalar için 41 kadar farklı kaya biriminin ince kesitleri hazırlanmıştır.

X ışını floresans tekniği

X ışını floresansı (XRF), jeolojik numunelerdeki ana oksit (ağırlıkça%) ve seçilen iz element (ppm cinsinden) konsantrasyonlarını belirlemek için rutin olarak kullanılan tahribatsız ve kantitatif bir analitik tekniktir. Bir numune, X-ışını tüpünde (kaynak) üretilen yüksek enerjili radyasyon ışını ile bombardıman edildiğinde, bir elektron bir elementin en içteki atomik yörüngesinden yeterli enerjinin ışık dalgasının emilmesiyle çıkarılabilir. Bu, iç kabuğun elektronik geçişine (atom, uyarılmış durumdan toprak durumuna döndüğünde), daha yüksek bir enerji seviyesine (dış kabuk) sahip olan bir elektronun, boş düşük enerji seviyesini (iç kabuk) doldurduğu yüksek-düşük kuantum enerji durumuna yol açar).

Bu geçiş sırasında elementin karakteristik röntgeni olarak adlandırılan floresan ışığı (foton) yayılmıştır. Karakteristik X ışınının dalga boyunun (X ışını enerjisiyle ters orantılı), tüm elemanlarda veya bileşiklerde kimyasal kombinasyondan bağımsız olduğu kabul edilmiştir. Bu X-ışını ışığının enerjisi, yörüngesel enerjilerdeki farka eşittir (belirli bir yörüngesinin enerjisi, elektronik geçiş sırasında yer alan ve her zaman aynı olan (bir elementin özelliği) ana kuantum sayısının (n) bir işlevidir).

Ayrıca, seviyeler arasındaki enerjiler arasındaki farklar, çekirdek üzerindeki artan yük nedeniyle atom numarası ile düzenli olarak artar; bu nedenle K (n = 1) ila L (n = 2) kabuk elektronik geçişlerinden kaynaklanan radyasyon, daha ağır elemanlar için daha kısa dalga boylarında görmüştür. Bu nedenle, belirli bir eleman tarafından yayılan karakteristik X ışını ışığının benzersiz enerjisinin (dalga boyuyla ters orantılı) belirlenmesi, söz konusu eleman için bir parmak izi görevi görür. Enerji Dağıtıcı XRF (EDXRF) sistemleri, numuneyi oluşturan elementlerin karakteristik özelliği olan farklı enerji X-ışınları nedeniyle ortaya çıkan spektral zirveleri çözmüştür.

Öte yandan, Dalgaboyu Dispersif XRF (WDXRF) sistemlerinde bilinen bir kafes d-aralığına sahip bir analizör kristali, bir kırınım ızgarası olarak kullanmıştır; bu, sadece bir X-ışını dalga boyunun belirtilen herhangi bir kırılma açısında geçmesine izin vermiştir. Bu, hem kalitatif hem de kantitatif analizler için dedektöre ulaşmasının ilgilenilen unsur

dışındakiler dışındaki tüm enerjiyi kısıtlar. Kantitatif analizler için, detektörde alınan tepe şiddeti veya sayım oranı (birim zamanda belirli bir enerjide X-ışını fotonlarının sayısı), her iki dahili ölçümün tekrarlayan analizlerinden elde edilen kalibrasyon eğrileri kullanılarak numunede temel konsantrasyona dönüştürülür. X-ışını Floresan tekniğinin ayrıntılı açıklaması Jenkins (1999) ve Van Grieken ve Markowicz (2002) 'de bulunmuştur.

XRF numune hazırlama ve analiz

Çalışma alanındaki plütonik kayaçların jeokimyasal özelliklerini belirlemek için, ana, iz ve nadir toprak elementini hesaplamak amacıyla Kanada'daki Acme Analiz laboratuvarında 41 örneğin analizi yapılmıştır.

Bu laboratuvarında, ana oksitler XRF ile analiz edildi ve nadir toprak elementleri ICP-MS yöntemleri ile analiz edilmiştir. 0.2 g toz numunesinin 1.5 g LiBO₂ ile karıştırılarak analiz edildiği ana oksit analizleri için,% 5 HNO₃ içeren sıvının karıştırılması, Nadir Toprak Element veya İz Element analizleri 0.25 g tozun dört farklı şekilde çözündürülmesi ile analiz edilmiştir.

Asitler ana oksitler ağırlıkça % olarak ölçülürken, İz Elementler ve Nadir Toprak Elementleri ppm cinsinden ölçülmüştür. Tutuşma Kaybı (LOI) tahminleri için 1 g numune tozu platin potaya yerleştirildi ve bir ocak fırında 1 saat boyunca 1000 ° C'ye ısıtıldı. Daha sonra, sıcaklık 200°C'ye düşene kadar numune fırın içinde tutuldu, uzaklaştırıldı ve bir desikatörde oda sıcaklığına soğutuldu. Örnek tartılmış ve kuru ağırlıktaki fark kullanılarak, % LOI kaybı hesaplanmıştır. LOI, numunede bulunan yapısal su, karbonat radikalleri veya benzeri miktarları tahmin eder ve XRF analizi ile belirlenemez.

Tüm XRF analizleri, 4 KW Rh hedefine sahip ve 60 KV ve 50 mA'da işletilen, Rigaku, ZSX primus-II WDXRF bulunan Bureau Veritas Mineral Laboratories, Vancouver, Kanada'da yeni oluşturulan tesis kullanılarak yapılmıştır.

ICP-MS ANALİZİ

ICP-MS (İndüktif Eşleşmiş Plazma Kütle Spektrometresi) analizi için 41 temsili numuneden oluşan bir alt set seçildi. Girişimsiz kayaçların çözünmesini sağlamak için tozlar yerine erimiş cam diskler analiz edilmiştir. Tüm bu kaya örneklerine ek olarak, ICP-MS ile toplam 16 mineral ayrıntısı (amfibol, biyotit ve plajiyoklas ve K-feldispat) analiz edilmiştir. Tüm ICP-MS analizleri, Vancouver, Kanada'da bulunan Bureau Veritas Mineral Laboratories'deki yeni oluşturulan tesis kullanılarak yapılmıştır.

RADYOJENİK İZOTOP ANALİZİ

Ladakh batholith granit örneklerinden on altı temsili tüm kaya örneğinin alt kümeleri analiz edilmiştir. Sr ve Nd radyojenik izotop analizi, Orta Doğu Teknik Üniversitesi (ODTÜ) Jeoloji Bölümü'nde bulunan otomatik VG 354 çok hücreli termal iyonizasyon kütle spektrometresi kullanılarak yapılmıştır.

İzotoplar, aynı protona sahip fakat farklı nötron miktarlarına sahip bir elementin atomlarıdır, dolayısıyla farklı kütlelere sahiptirler. Başka bir atomun radyoaktif bozunması

ile oluşan atom, radyojenik izotop olarak adlandırılır. Bir ana atomun yarısının radyoaktif bozulması için geçen zaman yarı ömür olarak tanımlanır. Bu izotop için özel bir sabite bağlı olarak, bir kız izotopuna radyoaktif bozunma, belirli bir zamandaki atomların sayısı ile doğru orantılıdır, böylece laboratuvarında izotop sistemlerinin formülasyonunu sağlar. Laboratuvarında, Stronsiyum ve Neodimyum izotop oranı deneyleri yapılır. Tam kayaç numuneleri bir çeneli kırıcı tarafından ezilir ve kaya kırma ve mineral zenginleştirme laboratuvarımızdaki bir akik disk değirmeni tarafından <63 mikron'a ulaştırılır.

Tartım, kimyasal çözme, kromatografi ve filament yükleme prosedürleri, ultra saf asitlerin ve suyun kullanıldığı 100 sınıfı temiz bir laboratuvarında yapılır. Deney kalitesi uluslararası sertifikalı standartlar kullanılarak izlenir. Belli miktarlarda tartılan ve PFA şişelerine konulan örnekler, emniyetli sıcak kutularda ocaklarda farklı asitlerle çözülür.

Stronsiyum ve Neodimyum, özel reçineler ve asit kombinasyonları içeren teflon kolonların kullanıldığı bir iyon kromatografi yöntemi ile diğer elementlerden ayrılır.

Zenginleştirilmiş numune, çözünmüş bir formda birkaç yüz nanogram gibi bir renyum filamentine yüklenir. Ölçümler, çoklu koleksiyonlu Triton Termal İyonizasyon Kütle Spektrometresi (Thermo-Fisher) kullanılarak yapılır. Veriler, 2 sigma standart hatalarıyla $87\text{Sr} / 86\text{Sr}$ ve / veya $143\text{Nd} / 144\text{Nd}$ izotop oranları olarak rapor edilmiştir. Ölçümler sırasında, cihazın kalibrasyonu için Sr NBS 987 ve Nd LaJolla standartları ölçülür ve gerekli önyargı düzeltmeleri yapılır.

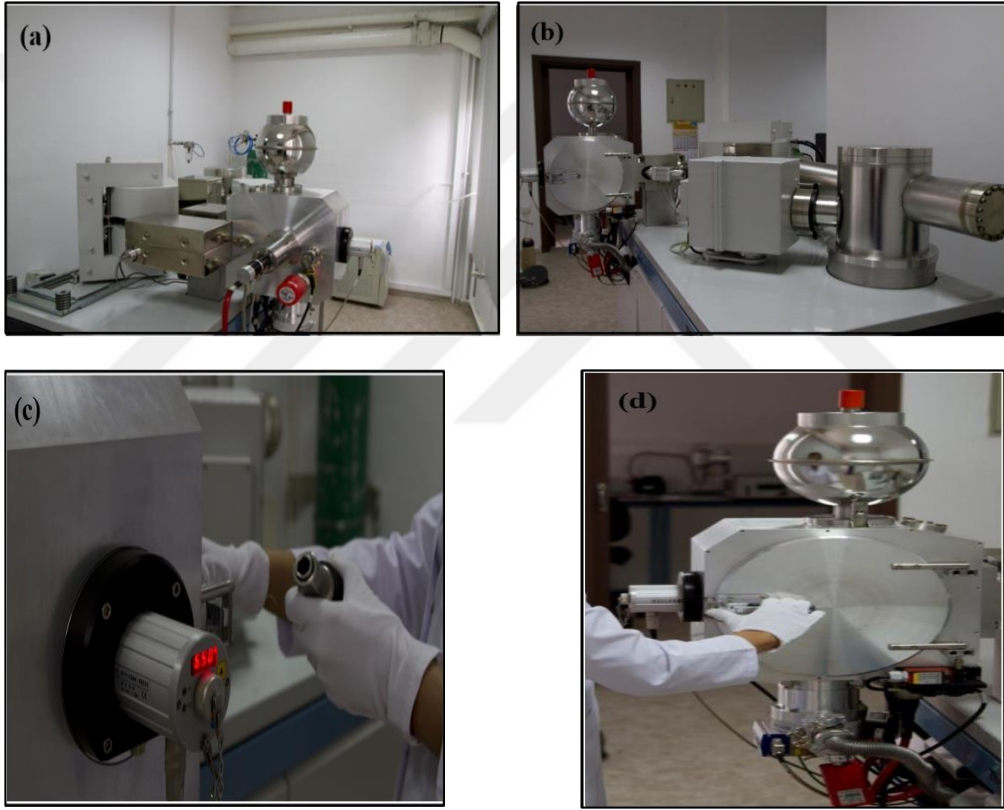
Analitik metot

Strontium ve Neodim izotop jeokimyası deneyleri Köksal ve ark. Orta Doğu Teknik Üniversitesi Merkez Laboratuvarı (ODTÜ) (Ar - Ge Eğitim ve Ölçüm Merkezi, Radyojenik İzotop Laboratuvarı). 2017 yılında TLM-ARG-RIL-01 (Sr İzotop Oranı Analizi Deney Talimatı) ve TLM-ARG-RIL-02 (İzotop Oranı Analizi Deney Talimatı) detay ve şartlarda verilen yöntemlerden uyarlanmıştır. Numuneler çene kırıcı ve disk agat öğütücü kullanılarak kil boyutunda öğütüldü ve kimyasal işlemler başlamıştır. Tartım, kimyasal kod çözme ve kromatografi temiz laboratuvar koşullarında 100 laboratuvar temizlik standardı altında gerçekleştirildi; Ultra saf su ve kimyasallar kullanılarak yapılmıştır.

Yaklaşık 80 mg numune tartılmış ve PFA şişelerine aktarılmıştır. Numuneler, > 100 °C'lik bir ısıtıcı plaka üzerinde 4 gün boyunca 4 mL% 52 HF içerisinde tamamen çözülmüştür. Buharlaşmaya yakın buharlaştırıcıdaki kurutulmuş numuneler önce bir gün 4 mL 6 N HCl içinde çözüldü. Kurutulmuş numune tekrar buharlaştırmak için yakın ısıtıcı masasına alındı, daha sonra 1 mL 2.5 N HCl içinde alındı ve kromatografi için hazırlanmıştır. Stronsiyum elemanı, Teflon kolonlarında Bio Rad AG50 W-X8, 100-200 ağ reçinesi kullanılarak 2 mL hacimlerde 2.5 N HCl aside ayrılmıştır. Stronsiyum toplandıktan sonra, 6 N HCl ile nadir toprak elementlerinin bir kısmı toplanmıştır. Stronsiyum Ta-aktivatörüne ve 0.005 N H_3PO_4 'e tek Re-filament üzerine yüklendi ve statik modda ölçüldü. $87\text{Sr} / 86\text{Sr}$ verileri, $86\text{Sr} / 88\text{Sr} = 0.11194$ olarak normalleştirilmiştir. Sr NBS 987 standardı, ölçümler sırasında $0,710261 \pm 15$ (n = 4) olarak ölçülmüştür.

Neodim element, 0.22 N HC1 asit ve 2 ml hacimde HDEHP (bis-eteteksil fosfat) kaplı biyo-boncuklar-teflon kolonlarında Bio Radite kullanılarak diğer nadir toprak elementlerinden ayrılmıştır. Ayrılan Neodimyum, Re-filament içine 0.005 N H3P04 ile yüklendi, statik modda çift filament tekniği kullanılarak ölçmüştür. Analiz sırasında, $^{143}\text{Nd} / ^{144}\text{Nd}$ verileri $^{146}\text{Nd} / ^{144}\text{Nd} = 0.7219$ ile normalleştirildi. Nd LaJolla standardı, 0.511846 ± 5 ($n = 3$) olarak ölçmüştür.

Stronsiyum ve neodim izotop oranının ölçüm sonuçları üzerinde yanlışlık düzeltmesi yapılmamıştır. Ölçümler, Triton Termal İyonizasyon Kütle Spektrometresi (Thermo-Fisher) kullanılarak çoklu toplama ile gerçekleştirildi. Analitik belirsizlikler 2 sigma seviyesindedir.



Şekil 1. Birleşik şekil (a), (b), (c) & (d), çalışma alanının Triton Termal İyonizasyon Kütle Spektrometresi (Thermo-Fisher) numuneleri analizini kullanarak analitik çalışmayı göstermektedir.

ELEKTRON MİKROPROB ANALİZİ

Tüm mineral analizleri bir Cameca-SX Five elektron probu mikro analiz cihazı kullanılarak yapılmıştır. Analiz ve kalibrasyon 15 kV hızlanma voltajı ve 20 nA ışın akımı ile yapılmıştır. Kalibrasyonda hem sentetik hem de doğal standartlar sırasıyla 20 s ve 10 s sayım zamanlarında ve arka plan konumlarında kullanılmıştır. Mikroprob verilerinin azaltılmasında Henoc ve Maurice (1978) tarafından modifiye edilen ZAF düzeltme prosedürü kullanılmıştır. Mutlak hata, ana öğeler için mevcut miktarın% 2'sidir.

Mineral bileşimleri, Hindistan Teknoloji Enstitüsü Bombay'daki (IITB) Yer Bilimleri Bölümü'nde beş dalga boyu dağılım spektrometresi (WDS) ile donatılmış CAMECA SX-FIVE elektron mikropob analizörü (EMP) kullanılarak analiz edilmiştir. Analizler 15 kV hızlanma voltajı, 20 nA örnek akımı ve 1 lm ışın çapı ile yapılmıştır. Her bir eleman, 20 saniye boyunca tepe konumunda ve 10 saniye boyunca arka plan konumunda ölçmüştür. Her eleman için cihaz kalibrasyonu, hem doğal hem de sentetik standartlar kullanılarak yapılmıştır. Önemli dokuların yüksek çözünürlüklü X-ışını haritaları, 50 ms'lik bir bekleme süresi ve 1 mm'lik adım boyutu ile elde edilmiştir. Granit, granodiyorit, monzonit, monzodiorit ve diorit dahil toplam on iki örnek. Seçilen FeP Ti oksit, plajiyoklas, K-feldispat, biyotit, hornblend, muskovit, apatit, titanyum, zirkon ve klorit örneklerinin kloritlerinin EMP analizleri bildirilmiştir.

Özellikler

SX- Beş Maksimum Hızlanma Gerilimi olan W Sütun modeliyle Analitik Modda 30KV ve Işın Çapı: 600 nm @ 15 KV, 100nA: 400 nm @ 10 KV, 10nA Maksimum Işın Akımı: Işın Kararlılığı ile 10 uA'ya kadar: 0.5 Saatte% @ 20kV, 20nA Cihaz, Maksimum Hızlanma Gerilimine Sahip LaB6 Kolonlu SX-Five ile birlikte: Analitik Modda Işın Çapı ile 30KV: 100 nm @ 20 KV, 10nA: 200 nm @ 10 KV, 10nA Maksimum Işın Akımı: Yukarı ila 1 uA ve Kiriş Stabilesi: saatte% 0.2, 20kV, 10nA

EPMA, odaklanmış bir elektron ışınıyla (tipik enerji = 5-30 keV) bir numunenin mikro hacmini bombalayarak ve böylece çeşitli element türleri tarafından yayılan X-ışını fotonlarını toplayarak çalışır. Bu X ışınlarının dalga boyları yayan türlerin karakteristik özellikleri olduğundan, numune kompozisyonu WDS spektrumları (Dalga Boyu Dispersif Spektroskopisi) kaydedilerek kolayca tanımlanabilir. WDS spektrometreleri Bragg yasasına dayanır ve monokromatör olarak çeşitli hareketli, şekilli monokristalleri kullanır.

EPMA, malzemelerin yüzeyindeki mikronize hacimlerin tahribatsız elementel analizinin, ppm seviyesindeki hassasiyetle, tamamen kalitatif ve kantitatif bir yöntemdir. Birkaç gün içinde% 1 tekrarlanabilirliğe rutin miktar tayini yapılmıştır. Mevcut olan en kesin ve doğru mikro analiz tekniğidir ve B'den U'ya ve üzerindeki tüm elementler analiz edilebilir. EPMA, rutin analiz oturumlarıyla tamamen uyumludur ve sonuçların kolayca ve doğrudan yorumlanabilmesini sağlar.

- EPMA cihazları, eşzamanlı X-ışını (WDS), SEM ve BSE görüntüleme ve ayrıca sofistike görünür ışık optiği sağlayan eksiksiz bir yerleşik mikroskop aracı seti ile donatılmıştır; 40 - 400.000 arasında değişen görüntü büyütme ile çok esnek numune incelemesi sağlarlar.

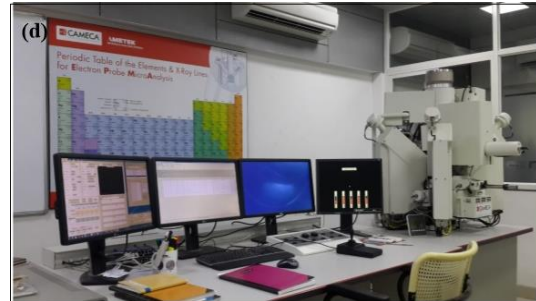
- Tabakalı malzemelerde kalınlığın ve element bileşiminin nm'den mm'ye kadar kalın tabakaların belirlenmesi mümkündür.

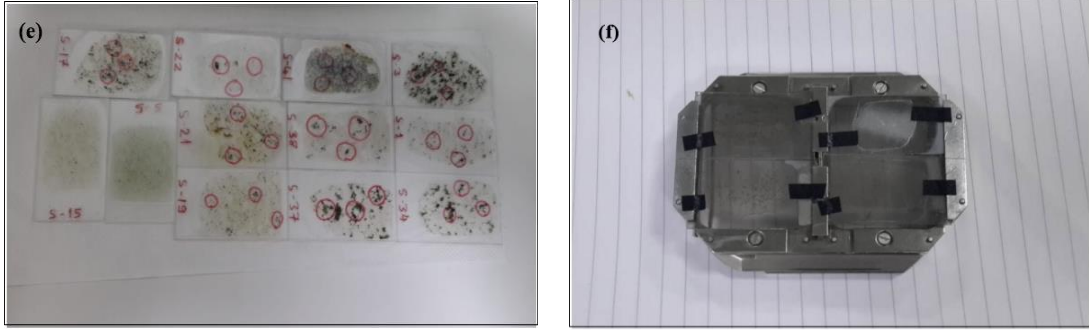
- EPMA, standart SEM / EDS sistemlerinden çok daha iyi sonuçlar sağlar. WDS'nin dahili özelliklerinden ötürü, genel hassasiyet, ışık elementlerinin analizi ve kalitatif spektrumun hatalı yorumlanması riskleri EPMA'da üstündür. Spektral çözünürlük ve dedektör ölü zamanı, EDS'den (Enerji Dağılım Spektroskopisi) çok daha iyidir.

• Eksitasyon ışını düzenleme sistemi ve karmaşık örnek aşaması yetenekleri, bu tekniğin olağanüstü bir stabilite ve ölçüm tekrarlanabilirliği sağladığını garanti eder.

Kullanımı

1. Nitel analiz: WDS Spektrumu-Mevcut elementleri bulmak
2. Kantitatif analiz: Herhangi bir katı maddenin kimyasal bileşiminin doğru miktar tayini
3. BSE Görüntüleme: (Faz Tanımlama, Mineral Tanımlama)
4. SE Görüntüleme (Kullanım: Topografya)
5. Katodoluminans Görüntüleme (Kullanım: Malzemelerdeki kusurları ve safsızlıkları ortaya çıkarır)
6. X-Işını Haritalaması: Elementel dağılım
7. Eşleme Miktarı
8. Coğrafi Miktar: Katyon Hesabı
9. Yaş Miktarı: Monazit Arkadaşlığı.





Şekil 2. Tüm rakam (a-d) çalışma alanı örneklerinin EPMA analizinin analitik çalışmasını gösterir, (e) ince kesit slaytlar üzerindeki vurgulanan analiz noktasını gösterir, (f) mineral kimyası için numunelerin EPMA analizi için kullanılan özel olarak tasarlanmış ince kesit durumunu göstermektedir

Çizelge 1. Örneklerin enlem, boylam ve açıklamalarını gösteren tablo

Örnek Numarası	Yer				Açıklama
	Enlem (K)	Boylam (B)	Yer adı		Kayaç Özellikleri
AM1	K 34 ⁰ 13.463"	B 77 ⁰ 16.323"	Basgo	Ladakh Batoliti	Orta-İri taneli Plajiyoklas, kuvars, biyotit, opak mineraller Biyotit Granit
AM2	K 34 ⁰ 13.469"	B 77 ⁰ 16.329"	Basgo	Ladakh Batoliti	Orta-İri taneli Plajiyoklas, kuvars, biyotit, K-feldispat, opak mineraller Biyotit Granit
AM3	K 34 ⁰ 13.225"	B 77 ⁰ 16.638"	Basgo	Ladakh Batoliti	Orta-İri taneli Plajiyoklas, kuvars, biyotit, K-feldispat, opak mineraller, klorit biyotit Diyorit
AM4	K 34 ⁰ 13.213"	B 77 ⁰ 16.645"	Basgo	Ladakh Batoliti	Orta-İri taneli Plajiyoklas, kuvars, biyotit, K-feldispat, Biyotit Granit

AM5	K 34 ⁰ 11.800"	B 77 ⁰ 19.500"	Basgo	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, K-feldispat, opak mineraller, klorit biyotit Biyotit Granit
AM6	K 34 ⁰ 10.109"	B 77 ⁰ 20.047"	Basgo	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, K-feldispat, Granodiyorit
AM7	K 34 ⁰ 10.105"	B 77 ⁰ 20.045"	Basgo	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, K-feldispat, opak mineraller Granodiyorit
AM8	K 34 ⁰ 10.104"	B 77 ⁰ 20.050"	Basgo	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, K-feldispat, Granodiyorit
AM9	K 34 ⁰ 10.166"	B 77 ⁰ 20.081"	Basgo	Ladakh Batolit	İri taneli ,Plajiyoklas, kuvars, biyotit, K-feldispat, opak mineraller Granodiyorit
AM10	K 34 ⁰ 10.163"	B 77 ⁰ 20.065"	Basgo	Ladakh Batolit	İnce-Orta taneli Plajiyoklas, kuvars, biyotit Biyotit-Granit
AM11	K 34 ⁰ 09.888"	B 77 ⁰ 20.333"	Nimu	Ladakh Batolit	İnce-Orta taneli Plajiyoklas, kuvars, amfibol, biyotit, K-feldispat, kloritlenmiş biyotit ve serisitleşmiş plajiyoklas Granit

AM12	K 34 ⁰ 09.872"	B 77 ⁰ 20.344"	Nimu	Ladakh Batolit	İnce-Orta taneli Plajiyoklas, kuvars, biyotit Granodiyorit
AM13	K 34 ⁰ 09.760"	B 77 ⁰ 20.423"	Nimu	Ladakh Batolit	İnce-Orta taneli Plajiyoklas, kuvars, biyotit Granodiyorit
AM14	K 34 ⁰ 09.705"	B 77 ⁰ 20.476"	Nimu	Ladakh Batolit	İnce-Orta taneli Plajiyoklas, kuvars, biyotit Biyotit-Granit
AM15	K 34 ⁰ 09.650"	B 77 ⁰ 20.522"	Nimu	Ladakh Batolit	İnce-Orta taneli, Plajiyoklas, kuvars, amfibol, biyotit, K-feldispat, kloritize biyotit ve serisitize plajiyoklas Granit
AM16	K 34 ⁰ 11.842"	B 77 ⁰ 22.574"	Nimu	Ladakh Batolit	İri taneli Plajiyoklas, kuvars, biyotit, amfibol, Biyotit-Hornblend Granodiyorit
AM17	K 34 ⁰ 11.830"	B 77 ⁰ 22.600"	Nimu	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, amfibol, Biyotit-Granodiyorit
AM18	K 34 ⁰ 11.805"	B 77 ⁰ 22.615"	Nimu	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, amfibol, K-feldispat Biyotit hornblend Granodiyorit
AM19	K 34 ⁰ 11.752"	B 77 ⁰ 22.790"	Nimu	Ladakh Batolit	Orta- İri taneli, Plajiyoklas, kuvars, biyotit, amfibol, K-feldispat Biyotit Granodiyorit

AM20	K 34° 11.794"	B 77° 22.669"	Nimu	Ladakh Batolit	İri taneli, Plajiyoklas, kuvars, biyotit, K-feldispat Biyotit Granodiyorit
AM21	K 34° 11.590"	B 77° 22.622"	Umla	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat Biyotit Granodiyorit
AM22	K 34° 11.120"	B 77° 23.953"	Umla	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, amfibol, biyotit, K-feldispat, kloritlenmiş biyotit ve serisitleşmiş plajiyoklas Kuvars Granit
AM23	K 34° 10.425"	B 77° 25.339"	Umla	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat Kuvars Granodiyorit
AM24	K 34° 10.436"	B 77° 25.334"	Umla	Ladakh Batolit	Orta-İri taneli Plajiyoklas, amfibol, kuvars , biyotit, K-feldispat, Granodiyorit
AM25	K 34° 10.457"	B 77° 25.346"	Umla	Ladakh Batolit	Orta-İri taneli, Plajiyoklas, amfibol, olivin, piroksen, kuvars ,biyotit, K-feldispat, Monzonit
AM26	K 34° 10.567"	B 77° 25.445"	Umla	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat Granodiyorit

AM27	K 34 ⁰ 10.615"	B 77 ⁰ 25.545"	Umla	Ladakh Batolit	Orta-İri taneli, Plajiyoklas, kuvars, amfibol, biyotit, K-feldispat, kloritlenmiş biyotit ve serisitleşmiş plajiyoklas Granodiyorit
AM28	K 34 ⁰ 10.756"	B 77 ⁰ 25.645"	Umla	Ladakh Batolit	İri taneli, Plajiyoklas, kuvars, kloritlenmiş biyotit, biyotit, K-feldispat Biyotit Granodiyorit
AM29	K 34 ⁰ 10.854"	B 77 ⁰ 25.770"	Umla	Ladakh Batolit	Orta-İri taneli, Plajiyoklas, amfibol, olivin, piroksen, kuvars, biyotit, K-feldispat, Monzonit
AM30	K 34 ⁰ 10.994"	B 77 ⁰ 25.840"	Umla	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat, Granodiyorit
AM31	K 34 ⁰ 08.168"	B 77 ⁰ 29.956"	Taru	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat Kuars Granodiyorit
AM32	K 34 ⁰ 08.179"	B 77 ⁰ 29.942"	Taru	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat, Granodiyorit
AM33	K 34 ⁰ 08.174"	B 77 ⁰ 29.940"	Taru	Ladakh Batolit	Orta-İri taneli, Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat, Granodiyorit

AM34	K 34 ⁰ 08.168"	B 77 ⁰ 29.942"	Taru	Ladakh Batolit	İri taneli, Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat Granodiyorit
AM35	K 34 ⁰ 08.164"	B 77 ⁰ 29.938"	Taru	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, kloritleşmiş biyotit, biyotit, K-feldispat Biyotit Granodiyorit
AM36	K 34 ⁰ 08.118"	B 77 ⁰ 30.028"	Taru	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, K-feldispat Biyotit Granodiyorit
AM37	K 34 ⁰ 08.119"	B 77 ⁰ 30.032"	Taru	Ladakh Batolit	Orta-İri taneli, Plajiyoklas, kuvars, amfibol, biyotit, K-feldispat Biyotit Granodiyorit
AM38	K 34 ⁰ 08.119"	B 77 ⁰ 30.042"	Taru	Ladakh Batolit	Orta- İri taneli Plajiyoklas, kuvars, amfibol, biyotit, K-feldispat, kloritlenmiş biyotit ve serisitleşmiş plajiyoklas Kuvars Granit
AM39	K 34 ⁰ 08.121"	B 77 ⁰ 30.065"	Taru	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, amfibol, biyotit, K-feldispat, kloritlenmiş biyotit ve serisitleşmiş plajiyoklas Kuvars Granit
AM40	K 34 ⁰ 08.125"	B 77 ⁰ 30.082"	Taru	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, amfibol, K- feldispat, kloritlenmiş biyotit ve serisitleşmiş plajiyoklas

					Granit
AM41	K 34 ⁰ 08.130"	B 77 ⁰ 30.120"	Taru	Ladakh Batolit	Orta-İri taneli Plajiyoklas, kuvars, biyotit, amfibol Monzodiyorit

EK-2. MİNERAL KİMYASI ANALİZ SONUÇLARI

Çizelge 2. Amfibolün 23 Oksijen bazlı verilerle EPMA analizi ve Schmidt (1992) formülüne göre basınç hesaplaması

Örnek no.	AM3	AM3	AM3	AM3	AM3	AM3
Plüton/Alan	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Kayaç Türü	Diyorit	Diyorit	Diyorit	Diyorit	Diyorit	Diyorit
Nokta analizi	1	2	3	4	5	6
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	46.74	45.98	46.46	46.03	41.54	42.54
TiO ₂	1.04	1.24	0.95	1.26	1.73	1.39
Al ₂ O ₃	7.02	7.69	7.33	7.61	10.73	10.37
Cr ₂ O ₃	0.01	0.01	0.01	0.02	0.00	0.03
FeO	16.35	16.53	16.91	16.72	19.33	19.20
MnO	0.55	0.51	0.57	0.62	0.49	0.55
MgO	11.89	11.47	11.53	11.32	8.85	9.22
CaO	11.81	11.78	12.11	11.87	11.89	12.00
Na ₂ O	1.10	1.23	0.98	1.14	1.40	1.41
K ₂ O	0.73	0.84	0.73	0.76	1.02	0.78
Si	6.99	6.90	6.93	6.90	6.36	6.45
Al (iv)	1.01	1.10	1.07	1.10	1.64	1.55
Total (Si + Al (iv))	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.23	0.26	0.22	0.24	0.29	0.30
Ti	0.12	0.14	0.11	0.14	0.20	0.16
Cr	0.00	0.00	0.00	0.00	0.00	0.00
Fe(iii)	0.09	0.04	0.22	0.09	0.34	0.36
Fe(ii)	1.95	2.04	1.89	2.00	2.14	2.07
Mn	0.07	0.06	0.07	0.08	0.06	0.07
Mg	2.65	2.57	2.56	2.53	2.02	2.08
Ca	1.89	1.89	1.93	1.91	1.95	1.95
C + B	7.00	7.00	7.00	7.00	7.00	7.00
Na ***	0.32	0.36	0.28	0.33	0.42	0.42
K	0.14	0.16	0.14	0.14	0.20	0.15
TOTAL	15.46	15.52	15.42	15.48	15.61	15.57
A site (Na+K)	0.46	0.52	0.42	0.48	0.61	0.57
T/S	1.00	1.00	1.00	1.00	0.99	0.99
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.95	0.98	0.90	0.96	0.86	0.85
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.05	0.02	0.10	0.04	0.14	0.15
Mg/(Mg+Fe ²⁺)	0.58	0.56	0.58	0.56	0.49	0.50
Fe ³⁺ /(Fe ³⁺ + [6]Al)	0.29	0.13	0.51	0.28	0.53	0.55
Mineral (Kalsik)	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Hastingsit	Magnezyum-hastingsit
(Ca+Na)B	2.21	2.25	2.22	2.24	2.36	2.36

Çizelge 2'in devamı

Plüton/Alan	Basgo	Basgo	Umla	Umla	Umla	Umla
Kayaç Türü	Diyorit	Diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	7	8	1	2	3	4
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	43.16	43.37	45.29	45.45	46.86	46.19
TiO ₂	1.22	1.40	1.42	1.69	1.26	1.00
Al ₂ O ₃	9.87	9.38	7.49	7.18	6.39	6.82
Cr ₂ O ₃	0.00	0.03	0.01	0.00	0.00	0.02
FeO	18.68	17.48	16.47	15.99	15.20	16.54
MnO	0.51	0.49	0.95	0.96	0.93	0.92
MgO	9.65	10.24	11.23	11.36	12.57	11.60
CaO	11.94	11.93	11.51	11.66	11.75	11.87
Na ₂ O	1.30	1.24	1.31	1.29	1.22	1.16
K ₂ O	0.98	1.03	0.86	0.83	0.69	0.71
Si	6.54	6.60	6.87	6.90	7.02	6.95
Al (iv)	1.46	1.40	1.13	1.10	0.98	1.05
Total (Si+Aliv)	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.31	0.28	0.21	0.18	0.15	0.17
Ti	0.14	0.16	0.16	0.19	0.14	0.11
Cr	0.00	0.00	0.00	0.00	0.00	0.00
Fe(iii)	0.30	0.23	0.04	0.00	0.07	0.18
Fe(ii)	2.07	1.99	2.05	2.03	1.84	1.91
Mn	0.07	0.06	0.12	0.12	0.12	0.12
Mg	2.18	2.32	2.54	2.57	2.81	2.60
Ca	1.94	1.95	1.87	1.90	1.89	1.91
C + B	7.00	7.00	7.00	7.00	7.00	7.00
Na	0.38	0.37	0.39	0.38	0.35	0.34
K	0.19	0.20	0.17	0.16	0.13	0.14
TOTAL	15.57	15.57	15.55	15.54	15.49	15.47
A site (Na+k)	0.57	0.57	0.55	0.54	0.49	0.47
T/S	0.99	1.00	1.00	1.00	1.00	1.00
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.87	0.90	0.98	1.01	0.96	0.92
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.13	0.10	0.02	-0.01	0.04	0.08
Mg/(Mg+Fe ²⁺)	0.51	0.54	0.55	0.56	0.60	0.58
Fe ³⁺ /(Fe ³⁺ +6[Al])	0.49	0.45	0.15	0.00	0.31	0.52
Mineral (Kalsik)	Edenit	Edenit	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend
(Ca+Na)B	2.32	2.31	2.26	2.28	2.24	2.25

Çizelge 2'in devamı

Örnek no.	AM24	AM24	AM24	AM24	AM24	AM24
Plüton/Alan	Umla	Umla	Umla	Umla	Umla	Umla
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	5	6	7	8	9	10
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	45.52	46.28	45.59	46.79	45.40	47.00
TiO ₂	1.48	1.27	1.53	1.28	1.43	0.79
Al ₂ O ₃	7.34	6.93	7.49	6.84	7.64	7.16
Cr ₂ O ₃	0.00	0.00	0.00	0.02	0.00	0.00
FeO	16.87	16.54	16.69	16.06	16.83	16.43
MnO	0.94	0.93	0.82	0.88	0.91	0.96
MgO	11.32	11.61	11.44	11.90	11.41	12.14
CaO	11.69	11.68	11.52	11.73	11.72	12.00
Na ₂ O	1.36	1.19	1.33	1.24	1.33	1.18
K ₂ O	0.83	0.79	0.90	0.76	0.88	0.69
Si	6.86	6.95	6.87	7.00	6.82	6.94
Al (iv)	1.14	1.05	1.13	1.00	1.18	1.06
Total (Si+Aliv)	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.16	0.18	0.20	0.20	0.17	0.19
Ti	0.17	0.14	0.17	0.14	0.16	0.09
Cr	0.00	0.00	0.00	0.00	0.00	0.00
Fe(iii)	0.09	0.08	0.03	0.00	0.13	0.22
Fe(ii)	2.03	2.00	2.07	2.00	1.98	1.81
Mn	0.12	0.12	0.10	0.11	0.12	0.12
Mg	2.54	2.60	2.57	2.65	2.55	2.67
Ca	1.89	1.88	1.86	1.88	1.89	1.90
C + B	7.00	7.00	7.00	7.00	7.00	7.00
Na	0.40	0.35	0.39	0.36	0.39	0.34
K	0.16	0.15	0.17	0.15	0.17	0.13
TOTAL	15.56	15.50	15.56	15.51	15.56	15.47
A site (Na+k)	0.56	0.50	0.56	0.51	0.56	0.47
T/S	1.00	1.00	1.00	1.00	1.00	1.00
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.96	0.96	0.99	1.00	0.94	0.89
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.04	0.04	0.01	0.00	0.06	0.11
Mg/(Mg+Fe ²⁺)	0.56	0.57	0.55	0.57	0.56	0.60
Fe ³⁺ /(Fe ³⁺ +6[Al])	0.37	0.31	0.14	0.02	0.44	0.54
Mineral (Kalsik)	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend
(Ca+Na)B	2.28	2.22	2.25	2.24	2.27	2.24

Çizelge 2'in (devamı)

Örnek no.	AM37	AM37	AM37	AM37	AM37	AM37
Plüton/Alan	Taru	Taru	Taru	Taru	Taru	Taru
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	1	2	3	4	5	6
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	47.30	46.90	46.02	46.46	47.57	47.49
TiO ₂	0.79	0.68	1.53	0.91	0.73	0.62
Al ₂ O ₃	6.88	7.03	7.22	7.11	6.59	7.03
Cr ₂ O ₃	0.00	0.01	0.00	0.06	0.02	0.00
FeO	15.80	16.33	16.77	16.38	16.33	16.68
MnO	0.85	0.79	0.86	0.77	0.82	0.86
MgO	12.23	11.87	11.45	11.61	12.22	12.02
CaO	11.64	11.57	11.58	11.72	11.78	11.64
Na ₂ O	1.22	1.12	1.24	1.17	1.13	1.18
K ₂ O	0.56	0.69	0.72	0.64	0.60	0.64
Si	7.05	7.03	6.91	6.98	7.06	7.03
Al (iv)	0.95	0.97	1.09	1.02	0.94	0.97
Total(Si+Al iv)	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.26	0.27	0.19	0.24	0.21	0.26
Ti	0.09	0.08	0.17	0.10	0.08	0.07
Cr	0.00	0.00	0.00	0.01	0.00	0.00
Fe(iii)	0.05	0.10	0.06	0.10	0.13	0.11
Fe(ii)	1.92	1.95	2.05	1.96	1.90	1.95
Mn	0.11	0.10	0.11	0.10	0.10	0.11
Mg	2.72	2.65	2.56	2.60	2.70	2.65
Ca	1.86	1.86	1.86	1.89	1.87	1.85
C + B	7.00	7.00	7.00	7.00	7.00	7.00
Na	0.35	0.32	0.36	0.34	0.32	0.34
K	0.11	0.13	0.14	0.12	0.11	0.12
TOTAL	15.46	15.46	15.50	15.46	15.44	15.46
A Site (Na+k)	0.46	0.46	0.50	0.46	0.44	0.46
T/S	1.00	1.00	1.00	1.00	1.00	1.00
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.97	0.95	0.97	0.95	0.94	0.95
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.03	0.05	0.03	0.05	0.06	0.05
Mg/(Mg+Fe ²⁺)	0.59	0.58	0.56	0.57	0.59	0.58
Fe ³⁺ /(Fe ³⁺ +6[Al])	0.17	0.27	0.24	0.28	0.37	0.30
Mineral (Kalsik)	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend
Ca+Na	2.21	2.18	2.22	2.23	2.20	2.19

Çizelge 2'in devamı

Örnek no.	AM37	AM37	AM37	AM41	AM41	AM41
Plüton/Alan	Taru	Taru	Taru	Taru	Taru	Taru
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	M.diyorit	M.diyorit	M.diyorit
Nokta analizi	7	8	9	1	2	3
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	45.13	45.14	45.76	45.868	46.208	46.09
TiO ₂	1.67	1.78	1.47	1.597	1.419	1.044
Al ₂ O ₃	7.75	7.74	7.44	7.239	7.007	7.176
Cr ₂ O ₃	0.03	0.00	0.01	0.046	0	0
FeO	17.39	17.19	16.69	16.229	16.787	16.293
MnO	0.94	0.93	1.02	1.016	0.998	0.913
MgO	10.88	11.05	11.39	11.25	11.316	11.141
CaO	11.41	11.59	11.80	11.661	11.606	11.453
Na ₂ O	1.34	1.31	1.20	1.291	1.216	1.153
K ₂ O	0.89	0.82	0.82	0.823	0.779	0.783
Si	6.82	6.80	6.86	6.920	6.951	7.005
Al (iv)	1.18	1.20	1.14	1.080	1.049	0.995
Total (Si+Aliv)	8.00	8.00	8.00	8.000	8.000	8.000
Al (vi)	0.20	0.17	0.17	0.207	0.193	0.290
Ti	0.19	0.20	0.17	0.181	0.161	0.119
Cr	0.00	0.00	0.00	0.005	0.000	0.000
Fe(iii)	0.04	0.10	0.13	0.000	0.031	0.000
Fe(ii)	2.15	2.07	1.96	2.047	2.080	2.071
Mn	0.12	0.12	0.13	0.130	0.127	0.118
Mg	2.45	2.48	2.54	2.530	2.538	2.524
Ca	1.85	1.87	1.89	1.885	1.870	1.865
C + B	7.00	7.00	7.00	6.985	7.000	6.987
Na	0.39	0.38	0.35	0.378	0.355	0.340
K	0.17	0.16	0.16	0.158	0.149	0.152
TOTAL	15.56	15.54	15.51	15.521	15.504	15.479
A site (Na+K)	0.56	0.54	0.51	0.536	0.504	0.492
T/S	1.00	1.00	1.00	1.001	0.999	1.001
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.98	0.96	0.94	1.022	0.985	1.019
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.02	0.04	0.06	-0.022	0.015	-0.019
Mg/(Mg+Fe ²⁺)	0.53	0.55	0.56	0.553	0.550	0.549
Fe ³⁺ /(Fe ³⁺ + [6]Al)	0.18	0.36	0.43	0.000	0.139	0.000
Mineral (Kalsik)	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend
Ca+Na	2.24	2.25	2.24	12.952	12.822	12.606

Çizelge 2'in devamı

Örnek no.	AM41	AM41	AM41	AM41	AM41
Plüton/Alan	Taru	Taru	Taru	Taru	Taru
Kayaç Türü	M.diyorit	M.diyorit	M.diyorit	M.diyorit	M.diyorit
Nokta analizi	4	5	6	7	8
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	45.476	45.294	45.787	46.061	44.939
TiO ₂	1.42	1.262	1.071	1.348	1.494
Al ₂ O ₃	7.713	8.252	7.565	7.197	7.745
Cr ₂ O ₃	0.01	0.002	0.041	0	0
FeO	17.051	15.943	17.023	16.395	16.821
MnO	0.982	0.998	0.947	0.935	1.001
MgO	10.924	11.415	11.032	11.343	10.768
CaO	11.635	11.963	11.887	11.665	11.738
Na ₂ O	1.334	1.293	1.039	1.263	1.346
K ₂ O	0.901	0.872	0.79	0.816	0.933
Si	6.857	6.795	6.885	6.946	6.827
Al (iv)	1.143	1.205	1.115	1.054	1.173
Total (Si+Aliv)	8.000	8.000	8.000	8.000	8.000
Al (vi)	0.228	0.254	0.225	0.225	0.214
Ti	0.161	0.142	0.121	0.153	0.171
Cr	0.001	0.000	0.005	0.000	0.000
Fe(iii)	0.029	0.122	0.189	0.000	0.040
Fe(ii)	2.121	1.878	1.952	2.067	2.097
Mn	0.125	0.127	0.121	0.119	0.129
Mg	2.456	2.553	2.473	2.550	2.439
Ca	1.879	1.923	1.915	1.884	1.911
C + B	7.000	7.000	7.000	6.999	7.000
Na	0.390	0.376	0.303	0.369	0.396
K	0.173	0.167	0.152	0.157	0.181
TOTAL	15.563	15.543	15.454	15.525	15.577
A site (Na+K)	0.563	0.543	0.454	0.526	0.577
T/S	0.999	0.997	0.996	1.000	0.999
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.986	0.939	0.912	1.002	0.981
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.014	0.061	0.088	-0.002	0.019
Mg/(Mg+Fe ²⁺)	0.537	0.576	0.559	0.552	0.538
Fe ³⁺ /(Fe ³⁺ +6[Al])	0.113	0.324	0.456	0.000	0.156
Mineral (Kalsik)	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend	Magnezyum-hornblend
Ca+Na	12.969	13.256	12.926	12.928	13.084

Çizelge 3. Trans-Himalaya Kemerı çevresinde (Hindistan) Ladakh Batholith'in Leh bölgesinden toplanan örnekler, Biyotit mineralinin EPMA analizi

Örnek no.	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1
Plüton/Alan		Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Kayaç Türü	Granit	Granit	Granit	Granit	Granit	Granit	Granit	Granit
Nokta analizi	1	2	3	4	5	6	7	8
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.46	36.65	35.98	37.21	37.23	36.91	36.82	37.39
TiO ₂	3.53	3.64	3.69	2.83	3.72	3.66	3.07	3.53
Al ₂ O ₃	14.44	14.07	13.93	13.52	13.91	14.03	13.77	13.78
FeO	19.84	20.72	20.18	19.88	20.65	20.51	20.44	19.68
MnO	1.18	0.79	0.80	0.63	0.70	0.67	0.76	0.71
MgO	10.62	10.18	9.99	11.13	10.55	10.09	10.64	11.09
CaO	0.01	0.04	0.00	0.00	0.03	0.03	0.00	0.04
Na ₂ O	0.06	0.12	0.09	0.06	0.07	0.10	0.07	0.12
K ₂ O	9.67	9.33	9.27	9.56	9.38	9.59	9.06	9.38
Cl	0.03	0.05	0.05	0.03	0.03	0.02	0.03	0.04
F	0.67	0.70	0.66	0.78	0.66	0.63	0.72	0.75
Si	5.67	5.64	5.63	5.74	5.67	5.67	5.70	5.70
Al iv	2.33	2.36	2.37	2.26	2.33	2.33	2.30	2.30
Al T	2.57	2.55	2.57	2.46	2.50	2.54	2.51	2.48
Al vi	0.24	0.19	0.20	0.20	0.17	0.21	0.21	0.18
Ti	0.40	0.42	0.43	0.33	0.43	0.42	0.36	0.41
Fe(ii)	2.51	2.67	2.64	2.57	2.63	2.64	2.65	2.51
Mn	0.15	0.10	0.11	0.08	0.09	0.09	0.10	0.09
Mg	2.39	2.33	2.33	2.56	2.40	2.31	2.46	2.52
Ca	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
Na	0.02	0.03	0.03	0.02	0.02	0.03	0.02	0.04
K	1.87	1.83	1.85	1.88	1.82	1.88	1.79	1.82
Cl	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
F	0.32	0.34	0.32	0.38	0.32	0.31	0.35	0.36
Toplam	15.58	15.59	15.58	15.64	15.57	15.59	15.59	15.58
Fe/Fe+Mg	0.51	0.53	0.53	0.50	0.52	0.53	0.52	0.50

Çizelge 3'in devamı

Örnek no.	AM1	AM3	AM3	AM3	AM3	AM3	AM3	AM3
Plüton/Alan	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Kayaç Türü	Granit	Diyorit	Diyorit	Diyorit	Diyorit	Diyorit	Diyorit	Diyorit
Nokta analizi	9	1	2	3	4	5	6	7
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.38	36.77	36.82	37.57	36.89	36.14	35.93	36.32
TiO ₂	3.30	2.73	2.46	1.72	2.65	2.77	3.33	2.14
Al ₂ O ₃	14.09	14.28	14.73	15.68	14.81	14.68	13.91	15.13
FeO	19.88	20.00	19.84	19.30	19.77	19.92	19.64	19.48
MnO	0.71	0.32	0.37	0.34	0.37	0.33	0.34	0.40
MgO	10.85	11.06	11.16	11.61	10.99	11.61	11.29	10.70
CaO	0.00	0.10	0.14	0.09	0.23	0.31	0.25	0.37
Na ₂ O	0.10	0.26	0.14	0.11	0.13	0.17	0.36	0.14
K ₂ O	9.63	8.40	8.62	8.80	9.07	7.63	7.05	8.15
Cl	0.03	0.09	0.07	0.08	0.08	0.08	0.06	0.07
F	0.69	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Si	5.70	5.69	5.67	5.70	5.66	5.60	5.64	5.67
Al iv	2.30	2.31	2.33	2.30	2.34	2.40	2.36	2.33
Al T	2.53	2.60	2.68	2.80	2.68	2.68	2.57	2.78
Al vi	0.23	0.29	0.35	0.50	0.34	0.27	0.21	0.45
Ti	0.38	0.32	0.29	0.20	0.31	0.32	0.39	0.25
Fe(ii)	2.54	2.59	2.56	2.45	2.54	2.58	2.58	2.54
Mn	0.09	0.04	0.05	0.04	0.05	0.04	0.04	0.05
Mg	2.47	2.55	2.56	2.62	2.51	2.68	2.64	2.49
Ca	0.00	0.02	0.02	0.01	0.04	0.05	0.04	0.06
Na	0.03	0.08	0.04	0.03	0.04	0.05	0.11	0.04
K	1.87	1.66	1.69	1.70	1.78	1.51	1.41	1.62
Cl	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
F	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Toplam	15.60	15.55	15.56	15.56	15.59	15.51	15.43	15.51
Fe/Fe+Mg	0.51	0.50	0.50	0.48	0.50	0.49	0.49	0.51

Çizelge 3'in devamı

Örnek no.	AM3	AM3	AM3	AM3	AM17	AM17	AM17	AM17
Plüton/Alan	Basgo	Basgo	Basgo	Basgo	Nimu	Nimu	Nimu	Nimu
Kayaç Türü	Diyorit	Diyorit	Diyorit	Diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	8	9	10	11	1	2	3	4
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	35.72	36.80	37.14	37.11	37.68	36.77	37.50	37.10
TiO ₂	2.90	2.62	2.52	2.16	1.94	2.65	2.31	2.22
Al ₂ O ₃	14.34	14.69	14.70	14.89	15.31	15.10	15.68	15.29
FeO	19.90	19.46	19.78	19.54	17.81	18.56	18.84	18.81
MnO	0.32	0.37	0.39	0.30	0.77	0.68	0.71	0.77
MgO	10.08	11.09	11.14	11.16	11.57	10.90	11.15	11.12
CaO	0.24	0.05	0.28	0.11	0.04	0.09	0.00	0.14
Na ₂ O	0.17	0.12	0.15	0.17	0.04	0.07	0.06	0.09
K ₂ O	8.78	8.92	8.52	8.49	9.17	9.24	9.65	8.49
Cl	0.08	0.09	0.08	0.07	0.08	0.05	0.04	0.05
F	0.00	0.00	0.00	0.00	0.06	0.00	0.02	0.00
Si	5.65	5.68	5.69	5.72	5.75	5.67	5.67	5.70
Al iv	2.35	2.32	2.31	2.28	2.25	2.33	2.33	2.30
Al T	2.67	2.67	2.66	2.70	2.75	2.74	2.80	2.77
Al vi	0.32	0.35	0.35	0.42	0.51	0.42	0.47	0.47
Ti	0.35	0.30	0.29	0.25	0.22	0.31	0.26	0.26
Fe(ii)	2.63	2.51	2.54	2.52	2.27	2.39	2.38	2.42
Mn	0.04	0.05	0.05	0.04	0.10	0.09	0.09	0.10
Mg	2.38	2.55	2.55	2.56	2.63	2.51	2.52	2.55
Ca	0.04	0.01	0.05	0.02	0.01	0.01	0.00	0.02
Na	0.05	0.03	0.05	0.05	0.01	0.02	0.02	0.03
K	1.77	1.76	1.67	1.67	1.78	1.82	1.86	1.66
Cl	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
F	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.00
Toplam	15.57	15.56	15.53	15.53	15.54	15.56	15.60	15.50
Fe/Fe+Mg	0.53	0.50	0.50	0.50	0.46	0.49	0.49	0.49

Çizelge 3'in devamı

Örnek no.	AM17	AM17	AM17	AM17	AM17	AM17	AM19	AM19
Plüton/Alan	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	5	6	7	8	9	10	1	2
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.36	37.71	37.18	38.04	38.08	37.84	36.42	36.04
TiO ₂	2.03	1.83	2.33	2.22	1.46	1.28	2.15	2.13
Al ₂ O ₃	15.88	15.80	15.39	15.36	16.70	16.99	14.41	15.03
FeO	18.19	18.31	19.13	17.97	17.33	17.66	18.46	17.79
MnO	0.71	0.65	0.73	0.70	0.68	0.64	1.64	1.65
MgO	11.30	11.84	11.26	11.37	11.91	12.06	10.87	10.56
CaO	0.00	0.00	0.05	0.05	0.04	0.10	0.12	0.21
Na ₂ O	0.06	0.05	0.05	0.07	0.05	0.05	0.10	0.13
K ₂ O	9.49	9.52	9.29	9.00	9.14	8.67	9.11	9.03
Cl	0.04	0.07	0.04	0.07	0.07	0.05	0.07	0.09
F	0.00	0.00	0.01	0.00	0.00	0.00	0.05	0.05
Si	5.68	5.69	5.66	5.77	5.71	5.68	5.70	5.66
Al iv	2.32	2.31	2.34	2.23	2.29	2.32	2.30	2.34
Al T	2.85	2.81	2.76	2.75	2.95	3.00	2.66	2.78
Al vi	0.53	0.50	0.42	0.51	0.66	0.68	0.35	0.44
Ti	0.23	0.21	0.27	0.25	0.16	0.14	0.25	0.25
Fe(ii)	2.31	2.31	2.43	2.28	2.17	2.21	2.41	2.34
Mn	0.09	0.08	0.09	0.09	0.09	0.08	0.22	0.22
Mg	2.56	2.66	2.56	2.57	2.66	2.70	2.53	2.47
Ca	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.04
Na	0.02	0.02	0.01	0.02	0.01	0.02	0.03	0.04
K	1.84	1.83	1.80	1.74	1.75	1.66	1.82	1.81
Cl	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02
F	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.03
Toplam	15.59	15.61	15.60	15.48	15.52	15.51	15.64	15.61
Fe/Fe+Mg	0.47	0.46	0.49	0.47	0.45	0.45	0.49	0.49

Çizelge 3'in devamı

Örnek no.	AM19	AM19	AM19	AM19	AM19	AM19	AM19	AM19
Plüton/Alan	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	3	4	5	6	7	8	9	10
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	36.33	36.47	36.24	37.41	36.74	36.34	37.23	37.17
TiO ₂	2.85	2.11	2.29	2.81	2.35	1.99	2.79	2.77
Al ₂ O ₃	14.85	15.36	14.86	14.95	14.89	14.63	15.41	15.23
FeO	18.15	17.51	17.78	18.16	18.56	18.25	17.91	17.88
MnO	1.44	1.66	1.73	1.58	1.51	1.52	1.56	1.58
MgO	10.41	10.96	10.65	10.80	10.70	10.83	10.89	10.75
CaO	0.07	0.11	0.25	0.03	0.23	0.31	0.00	0.02
Na ₂ O	0.11	0.11	0.12	0.10	0.10	0.13	0.12	0.11
K ₂ O	8.98	9.17	8.93	9.24	8.62	8.28	9.15	9.28
Cl	0.06	0.05	0.08	0.07	0.10	0.07	0.06	0.09
F	0.00	0.00	0.01	0.00	0.00	0.02	0.05	0.02
Si	5.67	5.66	5.67	5.71	5.69	5.71	5.67	5.68
Al iv	2.33	2.34	2.33	2.29	2.31	2.29	2.33	2.32
Al T	2.73	2.81	2.74	2.69	2.72	2.71	2.77	2.75
Al vi	0.39	0.47	0.41	0.40	0.41	0.42	0.44	0.43
Ti	0.33	0.25	0.27	0.32	0.27	0.23	0.32	0.32
Fe(ii)	2.37	2.27	2.33	2.32	2.40	2.40	2.28	2.29
Mn	0.19	0.22	0.23	0.20	0.20	0.20	0.20	0.20
Mg	2.42	2.53	2.48	2.46	2.47	2.54	2.47	2.45
Ca	0.01	0.02	0.04	0.00	0.04	0.05	0.00	0.00
Na	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.03
K	1.79	1.82	1.78	1.80	1.70	1.66	1.78	1.81
Cl	0.02	0.01	0.02	0.02	0.03	0.02	0.02	0.02
F	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01
Toplam	15.54	15.61	15.59	15.53	15.53	15.54	15.53	15.53
Fe/Fe+Mg	0.49	0.47	0.48	0.49	0.49	0.49	0.48	0.48

Çizelge 3'in devamı

Örnek no.	AM19	AM19	AM19	AM21	AM21	AM21	AM21	AM21
Plüton/Alan	Nimu	Nimu	Nimu	Umla	Umla	Umla	Umla	Umla
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	11	12	13	1	2	3	4	5
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	36.82	37.38	37.35	37.37	36.60	37.44	37.36	37.69
TiO ₂	2.02	2.63	2.72	3.43	3.00	1.53	2.53	2.70
Al ₂ O ₃	15.14	15.46	15.18	15.08	15.26	15.98	15.37	15.88
FeO	18.04	17.72	18.01	18.01	18.04	17.89	17.07	17.53
MnO	1.72	1.41	1.46	0.58	0.54	0.59	0.56	0.61
MgO	10.79	10.96	10.80	10.82	11.02	11.92	11.29	11.51
CaO	0.11	0.00	0.00	0.00	0.01	0.01	0.05	0.02
Na ₂ O	0.12	0.09	0.09	0.06	0.06	0.08	0.09	0.07
K ₂ O	8.77	9.55	9.30	9.62	9.39	9.54	9.09	9.65
Cl	0.06	0.09	0.05	0.05	0.07	0.06	0.07	0.07
F	0.02	0.04	0.00	0.00	0.00	0.03	0.00	0.00
Si	5.71	5.69	5.70	5.69	5.64	5.69	5.74	5.67
Al iv	2.29	2.31	2.30	2.31	2.36	2.31	2.26	2.33
Al T	2.77	2.77	2.73	2.71	2.77	2.86	2.78	2.82
Al vi	0.47	0.46	0.43	0.40	0.41	0.55	0.52	0.49
Ti	0.24	0.30	0.31	0.39	0.35	0.17	0.29	0.31
Fe(ii)	2.34	2.25	2.30	2.29	2.32	2.27	2.19	2.21
Mn	0.23	0.18	0.19	0.07	0.07	0.08	0.07	0.08
Mg	2.49	2.49	2.46	2.46	2.53	2.70	2.58	2.58
Ca	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Na	0.04	0.03	0.03	0.02	0.02	0.02	0.03	0.02
K	1.73	1.85	1.81	1.87	1.84	1.85	1.78	1.85
Cl	0.02	0.02	0.01	0.01	0.02	0.01	0.02	0.02
F	0.01	0.02	0.00	0.00	0.00	0.01	0.00	0.00
Toplam	15.55	15.56	15.53	15.50	15.55	15.64	15.48	15.54
Fe/Fe+Mg	0.48	0.48	0.48	0.48	0.48	0.46	0.46	0.46

Çizelge 3'in devamı

Örnek no.	AM21	AM21	AM21	AM21	AM21	AM21	AM21	AM21
Plüton/Alan	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	6	7	8	9	10	11	12	13
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.13	37.40	37.40	37.13	37.67	37.07	36.95	37.61
TiO ₂	2.54	2.03	2.26	3.09	2.97	2.78	2.67	2.77
Al ₂ O ₃	15.52	16.00	15.93	15.10	15.43	15.44	15.66	16.32
FeO	17.67	17.15	17.25	17.89	18.05	18.44	18.40	17.10
MnO	0.65	0.48	0.54	0.58	0.62	0.59	0.56	0.48
MgO	11.38	11.95	11.35	10.83	11.05	11.18	11.24	11.45
CaO	0.02	0.01	0.04	0.01	0.00	0.00	0.01	0.00
Na ₂ O	0.08	0.08	0.08	0.03	0.09	0.14	0.11	0.07
K ₂ O	9.39	9.25	9.48	9.63	9.61	9.47	9.50	9.76
Cl	0.07	0.07	0.06	0.06	0.06	0.08	0.06	0.06
F	0.03	0.11	0.03	0.02	0.06	0.02	0.00	0.00
Si	5.67	5.68	5.70	5.70	5.70	5.65	5.63	5.65
Al iv	2.33	2.32	2.30	2.30	2.30	2.35	2.37	2.35
Al T	2.80	2.87	2.86	2.73	2.75	2.77	2.81	2.89
Al vi	0.47	0.55	0.56	0.43	0.45	0.42	0.44	0.54
Ti	0.29	0.23	0.26	0.36	0.34	0.32	0.31	0.31
Fe(ii)	2.26	2.18	2.20	2.30	2.28	2.35	2.34	2.15
Mn	0.08	0.06	0.07	0.07	0.08	0.08	0.07	0.06
Mg	2.59	2.71	2.58	2.48	2.49	2.54	2.55	2.57
Ca	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Na	0.02	0.02	0.02	0.01	0.03	0.04	0.03	0.02
K	1.83	1.79	1.84	1.88	1.85	1.84	1.85	1.87
Cl	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.02
F	0.02	0.05	0.02	0.01	0.03	0.01	0.00	0.00
Toplam	15.55	15.55	15.54	15.52	15.52	15.58	15.59	15.53
Fe/Fe+Mg	0.47	0.45	0.46	0.48	0.48	0.48	0.48	0.46

Çizelge 3'in devamı

Örnek no.	AM21	AM21	AM22	AM22	AM22	AM22	AM24	AM24
Plüton/Alan	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	14	15	1	2	3	4	1	2
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.64	37.47	37.12	37.53	38.13	38.14	37.58	37.57
TiO ₂	2.58	2.75	1.34	3.05	3.02	2.69	1.93	1.92
Al ₂ O ₃	15.95	15.99	15.60	13.88	14.91	14.52	15.24	15.53
FeO	17.56	17.20	18.25	18.04	17.82	17.48	19.12	18.44
MnO	0.51	0.58	0.51	0.61	0.52	0.48	0.67	0.69
MgO	11.42	11.26	12.57	12.33	11.62	12.16	11.38	11.14
CaO	0.00	0.00	0.07	0.21	0.03	0.18	0.02	0.01
Na ₂ O	0.09	0.08	0.07	0.09	0.09	0.09	0.07	0.07
K ₂ O	9.51	9.73	8.73	8.87	9.23	8.50	9.57	9.55
Cl	0.07	0.04	0.06	0.05	0.04	0.05	0.09	0.09
F	0.06	0.02	0.41	0.50	0.42	0.56	0.00	0.03
Si	5.68	5.67	5.67	5.73	5.75	5.79	5.71	5.73
Al iv	2.32	2.33	2.33	2.27	2.25	2.21	2.29	2.27
Al T	2.84	2.85	2.81	2.50	2.65	2.60	2.73	2.79
Al vi	0.52	0.53	0.48	0.22	0.40	0.39	0.44	0.52
Ti	0.29	0.31	0.15	0.35	0.34	0.31	0.22	0.22
Fe(ii)	2.22	2.18	2.33	2.30	2.25	2.22	2.43	2.35
Mn	0.07	0.07	0.07	0.08	0.07	0.06	0.09	0.09
Mg	2.57	2.54	2.86	2.80	2.61	2.75	2.58	2.53
Ca	0.00	0.00	0.01	0.03	0.01	0.03	0.00	0.00
Na	0.03	0.02	0.02	0.03	0.03	0.03	0.02	0.02
K	1.83	1.88	1.70	1.73	1.78	1.65	1.86	1.86
Cl	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02
F	0.03	0.01	0.20	0.24	0.20	0.27	0.00	0.02
Toplam	15.53	15.53	15.62	15.55	15.48	15.43	15.63	15.59
Fe/Fe+Mg	0.46	0.46	0.45	0.45	0.46	0.45	0.49	0.48

Çizelge 3'in devamı

Örnek no.	AM24	AM24	AM24	AM24	AM24	AM24	AM24	AM37
Plüton/Alan	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Taru
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	3	4	5	6	7	8	9	1
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.22	36.81	36.74	36.84	36.76	37.28	36.49	37.535
TiO ₂	3.42	3.52	3.16	3.20	1.97	3.75	3.13	3.228
Al ₂ O ₃	14.54	14.44	13.95	14.12	14.52	14.39	14.15	14.612
FeO	19.44	19.28	19.70	19.48	18.91	19.33	19.16	18.73
MnO	0.75	0.79	0.58	0.75	0.62	0.73	0.66	0.607
MgO	10.86	10.46	11.03	10.79	11.31	10.83	10.73	11.288
CaO	0.04	0.00	0.11	0.09	0.23	0.00	0.02	0
Na ₂ O	0.11	0.05	0.12	0.11	0.17	0.09	0.06	0.089
K ₂ O	9.41	9.52	8.90	9.17	8.51	9.45	9.61	9.587
Cl	0.08	0.09	0.13	0.09	0.12	0.08	0.10	0.123
F	0.00	0.00	0.04	0.00	0.00	0.03	0.00	0
Si	5.66	5.66	5.68	5.68	5.73	5.67	5.67	5.6924
Al iv	2.34	2.34	2.32	2.32	2.27	2.33	2.33	2.3076
Al T	2.61	2.62	2.54	2.57	2.67	2.58	2.59	2.611552
Al vi	0.27	0.28	0.22	0.25	0.39	0.24	0.26	0.303952
Ti	0.39	0.41	0.37	0.37	0.23	0.43	0.37	0.3682
Fe(ii)	2.47	2.48	2.55	2.51	2.46	2.46	2.49	2.375198
Mn	0.10	0.10	0.08	0.10	0.08	0.09	0.09	0.077963
Mg	2.46	2.40	2.54	2.48	2.62	2.45	2.49	2.552119
Ca	0.01	0.00	0.02	0.01	0.04	0.00	0.00	0
Na	0.03	0.01	0.04	0.03	0.05	0.03	0.02	0.026167
K	1.83	1.87	1.76	1.81	1.69	1.83	1.91	1.854602
Cl	0.02	0.02	0.03	0.02	0.03	0.02	0.03	0.031614
F	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0
Toplam	15.56	15.55	15.56	15.57	15.57	15.53	15.62	15.5582
Fe/Fe+Mg	0.50	0.51	0.50	0.50	0.48	0.50	0.50	0.482047

Çizelge 3'in devamı

Örnek no.	AM37	AM37	AM37	AM37	AM37	AM37	AM37	AM37
Plüton/Alan	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	2	3	4	5	6	7	8	9
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.147	37.862	36.77	37.589	36.864	37.074	37.058	36.913
TiO ₂	2.682	3.057	2.326	2.425	2.423	2.484	2.877	2.813
Al ₂ O ₃	14.874	14.809	15.129	14.964	15.093	15.121	14.62	14.824
FeO	18.352	18.652	18.795	18.151	19.432	19.312	19.156	18.703
MnO	0.659	0.562	0.609	0.713	0.632	0.643	0.794	0.66
MgO	11.232	11.539	11.334	11.845	11.193	11.034	11.446	11.362
CaO	0.021	0.007	0	0.025	0.031	0	0.1	0.005
Na ₂ O	0.128	0.095	0.106	0.047	0.092	0.061	0.065	0.091
K ₂ O	9.295	9.174	9.614	9.637	9.164	9.629	8.783	9.159
Cl	0.129	0.106	0.104	0.112	0.104	0.112	0.095	0.105
F	0	0	0	0.046	0	0	0	0
Si	5.70	5.71	5.65	5.70	5.65	5.66	5.67	5.66
Al iv	2.30	2.29	2.35	2.30	2.35	2.34	2.33	2.34
Al T	2.69	2.63	2.74	2.68	2.73	2.72	2.63	2.68
Al vi	0.39	0.35	0.39	0.38	0.37	0.38	0.30	0.34
Ti	0.31	0.35	0.27	0.28	0.28	0.29	0.33	0.32
Fe(ii)	2.35	2.35	2.41	2.30	2.49	2.47	2.45	2.40
Mn	0.09	0.07	0.08	0.09	0.08	0.08	0.10	0.09
Mg	2.57	2.60	2.60	2.68	2.56	2.51	2.61	2.60
Ca	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00
Na	0.04	0.03	0.03	0.01	0.03	0.02	0.02	0.03
K	1.82	1.77	1.88	1.86	1.79	1.88	1.71	1.79
Cl	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03
F	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Toplam	15.56	15.51	15.66	15.61	15.61	15.62	15.54	15.57
Fe/Fe+Mg	0.48	0.48	0.48	0.46	0.49	0.50	0.48	0.48

Çizelge 3'in devamı

Örnek no.	AM37	AM38	AM38	AM38	AM38	AM38	AM38	AM38
Plüton/Alan	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	10	1	2	3	4	5	6	7
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.312	37.10	37.05	37.37	36.89	34.98	36.75	36.72
TiO ₂	1.734	3.56	3.78	3.53	3.21	3.42	3.29	3.60
Al ₂ O ₃	15.433	14.91	15.02	15.18	14.43	14.94	14.88	14.45
FeO	18.618	18.67	18.41	18.37	18.93	19.55	19.53	18.55
MnO	0.623	0.47	0.40	0.46	0.47	0.58	0.54	0.44
MgO	11.86	10.58	10.34	10.86	10.96	11.67	10.77	11.27
CaO	0	0.01	0.05	0.00	0.17	0.21	0.01	0.09
Na ₂ O	0.077	0.09	0.08	0.10	0.12	0.11	0.04	0.12
K ₂ O	9.282	9.30	9.14	9.29	8.02	7.68	9.45	9.04
Cl	0.126	0.12	0.06	0.07	0.10	0.09	0.09	0.06
F	0.027	0.13	0.00	0.08	0.14	0.06	0.11	0.08
Si	5.68	5.67	5.68	5.67	5.71	5.46	5.62	5.65
Al iv	2.32	2.33	2.32	2.33	2.29	2.54	2.38	2.35
Al T	2.77	2.69	2.71	2.72	2.63	2.75	2.68	2.62
Al vi	0.46	0.36	0.39	0.39	0.34	0.20	0.31	0.26
Ti	0.20	0.41	0.44	0.40	0.37	0.40	0.38	0.42
Fe(ii)	2.37	2.39	2.36	2.33	2.45	2.55	2.50	2.38
Mn	0.08	0.06	0.05	0.06	0.06	0.08	0.07	0.06
Mg	2.69	2.41	2.36	2.46	2.53	2.71	2.46	2.58
Ca	0.00	0.00	0.01	0.00	0.03	0.04	0.00	0.01
Na	0.02	0.03	0.02	0.03	0.04	0.03	0.01	0.03
K	1.80	1.81	1.79	1.80	1.58	1.53	1.84	1.77
Cl	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.02
F	0.01	0.06	0.00	0.04	0.07	0.03	0.05	0.04
Toplam	15.63	15.48	15.42	15.47	15.40	15.54	15.57	15.52
Fe/Fe+Mg	0.47	0.50	0.50	0.49	0.49	0.48	0.50	0.48

Çizelge 3'in devamı

Örnek no.	AM38	AM38	AM38	AM38	AM38	AM38	AM38	AM38
Plüton/Alan	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	8	9	10	11	12	13	14	15
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	36.52	37.71	35.93	38.05	37.56	36.96	36.47	36.71
TiO ₂	3.37	3.37	3.56	2.93	3.36	3.33	3.30	3.79
Al ₂ O ₃	14.50	14.75	13.80	15.55	15.34	14.96	14.46	14.68
FeO	17.86	18.55	18.81	18.12	18.68	18.94	18.91	19.04
MnO	0.44	0.51	0.45	0.37	0.50	0.54	0.52	0.45
MgO	10.94	11.42	10.54	11.38	10.92	10.79	10.86	10.62
CaO	0.01	0.08	0.35	0.03	0.00	0.00	0.18	0.00
Na ₂ O	0.09	0.08	0.15	0.08	0.09	0.08	0.11	0.05
K ₂ O	9.22	9.02	7.59	9.19	9.58	9.47	8.76	9.59
Cl	0.08	0.08	0.11	0.07	0.06	0.08	0.09	0.05
F	0.12	0.12	0.07	0.01	0.08	0.10	0.04	0.08
Si	5.68	5.70	5.69	5.72	5.66	5.65	5.66	5.63
Al iv	2.32	2.30	2.31	2.28	2.34	2.35	2.34	2.37
Al T	2.66	2.63	2.58	2.75	2.73	2.69	2.64	2.65
Al vi	0.34	0.33	0.27	0.47	0.39	0.34	0.30	0.29
Ti	0.39	0.38	0.42	0.33	0.38	0.38	0.39	0.44
Fe(ii)	2.32	2.35	2.49	2.28	2.36	2.42	2.45	2.44
Mn	0.06	0.07	0.06	0.05	0.06	0.07	0.07	0.06
Mg	2.54	2.57	2.49	2.55	2.46	2.46	2.51	2.43
Ca	0.00	0.01	0.06	0.00	0.00	0.00	0.03	0.00
Na	0.03	0.02	0.05	0.02	0.03	0.02	0.03	0.02
K	1.83	1.74	1.53	1.76	1.84	1.85	1.73	1.88
Cl	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.01
F	0.06	0.06	0.03	0.00	0.04	0.05	0.02	0.04
Toplam	15.51	15.47	15.37	15.46	15.52	15.54	15.51	15.54
Fe/Fe+Mg	0.48	0.48	0.50	0.47	0.49	0.50	0.49	0.50

Çizelge 3'in devamı

Örnek no.	AM38	AM38	AM41	AM41	AM41	AM41	AM41	AM41
Plüton/Alan	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Kayaç Türü	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit	G.diyorit
Nokta analizi	16	17	1	2	3	4	5	6
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.33	37.62	37.25	37.58	37.03	37.16	36.85	37.44
TiO ₂	3.28	2.90	2.07	2.26	3.68	3.17	1.68	3.13
Al ₂ O ₃	15.21	15.88	15.17	15.49	14.28	14.31	15.36	14.48
FeO	18.88	18.40	18.10	18.51	18.71	18.95	18.26	19.11
MnO	0.47	0.37	0.69	0.66	0.72	0.72	0.66	0.71
MgO	10.65	11.18	11.50	11.36	10.86	10.99	11.99	11.18
CaO	0.01	0.07	0.08	0.02	0.01	0.01	0.04	0.05
Na ₂ O	0.08	0.05	0.08	0.10	0.09	0.07	0.06	0.08
K ₂ O	9.48	8.96	9.70	9.71	9.26	9.32	9.16	9.45
Cl	0.09	0.07	0.06	0.09	0.08	0.08	0.09	0.11
F	0.11	0.01	0.11	0.11	0.12	0.05	0.23	0.10
Si	5.67	5.67	5.70	5.69	5.68	5.70	5.67	5.69
Al iv	2.33	2.33	2.30	2.31	2.32	2.30	2.33	2.31
Al T	2.72	2.82	2.74	2.76	2.58	2.59	2.78	2.60
Al vi	0.40	0.49	0.44	0.45	0.27	0.29	0.45	0.29
Ti	0.38	0.33	0.24	0.26	0.42	0.37	0.19	0.36
Fe(ii)	2.40	2.32	2.32	2.34	2.40	2.43	2.35	2.43
Mn	0.06	0.05	0.09	0.08	0.09	0.09	0.09	0.09
Mg	2.41	2.51	2.63	2.56	2.48	2.51	2.75	2.53
Ca	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01
Na	0.02	0.01	0.02	0.03	0.03	0.02	0.02	0.02
K	1.84	1.72	1.89	1.88	1.81	1.82	1.80	1.83
Cl	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
F	0.05	0.00	0.05	0.05	0.06	0.02	0.11	0.05
Toplam	15.51	15.45	15.64	15.61	15.51	15.55	15.64	15.56
Fe/Fe+Mg	0.50	0.48	0.47	0.48	0.49	0.49	0.46	0.49

Çizelge 3'in devamı

Örnek no.	AM41	AM41	AM41	AM41
Plüton/Alan	Taru	Taru	Taru	Taru
Kayaç Türü	Monzodiyorit	Monzodiyorit	Monzodiyorit	Monzodiyorit
Nokta analizi	7	8	9	10
Mineral	Bt	Bt	Bt	Bt
SiO ₂	37.01	37.18	36.68	37.59
TiO ₂	2.43	3.47	3.11	1.90
Al ₂ O ₃	14.54	14.68	14.28	15.33
FeO	18.71	18.75	18.65	17.70
MnO	0.73	0.66	0.56	0.61
MgO	10.83	10.57	10.80	11.63
CaO	0.00	0.00	0.00	0.17
Na ₂ O	0.08	0.07	0.10	0.11
K ₂ O	9.30	9.39	9.39	8.48
Cl	0.08	0.07	0.10	0.08
F	0.15	0.06	0.04	0.09
Si	5.74	5.69	5.70	5.76
Al iv	2.26	2.31	2.30	2.24
Al T	2.66	2.65	2.61	2.77
Al vi	0.40	0.34	0.31	0.53
Ti	0.28	0.40	0.36	0.22
Fe(ii)	2.43	2.40	2.42	2.27
Mn	0.10	0.09	0.07	0.08
Mg	2.50	2.41	2.50	2.66
Ca	0.00	0.00	0.00	0.03
Na	0.02	0.02	0.03	0.03
K	1.84	1.83	1.86	1.66
Cl	0.02	0.02	0.03	0.02
F	0.07	0.03	0.02	0.04
Toplam	15.57	15.50	15.56	15.47
Fe/Fe+Mg	0.49	0.50	0.49	0.46

Çizelge 4. Trans-Himalaya Kuşağı (Hindistan) çevresindeki Ladakh Batholith'in Leh bölgesinden toplanan numunelerin XRF ve CIPW değerleri

Plüton/Alan	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Örnek no	AM1	AM2	AM3	AM4	AM5	AM6	AM7
Kaya Tipi	Granit	Granit	Diyorit	Granit	Granit	G.diyorit	G.diyorit
SiO₂	70.4	72.4	59.6	73.8	73.2	69.5	67.3
Al₂O₃	14.4	13.6	16.5	13.2	11.7	13.3	13.3
Fe₂O₃	3.94	2.86	7.29	2.63	3.88	4.21	5.49
CaO	1.86	1.59	5.53	1.28	2.45	2.74	4.12
MgO	0.55	0.57	2.84	0.43	1.15	1.73	1.3
Na₂O	3.72	3.3	3.79	3.95	3.1	3.04	2.53
K₂O	4.44	4.77	2.52	3.9	1.5	1.86	1.49
MnO	0.08	0.07	0.12	0.1	0.08	0.09	0.08
TiO₂	0.26	0.025	0.82	0.2	0.44	0.48	0.72
P₂O₅	0.08	0.07	0.22	0.05	0.07	0.09	0.1
Cr₂O₃	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Toplam (LOI hariç)	99.74	99.265	99.24	99.55	97.58	97.05	96.44
LOI	-0.38	-0.29	0.14	-0.39	1.41	2.08	2.72
CIPW norm.(%)							
Qtz	27.19	30.89	13.62	32.66	42.66	36.5	36.4
Plg	40.18	35.35	52.64	39.45	37.93	38.73	41.19
Or	26.24	28.19	14.89	23.05	8.86	10.99	8.81
Cm	0.28	0.28	0	0.27	0.69	1.52	0.27
Di	0	0	2.37	0	0	0	0
Hyp	1.37	1.42	5.97	1.07	2.86	4.31	3.24
Ol	0	0	0	0	0	0	0
Rt	0.17	0	0	0.09	0.35	0.38	0.63
Ilm	0.17	0.06	0.26	0.21	0.17	0.19	0.17
Mag	0	0.14	0	0	0	0	0
Hem	3.94	2.76	7.29	2.63	3.88	4.21	5.49
Ap	0.19	0.16	0.51	0.12	0.16	0.21	0.23
Spn	0	0	1.68	0	0	0	0

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Basgo AM8 G.diyorit	Basgo AM9 G.diyorit	Basgo AM10 Granit	Nimu AM11 Granit	Nimu AM12 G.diyorit	Nimu AM13 G.diyorit	Nimu AM14 Granit
SiO ₂	64.3	71.6	73.5	74.4	67.6	65.1	72
Al ₂ O ₃	14.2	13.7	12.2	12.1	14.4	12.9	13.1
Fe ₂ O ₃	7.56	3.22	4.33	3.34	5.2	4.59	3.23
CaO	2.88	1.22	2.05	3.08	2.23	4.46	1.18
MgO	2.88	1.49	1.34	0.55	1.83	2.71	1.21
Na ₂ O	3.48	5.29	2.43	3.5	4.31	2.71	4.38
K ₂ O	1.02	0.94	1.47	1.33	1.79	1.54	2.73
MnO	0.13	0.06	0.09	0.08	0.08	0.1	0.06
TiO ₂	0.79	0.32	0.41	0.26	0.45	0.48	0.29
P ₂ O ₅	0.09	0.06	0.07	0.05	0.08	0.12	0.07
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.03	0.01
Toplam (LOI hariç)	97.34	97.91	97.9	98.7	97.98	94.74	98.26
LOI	2.08	1.03	1.4	0.68	1.39	4.56	1.03
CIPW norm.(%)							
Qtz	29.94	32.57	47.55	42.01	28.4	30.8	31.94
Plg	43.15	50.42	30.27	42.99	47.01	41.42	42.46
Or	6.03	5.56	8.69	7.86	10.58	9.1	16.13
Cm	2.35	1.91	3.05	0	1.51	0	0.96
Di	0	0	0	0.77	0	1.23	0
Hyp	7.17	3.71	3.34	1.01	4.56	6.18	3.01
Ol	0	0	0	0	0	0	0
Rt	0.64	0.25	0.31	0	0.36	0	0.22
Ilm	0.28	0.13	0.19	0.17	0.17	0.21	0.13
Mag	0	0	0	0	0	0	0
Hem	7.56	3.22	4.33	3.34	5.2	4.59	3.23
Ap	0.21	0.14	0.16	0.12	0.19	0.28	0.16
Spn	0	0	0	0.42	0	0.9	0

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Nimu AM15 Granit	Nimu AM16 G.diyorit	Nimu AM17 G.diyorit	Nimu AM18 G.diyorit	Nimu AM19 G.diyorit	Nimu AM20 G.diyorit	Umla AM21 G.diyorit
SiO ₂	72.6	68.9	65	65.9	72.1	66.3	68.7
Al ₂ O ₃	12.6	15.1	16.3	16.6	13.7	15.9	15.1
Fe ₂ O ₃	2.67	4.5	5.33	4.78	3.24	4.85	3.83
CaO	1.55	3	3.96	3.77	2.17	3.85	3.12
MgO	0.92	1.1	1.47	1.35	0.57	1.17	0.98
Na ₂ O	4.43	4.62	4.83	5.01	3.24	4.77	4.98
K ₂ O	2.69	1.8	1.42	1.56	4.26	1.54	1.58
MnO	0.06	0.11	0.12	0.12	0.12	0.12	0.09
TiO ₂	0.24	0.49	0.65	0.59	0.23	0.58	0.5
P ₂ O ₅	0.05	0.12	0.2	0.2	0.08	0.17	0.16
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Toplam (LOI hariç)	97.82	99.75	99.29	99.89	99.72	99.26	99.05
LOI	1.23	-0.18	-0.02	-0.01	-0.16	-0.22	-0.1
CIPW norm.(%)							
Qtz	32.16	27.41	21.36	21.26	31.68	23.27	26.05
Plg	44.04	53.19	59.21	59.79	37.66	57.79	56.32
Or	15.9	10.64	8.39	9.22	25.18	9.1	9.34
Cm	0	0.38	0.1	0.29	0	0	0
Di	0.17	0	0	0	0	0	0
Hyp	2.21	2.74	3.66	3.36	1.42	2.91	2.44
Ol	0	0	0	0	0	0	0
Rt	0	0.37	0.51	0.45	0.09	0.28	0.33
Ilm	0.13	0.24	0.26	0.26	0.26	0.26	0.19
Mag	0	0	0	0	0	0	0
Hem	2.67	4.5	5.33	4.78	3.24	4.85	3.83
Ap	0.12	0.28	0.46	0.46	0.19	0.39	0.37
Spn	0.42	0	0	0	0	0.4	0.18

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Umla AM22 Granit	Umla AM23 G.diyorit	Umla AM24 G.diyorit	Umla AM25 Monzonit	Umla AM26 G.diyorit	Umla AM27 G.diyorit	Umla AM28 G.diyorit
SiO ₂	75.7	70.6	65	54.5	66.4	67.2	67.3
Al ₂ O ₃	12.5	15	14.5	17.7	15.4	15	16.3
Fe ₂ O ₃	2.03	2.86	6.71	9.99	4.52	4.74	3.79
CaO	0.95	3.29	3.18	3.94	3.38	3.36	3.62
MgO	0.19	0.89	2.16	3.07	1.49	1.58	1.09
Na ₂ O	3.05	4.26	3.47	4.02	4	3.85	4.59
K ₂ O	5.2	2.29	3.67	4.6	3.16	3.24	2.59
MnO	0.04	0.07	0.16	0.23	0.11	0.11	0.09
TiO ₂	0.14	0.28	0.7	0.87	0.46	0.52	0.34
P ₂ O ₅	0.02	0.09	0.2	0.27	0.13	0.12	0.11
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Toplam (LOI hariç)	99.83	99.64	99.76	99.2	99.06	99.73	99.83
LOI	-0.22	0.15	0.12	0.51	0.07	0.12	0.06
CIPW norm.(%)							
Qtz	35.8	29.08	21.59	1.5	22.2	23.58	21.84
Plg	30.39	51.09	42.51	50.68	48.58	46.65	55.06
Or	30.73	13.53	21.69	27.18	18.67	19.15	15.31
Cm	0.17	0	0	0	0	0	0
Di	0	0	0	0	0.01	0.33	0.15
Hyp	0.47	2.22	5.38	7.65	3.71	3.78	2.65
Ol	0	0	0	0	0	0	0
Rt	0.09	0	0.14	0.29	0	0	0
Ilm	0.09	0.15	0.34	0.49	0.24	0.24	0.19
Mag	0	0	0	0	0	0	0
Hem	2.03	2.86	6.71	9.99	4.52	4.74	3.79
Ap	0.05	0.21	0.46	0.63	0.3	0.28	0.25
Spn	0	0.49	0.93	0.79	0.82	0.97	0.59

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Umla AM29 Monzonit	Umla AM30 G.diyorit	Taru AM31 Granit	Taru AM32 G.diyorit	Taru AM33 G.diyorit	Taru AM34 G.diyorit	Taru AM35 G.diyorit
SiO ₂	58.9	67.9	74.2	69.7	64	67.4	65.6
Al ₂ O ₃	16.9	14.3	13.2	15.3	16.2	15.1	15.3
Fe ₂ O ₃	6.98	5.3	2.49	3.07	5.29	5.06	5.75
CaO	4.46	4	1.42	3.65	4.43	3.98	3.99
MgO	2.16	1.2	0.32	0.95	1.76	1.45	1.81
Na ₂ O	4.82	3.34	3.3	4.66	4.82	4.38	4.24
K ₂ O	2.91	2.78	4.61	1.41	1.79	1.69	1.8
MnO	0.1	0.1	0.04	0.07	0.16	0.11	0.13
TiO ₂	1.08	0.45	0.15	0.32	0.55	0.49	0.57
P ₂ O ₅	0.69	0.11	0.04	0.09	0.14	0.14	0.17
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Toplam (LOI hariç)	99.01	99.49	99.78	99.23	99.15	99.81	99.37
LOI	0.22	0.08	-0.19	0.2	0.05	-0.1	0.11
CIPW norm.(%)							
Qtz	9.27	28.5	33.95	28.4	18.21	25.65	23.56
Plg	56.67	44.08	34.71	56.1	58.07	53.61	53.28
Or	17.2	16.43	27.24	8.33	10.58	9.99	10.64
Cm	0	0	0.3	0	0	0	0
Di	0	1.66	0	0.01	1.94	0.78	0
Hyp	5.38	2.22	0.8	2.36	3.48	3.25	4.51
Ol	0	0	0	0	0	0	0
Rt	0.47	0	0.1	0	0	0	0.05
Ilm	0.21	0.21	0.09	0.15	0.34	0.24	0.28
Mag	0	0	0	0	0	0	0
Hem	6.98	5.3	2.49	3.07	5.29	5.06	5.75
Ap	1.6	0.25	0.09	0.21	0.32	0.32	0.39
Spn	1.22	0.83	0	0.59	0.91	0.9	0.91

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Taru AM36 Granodiyorit	Taru AM37 Granodiyorit	Taru AM38 Granit	Taru AM39 Granit	Taru AM40 Granit	Taru AM41 Monzodiyorit
SiO ₂	66.9	65.5	73.4	75.1	75.8	51.8
Al ₂ O ₃	15.5	15.9	13.5	13	12.3	17.9
Fe ₂ O ₃	4.7	5.3	2.3	2.17	2.06	11.1
CaO	3.92	4.2	1.53	1.77	1.3	5.69
MgO	1.49	1.62	0.38	0.31	0.3	4
Na ₂ O	4.56	4.66	3.38	3.56	2.76	4.76
K ₂ O	1.66	1.49	4.74	3.52	4.96	2.16
MnO	0.11	0.12	0.04	0.03	0.04	0.35
TiO ₂	0.48	0.54	0.19	0.13	0.13	1.14
P ₂ O ₅	0.14	0.15	0.03	0.03	0.04	0.36
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.01
Toplam (LOI hariç)	99.47	99.49	99.5	99.63	99.7	99.27
LOI	0.03	-0.09	-0.21	-0.37	-0.13	0.46
CIPW norm.(%)						
Qtz	24.15	22.09	31.84	36.75	37.64	0
Plg	55.51	57.5	35.99	38.71	29.54	61.37
Or	9.81	8.81	28.01	20.8	29.31	12.76
Cm	0	0	0.1	0.19	0.12	0
Di	0.29	0.3	0	0	0	1.7
Hyp	3.58	3.9	0.95	0.77	0.75	8.3
Ol	0	0	0	0	0	0.61
Rt	0	0	0.14	0.1	0.08	0
Ilm	0.24	0.26	0.09	0.06	0.09	0.75
Mag	0	0	0	0	0	0
Hem	4.7	5.3	2.3	2.17	2.06	11.1
Ap	0.32	0.35	0.07	0.07	0.09	0.83
Spn	0.87	0.99	0	0	0	1.83

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Basgo AM1 Granit	Basgo AM2 Granit	Basgo AM3 Diyorit	Basgo AM4 Granit	Basgo AM5 Granit	Basgo AM6 G.diyorit	Basgo AM7 G.diyorit
V	23	24	144	14	70	74	181
Co	3.3	3.5	15.7	2.6	6.4	9.7	8.3
Ni	3.6	2.7	7.9	2.1	12.3	22.9	3.7
Cu	4.9	4.1	40.5	4	12.3	16.3	13.2
Zn	62	61	72	110	69	110	56
Ga	14	13	15.8	11.6	9.5	11.8	11.5
Rb	164.7	154.1	81.6	110.6	46.9	60.8	44.1
Ba	713	599	503	428	416	275	241
Th	20.1	20.8	9.6	14.4	10.4	7.9	5.5
U	3.8	2.9	1.7	1.7	1.7	1.8	1.3
Nb	7.6	6.5	6.3	8.8	4.2	4.3	3.9
La	40.7	23.6	26.5	27.5	18.2	17.6	15.2
Ce	77.4	47.9	58.6	49.8	36.5	36.6	29.7
Pb	4.2	3.6	2.2	4.5	10	4.9	3.9
Pr	7.83	5.21	6.73	4.87	3.93	4.14	3.65
Sr	263	232	561.9	113.3	304.8	310.9	325.7
Nd	26	18.8	25.4	15.6	14	16.2	15
Zr	196.1	161.2	193.7	117.4	144.6	155.1	121.2
Hf	5.6	4.5	5.3	3.6	4.3	4.6	3.3
Sm	4.27	3.6	4.59	3.13	2.67	2.83	2.83
Eu	0.73	0.7	1.18	0.4	0.63	0.8	0.88
Ti	1558.3	149.8	4914.6	1198.7	2637.1	2876.8	4315.3
Gd	3.64	2.9	4.21	2.93	2.46	2.96	2.97
Tb	0.53	0.43	0.66	0.48	0.38	0.45	0.44
Dy	3.21	2.58	3.76	3.02	2.51	2.75	2.82
Y	18.1	15.1	19.3	17.5	13.7	15.7	16.3
Ho	0.64	0.52	0.74	0.64	0.46	0.6	0.6
Yb	1.82	1.7	2.08	2.13	1.53	1.62	1.6
Er	1.83	1.58	2	1.84	1.39	1.77	1.61
Tm	0.28	0.24	0.3	0.3	0.21	0.24	0.24
Lu	0.29	0.27	0.31	0.33	0.24	0.26	0.28
(La/Yb)n	14.77	9.17	8.41	8.53	7.85	7.17	6.27
(Gd/Yb)n	1.61	1.37	1.63	1.10	1.29	1.47	1.49
Eu/Eu*	0.56	0.65	0.82	0.40	0.75	0.85	0.93

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Basgo AM8 G.diyorit	Basgo AM9 G.diyorit	Basgo AM10 Granit	Nimu AM11 Granit	Nimu AM12 G.diyorit	Nimu AM13 G.diyorit	Nimu AM14 Granit
V	191	50	90	55	79	70	39
Co	16.6	6.5	5.2	4.6	9.3	13.7	5.5
Ni	6.8	9.1	4.8	3.6	12.2	94	28.8
Cu	27.5	8	8.9	10.7	13.3	20.3	10
Zn	130	89	74	131	113	91	94
Ga	14	10.9	9.9	8	12.2	11.9	12.1
Rb	34.5	37.3	41.1	37.8	47	65.8	98.8
Ba	257	341	244	228	291	221	494
Th	5.7	7.8	6.1	6.2	6.2	12.1	11.1
U	1.3	2.1	1.3	1.1	1.2	4	3.8
Nb	3.9	4.4	2.6	2.8	4	7.5	6.3
La	14.2	15.4	14	10.5	15.8	25.9	19.6
Ce	28.4	30.8	28.1	20.2	32	49.9	37.9
Pb	3.6	6.9	2.3	4.4	7.4	15.4	14.9
Pr	3.43	3.45	3.25	2.37	3.57	5.52	3.97
Sr	582.3	391.7	177.8	233.7	271.8	188.7	218.4
Nd	13.6	12.5	12.4	8.5	13.7	19.7	14.8
Zr	110.1	82.8	86.6	75.5	134.3	193	93.4
Hf	3.3	2.5	2.5	2.2	3.7	5.3	2.9
Sm	2.73	2.35	2.47	1.84	2.48	3.77	2.52
Eu	0.8	0.68	0.76	0.52	0.72	0.93	0.62
Ti	4734.8	1917.9	2457.3	1558.3	2697.0	2876.8	1738.1
Gd	2.99	2.3	2.45	1.7	2.35	3.46	2.17
Tb	0.43	0.34	0.41	0.28	0.37	0.53	0.33
Dy	2.93	2.07	2.37	1.95	2.43	2.93	1.81
Y	16.3	11.2	14.1	10.3	12.9	16.7	10.9
Ho	0.6	0.44	0.52	0.37	0.5	0.59	0.37
Yb	1.74	1.2	1.48	1.12	1.48	1.79	1.08
Er	1.64	1.23	1.49	1.1	1.43	1.71	1.12
Tm	0.25	0.17	0.22	0.16	0.2	0.26	0.16
Lu	0.26	0.18	0.23	0.2	0.23	0.27	0.17
(La/Yb)n	5.39	8.47	6.25	6.19	7.05	9.55	11.98
(Gd/Yb)n	1.38	1.54	1.33	1.22	1.28	1.55	1.61
Eu/Eu*	0.86	0.89	0.95	0.89	0.91	0.78	0.80

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Nimu AM15 Granit	Nimu AM16 G.diyorit	Nimu AM17 G.diyorit	Nimu AM18 G.diyorit	Nimu AM19 G.diyorit	Nimu AM20 G.diyorit	Umla AM21 G.diyorit
V	33	52	57	41	28	54	27
Co	3.9	5.8	6	5.2	2.2	6.1	3
Ni	20.7	2.5	1.8	1.8	2	2.2	1.8
Cu	8.9	9.7	4.8	9.4	4.2	4.5	5
Zn	88	95	110	123	184	105	88
Ga	11.1	13.2	14.8	15	10.3	14.5	12
Rb	97.7	45.3	41.8	71.3	63.1	45.2	44
Ba	548	369	324	179	1138	263	342
Th	8.6	4.2	4.3	2.8	21.9	4.5	3.7
U	2.5	1	0.7	0.6	2.8	1.1	0.6
Nb	5	4.2	5.9	5	2.6	5.1	5.2
La	19.7	17.9	20.7	16.5	24	18.7	13.7
Ce	35.6	34.4	45.2	32.3	36.1	36.5	27.4
Pb	11.1	2.2	1.6	1.6	3.5	1.4	1.7
Pr	3.65	3.8	5.37	3.46	3.52	4.06	3.13
Sr	228.7	293.9	379.7	376.2	247.3	311	326.6
Nd	12.6	13.4	20.8	13.3	11.2	15	12.7
Zr	66.6	147.6	219.2	227.8	121	171.8	206.4
Hf	2	4	5.3	5.3	3.6	4.7	4.8
Sm	2.25	2.46	4.36	2.25	1.94	2.77	2.28
Eu	0.57	1.09	1.54	0.95	0.75	1.11	1.38
Ti	1438.4	2936.8	3895.7	3536.1	1378.5	3476.2	2996.7
Gd	1.81	2.62	4.27	2.32	1.96	2.64	2.18
Tb	0.27	0.38	0.62	0.28	0.28	0.4	0.3
Dy	1.74	2.48	3.83	1.57	1.73	2.76	1.81
Y	9.5	15.1	21.7	7.7	10.3	15.7	11.3
Ho	0.32	0.53	0.82	0.27	0.35	0.57	0.36
Yb	0.91	1.77	2.2	1.06	1.36	1.66	1.05
Er	0.89	1.5	2.36	0.7	1.2	1.71	1.07
Tm	0.13	0.25	0.35	0.12	0.18	0.25	0.16
Lu	0.14	0.27	0.35	0.2	0.24	0.26	0.16
(La/Yb)n	14.29	6.68	6.21	10.28	11.65	7.44	8.62
(Gd/Yb)n	1.60	1.19	1.56	1.76	1.16	1.28	1.67
Eu/Eu*	0.85	1.32	1.09	1.28	1.18	1.25	1.89

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Umla AM22 Granit	Umla AM23 G.diyorit	Umla AM24 G.diyorit	Umla AM25 Monzonit	Umla AM26 G.diyorit	Umla AM27 G.diyorit	Umla AM28 G.diyorit
V	13	41	104	152	67	77	56
Co	1.3	4.3	12	17.3	7.8	8.7	5.9
Ni	1.7	1.8	3.7	6.2	2.3	2.6	2.1
Cu	3.2	2.8	6.1	12.4	3	3.3	4.1
Zn	47	34	68	111	54	53	49
Ga	9.7	12.1	14	19.1	13.9	13.2	14.4
Rb	81.5	59.6	111.4	163.2	85.1	87.2	69.2
Ba	704	349	610	704	529	566	417
Th	3.6	4	4.9	1.7	3.7	6.4	3.2
U	0.6	1.4	1.4	1.1	0.9	1.5	0.9
Nb	2.6	2.7	6.7	5.2	4.4	5.9	3
La	12.7	12.5	20.5	15	18.3	17.1	15
Ce	19.4	21.4	44.8	26.3	33.2	38.9	23.4
Pb	2.5	1.1	1.5	1.6	1.1	0.9	1.1
Pr	1.76	2.28	5.25	2.91	3.55	4.83	2.21
Sr	165.3	304.9	267.4	272	296.2	281.1	333.6
Nd	5.3	8.1	19	10.8	13.5	19.1	7.6
Zr	102.1	82.4	211	74.8	132.2	89.3	119.2
Hf	3.3	2.6	5.6	2.1	3.6	2.6	3.3
Sm	0.69	1.54	4.01	2.48	2.65	3.53	1.45
Eu	0.5	0.53	0.85	0.54	0.75	0.79	0.57
Ti	839.1	1678.2	4195.4	5214.3	2757.0	3116.6	2037.8
Gd	0.5	1.47	3.63	2.53	2.25	3.21	1.3
Tb	0.07	0.22	0.58	0.39	0.36	0.55	0.22
Dy	0.41	1.28	3.52	2.39	2.09	3.2	1.25
Y	2.6	8.3	20.7	13.6	12.9	18.7	7.8
Ho	0.09	0.28	0.71	0.44	0.46	0.62	0.26
Yb	0.43	0.87	2.31	1.32	1.36	1.92	0.81
Er	0.28	0.86	2.12	1.31	1.24	1.87	0.74
Tm	0.05	0.12	0.32	0.2	0.19	0.28	0.12
Lu	0.09	0.14	0.36	0.22	0.21	0.28	0.13
(La/Yb)n	19.50	9.49	5.86	7.50	8.89	5.88	12.23
(Gd/Yb)n	0.93	1.36	1.26	1.54	1.33	1.34	1.29
Eu/Eu*	2.51	1.07	0.68	0.66	0.93	0.71	1.26

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Umla AM29 Monzonit	Umla AM30 G.diyorit	Taru AM31 Granit	Taru AM32 G.diyorit	Taru AM33 G.diyorit	Taru AM34 G.diyorit	Taru AM35 G.diyorit
V	101	90	21	53	79	80	94
Co	12.6	7	2.6	6	9.8	8.1	9.7
Ni	8.7	3.9	2.3	2.1	3.5	3.2	3.2
Cu	23.8	4.4	5.4	3.5	5.2	6	4.8
Zn	134	103	56	48	65	65	74
Ga	19.1	17.7	10.6	15	16.6	13.3	17.6
Rb	60.3	92.8	121.5	90.6	92.6	67.5	54.1
Ba	792	455	878	156	224	213	210
Th	8.2	13.1	3.8	3.1	5.9	4.4	4.6
U	2	7.7	0.8	0.9	1.1	0.8	0.9
Nb	17.5	5.8	1.5	3.9	14.7	5.4	5.4
La	50.8	31.1	6.4	14	29.3	20.6	21.2
Ce	102.5	58.8	9.6	23.3	66.1	43.3	44
Pb	3.7	2.1	1.8	2	1	1.5	1
Pr	11.47	6.28	0.86	2.32	7.76	4.95	5.09
Sr	1075.8	335.8	248.9	346.4	346.7	352.6	357.6
Nd	40.8	23.2	2.7	7.2	29	19.5	19.3
Zr	265.4	130.2	108.4	115.4	148.6	130.1	143.1
Hf	6	3.6	3.5	3.3	4.1	3.2	3.9
Sm	6.04	4.07	0.31	1.44	6	3.74	3.53
Eu	1.56	1.13	0.34	0.51	0.82	0.71	0.8
Ti	6472.9	2697.0	899.0	1917.9	3296.4	2936.8	3416.3
Gd	4	3.62	0.32	1.38	6.31	3.55	3.25
Tb	0.43	0.48	0.06	0.22	1.02	0.58	0.54
Dy	2.14	2.96	0.35	1.39	6.77	3.57	3.21
Y	10.5	17.7	2.5	8.9	46	22.3	22.1
Ho	0.31	0.55	0.08	0.36	1.38	0.75	0.7
Yb	0.73	1.8	0.31	0.93	5.16	2.14	2.27
Er	0.91	1.76	0.25	0.92	4.45	2.17	2.2
Tm	0.1	0.27	0.05	0.14	0.73	0.31	0.34
Lu	0.1	0.28	0.07	0.16	0.78	0.32	0.36
(La/Yb)n	45.95	11.41	13.63	9.94	3.75	6.36	6.17
(Gd/Yb)n	4.40	1.62	0.83	1.19	0.98	1.33	1.15
Eu/Eu*	0.92	0.89	3.31	1.10	0.41	0.59	0.72

Çizelge 4'in devamı

Plüton/Alan Örnek no Kaya Tipi	Taru AM36 G.diyorit	Taru AM37 G.diyorit	Taru AM38 Granit	Taru AM39 Granit	Taru AM40 Granit	Taru AM41 Monzodiyorit
V	78	82	27	21	13	216
Co	8.3	8.8	3.2	2.5	1.9	24.7
Ni	3.2	2.9	1.6	2	2.2	4.9
Cu	6.2	4.8	6.5	4.5	5.4	97.3
Zn	64	72	41	38	54	155
Ga	16.6	15.2	9.5	9	8.2	18
Rb	56.8	70.1	77.5	58.8	88.5	119.7
Ba	187	184	929	944	1543	151
Th	3.7	4.1	8.5	5.1	7.1	2
U	1	1.1	1.1	0.6	1.1	0.7
Nb	6.2	7	2.4	1.2	1.6	8.7
La	21.6	23.4	7.8	6.3	6.6	26.7
Ce	46.7	48.6	16.8	9.4	10.1	58.1
Pb	1.4	1.7	2.4	1.5	1.8	1.2
Pr	5.59	5.21	2.17	0.9	0.99	7.24
Sr	349.5	361.4	258.9	309.5	302.8	343.8
Nd	21.7	19.1	8.6	3.5	3.2	28.9
Zr	112.6	130.4	92.6	55.3	38.6	73.8
Hf	3.2	3.8	3.1	1.7	1.2	2
Sm	4.44	3.53	1.64	0.3	0.35	6.41
Eu	0.81	0.8	0.74	0.59	0.5	0.73
Ti	2876.8	3236.5	1138.8	779.1	779.1	6832.5
Gd	4.02	3.54	1.82	0.45	0.41	6.45
Tb	0.66	0.58	0.26	0.05	0.05	1.03
Dy	4.4	3.83	1.66	0.36	0.31	6.31
Y	24.4	24.1	8.7	2.2	1.9	39.8
Ho	0.85	0.78	0.38	0.08	0.06	1.37
Yb	2.74	2.94	0.92	0.33	0.28	4.31
Er	2.51	2.53	0.87	0.21	0.21	4.02
Tm	0.37	0.41	0.14	0.04	0.04	0.63
Lu	0.42	0.47	0.15	0.05	0.05	0.64
(La/Yb)n	5.21	5.26	5.60	12.61	15.56	4.09
(Gd/Yb)n	1.18	0.97	1.59	1.10	1.18	1.20
Eu/Eu*	0.58	0.69	1.32	4.97	4.08	0.35

EK-4. İZOTOP ANALİZ SONUÇLARI

Çizelge 5. Trans-Himalaya kuşağı (Hindistan) Leh bölgesindeki Ladakh Batoliti kayaç örneklerinin Rb-Sr izotop analiz sonuçları

Örnek no	Kayaç Tipi	SiO ₂ (%ağırlık)	Rb (ppm)	Sr (ppm)	Rb/Sr	⁸⁷ Sr/ ⁸⁶ Sr (ölçülen)	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr / ⁸⁶ Sr (ilksel)
AM-1	Basgo Granit	70.4	164.7	263	0.626235741	0.705988	1.812952471	0.704442706
AM-3	Basgo Diyorit	59.6	81.6	561.9	0.14522157	0.704911	0.420416444	0.704552653
AM-16	Nimu Granodiyorit	68.9	45.3	293.9	0.154134059	0.705822	0.446218101	0.70544166
AM-17	Nimu Granodiyorit	65	41.8	379.7	0.110086911	0.704842	0.318701607	0.704570351
AM-18	Nimu Granodiyorit	65.9	71.3	376.2	0.189526847	0.705283	0.548680223	0.704815325
AM-19	Nimu Granodiyorit	72.1	63.1	247.3	0.255155681	0.705875	0.738675698	0.70524538
AM-20	Nimu Granodiyorit	66.3	45.2	311	0.145337621	0.704766	0.420752412	0.704407366
AM-33	Taru Granodiyorit	64	92.6	346.7	0.267089703	0.705063	0.77322469	0.704403932
AM-34	Taru Granodiyorit	67.4	67.5	352.6	0.191435054	0.70487	0.554204481	0.704397617
AM-35	Taru Granodiyorit	65.6	54.1	357.6	0.151286353	0.704725	0.437973993	0.704351687
AM-36	Taru Granodiyorit	66.9	56.8	349.5	0.162517883	0.704713	0.47048927	0.704311972
AM-37	Granodiyorit	65.5	70.1	361.4	0.193967903	0.70477	0.561537078	0.704291367
AM-38	Taru Granit	73.4	77.5	258.9	0.299343376	0.704985	0.866599073	0.704246343
AM-39	Taru Granit	75.1	58.8	309.5	0.189983845	0.704848	0.550003231	0.704379198
AM-40	Taru Granit	75.8	88.5	302.8	0.292272127	0.70512	0.846127807	0.704398792
AM-41	Taru Mafik Magmatik Anklav (Monzodiyorit)	51.8	119.7	343.8	0.348167539	0.704995	1.007945026	0.704135865

Çizelge 6. Trans-Himalaya kuşağı (Hindistan) Leh bölgesindeki Ladakh batoliti'nin granit kayaçların Sm-Nd izotop analizleri

Örnek no	Kayaç Tipi	SiO ₂ (%ağırlık)	Sm (ppm)	Nd (ppm)	Sm/Nd	¹⁴³ Nd/ ¹⁴⁴ Nd (ölçülen)	¹⁴⁷ Sm/ ¹⁴⁴ Nd	¹⁴³ Nd/ ¹⁴⁴ Nd (ilksel)	εNd (ilksel)
AM-1	Basgo Granit	70.4	4.27	26	0.164230769	0.512686	0.099343192	0.51264701	1.7
AM-3	Basgo Diyorit	59.6	4.59	25.4	0.180708661	0.512702	0.109310669	0.512659098	1.9
AM-16	Nimu Granodiyorit	68.9	2.46	13.4	0.18358209	0.51273	0.111048806	0.512686416	2.5
AM-17	Nimu Granodiyorit	65	4.36	20.8	0.209615385	0.512731	0.126796346	0.512681235	2.3
AM-18	Nimu Granodiyorit	65.9	2.25	13.3	0.169172932	0.512734	0.102332707	0.512693837	2.6
AM-19	Nimu Granodiyorit	72.1	1.94	11.2	0.173214286	0.512721	0.104777321	0.512679877	2.3
AM-20	Nimu Granodiyorit	66.3	2.77	15	0.184666667	0.512726	0.111704867	0.512682158	2.4
AM-33	Taru Granodiyorit	64	6	29	0.206896552	0.512726	0.125151724	0.512676881	2.3
AM-34	Taru Granodiyorit	67.4	3.74	19.5	0.191794872	0.512733	0.116016718	0.512687466	2.5
AM-35	Taru Granodiyorit	65.6	3.53	19.3	0.182901554	0.51272	0.11063715	0.512676577	2.3
AM-36	Taru Granodiyorit	66.9	4.44	21.7	0.204608295	0.512723	0.123767558	0.512674424	2.2
AM-37	Granodiyorit	65.5	3.53	19.1	0.184816754	0.512719	0.111795654	0.512675123	2.2
AM-38	Taru Granit	73.4	1.64	8.6	0.190697674	0.512722	0.115353023	0.512676727	2.3
AM-39	Taru Granit	75.1	0.3	3.5	0.085714286	0.512702	0.051848571	0.512681651	2.4
AM-40	Taru Granit	75.8	0.35	3.2	0.109375	0.512721	0.066160938	0.512695033	2.6
AM-41	Taru Mafik Magmatik Anklav (Monzodiyorit)	51.8	6.41	28.9	0.221799308	0.512724	0.134166401	0.512671343	2.2

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EK-5

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This thesis was unanimously accepted by the following jury on 12/07/2019.

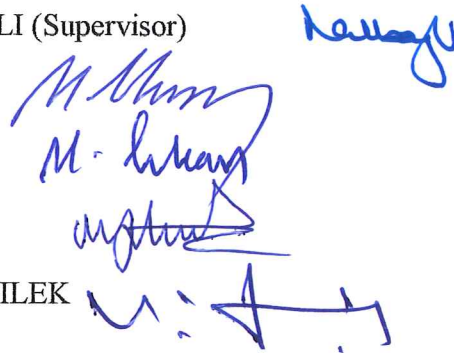
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Asst. Prof. Dr. Mehmet DEMIRBILEK

The image shows five handwritten signatures in blue ink, corresponding to the names listed on the left. The signatures are written in a cursive style. The first signature is for Nurdane ILBEYLI, the second for Yasar KIBICI, the third for M. Erkan KARAMAN, the fourth for M. Gurhan YALCIN, and the fifth for Mehmet DEMIRBILEK.

ABSTRACT

PETROGRAPHY, GEOCHEMISTRY AND PETROGENESIS OF THE INTRUSIVE ROCKS IN THE LEH (LADAKH BATHOLITH) REGION, TRANS- HIMALAYA (INDIA)

Azimuddin MIRZA

**PhD Thesis in Geological Engineering
Supervisor: Assoc. Dr. Nurdane ILBEYLI
July 2019; 265 pages**

The Ladakh Batholith is a part of the Trans-Himalayan Plutonic Belt located in Jammu & Kashmir (India), which represents subduction-related And-type magmatism, intruding an island arc setting. The Indus suture zone lies to the south and the Shyok tectonic zone lies to the north part of the Ladakh batholith that extends with WNW-ESE direction having ~600 km in length, 30-80 km in width and 3 km in thickness.

The intrusive rocks of the Basgo, Nimu, Umla, and Taru regions of the Ladakh batholith and its surroundings show different compositions ranging from medium-coarse-grained to generally grayish colored monzodiorite to granitic rocks. These rocks are having common mafic magmatic enclaves and dykes that cut these rocks in different directions.

The intrusive rocks of Basgo, Nimu, Umla and Taru region are medium to coarse grained with having common holocrystalline and hypidiomorphic granular texture. The main minerals of these rocks are K-feldspar, plagioclase, quartz, biotite, hornblende; sphene, apatite, zircon, Fe-Ti oxide forms accessory minerals.

Petrographically, they are fine to medium grained monzonite, monzodiorite, diorite, granodiorite and granite rocks. They consist of plagioclase (An_{55-99}), K-feldspar (Or_{85-99}). Amphiboles are mainly Edenite, Magnesio-Hornblende and Hastingsite in composition. In terms of Al-Mg-Fe(t) content, all samples are plotted in field of annite have relatively more Fe content than Mg. Biotites from all granitoids were accompanied with amphibole group of minerals, which is a typical characteristic of calc-alkaline subduction related metaluminous (I-type) granitoids. Fe-Ti oxide with poikilitic, perthitic, myrmekitic textures and graphic textures. The geothermobarometry results of intrusive rocks have crystallization temperatures ranging from 452 to 628°C and pressures ranging from 2.3 to 3.9 kbar. Depth of crystallization for the diorite to be 12.8 km and granodiorite to be around 8.3 km that indicated by using the Al-hornblende barometry calculations.

The calc alkaline rocks are metaluminous/peraluminous I-to S-type of pluton ranging from monzodiorite to granite. A/CNK (0.87-1.31) indicating I-type parental magma for most of the samples, whereas some samples shows transition between I & S- type granitoids. SiO_2 values of Ladakh Batholith samples are vary between 51.8% and 75.8%.

Binary Harker diagrams show a strong negative correlation when Al_2O_3 , TiO_2 , Fe_2O_3 , MgO , CaO , Na_2O , P_2O_5 are plotted against the increasing amount of silica, while K_2O values have strong positive correlation.

Chondrite-normalized REE patterns of intrusive rocks shows enrichment in LREE pattern whereas depletion in HREE pattern. Total REE content of 20–181 ppm, and with $(\text{La/Yb})_N = 3.75\text{--}45.95$ showing moderately to highly LREE enrichment. Negative Eu anomalies $(\text{Eu}/\text{Eu}^* = 0.35\text{--}4.97)$ and $(\text{Gd/Yb})_N = 0.83\text{--}4.40$ also shows moderately HREE fractionation.

Sr-Nd isotope analyses of the Ladakh intrusive rocks showing range for initial $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$ (0.70414 to 0.70544) and $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ (0.512647 to 0.512695) ratios with high values of $\epsilon\text{Nd}_{(t)}$ (1.68 to 2.62), with similarities to I-type granites that generated in an arc setting. In the $\text{Sr}_i\text{-Nd}_i$ diagram, samples are located in the low Sr and high Nd area, while some granodiorite composition samples are located in the area representing the high Sr and high Nd area.

Petrography, rock and isotope geochemistry show that fractional crystallization and magma mixing / mingling processes are effective in the formation of Ladakh intrusive rocks.

KEYWORDS : Jammu and Kashmir, India, Trans-Himalaya, Ladakh Batholith, Intrusive Rock, Mineral Chemistry, Geochemistry, Radiogenic Isotope Geochemistry, Petrogenesis, Fractional Crystallization, Magma Mixing/Mingling

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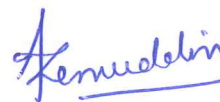
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CERTIFICATE OF ACADEMIC DECLARATION

I declare that this PhD thesis entitled “**PETROGRAPHY, GEOCHEMISTRY AND PETROGENESIS OF THE INTRUSIVE ROCKS IN THE LEH (LADAKH BATHOLITH) REGION, TRANS-HIMALAYA (INDIA)**”, which I, Azimuddin MIRZA (Student ID No. 20135120003), submitted in the partial fulfilment for the award of the degree of Doctor of Philosophy (PhD) in Geological Engineering from Akdeniz University, Antalya (Turkey) is a record of research work carried out by myself. The content of this thesis is my own work and in full or in parts, have not been submitted elsewhere for a degree at this or any other university.

12/07/2019

Azimuddin MIRZA



SYMBOLS AND ABBREVIATIONS

Symbols

Al_2O_3	: Aluminium Oxide
Ba	: Barium
CaO	: Calcium Oxide
Ce	: Cerium
Co	: Cobalt
CO_2	: Carbondioxide
Cr_2O_3	: Chromium Oxide
Cu	: Copper
Dy	: Dysprosium
Eu	: Europium
Er	: Erbium
Fe_2O_3	: Iron Oxide
Ga	: Galium
Gd	: Gadolinium
Hf	: Hafnium
Ho	: Holmium
Km	: Kilometer
K_2O	: Potassium Oxide
La	: Lanthanum
Lu	: Lutetium
M	: Meter
MgO	: Magnesium Oxide
Mm	: Milimetre

MnO	: Manganese Oxide
My	: Million years
Na ₂ O	: Sodium Oxide
Nb	: Niobium
Nd	: Neodymium
Ni	: Nickel
P ₂ O ₅	: Diphosphorus Pentaoxide
Pb	: Lead
Pr	: Praseodymium
Rb	: Rubidium
SiO ₂	: Silicon Dioxide
Sm	: Samarium
Sr	: Strontium
Ta	: Tantalum
Tb	: Terbium
Th	: Thorium
TiO ₂	: Titanium Dioxide
Tm	: Thulium
U	: Uranium
V	: Vanadium
Y	: Yttrium
Yb	: Ytterbium
Zn	: Zinc
Zr	: Zircon

Abbreviations

BS	: Bangong Suture
DP	: Deosai Plateau
IC	: Indus confluence
ISZ	: Indus Suture Zone
JS	: Jinsha Suture
KG	: Kaghan
ATF	: Altyn Tagh Fault
HFF	: Himalayan Frontal Fault
BNS	: Banggong-Nujiang Suture
KF	: Kunlun Fault
NBT	: North Border Thrust
NHG	: North Himalayan Granite
THSZ	: Trans Himadri Shear Zone
MZB	: Main Zaskar Backthrust
MBT	: Main Boundary Thrust
MCT	: Main Central Thrust
SSZ	: Shyok Suture Zone
STD	: South Tibet Detachment
WP	: Western Pakistan
ZP	: Zhepure Shan
ZS	: Zaskar Shear Zone
W	: West

E	: East
S	: South
SW	: South West
SE	: South East
HFSE	: High Field Strength Element
HREE	: High Rare Earth Element
N	: North
NW	: North West
LILE	: Large Ion Lithophile Element
LREE	: Light Rare Earth Element
ppm	: Parts per million
REE	: Rare Earth Element
Pl	: Plagioclase
Qtz	: Quartz
Op	: Opaque mineral
Bt	: Biotite
Ser	: Sericite
Ap	: Apatite
Spn	: Sphene
Zrn	: Zircon
Mnz	: Monazite
Mc	: Microcline
Or	: Orthoclase
Myrm	: Myrmekite Texture

Gph	: Graphic Texture
Kfs	: Potassium Feldspar
Pert	: Perthitic Texture
Hbl	: Hornblende
Saus	: Saussuritisation
Alt	: Alteration
Or	: Orthoclase
Ab	: Albite
An	: Anorthite
HM	: Hematite-Magnetite
FMQ	: Fayalite-Magnetite-Quartz
Hed	: Hedenbergite
WM	: Wustite-Magnetite
NNO	: Nickel-Nickel Oxide
MORB	: Mid-Ocean Ridge Basalt
DM	: Depleted Mantle
OIB	: Ocean Island Basalt
IAB	: Island-Arc Basalt
AFC	: Assimilation-Fractional Crystallization

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1. INTRODUCTION

Himalaya is the youngest but the longest mountain chain, which poses the complex and intricate problems regarding its, origin, structure, tectonics, metamorphism, magmatism and natural resources. Complexities in the geology of this mountain system, yet the problems are highly fascinating (Figure 1.1a-c).

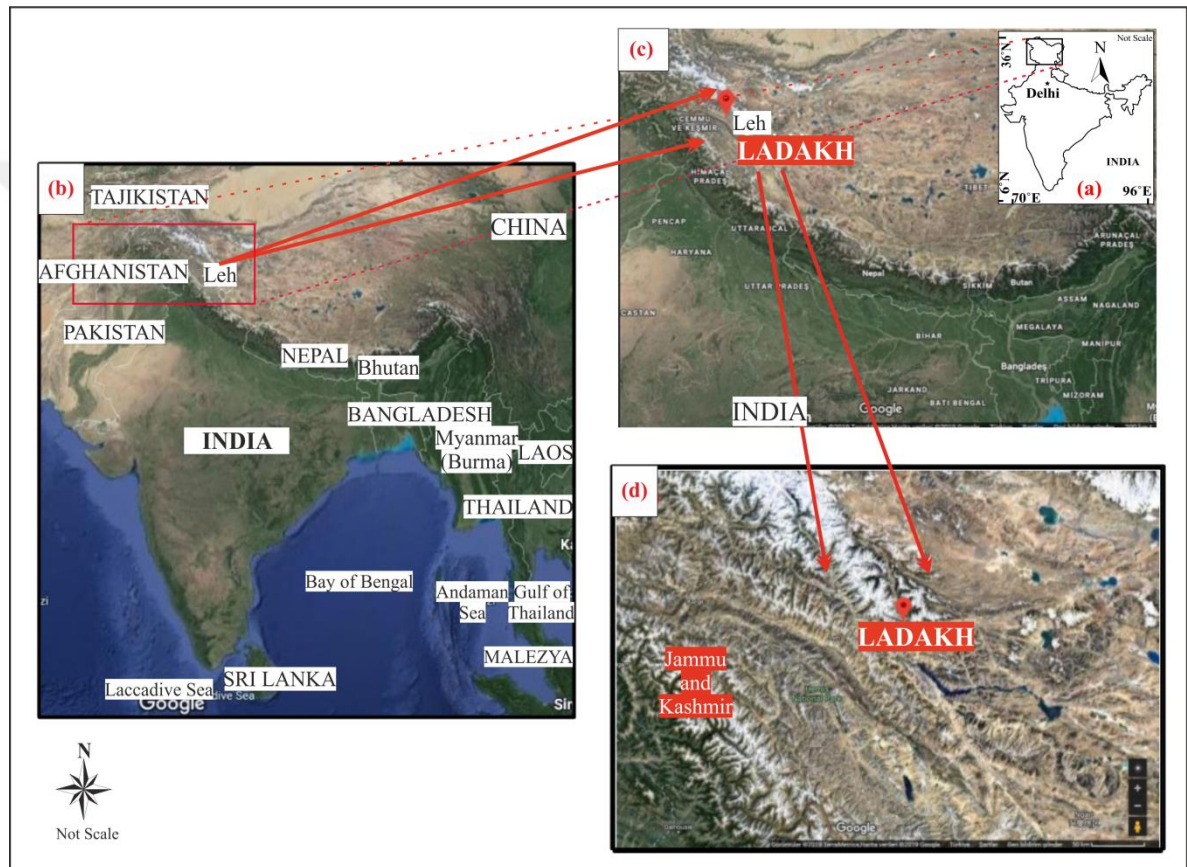


Figure 1.1. a-d) Shows the google images of Leh, Ladakh area of Jammu and Kashmir state of India (Anonymous 1)

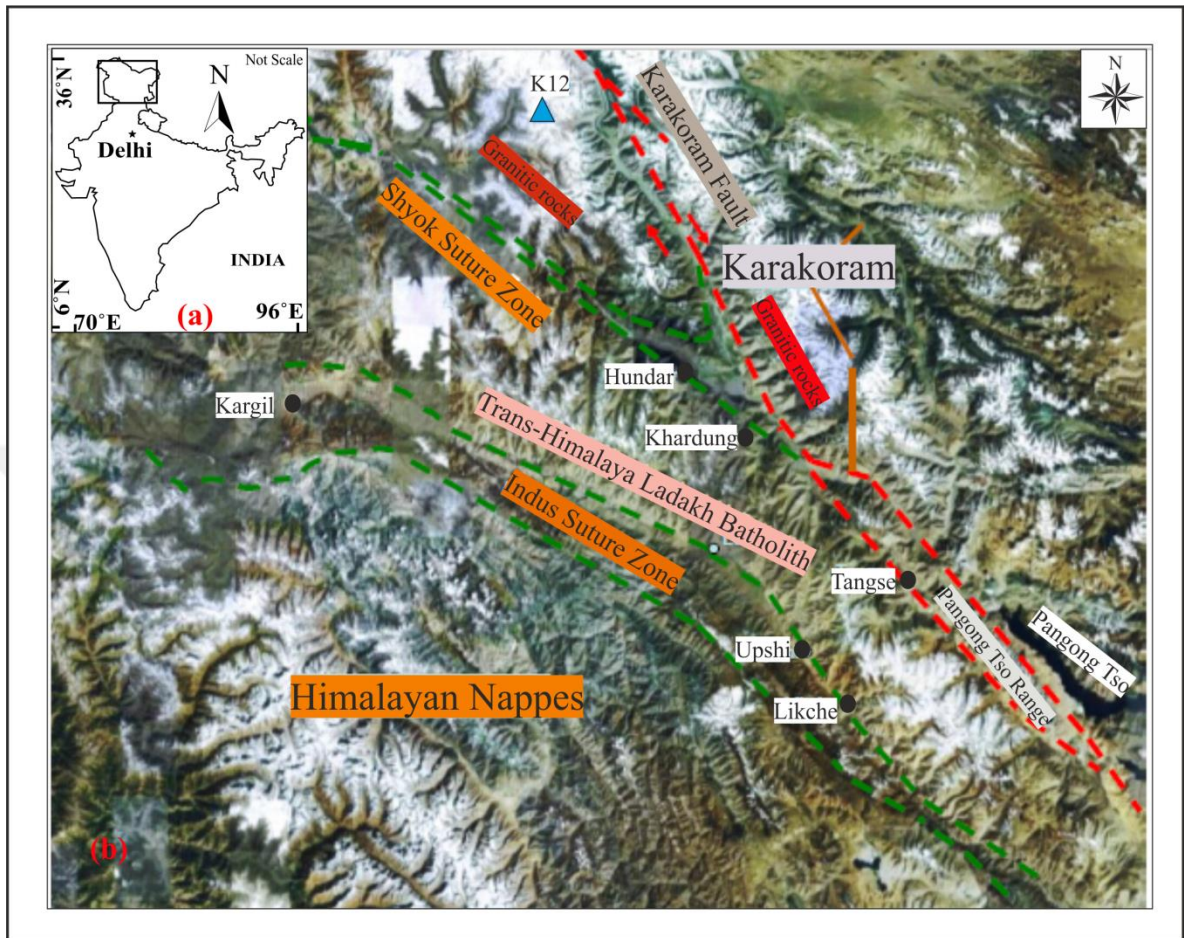


Figure 1.2. a) Shows the boundaries of the geological units as discussed in this chapter showing suture zones with Trans-Himalaya Ladakh Batholith along the region of Leh are superimposed on a satellite picture of Central Ladakh (Anonymous 2)

The Himalayan chain of mountains is considered as a substantial example of continental collision that took place between Eurasian and Indian plates during Cenozoic times (Molnar and Tapponnier, 1975; Gansser, 1977) (Figure 1.3). The mechanism between the collision of Eurasian and Indian plates is responsible for the reconstruction of tectonic structures of the regions of Kun Lun and the Karakoram and also the upliftment of the Himalaya and the Tibetan Plateau (Matte et al., 1996; Searle et al., 1999; Upadhyay, 2002; and references therein) (Figure 1.4).

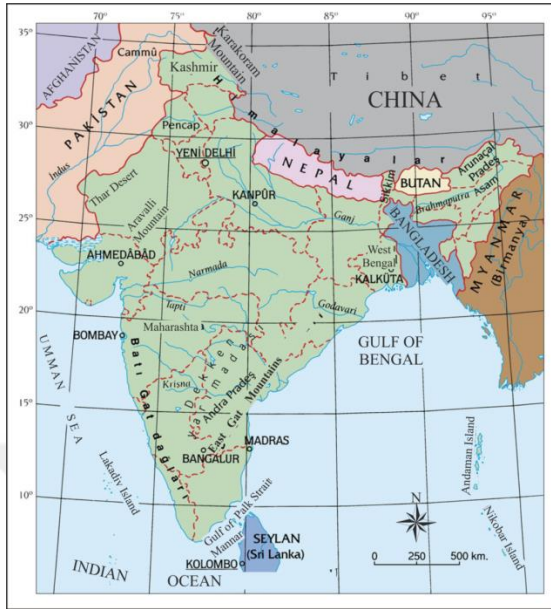


Figure 1.3. This map shows the associated boundaries of India with other countries (Anonymous, 3).

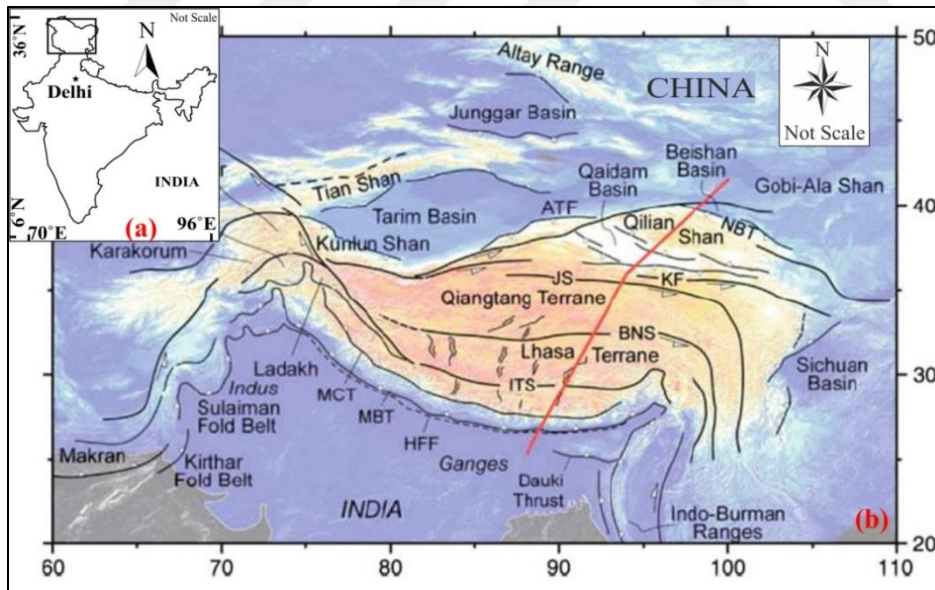


Figure 1.4. (a) Study area of Ladakh Batholith in the north of India (Valdiya 1988) (b) Tibetan Plateau and its surrounding regions are shown by the Tectonic map. Elevations are shown by the shades of different colors. Profile is shown by the Red line: MBT- Main Boundary Thrust of Himalaya, KF- Kunlun Fault, ATF- Altyn Tagh Fault, MCT- Main Central Thrust, BNS- Banggong-Nujiang Suture, ITS- Indus-Tsangpo Suture, NBT- North Border Thrust, HFF- Himalayan Frontal Fault, JS- Jinsha Suture. Source Jiménez Munt et al. (2008).

The Indus Tsangpo Suture Zone (ITSZ) from the south and Shyok Suture Zone (SSZ) from the north that bounds the Trans-Himalayan magmatic arc (e.g. Shah et al.,

1976; Shanker et al., 1976, Gansser, 1977; Franket al., 1977; Sharma and Kumar, 1978; Thakur, 1981; Beck et al., 1995) (Figure 1.5) and which was active from 102 ± 2 Ma (Honegger et. al., 1982) to 50 ± 1 Ma (Weinberg and Dunlop, 2000) with adding up high magmatism pulses about 60 Ma (e.g. Scharer et al., 1984; Singh et al., 2007; Upadhayay et al., 2008), and forming a Cordilleran-type magmatic arc system.

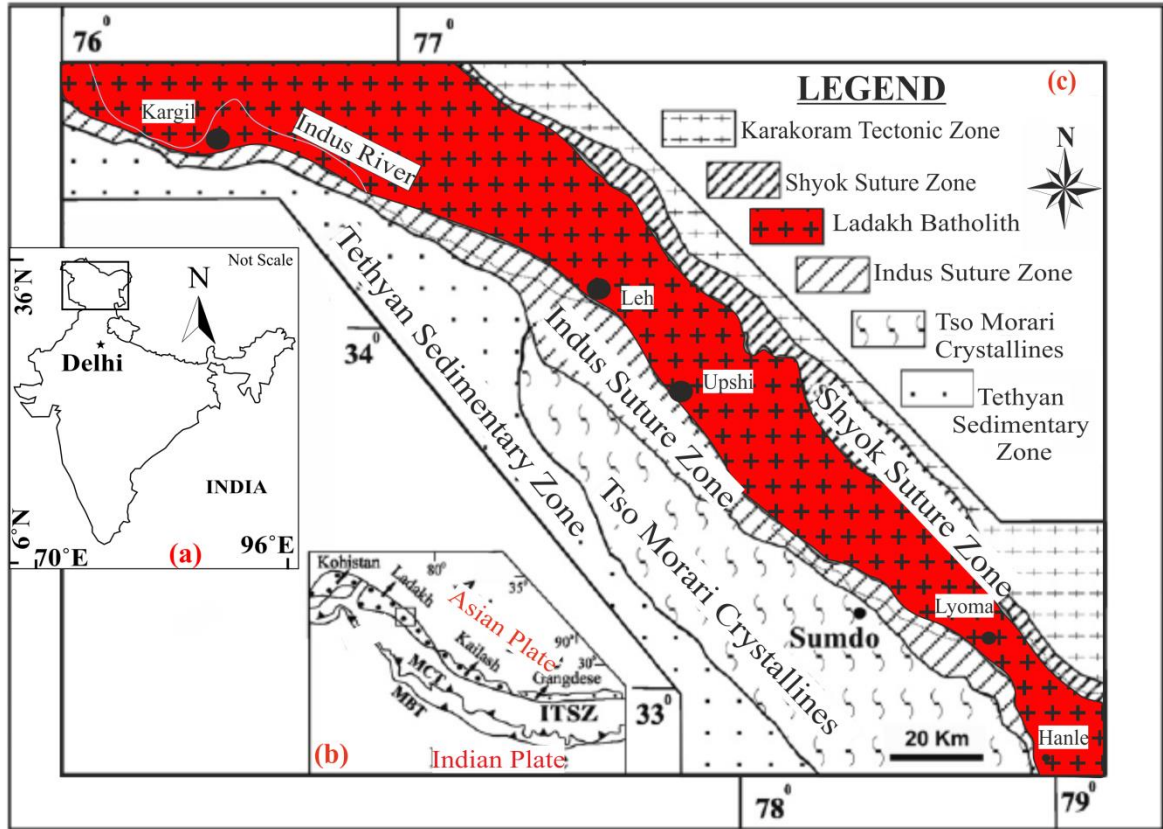


Figure 1.5. (a) Study area of Ladakh Batholith in the north of India (Valdiya 1988) (b) Subduction of Indian Plate under the Eurasian Plate that moves throughout the length of the Indus-Tsangpo Suture Zone is shown by the easiest way of tectonic setting of the Trans-Himalayan batholiths of Kohistan, Ladakh, Kailash and Gangdese (Singh 2007). (c) Geological map shows the bounding of the Ladakh Batholith from the Indus- Tsangpo Suture Zone in the south and the Shyok Suture Zone in the north. UHP metamorphosed Indian Plate is shown as the Tethyan Sedimentary Zone covers the Tso Morari Crystallines (Singh 2007).

The Indus- Tsangpo Suture Zone in the south is composed of exotic limestone ranges, molasses, flysoid, ophiolitic melange and Dras volcanics that decepted as a result of shutdown of Neo-Tethyan ocean during the motion of Indian plate towards the north direction (e.g. Gansser, 1964; Sharma and Kumar, 1978; Honegger et al., 1982; Thakur, 1992; Rowley, 1996; Jain et al., 2003; Leech et al., 2005; Jain et al., 2008; Jain, 2014 and references therein).

The Shyok Formations of wide zone has a large extent of massive to porphyritic andesite, dacite, rhyolite, tuff, chert, slate, quartzite, sandstone, limestone, marble, molasse and ophiolitic melange are well unprotected in Shyok-Nubra valleys that are corresponded with the same type of lithologies of Cretaceous-Lower Eocene Nubra Formation (Rai, 1982).

However, along Indus and Shyok Suture Zones, two subduction models have also been put forwarded (e.g. Rai, 1983; Brookfield and Reynolds, 1981; Reynolds et al., 1983; Coward and Butler, 1985; Srimal, 1986; Sharma, 1987; Weinberg and Dunlap, 2000; Dubois-Cote et al., 2005; Jain, 2014) (Figure 1.5 (b)).

While moving from south to north, the Shyok-Nubra junction area form triple point that leads to three tectonic ranges i.e. Ladakh, Saltoro and Karakoram ranges (e.g. Weinberg et al., 2000) (Figure 1.5.(a)).

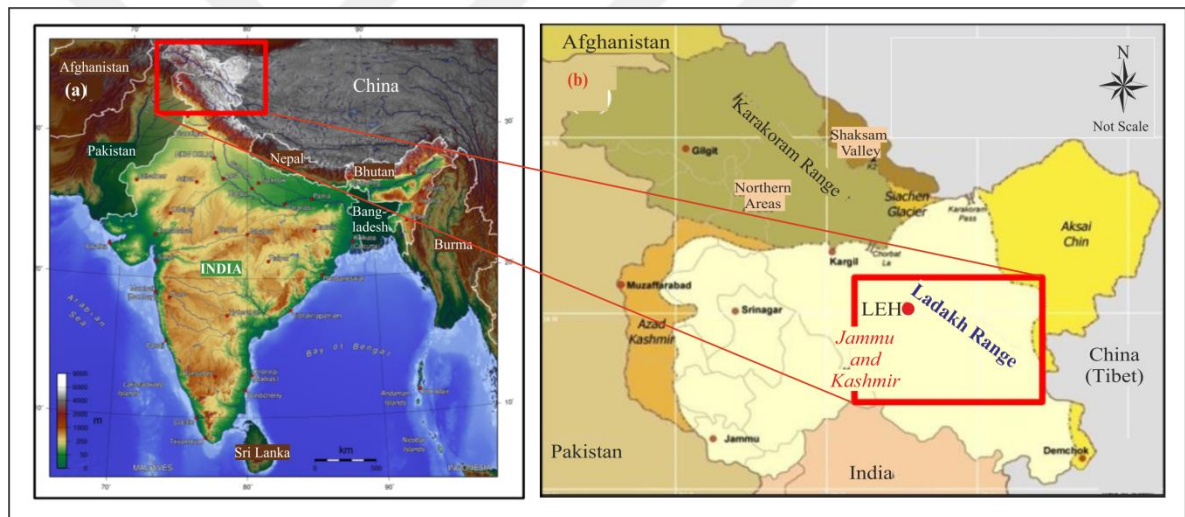


Figure 1.6. (a) This map collected from the Google images (Anonymous 4). **(b)** This map shows the Jammu and Kashmir state of India in which squared box highlights the study area of Ladakh Range.

The Ladakh Batholith is a part of the Trans-Himalayan Plutonic Belt (a Cretaceous-Palaeogene Andean-type magmatic arc) that cut out north of the Indus suture zone and stretched over 2500 km throughout the length of the southern edge of the Eurasian continent. The Ladakh Batholith occurs as a linear body trending to WNW-ESE, is about 600 km long, 30-80 km wide and 3 km thickness that covers a major part of the Ladakh range (Singh et al., 2007) (Figure 1.4, 1.5). The Ladakh Batholith is situated in the Trans-Himalayan area in the north-eastern part of Ladakh district of Jammu and Kashmir, India (Figure 1.5, 1.6). The Khardung Formation and the Shyok Formation to the northeast region that occupied northern part of the Ladakh range, which splits Ladakh range from Saltoro range throughout the length of Khalsar thrust (KT) (Figures 1.6, 1.7). The rocks of Khardung Formation equivalent to those of Shyok Formation is considered by Thakur et al.

(1981). Saltoro range bounded between Nubra Formation in the north and Shyok Formation in the south, which is predominantly consist of medium to coarse-grained mesocratic calc-alkaline granitoids (e.g. Thakur and Mishra, 1984; Upadhayay and Sinha, 1998). Nubra Formation is tectonically set side by side by Karakoram Range along dextral strike slip Karakoram Fault (KF) to the north. Leucogranites is formed in syn-to post-collisional tectonic environments, which is mostly consisted by the Karakoram Range (12-18 Ma; Weinberg et al., 2000, Searle et al., 1998; 20-25 Ma; Parrish and Tirrul, 1989; Schärer et al., 1990)

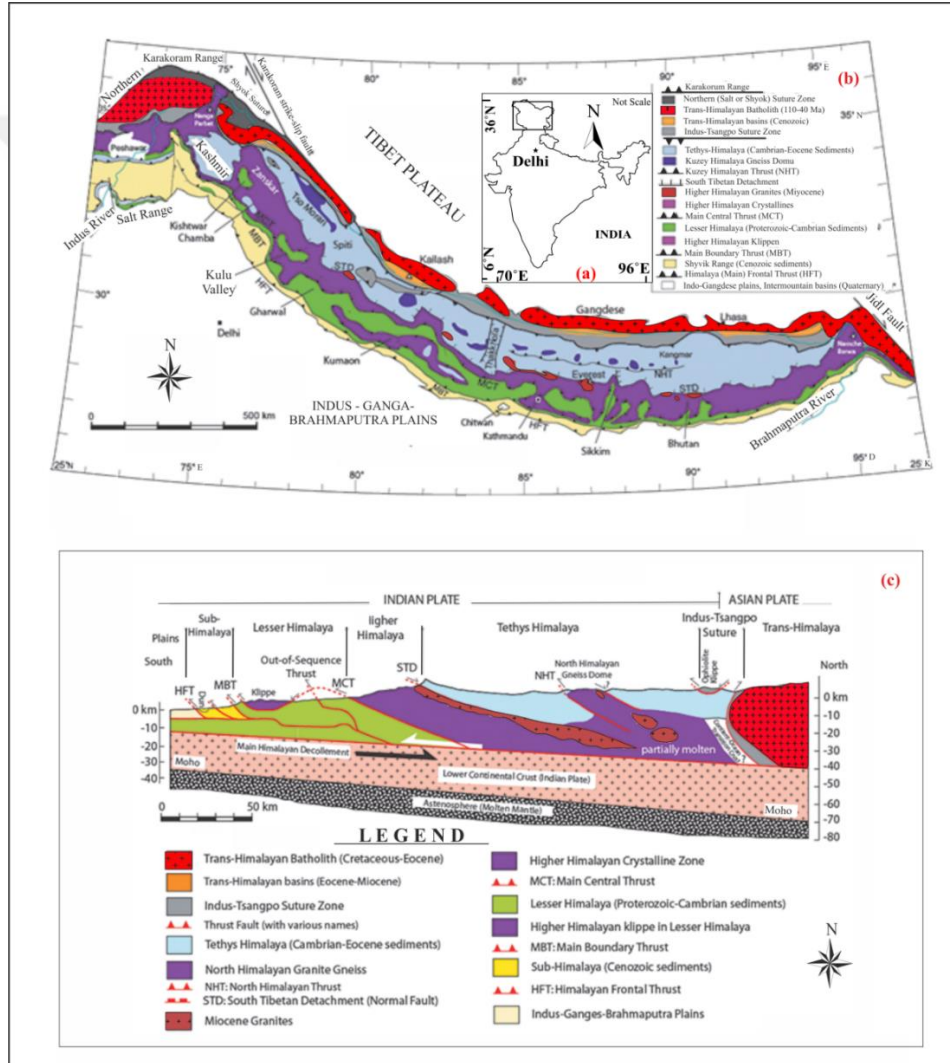


Figure 1.7. (a) Study area of Ladakh Batholith in the north of India (Valdiya 1988) **(b)** Himalayaların genel jeoloji haritası (Anomynous 5) **(c)** Himalayalardan alınan Güney-Kuzey yönlü enine kesit (Anomynous 6)

The Ladakh are unprotected throughout the length of the ISZ and the SSZ in the northwest Himalaya that constitute the lithounits. The Kohistan-Dras island arc in the south

is separated by the SSZ from the Karakoram-Tibet terrain in the north (Gansser, 1977; Coward et al., 1986; Searle, 2011) (Figure 1.5 (b)). The tectonized remaining part of a crustally-contracted back-arc basin is represented by the Shyok suture zone (e.g. Rai, 1982; Srimal, 1986). The immensity of the Shyok Formation is concept to imprint an older suture of Cretaceous age that constitutes a sequence of folded and faulted metasedimentary and metavolcanic rocks, which is mainly comprised by tectonically compressed backarc basin (e.g. Weinberg et al., 2000; Dunlap and Wysoczanski, 2002; Rehman et al., 2011) (Figure 1.5, 1.7).

The Ladakh-Kohistan that covers the western part of Trans-Himalayan Belt and the Gangdese magmatic belt covered the eastern part, which occur as an irregular bodies from north Kohistan through Ladakh to Lhasa with covering an interspace of about 3000 km (Harris et al., 1988) (Figure 1.5,1.7).

During Early Cretaceous- Lower Eocene times, the formation of the Trans-Himalayan magmatic arc, which is a consequence of the subduction of Neo-Tethyan oceanic crust beneath the southern active edge of the Asian plate (Tahirkheli, 1979; Honegger et al., 1982; Maluski et al., 1982; Bard, 1983; Scharer et al., 1984; Petterson and Windley, 1985; Debon et al., 1986, 1987; Harris et al., 1988; Khan et al., 1989; Sharma, 1990; Ahmad et al., 1998; Rolland et al., 2000; Weinberg and Dunlap, 2000).

The extended long belt of tonalite-diorite-granodiorite-granite coalition is formed by the Trans-Himalayan Ladakh Batholith that lies directly to the north of the Indus-Tsangpo Suture (Sharma, 1990; Ahmad et al., 1998) (Figure 1.5(b)). The Indus Suture Zone (ISZ) is separated by the trench deposits and volcano-sedimentary constituent of the Ladakh magmatic-arc from the continental slope and the shelf sediments of the northern edge of the Indian plate, which is essentially a thrust zone (Sharma, 1991; Thakur, 1992) (Figure 1.4, 1.5(a,b)).

Several Calc-alkaline rocks varying from gabbro to diorite, granodiorite, granite and leucogranite is consist by this pluton (Rai, 1980; Honegger et al., 1982; Sharma and Choubey, 1983). At period of the India-Asia collision, the Andean-type magmatic emplacement (gabbro-diorite-granodiorite-granite) throughout the length of the Kohistan-Ladakh Batholith has been come to an end about 60-50 Ma ago (Searle et al., 1999). (Figure 1.5(a)). The evolution of magmatism has been took place from pre-collisional subduction-related to post collisional types (Debon et al., 1987; Searle et al., 1988). Searle (1983) defined the three significant deformation stages in the Western Himalaya: (i) a pre-collision ophiolite obduction phase around 75-60 Ma, (ii) a continental collision stage around 45-25 Ma, and (iii) a post-collision stage later to 15 Ma, (Figure 1.4).

The process of growth of crust and temporal evolution in the direction of enlarged with more develop felsic magmas is not only noticed in the Ladakh-Kohistan batholith (Petterson and Windley, 1985; Raz and Honegger, 1989), but also noticed in the Andes (Pitcher, 1993) and in the Sierra Nevada (Bateman, 1983).

Most of the calc-alkaline granites in the Earth's crust, such as the Ladakh pluton in the Trans- Himalayan region of India (Sharma, 1991) and the Circum-Pacific belt in coastal Peru (Pitcher, 1978) consisting of subduction related tectonic environments. In many respects, the mantle geochemical signatures of plutons are mostly compatible with I-type Cordilleran batholiths of Peru (Honegger et al., 1982).

From last few decades, Ladakh has attracted the attentions of the geoscientist from all around the world, as a come of plate to plate collision. The magmatism in such zones, play an important role for understanding the thermodynamics of subducting plates. The petrological and geochemical data of these magmatic rocks particularly Ladakh granitoids which contribute at least 60% of the rocks of the Indus suture zone is limited.

Geographically, the Trans-Himalayan Batholith is subdivided into three different ranges such as the Kohistan Batholith in Pakistan, the Ladakh Batholith/Plutonic Complex in India and the Gangdese/Kangdese Batholith in Tibet (Honegger et al., 1982; Debon et al., 1986; Harris et al., 1988; Ahmad et al., 1998) (Figure 1.4). For understanding the history of the batholith, so much work has been done by many geologist and also so many scientists has been devoted for considering a change from I-to S-type magmatism that implement a sign of terminal accretion of India to Asia (Searle et al., 1987, 1988; St-Onge et al., 2010). Several U/Pb ID-TIMS analyses of zircon from crosscutting leucocratic dyke near Chumatang and a hornblende-bearing granodiorite have been reported by St-Onge et al. (2010). As a result they argued that there is a change in the chemistry of granites from I-type granodiorite to emplacement of S-type leucocratic dykes at ~57.7 to ~47 Ma respectively is the indicative collision of the India and Eurasia.

Geographically, the batholith is considered to have developed the Lhasa block/Eurasian continent at the southern edge and (Kohistan/West Ladakh) as an intra-oceanic arc in the West and as an Andean-type margin in the east (Rolland et al., 2000, 2002) (Figure 1.6).

The Ladakh Batholith composition ranges from olivine norite (rock types) to leucogranites with dominating granodiorites (Thakur, 1981; Honegger et al., 1982). Continental, subduction-related batholith collectively represents olivine-orthopyroxene-bearing norites, gabbros, diorites, granodiorites, granites and leucogranites (Honegger et al., 1982). Evidence for the existence of precursory continental crust includes the presence of granitic gneisses and meta-sedimentary sequences in the Ladakh Range (Honegger and Raz, 1985) (Figure 1.5).

The sequence of cross cutting leucocratic granite dykes intrusion is marked by final stage that exposed around the Gilgit - Indus Rivers confluence in Pakistan and at Chumathang in Ladakh (Petterson and Windley, 1985). The batholith was extract from the mantle with almost nearby- chondritic isotope ratios and insignificant crustal effect is suggested by the Sm-Nd and Sr isotopic ratios (Honegger et al., 1982; Scharer et al., 1984; Petterson et al., 1985).

The Himalayan granitoids are also divided on the basis of geographical distribution granitic plutons constitute five major belts in the Himalaya and adjoining Karakoram (Le Fort, 1988). These belts from North to South include: (1) Karakoram Axial Batholith, (2) Trans-Himalayan Batholith, (3) North Himalayan Granite Belt, (4) Granitoids of the Higher Himalayan Crystalline (HHC) Belt and (5) Lesser Himalayan Granite Belt.

In the present study, the Ladakh Batholith around Leh region has been chosen to perceive the intended meaning of the genesis of plutonic rocks in the geodynamic substructure of the India- Eurasia junction, the poorly known outlying plutons has been confined to Ladakh Batholith in between Shyok tectonic zone and Indus suture zone are studied. The updated research examination that represent the interrelationships between different lithounits have been reported that moves in a constant direction to a main transect Leh-Saboo-Khardung-Khalsar-Diskit (Figure 1.4, 1.5), by covering insufficient geological consequential sections from the Shyok Suture Zones and the Indus Tsangpo Suture Zones of the eastern Ladakh Himalaya. This traverse is certainly critical to intend the meaning of the nature of magmatism, mode of emplacement of magma and their coeval melt interactions and pre-existing lithounits, which make it possible to us to summarise the series of geological events that are handled in subduction to collisional tectonic regimes of eastern part of the Ladakh Himalaya.

As this region, exhibits a great samples of alkaline magmatism and calc-alkaline of same age in a collision-related tectonic setting. The northern part of the Ladakh comprises the Shyok valley, which is elongated from NW-SE headed tectonic zone edges to the north of Ladakh magmatic arc and south of Karakoram and Pangong mountains This zone is associated with the number of granitoid bodies. There is less studied and few literature is accessible on their petrography, geochemical and petrogenesis. An effort has been made in this thesis for documenting the petrogenesis of the deficiently to perceive the intended meaning of granitoids rocks and for discussing the petrographic and geochemical characteristics between the Ladakh Batholith of Leh regions around the Trans-Himalayan Mountain Belt.

From all previous studies, the conclusions have been consolidated to yield a combined frame of the regional geology and also to a greater extent that regulate the youngest calc-alkaline plutonism throughout the length of northern part of the Indus Suture zone in Ladakh.

1.1. Scope and Objective of This Thesis

The Ladakh Batholith covers a significant part of the Trans-Himalayas belt. The Basgo, Nimmu, Umla and Taru area of the Ladakh Batholith, which is 50 to 60 km west side of Leh region of Ladakh district. This above mentioned study research area have been selected for research as they provide a productive examples of calc-alkaline and alkaline magmatism of identical age in a collisional tectonic setting. This thesis response the results of an integrated field, geochemical and isotopic study of granitoid rocks generated during the Andean-type magmatic emplacement along the Kohistan-Ladakh Batholith. The

purpose of the study is to document and evaluate the nature and evolution of granitoid magmatism leading to stabilization of crust, and to use this Information to examine broader tectonic questions concerning the evolution of the province.

Most of the previous and well experienced scientists has been studied area in and around Leh region about geochronology and still this Himalayan belt is become a contradiction subject for scientists and geologists. The objective of this study is to characterize mineralogy, petrography, geochronology, geochemistry and isotope geochemistry and petrogenesis of Ladakh Batholith. The results obtained in this project using the above mentioned methods and analysis with the help of the current geochemical and petrological data of these rocks will be used to answer the following specific questions of this study are as follows.:

1. To identify the magmatic processes involved in their genesis, such as fractional crystallization, assimilation and magma mixing/mingling and the extent of crustal assimilation in the evolution of these rock units.
2. Characterize the intrusive rocks within the Ladakh Batholith of Leh region in terms of their field relationships such as Petrography, Geochemistry and Strontium (Sr), Neodymium (Nd) isotopic composition.
3. Use of whole-rock major oxides, trace and rare earth elements (REE) data to evaluate the petrogenesis of the rocks and, employing Sr, Nd isotopes to examine the relative contributions of mantle and crustal components, and thereby, infer the crustal residence time of the source regions.
4. Utilize the above data to evaluate the more general problem of the crustal evolution of the Trans-Himalaya Batholith in Ladakh around Leh region, and test the rift and accretionary tectonic models.
5. What were the factors involved in the evolution of igneous plutonic rocks?
6. To describe the composition of their source or sources and to place constraints upon the sources from which they were derived.
7. It also gives a complete idea about collision tectonic setting of Ladakh Batholith around the Leh region of Ladakh district.
8. To characterize the intrusive rocks from the Massif and identify the differences between them in terms of their mineralogy, major oxides and trace elements and Sr, Nd isotopic compositions.

But in this present study, we deal with the petrological, geochemical and isotopical characteristics of the Ladakh Batholith that unprotected connecting the Indus suture zone and the Shyok suture zone to reveal the compositional differences of magma origin and the procedure for genesis of these rock types. This study also attempts to regulate the suturing and the timing of magmatism to percieve the intended meaning of the Indus Suture Zone in Ladakh.

1.2. Description and Organization of the thesis: Presentation of Data

The thesis contains six chapters:

1. This Chapter covers the introduction section of study area of the intrusive rocks in the Ladakh Batholith around the region of Leh, Ladakh.
2. Chapter 2 presents a Literature review of study area of the intrusive rocks in the Ladakh Batholith around the region of Leh, Ladakh.
3. Chapter 3 describes the Material and Method of the study area of the intrusive rocks in the Ladakh Batholith.
4. Chapter 4 gives Results and Discussion that includes sub-topics like
 - ✓ 4.1. Field work and geological setting of the study area.
 - ✓ 4.2. Petrography of the intrusive rocks.
 - ✓ 4.3. Mineral geochemistry of the study area, this is subdivided into two Sections. The first Section deals with the classification of feldspar, amphibole, clinopyroxene, biotite and Fe-Ti oxides. Geothermo-barometer and oxygen fugacity calculations are the main subject of the second Section.
 - ✓ 4.4. Whole-rock geochemistry of the study area presents the geochemical characteristics of the intrusive rocks in the Ladakh Batholith around the region of Leh, Ladakh. This chapter is also subdivided into two Sections. In the first Section, the plutonics are classified on the basis of their major element contents. The second Section presents the interpretation of their trace element characteristics, as shown by trace element variation diagrams, REE patterns, multi-element patterns and tectonic discrimination diagrams.
 - ✓ 4.5. Isotope geochemistry of study area presents the petrogenetic modelling for the plutonics using their trace elements and Sr, Nd isotope compositions. It also presents the results of a Sr, Nd isotopic tracer study undertaken to test the proposed tectonic models for the development of the province.
 - ✓ 4.6. Petrogenesis of the study area covers tectonic setting and tectonic discrimination diagrams with petrogenetic model of subducting plates.
5. Chapter 5 describes the discussion of whole thesis and the conclusions of this thesis. It integrates the results presented in previous chapters and discusses their implications for the crustal evolution and tectonic development of the study area.
6. Chapter 6 gives the References that used in the thesis.
7. Chapter 7 Appendix

Appendix 1 Mineral Chemistry data. Geochemistry data of major oxides and CIPW norm is presented in **Appendix 2**. Geochemistry data of trace elements are given in **Appendix 3**. Sr and Nd isotope analytical procedures and nomenclature **Appendix 4**.

2. LITERATURE REVIEW

Introduction

The geology of the Trans-Himalaya is completely distinct from that of the lower and the Higher Himalaya. The Trans-Himalaya includes the Indus Suture Zone and the Tethyan Zone. The rocks of these zones are mostly belonging to fossiliferous Cambrian to the Tertiary Sequence.

2.1. Geological and Regional Setting of the Ladakh Batholith

The Himalayas are a major example of continent-continent collision that took place between Indian and Eurasian plates. The Ladakh Batholith is a cutcrop of the calc-alkaline Trans- Himalayan batholith, that stretched about 2500 km to perceive the intended meaning of the southern margin of the Eurasian plate. The Ladakh Trans-Himalaya region is comprised comparatively by younger rocks isolating the Eurasian plate from the Indian plate. which are divided into three different lithotectonic units: (i) the Indus suture zone followed by Indus river valley, (ii) the Shyok suture zone or the Shyok ophiolitic mélange followed by Shyok River; and (iii) the Ladakh magmatic arc or the Ladakh Batholith in the relating part that acts as blockade between Shyok and Indus valleys.

The rocks of the Indus Suture Zone, the North Indian continental edge, and the southern edge of the Asian plate are exposed by the Ladakh and Zaskar ranges (Searle et al., 1997b; Steck, 2003) (Figure 2.1). The real zone of collision between the Indian plate to the South and the southern edge of Asia to the North (Ladakh Batholith) is marked by the Indus Suture Zone. The northern boundary that corresponds to the Ladakh Batholith and the Main Zaskar Backthrust is the southern boundary of the suture zone, which places compositionally lower Mesozoic shelf carbonates (Neo-Tethyan shelf) northward over the suture zone along a South- dipping thrust or steep southwest (Searle et al., 1997b; Corfield and Searle, 2000) (Figure 2.1).

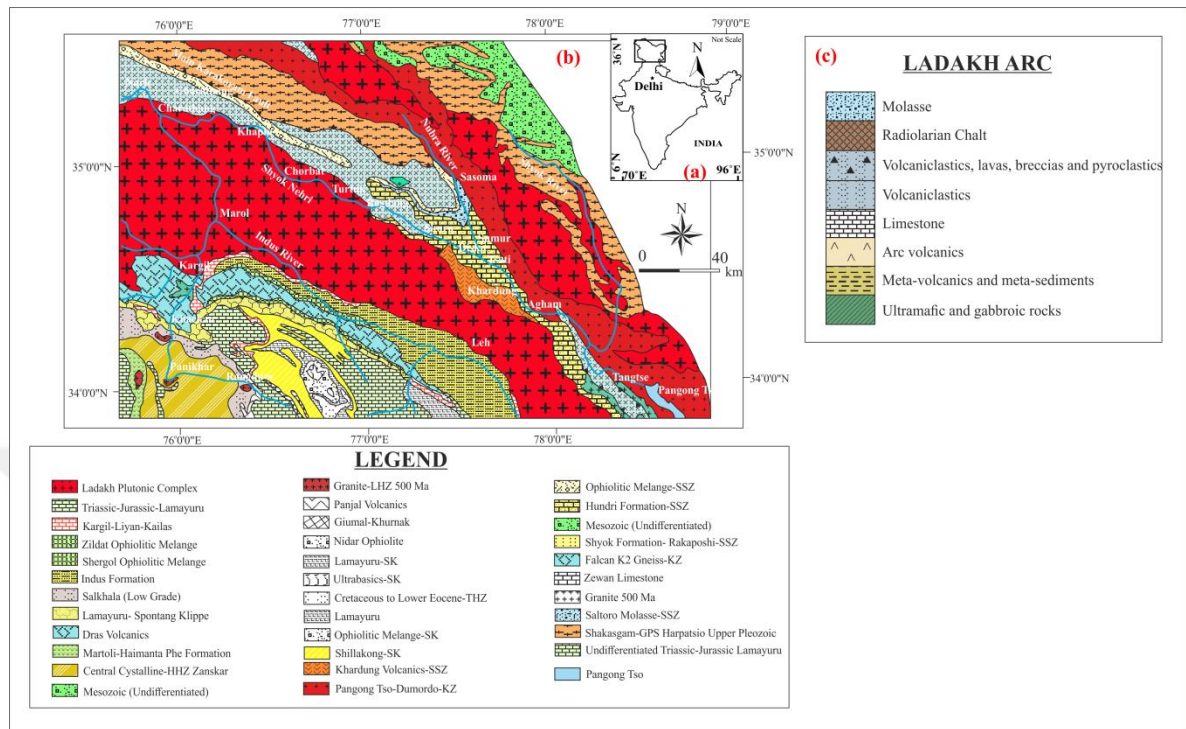


Figure 2.1. (a) Study area of Ladakh Batholith in the north of India (Valdiya 1988) (b) Geological map of Ladakh showing the Shyok, Nubra, Leh and Zaskar regions (Modified After Thakur 1992), (c) Vertical geological section of Ladakh region (Modified After Robertson vd. 2002)

The Trans-Himalayan batholith in Ladakh has been separated by the two main tectonic suture zones like the Shyok Suture to the north and the Indus Suture to the south (Thakur and Misra, 1984; Upadhyay, 2002) (Figure 2.1): the previous collisional boundary arc represented by the Karakoram block and the Kohistan-Ladakh island, and the major boundary zones has been represented by the latter zone between the Indian and Asian plates (Gansser, 1977). The Indus Group consisting of at least 2 km thick pile of mainly continental sediments, loosely boundary between the the Indus Suture zone and Ladakh Batholith and records the intermountain and forearc basin development (Garzanti and van Haver, 1988; Sinclair and Jaffey, 2001; Kirstein et al., 2006). Since from Miocene times, the major dextral strike-slip fault has been active and that bound the southwestern edge of the Tibetan Plateau and the batholith that covers and bounds to the north-east extent by the Karakoram fault (Searle et al., 1992; Searle, 1996). Various categories of igneous bodies are appeared from gabbro to granite, with biotite- and hornblende-bearing granodiorite as the uppermost rock types are ranged by the Ladakh Batholith (Honegger et al., 1982; Sharma, 1990; Weinberg, 1997). The Ladakh Batholith has run away the intense brittle deformation upto a large range and also has largely undeformed area. However, within the NNW-trending dextral Thanglasgo Shear Zone, an enormous power of penetrative ductile shear fabrics have been remark and in a dispersed deformation zone to the north of Leh (Weinberg and Dunlap, 2000).

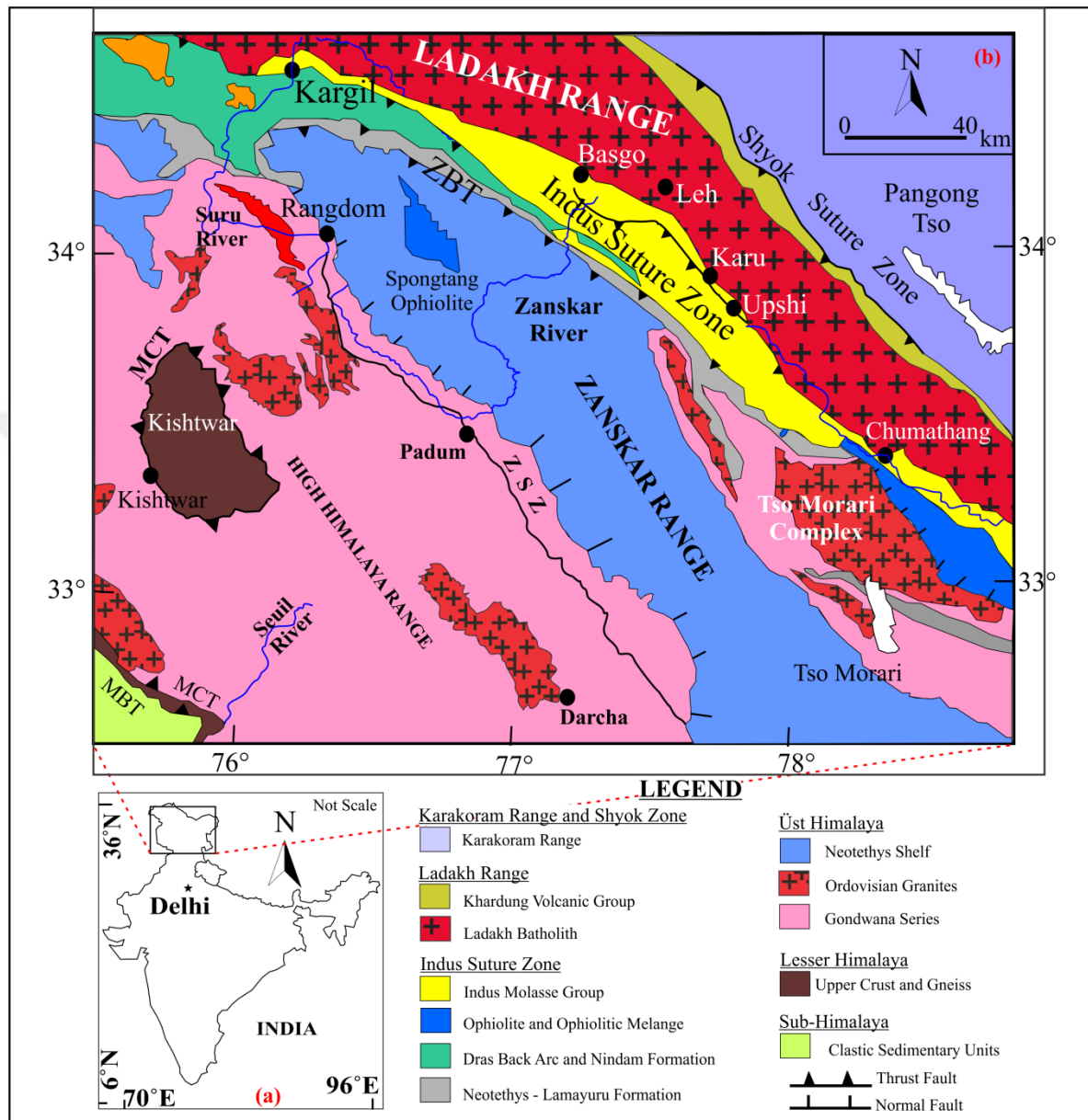


Figure 2.2. (a) Study area of Ladakh Batholith in the north of India (Valdiya 1988) **(b)** Map showing the Northern Ladakh-Zaskar Himalaya. Modified after, Thakur (1981), Thakur and Misra (1983, 1984), Steck (2003), Epard and Steck (2008). Dissemination of structures principal and geological units throughout the length of the northern Indian plate, the Indus Suture Zone, the Ladakh Batholith, and the Karakoram (southern margin of Asia). MBT- Main Boundary Thrust, MCT- Main Central Thrust; ZBT- Main Zaskar Backthrust, ZSZ- Zaskar Shear Zone.

The Great Karakoram Mountains (Saser Muztagh) to the northeast, the Ladakh range in the middle and a small part of Jasker Mountain to the southwest from the prominent ranges. The most pictures valleys of Ladakh are the Indus valley to the South

and the Shyok- Nubra valley to the North of Leh. Several glaciers occupy the higher reaches in the North and North-east of the area. General altitude and site coordinates of the area varies between 2995 m ($34^{\circ} 46'$; $77^{\circ} 15'$) and 7672m ($34^{\circ} 51'$; $77^{\circ} 45'$). The area is nourished by the shyok and Indus Rivers which follow an almost parallel northwest – southeast course in this quadrangle and the South easterly flowing Nubra River joins Shyok River near Diskit. The quadrangle shows following geological set up from SW to NE (Figure 2.1). The Zaskar sedimentary belt comprises undifferentiated Kuling-Lilang and Lilang group of rocks (Figure 2.1).

The Indus Tectonic Belt comprises Indus Group of Volcano sedimentary sequence and Sangleuma Group of rocks with ophiolite association The Ladakh Granitoid Complex. The Shyok-Nubra Belt of volcano sedimentary assemblages with intrusion of granitoids. The Karakoram Belt of Granitoids with associated older metamorphites and Karakoram sedimentaries. Undifferentiated Kuling- Lilang Group of Permian to Jurassic age bounded on both the sides by thrusts is exposed in the southwestern part of the area. It comprises of black, grey, green and purple shale and greyish limestones bands.

Undifferentiated Lilang Group of rocks of Triassic to Jurassic age exposed in the southwestern corner of the quadrangle comprises limestone, dolomite and quartzite. Rocks of Indus Tectonic Belt of Late Cretaceous to Early Miocene ages are sandwiched between the Ladakh Granitoid Complex in the north and the Spiti- Zasker Phanerozoic sedimentary belt to the south. The zone comprises two separate parallel belts designated as Indus Group and Sangeluma Group. The Ladakh Batholith is bounded by the Karakoram fault in the east, the Indus suture zone in the south and the Shyok suture zone in the north. However, the accurate position of the Shyok suture in eastern Ladakh is undetermined due to constricted entrance to the area (Rolland et al., 2000; Rolland and Pêcher, 2001; Weinberg and Dunlap, 2001) (Figure 2.1). The Ladakh Batholith is bound to the southern edge by the Indus Suture Zone, which mainly isolates the batholith from the disfigured sedimentary successions of the Indus Molasse excluded where the molasse onlaps the batholith (Frank et al., 1977).

Eocene to Miocene sediments including siltstones, limestones and conglomerates, which is comprised by the Indus Molasse (Searle et al., 1990). The batholith appearance the southern margin of the Shyok tectonic belt, which is constitutes of Paleozoic to Eocene metasedimentary, volcanic and metamorphic rocks bound by WNW-trending thrusts (Srimal et al., 1987). The Ladakh Granitoid Complex of Cretaceous to Tertiary age includes Leucocratic granite and pink porphyritic granite, biotite- hornblende granite, granodiorite, quartz monzodiorite, diorite, tonalite, hybrid rock and lamprophyre dyke. The older metasedimentary rocks occurring as thin bands within Ladakh Granitoid Complex comprises slate, quartzite, schist and gneisses. The Ladakh Batholith is characterised by coarse-grained granite and granodiorite with abundant diorite enclaves concentrated at the margins and nearly absent towards its core. In the core of the batholith, large potassium feldspar dominates the mineralogy. The major segment of the Ladakh Batholith constitute the Late Cretaceous-Eocene (102-50 Ma) granitoids which is bounded on its southern and northern margin by the Indus Group and the Shyok suture zone, respectively.

2.2. Previous Studies in the Ladakh Batholith around Leh Region

The earlier and previous references of the geology of the Ladakh are available from the works of Stoliczka (1866) and Drew (1875), which carried out the pioneering work in the parts of mountain ranges. The involvement in the research of Ladakh region is carried out by number of scientists (Wadia, 1937; Norin, 1946; Tewari, 1964; Shankar, et al., 1976; Shah et al., 1976; Frank et al., 1977; Fuchs, 1977; Sharma and Kumar, 1978; Thakur, 1981; and Brookfield and Andrew, 1984).

The role that played during the geotectonic evolution of the Himalaya and its characteristic rock assemblage, the Indus Suture Zone in Ladakh region is one of the most fascinating areas for geological studies. The significance of the Indus Suture Zone was realized and debated soon after Gansser (1964) assigned it a formal name.

Extension of Indus Suture Zone towards China and Pakistan, (Gupta et al., 1970; Gansser, 1974, 1977; Shanker et al., 1976; Kaila and Narain, 1976; Frank et al., 1977; Fuchs, 1977; Gansser, 1977; Sharma and Gupta, 1978; Thakur and Virdi, 1979; Tahirkheli et al., 1979; Klootwijk and Conaghan, 1979; Powell, 1979; Srikantia and Razdan, 1980; Rai, 1980, 1982; Thakur, 1981, 1983; Honegger et al., 1982; Searle, 1983; Windley, 1983; Allegre et al., 1984; Thakur and Mishra, 1984). The meeting point between the Indian Plate and the Karakoram- Tibet block of Eurasian Plate is made by the Indus- Tsangpo Suture Zone. It extends for about 2500 km of north of Himalaya from east to west and is characterized by ophiolitic melanges and ophiolites, molasse sedimentaries and plutonic-volcanic rocks (Gansser, 1977; Sharma and Kumar, 1978) (Figure 2.1).

Some of the scientists and geologist workers suggested that there are two sutures in Ladakh, i.e; the Indus Suture Zone and the Shyok Suture Zone. The Shyok Suture is interpreted as a paleo- suture and different from Indus Suture Zone (Gansser, 1980; Honegger et al., 1982). However, the field evidences are opposing towards the presence of paleo-Subduction throughout the length of the Shyok Suture Zone is presented by Rai (1982).

On the basis of Deep Seismic Sounding (DSS) profiling across the Himalaya, Kaila and Narain (1976) suggested that the Northern Boundary of the Indian plate does not coincide with the Indus Suture Line but lies further north at the southern margin of Tien-Shan in China.

The two main volcanic activities that are associated with Indus Suture Zone i.e. the Dras volcanics and the Sumdo volcanics. The Dras and the Sumdo volcanics lie in the south zone and the younger Khardung volcanics lying in the north (Figure 2.1).

Dras volcanics are mainly comprises of basalt and volcanic sediments. The K/Ar dating gave an age of 77.5 ± 1 or 77.5 ± 1 Ma for these volcanic rocks (Sharma et al., 1978). Red jasper shales, limestone bands and radiolarian chert are also associated with with Dras volcanics and ophiolitic mélange have yielded Upper Cretaceous Fauna. On geochemical

point of view, the volcanic rocks are arc tholeiites and calc-alkaline in character (Gergan, 1978). The second volcanic belt in the Shyok- Khardung was delineated by Sharma and Gupta (1978). The earliest knowledge about the volcanics in the area is known from the work of Lydekker (1883) and Norin (1946), who considered these volcanics equivalent to Panjal volcanics. Sharma et al. (1978) reported first radiometric age of the Khardung volcanics by K/Ar is 38 ± 2 or 38 ± 2 Ma. They also suggested that this volcanic activity in Khardung area and Shyok valley is much younger than that of the Indus Valley (Dras Volcanics). The Khardung volcanics form a thick succession of acid and intermediate volcanics, volcano- clastics, tuffs and sediments.

It is now well accepted that the Indus Flysch and the Indus Molasse form two distinct linear belts. The former being lowers Cretaceous to Eocene and the later post - Middle Miocene (Sharma and Kumar, 1978). The geological importance of Ladakh granites has increased significantly due to its close associations with the Indus Suture Zone.

The Ladakh granite represent the various phase of igneous activity is considered by Shanker et al. (1976). They classified granite on the basis of mineral composition such as biotite granite, hornblende granite, and tourmaline granite with different shades of grey and pink. The Ladakh Batholith is zoned in nature and become more acidic towards the core is observed by Sharma and Kumar (1978). The three zones that they recognized i.e. aureole zone, border zone, core zone.

The geochemistry of these granitoids rocks of Ladakh has been recently discussed by several scientist and workers (Varadarajan et al., 1980; Honegger, et al., 1982; Sharma and Choubey, 1983). These studies suggest that the magma responsible for the origin of Ladakh granitoids is calc-alkaline in charater.

Maximum quantity and quality of the previous work in the Ladakh Batholith has concentrated on the geochronology and age, sources of the granite on the Higher Himalayas. The age of the Ladakh Granite has been discussed by various scientists and plays a crucial role in the paleo-geographic and paleo-tectonic reconstruction of this region but still it's a matter of controversial.

The intruding of the Trans-Himalayan calc-alkaline batholith throughout the length of collision zone about 2500 km during India's northward drift Tethyan oceanic lithosphere was a subducted northward under the active Andean-type southern edge of Asia. The batholith comprises of the more primal olivine norite and gabbro but also dominantly constitute of biotite- and hornblende-bearing granodiorite and more produce tonalite and biotite granite.

Previous studies focuses on the tectonic setting and rock dating to understand the age of this batholith. The good amount of published work concerning to this segment of the Himalayan orogeny (Searle et al., 1988, 1990, 1997b; Jain and Singh, 2009) contributes the factors within which we can evaluate the consequential of the detailed field observations and geochronological data. Significance of the proposed research topic should demonstrate

the gap is to be filled by the analysis of this existing literature. Considering literature from all the sources should be listed and displayed below.

Most of the scientists and researchers have been published their journals on rock dating techniques of Ladakh Batholith region. It has been constrained mostly by Rb-Sr whole-rock isochron analysis and zircon and monazite U-Th-Pb dating techniques. So, some of the researchers are listed below those who published their journals in this region.

Frank et al. (1977) they have presented the work over the evolution of the region and to gain perception into the cooling history of the Ladakh Batholith to acknowledge the key periods by new multiple low temperature thermochronometry data (zircon (U-Th)/He, apatite fission track and apatite (U-Th)/He).

Searle et al. (1990) they have shared their research work over the evolution of the intermountain Indus molasse basin and restoration, Ladakh Himalaya, India. Palaeocurrents show sediment transport, axis-parallel, predominant E-W, with inferior lateral input paths being conserved. The Indus molasse basin is deformed by the number of activity like N-directed back thrusts, post-Eocene and many of which cut the entire stratigraphy and, therefore, were active at least into late Tertiary times.

Singh (1993) has worked over the geological set up of a part of the Ladakh Granitoid Complex around the Ladakh Himalaya.

Rolland et al. (2000) they presented their research work over the arc evolution throughout the length of the Asian margin and Mid-Cretaceous back-arc formation: the Shyok Suture Zone in the northern Ladakh

Rolland and Pêcher (2001) they replied to the comments on “Middle Cretaceous back-arc formation and arc evolution throughout the length of the Asian margin: the Shyok Suture Zone on northern Ladakh of Northwestern part of the Himalaya.

Weinberg and Dunlap (2001) they have commented on “Middle Cretaceous back-arc formation and arc evolution throughout the length of the Asian margin: the Shyok Suture Zone in northern Ladakh (NW Himalaya)”. In: Rolland, Pêcher (Eds.) Data displays a northwest-southeast evolution from these two areas, from back-arc to arc formations in northern Ladakh. The opening of this back-arc basin developed on the northwestern side of the Ladakh Arc. Closing of this back-arc was progressively to eastward.

Jamieson et al. (2003) they focused research over the tectonic forcing of longitudinal valleys in the Himalaya: morphological inspection of the Ladakh Batholith, North India. This study investigates geomorphic variations in transverse catchments that drain the Ladakh Batholith, into the Indus and Shyok rivers. On different structural characteristics of its northeastern and southwestern boundaries, batholith has been divided into three different types of zones. Using three digital datasets was carried out for morphometric analysis of 62 catchments that drain into the Indus and Shyok valleys.

Ravikant (2005) they focused his research over the effectiveness of Rb–Sr geochronology in regulating Miocene and Cretaceous episodic proceeding in the eastern Karakoram, Ladakh, India. Rb–Sr geochronology techniques can date such young events was applied to the different stages of granitoids and their mineral segregation, from mostly enclosed by the Pangong transpressional zone of the dextral Karakoram fault (KF).

Singh et al. (2007) they worked over the SHRIMP-II U–Pb zircon age from a granodiorite that nearer to its northern edge with the Shyok Suture Zone (SSZ) by calculating the age of 60.1 ± 0.9 Ma in so much as from its southern edge that near to the Indus-Tsangpo Suture Zone (ITSZ) diorite yields an age of 58.4 ± 1.0 Ma. After crystallization, the northward leaning of the Ladakh Batholith also indicated by the depth of emplacement data.

Vadlamani et al. (2009) they have presented their work over the zircon U–Pb and Hf isotopic constraints on petrogenesis of the Cretaceous-Tertiary granites in eastern Karakoram and Ladakh, India. Granitic rocks composed from the Karakoram terrane and Ladakh Batholith have been managed to restrain these geological activities by performing the analysis of Zircon U–Pb dating and Hf isotope.

Kumar (2010) they focused their research over the mafic to hybrid microgranular enclaves in the Ladakh Batholith in the northwest Himalaya: implications on calc-alkaline magma chamber processes. Evidences from the field and microstructural slightly suggested that the Ladakh granitoids and their microgranular enclaves are consequence of multitype magma mingling and mixing processes are associated with the fractional differentiation of some batches of mafic and felsic magmas that produced in open magma chamber of subduction setting.

Marc et al. (2010) they research over the Implications for the age of the India–Asia collision in the Ladakh Himalaya by calculating the age determinations of zircon for the Ladakh Batholith at Chumathang of Northwest India.

White et al. (2011) they have presented the deconvolving episodic age spectra from zircons of the Ladakh Batholith around the northwest part of the Indian Himalaya.

Kumar et al. (2011) they worked over the geochemistry, Hf isotope and zircon U–Pb geochronology of granitoids and its enclaves from Ladakh Batholith around northwest part of the Indian Higher Himalayas.

Heri et al. (2015) they presented their scientific research over the isotope geochemistry and geochronology of Eocene dykes that intrudes into the Ladakh Batholith. They studied that the eastern dykes shows negative $\epsilon_0(\text{Nd})$ and positive $\epsilon_0(\text{Sr})$ values due to corroded quartz xenocrysts, whereas the western dykes reveal positive $\epsilon_0(\text{Nd})$ and near-zero $\epsilon_0(\text{Sr})$ values because they do not contain quartz xenocrysts. The variation in Sr–Nd isotopes ($\epsilon_0(\text{Nd})=+3.6$ to -9.6 , $\epsilon_0(\text{Sr})=0.4$ to 143) and the quartz xenocrysts can described by varying several levels of crustal assimilation of the parent magma of the dykes. Five

dykes were dated by ^{40}Ar - ^{39}Ar progressively heating from isolated minerals: one biotite isolate dated both by Rb-Sr and ^{40}Ar - ^{39}Ar provide an age of 45 Ma and ages for amphibole ranges 50 and 54 Ma.

2.2.1 Previous Studies on the intrusive rocks in the Ladakh Batholith around Leh Region

It is suggested from foregoing studies of the Ladakh Batholith about the magmatic rocks that intruded between 102 ± 2 Ma (U-Pb ages, west of Leh near Kargil; Honegger et al., 1982; Scharer et al., 1984) and 60 ± 5 Ma (Rb-Sr whole-rock isochron age, Leh, Honegger et al., 1982; Scharer et al., 1984). Biotite mineral from Leh region has been yielded an age of 48.7 ± 1.6 Ma by doing the K-Ar dating (Honegger et al., 1982), during that period of time, it is suggesting a consequential cooling of the igneous rocks. It has based a data information of fast cooling event from 23°C in the Leh-Khardung La region of Ladakh during the Miocene ca. 22 Ma (Kirstein et al., 2006).

One category of writers, enclosed by the Indus Suture Zone in Ladakh around northwestern part of India (e.g. De Sigoyer et al., 2007, 2008) have proposed the Paleocene/Eocene frontier as manifested by continental subduction (ca. 55-57 Ma) by an initial contact of the Indian and Asian continents and overly controlled with the modeling and dating of ultra-high-pressure (UHP) coesite-eclogite metamorphism along the northern margin of the Indian plate at Tso Moriri in the Puga gneiss (53.3 ± 0.7 Ma: Leech et al., 2005, 2007). At ca. 50 Ma, these scientists later on bring out the idea that the initial India-Asia contact was come after by continental collision.

The constrained over the closing of the Neo-Tethys Ocean distracting the Asian and Indian continents by reporting the passage from marine to continental facies sedimentation is given by the another category of writers (Garzanti et al., 1987; Searle et al., 1988, 1990; Rowley, 1996; Searle et al., 1997b; Rowley, 1998; Zhu et al., 2005; Green et al., 2008).

The scientific suggestion by the third category of writers (Aitchison et al., 2002, 2003, 2007; Aitchison and Davis, 2004; Ali and Aitchison, 2005, 2007) that the India-Asia collision did not happen until 30-35 Ma on the foundation of paleomagnetic reconstructions of the northward drift of India, the Zhepure Shan peak in South Tibet (North Indian shelf) shows a late Eocene (Priabonian ~ 35 Ma) marine nannofossil clusters (Wang et al., 2002) and the Gangrinboche conglomerates shows a late Oligocene-Early Miocene age (similar to the age of Hemis conglomerates in Ladakh) in southwest Tibet.

Although the Ladakh Batholith is studied in several geological senses, previous studies involving mineral chemistry, whole-rock geochemistry (major-trace-REE) and isotope geochemistry are limited. Therefore our study is mainly focus on petrology (mineralogy, petrography) geochemistry and petrogenesis of the Ladakh batholith and its enclaves.

3. MATERIAL AND METHOD

Methods and Analytical Techniques used in this thesis

Several petrographic and geochemical techniques will be applied to the Ladakh Batholith granite samples to characterize and interpret the mineralogy. The proposed work will be an integration of both laboratory as well as field investigations. The following essential tools that going to be include are listed below:

- (1) Use of 1:250.000 geological map of Ladakh region published by Geological Survey of India, Kolkata. Also toposheet, LandSAT images and Google Earth images will be used for studying and to plan sample collection from the mentioned region.
- (2) Field work includes the sample collection around the Leh Ladakh region. The samples are collected from 50 to 60 km towards west of Leh region.
- (3) Mineralogy-petrography deals with the study of optic mineralogical properties that will be analyzed by the optical microscope. Firstly, thin section will be prepared for all collected samples and then figure out the minerals and accessory minerals present in the samples. The study of mineralogical petrography will be carried out by using Nikon-polarized microscope. EMPA (Electron Microprobe) analysis for mineral compositions and geothermobarometry.
- (4) Major element geochemistry is analyzed by XRF. Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) will be use for the analysis of trace elements and also REEs (ppm). Radiogenic isotope geochemistry like Rb-Sr (whole-rock), Sm-Nd (whole-rock).

3.1. Field Observation and Sample Collection

During field work conducted in July 2015, hand specimens were collected from 50 to 60 km towards West of Leh region. Representative samples, each weighing 0.5 to 1kg, of Basgo, Nimmu, Umla and Taru Granite, microgranites, leucogranites. Diorite, granodiorite and metasediments were collected in cloth bags duly annotated with sample number, rock type and location (Appendices 1). However, samples from some of the areas could not be collected due to their inaccessibility owing to law and order situation.

3.2. Sample preparation

The samples were crushed using jaw crusher at Akdeniz University Laboratories Complex. The crushed samples were carefully sorted, washed to remove the dust particles and dried at 110°C. Size of the crushed samples was further reduced by roll crusher, which was thoroughly cleaned after each sample to avoid the contamination. The ground material was passed through sample splitter to get the representative sample of each rock type. About 200 g of each sample were powdered in TEMA tungsten carbide grinding mill, and

stored in air-tight plastic bottles for further laboratory analyses. Around 41 thin sections of different rock units were prepared for the petrographic studies.

3.3. Thin Section Preparation and Petrography

Samples collected from the field were cut in half with a diamond blade water saw. The samples were then cut to smaller sizes suitable for thin section preparation. Forty-one samples were sent to Ankara University, where samples were thin sections prepared. Petrographic analysis was conducted under Optical Mineralogy laboratory by using a polarized petrographic microscope having a configuration of Nikon 50ipol and 100ipol microscopes and Clemex 6.0 program. Photomicrographs of the thin sections were taken using an attached digital camera at facilities at the Faculty of Engineering, Department of Geological Engineering, Akdeniz University, Antalya.

This section describes the geochemical methods and analytical techniques used in this study. For each of the methods, first a brief summary of basis and analytical instrument is given, following which a detailed account of analytical protocol is described. The following methods and related instrumentation techniques used in this study are described.

1. Major oxides and trace elements analysis using X-ray fluorescence (XRF) and ICP-MS.
2. Rb-Sr, Sm-Nd Radiogenic isotope analysis by using Mass Spectrometer.



Figure 3.1. Above picture shows the working at Optical Mineralogy Laboratory by using a Nikon Polarized microscope at Department of Geological Engineering, Akdeniz University, Antalya.

3.4. Major oxides and trace element analysis using X-ray fluorescence (XRF)

3.4(A). X-ray fluorescence technique

X-ray fluorescence (XRF) is a non-destructive and quantitative analytical technique routinely used to determine major (in wt %) and selected trace element (in ppm) concentrations in geological samples. When a sample is bombarded with a beam of high-energy radiation produced in the X-ray tube (source), an electron can be ejected from the innermost atomic orbital of an element by absorption of light wave of sufficient energy. This results in the inner shell electronic transition (as the atom returns to ground state from the excited state) from higher to lower quantum energy state during which an electron from a higher energy level (outer shell) fills the vacant lower energy level (inner shell).

During this transition fluorescent light (photon) called characteristic X-ray of the element is emitted. The wavelength (inversely proportional to the X-ray energy) of the characteristic X-ray is assumed to be independent of chemical combination in all elements or compounds. The energy of this X-ray light is equal to the difference in orbital energies (energy of a specific orbital is a function of principal quantum number, n) that took part during the electronic transition and is always the same (characteristic of an element).

Furthermore, the differences in energies between the levels increase regularly with atomic number because of the increasing charge on the nucleus; therefore the radiation resulting from K ($n=1$) to L ($n=2$) shell electronic transitions appears at shorter wavelengths for heavier elements. Hence, determination of the unique energy (inversely proportional to wavelength) of the characteristic X-ray light emitted by a particular element serves as a fingerprint for that specific element. Energy-Dispersive XRF (ED-XRF) systems resolve spectral peaks arising due to different energy X-rays characteristic of the elements making up the sample.

On the other hand, in the Wavelength Dispersive XRF (WD-XRF) systems an analyzer crystal with a known lattice d -spacing is used as a diffraction grating, which allows only one X-ray wavelength to pass through at any given diffraction angle as per the Bragg's equation (equation 1). This restricts all energy except for that of the element of interest from reaching the detector for both qualitative and quantitative analyses. For quantitative analyses, the amount of peak intensity or count rate (number of X-ray photons at a given energy per unit time) received at the detector is converted into elemental concentration in the sample by using calibration curves obtained from repetitive analyses of both internal and external multiple standards. Detailed description of X-ray Fluorescence technique can be found in Jenkins (1999) and Van Grieken and Markowicz (2002).

3.4(B). XRF sample preparation and analysis

To determine the geochemical characteristics of plutonic rocks in the study area, the analyzes of 41 samples were carried out in Acme Analysis laboratory in Canada, for calculating major, trace and rare earth elements.

In this laboratory, the main elements were analyzed by XRF and the rare earth elements were analyzed by ICP-MS methods. For major element analyzes in which 0.2 g of the powder sample was analyzed by mixing with 1.5 g of LiBO_2 , stirring liquid with containing 5% HNO_3 , while the Rare Earth Element or Trace Element analyzes were analyzed by dissolving 0.25 g of powder in four different acids

Major oxides were measured in weight %, whereas Trace Elements and Rare Earth Elements were measured in ppm. For Loss on Ignition (LOI) estimates, 1g of sample powder was placed in platinum crucible and heated to 1000°C for 1 hr in a muffle furnace. Subsequently, sample was kept in the furnace till the temperature dropped to 200°C , removed, and cooled in a desiccator to the room temperature. Sample was weighed and using the difference from the dry weight, LOI wt% loss was estimated. LOI estimates amount of structural water, carbonate radicals or the like present in the sample and cannot be determined by XRF analysis.

All XRF analyses were done by using the newly created facility in Bureau Veritas Mineral Laboratories, Vancouver, Canada with a Rigaku, ZSX primus-II WDXRF, having 4 KW Rh target and operated at 60 KV and 50 mA.

3.4(C). ICP-MS analysis

A subset of 41 representative samples was chosen for ICP-MS (Inductively Coupled Plasma Mass Spectrometry) analysis. Fused glass discs were analysed preferably powders to make sure dissolution of the intrusive rocks. All ICP-MS analyses were done by using the newly created facility in Bureau Veritas Mineral Laboratories, Vancouver, Canada.

3.4(D). Radiogenic isotope analysis

Subsets of sixteen representative whole-rock samples from the Ladakh Batholith granite samples were analyzed. Sr and Nd radiogenic isotope analysis were conducted by using the automatical VG 354 multicollector thermal ionisation mass spectrometer at the Department of Geology, Middle East Technical University (METU), Ankara, Turkey.

Isotopes are atoms of an element with same proton but different neutron amounts, thus they have different masses. Atom formed by radioactive decay of another atom is named as radiogenic isotope. Time elapsed for radioactive decay of half of a mother atom is defined as half-life. Radioactive decay to a daughter isotope, depending on a special constant for this isotope, is directly proportional to the number of atoms in a given time, thus allowing formulation of isotope systems. In the laboratory, Strontium and Neodymium isotope ratio experiments are performed. Whole-rock samples are crushed by a jaw crusher

and pulverized to <63 microns by an agate disc mill in our rock crushing and mineral enrichment laboratory.

Weighing, chemical dissolving, chromatography and filament loading procedures are done in a 100-class clean laboratory, where ultra-pure acids and water are used. Experiment quality is monitored by using internationally certified standards. Samples, weighed in certain amounts and put into PFA vials, are dissolved with different acids on hotplates in safety hot-boxes.

Strontium and Neodymium are separated from other elements by an ion chromatography method in which teflon columns with special resins and acid combinations are used.

Enriched sample is loaded on a rhenium filament as few hundred nanograms in a dissolved form. Measurements are performed by using Triton Thermal Ionization Mass Spectrometer (Thermo-Fisher) with multi-collection. Data are reported as $^{87}\text{Sr}/^{86}\text{Sr}$ and/or $^{143}\text{Nd}/^{144}\text{Nd}$ isotope ratios with 2 sigma standard errors. During measurements, Sr NBS 987 and Nd LaJolla standards are measured for instrument calibration, and necessary bias corrections are made.

Analytical Method

Strontium and Neodymium isotope geochemistry experiments were performed by Köksal et al. at Central Laboratory of Middle East Technical University (METU) (R and D Training and Measurement Center, Radiogenic Isotope Laboratory). In 2017, the TLM-ARG-RIL-01 (Sr Isotope Ratio Analysis Experiment Instruction) and TLM-ARG-RIL-02 (Nd Isotope Ratio Analysis Experiment Instruction) are adapted from the methods given in the details and conditions. Samples were grinded in clay size by using jaw crusher and disc agate grinder and chemical processes were started. Weighing, chemical decoding and chromatography was took place under 100 laboratory cleaning standards in clean laboratory conditions; It was carried out by using ultrapure water and chemicals.

Approximately 80 mg of samples were weighed and transferred to PFA bottles. The samples were completely dissolved in 4 mL of 52% HF for 4 days on a >100°C heater plate. The dried samples on evaporator near the evaporation were first dissolved in 4 mL of 6 N HCl for one day. The dried sample was taken up again on the heater table near to evaporate then in 1 mL of 2.5 N HCl and prepared for chromatography. The strontium element was isolated into 2 mL volumes of 2.5 N HCl acids by using the Bio Rad AG50 W-X8, 100-200 mesh resin in the Teflon columns. After collection of strontium, a fraction of rare earth elements was collected with 6 N HCl. Strontium was loaded onto Ta-activator and 0.005 N H_3PO_4 onto single Re-filament and measured in static mode. The $^{87}\text{Sr}/^{86}\text{Sr}$ data were normalized to $^{86}\text{Sr}/^{88}\text{Sr}=0.11194$. The Sr NBS 987 standard was measured as 0.710261 ± 15 (n=4) during measurements.

The neodymium element was separated from other rare earth elements using 0.22 N HCl acid and 2 ml volume of HDEHP (bis-ethyexyl phosphate) coated biobeads-Bio Radite in teflon columns. The separated Neodymium was loaded in Re-filament with 0.005 N H₃PO₄, measured in static mode using double filament technique. During the analysis, the data of ¹⁴³Nd/¹⁴⁴Nd were normalized with ¹⁴⁶Nd/¹⁴⁴Nd=0.7219. Nd LaJolla standard was measured as 0.511846±5 (n=3).

No bias correction has been made on the results of the measurement of strontium and neodymium isotope ratio. Measurements were performed by multi-collection using Triton Thermal Ionization Mass Spectrometer (Thermo-Fisher). Analytical uncertainties are at 2 sigma level.

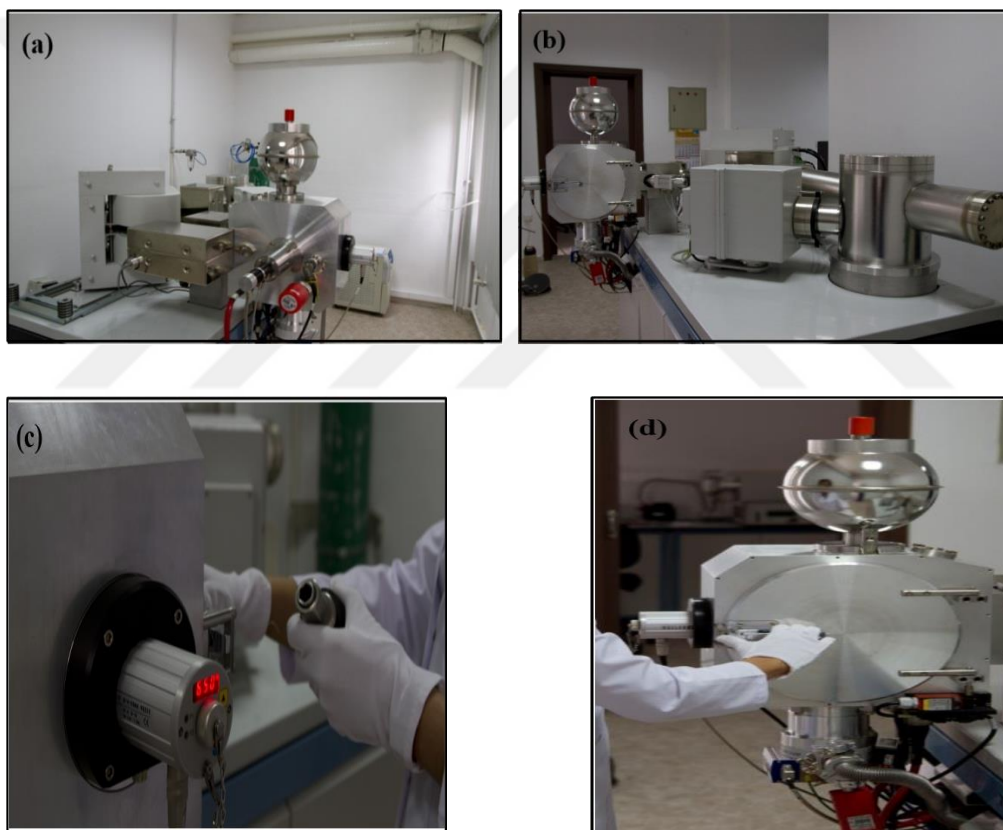


Figure 3.2. Above figure (a), (b), (c) and (d) shows the analytical working by using Triton Thermal Ionization Mass Spectrometer (Thermo-Fisher) samples analysis of study area.

3.4(E). Electron Microprobe Analysis

All mineral analyses were carried out by using a Cameca-SX Five electron probe micro analyzer. The analysis and calibration was performed with 15 kV accelerating voltage and 20 nA beam current. Both synthetic and natural standards were used in calibration with counting time of 20 s and 10 s on peak and background positions

respectively. ZAF correction procedure, as modified by Henoc and Maurice (1978), was used for the reduction of microprobe data. Absolute error is 2% of the amount present for major elements.

Mineral compositions were analyzed by using CAMECA SX-FIVE electron microprobe analyzer (EMP) equipped with five wavelength dispersive spectrometers (WDS) in the Department of Earth Sciences at Indian Institute of Technology Bombay (IITB), India. The analyses were performed with 15 kV accelerating voltage, 20 nA specimen current and 1 μ m beam diameter. Each element was measured for 20 s on peak position and 10s on background positions. Instrument calibration for each element was conducted using both natural and synthetic standards. The high resolution X-ray maps of important textures were acquired with a dwell time of 50 ms and step size of 1 μ m. Total twelve samples including granite, granodiorite, monzonite, monzodiorite, and diorite. The selected EMP analyses of Fe-Ti oxide, plagioclase, K-feldspar, biotite, hornblende, muscovite, apatite, titanium, zircon and chlorite of granite samples are reported.

Specifications

SX- Five with W Column model having maximum accelerating voltage is 30KV and Beam Diameter in Analytical Mode: 600 nm @ 15 KV, 100nA : 400 nm @ 10 KV, 10nA Maximum Beam Current: Up to 10 μ A with Beam Stability: $\pm$ 0.5% per hour @ 20kV, 20nA The instrument along with SX- Five with LaB6 Column having Maximum Accelerating Voltage: 30KV with Beam Diameter in Analytical Mode: 100 nm @ 20 KV, 10nA: 200 nm @ 10 KV, 10nA Maximum Beam Current: Up to 1 μ A and Beam Stability: $\pm$ 0.2% per hour @ 20kV, 10nA.

EPMA works by bombarding a micro-volume of a sample with a focused electron beam (typical energy=5-30 keV) and collecting the X-ray photons thereby emitted by the various elemental species. Because the wavelengths of these X-rays are characteristic of the emitting species, the sample composition can be easily identified by recording WDS spectra (Wavelength Dispersive Spectroscopy). WDS spectrometers are based on the Bragg's law and use various moveable, shaped monocrystals as monochromators.

- EPMA is a fully qualitative and quantitative method of non-destructive elemental analysis of micron-sized volumes at the surface of materials, with sensitivity at the level of ppm. Routine quantification to 1% reproducibility is obtained over several days. It is the most precise and accurate micro-analysis technique available and all elements from B to U and above can be analyzed. EPMA is fully compatible with routine analysis sessions, with easy and direct interpretation of the results.

- EPMA instruments are equipped with a complete kit of built-in microscopy tools that allow simultaneous X-ray (WDS), SEM and BSE imaging, plus sophisticated visible light optics; they provide very flexible sample inspection with image magnification ranging from 40 to 400,000.

- Determination of thickness and elemental composition from nm to mm thick layers in stratified materials is possible.

- EPMA provides much better results than standard SEM/EDS systems. Because of the internal properties of WDS, the general sensitivity, analysis of light elements and risks of erroneous interpretation of qualitative spectra are all superior with EPMA. Spectral resolution and detector dead time are much better than EDS (Energy Dispersive Spectroscopy).

- The excitation beam regulation system and sophisticated sample stage capabilities guarantee that this technique provides outstanding stability and measurement repeatability.

USES:

1. Qualitative analysis: WDS Spectrum-To find out the elements present
2. Quantitative analysis: Accurate Quantification of Chemical composition of any solid material
3. BSE Imaging: (Phase Identification, Mineral Identification)
4. SE Imaging (Use: Topography)
5. Cathodoluminance Imaging (Use: Reveals the defects and impurities in materials)
6. X-Ray Mapping: Elemental distribution
7. Mapping Quant
8. Geo Quant: Cation Calculation
9. Age Quant: Monazite Dating.

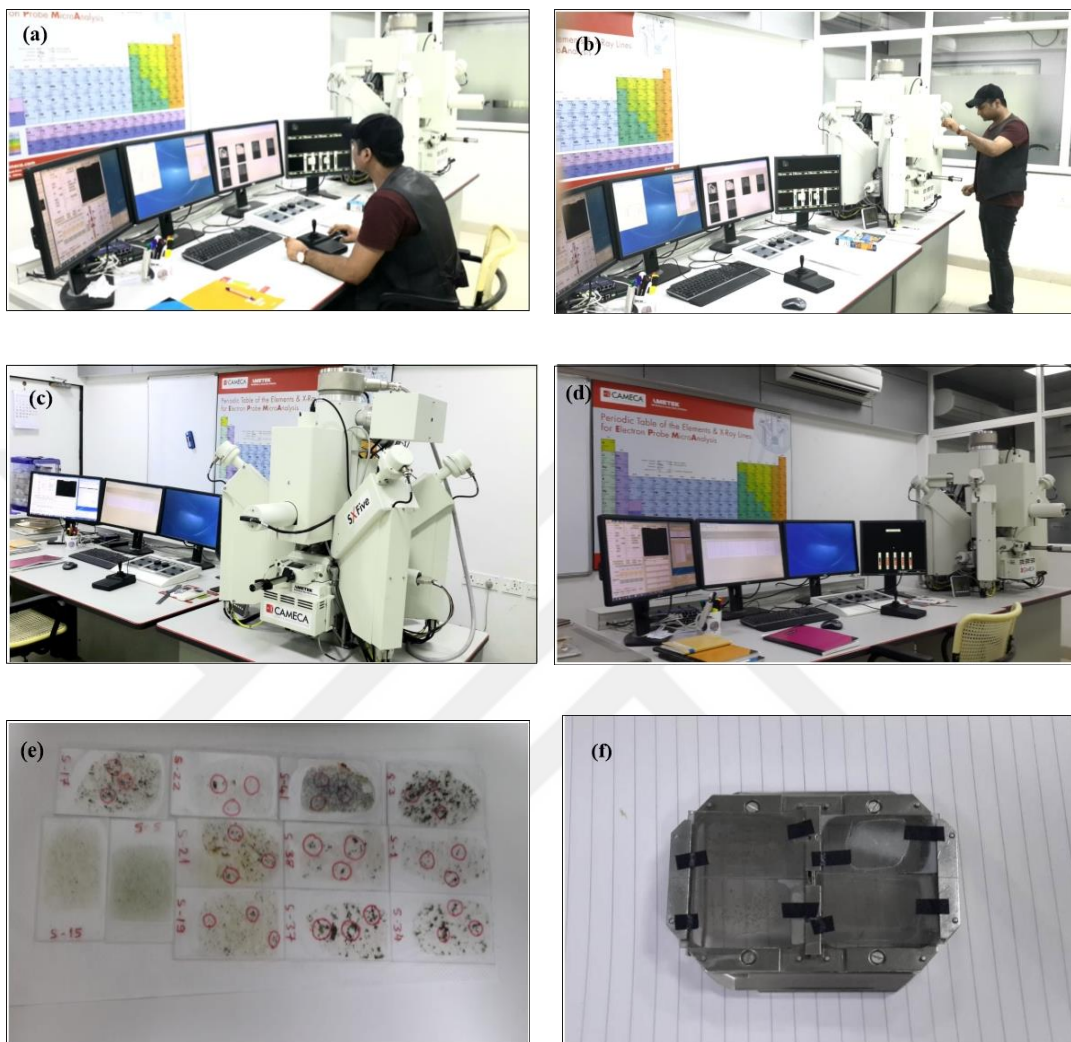


Figure 3.3. Above figure (a), (b), (c) and (d) shows the analytical working of EPMA analysis of study area samples. Figure (e) shows the highlighted analyzing point of minerals over thin section slides. Figure (f) shows the specially designed thin sections case used for the EPMA analysis of samples for mineral chemistry.

Table 3.1. Describe the summary of method and analytical techniques used for the Ladakh Batholith.

ANALYTICAL TECHNIQUES	NUMBER OF SAMPLES	ELEMENTS	LABORATORY
XRF (whole-rock)	41	Major elements Trace elements (Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Nd, Pb, Th, U)	Bureau Veritas Mineral Laboratories, Vancouver, Canada
ICP-MS (whole-rock)	41	Sc, V, Cr, Ni, Co, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, U	Bureau Veritas Mineral Laboratories, Vancouver, Canada
MASS SPECTROMETRY (whole-rock)	16	$^{87}\text{Sr}/^{86}\text{Sr}$, $^{143}\text{Nd}/^{144}\text{Nd}$	Department of Geology, Middle East Technical University (METU), Ankara, Turkey
ELECTRON MICROPROBE (mineral)	12	Major elements	Department of Earth Science, Indian Institute of Technology Bombay, Mumbai, India

4. DATA AND DISCUSSION

4.1. Geological Setting

The Himalayas, highest mountain range in the world, extend along the northern frontiers of Pakistan, India, Nepal, Bhutan, and Burma. Its origin was geologically driven as a conclusion of the collision of the Indian subcontinent with Asia. This process of plate tectonics is ongoing, and the gradual northward drift of the Indian subcontinent still causes earthquakes. Lesser mountain ranges proceed southward from the main body of the Himalayas at both the eastern and western ends. The Himalayan system spanning about 2,400 km in length and varying in width from 240 to 330 km, is made up of three parallel ranges i.e. the Greater Himalayas, the Lesser Himalayas, and the Outer Himalayas and are sometimes collectively called the Great Himalayan Range.

The geodynamic evolution of the Himalaya has at least 5 (five) different chronological stages: (a) Late Mesozoic subduction and accretion, (b) Cenozoic collision, (c) Late collision extensional tectonics, (d) Post-collision sedimentation in foredeeps and (e) Present-day geodynamics (Jain et al., 2002). This geodynamic evolution has been modelled into a global framework of underthrusting Indian Plate under the Eurasian Plate along two major suture zones i.e., the Indus-Tsangpo Suture Zone (Main Mantle Thrust) and the Shyok Suture Zone (Northern Suture Zone).

The overthrust Eurasian Plate reveals its character in a Late Mesozoic Andean-type Kohistan-Ladakh Batholith Complex, which is separated from the Karakoram metamorphic and its batholithic complexes by the Shyok Suture Zone. The suture between the two plates is exposed into two suture zones of the Indus-Tsangpo and Shyok; both are characterised by island-arc setting, fore-arc and back-arc sediments and ophiolite emplacement.

The closing of the Tethys Ocean is mainly confined along the Kohistan Arc and the Indus-Tsangpo Suture Zone (ITSZ). The northern margin of the Indian Plate in the Higher Himalaya encompasses a basement and its sedimentary cover of Proterozoic age in the Higher Himalayan Crystalline (HHC). This basement is overlain by a Paleo-Mesozoic platform sequence of the Tethyan Sedimentary Zone. Subsequent crustal shortening of the Indian Plate during Continental Collision has considerably deformed the Higher Himalayan basement metamorphics. This is thrust southward along the Main Central Thrust (MCT) and its numerous splays over a central part of the dismembered Indian Plate whose Proterozoic-Paleozoic sedimentary basins in the Lesser Himalaya was covered by two marine transgressions during the Permian and Eocene (Ganseer, 1964; Valdiya, 1980; Thakur, 1993; Jain et al., 2002 and references therein). The whole succession is thrust southward over the Cenozoic Foredeep Molasse deposits along the Main Boundary Thrust (MBT). However, the southern margin of the Himalaya is in contact with a Proterozoic basement of the Aravalli and its platform in the Vindhyan Basin, which is covered by the Holocene alluvium of the Indo-Gangetic Plains.

The Himalayan collision zone contains various granitoids with ages ranging from Proterozoic to Recent. The Himalayan granitoids can be broadly classified into two main types in relation to the Himalayan orogeny: (i) pre-collisional bodies now occurring as granite/gneiss and (ii) syn- to post-collisional bodies being leucocratic in nature. Geochronological data, reported on a variety of granitoids and minerals using radioactive decay techniques, have constrained the age of emplacement, cooling and exhumation history (Pande, 1999; Jain et al., 2000; Hodges, 2000; Singh, 2001 and references therein). Age data from the granitoids of the Himalaya reveal distinct episodes of magmatic activity around 2100-1800 Ma, 1200-1000 Ma, 600-400 Ma, 100-50 Ma and 25-15Ma (Singh, 2001).

The Trans-Himalayan plutons, which make mention to as the Ladakh, Kohistan and Karakoram batholiths and Gangdese magmatic belt are manifestations of the subducting Indian Plate (Coward et al., 1982; Honegger et al., 1982; Dietrich et al., 1983; Khan et al., 1989; Rolland et al., 2000). The Trans-Himalayan plutons are compatible with I-type Cordilleran batholiths of Peru. Initial Sr, Nd, and Pb isotopic compositions of the Gangdese and Ladakh Batholiths indicate that these bodies have predominantly mantle-derived components. U-Pb ages vary from 105 to 45 Ma ages for Trans-Himalayan plutons. These ages and geochemistry point to northward subduction of the Tethyan oceanic lithosphere beneath the Eurasian Plate, formation of magma and minor crustal contamination during rise of these batholiths. The calc-alkaline Kohistan and Dras island arcs are also product of subduction. They are developed in oceanic regime and later accreted to the Indian Plate.

On the basis of the geographical distribution, granitic plutons constitute five major belts in the Himalaya and adjoining Karakoram (Le Fort, 1988). From north to south, these belts include: (i) Karakoram Axial Batholith, (ii) Trans-Himalayan Batholith, (iii) Northern Himalayan Granite Belt, (iv) Granitoids of the Higher Himalayan Crystalline (HHC) Belt, and (v) Lesser Himalayan Granite Belt (Figure 4.1).

The Ladakh Batholith, which is the study area, is located within the Trans-Himalayan Batholith belt. Between ca. 68 and 45 Ma, it is precedently consisted of subduction associated with calc-alkaline felsic magmatic pulses (By using SHRIMP and LA-ICP-MS methods for the analyses of U-Pb dating of zircons from the granitoids; e.g. Schärer et al., 1984; Harrison et al., 1992; Rowley, 1996; Singh et al., 2007; Upadhyay et al., 2008; Ravikant et al., 2009; St-Onge et al., 2010; Bouilhol et al., 2013) with a special case of a 102.8 ± 3.2 Ma old granodiorite magmatic pulse that make a record from the Kargil area in the northwestern part of the Ladakh Batholith that located on U-Pb zircon (Honegger et al., 1982).

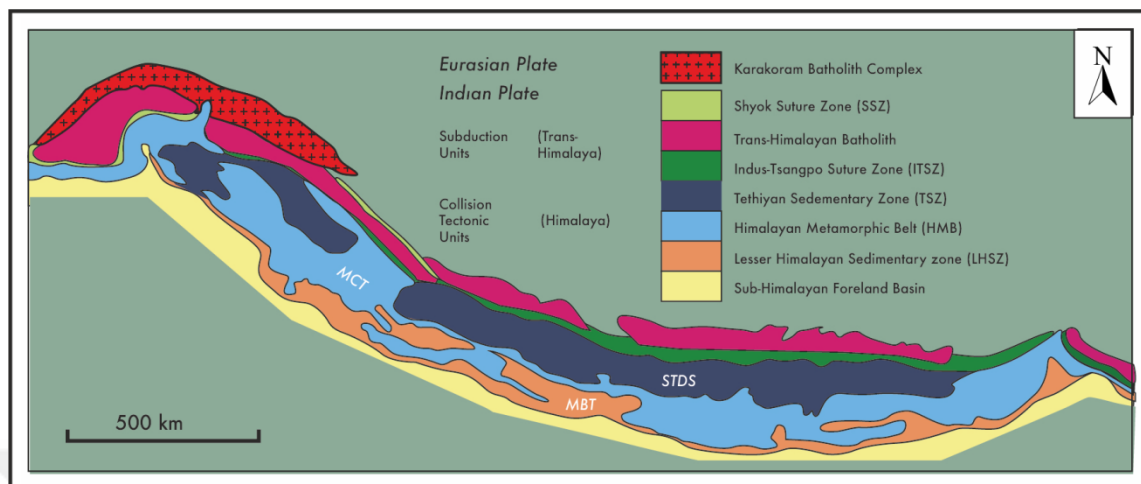


Figure 4.1. Modified regional geological map of the plate tectonic of Himalaya (Modified After Singh & Jain 2002). Abbreviations: SSZ-Shyok Suture Zone. ITSZ-Indus Tsangpo Suture Zone. THSZ/STDZ-Trans Himadri Shear Zone/South Tibetan Detachment Zone. MCT-Main Central Thrust. MBT-Main Boundary Thrust.

Table 4.1. It shows the brief information about greater, lesser and lower Himalayas (Anonymous 7)

Greater / Inner Himalayas (Himadri)	Lesser / Middle Himalayas (Himachal)	Outer / Lower Himalayas
The highest mountain range of the Himalayas	Situated to the South of Himadri	This is the outer most range to the south of the Lesser Himalayas
These ranges have an average height of about 6000m	Average height is about 3000m	These discontinuous ranges join the lesser Himalayas in the extreme east
Highest mountain peak are situated in this range (e.g. Kanchanjunga-8595m, Nangaparbat-8126m)	Many health resorts are situated on the southern slope of the mountain range e.g; Shimla and Darjeeling	It is average height about 1200m
The Source of Ganges and Yamuna	-----	There are several elongated flat valleys running parallel to the mountain ranges. They are called 'duns' (e.g; Dehradun)

4.1.1. Tectonic zones

The Himalayan Mountain Range comprises 2500 km (Valdiya, 1980) from the Nanga Parbat peak (8125 m) in the west to the Namche Barwa peak (7782 m) in the east (Hodges, 2000). From the Trans-Himalayan zone in the north to the Gangetic plain in the south the range has a width of 200 to 250 km (Le Fort, 1975). Central Himalaya is the

narrowest part of the Himalaya at 100 to 150 km wide and represents the most drastic transition from the Indo-Gangetic Plain in the south to the Tibetan Plateau in the north (Hodges, 2000). As a result of the tectonic events from Himalaya's evolution, as briefly described in the Chapter I, division of the Himalayan Range by tectonic zones was first proposed by Gansser (1964) who separated the range into five zones. Clear boundaries of each zone are represented by the major faults throughout the range. These zones beginning in the north are 1) Indus-Tsangpo Suture Zone (ITSZ), 2) Tethyan Sedimentary Zone (TSZ), 3) Higher Himalayan Zone (HH), 4) Lesser Himalayan Zone (LH) and 5) Sub-Himalayan Zone (SHZ).

These zones are often referred to throughout the literature by various similar names, for instance; the ITSZ is also referred to as the Indus Suture Zone or Trans-Himalayan Zone. The TSZ is also known as the Tibetan-Tethys Himalaya Zone, Tethyan Himalayas, Tethyan Sedimentary Series, or Higher Himalayan Sedimentary Zone. The HH is also known as High Himalayan Crystalline Zone or Greater Himalaya. The SHZ also comprises the Siwalik Hills, which some authors separate entirely (Kothyari et al., 2010). Throughout this thesis and further description of each zone, the zone names of ITSZ, TSZ, HH, LH, and SHZ will be used.

A publication by Le Fort (1975) highlighted Gansser's publication from 1964 with discussion of zone division by stating that the TSZ can be combined with the HH zone. Work by Valdiya in 1980, researched in more detail the Lesser Himalaya with his book, *Geology of the Kumaun Lesser Himalaya* (1980). Research by Valdiya was followed by numerous authors who have expanded upon previous knowledge with their own naming system and placement of important tectonic attributes. These new additions and variations in the description and understanding of the Himalaya have led to disagreement between researchers resulting in a complicated description of the Himalaya. However, Gansser (1993) states that the compilation of his previous work and that of Le Fort (1989) has become the most complete regional description of the Himalayan Range. Since 1993, there have been numerous other articles published which were used in this study along with the original works by Gansser (1964), Le Fort (1975) and Valdiya (1980).

Indus-Tsangpo Suture Zone (ITSZ)

The northern extent of India is made up of the Indus-Tsangpo Suture Zone (ITSZ). General consensus among various authors is that this zone holds evidence of past collision events. Oceanic crust fragments which are present in this zone represent a once Neo-Tethyan Ocean and the resulting collision (Kravchenko, 1979; Valdiya, 1984; Bickle et al., 2001; Najman et al., 2004). In addition, the findings of ophiolites within southcentral Xizang and Ladakh (Hodges, 2000) represent the Neo-Tethyan Ocean floor, confirming the presence of an ocean before continental collision. Surrounding the ophiolites within the suture zone are Trans-Himalayan and Indian plate turbidites. These turbidites are of ages varying from Jurassic to Cretaceous in the Trans-Himalayan and Triassic to Cretaceous on the Indian plate (Hodges, 2000). According to Hodges (2000), activities of collision allowed the turbidites to enter the suture zone which had previously been deposited on the

continental arc of Gangdese. Limestone is also exposed on the north Indian shelf and its slopes which represent remains of the Indian plate (Hodges, 2000).

The northern tectonic boundary between the Tibetan Plateau (Lhasa terrane) and the Himalaya (Indian plate) is bounded by the Indus-Tsangpo or Yarlung Zangbo suture zone. The frontier along the Indus and Zangbo rivers flow in opposite directions is generally marked by a topographic depression (Heim and Gansser, 1939). The Indus–Tsangpo suture zone is lesser than 15 km, which is narrow belt of oceanic rocks, showing obducted remnants of the Tethys Sea (Ding et al., 2005). The upright tectonic slices called as exotic blocks which is consists of almost suture zone that are purposefully dislocated and deformed (Diener, 1895, 1898; von Krafft, 1902; Heim and Gansser, 1939).

The wild flysch hold the blocks of Permian limestone, Early Triassic pelagic limestone, lensed shape of serpentinite, Late Cretaceous polytactic calcschist, and pillow and immensed alkali basaltic lava consisting by the discontinuous zone. At temperature 350–450 °C and recording a pressure of about 1 GPa, this zone also consist ophiolites as narrow fine sheets and obducted masses, radiolarites with basic lavas, and some blueschists (Masclé et al., 2012). Tethys Himalaya's mesozoic sediments are metamorphosed throughout the length of the medial segment of the suture. The southern part of the suture are aligned with the post-metamorphic granitic intrusions (Gansser, 1977). The metamorphic flysch enveloped with the nonmetamorphic and nearly horizontal Kailas Conglomerate throughout the length of the Great Counterthrust, towards east of the Kailas Valley (Heim and Gansser, 1939, p. 188). The compound geometry of the Indus-Tsangpo suture zone concluded from the following series of events: (1) nappe movements, (2) isoclinal and shortening folding, and (3) backfolding (Burg, 1992, p. 42).

Tethyan Sedimentary Zone (TSZ)

Just south of the ITSZ is the Tethyan Sedimentary Zone (TSZ). This zone continues to the South Tibetan Detachment Zone (STDZ). Sedimentary rocks and low grade shelf deposits of Late Precambrian to Eocene time comprise this zone with numerous folds and thrusts (Webb et al., 2007; Searle et al., 2010). The sedimentary rock covers a crystalline core, 10 similar to that of the High Himalayan zone. This crystalline core is made up of amphiboles, migmatites, gneiss, and schists (Srikantia, 1987). In addition, the findings of coesite within eclogites represent high pressure metamorphism (Ahmad, 2011).

High Himalayan (HH)

The High Himalayan (HH) begins south of the Southern Tibet Detachment Zone (STDZ) (Singh, 2010). This zone extends from Zaskar in the west to Bhutan and Arunachal Pradesh in the east over roughly 2200 km (Searle et al., 2008, 2010). In the south, the Main Central Thrust (MCT) separates this zone from the Lesser Himalaya. Steep relief and elevations ranging from 1200 to 7800 m, with an average of 4700 m, comprise this crystalline zone (Singh, 2010). Significance of the MCT is given by being responsible for the highest mountains of the area (Singh and Hasnain 1998; Bickle et al., 2001; Searle

et al., 2008). According to Gansser (1993), this thrust is made up of 12 km of Tethyan sediments which cover 15 km crystalline rocks and has progressed southward (by 100 to 150 km) to cover the LH. Interestingly, the definition and location of the MCT presented by Searle et al. (2008) is the zone where metamorphic rocks of the HH reside over rocks lacking metamorphism, the LH. This definition doesn't include information about the sediments and may differ from the definition given by Gansser (1993). The rocks of the HH, according to Singh and Hasnain (1998) and Singh (2010), are metasediments from the middle and deep crust which are high grade late Proterozoic. There are also granites of biotite and muscovite, with some carbonate and calcsilicate rocks with ages of Cambro to Ordovician (Singh, 2010). As stated by Searle et al. (2010) these granites formed within the middle crust during partial melting of a migmatite zone.

Leucogranite intrusions of Early Miocene or Pliocene age are present within the northern part of this zone (Searle et al., 2010) containing tourmaline, biotite, muscovite, and garnet (Singh, 2010). According to Singh and Hasnain (1998) and Singh (2010), further metamorphism and deformation occurred between 500 Ma and 35 to 20 Ma, resulting in varied rock types.

Lesser Himalayan (LH)

South of the Main Central Thrust (MCT) and north of the Main Boundary Thrust (MBT) is the Lesser Himalayan Zone (LH). This zone is of low relief Precambrian to Paleozoic rocks of pre-Himalaya with an average elevation of 2500 m (Singh, 2010). Thickness within this zone ranges from 8 to 10 km (Hodges, 2000). A variety of rock age in this zone has been given by various researchers which span from the earliest with Precambrian to Paleozoic (Hodges, 2000; Singh, 2010). In a recent study by Fuchs (2011), the age of rare fossils found in this zone has been dated as Precambrian to Early Cambrian, which coincides with ages indicated by other authors. Lave and Avouac (2001) describe this zone as containing low grade metasediments, with lower greenschist and amphibolite faces (Hodges, 2000). The presence of impure quartzites and marble, phyllites, schists, metamorphic mafic rocks, and augen orthogenesis (Hodges, 2000), indicates an increase of metamorphism from low to medium and high grade. A review written by Hodges (2000) covering the LH and its characteristics given by previous researchers indicates that there is debate and uncertainty of the exact stratigraphy, age, and correlation of subzones within the LH. Unconformities in the east thinning to the west have opened up debate of a Neo-Tethys origin, with limestone and calcareous sandstone overlying in the west.

The fossiliferous make up of sandstones have not been dated to an exact age at present and the rarity of fossils found within the LH also makes dating difficult. Subzones of the region have been split by previous researches (Valdiya, 1980, 2011; Hodges, 2000; Fuchs, 2011) as allocthonous and autochthonous and their correlation debated as to a Tibetan or Indian base. Fuchs (2011) and Hodge (2000) have differing views of this separation of rock type with Fuchs (2011) insistent of its correlation while Hodges (2000) is not convinced the crystalline sequence is related to the HH stratigraphically. Further, Kohn (2010) makes note of the origin of gneiss rocks found in the lower LH which cannot be

from the Indian basement or a result of collision in the Paleoproterozoic. The importance of the MBT is evident in the events of overthrusting of basin sediments from the Sub-Himalayan Zone (Singh and Hasnain, 1998; Bickle et al., 2001). Lesser Himalaya quartzite rocks of Neoproterozoic to Early Cambrian are exposed as they thrust over the MBT and into the Siwalik sandstones found in the SHZ. Colluvial fans along the MBT provide evidence of uplifting events of the normal fault followed by rapid erosion (Kothyari et al. 2010). Characteristics of streams across the MBT are marked by waterfalls and knickpoints from steep elevation and most importantly tectonic activity has resulted in landslides throughout the area (Kothyari et al., 2010).

Sub-Himalayan Zone (SHZ)

Tracing the southern extent of the Himalayan Range lays the Sub-Himalayan Zone (SHZ). The SHZ is bounded by the Main Boundary Thrust (MBT) in the north and in the south by the Main Frontal Thrust (MFT). Information of the sediments from west to east across this zone is attributed to the amount of research conducted in the areas according to Hodges (2000). In the west there are two groups of rocks, the Rawalpindi Group of upper Paleozoic to lower Miocene siltstones and sandstones and the Siwalik Group of lower Miocene to Pleistocene sedimentary fluvial molasses rocks (sandstones). In the east, the zone is dominated by the Siwalik group (Hodges, 2000). Along the 1500 km long MBT, the metamorphic rocks from the Lesser Himalayan Zone have been thrust over and onto the un-metamorphosed SHZ (Singh and Hasnain, 1998; Kothyari et al., 2010). The Siwalik Hills are of elevations from 500 to 1000 m (Lave and Avouac, 2001) as ridges form from thrusts (DeCelles et al., 2001). The Siwalik Group of sandstone, conglomerate, siltstone, and mudstone (Hodges, 2000) are of Neogene age (Kothyari et al., 2010) and make up the 10 to 25 km width of the zone (DeCelles et al., 2001). These molasses sediments were deposited by rivers as the Himalaya rose and later eroded (Singh, 2010). According to Kothyari et al. (2010), there were two episodes of sediment deposition with varying rates. The rate of deposition between 6.5 and 8 Ma was 42 cm/1000 years and from 8 to 9 Ma the deposition slowed by about half its previous rate as rapid uplift and erosion occurred near the MBT. From 9 to 10 Ma the rate increased again to 45 cm/1000 years, resulting in sediment thickness increasing from about 2 km in the south to more than 10 km in the north (Hodges, 2000).

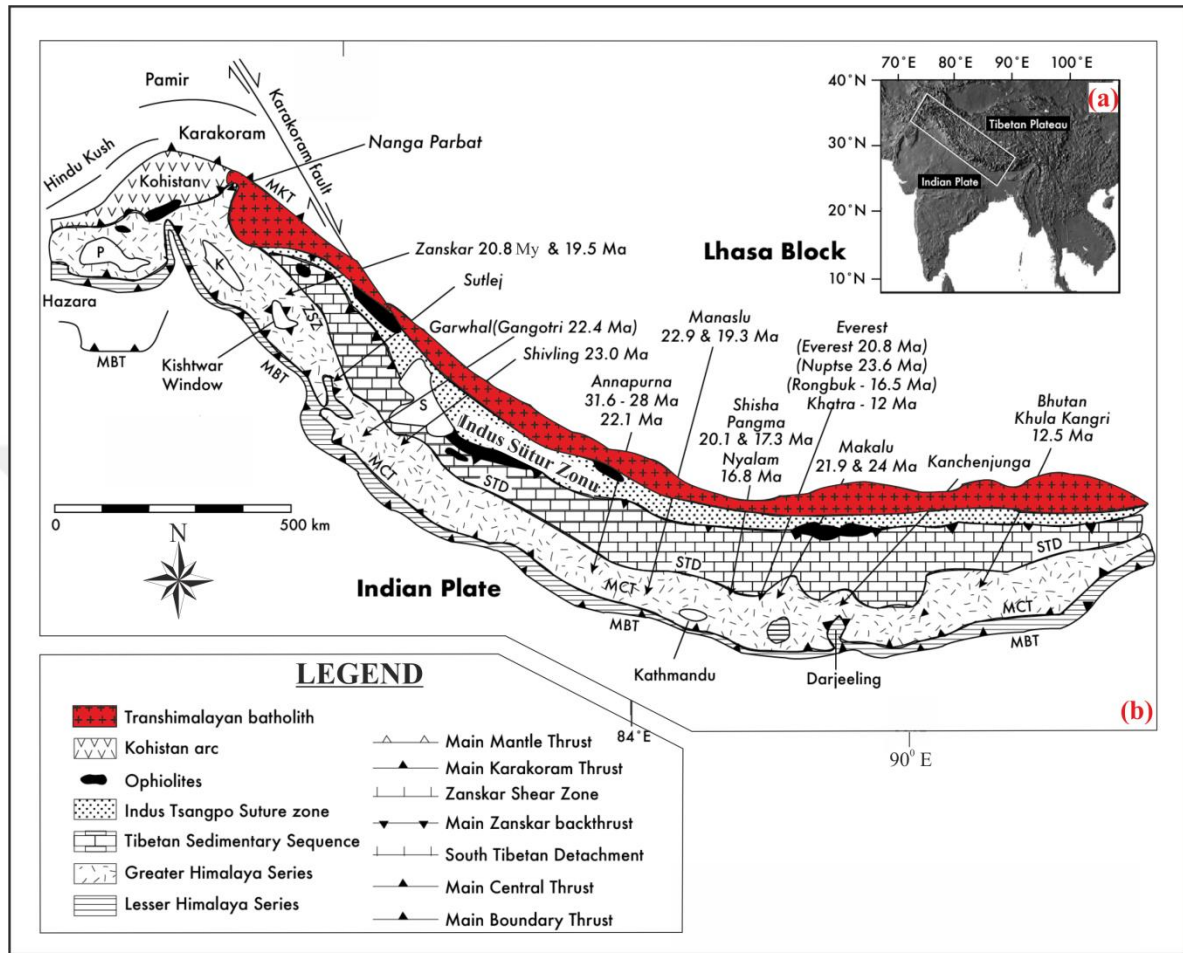


Figure 4.2. Modified Geological map of the Himalaya showing U-(Th)-Pb ages along the orogen. Godin et al. (2006) for sources of data.

On the surface the MBT is clearly visible, whereas the MFT is not exposed (DeCelles et al., 2001; Lave and Avouac, 2001; Kothiyari et al., 2010). According to Cattin and Avouac (2000), and later confirmed by Lave and Avouac (2001), the MFT is the most active fault in the region with active deformation of crustal shortening. This shortening has been absorbed by slipping of the thrust at 21 mm per year (Lave and Avouac, 2001). Interestingly, Lave and Avouac (2001) point out the highest peaks within the Himalaya are 100 to 150 km north, but parallel, to this thrust. Beneath the surface, the fault continues 5 km where it then extends horizontally and connects to a ramp structure at the front of the Higher Himalaya (Cattin and Avouac, 2000; Lave and Avouac, 2001). This ramp structure is given the name of Main Himalayan Thrust (MHT).

4.1.2. Evolution of Himalaya

Continental clash of the Indian and Eurasian plates over the past 100 million years has led to the formation of the Himalaya Mountains. As the two plates collided underneath Tibet, the Neo-Tethys Ocean that once separated India and Asia by 2000 km (Clift et al., 2008) closed by the end of the Paleocene (~58 Ma) (Le Forte, 1996). Evidence of this closure exists in oceanic crust remnants in some regions of the Himalayan Mountains (van Hinsbergen et al., 2012). Tectonic activity, including thrusts, faults and folds, permanently transformed the region as continental collision continued. Thrusts developed throughout the Himalaya as the continents continued to collide, thereby creating zones or series of rock types. These zones of rock types are bounded by various thrust sheets throughout the range. More intense thrust faulting led to the clearest division of the range and includes the Main Central Thrust (MCT), the Main Boundary Thrust (MBT), and the still active Main Frontal Thrust (MFT). These thrusts define three zones consisting of the High Himalaya (HH), Lesser Himalaya (LH) and the Sub-Himalaya Zone (SHZ).

In addition to the development of rock zones, continental collision also led to uplift of the great Himalaya taking place around 20-22 Ma (Valdiya, 2002). As the Himalaya reached greater heights, seasonal monsoons developed, altering both the climate and vegetation. A second consequence of the great height of the Himalaya is the reversal in drainage pattern. Since the Precambrian, rivers in northern India flowed north, but during the Oligocene these rivers started to flow in a southerly direction (Valdiya, 2002). These rivers carried large amounts of sediment from the Himalaya to the gently sloping Gangetic plain where deposition occurred. Still today, large volumes of sediment are carried from the range by these rivers as processes of erosion and weathering continue to take place in the high mountain regions.

The collision of the two tectonic plates continues to occur today, with crustal shortening occurring at a rate of 0.92 cm/year (Kothyari et al., 2010). While the evolution of the Himalaya spans many millions of years with the majority of tectonic events occurring before present, there are still very active areas within the range further altering the landscape. Figure 4.2 shows a brief timeline of the main tectonic events (from Valdiya, 2002).

It is now widely accepted that the collision between the Indian Plate and the collage of previously sutured micro-continental plates of Central Asia occurred during the mid to late Eocene, at approximately 50-45 Ma (Alleigre et al., 1984; Searle et al., 1987). The timing for the extreme clash of two plates are deduced from (i) Indus Suture Zone (ISZ): the ending of marine sedimentation (ii) Along the suture zone; the beginning of continental molasse sedimentation (iii) Along the Trans-Himalayan (Ladakh-Kohistan-Gangdese) Batholith, the ending of Andean-type calc-alkaline magmatism and (iv) In the Himalayan Ranges, the beginning of the main collision-related thrust systems.

The post-collision crustal shortening in the Indian Plate can only be deduced from the restoration of balanced cross sections across the Himalaya. It is widely recognized that

in general terms, southward-propagating thrust stacking had occurred across the Himalaya since the mid-Eocene collision and suturing (Molnar, 1984; Mattauer, 1986; Searle et al., 1987). The climax of crustal shortening and thrust stacking occurred during the mid-Tertiary in the High Himalaya and Zaskar Ranges, with thrusts propagating southwestwards from the Main Central Thrust (MCT) system to the Lesser Himalaya and the late Tertiary Main Boundary Thrust (MBT) system (Figure 4.2). The youngest thrusts occur throughout the length of the southern edge of the Himalaya, in the Siwalik molasse deposits of the Indian foreland basin, where the Main Frontal Thrust (MFT) terminates at tip lines below the Indo-Gangetic plains. Four major tectonic zones constitute the Ladakh-Zaskar Himalaya. These are, from north to south, the Ladakh (Trans-Himalayan) batholith, the Indus Suture Zone, the Tibetan-Tethys (Zaskar shelf) Zone, and the High Himalaya. A generalized geological map depicting these zones is shown in (Figure 4.2). And (Figure 2.2.) shows a late Cretaceous and Tertiary time chart for the Ladakh-Zaskar Himalaya (after Searle, 1983, 1986) updated with all radiometric ages and stratigraphic time spans for the four tectonic zones.

4.1.3. Ladakh Batholith

The Ladakh Batholith, which is cropcut of the Trans-Himalayan Belt (a Cretaceous-Palaeogene Andean-type magmatic arc) that cut out north of the Indus suture zone and stretched upwards 2500 km throughout the length of the southern edge of the Eurasian continent. The Ladakh Batholith trends WNW-ESE, prolonged with 600 km, 30-80 km broad and 3 km thickness (Singh et al., 2007). It has 110 and 40 Ma with most influential stages around 60 Ma (Honegger et al., 1982). The batholith is made up of norite, gabbro to granite.

The Karakoram fault within the east, the Indus suture zone within the south and the Shyok suture zone within the north that bounds the Ladakh Batholith. However, due to constricted entrance to the area, so the accurate position of the Shyok suture in the east part of Ladakh is undetermined (Rolland et al., 2000; Rolland and Pêcher, 2001; Weinberg and Dunlap, 2001).

The southern part of the Ladakh Batholith is bound by the Indus Suture Zone. It mainly splits the batholith from the disfigured sedimentary sequences of the Indus Molasse excludes where the molasse overlaid the batholith (Frank et al., 1977). Eocene to Miocene sediments including limestones, siltstones and conglomerate comprises by the Indus Molasse (Searle et al., 1990). The southern edge of the Shyok tectonic belt of batholith comprised of metasedimentary, volcanic and metamorphic rocks (Paleozoic to Eocene) covered by WNW-trending thrusts (Srinial et al., 1987).

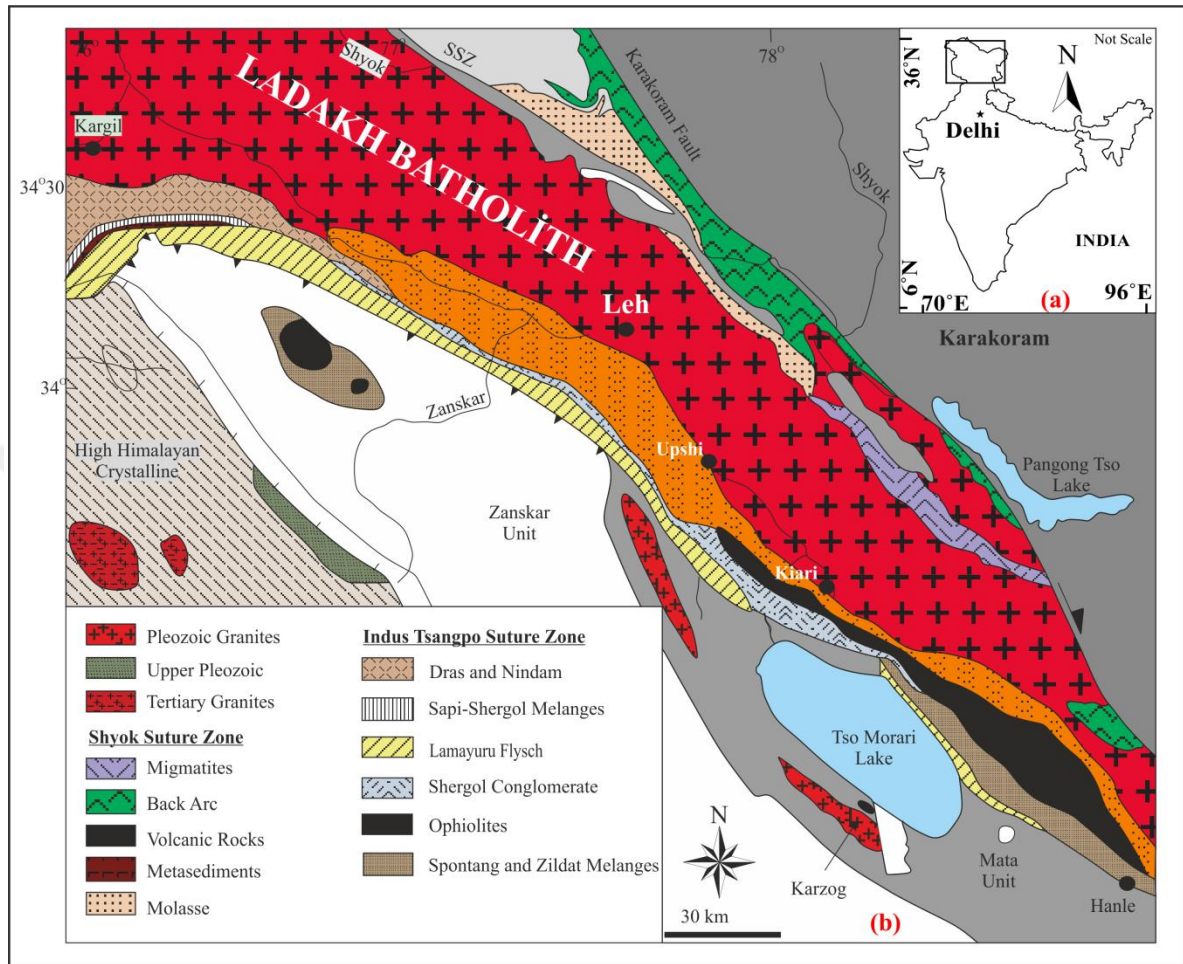


Figure 4.3. (a) Study area of Ladakh Batholith in the north of India (Valdiya 1988) **(b)** Modified map of Geology of the Ladakh-Zaskar, which is (modified after Mahe'o et al., 2000).

The Ladakh Granitoid Complex of Cretaceous to Tertiary age includes leucocratic granite and pink porphyritic granite, biotite- hornblende granite, granodiorite, quartz monzodiorite, diorite, tonalite, hybrid rock and lamprophyre dyke. The older metasedimentary rocks occurring as thin bands within Ladakh Granitoid Complex comprises slate, quartzite, schist and gneisses.

The Ladakh Batholith is characterised by coarse-grained granite and granodiorite with abundant diorite enclaves concentrated at the margins and nearly absent towards its core. In the core of the batholith, large potassium feldspar dominates the mineralogy. The Ladakh Batholith comprises the Late Cretaceous-Eocene (102-50 Ma) granitoids which is bounded on its southern and northern margin by the Indus Group and the Shyok suture zone, respectively.

The Ladakh Batholith, which is a crocput of about 2000 km long Trans-Himalayan batholith, is situated to the north of the ISZ (Indus Suture Zone) in the Ladakh Ranges

(Figure 4.3). The Trans-Himalayan belt continues westward to include the Kohistan batholith that situated in the Pakistan's northern part (Petterson and Windley, 1985) and eastward to include the Gangdese batholith in south Tibet (Tapponnier et al., 1981; Alleigre et al., 1984). The Ladakh Batholith ranges in composition from olivine norite to leucogranites with grandiorites dominating (Thakur, 1981; Honegger et al., 1982).

The presence of granitic gneisses and meta-sedimentary sequences in the Ladakh Range provides evidence for the existence of precursory continental crust (Honegger and Raz, 1985). Furthermore, a substantial component of inherited lead in zircons extracted from samples of the batholith implies involvement of continental crust during 'petrogenesis' (Scharer et al., 1984).

Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of around 0.704 (Scharer et al., 1984) and 0.705 (Honegger et al., 1982) are un-enriched, inferring a primary mantle that is a derivation of the magmas. The amount of isotopic enrichment due to the envisaged crustal component remains to be quantified. Available geo-chronological determinations displayed that the Ladakh Batholith is dominated and composite by pre-collisional magmatic events. U-Pb zircon ages of 103 ± 3 Ma (Honegger et al., 1982) and 101 ± 2 Ma (Scharer et al., 1984) from samples collected near Kargil refer to important mid-Cretaceous magmatism. A second U-Pb determination of monazite/allanite from a biotite-granite near Leh that displaying an age of 60.7 ± 0.4 Ma, whereas a Rb-Sr isochron age of 73 ± 2.4 Ma (Scharer et al., 1984) and a $^{39}\text{Ar}/^{40}\text{Ar}$ age of 82 ± 6 Ma (Sckirer and Allbgre, 1982) may indicate a continuity of magmatic activity for some 40 Ma, finally terminating with continent-continent collision (Figure 4.3). Likewise, a span of K-Ar mineral ages of 50-40 Ma is considered to reflect a cooling period associated with uplift.

The termination of magmatism of granites in the Ladakh Batholith is at the same time with the closing of Neotethys along the ISZ and the differ from marine to continental sedimentation. Clasts of granites, andesites and rhyolites are particularly widespread in the conglomerates of the Chogdo, Nurla and Hemis Formations of the Indus Group molasse, which unconformably, overlies the batholith. Volcanic rocks overlying the Ladakh Batholith include andesites and rhyolites (Srimal et al., 1987). Late-stage garnet muscovite leucogranitic dykes intrude the granite and may reflect a final phase of intracrustal melting after the 50 Ma collisions along the ISZ. Granitoids of the Ladakh Batholith intrude the Dras island arc volcanics and rocks of the suture zone around Kargil. This provides strong evidence that the Dras island arc was merged to the Karakoram-Lhasa Blocks by the mid-Cretaceous and that the Shyok (Northern) Suture between the Ladakh and Karakoram terranes closed in the mid-Cretaceous (Coward et al., 1986; Pudsey, 1986; Searle et al., 1988) and not in the late Tertiary (Thakur, 1981, 1987).

The Ladakh Batholith has undergone an unknown amount of post-collision shortening evidenced by thrusting within the granitoids. Near Kargil, a several late stage shear zones with mylonitized amphibolites and greenschists cut intrusive rocks of the batholith are found.

4.1.4. Ladakh Granitoids

As per mentioned earlier, the granitoids of batholithic dimension occupies the major part of the Ladakh range in the Trans-Himalaya. In the following discussion the granitoids of the study area have been classified on the basis of field observations (i.e. mineralogical variations and the grain size of the mineral).

Field studies suggest the following differentiates and their chronological sequences of granitic rocks.

Table 4.2. shows the ages of the rocks according to chronological sequences of granitic rocks.

Rock Type	
Younger	Quartz veins Pegmatite dykes and veins Biotite granite Hornblende- biotite granite
Older	Porphyritic granite

Porphyritic granite is one of the most important units of Ladakh granitoids and also found at higher peaks as a relict patches. The presence of porphyritic granite boulders in some of the stream sections also suggest that a large cover of these rocks might have been eroded off. The biotite granite, aplite and pegmatite are the main intrusives in this granite. The frequency of such veins and dykes as compared to central part of the porphyritic granite is more in the marginal part. It is slightly pinkish in color, coarse-grained and massive in nature. It composed of quartz, feldspar, biotite, muscovite and small amount of hornblende. The size of these phenocrysts varies from 2 cm to maximum of 8 cm and they are randomly oriented. Size, shape and frequency of such phenocrysts determined on the outcrop at several locations suggest that around 60% of this granite is covered by phenocrysts.

Quartz in this granite is colorless euhedral to subhedral, the size of these grains that varies from few mm to 0.8 cm. The quartz veins are found along the fractures in feldspar phenocrysts are observed. Biotite is dark brown in color and flakes are varies from 0.5 cm to 1.2 cm, while muscovite flakes are smaller than biotite, sphene and chlorite is generally associated with biotite.

Hornblende granite occurs as a crescent shape body, with its concave and steep side towards the southeast which forms a ridge. The Hornblende granite is dark grey to brownish in color, medium to coarse grained massive in nature. The main constituents of this granite are quartz, hornblende, feldspar and biotite.

The main constituents of biotite bearing granite are quartz, potash feldspar, plagioclase, biotite and muscovite. Minor quantity of sphene and muscovite is also visible

to naked eyes. This rock is characteristically poor in hornblende. This granite is brownish to White in Color, medium to coarse grained and massive in nature.

Quartz is water clear, rounded to subround. Besides, milky quartz is also present at places. Due to leaching of Iron (magnetite) a thin film of brownish material is common on quartz. The size of quartz crystal vary from mm to maximum 5 mm. Micro veins of quartz are also observed in biotite granite along the fractures. The feldspar crystals are milky White and light pinkish in Color. Some of the feldspar crystals are well developed while others are subrounded to round. The micro veins of feldspar in biotite granite can also be seen. Flakes of biotite and muscovite are common. Biotite is brownish to dark green in color and these flakes are randomly oriented. Along the cleavage of biotite flakes a thin film of quartz and plagioclase is present at places. Muscovite flakes are clear and small in size. Chlorite is dark grey and weathered. It is found as aggregates in the vicinity of plagioclase and biotite.

Among the accessory minerals, sphene is common. It is yellowish green in color and perfectly crystallized. The crystals of very small dimensions of sphene are generally found near to biotite and hornblende. Magnetite is generally found in disseminated cubic crystals. Due to weathering brownish patches around the crystals are very common.

Pegmatites and aplites are widely distributed throughout the granitoid rocks of Ladakh. All granitic pegmatites are similar in a way that they are composed essentially of quartz and feldspar, with some muscovite, biotite, tourmaline and beryl.

4.1.5. Indus Suture Zone (ISZ)

The Indus Suture Zone (ISZ) defines the collision zone between the Karakoram-Lhasa Block to the north and the Indian Plate (Gansser, 1964, 1977; Allegre et al., 1984; Searle et al., 1987) and can be traced for over 2000 km from Kohistan and Ladakh in the east right across southern Tibet to the NE Frontier region of India-Burma. In Tibet it is commonly referred to as the Yarlung-Tsangpo Suture; in the west part of the Himalaya it is the Indus Suture Zone. To the west of Ladakh, the ISZ is folded around the giant Nanga Parbat fold, a 35 km wavelength, upright anticlinorium that exposes Indian Plate gneisses equivalent to the Central Crystalline Complex in its core (Figure 4.3). The ISZ has been offset by the late Tertiary culmination of Nanga Parbat and downfaulted west of Nanga Parbat along the Rakhiot Fault zone. It continues westwards as the Main Mantle Thrust (MMT) across southern Kohistan (Tahirkheli and Jan, 1979). In Ladakh, the Indus Suture is bounded to the south by the backthrust shelf sediments of the Zaskar Supergroup and the Tso Moriri crystalline complex, and to the north by the Ladakh Batholith. The geology of the ISZ has been explained by Gupta and Kumar (1975), Shah et al. (1976), Frank et al. (1977), Fuchs (1977, 1979), Bassoullet et al. (1978, 1981), Andrieux et al. (1981), Thakur (1981, 1987), Baud et al. (1982), Searle (1983, 1986) and Brookfield and Andrews-Speed (1984a, b). The Ladakh's Indus Suture Zone consists of three major linear thrust belts, the Lamayuru complex, the Nindam-Dras Volcanic Group and the Indus Group molasse. They are separated by major fault zones or ophiolitic melange belts (Figure 4.3) is a

palaeogeographic reconstruction of the Neo-Tethyan basin showing the pre-Eocene stratigraphy of the rocks now preserved in the ISZ in Ladakh.

4.1.6. Indus group molasses

The term “molasses” refers as terrestrial or shallow marine deposits in front of rising mountain chains formed with the comprising of sandstones, shales and conglomerates. A continental clastic sequence approximately 2000 m in thickness, comprising alluvial fan, braided stream and fluvio-lacustrine sediments, constitutes the Indus Group (Brookfield and Andrews-Speed, 1984a,b; Van Haver, 1984). Fragments in the conglomerates were mainly obtained from the uplifted and eroded Ladakh Batholith towards north, but also from the suture zone itself (cherts, limestones, serpentinised peridotites) and the Zaskar shelf carbonates towards south. Palaeo-currents show dominantly east to west basin axis-parallel sediment transport paths (Pickering et al., 1987). Near Kargil the Indus molasse unconformably rests on the Ladakh granitoids along the northern edge of the ISZ. The clash of India with the Karakoram and Lhasa Blocks and the closing of Tethys at 50 Ma mark the initiation of Indus Group molasse sedimentation (Searle et al., 1987). The Chogdo Formation at the base of the molasse rests stratigraphically above late Palaeo.

4.1.7. Tectonic origin of the Himalayas

The magnificent heights to which the Himalayas have been uplifted is as a result of several orogenic movements. The tectonic history of the Himalayas is a much debated subject. Some workers have recognized five phases of deformation on the basis of small scale shortening structures. Others have deciphered four major tectonic movements, the earliest dating back to the Precambrian or Lower Paleozoic, while the other three postdating the Permian. A few workers however, recognise only three episodes of orogenic activity, post-dating the Cretaceous.

The first phase of Himalayan orogeny-the Daling event (Precambrian or Lower Paleozoic) is marked by medium grade metamorphism but intense deformation accompanied by both acid and basic igneous intrusives. The second phase of orogeny known as the Ladakh phase involved the beginning of earth movements which were responsible for the major uplift of the Himalayas. It is during this phase that the Indian plate is believed to have collided with the Asian plate. This caused a shallowing of seas, emplacement of ophiolites along the Indus Suture zone, granitic intrusions, palaeogenesis, and granitization. Patches of Eocene rocks over the Tal (Jurassic), Krols (Permo-Triassic), Simla Slates (Paleozoic), and Deoban rocks (Paleozoic) indicate folding and erosion of these sedimentary basins before transgression of the sea in Eocene period, and subsequent deposition of Eocene sediments. This phase of the Himalayan orogeny was active from Late Cretaceous to early Eocene times.

The third and most vigorous of all orogenic movements is termed the Dharamsala phase which culminated in the Middle Miocene. The consequent compression due to under-

thrusting of the Indian plate beneath the Tibetan (Asian) plate caused large scale isoclinal and recumbent folding of the Precambrian crystalline rocks. This resulted in the thrusting of huge blocks of these rocks that moved southwards, and came to rest upon the younger sedimentaries. Most of the thrust sheets of the Lesser Himalayas and widespread regional metamorphism and acid igneous activity are associated with this phase. Due to the great uplifting, a foredeep was created in front of the rising Himalayas into which the Siwalik molasse sediments were deposited.

The fourth phase of Himalayan orogeny is the Siwalik phase. This phase was very active from the Late Pliocene to Middle Pliocene period. Most of the present structures of the Himalayas developed during this phase. The Siwalik sediments were also uplifted. Tectonic creep along some of the thrust faults of the Himalayas, translation of upper Siwalik rocks over the subrecent gravel beds, and seismicity in the region strongly suggest that this phase has not yet ceased.

4.1.8. Ladakh Region

Ladakh is situated between 30° to 36° E latitude and 76° to 79° N longitude. It is part of the state of Jammu and Kashmir, has an area of 96,701 sq. Km and comprising a population of 200,000 habitants. Ladakh is bounded on the north by the eastern range of the Karakoram Mountains and the Tibetan Plateau. Across the Kashmir Valley and over the famous Zoji La pass (Zoji La pass) lies Ladakh - “the Land of High Passes”. It is a magical land, so completely different from the green landscape of some other parts of the Himalayas. It is nature at its extreme. A land of freezing winds and burning hot sunlight, Ladakh is a cold desert lying in the rain shadow of the Great Himalayas and other smaller ranges. Little rain and snow reaches this dry area, where the natural forces have created a fantastic landscape. Parts of Ladakh are under the illegal occupation of Pakistan and China, respectively. The border of Ladakh touches those of Afghanistan, Pakistan, China, the Kashmir Valley (India) and Himachal Pradesh (India).



Figure 4.4. The terrace type of cultivation in the cold arid deserts of Leh, Ladakh.

Ladakh has an average elevation of 2,700 m to 4,200 m. The aridity of this region is due to its location in the rain shadow area of the Great Himalayas, elevation and radiation of heat from the bare soil. The Great Himalaya Mountain, lying to the south, forms a barrier to monsoon in this area. The most striking physical feature of Ladakh, however, is the parallelism of its mountain ranges. The region is extremely dry, with rainfall as low as 10 cm each year. It has many lakes and springs, the famous springs are the sulphur springs of Panamic (Nobra), Chumathang and Puga of Changthang, which are famous for early curing of joints/ rheumatic diseases. Many mineral springs are also found in some remote parts of Ladakh. People of region use the spring water as medicine to prevent and cure themselves from many diseases. In Ladakh, large rivers and their tributaries have carved deep gorges far below their steep banks. However, their water is not of much use as the terraced fields lie high above the gorges.

Earlier Ladakh could only be reached over high passes (Figure 4.4.). The Zoji La pass connecting Ladakh to Kashmir is at 14,000 ft and is the lowest approach from the west. The south east approach has to cross the 18,200 ft high Tanglang La. And to the north lie the Saser La and Karakoram passes, gateways to Central Asia from where trading caravans used to come for many centuries. The altitude ranges from 3000 m (lower Indus and Nubra valleys) to 7600 m (Zaskar and Karakoram ranges) (Gujja et al., 2003). The region of Ladakh normally remains land locked between November to June every year as Srinagar-Ladakh and Ladakh- Manali highways, which connect Ladakh with the other parts of the country, remain closed during this period because of snow and rigorous winter. Due to this region Ladakh is an isolated cold desert region (Figure 4.4) gives the glimpse the dry vegetation mostly Poplar and Willow at Leh, Ladakh.

4.1.9. The Ladakh–Zaskar area

The Ladakh-Zaskar zone is geographically situated in the North Western part of the Indian Himalaya. The Indian plate towards south from the Asian or Ladakh plate towards north is separated by the Indus Tsangpo Suture Zone (ITSZ) (Figure.4.3). The calc-alkaline Ladakh Batholith is mainly covered the north part of the Ladakh–Zaskar zone. Between 110 and 50 Ma, this batholith is developed (Honegger et al., 1982; Weinberg et al., 2000) over Asian continental boundary (Weinberg et al., 2000) during the north subduction of Neo- Tethys and the Indian continental boundary. The Indus Tsangpo Suture Zone is portriad precisely to the south eastern part by the Nidar ophiolite and connected with the Zildat ophiolitic melange. It is marked by the Sapi-Shergol ophiolitic melange situated in the northwest, which contains 90Ma blueschists (Honegger et al., 1989). Continental conglomerates and Tertiary molasse occur throughout the length of the ITSZ (Cannat and Mascle, 1990).

The Indian plate is specified by the continental boundary sedimentary units to the south. The units are characterised from the ITSZ towards south (Figure.2 1), these units are: During Permian to Early Cretaceous time over Indian continental slope, the Lamayuru and Karamba units are deposited (Bassoullet et al., 1981; Robertson and Degnan, 1993; Robertson, 2000). During Permian to Eocene time on the Indian continental shelf, the

carbonates of the Zaskar units are deposited (Cannat and Mascle, 1990). The Spontang ophiolite and its ophiolitic melange were carry off onto this sections. The South eastern part of the Ladakh-Zaskar, remnants of the subducted Indian continental boundary outcrop in the Tso Moriri domes. Around 55 Ma, these sections are undergo an eclogitic facies metamorphism (Guillot et al., 1997; de Sigoyer et al., 2000).

4.2. Regional Geology

The Great Karakoram Mountains (Saser Muztagh) to the northeast, Ladakh range in the middle and a small part of Jasker Mountain to the southwest from the prominent ranges. The most picturesque valleys of Ladakh are the Indus valley lies to the Southern part of Leh and the Shyok-Nubra valley lies to the Northern part of Leh. Several glaciers occupy the higher reaches in the North and North-east of the area. General altitude and site coordinates of the area varies between 2995 m ($34^{\circ} 46'$; $77^{\circ} 15'$) and 7672m ($34^{\circ} 51'$; $77^{\circ} 45'$). The area is nourished by the shyok and Indus Rivers which follow an almost parallel northwest-southeast course in this quadrangle and the South easterly flowing Nubra River joins Shyok River near Diskit. The quadrangle shows following geological set up from SW to NE.

The Zaskar sedimentary belt comprises undifferentiated Kuling-Lilang and Lilang group of rocks. The Indus Tectonic Belt comprises Indus Group of Volcano sedimentary sequence and Sanglungma Group of rocks with ophiolite association. The Shyok Nubra Belt of volcano sedimentary assemblages with intrusion of granitoids. The Karakoram Belt of Granitoids with associated older metamorphites and Karakoram sedimentaries. Undifferentiated Kuling-Lilang Group of Permian to Jurassic age bounded on both the sides by thrusts is exposed in the southwestern part of the area. It comprises of black, grey, green and purple shale and greyish limestones bands. Undifferentiated Lilang Group of rocks of Triassic to Jurassic age exposed in the southwestern corner of the quadrangle comprises limestone, dolomite and quartzite. Rocks of Indus Tectonic Belt of Late Cretaceous to Early Miocene age are sandwiched between the Ladakh Granitoid Complex in the north and the Spiti- Zaskar Phanerozoic sedimentary belt to the south. The zone comprises two separate parallel belts designated as Indus Group and Sanglungma Group.

The heavy mass of the Ladakh Batholith of Calc-alkaline granitoids constitute of the NW Indian Trans-Himalaya and the Kohistan-Ladakh magmatic arc forms throughout the length with the west part of the Kohistan batholith. The magmatic arc is covered towards the south by the Indus Tsangpo suture zone (ITSZ) and towards north by the Shyok suture zone during the age of large Early Cretaceous to Eocene geological time period (Figure 2.1). Because of subduction throughout the length of an intraoceanic arcs and arc-continent enlargement before the final India and Eurasia collision, the origination of ITSZ was progressed by the utilization of the Jurassic-Cretaceous Neotethyan oceanic crust (Frank et al., 1977; Honegger et al., 1982; Searle et al., 1987; Honegger et al., 1989). This was presented by the origination of a Paleocene-Eocene (Gangdese arc) and Early Cretaceous to Early Jurassic aged magmatic belts that evolved in an active continental boundary tectonic setting throughout the length of the most of the southern boundary of Asia (Lhasa terrane), (northern magmatic belt, Chu et al., 2006; Wen et al., 2008)

The involvement of several intrusions of leucocratic to mesocratic granitic rocks is comprised by the Ladakh Batholith (Schärer et al., 1984; Weinberg and Dunlap, 2000). As per the details are collected from the Geological Survey of India, batholith is divided into five units, diorite-tonalite, quartz monzodiorite-granodiorite, biotite-hornblende granite, leucogranite and pink porphyritic granite, with biotite- and hornblende-bearing granodiorite as the main rock type (Singh, 1993). These rocks were mainly located between 110 and 40 Ma with a major stage that established at around 60 Ma, which is indicated by the available geochronological data (Honegger et al., 1982; Schärer et al., 1984; Weinberg and Dunlap, 2000; Singh et al., 2007; Jain and Singh 2008), although for this huge batholith, more data are require to accurately constrain the time of emplacement.

4.2.1. Field geology

The samples are collected from the choosen area that is situated at the 50 to 60 km westside of Leh tehsil of Leh, Ladakh district of Jammu and Kashmir. Total 41 samples are collected from four different villages and plutons like The Basgo, Nimmu, Umla and Taru plutons of Leh-Ladakh district. Ladakh is the highest plateau of the Indian state of Kashmir with much of it being over 3.000 m. It lies between 32 to 36 degree north latitude and 75 to 80 degree east longitude.

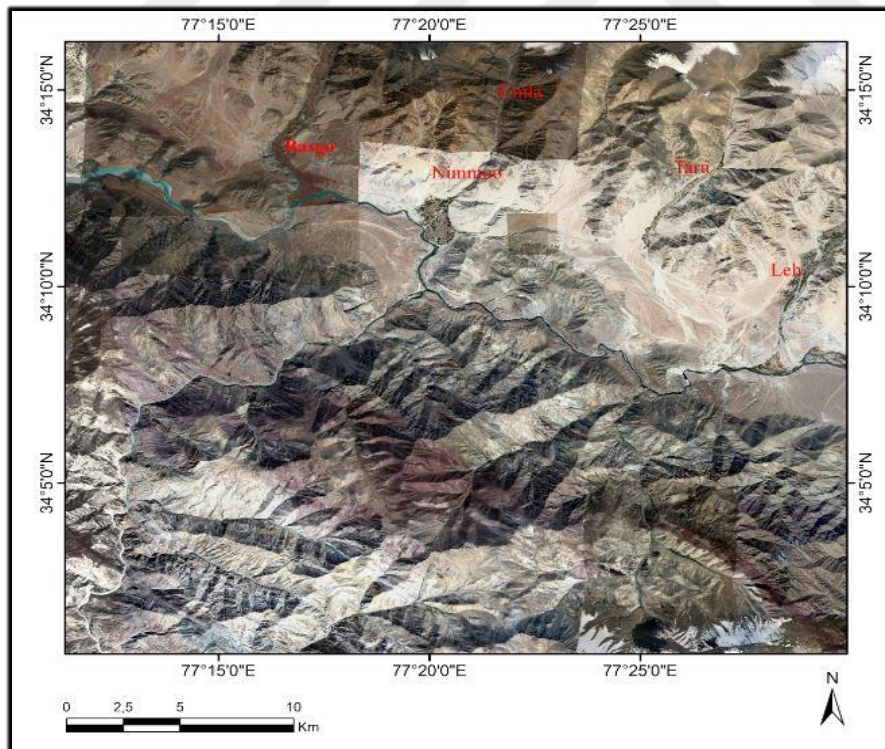


Figure 4.5. shows the field area on the Google map with mentioned Basgo, Nimmu, Umla and Taru plutons of Leh- Ladakh district.

The total area of 45110sq km makes Ladakh the largest district in India. Ladakh region is bifurcated in Kargil and Leh districts. Kargil lies at an altitude of 2750 m and Leh at 3505 m. The largest town in Ladakh is Leh. Ladakh is renowned for its remote mountain beauty and culture. It spans the Great Himalayan and Karakoram mountain ranges and the upper Indus River Valley.



Figure 4.6. shows the general view of Ladakh Batholith, 50 km away from the Leh district of Ladakh region. It shows the separate division of leucogranite from granite.



Figure 4.7. shows the general view of Ladakh Batholith in Taru village, 40 km away from the Leh district of Ladakh region.

4.2.2. The field relationship

The Basgo Pluton

The Basgo is Located at the elevation of 3292 meters above from sea level, Basgo is a historical town situated on the bank of Indus River in Ladakh. It was once the cultural and political centre of the region and today is frequently mentioned in the Ladakhi series of events.

The Basgo pluton is made up of biotite granodiorite to biotite granite. The biotite granodiorite and biotite granite having similar characteristics, but the percentage of quartz is more in biotite granodiorite than the biotite granite. Moreover, the biotite granodiorite consist of megacrysts of alkali feldspar whereas the biotite granite consists of plagioclase feldspar.



Figure 4.8. shows the medium to coarse grain of granodiorite and granite having visible grains of feldspar.

In this study, the grains sizes are medium to coarse. The biotite granodiorite shows grey and dark grey pattern of grains. It is characterised by prismatic, light pink-coloured feldspar crystals set in a grey, medium-grained groundmass. The biotite granite shows similar field characteristics to those of the biotite granodiorite. Unlike the biotite granodiorite, the granite has prismatic/tabular, light pink-coloured alkali feldspar megacrysts.



Figure 4.9. shows the medium to coarse grain of biotite granodiorite and granite of basgo pluton.

The Nimmu Pluton

Nimmu is located in the South east of Ladakh Region and is 35 km from Leh, Jammu and Kashmir, India. The all extreme and harsh valley of Nimmu is located in the South eastern part of the Ladakh region. At an elevation of around 3000 meters, Nimmu has Indus river flowing alongside it. Nimmu is a stop for all the river rafting groups and is the main starting point for the annually-held all-India river rafting expedition, which is done in the Indus River. The temperature here varies from +40 °C in summer to -29 °C in winter.

The Nimmu pluton consists of biotite amphibole granodiorite, biotite granodiorite to biotite granite. The biotite amphibole granodiorite, biotite granodiorite and biotite- granite having similar characteristics, but the percentage of quartz is more in biotite granodiorite than the biotite granite.



Figure 4.10. shows the medium to coarse grain of biotite granodiorite having quartz vein.



Figure 4.11. shows the wide view of Ladakh Batholith and Indus Molasses near the road route from leh to Nimmu. Photograph was clicked from the right side view, when moving towards Leh direction.

Above figure shows the great view of Ladakh Batholith separated with Indus Molasses about 2 km from Nimmu, the Zaskar river flows into the Indus through Nimmu Gyasho.

The red brown Indus, valley floor broadens considerably for the final 35 km from Leh, flanked by the stok range towards south, the Karakoram Range towards north and tucked into one of the sheltered side valleys is Leh.



Figure 4.12. shows the clear view of Ladakh Batholith with Indus Molasses along with Indus river flowing through it.

Above figure shows the broaden view of Ladakh Batholith having alternate light and dark segments due to presence of hornblende, biotite granodiorite to quartz granodiorite. The red and Brown covered sand and silt area shows the Indus molasses.



Figure 4.13. shows the famous spot called Magnetic hill near Nimmu.

Above mentioned figure shows one of the famous spot called Magnetic Hill and it's popular for its Magnetic field. The dark colored hill reflects the concentration of heavy minerals rich in Ferro manganesian.

In this study area, granite samples are medium-to coarse-grained with largely felsic massive porphyritic igneous rock comprising of feldspar, quartz, biotite and minor amount of amphibole. The color varies from light grey to dark grey that reflect accordingly the concentration of biotite and hornblend in the granodiorite to granite samples.

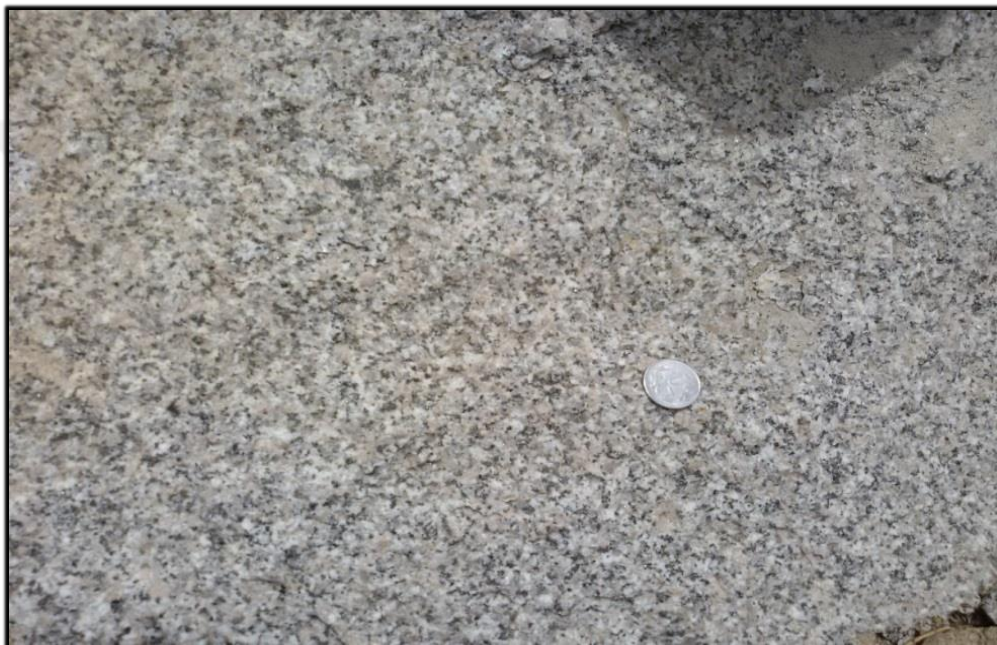


Figure 4.14. shows the medium- to coarse-grained of biotite granodiorite having small lath-shaped grain of feldspar.

The Umla Pluton

The Umla village is situated about 25 km westside of Leh. In this study area, the Umla Pluton comprises of granite, quartz granodiorite and biotite granite. The granite samples of this area are medium to coarse grains contain plagioclase, K-feldspar, quartz, amphibole and biotite in varying amounts and is mainly characterised by a higher proportion of mafic minerals, especially biotite compared to other. The color of these granites are varies from light to dark grey due to variation of biotite and hornblende.

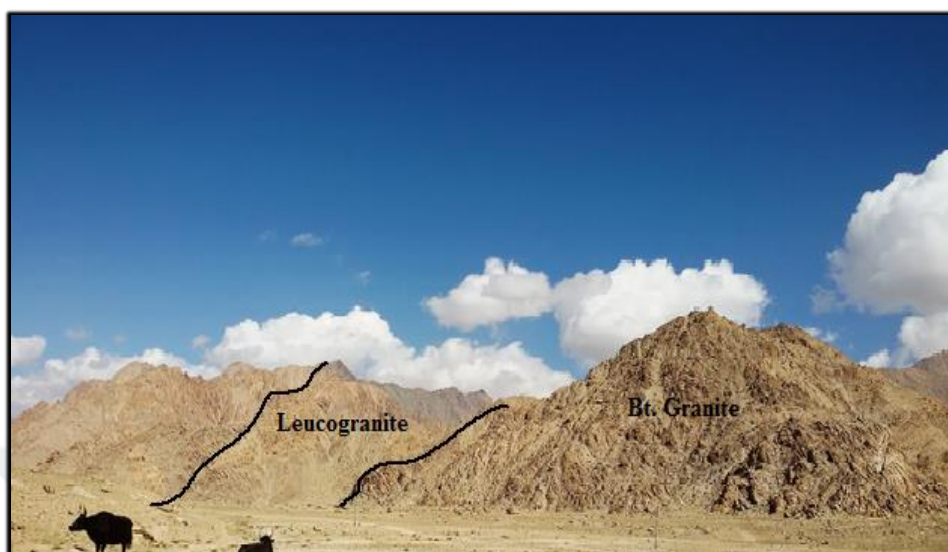


Figure 4.15. shows the dark part of granite due to presence of biotite and hornblende. Another partition shows the leuogranite. Bt- Biotite.



Figure 4.16. shows the biotite granodiorite rock sample associated with enclaves.



Figure 4.17. shows the 5-6 cm elongated mafic enclaves associated with the host rock.

The Taru Pluton

Taru is a village in Leh Tehsil in Leh, Ladakh District of Jammu and Kashmir state, India. It is located 5 km towards east from district head quarters of Leh, which is 298 km from state capital Srinagar of Jammu and Kashmir. Taru is surrounded by Leh Ladakh Tehsil towards west, Chuchot Tehsil towards south, Panamic Tehsil towards north, and Nubra Tehsil towards north. In this study area, the Taru pluton consists of quartz granodiorite, biotite amphibole monzodiorite, biotite amphibole granodiorite and granite. They all are having similar petrographic characteristics but sometimes vary according to the percentage of quartz, plagioclase feldspar and alkali feldspar.



Figure 4.18. shows the quartz granodiorite sample near Taru village, Leh.

The granite samples are medium to coarse grain containing different mineral phases from mafic to accessory phases like plagioclase feldspar, alkali feldspar, amphibole, biotite with variable proportion and size.



Figure 4.19. shows the wide view of Taru granites associated with enclaves at Taru Village, Leh.



Figure 4.20. shows the great view of one of the famous spots called Moon Land at Lamayuru, Leh Ladakh.

4.2.3. The dykes

The dyke is located near Taru on the Leh-Nimmu road. It is a melanocratic rock with megaphenocrysts of dark mica in an aphanitic groundmass. The dyke is not clearly exposed but in-situ parts of it are observed to occur intruding into a 5 m wide subvertical

dyke of microgranite porphyry trending N70°E (Figure 4.21). The dyke appears to be restricted within the microgranite porphyry and much of it now occurs as rubble at the base of the granite porphyry dyke. The microgranite porphyry dyke along with other doleritic and andesitic dyke swarm, trend N70°-80°E, and intrude the dominant component of the Ladakh Plutonic Complex composed of metaluminous, calc-alkaline, biotite-hornblende granite to granodioritic rocks (Sharma, 1992).

Dyke samples are aphanitic to finely grained, with minor quartz, hornblende and biotite. The color ranges with dark greyish to greenish, in which greenish colors are assigned to chlorisation and saussuritisation. And some of the samples are having light to dark red brownish matrix.



Figure 4.21. shows the dyke located at the Taru on the Leh-Nimmu road within the Ladakh Batholith, Leh-Ladakh district.

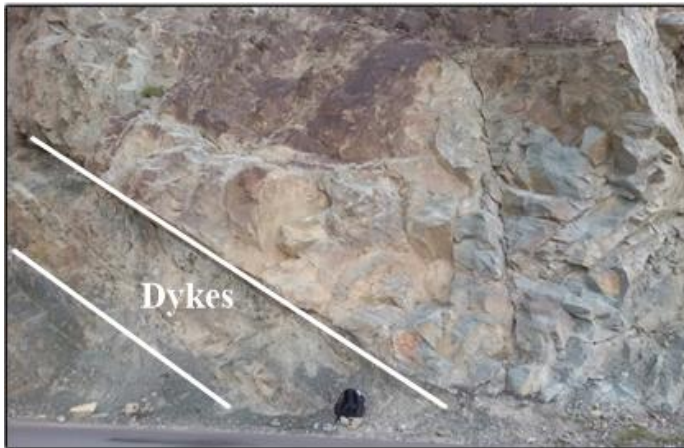


Figure 4.22. shows the close view of the dyke located at the Taru on the Leh-Nimmu road within the Ladakh Batholith, Leh-Ladakh district.

4.2.4. Enclaves

The evolutionary history of magma chamber has been essentially recorded, despite the fact that the quantity of microgranular enclaves in comparison to the host granitoid magma is considerably low.

The granitoids of Indus-Shyok valleys have been hosted in two main types of enclave are xenoliths and microgranular enclaves. However, brecciated (dismembered) synplutonic mafic dykes and mafic to hybrid microgranular enclaves are ordinary in Ladakh granitoids (Kumar, 2010) as add up to some not enough xenoliths of Shyok Formation limited to boundaryline parts of Ladakh granitoids.

The occurrence of broadly coeval felsic magmatism in Indus-Shyok Suture Zones are strongly point to Tirit granitoids (ca 68 Ma, Weinberg et al., 2000; ca 74 Ma, Upadhyay, 2008; ca 105 Ma, Kumar et al., 2014) and Ladakh granitoids (50-70 Ma) of U-Pb zircon ages. Several number of pulses that forms a sequences of intrusive bodies of batholithic dimensions that extensively occurred by felsic magmatism. Rounded to ellipsoidal of swarms, microgranular enclaves as from mafic to hybrid which is formed by several coeval mafic to hybrid magma pulses which are blended to syn-crystallized with the host granitoid magmas at an initial stages about 20-50% crystallinity (Kumar, 2010).

In most of the calc-alkaline plutons at local or regional levels, which are representative of mafic-felsic magma blending, flowage textures and mingling comprises of common enclaves of displaying different shapes and sizes (e.g. Dorais et al., 1990; Didier and Barbarin, 1991, Barbarin, 2005). In Ladakh intrusive rocks, several new characteristics of flowage and magma mingling have been recorded from this crosscut. The mafic to hybrid swarms of microgranular enclaves of different shapes and size, syn-plutonic mafic dykes brecciated to express angular enclaves with displaying sharp contacts with host granitoids on two dimensional parts, and post-plutonic mafic dykes contain by the calc-alkaline Ladakh intrusive rocks.

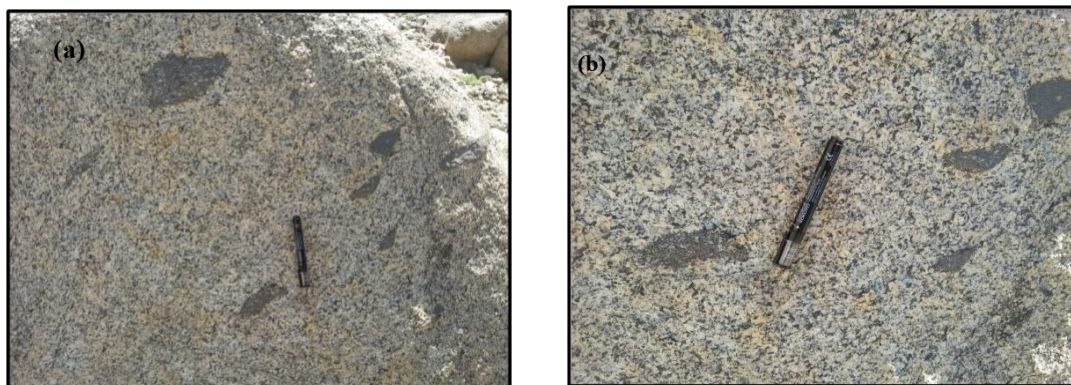


Figure 4.23. Field observations along Taru and Umla area of Ladakh Granitoids: **(a)** Microgranular enclaves isolated by felsic streak displaying magmatic flowage with closely-spaced swarms, in and

around showed samples. **(b)** Swarms are mainly trending E-W displaying magmatic deformation with parallel to sub-parallel and extended microgranular enclaves.



Figure 4.24. (c) Several shapes and sizes of microgranular enclaves are hosted in intrusive rocks (d) Predecessor diorite rock mass (melanocratic in nature) nearly connected with Ladakh intrusive rocks, (e) and (f) Several times the Diorite bulk is damaged by intrusions of intrusive rocks to form enclaves.

Elongated to sub-rounded swarms of microgranular enclaves mainly trended to E-W are lined up from parallel to sub-parallel (Figure 4.23), and due to exertions of pressure towards north on crystallizing host granitoid magma chamber they have obtained the extended shapes. Various shapes and sizes of homogeneous to heterogeneous microgranular enclaves are unsystematically distributed over single outcrop (Figure 4.23).

The magma chamber was being prepared by mafic to hybrid magma pulses irregularly in all through the crystallizing history of host granitoid magma that indicated by the remarked characteristics of microgranular enclaves. With the progressive crystallization, the density and viscosity of host granitoid magma were increases and it is literally decides how far the fractured or ruptured mafic enclave bodies will get disseminated within host granitoids. If there is no indication of solid state distortion then the extension of enclaves is of magmatic origin. Enclave magma mingling and flowage is indicated by the minerals in enclave correspond well with the minerals of host granitoids (e.g. Vernon et al., 1988). The difference in the crystallinity, viscosity, timing of enclave deformation and differential force during the flowage of host granitoid magma is a

reflection of the elongation of enclaves (e.g. Arvin et al., 2004). Accordingly, enclave magma bubbles of various shapes and sizes cannot be used as solid state force identification (Vernon et al., 1988). The observation of rounded to subrounded, elongated to non-elongated, homogeneous to heterogeneous swarms, folded to stretched and enclosed mafic schlierens frequently following the direction of flow of host magma driven by convection currents (e.g. Arvin et al., 2004; Kumar et al., 2004; Kumar 2010). Meta-sedimentary xenoliths of Shyok Formation comprises to the Ladakh granitoids.



Figure 4.25. (g-l) Field observations along the area of Taru and Umla granites of the study area showing elongated to elipsoidal-shaped microgranular enclaves, mingling and mixing of

heterogeneous magma, hybrid microgranular, subrounded microgranular enclaves in Ladakh intrusive rocks.

Mineral assemblage to Ladakh intrusive rocks are mainly comprises of biotite, hornblende, k-feldspar, plagioclase and quartz. These are emplaced in different episodes like configurationally (calc-alkaline) and tectonically (subduction-related). During early to diminish levels of their crystallization, interaction of the Ladakh granitoid magmas were with several number of pulses of coeval mafic to hybrid magmas, which formed microgranular enclaves and disrupted syn-plutonic mafic dykes. The metapelitic rocks of Shyok Formation intrude Ladakh granitoids at comparatively very lower level.

Table 4.3. shows the latitude, longitude, location and description of the samples.

Sample No.	Location			Tectonic Setting	Description
	Latitude (N)	Longitude (E)	Village name		Rock Properties
AM1	N 34 ⁰ 13.463"	463"E 77 ⁰ 16.323"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, opaque minerals Biotite Granite
AM2	N 34 ⁰ 13.469"	E 77 ⁰ 16.329"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar, opaque minerals Biotite Granite
AM3	N 34 ⁰ 13.225"	E 77 ⁰ 16.638"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar, opaque minerals, chloritized biotite Diorite
AM4	N 34 ⁰ 13.213"	E 77 ⁰ 16.645"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar Biotite Granite
AM5	N 34 ⁰ 11.800"	E 77 ⁰ 19.500"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar, opaque minerals, chloritized biotite Biotite Granite
AM6	N 34 ⁰ 10.109"	E 77 ⁰ 20.047"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar Granodiorite
AM7	N 34 ⁰ 10.105"	E 77 ⁰ 20.045"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar, opaque minerals

					Granodiorite
AM8	N 34 ⁰ 10.104"	E 77 ⁰ 20.050"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar Granodiorite
AM9	N 34 ⁰ 10.166"	E 77 ⁰ 20.081"	Basgo	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar, opaque minerals Granodiorite
AM10	N 34 ⁰ 10.163"	E 77 ⁰ 20.065"	Basgo	Ladakh Batholith	Fine to Medium grained Plagioclase, quartz, biotite Biotite Granite
AM11	N 34 ⁰ 09.888"	E 77 ⁰ 20.333"	Nimmu	Ladakh Batholith	Fine to Medium grained Plagioclase, quartz, amphibole, biotite, K-feldspar, chloritized biotite and sericitised plagioclase Granite
AM12	N 34 ⁰ 09.872"	E 77 ⁰ 20.344"	Nimmu	Ladakh Batholith	Fine to Medium grained Plagioclase, quartz, biotite Granodiorite
AM13	N 34 ⁰ 09.760"	E 77 ⁰ 20.423"	Nimmu	Ladakh Batholith	Fine to Medium grained Plagioclase, quartz, biotite Granodiorite
AM14	N 34 ⁰ 09.705"	E 77 ⁰ 20.476"	Nimmu	Ladakh Batholith	Fine to Medium grained Plagioclase, quartz, biotite Biotite Granite
AM15	N 34 ⁰ 09.650"	E 77 ⁰ 20.522"	Nimmu	Ladakh Batholith	Fine to Medium grained, Plagioclase, quartz, amphibole, biotite, K-feldspar, chloritized biotite and sericitised plagioclase Granite
AM16	N 34 ⁰ 11.842"	E 77 ⁰ 22.574"	Nimmu	Ladakh Batholith	Coarse grained Plagioclase, quartz, biotite, amphibole, Biotite-Hornblend Granodiorite
AM17	N 34 ⁰ 11.830"	E 77 ⁰ 22.600"	Nimmu	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, amphibole Biotite Granodiorite
AM18	N 34 ⁰ 11.805"	E 77 ⁰ 22.615"	Nimmu	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, amphibole, K-feldspar Biotite Hornblend Granodiorite

AM19	N 34 ⁰ 11.752"	E 77 ⁰ 22.790"	Nimmu	Ladakh Batholith	Medium to coarse grained, Plagioclase, quartz, biotite, amphibole, K- feldspar Biotite Granodiorite
AM20	N 34 ⁰ 11.794"	E 77 ⁰ 22.669"	Nimmu	Ladakh Batholith	Medium to coarse grained, Plagioclase, quartz, biotite, K- feldspar Biotite Granodiorite
AM21	N 34 ⁰ 11.590"	E 77 ⁰ 22.622"	Umla	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K- feldspar Biotite Granodiorite
AM22	N 34 ⁰ 11.120"	E 77 ⁰ 23.953"	Umla	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, amphibole, biotite, K-feldspar, chloritized biotite and sericitised plagioclase Quartz Granite
AM23	N 34 ⁰ 10.425"	E 77 ⁰ 25.339"	Umla	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K- feldspar Quartz Granodiorite
AM24	N 34 ⁰ 10. 436"	E 77 ⁰ 25.334"	Umla	Ladakh Batholith	Medium to coarse grained Plagioclase, amphibole, quartz, biotite, K- feldspar Granodiorite
AM25	N 34 ⁰ 10.457"	E 77 ⁰ 25.346"	Umla	Ladakh Batholith	Medium to coarse grained, Plagioclase, amphibole, olivine, pyroxene, quartz, biotite, K- feldspar Monzonite
AM26	N 34 ⁰ 10.567"	E 77 ⁰ 25.445"	Umla	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K- feldspar Granodiorite
AM27	N 34 ⁰ 10.615"	E 77 ⁰ 25.545"	Umla	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, amphibole, biotite, K-feldspar, chloritized biotite and sericitised plagioclase Granodiorite
AM28	N 34 ⁰ 10.756"	E 77 ⁰ 25.645"	Umla	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K- feldspar Biotite Granodiorite

AM29	N 34 ⁰ 10.854"	E 77 ⁰ 25.770"	Umla	Ladakh Batholith	Medium to coarse grained, Plagioclase, amphibole, olivine, pyroxene, quartz, biotite, K-feldspar Monzonite
AM30	N 34 ⁰ 10.994"	E 77 ⁰ 25.840"	Umla	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K-feldspar Granodiorite
AM31	N 34 ⁰ 08.168"	E 77 ⁰ 29.956"	Taru	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K-feldspar Quartz Granodiorite
AM32	N 34 ⁰ 08.179"	E 77 ⁰ 29.942"	Taru	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K-feldspar Granodiorite
AM33	N 34 ⁰ 08.174"	E 77 ⁰ 29.940"	Taru	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K-feldspar Granodiorite
AM34	N 34 ⁰ 08.168"	E 77 ⁰ 29.942"	Taru	Ladakh Batholith	Coarse grained Plagioclase, quartz, chloritized biotite, biotite, K-feldspar Granodiorite
AM35	N 34 ⁰ 08.164"	E 77 ⁰ 29.938"	Taru	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, chloritized biotite, biotite, K-feldspar Biotite Granodiorite
AM36	N 34 ⁰ 08.118"	E 77 ⁰ 30.028"	Taru	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, K-feldspar Biotite Granodiorite
AM37	N 34 ⁰ 08.119"	E 77 ⁰ 30.032"	Taru	Ladakh Batholith	Medium to coarse grained, Plagioclase, quartz, amphibole, biotite, K-feldspar Biotite Granodiorite
AM38	N 34 ⁰ 08.119"	E 77 ⁰ 30.042"	Taru	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, amphibole, biotite, K-feldspar, chloritized biotite and sericitised plagioclase Quartz Granite
AM39	N 34 ⁰ 08.121"	E 77 ⁰ 30.065"	Taru	Ladakh Batholith	Medium to coarse grained, Plagioclase, quartz, amphibole, biotite, K-feldspar, chloritized biotite and sericitised plagioclase

					Quartz Granite
AM40	N 34 ⁰ 08.125"	E 77 ⁰ 30.082"	Taru	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, amphibole, K- feldspar, chloritized biotite and sericitised plagioclase Granite
AM41	N 34 ⁰ 08.130"	E 77 ⁰ 30.120"	Taru	Ladakh Batholith	Medium to coarse grained Plagioclase, quartz, biotite, amphibole Monzodiorite

4.3. Petrography

4.3.1. Introduction

The present chapter deals with the petrographic and petrological studies of the Basgo, Nimmu, Umla and Taru plutonic rocks around the Ladakh Batholith. In the field studies the intrusive rocks are subdivided into four rock types depend on color and also grain sizes: (1) Granite, (2) Granodiorite, (3) Monzonite, (4) Monzodiorite and (5) Diorite.

For modelling the chemical variation in intrusive rocks, it's primarily thing to figure out the crystallizing phases. It is particularly important to recognize texturally that which minerals are indicating early crystallizing phases and which is crystallized from trapped interstitial melt. It is important to describe the sub solidus modification which may affect magma and that results in the change of original mineralogy.

4.3.2. Optical studies of granitoid rocks

The systematic examination of important characteristics of *the rock forming minerals*, common to all members, has been carried out and the results are discussed below:

In the thin sections, main minerals are as follows

Quartz

Quartz is an important constituent of the granites. Quartz commonly occurs as colorless xenomorphic grains and shows first order polarization colors and wavy extinction. In some of the granites, quartz occurs in association with potash feldspar and plagioclase. In general the grain size varies from 1.5 mm x 0.70 mm to 0.1 mm x 0.7 mm. The stress undergone different granitic rocks are registered by the quartz grains in the form of undulate and linear banded extinction. Some of the places it shows sutured outline and at places has recrystallized in the interstices between grains of other minerals. Under high magnification quartz shows inclusions of dusty opaque minerals, however no definite pattern has been observed of these inclusions.

Three generations of quartz has been recognized:

1. Interstitial quartz (xenomorphic and poikilitic)
2. Recrystallized quartz
3. Worm like blebs of quartz

The wide variation in the nature and mode of occurrence of quartz in the different types of granite is a indicative of a long period of crystallization. The occurrence of automorphic crystals with occasionally corroded margins or rounded blebs of quartz occurring as inclusions in large crystals of plagioclase indicate early crystallization at high temperature above 573⁰C (Mehnert, 1968).

The interstitial quartz (Xenomorphic) is mostly present in the granites. The textural relationship between this form and adjoining minerals (feldspar, etc) indicates that this generation of quartz might have formed more or less simultaneously with the crystallization of other mineral constituents.

The vermicular (worm like) quartz is closely associated with albite and orthoclase forms myrmekitic texture such as vermicular quartz indicates a late low temperature crystallization between preaqueous and post- aqueous phase (Hibbard, 1979). This type of quartz does not show sutured boundaries nor was any effect of stress which further suggests that during crystallization of quartz the whole material in semiliquid or in liquid stage. It is concluded that all three generations i.e; interstitial, recrystallized and worm like blebs of quartz have formed with falling temperature.

Plagioclase

Plagioclase is the most common constituent widely distributed from different types of granite of Ladakh Batholith. In composition it varies from albite to andesine. Commonly the crystals are subhedral to euhedral and vary in different sizes. Where plagioclase is in contact with orthoclase or quartz, it usually has its own crystal boundaries, since it is crystallized before them, but where it lies against the ferromagnesium minerals, the later have better developed faces.

Plagioclase in granodiorite and quartz- monozodiorite is dominant amongst the other constituents. The crystals are euhedral to subhedral in shape and they vary in size from 1.9 mm × 0.5 mm to 0.5 mm × 0.30 mm. Plagioclase laths show complex twinning and occasionally these twins are deformed and show micro fractures. The anorthosite content varies from An₂₅ to An₄₀. The crystal boundaries are sharp, rarely corroded and generally do not show albitic intergrowth. Few of the plagioclase crystal are zoned with high An content in core and some of the plagioclase show cloudy appearance due to dusty opaque inclusions. Besides, epidote, hornblende and rutile crystals have also been observed within plagioclase as inclusions.

The first generation of plagioclase are clouded and generally found as skeletal and rarely euhedral with corroded boundaries. Plagioclases are very much altered i.e. sericitised, saussuritised with released calcite along cleavage and fractures.

The second generation of plagioclase is not much altered, shows deformation of twin lamellae that occurred as euhedral phenocrysts. Orthoclase is found frequently as relict in crystals of oligoclase and vice versa which indicates a more or less simultaneous crystallization of alkali feldspar and plagioclase from the melt. Plagioclase of second generation is also involved in myrmekitic intergrowth and in various perthite developments.

The third generation of plagioclase is commonly occur as stringe, blebs and veins in association with earlier formed plagioclase and sometimes with alkali feldspar phenocrysts. These generations of plagioclase are albitic in composition.

(a) Twinning of Plagioclase

The plagioclase in biotite bearing granite shows the variety of twins such as polysynthetic, albite, simple and complex or mechanical twins. The mechanical twinning in plagioclase has a characteristic features like lamellae tend to curve and taper to a point. They form cluster and tend to be thicker and more numerous at grain boundaries. Such type of glide twins suggest a high stress during the origin (Vance., 1962). Other complex twins matched with the Goari's (1951) that proposed C twin which are connected with the crystallization of plagioclase from melt.

(b) Clouding of Plagioclase

In clouded plagioclase the following observations are made:

1. The calcic plagioclases are cloudier.
2. The boundary between clouded and unclouded plagioclase do not show a change in An content.
3. In most of the cases the particles are responsible for clouding are very minute and even they couldn't identified with high magnifications. Some of the minute particles has been identified as magnetite, ilmenite, sericite, biotite, and hornblende.
4. The clouds that appear on plagioclase is varies from grain to grain and it is also caused by the alteration of plagioclase.

Myrmekites

Some of the following observation on myrmekites has been observed:

1. Generally, it is observed along the border of plagioclase and orthoclase crystals.
2. Myrmekitic overgrowth is more in biotite granite and porphyritic granite type as comparative to granodiorite, quartz- monzo- diorite type.
3. Some of the crystals having myrmekitic growth are bounded by albitic rim.

4. The myrmekitic plagioclase is at the contact of K- Feldspar the worm like quartz are seen projected in to the K feldspar.
5. The development of myrmekites is noted at the interface of perthite and plagioclase, with the convexity of myrmekitic pointing towards the perthite.
6. Myrmekite is totally enclosed in perthite without any connection with adjoining plagioclase and quartz.

Since the myrmekite was first describe by Sederholm (1916), with an existence of two schools of thoughts. The first school of thought, replacement origin with two different views, and one is replacement of potash feldspar by plagioclase (Sederholm, 1916; Binns, 1966) and the other is the replacement of plagioclase by potash feldspar (Drescher- Kaden, 1948; Osterwald, 1955) for the release of quartz during the intergrowth formation. While the second school (Schwankte, 1909; Spencer, 1945; Ashworth, 1972) believes that the ex-solution derives from both the component of myrmekite, (plagioclase and quartz) which are held in solid solution in the form of albite and K-feldspar.

Alkali Feldspar

Alkali feldspar (perthite, orthoclase and microcline) are the important constituents of different types of granite. Alkali feldspar crystals are as hypidiomorphic, xenomorphic and idiomorphic and are of two generations (a) early-crystallized phenocrysts and (b) interstitial-xenomorphic grains.

The early-crystallized phenocrysts are mostly orthoclase and perthite and show marked alteration, clouding and contain inclusion of plagioclase. Small patches of microcline are also observed.

The second generation of potash feldspar occurs as interstitial xenomorphic grains, and is represented by orthoclase, microcline, and perthite.

Microcline found only in few sections show rarely euhedral laths which show cross hatched twinning and sometime perthitic texture. The intensity of cross-hatched twinning is poor and varies some times within a single grain.

The orthoclase is colorless and sometimes shows development of imperfect cleavage and present as an altered and clouded. The alkali feldspar crystal most commonly shows Carlsbad twinning. The twinning has been studied in details by several workers and divergent views have been put forward regarding its divergent views have been put forward regarding its origin (Boggild, 1911, Reihnhard and Bachlin, 1936; Laves, 1950, 1954; Smith, 1974). While supporting the views of Laves and Barth (1969) suggested that most of the twinned microcline grains in granites, gneisses and crystalline schists are due to the inversion from orthoclase. It is stable at a relatively lower temperature than orthoclase. Therefore occurrence of microcline in biotite granite, aplite and pegmatite and porphyritic granite indicates comparatively lower temperature of crystallization of the rocks in comparison to the hornblende granite, which is devoid of microcline.

Potash feldspars granites are characterized by perthite intergrowth. This type of intergrowth is dominant in orthoclase whereas the perthite associated with microcline was rarely observed.

Perthites are considered to be the result of exsolution of sodic phase from the homogeneous soda- potash feldspar (Spencer, 1937, 1938; Barth, 1969; Smith, 1974; Yund and Ackermund, 1979; Yund et al., 1980).

Hornblende

Hornblende is most common mineral present in granite varies with different dimension and showing green, grey to bluish green color, high refractive index and two sets of amphibolic (prismatic) cleavages. The mineral is strongly pleochroic from pale green to green or bluish green and shows 12-20° extinction angles. Sometimes with structural continuity, it shows alteration to green biotite. A sieve structure is formed due to the presence of plagioclase and quartz inclusions in the hornblende.

Muscovite

Muscovite is a subordinate constituent of biotite-bearing granite, aplite and pegmatite. It has at times formed by the alteration of biotite while muscovite associated with pegmatite has developed due to late hydrothermal fluids. Muscovite as inclusion and along cleavage planes is also found in plagioclase. Some of the muscovite flakes are bent which suggest deformation of the rocks.

Biotite

Biotite is a common mineral in all granites, though it is absent in few varieties, i.e. aplite, etc. Biotite shows greenish brown to light brown pleochroism whereas in some of the sample shows brownish grey to light green. The change in color of biotite is due to the difference in the ratio of ferrous to ferric iron and titanium (Hall, 1941; Hayama, 1959; Marin, 1971).

The brownish color in biotite is suggested to be due to the presence of ferrous iron (Harker, 1932), Barth (1936) suggested the increase of FeO causes the reddish color in biotite. However, Hall (1941) suggested that the red color in the biotite is due to the excess of MgO in presence of TiO₂.

The alteration of biotite into clear muscovite and bluish green chlorite is quite common. The observed alteration of biotite in later formed bodies may be due to hydrothermal solutions at moderate temperature and pressure (Schwartz, 1958).

In various thin sections the flakes of biotite, and muscovite are bent which also suggest the effect of deformation. Sieved structures are also observed. Inclusion of various minerals such as zircon, apatite, sphere, and magnetite are commonly seen in biotite.

In the thin sections, accessory minerals are as follows:

Zircon, apatite, sphene and magnetite are the mainly accessory minerals are found in the granites of Ladakh Batholith. Besides this chlorite and epidote are the common secondary minerals. It is occur as euhedral zoned crystal with well-developed faces and is characterized by high relief and strong birefringence, straight extinction under polarized light. It is mostly occur as inclusions in biotite and hornblende.

Apatite is commonly embedded in biotite laths and shows well faces in euhedral form. It is distinguished by high relief, straight extinction in prismatic sections and grey interference color. Small grains of apatite show inclusions in biotite.

Sphene is present in acute rhombic cross sections and occurs as euhedral crystal. Calcite, rutile, ilmenite are some of the minor constituents present in studied granitoid rocks.

In the thin sections, secondary minerals are as follows:**Chlorite**

Chlorite is the altered form of biotite in which chlorite is form in as euhedral with well-developed faces. Most of the biotite minerals are fully or partially chloritized in the rocks of the Ladakh granitoids.

Epidote

Epidote is the common secondary mineral mild to strong birefringence, the colors often vary within the same crystal (harlequin colors) with high relief. It is formed largely under conditions of low to medium grade metamorphism in association with Ca-poor plagioclase.

To sum up from the above, the quartz present in different types of rocks is undeformed to deform. The feldspar indicates a high temperature for the formation of these rocks. The twinning and zoning in feldspar of biotite-bearing granite clearly suggest that the rock formed from a melt during its rise in an organic belt where pressure and temperature fluctuations are common. The presence of hornblende indicates a hydrous nature of magma during crystallization.

4.3.3. The Basgo Pluton

The Basgo pluton is made up of biotite granodiorite to biotite granite. The biotite granodiorite and biotite granite having similar characteristics, but the percentage of quartz is more in biotite granodiorite than the biotite granite. Moreover, the biotite granodiorite consist of megacrysts of alkali feldspar whereas the biotite granite consists of plagioclase

feldspar. The brief discussions about petrographic characteristics of biotite granodiorite and biotite granite are as follows:

In this thin section study, the modal estimation of the plutonic rocks likes 35-40% plagioclase and alkali feldspar, 30-35% quartz, 5-10% biotite, 3-5% amphibole. In this study area, the granite rock units are medium to coarse-grained with hypidiomorphic and granular textures. The alkali feldspar is mostly orthoclase but microcline is observed in lesser amounts. Alkali feldspars are present in megacrystal with simple twinning and having an inclusion of biotite and plagioclase crystal. Alkali feldspar megacrysts are euhedral to

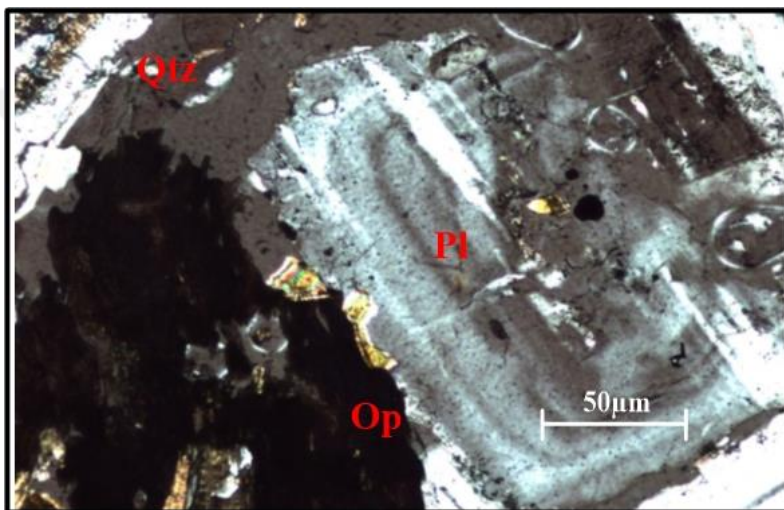


Figure 4.26. shows the growth zones in lath shaped plagioclase crystal. Qtz- Quartz, Pl- Plagioclase and Op- Opaque mineral. (Sample- AM1).

subhedral in shape and poikilitically enclose plagioclase, amphibole, biotite, apatite and opaque minerals. Both variety of alkali feldspar are developed like orthoclase is more superior over microcline. Plagioclase megacrysts are lath-shaped and showing strong oscillatory zoned crystals. The Oscillatory zoning in plagioclase with accentuated by secondary sericite and muscovite and clay minerals (Figure 4.25).

Plagioclase is displaying as euhedral to subhedral crystals with showing lamellar twinning and coarser than K-feldspar. Sometimes plagioclase twinning is partially erased due to alteration. Small grains of biotite, apatite and opaque minerals are enclosed by plagioclase feldspar (Figure 4.25). Some plagioclase crystals occasionally have a sieve texture caused by small inclusions of biotite. Quartz is subhedral to anhedral and sometimes poikilitically encloses earlier crystallized minerals. Quartz is predominantly interstitial and has accommodated small amounts of strain, as revealed by undulose extinction. It occasionally forms vermicular intergrowths with plagioclase and alkali feldspar.

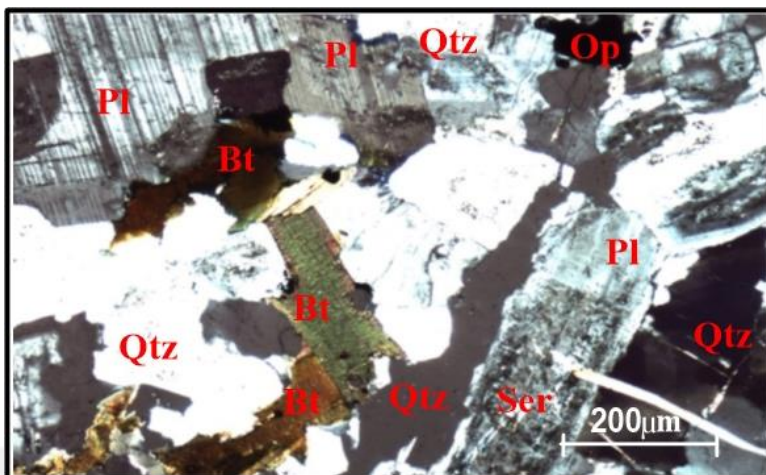


Figure 4.27. shows the lath shaped grains of Plagioclase. Plagioclase grain shows the sericitised central part with cloudy and dusty color. It also shows the large crystals of Biotite and chlorite. It also shows the poikilitic texture in which large crystal of plagioclase having inclusions of quartz, opaque minerals and biotite crystal. It also shows chloritised biotite and sericitised plagioclase. Qtz- Quartz, Bt- Biotite, Pl- Plagioclase, Op- Opaque mineral, Ser- Sericite. (Sample- AM2).

Apatite is present in the form of high relief prismatic form with long euhedral shaped grain and having inclusions in biotite. They are also associated with opaque and biotite minerals (Figure 4.25).

Sphene is present in yellow rhombohedral shaped grains with high relief and birefringences and common around opaque minerals (Figure 4.27).

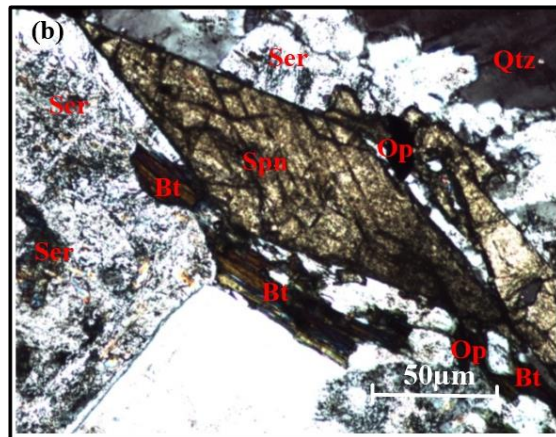
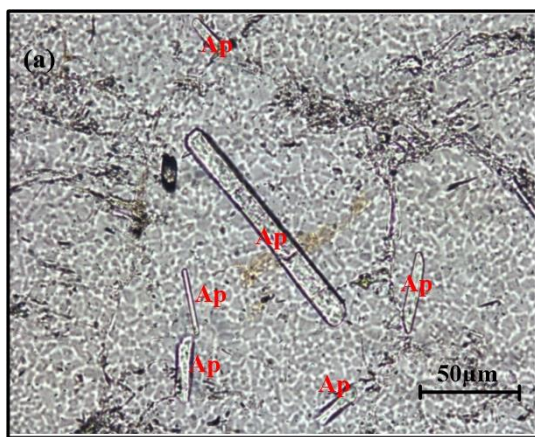


Figure 4.28. (a) shows the lath and tabular shaped grains of Apatite. **(b)** shows the sphene with yellow rhombohedral shaped grains with high relief and birefringences. Ap- Apatite, Bt- Biotite, Op- Opaque mineral, Ser- Sericite, Spn- Sphene, Quartz. (Sample- AM2).

Zircon is present in hexagonal shaped grain associated with opaque minerals and having an intrusion in biotite and hornblende minerals (Figure 4.28).

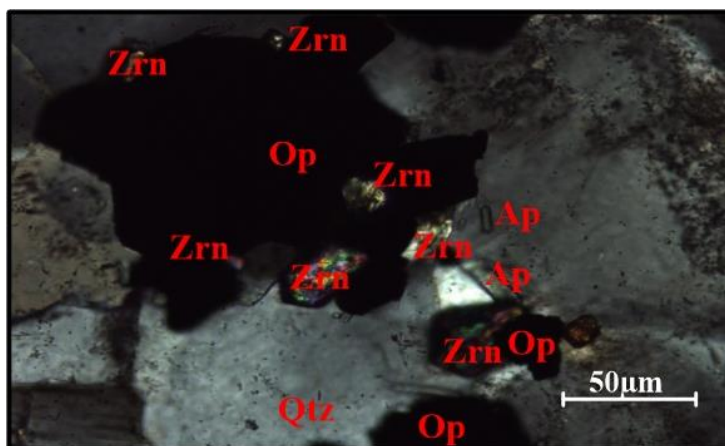


Figure 4.29. shows the association of hexagonal shaped grains of zircon with opaque minerals. Zrn- Zircon, Op- Opaque mineral, Ap- Apatite. (Sample- AM3).

Most of the plagioclase growth zones are accentuated by secondary sericite, muscovite, clay minerals and epidote, and having cloudy or dusty appearance due to partial alteration. The process of alteration is largely sericitization and epidotization (Figure 4.29).

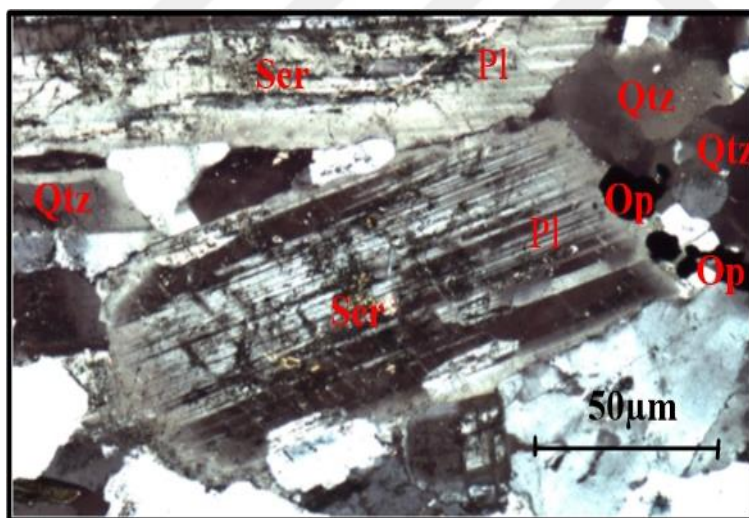


Figure 4.30. shows the lath shaped and polysynthetic twinned grains of plagioclase having sericitized form at the central part. This shows partial alteration and accentuated with accentuated by secondary sericite, muscovite, clay minerals and epidote, and having cloudy or dusty appearance. Qtz- Quartz, Ser- Sericite, Pl- Plagioclase, Op- Opaque mineral. (Sample AM3).

Some of the biotite grains are lath-shaped and having inclusions in amphibole. Some of the fine prismatic zircon is surrounded by apatite and having inclusions in biotite or plagioclase minerals (Figure 4.30). Some of the grains of amphibole or biotite minerals are completely altered by chlorite and subordinate epidote (Figure 4.30).

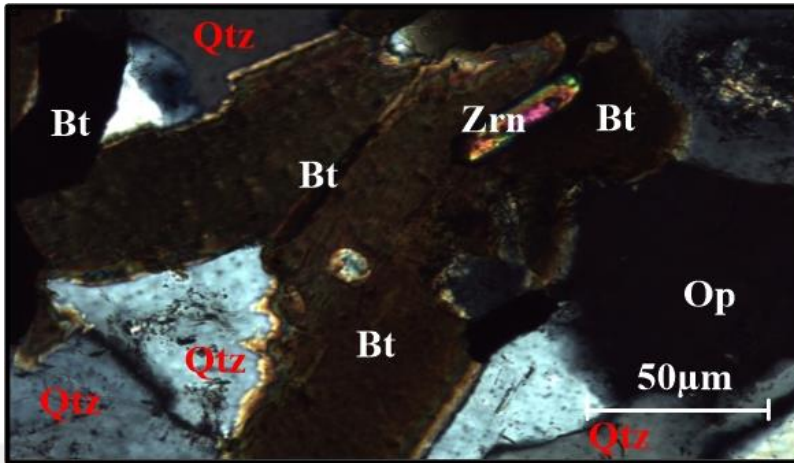


Figure 4.31. Figure shows the lath shaped grains of biotite with inclusions of euhedral (hexagonal) shaped crystal of zircon. Bt- Biotite, Qtz- Quartz, Zrn- Zircon, Op- Opaque mineral. (Sample- AM3).

The predominant minerals are alkali feldspar, plagioclase, quartz, hornblende and biotite. Apatite, zircon, microcline, rutile, monazite, allanite, titanite and opaque minerals are accessory minerals. Secondary minerals are mainly chlorite, sericite, epidote, and muscovite (Figure 4.31).

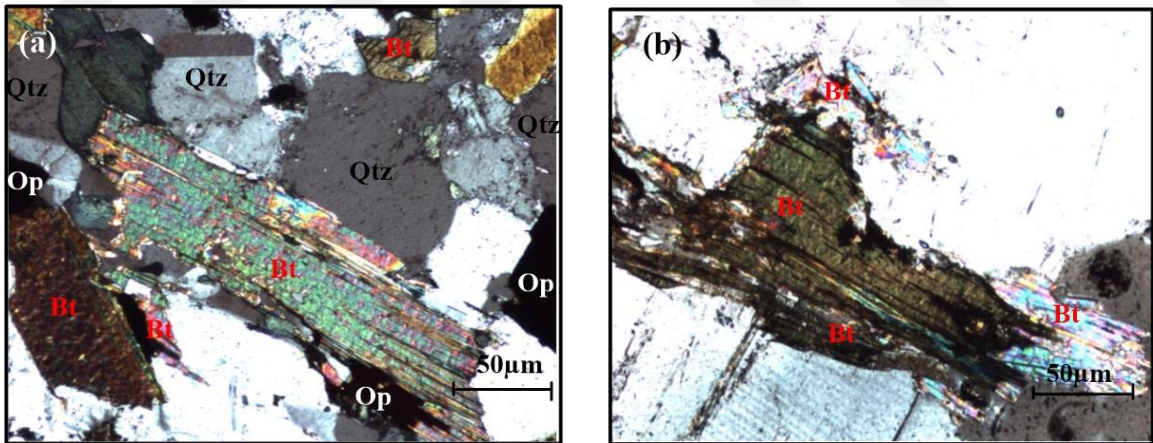


Figure 4.32. (a, b) shows the lath shaped grains of biotite which is partially or fully altered into chlorite grain. It also shows the chloritized biotite and early stage of alteration of biotite at the edges of the mineral. Op- Opaque mineral, Bt- Biotite, Qtz- Quartz. (Sample- AM3).

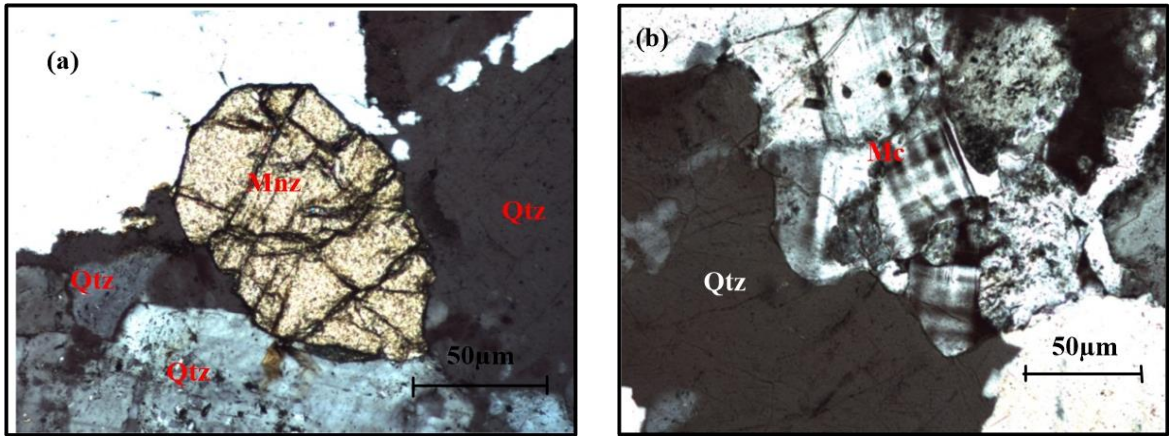


Figure 4.33. (a) shows the euhedral shaped grains of Monazite. (b) shows the Microcline with crosshatch (tartan) twinning. Mnz- Monazite, Qtz- Quartz, Mc- Microcline. (Sample- AM4).

Myrmekites textures are formed on the rims of bigger plagioclase grains including orthoclase in contact with quartz. It shows microphyric and granophyric textures, where alkali feldspar and quartz have co-precipitated (Figure 4.33, 4.34).

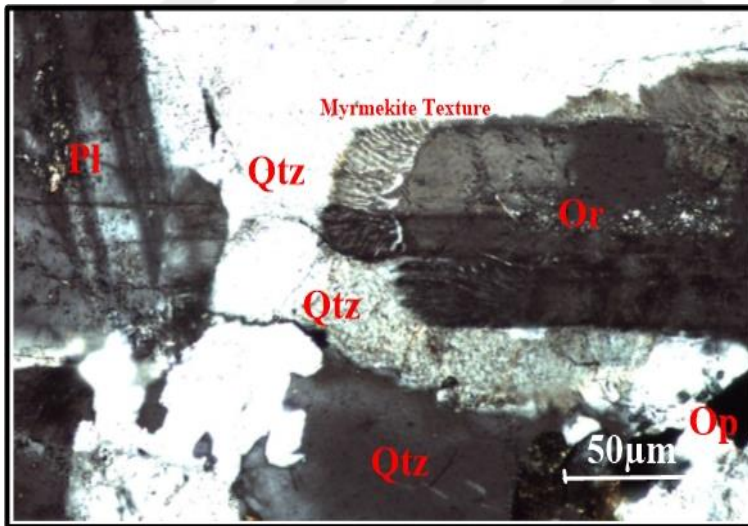


Figure 4.34. shows the myrmekite textures are developed on the rims of bigger grains of orthoclase in contact with quartz. Qtz- Quartz, Op- Opaque mineral, Or- Orthoclase, Pl- Plagioclase. (Sample- AM4).

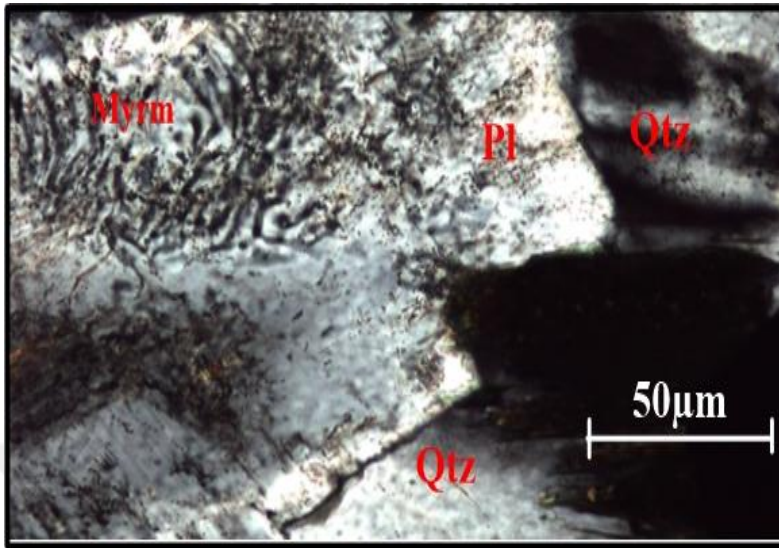


Figure 4.35. shows the myrmekite textures are developed on the rims of bigger grains of plagioclase in contact with quartz. Myrm- Myrmekite texture, Pl- Plagioclase, Qtz- Quartz. (Sample- AM4).

Graphic texture is displayed by some of the samples with making an intergrowth between alkali feldspar and quartz. In most of the felsic rocks showing intergrowth textures like antiperthitic, perthitic alkali feldspar that includes both orthoclase and microcline (Figure 4.35, 4.36).

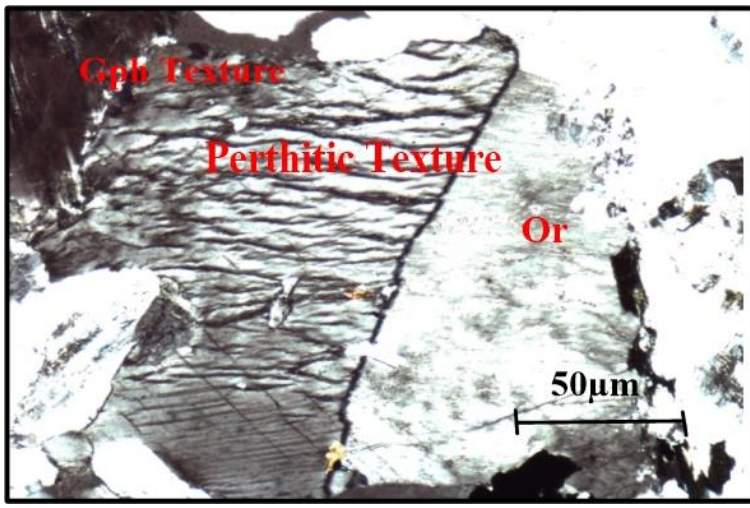


Figure 4.36. shows the perthitic and graphic texture in the orthoclase grain associated with quartz. Gph- Graphic Texture, Or- Orthoclase. (Sample- AM3).

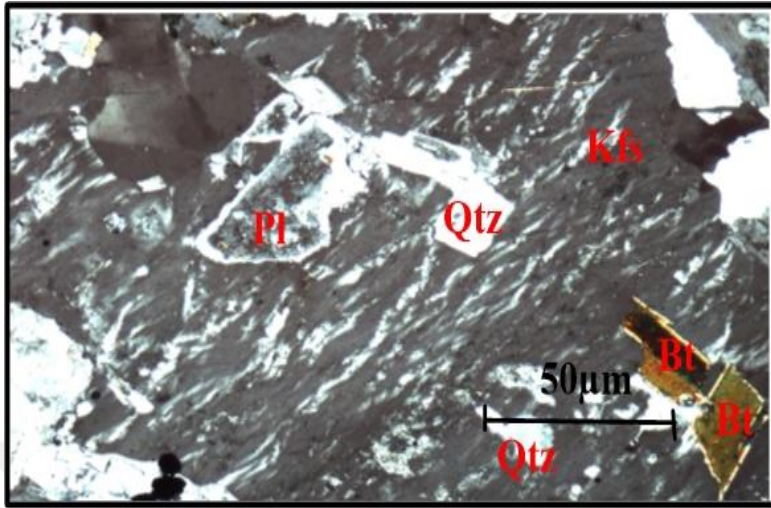


Figure 4.37. shows the perthitic texture in the megacrystal grain of K-feldspar. It also displays inclusions of biotite, plagioclase and quartz grains as a poikilitic texture. Qtz- Quartz, Pl- Plagioclase, Kfs- K-Feldspar, Bt- Biotite. (Sample-AM3).

4.3.4. The Nimmu Pluton

The Nimmu pluton consists of biotite amphibole granodiorite, biotite granodiorite to biotite granite. The biotite amphibole granodiorite, biotite granodiorite and biotite- granite having similar characteristics, but the percentage of quartz is more in biotite granodiorite than the biotite granite. The petrographical features of biotite amphibole granodiorite, biotite granodiorite and biotite granite are as follows.

The modal estimation of the plutonic rocks like 35-45% plagioclase and alkali feldspar, 35-40% quartz, 10-15% biotite, 5-10% amphibole. In this study area, granite samples are medium- to coarse-grained with largely felsic massive porphyritic igneous rock comprising of feldspar, quartz, biotite and minor amount of amphibole and having hypidiomorphic granular texture. The microscopic study shows the presence of zoned and partially altered plagioclase. Plagioclase shows poikilitic textures in which the large crystals of plagioclase containing small crystals of biotite and quartz (Figure 4.37). Hornblende and biotite are enclosed in plagioclase grain or mantled over the plagioclase. Some of other inclusions like epidote, chlorite in plagioclase.

Plagioclase is found as large lath shaped grains with euhedral to subhedral grain shape and is of polysynthetic albite and Carlsbad twinning composition with low extinction angles. Small grains of biotite are enclosed by plagioclase feldspar. The crystals of quartz and biotite are intruded in orthoclase or K-feldspar.

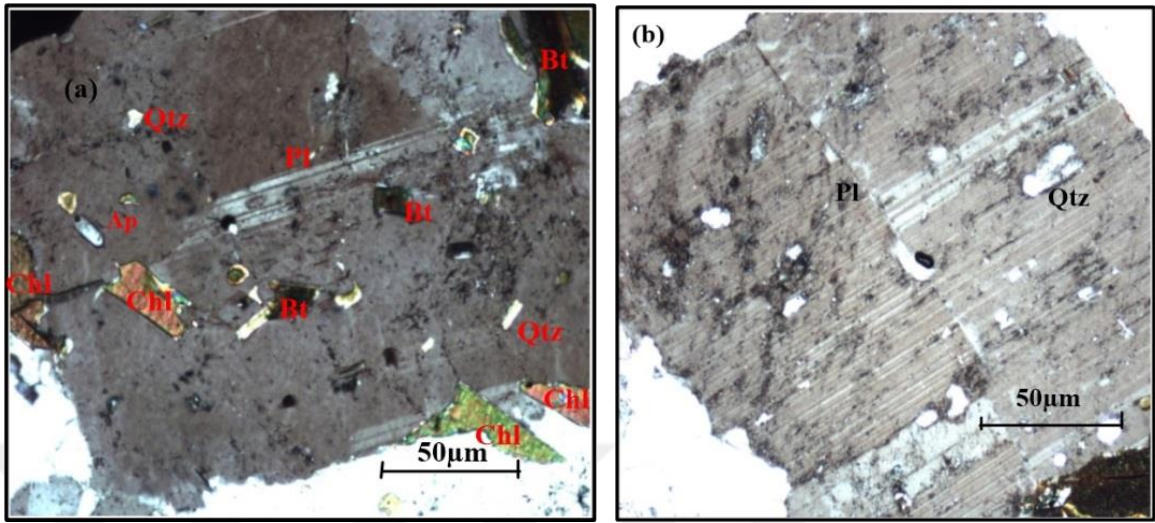


Figure 4.38. (a) shows the inclusions of biotite and apatite grains in plagioclase. (b) shows the inclusion of quartz grain inside plagioclase crystal in plane polarized light. Qtz- Quartz, Bt- Biotite, Pl- Plagioclase, Ap- Apatite. (Sample-AM17).

Alkali feldspar is most commonly found as microperthitic microcline which shows typical tartan twinning. It poikilitically encloses biotite, plagioclase and quartz (Figure 4.38).

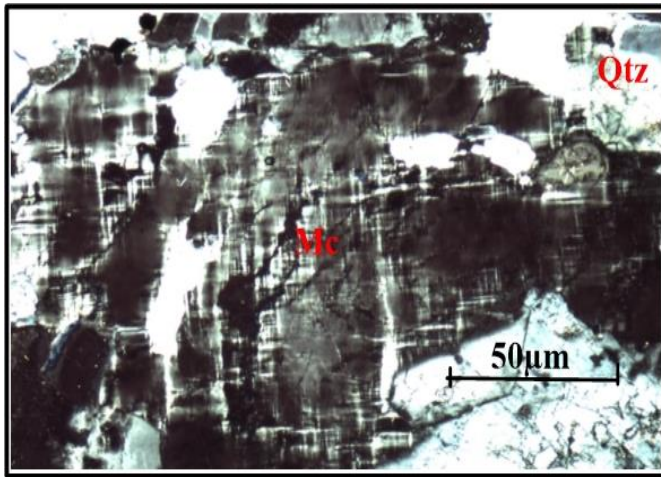


Figure 4.39. shows the microperthitic microcline which shows typical tartan twinning. Mc- Microcline, Qtz- Quartz. (Sample- AM17).

Biotite is large grain lath-shaped and altered form with having immature grains of biotite. Biotite grains are mantled over plagioclase grain.

Sphene occurs as rhombohedral shaped and associated with opaque minerals. Muscovite is present in lath shaped or elongated form (Figure 4.39).

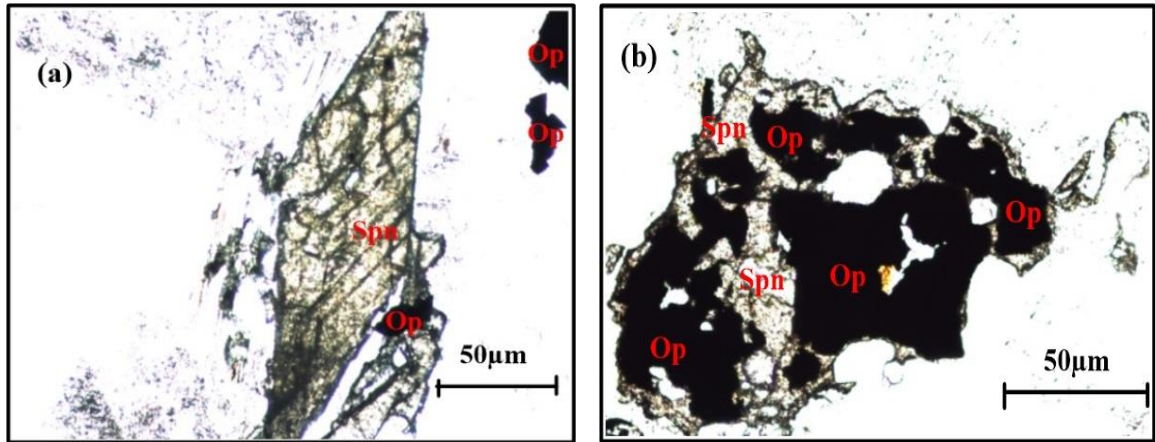


Figure 4.40. (a) shows the rhombohedral shape of sphene grain. (b) shows the crystals of sphene is associated with opaque minerals. Spn- Sphene, Op- Opaque mineral. (Sample- AM18).

Apatites occur as tabular or prismatic form and are intruded in biotite grain. And some of the grains of Apatite are associated with opaque minerals and having inclusions in sericitized plagioclase (Figure 4.40).

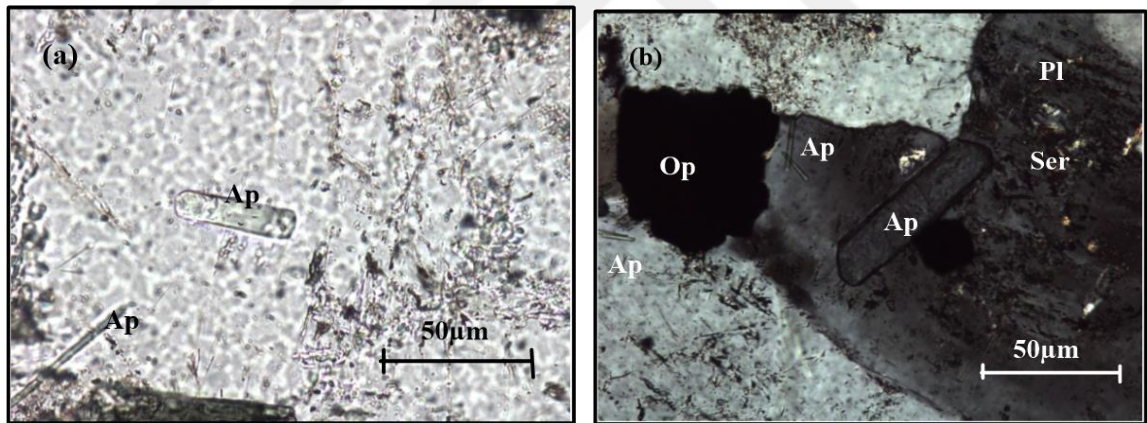


Figure 4.41. (a) shows the tabular or prismatic form of Apatite grain. (b) shows the crystals of Apatite is associated with opaque minerals and having an inclusions in sericitized plagioclase grain. Ap- Apatite, Op- Opaque mineral, Pl- Plagioclase, Ser- Sericite. (Sample- AM19).

Some of the fine prismatic zircon is surrounded by apatite and having inclusions in biotite or plagioclase minerals (Figure 4.2.16(a)). And some of the zircons are associated with opaque mineral (Figure 4.41).

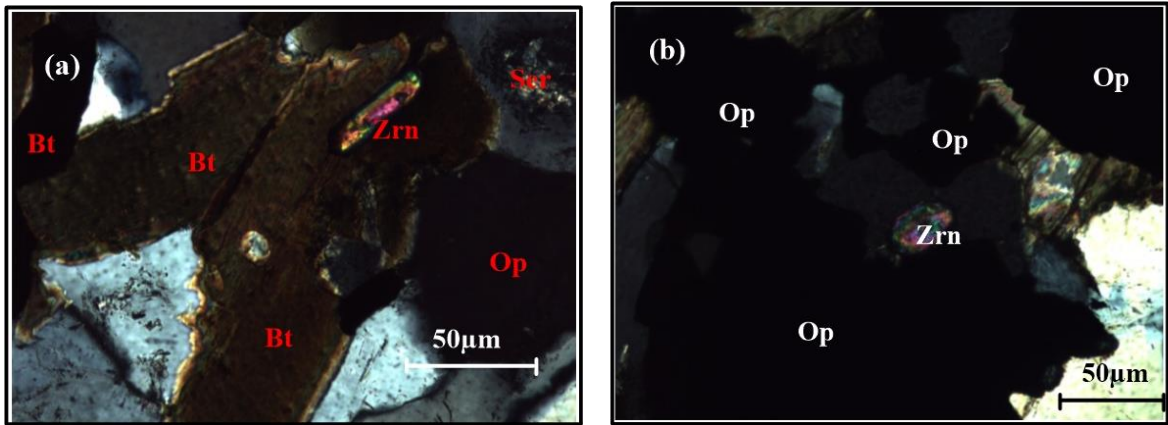


Figure 4.42. (a) shows the inclusions of fine zircon grain in biotite mineral grain. (b) shows the zircon grains are associated with opaque minerals. Bt- Biotite, Zrn- Zircon, Ser- Sericite, Op- Opaque mineral (Sample- AM20).

Mineral get crystallized between the boundaries of another mineral. Melt intrusion inside the recrystallized melt. The accessory minerals are consisting of sphene, apatite, zircon, monazite microcline, titanite. Secondary minerals are mainly chlorite, sericite, epidote, and muscovite.

Melt inclusions and recrystallization of minerals between the sutured boundaries of two quartz grain. It is also present as interlocking grains with sutured boundaries and appears to have crystallized late. Quartz is subhedral to anhedral and also fills the interstices between the early formed minerals. It has sutured boundaries and shows undulose extinction. Quartz displays graphic intergrowths with alkali feldspar and myrmekitic intergrowths with plagioclase feldspar.

The green pleochroism is most likely the conclusion of chloritisation which is shown under plane polarized light. Chlorite is found as alteration products after biotite. Biotite is partially to fully alter. Amphibole is occasionally replaced by biotite (Figure 4.42).

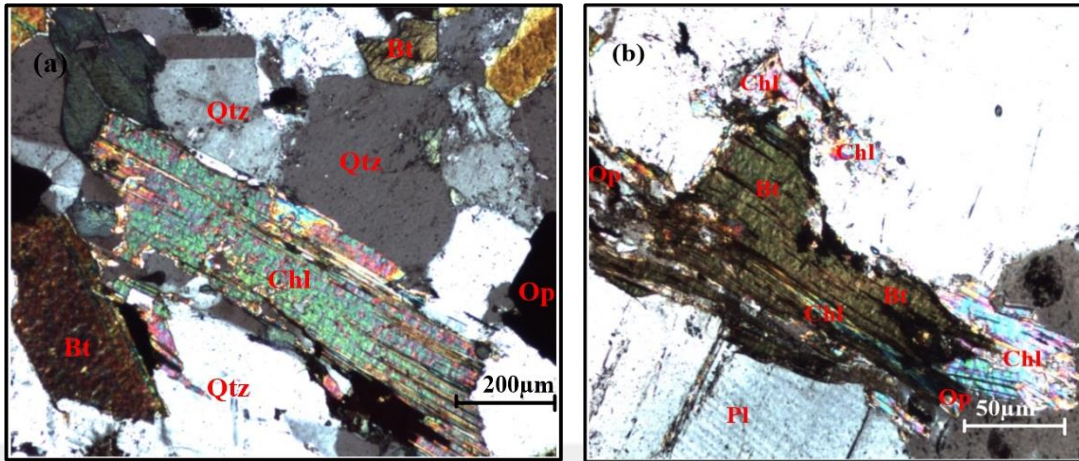


Figure 4.43. (a,b) shows the chloritization, in which biotite crystal altered into chlorite. Bt- Biotite, Qtz- Quartz, Op- Opaque mineral. (Sample- AM19).

Seritization occurs mainly along the zoning planes and around central parts of the feldspar crystals. Perthitic and antiperthitic intergrowth textures are showing in plagioclase crystal. It shows the exsolution of Na- from K-feldspar (Figure 4.43).

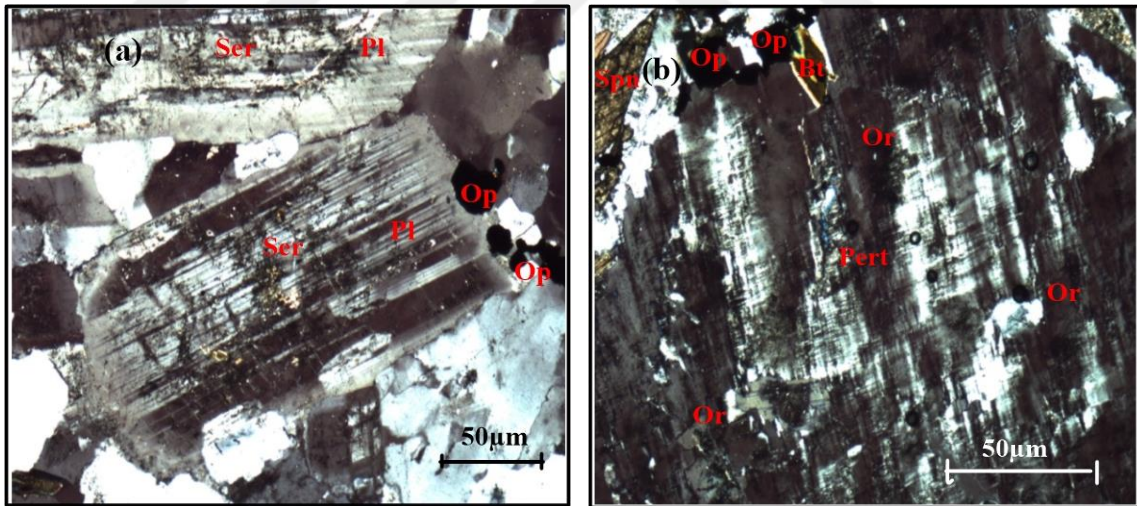


Figure 4.44. (a) shows the sericitization in the central part of plagioclase. (b) shows the perthitic texture in orthoclase. Pl- Plagioclase, Ser- Sericite, Op- Opaque mineral, Or- Orthoclase, Pert- Perthitic Texture, Spn- Sphene, Bt- Biotite. (Sample- AM20).

4.3.5. The Umla Pluton

In this study area, the Umla Pluton consists of granite, quartz granodiorite and biotite granite. The petrographical characteristics of granite, quartz granodiorite and biotite granite are more about similar but as comparison about the concentration of quartz among these then the percentage of quartz is more in quartz granodiorite than granite and biotite granite. In the study of thin section, the modal estimation of plutonic rocks likes 35-38%

plagioclase and alkali feldspar, 35-40% quartz, 10-15% biotite, 5-10% amphibole. The granite samples of this area are medium to coarse grains contain plagioclase, K-feldspar, quartz, biotite and amphibole in varying proportions and having hypidiomorphic with granular texture (Figure 4.44).

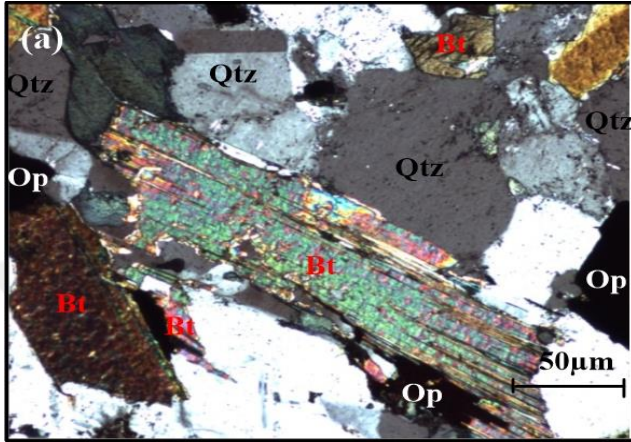


Figure 4.45. shows the crystal of biotite, lath shaped crystal of plagioclase. Some of the places show complete or partial alteration of plagioclase, called as Sericitization. Crystal of biotite is also completely altered to chlorite. Op- Opaque mineral, Qtz- Quartz, Bt- Biotite (AM21)

Accessory minerals comprises of the muscovite, apatite, zircon and opaque phases with chlorites are formed by the alteration of hornblende and biotite with abundant amount of opaque minerals (Figure 4.44).

Plagioclase is generally euhedral to subhedral crystals with showing lamellar twinning and occurs as coarser than K-feldspar. The growth zones or oscillatory zoning is commonly displayed in plagioclase feldspar. Insertions of fine prismatic zircons are displayed in some plagioclase crystals. Poikilitic texture is also occurs due to inclusions of biotite, quartz and apatite crystals in lath shaped grain of plagioclase (Figure 4.45).

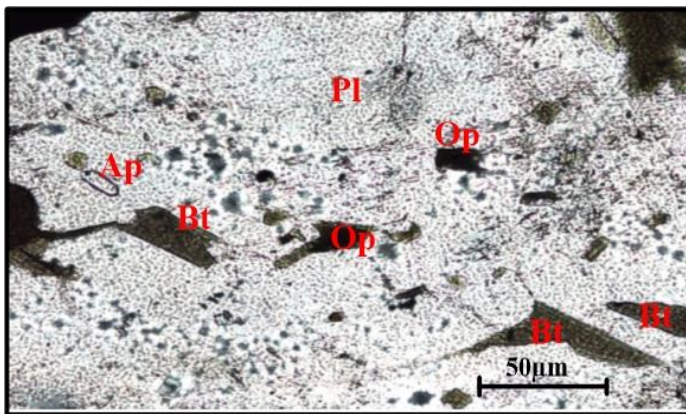


Figure 4.46. Plagioclase crystal shows the poikilitic texture due to presence of euhedral to subhedral inclusions of biotite grain. Prismatic and lath shaped crystal of apatite grain. And in some

of the place they are having an inclusion of opaque mineral in plagioclase grain. Bt- Biotite, Ap- Apatite, Op- Opaque mineral, Pl- Plagioclase. (Sample- AM22).

Undulated edges of amphiboles are showing the improvement of altered chlorite. The percentage of amphibole is less as compare to biotite and amphibole is mostly hornblende and formed as euhedral to subhedral crystals. (Figure 4.46).



Figure 4.47. shows the crushed margin of amphibole with chlorite due to alteration and associated with opaque minerals. Hbl- Hornblende, Bt- Biotite, Op- Opaque mineral, Qtz- Quartz. (Sample- AM22).

Both as brown and green biotite occurs in small amount. And green biotite is due to partial alteration of biotite is chlorite (Figure 4.47). Bending of biotite flakes indicate deformation.

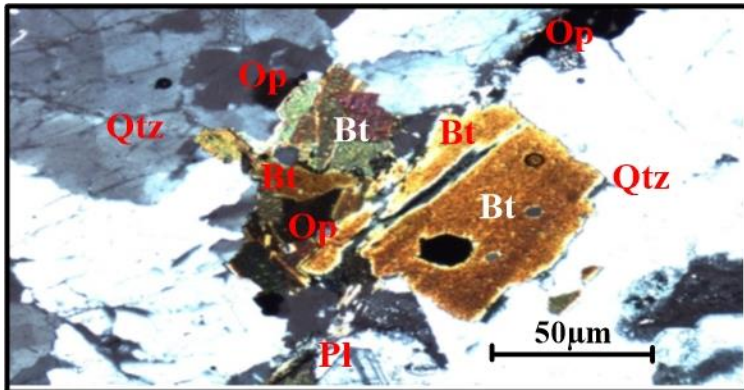


Figure 4.48. shows the biotite crystal with both brown and green color. Bt- Biotite, Qtz- Quartz, Op- Opaque mineral, Pl- Plagioclase. (Sample- AM29).

4.3.6. The Taru Pluton

In this study area, the Taru pluton consists of quartz granodiorite, biotite amphibole monzodiorite, biotite amphibole granodiorite and granite. They all are having similar

petrographic characteristics but sometimes vary according to the percentage of quartz, plagioclase feldspar and alkali feldspar.

In this thin section study, the modal estimation of the plutonic rocks likes 30-35% plagioclase and alkali feldspar, 40-45% quartz, 10-15% biotite, 5-10% amphibole. The granite samples are medium to coarse grain containing different mineral phases from mafic to accessory phases like plagioclase feldspar, alkali feldspar, amphibole, biotite with variable proportion and size.

Plagioclase is occurs in euhedral to subhedral grain shape and having normal twinning, simple twinning and polysynthetic albite twinning. Plagioclase is of albitic composition with low extinction angles (Figure 4.48).

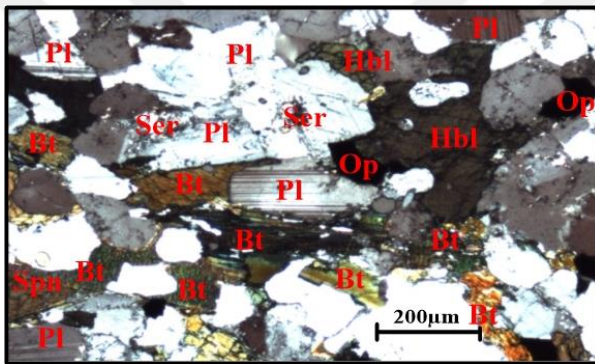


Figure 4.49. shows the biotite crystal with brown with partially or completely altered in to chlorite. Plagioclase shows normal twinning, simple twinning and polysynthetic albite twinning. It also shows the deformation around plagioclase and biotite boundaries. Pl- Plagioclase, Op- Opaque mineral, Bt- Biotite, Hbl- Hornblende, Spn- Sphene, Ser- Sericite. (Sample- AM32).

Plagioclase are mostly sericitised and/or (fully or partially) take the place of calcite. Saussuritisation is also observed in the plagioclase is due to matrix color ranges from greenish greyish to dark greenish greyish and process called as saussuritisation (Figure.4.49).

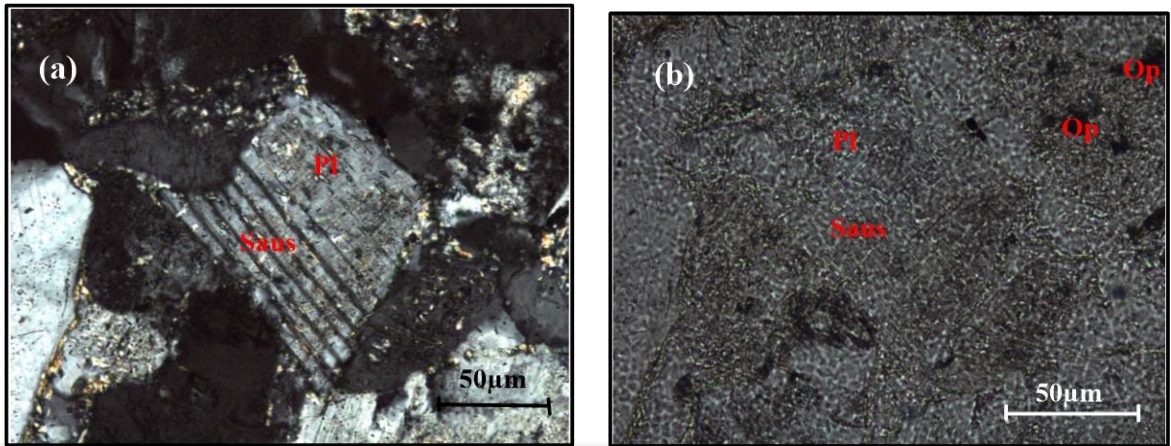


Figure 4.50. (a) Shows the Saussuritisation of plagioclase due to matrix color ranges from grey to dark grey in crossed nicol. (b) Shows the same Saussuritisation of plagioclase in plane polarized light. Saus- Saussuritisation, Pl- Plagioclase, Op- Opaque mineral. (Sample- AM34).

Plagioclase phenocrysts frequently display oscillatory magmatic zoning, if they are not fully sericitised or take the place of calcite. In some of the places plagioclase is occur as zoned altered grain due to sericitic alteration with white mica (Figure 4.50). After plagioclase, sericite occur as a secondary mineral. Alkali feldspar also displays sericitic alteration.

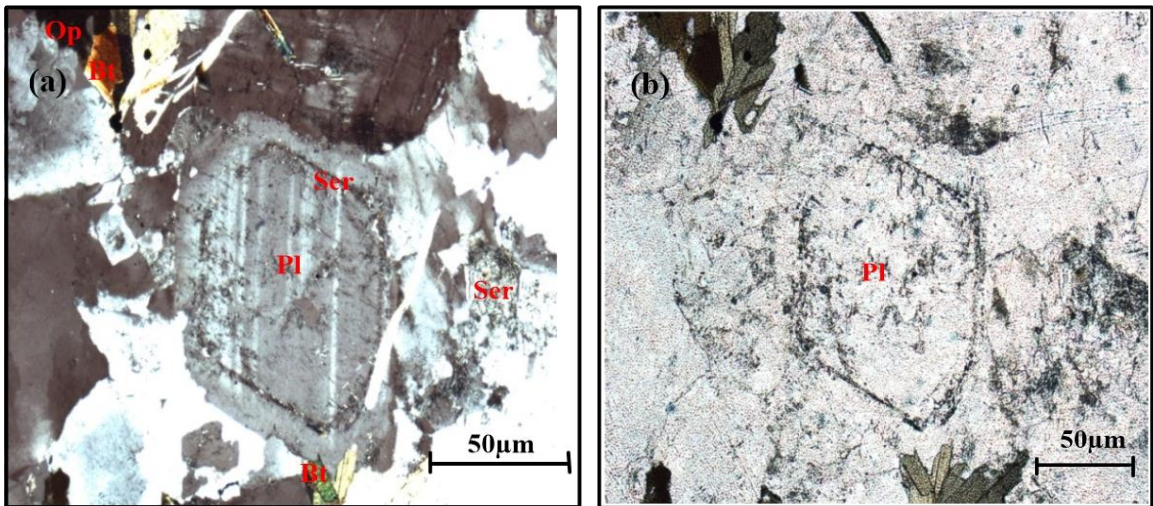


Figure 4.51. (a) Shows the plagioclase grain with zoned altered due to sericitic alteration with white mica in crossed polarized light. (b) shows the same zoned altered grain of plagioclase in plane polarized light. Pl- Plagioclase, Ser- Sericite, Op- Opaque mineral, Bt- Biotite. (Sample- AM33).

As the previous studies over Ladakh Batholith samples, it is concluded that they are mostly deformed. Quartz is in abundant form having anhedral shape and displays undulous extinction and evolution of subgrains. In some of the places there is an inclusion of small

grains of quartz in plagioclase (Figure 4.51). In this thin section study the alkali feldspar is mainly orthoclase but microcline has been also observed. The alkali feldspar is found as tabular and euhedral to subhedral crystals. It poikilitically encloses plagioclase, biotite, titanite and opaque minerals.

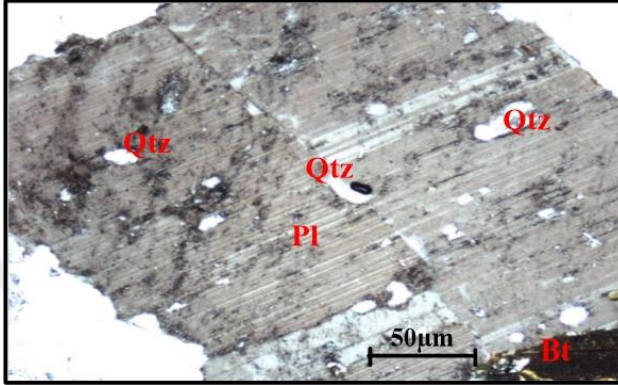


Figure 4.52. shows the inclusion of quartz crystals in plagioclase megacryst. Qtz- Quartz, Pl- Plagioclase, Bt- Biotite. (Sample- AM39).

Biotite and hornblende is found in subhedral to euhedral shape. Alteration phases associated with less abundant clinozoisite and the mafics are epidote (Figure 4.52). In most of the place, the biotite is slightly to moderately replaced by chlorite.

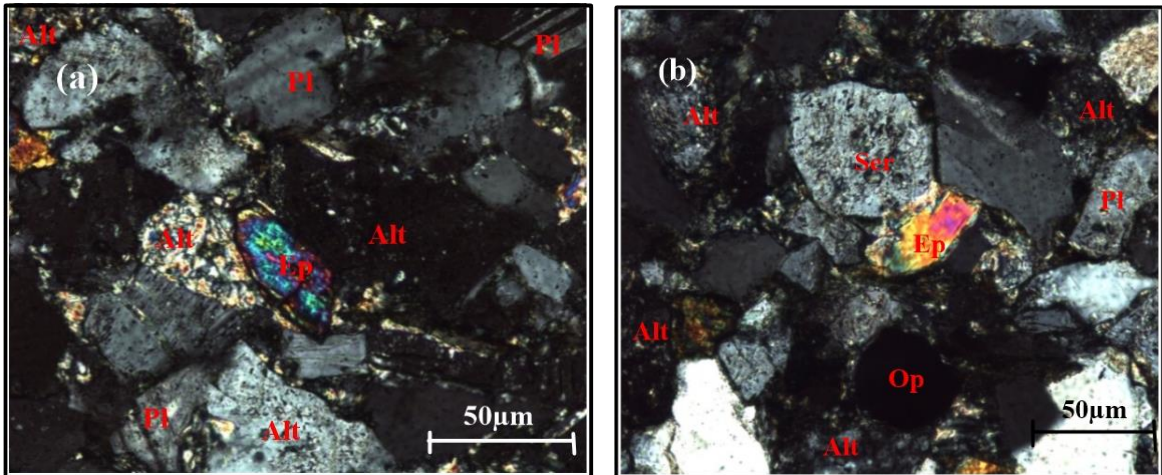


Figure 4.53. (a, b) shows the epidote is associated with opaque minerals. It also shows the alteration mafic phases with epidote. Pl- Plagioclase, Ep- Epidote, Op- Opaque mineral, Alt- Alteration to chlorite and sericite. (Sample- 40).

An improper late level of overgrowth with light green to yellow pleochroism is in variance with the dark colors of the mature biotite. The pleochroic green color of the meshwork is likely the conclusion of chloritisation. Under polar light, colors display the

existence of sericite/muscovite. Matrix colors range in between dark greyish to greenish, where greenish colors are assigned to chloritisation.

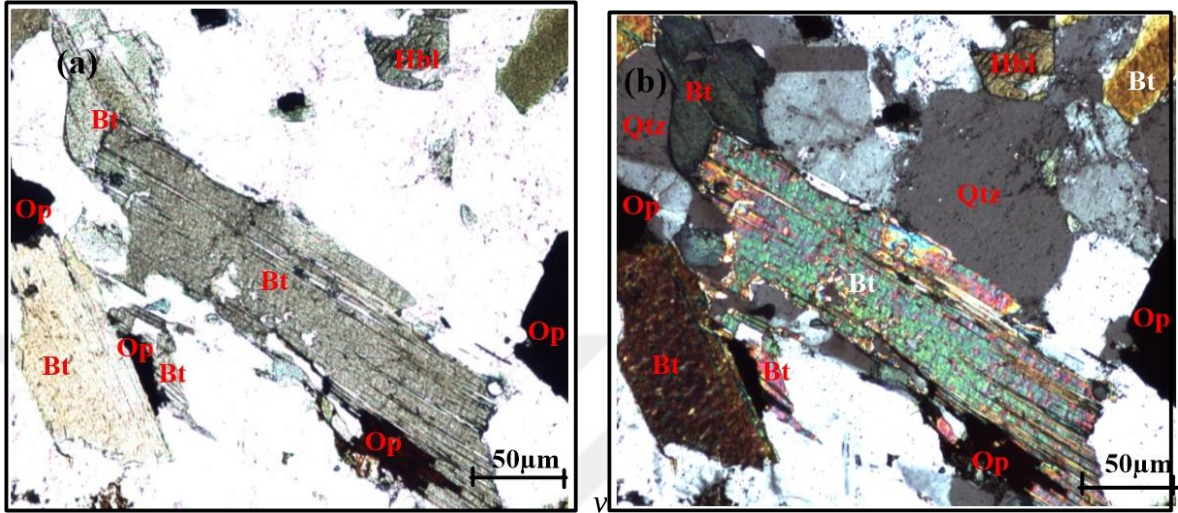


Figure 4.54. (a) shows the complete variation of biotite to chlorite in plane polarized light. (b) displays the green pleochroism of the meshwork is likely the conclusion of chloritisation under polarised light. Op- Opaque mineral, Bt- Biotite, Hbl- Hornblende. (Sample- AM39).

There is a brittle distortion with shattered hornblende and plagioclase crystals, not filled with cracks and distorted biotite crystals. Biotite contains inclusions of accessory minerals such as titanite, apatite, Zircon and opaques. In most of the places, shows the inclusion of zircon grains in biotite and associated with opaque minerals (Figure 4.54).

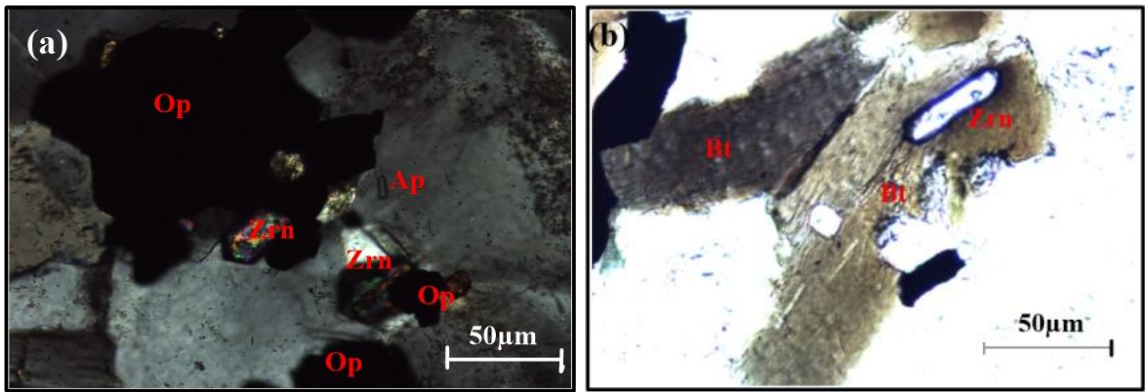


Figure 4.55. (a) shows the zircon grains are associated with opaque minerals. (b) shows the inclusions of zircon crystal in biotite grain. Op- Opaque mineral, Zrn- Zircon, Ap- Apatite, Bt- Biotite. (Sample- AM33).

Amphibole and biotite are found as mafic minerals. Subhedral amphibole encloses inclusions of apatite, titanite and opaques. Biotite has inclusions of zircon, apatite, titanite and opaque minerals. Associated minerals are titanite, opaques, apatite and zircon.

Titanite is found as inclusions enclosed within amphibole, alkali feldspar and biotite or as fine-grained discrete crystals. Apatite is fine-grained and forms elongated prismatic crystals or hexagonal crystals. Opaque minerals are generally magnetites.

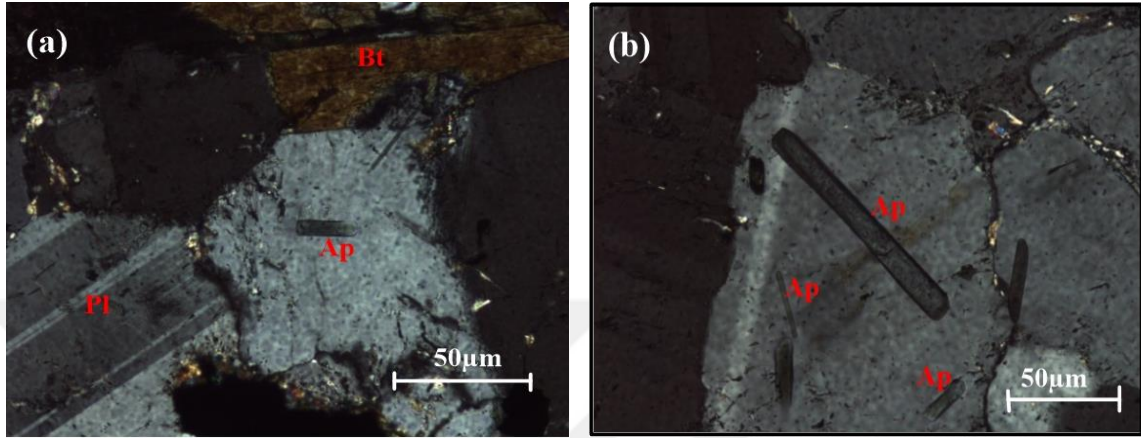


Figure 4.56. (a, b) shows the elongated prismatic crystal or hexagonal crystal of apatite grain. Pl- Plagioclase, Ap- Apatite, Bt- Biotite. (Sample- AM33).

Sphene occurs as a rhombohedral hexagonal large shape grain. In most of the places sphene grains are associated with opaque mineral (Figure 4.56).

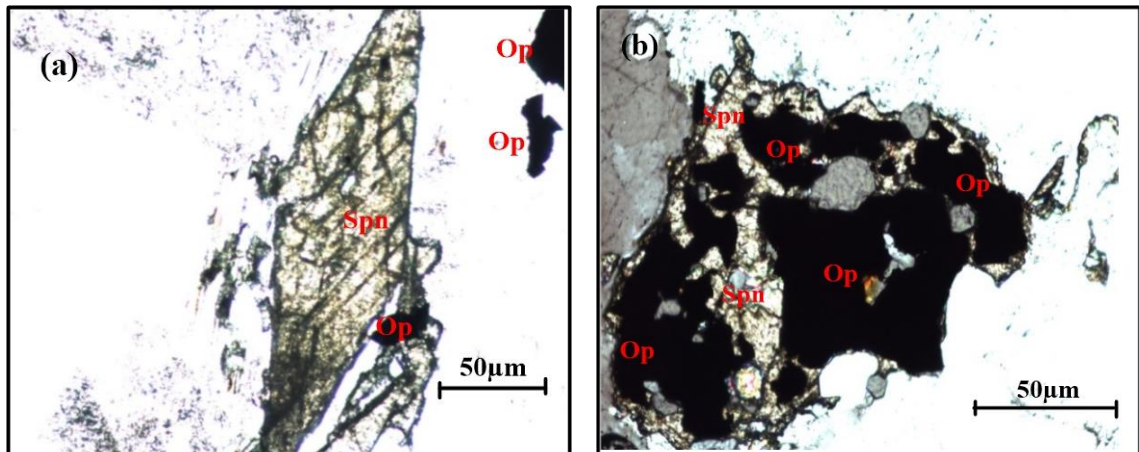


Figure 4.57. (a) shows the rhombohedral hexagonal shape of sphene crystal. (b) shows the sphene is associated with opaque minerals. Spn- Sphene, Op- Opaque mineral. (Sample- AM31).

In the study thin section, Sericite is the most common alteration products in the monzodiorite. Sericitic alteration occurs mainly along the zoning planes and around central parts of the feldspar crystals. It has affected both alkali feldspar and plagioclase feldspar. Chlorite is found as alteration products after biotite. Amphibole is occasionally replaced by biotite.

4.3.7. Enclaves

The enclaves are occurring as fine to medium grained with hypidiomorphic and granular texture. Mafic to hybrid microgranular enclaves are present in medium to coarse grained granites. The dominant phases of minerals are plagioclase feldspar, alkali feldspar and quartz. The mafic phases of minerals are mostly amphibole and biotite in which the percentage of amphibole in these mafic enclaves is much higher than biotite.

Plagioclase occurs as euhedral to subhedral shape and shows zoning. It also has normal twinning, simple twinning and polysynthetic albite twinning. It is commonly altered to sericite and epidote. The alkali feldspar is mostly orthoclase and occasionally sericitised. It shows a microperthitic texture. In most of the places, Quartz is occur as anhedral crystal and shows undulose extinction. It also displays graphic intergrowths with alkali feldspar. Quartz is intergrown with both plagioclase and alkali feldspar. Amphibole take place with euhedral to subhedral and sometimes prismatic in shape.

Biotite occurs as lath shaped with less percentage as compared to amphibole. Under polar microscope the greenish meshwork shows the partially or complete alteration of biotite into chlorite. The associated minerals are apatite, titanite, zircon and opaque minerals. Apatite is occurring as needle shaped prismatic form with euhedral shaped.

Mafic enclave having sharp, crenulate and rounded to elongate structures ranges from 5 to 10 cm in length. Felsic, mafic and mafic-felsic (intermediate) hybridized magmas bounded and blended into felsic host magma represented by microgranular enclaves.

Preferably based on macrostructural criteria that the microgranular enclaves have been differentiated from country-rock xenoliths, surmicaceous (biotite-rich) enclaves, quartz lumps, clots and clumps of mafic minerals. Such as roundness like corner, edge, surface as rounded, sub rounded or angular, shape like spheroidal, ellipsoidal, discoidal etc, contact relationships like sharp, diffuse, crenulated, straight and magmatic rock fabrics that related to igneous lamination, flowage, schlieren etc.

The characteristics of Microgranular enclaves are fine to medium grained, phenocryst-free or phenocryst-bearing, melanocratic to mesocratic, and forming rounded to elliptical shapes with varying in dimensions from few cm to more than one meter.

Microgranular enclaves show equigranular and hypidiomorphic textures occur as fine to medium grained in which hornblende, biotite, and euhedral laths of zoned plagioclase are frequently set interstitial to poikilitic K-feldspar and quartz. Porphyritic subhedral to anhedral mafic (hornblende-biotite) and felsic (K-feldspar-plagioclase-quartz) phenocrysts types bear as a microgranular enclaves.

4.3.8. Dykes

The Ladakh Batholith which is a cropcut of the Trans-Himalayan batholith stretched about 2500 km throughout the length of the south edge of the Eurasian continent. The

dykes are intruded within Ladakh Batholith at elevated angles, usually close to vertical and ranges approximately about 10 to 50 km west of Leh (NW India).

The crust of the intruded dykes within Ladakh Batholith is disintegrated to a dark brown to black colour contrary with the intensely brownish to orange color, so that it facilitates for the identification of dykes from a long distance. The aphanitic to fine-grained, hypidiomorphic and granular texture that presented in the dykes. Mostly the samples consist of plagioclase with small hornblende, quartz and biotite. Plagioclase is euhedral to subhedral and shows zoning.

Plagioclase phenocrysts are mostly sericitised and/or (fully or partially) take the place of calcite. It is commonly changed to sericite, carbonate and epidote. Quartz is anhedral and displays undulose extinction. It displays graphic intergrowths with alkali feldspar. Alkali feldspar is most commonly found as microperthitic microcline which shows typical tartan twinning but orthoclase is also present. The accessory minerals are biotite, apatite, titanite and opaque minerals.

The presence of greenish color are assigned to chloritisation and saussuritisation, where matrix colours in between dark greyish to greenish. Remnants of amphibole or biotite, which is predominantly restored by chlorite, calcite and subordinate epidote and clinozoisite in the dykes. Mostly chlorite, less calcite, sericite, epidote, rarely clinozoisite, allanite are stages of secondary mineral.

4.3.9. Summary

The petrographical characteristics of the thin section around the studied area of Basgo, Nimmu, Umla and Taru pluton have been summarised in Table 4.4.

Table 4.4. shows the Summarized petrographical characteristics of the intrusive rocks from the Ladakh Batholith region around Trans-Himalaya.

PLUTON	BASGO	NIMMU	UMLA	TARU
ROCK UNIT	biotite granodiorite to biotite granite	biotite amphibole granodiorite, biotite granodiorite to biotite granite	gabbro granite, quartz granodiorite and biotite granite	quartz granodiorite, biotite amphibole monzodiorite, biotite granodiorite, granite
TEXTURE	hypidiomorphic and granular texture, poikilitic	hypidiomorphic, hypidiomorphic porphyritic, poikilitic	hypidiomorphic and granular texture, poikilitic	hypidiomorphic and granular texture, poikilitic

GRAIN SIZE	medium to coarse	medium to coarse	medium to coarse	medium to coarse
MAFIC PHASE	amphibole, biotite	amphibole, biotite	amphibole, biotite	amphibole, biotite
ACCESSORY PHASE	titanite, opaques, apatite, zircon, allanite, sphene, monazite	titanite, opaques, apatite, zircon	titanite, opaques, apatite, zircon, allanite	titanite, opaques, apatite, zircon, monazite, sphene
QUARTZ and FELDSPAR TEXTURE	graphic, myrmekitic, perthitic or antiperthitic	graphic, myrmekitic, perthitic or antiperthitic	microperthite, zoning, myrmekite	graphic, myrmekitic, perthitic or antiperthitic
ALTERATION	sericite, chlorite, epidote	sericite, chlorite	sericite, chlorite	sericite, chlorite

4.4. Mineral Geochemistry

Introduction

In this mineral geochemistry chapter, interprets the electron microprobe analyses of the mineral phases (plagioclase, alkali feldspar, amphibole, biotite and Ti-Fe oxides) from the Ladakh Batholith around Leh region which is a part of large Trans-Himalayan belt. The analyses were undertaken to assess how the whole-rock major element variations were reflected in individual minerals and also to investigate conditions of crystallisation. A total of 712 point analyses were performed on 12 representative samples from the Basgo, Nimmu, Umla and Taru intrusive rocks by using a CAMECA SX-FIVE electron microprobe at the Indian Institute of Technology Bombay, India. The full electron microprobe data set is listed in Appendix.

This chapter is presented in two main Sections:

4.3.1. Classification of mineral phases: This Section classifies the mineral phases using the International Mineralogical Association (IMA) methodologies.

4.3.2. Geothermo-barometry and oxygen fugacity: This Section presents the determination of crystallisation temperatures, pressures and oxygen fugacities and hence provides vital information about the emplacement conditions of the granitic magmas.

4.4.1. Classification of mineral phases

4.4.1.1. Feldspars

12 representative samples are collected from the Basgo, Nimmu, Umla and Taru intrusive rocks were chosen for electron microprobe analysis (Table 4.5). A total of 228 feldspar crystals were analysed. Feldspars (plagioclase and alkali feldspar) are, in general, the most abundant mineral phases of the Ladakh granulites. All of selected samples have fresh feldspars and alteration effects are rare. Optically defined plagioclase crystals in each sample were analysed for compositional zoning and construction of the zoning profiles. Representative analyses of feldspars are plotted in Or-Ab-An diagram (Figure 4.57).

According to this data almost all of plagioclases are rich in orthoclase component and have composition between An_{55} to An_{90} in granulites and An_{70} to An_{79} in monzodiorite. K-feldspar crystals are poor in anorthite component in granulites (Or_{88} - Or_{92}), except in the monzodiorite sample. The microprobe data show oscillatory and discontinuous zoning in granulites and normal and oscillatory zoning in the mafic rock. Plagioclase crystal of the Ladakh granulites are generally zoned, analyses of at least two points (one near the margin and the other near the core) were performed on these zoned crystals. The mole fractions of the feldspar end-members (albite, orthoclase, anorthite) were calculated using the Na, K and Ca contents of feldspar (in atoms per formula unit). The data were then plotted on albite-orthoclase-anorthite ternary classification diagrams (Figure 4.57).

Table 4.5. Table showing the studied intrusive rocks of Ladakh Batholith around Leh area of Trans-Himalaya belt from which representative samples were chosen for electron microprobe analyses.

Intrusive Rocks	Rock Type
Basgo	Granite Diorite
Nimmu	Granite Granodiorite
Umla	Granite Granodiorite
Taru	Granite Granodiorite Monzodiorite

4.4.1.1(A). Chemical variations

The Basgo intrusive rocks from Ladakh Batholith comprises of diorite and granite. Figure 4.57(a,b) shows that the plagioclases from the diorite are mainly andesine and oligoclase, the exception being an oligoclase from three diorite samples. The main compositional range of plagioclase is restricted in the diorite (An_{55-80}). Potassium feldspar

in the diorite has compositions of (Or₈₉₋₉₇). Figure 4.57(b) shows that the plagioclases from the granite are widely spreaded in oligoclase and less spreaded in andesine upto albite. The plagioclase in the basgo granite samples are ranges (An₆₀₋₉₈). The Alkali feldspar showing the large compositional range as compared with other intrusive rocks from Nimmu, Umla nad Taru intrusive rocks, possibly because of exsolved lamellae of perthite. Potassium feldspar in the granite samples has composition of (Or₈₂₋₉₈).

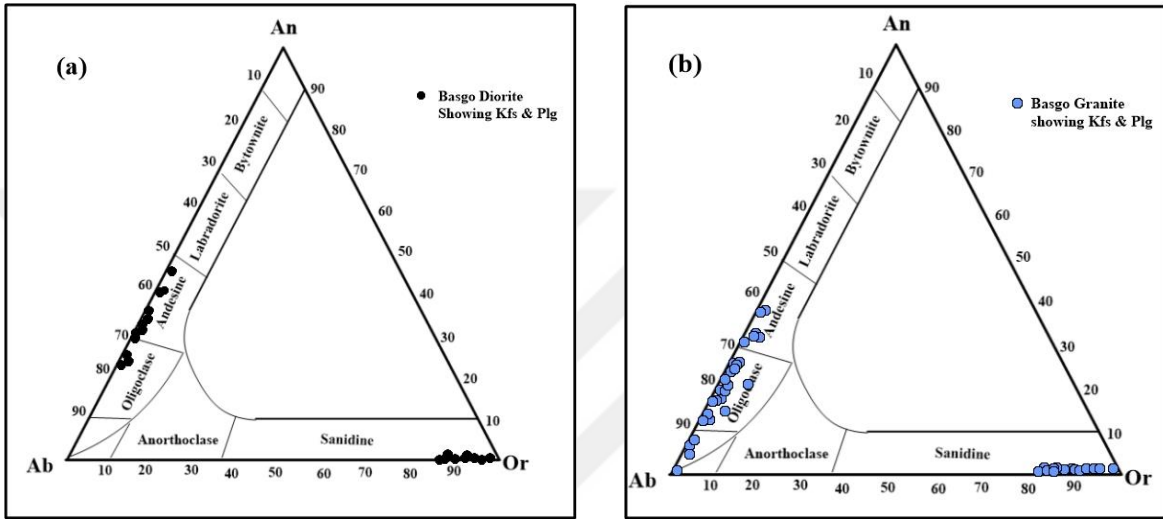


Figure 4.58. (a,b) showing the compositional values of feldspar in the Basgo intrusive rocks of diorite and granite rock type in the plots of Orthoclase, Albite and Anorthite ternary.

The Nimmu intrusive rocks from Ladakh Batholith comprises of granite and granodiorite. Figure 4.58(a,b) shows that the plagioclases from the Nimmu granite are mainly oligoclase. The main compositional range of plagioclase is restricted in the Nimmu granite (An₈₅₋₉₈). And small group of samples are falling in the field of albite. Potassium feldspar in the Nimmu granite has compositions of (Or₈₅₋₉₇). Figure 4.58(b) shows that the plagioclases from the Nimmu granodiorite are widely spreaded in oligoclase and the exceptionally only one granodiorite sample that falling in the field of andesine. The plagioclase in the Nimmu granodiorite samples are ranges (An₆₉₋₇₉). Potassium feldspar in the Nimmu granodiorite samples has composition of (Or₈₉₋₉₉), showing similar plots to that of granite samples.

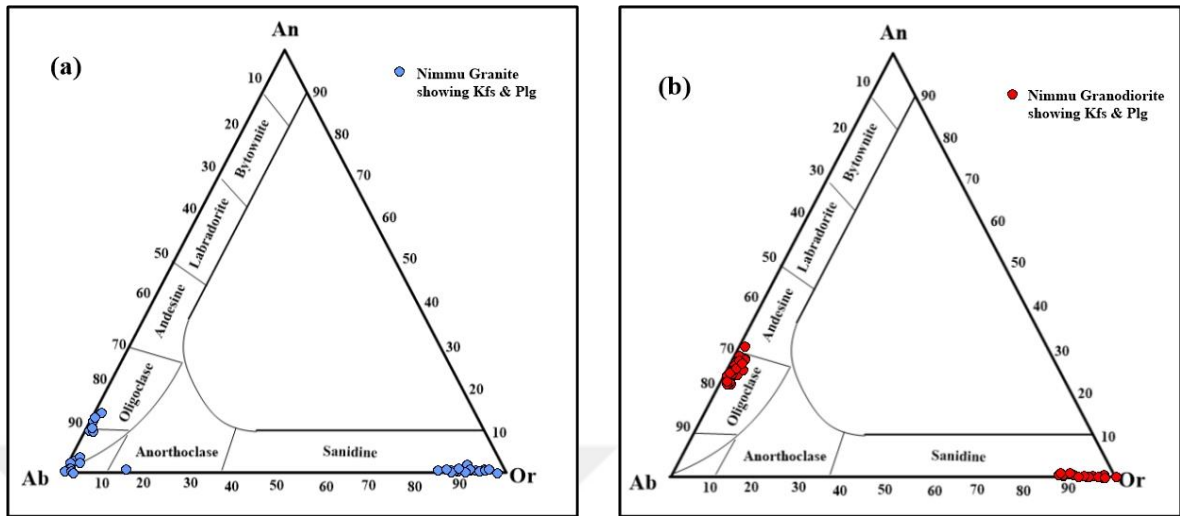
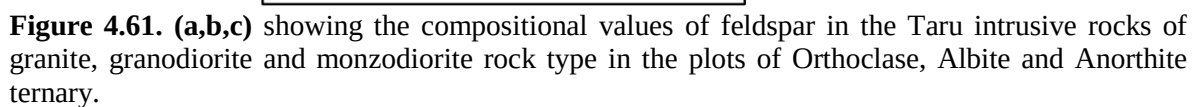
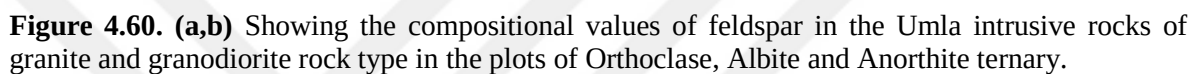


Figure 4.59. (a,b) showing the compositional values of feldspar in the Nimmu intrusive rocks of granite and granodiorite rock type in the plots of Orthoclase, Albite and Anorthite ternary.

The Umla intrusive rocks from Ladakh Batholith comprises of granite and granodiorite. Figure 4.59(a,b) shows that the plagioclases from the Umla granite are mainly oligoclase and spreaded with small group of samples are falling in the field of albite. The main compositional range of plagioclase is restricted in the Umla granite (An_{80-99}). Potassium feldspar in the Umla granite has compositions of (Or_{89-99}). Figure 4.59(b) shows that the plagioclases from the Umla granodiorite are widely spreaded in oligoclase and the exceptionally only one granodiorite sample that touching the field of andesine. The plagioclase in the Umla granodiorite samples are ranges (An_{70-83}). Potassium feldspar in the Umla granodiorite samples has composition of (Or_{89-99}), which is having similar to that of granite samples.

The Taru intrusive rocks from Ladakh Batholith comprises of granite, granodiorite and Monzodiorite. Figure 4.60(a) shows that the plagioclases from the Taru granite are mainly falling in the field of oligoclase. The main compositional range of plagioclase is restricted in the Taru granite (An_{75-85}). Potassium feldspar in the Taru granite has compositions of (Or_{89-99}). Figure 4.60(b) shows that the plagioclases from the Taru granodiorite are widely spreaded in oligoclase and the exceptionally only one granodiorite sample that touching the field of andesine. The plagioclase in the Taru granodiorite samples are ranges (An_{70-78}). Potassium feldspar in the Taru granodiorite samples has composition of (Or_{95-98}). Figure 4.60(c) shows that the plagioclases from the Taru monzodiorite are widely spreaded in oligoclase. The plagioclase in the Taru monzodiorite samples are ranges (An_{70-78}), which is similar to that of granodiorite. In the Taru monzodiorite, potassium feldspar showing no samples at the ternary plot.



In Figure 4.61, the anorthite compositions of plagioclases are plotted against the SiO_2 wt.% contents of the host rocks. In Figure 4.61, the anorthite contents generally decrease with increasing silica. For comparison a linear regression line has been plotted through all plagioclase data for the intrusive rocks. The anorthite contents of plagioclase crystals decreases from the Basgo Diorite to Basgo Granite intrusive rocks with increase in the content of silica, forming linear trends, whereas those from the Nimmu, Umla and Taru granite, granodiorite intrusive rock shows a steep decrease with silica, also forming a linear trends. The exceptional case of Taru Monzodiorite shows a slightly increase of Anorthite content with increase of silica. In theory, if they had been crystallized in equilibrium with the magma, their anorthite contents would have been decreased progressively with increasing silica, forming a linear or sublinear trend with a negative gradient and without substantial scatter. The negative linear trends shown by the Basgo, Nimmu, Umla and Taru intrusive rocks indicate that most of the plagioclase crystals in these plutonic rocks are in equilibrium with magma/magmas.

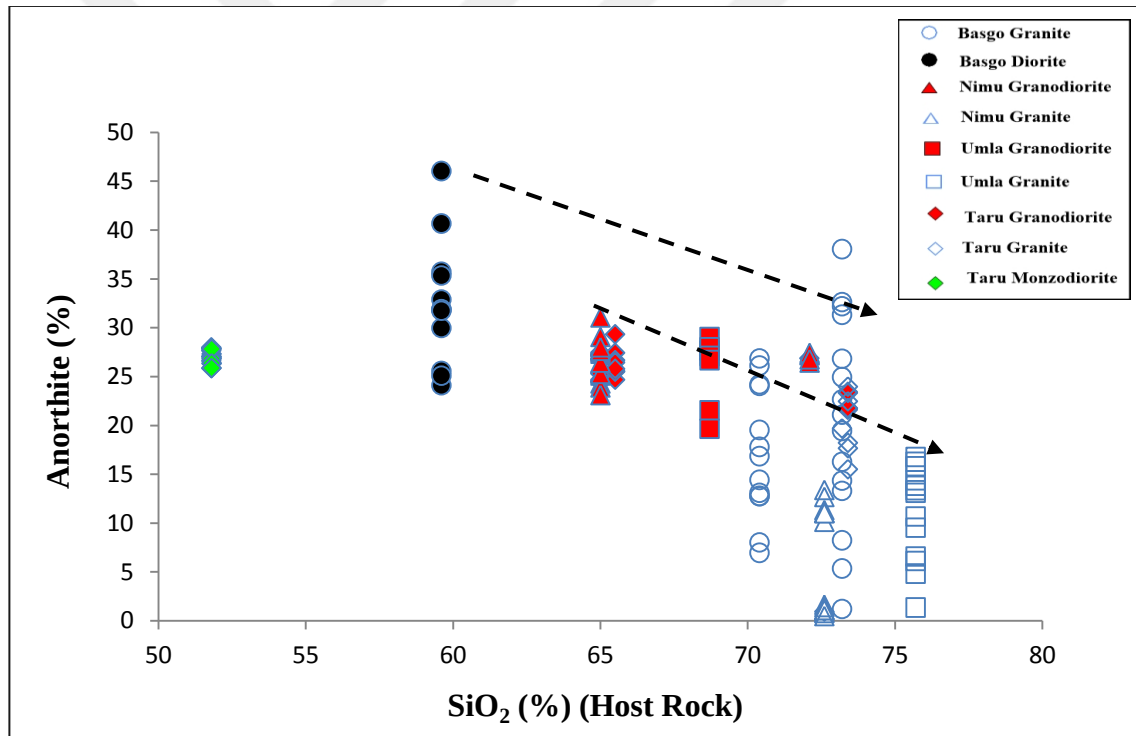


Figure 4.62. showing the variation in plagioclase An content (mol.%) with SiO_2 wt. % content of their host rock.

In Figure 4.62, the anorthite compositions of plagioclases are plotted against the intrusive rock type of study area of Leh, Ladakh Batholith around Trans-Himalayan belt. The graph shows the increase of Anorthite mol% from basgo granite to diorite reaches upto 45 mol%. From Figure 4.62, shows the continuous decrease pattern in granite content of Basgo, Nimmu, Umla and Taru intrusive rocks, whereas the granodiorite shows the increase pattern of Nimmu, Umla and Taru intrusive rock. The Taru monzodiorite and

granodiorites are showing near about same concentration and pattern in the graph. It is noticed from the graph that there is not much difference in the concentration of Nimmu, Umla and Taru granodioritic contents.

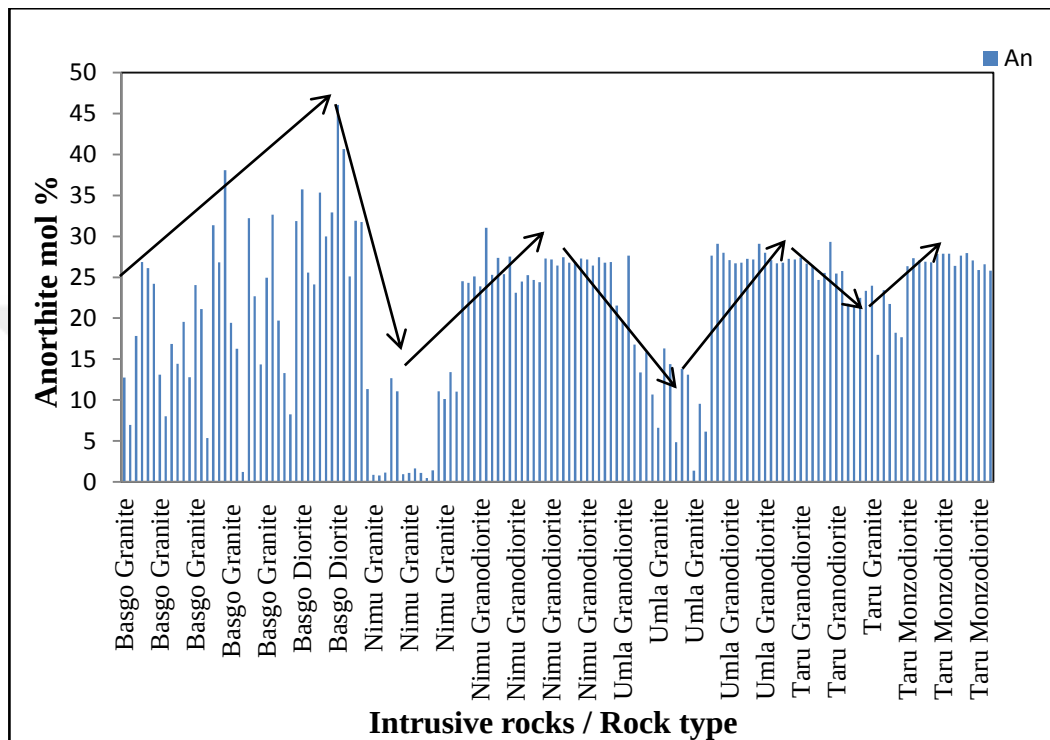


Figure 4.63. Diagram shows plagioclase compositional ranges from the Leh, Ladakh Batholith from Trans-Himalaya belt. Sample names along with rock type are listed on the x-axis; Anorthite mol % of Intrusive rock are plotted on y-axis.

4.4.1.2. Amphiboles

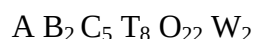
4.4.1.2(A). Calculations of amphibole end-members

Amphiboles are a highly complex group of minerals, because of the wide variety of cation sites available. Their compositional space is defined by A, B, C and T site occupancies. These sites are subdivided into 13 tetrahedral domains which comprise the amphibole end-members (Currie, 1991) (Table 4.6).

Table 4.6. Table displaying amphibole end-members used in the calculation scheme of Currie (1991).

Tremolite	Ferro- actinolite	Arfvedsonite	magnesio- arfvedsonite
(A)(B) (C) (T) (Ca₂) (Mg₅) (Si₈)	Ferro-anthophyllite	(A) (B) (C) (T) (Na) (Na₂) (Fe³⁺ Fe²⁺) (Si₈)	eckermannite
	tirodite		ferro- eckermannite
	dannemorite		kozulite
Winchite	Ferro-alumino	Edenite	magnesio-edenite
(CaNa) (Mg₄Al) (Si₈)	Ferro-ferri	(Na) (Ca₂) (Mg₅) (Si₈)	ferro-edenite
	magnesio-ferri		
Riebeckite	Magnesio-riebeckite	Kataphorite (Na) (CaNa) (Mg₄Al) (Si₇Al)	magnesio- alumino
(Na₂)(Fe³⁺₂Fe³⁺)(Si₈)	Ferro-glaucophane		ferro-alumino
	glaucophane		ferro-ferri
	holmquistite		magnesio-ferri
Hornblende	Ferro-alumino	Nyboite	magnesio- alumino
		(Na) (Na₂) (Mg₃Al₂) (Si₇Al)	ferro-alumino
	(Ca₂) (Mg₄Al) (Si₂Al)		ferro-ferri
	magnesio-ferri		magnesio-ferri
Barroisite	magnesio-alumino	Pargasite	ferro-pargasite
(CaNa) (Mg₃Al₂) (Si₇Al)	ferro-alumino	(Na) (Ca₂) (Mg₄Al) {Si₆Al₂}	hastingsite
	ferro-ferri		
	magnesio-ferri		magnesio- hastingsite
Tschermakite	magnesio-alumino	Taramite	magnesio- alumino
(Ca₂)(Mg₃Al₂)(Si₆Al₂)	ferro-alumino	(Na) (Na₂) (Mg₃Al₂) (Si₆Al₂)	ferro-alumino
	ferro-ferri		ferro-ferri
	magnesio-ferri		magnesio-ferri
Richterite (Na) (CaNa) (Mg₅) (Si₈)	ferro-richterite		

The nomenclature of amphiboles has been established by the Subcommittee on Amphiboles of International Mineralogical Association (IMA) (Leake, 1978; Rock and Leake, 1984; Leake et al., 1997). The general chemical formula of the amphiboles can be written as:



Where A = Na, K, Ca, Li

B = Na, Li, Ca, Mn^{2+} , Al, Fe^{3+} , Mn^{3+} , Ti^{4+} , Li

T = Si, Al, Ti^{4+}

W = (OH), F, Cl, O^{2-}

Minor elements such as Zn, Ni^{2+} , Co^{2+} , V^{3+} , Sc, Cr^{3+} and Zr are also observed as C cations

Mole fractions of amphibole end-members can be calculated by using analyses of amphiboles as source data and by site assignments (A, B, C and T). However this requires complex calculations because of the wide variety of cation sites and valencies of elements. Another problem is to reduce the results of electron microprobe analysis lacking H_2O and Fe_2O_3 determinations.

To recalculate chemical analysis of amphiboles on the basis of their structural formulae and also classify them according to the M A guidelines, Richard and Clarke (1990) and Currie (1991) developed computer programs. A CLASAMPH program written by Currie (1991) starts from an amphibole composition and attains site assignments of end-members followed by calculation of mole fractions based on these assignments. He argues that the calculation is relatively insensitive to a lack of water and ferrous iron determinations.

4.4.1.2 (B). Chemical variations

Amphibole is, in general, the most abundant mafic mineral in the Ladakh Batholith of Trans-Himalaya. A total of 132 electron microprobe analyses from five locations of Intrusive rocks in the study area (Basgo, Nimmu, Umla and Taru intrusive rocks location) were made from a sum of 12 representative samples. Their end-member calculations on the basis of Currie's software are presented in Appendix. Amphibole end-member calculations were carried out those from the diorite, granodiorite and monzodiorite.

Amphiboles from the Ladakh granitoids of study area are mostly edenite, magnesio-hornblende and hastingsite in composition. Amphiboles are generally exhibit considerable variation within the Ladakh granitoids of the study area. For example, in the Figure 4.63 classification of amphibole on the basis of binary plot shows Si- $Mg/Mg+Fe^{(2+)}$ binary plot with $(Na+K)A>0.5$ having six fields: magnesio-sadanagaite, pargasite, edenite, sadanagaite,

hastingsite, ferro-edenite. It also shows magnesio-hastingsite and ferro-pargasite are part of pargasite and hastingsite respectively which is differ according to the variation in the concentration of Al^{IV} and Fe^{3+} . Amphibole crystals from the basgo study area shows edenite, magnesio-hornblende and hastingsite. In the Figure 4.64, rest of the amphibole crystal analysis from the Umla and Taru with rock type of granodiorite and monzodiorite shows only magnesio-hornblende. The amphibole crystal of granodiorite and monzodiorite from Umla and Taru intrusive rocks respectively does not contain edenite and hastingsite.

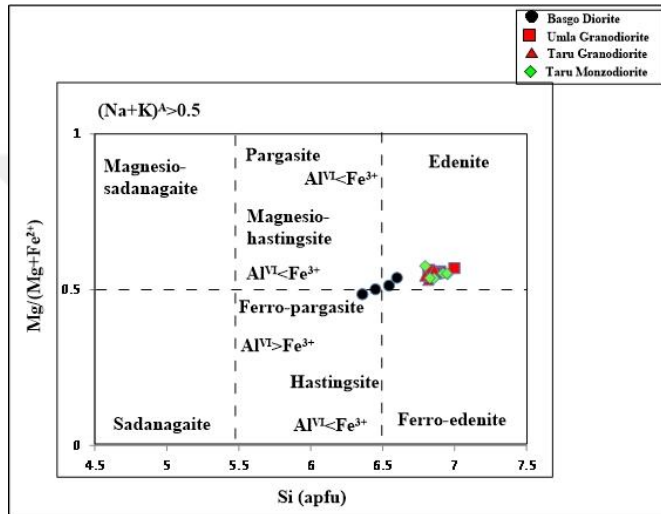


Figure 4.64. As per binary plot, the classification diagram of amphibole shows Si-Mg/Mg+Fe⁽²⁺⁾ binary plot with (Na+K)A>0.5 having six fields: magnesio-sadanagaite, pargasite, edenite, sadanagaite, hastingsite, ferro-edenite. It also shows magnesio-hastingsite and ferro-pargasite are part of pargasite and hastingsite respectively which is differ according to the variation in the concentration of Al^{IV} and Fe^{3+} given by Leake et al. (1997)

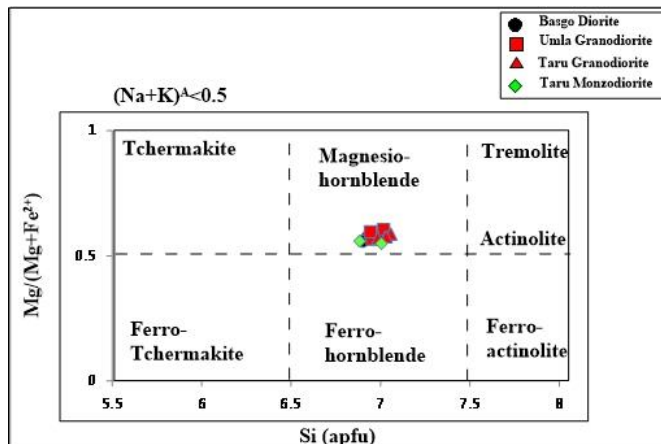


Figure 4.65. As per binary plot Si- Mg/Mg+Fe(2) binary plot with (Na +K)A <0.5 having six fields: tremolite, actinolite, ferroactinolite, magnesiohornblende, ferrohornblende, tschermakite, ferrotschermakite shows the classified diagram of amphibole given by Leake et al. (1997)

The microprobe data have been also marked on the classified diagram given by Leake et al. (1997) (Figure 4.64). All samples from the Ladakh granitoids of the study area are classified as calcic amphiboles, mainly edenite, magnesio-hornblende and, predominantly, magnesio-hastingsite and hastingsite. Amphiboles from the Basgo, Umla and Taru intrusive rocks two diagrams are plotted with $(Na+K)A > 0.50$ and $(Na+K)A < 0.50$ (Figures 4.64) as followed with the IMA classification scheme (Leake et al., 1997). Amphiboles from these intrusive rocks are mainly composition of edenite and magnesio-hornblende.

The further subdivision within calcic amphibole can be adopted from (Figure 4.64), a binary plot between Si-Mg/Mg+Fe showing the classification diagram as Magnesiohornblende ($Mg/Mg+Fe > 0.5$).

In Figure 4.63, amphiboles from the Basgo dioritic rock falls in the field of edenite, ferro-pargasite, hastingsite and magnesio-hastingsite. The data from the intrusive rocks are come into view to have high and low Mg/(Mg+Fe) values, and thus the compositions of amphiboles from the Basgo intrusive rocks fall in discrete areas which principally include hastingsite and edenite.

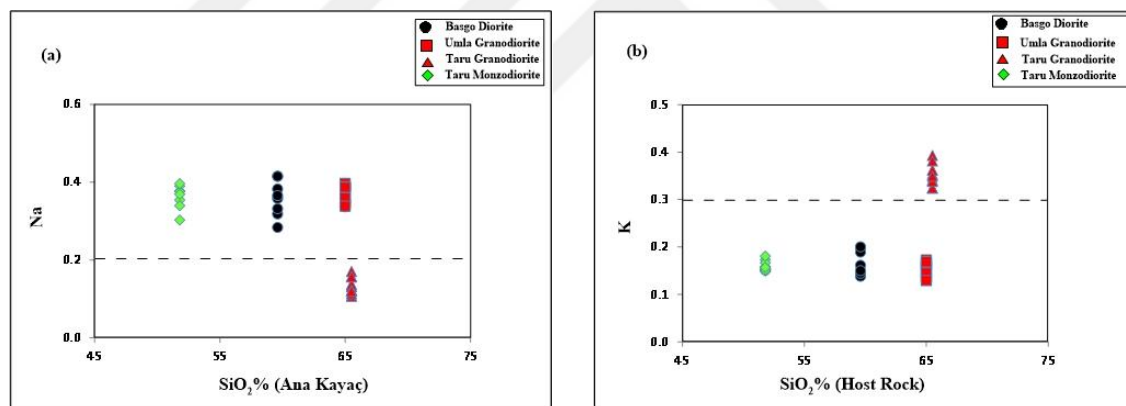


Figure 4.66. (a,b) Na (a) and K (b) formula units of amphiboles from the Ladakh granitoids are plotted against the SiO₂ wt.% content of their host rocks.

The compositional differences of amphiboles from the Ladakh granitoids from study area can be also seen on a plot of Na (formula unit) versus the SiO₂ wt.% of their host rocks (Figure 4.65(a)). Amphiboles from the Taru granodiorites have lowest value of Na, whereas those from the diorite, monzodiorite and granodiorite rock samples from Basgo, Umla and Taru intrusive rock samples respectively, shows have high Na contents.

Similar relationships can be also seen from the plot of K (formula unit) against the SiO₂ wt.% of their host rocks (Figure 4.65(b)). Amphiboles from the Taru granodiorites have Highest value of K, whereas those from the diorite, monzodiorite and granodiorite rock samples from Basgo, Umla and Taru intrusive rock samples respectively, shows have low K contents.

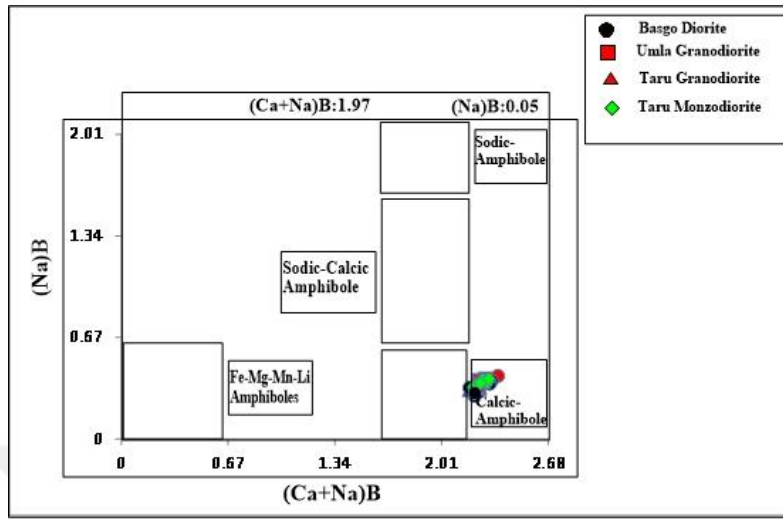


Figure 4.67. Classification of amphibole on the basis of binary plot showing Na-(Na+Ca) binary plot with the covering fields sodic amphibole, calcic amphibole, sodic-calcic amphibole, Fe-, Mg-, Mn-Li amphibole.

The classification of amphibole based on binary plot Na-(Ca+Na), with fields sodic amphibole, calcic amphibole, sodic-calcic amphibole, Fe- Mg-Mn-Li amphibole (Figure 4.66) is showing the amphibole type as calcic amphibole where, $Ca+Na > 1.5$ and $Na < 0.5$.

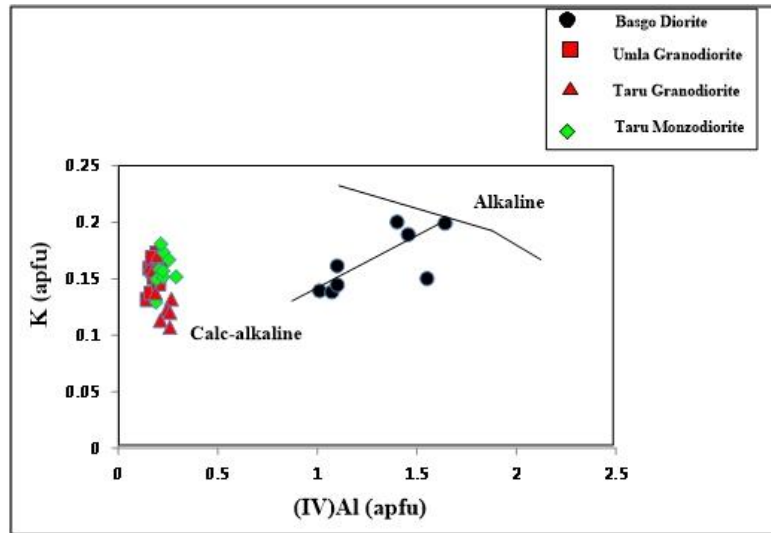


Figure 4.68. shows the binary plot between K(apfu) and (IV)Al(apfu) and K(apfu) showing two fields of calc-alkaline and alkaline.

As per Al (apfu) vs K (apfu) binary plot the amphiboles from Ladakh granitoids samples falls under Calc- alkaline field. This also proves that the granitoids are subduction related granitoids as evidenced by biotite. Figure 4.67 shows the slight increase of $Al^{(IV)}$ with K in dioritic rocks.

4.3.1.3. Biotites

Biotites are usually considered as ferro-magnesian mineral as amphibole in the Taru monzodioritic and granodioritic rocks as well as Umla granodioritic and granitic rocks. Biotites are connected to the trioctahedral phyllosilicate group, which is an important hydrous ferro-magnesian phase of biotite. In comparison with other silicate minerals, mainly major elements, like K, Mg, Fe, Al, Si, O, F, and Ti are structurally and chemically very sensitive.

Foster (1960) suggested that the biotites are originated from granitoids have been categories on the basis of comparative contents of cations per formula unit (pfu) engaged mostly at the T (tetrahedral) and M (octahedral) structural locations.

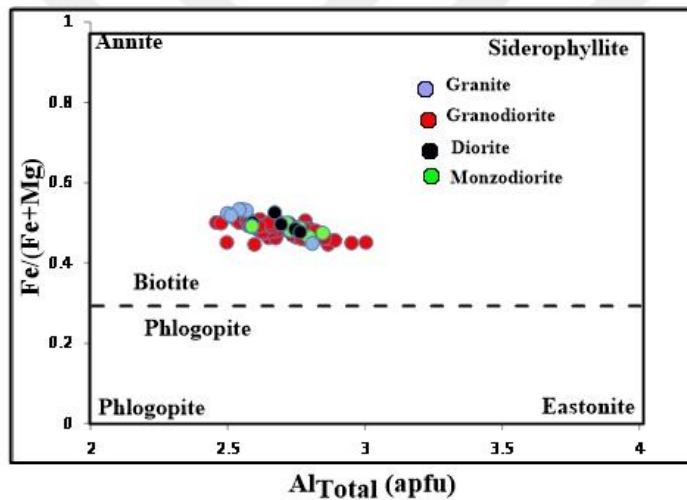


Figure 4.69. shows the variation diagram between Al total to Fe/(Fe+Mg), which is classified as phlogopite, biotite, eastonite, annite, siderophyllite as relative abundance of Al-Mg and Fe(t). Biotite classification diagram after Rieder et al. (1998).

In terms of Al-Mg-Fe(t) content biotite has been classified as phlogopite, biotite, eastonite, annite, siderophyllite as relative abundance of Al-Mg and Fe(t). All studied samples plot in field of annite have relatively more Fe content than Mg in Figure 4.68. Biotites from all granitoids were accompanied with amphibole group of minerals, which is a typical properties of calc-alkaline subduction related metaluminous (I-type) granitoids (e.g. Kumar and Pathak, 2010; Bora and Kumar, 2015).

The major elemental compositions of biotites from different granitoid rocks of the study area that shows nature of their host magma as calc-alkaline (I-type, metaluminous) orogenic suite (Abdel Rahman, 1994).

A slightly negative relationship between MgO and FeOt in biotites from Ladakh granitoids, suggests Mg-Fe substitution during their evolution. Substitution between Mg-Fe is typical feature of biotite which crystallized in calc-alkaline metaluminous (I-type) magmas (Abdel-Rahman, 1994).

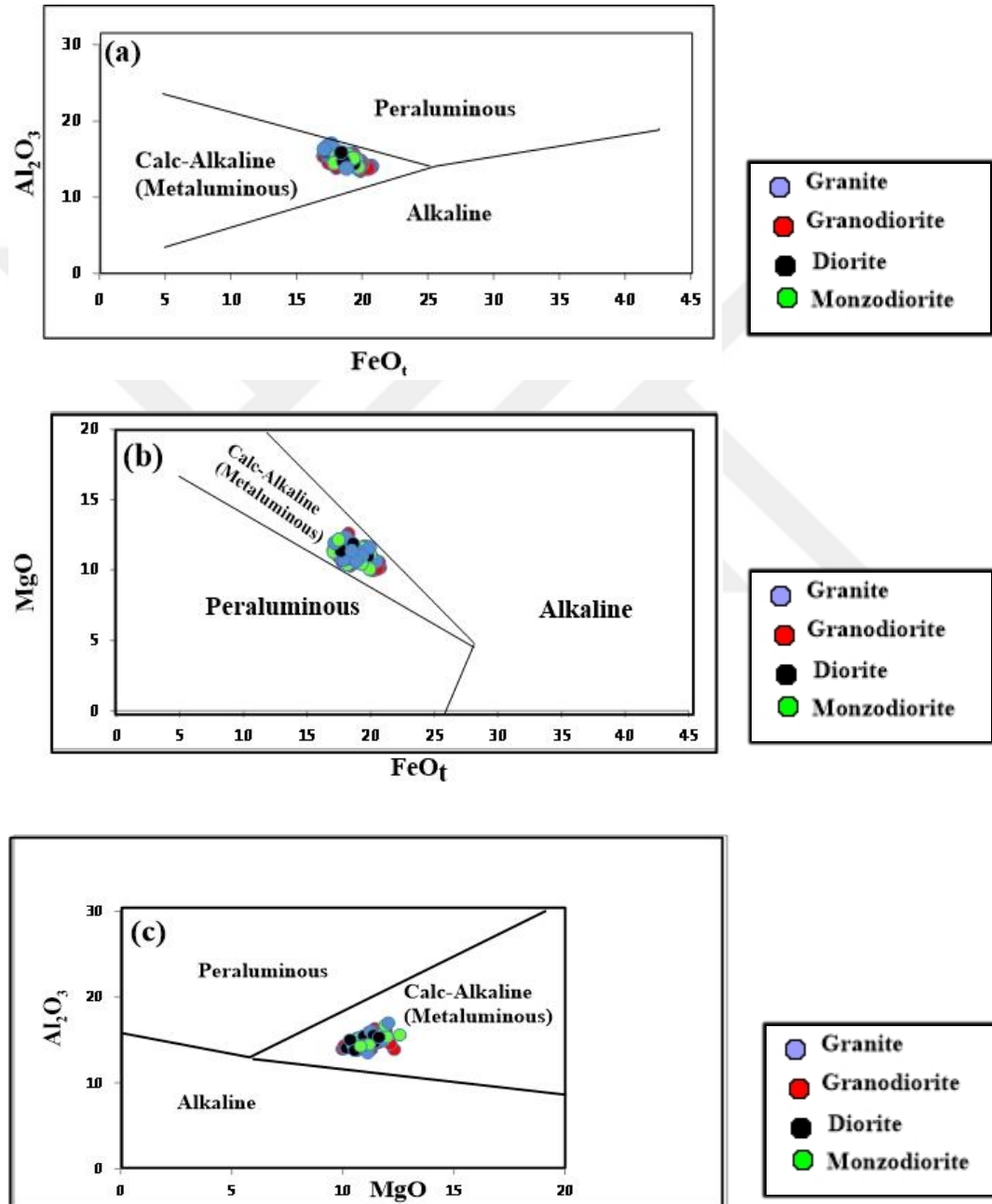


Figure 4.70. shows the (a) Al_2O_3 versus FeO_t , (b) MgO versus FeO_t , and (c) Al_2O_3 versus MgO graphs are marked for biotite configurations from granitoid plutons to differentiate the host granitoid melt varieties in different tectonic settings. Subduction-related, C-calc-alkaline, P-syn-collisional peraluminous and A-anorogenic alkaline are presented after Abdel-Rahman (1994).

In FeO(t)-MgO-Al₂O₃ constituents, biotites are crystallizes into metaluminous (I-type) granitoid melt marked on field “C”. In binary oxide constituents such as FeO(t)- Al₂O₃, MgO-Al₂O₃, and FeO(t)-MgO of biotites. During the evolution of biotite in metaluminous (I-type) calc-alkaline granitoid melts, the Ladakh granitoids evidently display strong Mg Fe, weak 2Al 3Fe, and moderate 2Al Mg exchanges.

In Figure 4.70 (a,b,c,d) showing the FeO(t)-Al₂O₃-MgO ternary diagram covering intrusive rocks of Leh region from Ladakh Batholith around the Trans-Himalayan belt. The ternary diagrams shows the plotting samples of Basgo, Nimmu, Umla and Taru intrusive rocks covering all rock type of granite, granodiorite, diorite and monzodiorite. All plotting samples are falling in the place of calc-alkaline orogenic suits.

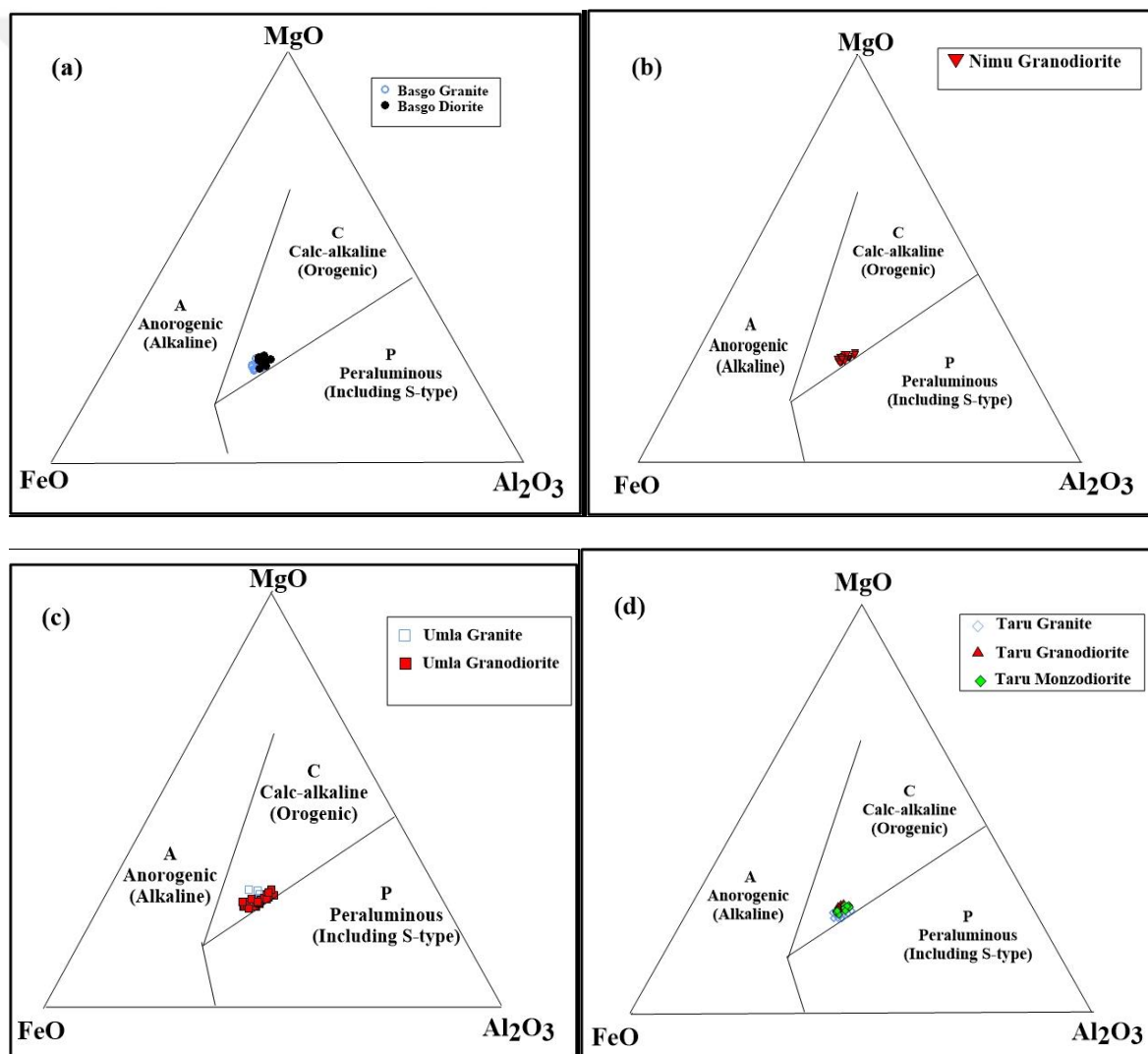


Figure 4.71. (a,b,c,d) shows the FeO(t)-Al₂O₃-MgO ternary diagram covering intrusive rocks of Leh, Ladakh Batholith from Trans-Himalayan belt. (a) Shows the FeO(t)-Al₂O₃-MgO ternary plot covering Basgo granite and Basgo diorite that falls in the field of calc- alkaline orogenic suits. (b)

shows the FeO(t)-Al₂O₃-MgO ternary plot covering Nimmu granodiorite that falls in the field of calc-alkaline orogenic suits. **(c)** shows the FeO(t)-Al₂O₃-MgO ternary plot covering Umla granite and granodiorite that falls in the field of calc-alkaline orogenic suits. **(d)** shows the FeO(t)-Al₂O₃-MgO ternary plot covering Taru granite, granodiorite and monzodiorite that falls in the field of calc-alkaline orogenic suits.

4.4.1.4. Fe-Ti Oxides

A total of 143 point analyses were performed on 12 samples from the Basgo, Nimmu, Umla, Taru, (Appendix). Only magnetite and ilmenite from these intrusive rocks have been studied in detail as restricted in occurrence of other opaque minerals. In the Basgo and Umla intrusive rocks show scarcity in the magnetite and ilmenite. Magnetites from the Ladakh granitoids have 0-0.221 wt% TiO₂ and 0.21-0.075 wt% Al₂O₃. Ilmenites from the intrusive rocks contain 0.205-14.43 wt% MnO and up to 0.015-0.97 wt% MgO.

Takasashi et al. (1980) have compared Ishahara's (1977) classification of granites as magnetite- and ilmenite-bearing with the I- and S-type granite classification of Chappell and White (1974). I-type granites generally contain magnetite and less commonly ilmenite without magnetite. The absence of magnetite is often associated with S-type granites, because of the C (graphite) content of the sedimentary source.

4.4.2. Calculations of pressures, temperatures and oxygen fugacities of the Ladakh Granitoids from Trans-Himalayan belt

The mineral compositions of the granitic plutons enable the use of a large number of thermometers and barometers that characterise emplacement conditions. However, only a portion of mineral compositions in igneous rocks represents true solidus conditions since some mineral phases continue to react during subsolidus cooling (e.g. feldspar, Fe-Ti oxides).

Water fugacity ($f_{\text{H}_2\text{O}}$) and oxygen fugacity (f_{O_2}) are two of the intensive properties that also control the crystallisation paths of a magma. Determination of these variables at magmatic conditions is also difficult because of phase and compositional changes caused by subsolidus re-equilibration (e.g. Czamanske and Wones, 1973; Wones, 1981). Nevertheless, there are several ways to approximate the pressure, temperature and oxygen fugacity during crystallisation of the Ladakh granitoids of Trans-Himalayan belt.

These are:

4.3.2.1. Amphibole-plagioclase geothermometer and barometer:

4.3.2.1(A). Al-in-homblende barometer (Schmidt, 1992)

4.3.2.1(B). Al-in-homblende barometer (Anderson et al., 1995)

4.3.2.1(C). Amphibole-plagioclase geothermometer

4.3.2.2. Feldspar geothermometer:

4.3.2.2(A). Two-feldspar geothermometry (Wen and Nekvasil, 1994)

4.3.2.3. Oxygen and water fugacities:

4.3.2.3(A). Oxygen fugacity (Wones, 1989)

4.4.2.1. Amphibole-plagioclase geothermometer and barometer

4.4.2.1(A). Al-in-hornblende barometer (Schmidt, 1992)

The utility of the Al in Hornblende barometer is grounded in the observation by Hammarstrom and Zen (1986) that the total aluminum content of hornblende that has equilibrated in rocks containing quartz, plagioclase, K-feldspar, biotite, titanite, Fe-Ti oxides, supercritical fluid, and melt increases with pressure.

Hammerstrom and Zen (1986) first experimentally determined that the Al content of hornblende in calc-alkaline granitoids varies linearly with pressure of crystallisation, thereby providing a means of determining depth of pluton emplacement (Equation 4.1):

$$P(\pm 3 \text{ kbar}) = -3.92 + 5.03 \text{ Al}_{\text{hbl}}^{\text{tol}} \quad r^2 = 0.80 \quad (\text{Eq. 4.1})$$

Hollister et al. (1987) discussed the thermodynamic basis for this barometer and refined the empirical calibration of Hammerstrom and Zen (1986) with additional hornblende compositional data from intrusives that crystallized at intermediate pressures (Equation 4.3.2):

$$P(\pm 1 \text{ kbar}) = -4.76 + 5.64 \text{ Al}_{\text{hbl}}^{\text{tol}} \quad r^2 = 0.97 \quad (\text{Eq. 4.2})$$

Both empirical calibrations (Equation 4.3.1, 4.3.2) are based on pressures generally derived from contact-aureole geobarometry. Hammerstrom and Zen (1986) and Hollister et al. (1987) emphasised that the barometer is restricted to calc-alkaline rocks containing the specific assemblage "quartz + plagioclase + potassium feldspar + hornblende + biotite + titanite + Fe-Ti oxide phase(s) (magnetite or ilmenite)".

Johnson and Rutherford (1989) equilibrated the specified assemblage (using natural samples of both volcanic and plutonic rocks) in reversed, /O₂-buffered, vapour-present experiments over the range from 2 to 8 kbar at 740-780 °C (Equation 4.3):

$$P(\pm 0.5 \text{ kbar}) = -3.46 + 4.23 \text{ Al}_{\text{hbl}}^{\text{tol}} \quad r^2 = 0.99 \quad (\text{Eq. 4.3})$$

Schmidt (1992) calibrated the Al-in-hornblende barometer experimentally under water-saturated conditions at pressures of 2.5-13 kbar and temperatures of 700-655 °C (Equation 4.3.4):

$$P (\pm 0.6 \text{ kbar}) = -3.01 + 4.76 \text{ Al}^{\text{tol}}_{\text{hbl}} \quad r^2 = 0.99 \quad (\text{Eq. 4.4})$$

The Al-in-hornblende geobarometer has been criticised by Anderson and Smith (1995) and Anderson (1996). They pointed out that many granitic intrusions are emplaced under conditions inconsistent with those of existing experimental calibrations, including $f_{\text{O}_2} < \text{NNO}$ (nickel-nickel oxide) and/or variable to high temperature. They also noted that the barometer fails by yielding elevated pressures for low f_{O_2} plutons with iron-rich hornblendes. Thus they recommend that the barometer is used for hornblende with $\text{Fe}/(\text{Fe}+\text{Mg}) < 0.65$.

Pressure estimates based on Ague's reaction closely mirror those produced by experimental calibrations of aluminum in hornblende such as that of Schmidt et al. (1992), suggesting that the additional compositional constraints and assumptions of Hammarstrom and Zen (titanite, Fe-Ti oxides, melt, etc.) are not required to estimate pressure using an experimental relationship such as that of Schmidt et al. Absolute pressure estimates still vary depending on the calibration used because of the temperature sensitivity of Al in hornblende and the different experimental conditions used; this will be discussed below. Estimates from the AH barometer typically record the pressure at the time of crystallization, as Al diffuses extremely slowly through hornblende below temperatures of $\sim 650^\circ\text{C}$ (Hammarstrom and Zen, 1986). Until the diffusion behavior of aluminum in hornblende under different conditions is extensively studied, the textural appearance and zonation of the crystal must be relied upon to judge the alteration history, or lack thereof, of hornblendes used for barometry.

35 point analyses of amphiboles from the Ladakh granitoids of Trans-Himalayan belt were performed on a subset of 12 representative samples from Basgo, Umla, Taru intrusive rocks. Pressure calculations were carried out only for the diorite, granodiorite and monzodiorite samples.

The granite samples from Nimmu field area are eliminated because the amphiboles from these rock units have the ratios of $\text{Fe}/(\text{Fe}+\text{Mg}) > 0.65$. Thus, the crystallisation pressures were determined only on 35 point analyses on 4 samples, out of 12 samples from the Basgo, Umla and Taru intrusive rocks by using the Schmidt's calibration. The results are presented in Table 4.7 and Appendix.

Table 4.7. Table displaying crystallisation pressures of the Intrusive rocks in the Leh, Ladakh Batholith region around Trans-Himalaya Belt.

INTRUSIVE ROCKS/ ROCK TYPE	PRESSURE (kbar) (± 0.6)	
	Schmidt (1992) Al in Hbl Barometry	Anderson et al. (1995) Al in Hbl Barometry
Basgo Intrusive Rocks Diorite	2.88-23.84	2.32-28.08
Umla Intrusive Rocks Granodiorite	2.73-3.43	2.13-3
Taru Intrusive Rocks Granodiorite	2.74-3.55	1.83-3.15
Taru Intrusive Rocks Monzodiorite	2.90-3.94	2.35-3.62

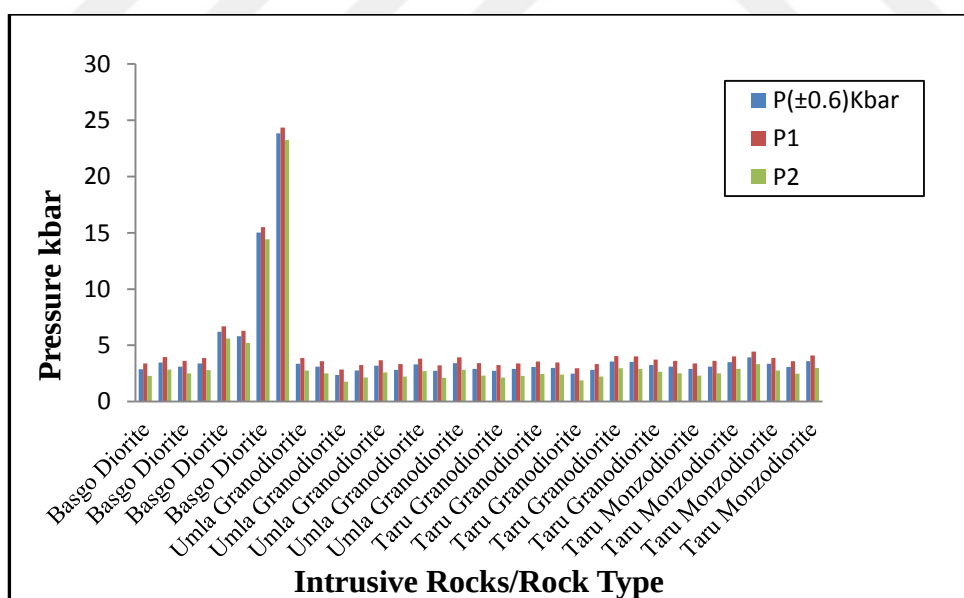


Figure 4.72. Histogram shows the distribution of crystallization between Pressure in kbar and samples from Leh Ladakh Batholith region from Trans-Himalayan belt as per Schmidt, 1992, Al in Hornblende Barometry.

As can be seen from Table 4.7 and Figure 4.71, the Basgo diorite shows the highest pressure (2.88-23.84 kbar) than the other rock units. The granodiorite from both Umla and

Taru intrusive rocks have lowest crystallization pressures that ranges between (2.36-3.43 kbar) and (2.48-3.55 kbar) respectively. Figure 4.71 shows the distribution of the crystallisation pressures of samples from Leh Ladakh Batholith region from Trans-Himalayan belt as per Schmidt, 1992, Al in Hornblende Barometry. As shown by the histogram, most of the intrusive rocks have crystallisation pressures between 2 to 3 kbar. Only about 10% of the intrusive rocks have pressures between 14.5 and 24 kbar and about 70% of those have pressures ranging from 2.3 to 3.9 kbar.

4.4.2.1(B). Al-in-hornblende barometer (Anderson et al., 1995)

The distribution crystallisation pressures were determined only on 35 point analyses from 4 samples out of 12 samples from the Basgo, Umla and Taru intrusive rocks using the Anderson's calibration. The results are presented in Table 4.7 and Appendix.

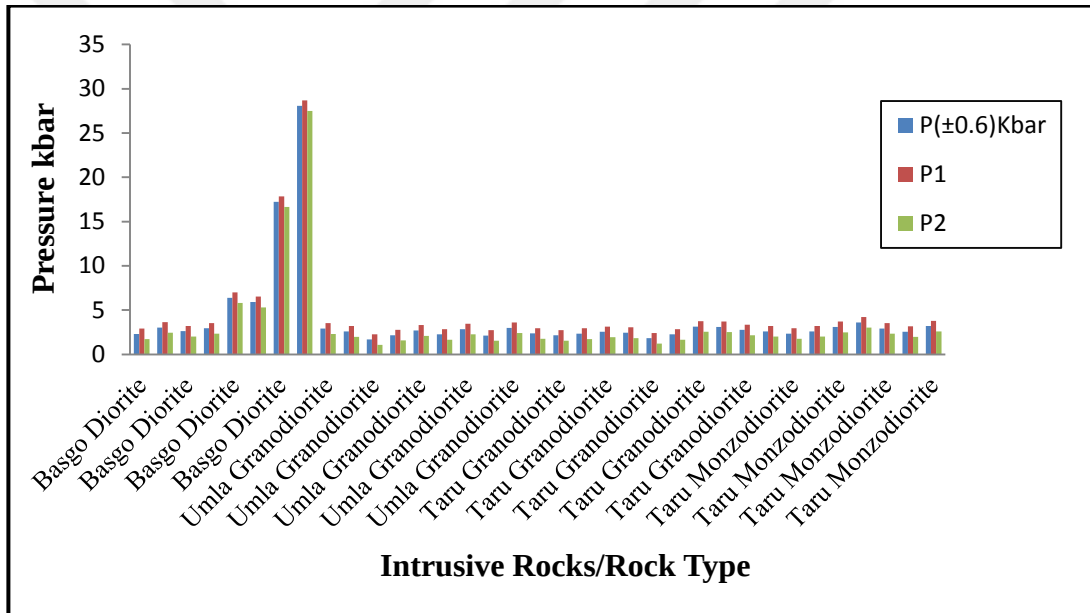


Figure 4.73. Histogram shows the distribution of crystallization between Pressure in kbar and samples from Leh Ladakh Batholith region from Trans-Himalayan belt as per Anderson et al., 1995, Al in Hornblende Barometry.

As can be seen from Table 4.7 and Figure 4.72, the Basgo diorite shows the highest pressure (2.32-28.08 kbar) than the other rock units. The granodiorite from both the Umla and Taru have the lowest crystallization pressures ranges in between (1.68-3 kbar).and (1.83-3.15 kbar) respectively Figure 4.72 shows the distribution of the crystallisation pressures of samples from Leh Ladakh Batholith region from Trans-Himalayan belt as per Anderson et al. 1995, Al in Hornblende Barometry. As shown by the histogram, most of the intrusive rocks have crystallisation pressures between 1.5 to 3.5 kbar. As comparing the calibration results of Anderson with Schmidt, 1992, it shows that the calculated Basgo dioritic pressure with Anderson calibration formulas is higher as compare to the Schmidt, 1992, calibrated pressure formula.

Table 4.7. Ladakh Batolitinin yer alan intrüzif kayalar numuneler olarak hornblend'de Al kullanılarak basınç ve derinlik Schmidt 1992 ve Anderson vd. 1995 'a göre hesaplanmıştır

INTRUSIVE ROCKS/ ROCK TYPE	PRESSURE (kbar) (± 0.6)		DEPTH (km)	
	Schmidt (1992) Al in Hbl Barometry	Anderson et.al., (1995) Al in Hbl Barometry	Schmidt (1992) Al in Hbl Barometry	Anderson et.al., (1995) Al in Hbl Barometry
Basgo Intrusive Rocks Diorite	4.1	3.9	13.7	12.8
Umla Intrusive Rocks Granodiorite	3	2.5	9.9	8.1
Taru Intrusive Rocks Granodiorite	3	2.5	10	8.3
Taru Intrusive Rocks Monzodiorite	3.3	2.9	11	9.5

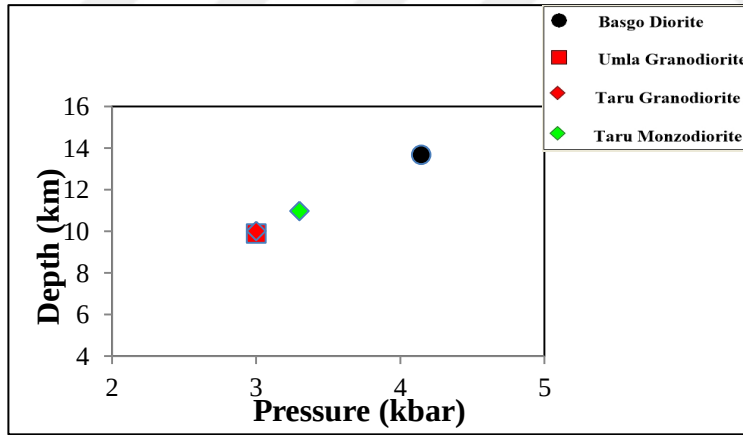


Figure 4.83. Ladakh Batolitin'deki yer alan intrüzif kayalar arasında derinliği (km) ile basınç (kbar) göstermektedir ve bu hesaplama Schmidt 1992'e göre edilmiştir

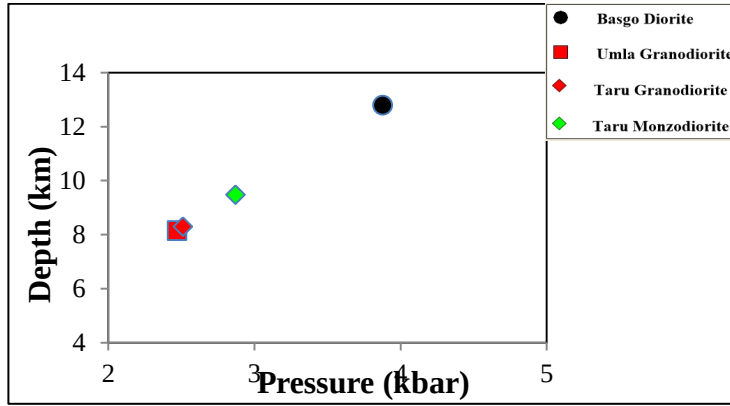


Figure 4.84. Ladakh Batolitin'deki yer alan intrüzif kayaçlar arasında derinliği (km) ile basınç (kbar) göstermektedir ve bu hesaplaması Anderson vd.1995'a göre edilmiştir

Table 4.8. Ladakh Batolitin'in yer alan intrüzif kayaçlar numuneler olarak hornblend'de Al kullanılarak basınç ve sıcaklığı Blundy ve Holland 1990 'a göre hesaplanmıştır

INTRUSIVE ROCKS/ ROCK TYPE	Blundy & Holland (1990)	
	TEMPERATURE (°C)	DEPTH (km)
Basgo Intrusive Rocks (Diorite)	645	15.8
Umla Intrusive Rocks (Granodiorite)	598	11.7
Taru Intrusive Rocks (Granodiorite)	586	11.8
Taru Intrusive Rocks (Monzodiorite)	604	13.1

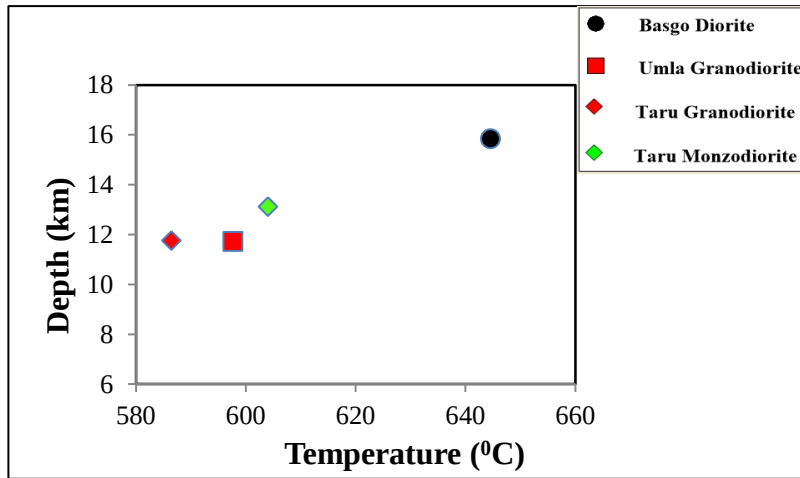
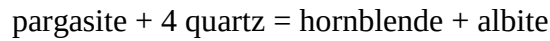
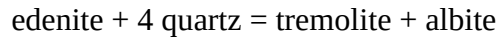


Figure 4.85. Ladakh Batolitin'deki yer alan intrüzif kayaçlar arasında derinliği (km) ile sıcaklık (°C) göstermektedir ve bu hesaplama (kalibrasyon) Blundy ve Holland 1990'a göre edilmiştir

From the above Figure and Table, shows the calculation of depth and pressure according to Schmidh 1990 and Anderson et. al; 1995. The samples are collected from the studied area of the Ladakh Batholith around Leh region covering the places Basgo, Umla and Taru. According to Schmidh 1990 and Anderson et. al; 1995, the depth varies from 13.7 to 9.9 km and 12.8 to 8.1 km respectively. Basgo diorite was deepest (13.7 or 12.8 km) near the southern edge with the Indus-Tsangpo Suture Zone (ITSZ) whereas Umla granodiorite samples was shallowest (9.9 or 8.1 km) that move towards the direction of northern boundary with the Shyok Suture Zone (SSZ). According to the calibration formula of Blundy and Holland 1990, the crystallizing temperature decreases from diorite to granodiorite with decrease in depth. It is also concluded that, as the elevation increases from SW to NE is inversely proportional with decrease in the pressure, temperature and depth. The depth difference of emplacement of nearly 3.8 to 4.7 km with the exposed elevation can be attributed by the tectonic activity.

4.4.2.1(C). Amphibole-plagioclase geothermometer

For this Amphibole-plagioclase geothermometer calculation, vast experimental studies has been performed by using synthetic amphibole from a wide range of starting materials and pressures and temperatures demonstrated that amphibole also has potential for indicating crystallisation temperatures. Spear (1980, 1981) described early calibrations of the hornblende-plagioclase thermometer based on pairs (hornblende-plagioclase) in metamorphic rocks for which temperature was already known. Nabelek and Lindsley (1985) proposed an experimentally-based thermometer using variations in Al^{iv} of hornblende. Blundy and Holland (1990) developed a new amphibole-plagioclase geothermometer using a combined set of experimental and empirical data and have formulated a calibration for the equilibria:



and their calibration is:

$$T = \frac{0.677P - 48.98 + Y}{-0.0429 - 0.008314 \ln K} \quad (\text{Eq4.5})$$

where;

$$K = \left(\frac{Si-4}{8-Si} \right) X_{Ab}^{Plag}$$

Si: number of atoms per formula unit in amphibole

P: pressure (kbar)

T: temperature (Kelvin)

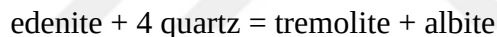
Y: plagioclase non-ideality

$$Y = 0 \text{ for } X_{ab} > 0.5 \text{ and } Y = -8.6 + 25.5 (1 - X_{ab})^2 \text{ for } X_{ab} < 0.5$$

They determined that the amphibole-plagioclase thermometer is robust to ferric iron recalculation from electron microprobe data and should yield temperatures of equilibration for hornblende-plagioclase assemblages with uncertainties of around ± 75 °C for rocks equilibrated at temperatures in the range 500-1100 °C. They also demonstrated that the thermometer should only be used in this temperature range and for assemblages with plagioclase less calcic than An₉₂ and with amphiboles containing less than 7.8 Si atoms per formula unit.

The Blundy and Holland's (1990) calibration was criticised by Hammerstrom and Zen (1992), Rutherford and Johnson (1992) and Poll and Schmidt (1992) generally on thermodynamic grounds.

Hornblende-plagioclase geothermometer temperatures obtained for the Leh, Ladakh granitoids range from 561 to 727 °C by using the Blundy and Holland (1990) calibration reaction. Another temperatures are obtained from HB 1 refers to Holland and Blundy (1994) Hbl-Plag thermometry calibration reaction, which is showing less value as compared to Blundy and Holland's (1990),



is calculated between the range from 452 to 629⁰C.

Another calibration equation is obtained from HB 2 refers to Holland and Blundy (1994) Hbl-Plag thermometry calibration reaction,



is calculated between the range from 463 to 628⁰C. This is showing near about the same temperature range of HB1.

In Figure 4.73, histogram displaying the distribution of crystallization temperatures in the Leh, Ladakh granitoids of Trans-Himalayan belt against Intrusive rocks. As per diagram shows the high temperature range in BH (Blundy and Holland's (1990) as compare to the HB1 (Holland and Blundy (1994)) and HB2 (Holland and Blundy (1994)). Because these HB1 and HB2 are showing near about same range of temperature. The intrusive rocks have crystallization temperatures ranging from 452 to 628 °C. About 1-2% of the basaltic diorite samples have temperatures between 628 to 727 °C.

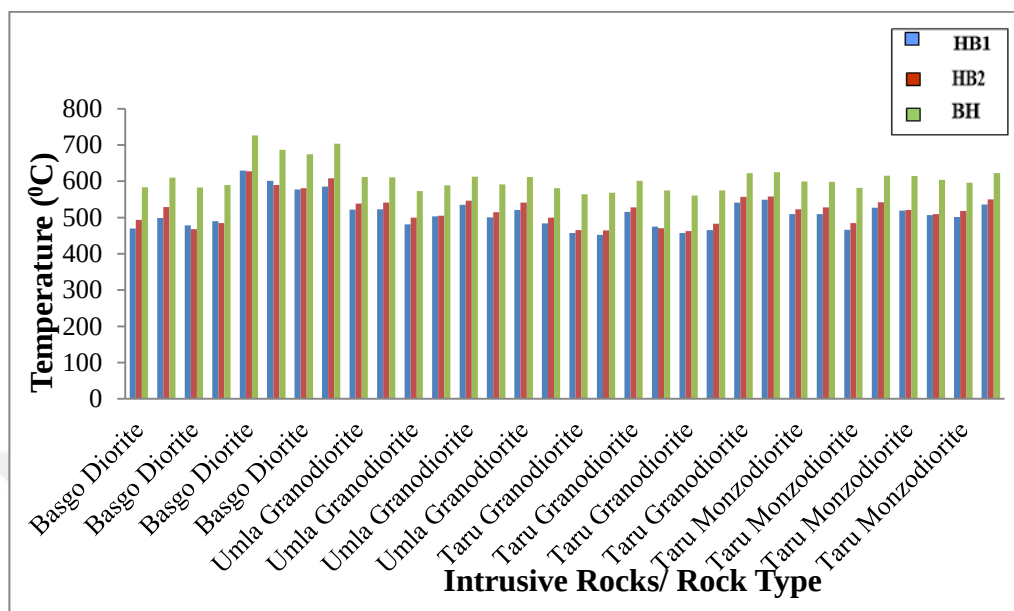


Figure 4.74. Histogram displaying the distribution of crystallization temperatures in the Leh, Ladakh granitoids of Trans-Himalayan belt. Abbreviations: BH (Blundy and Holland's (1990)), HB1 (Holland and Blundy (1994)) and HB2 (Holland and Blundy (1994)).

In Figure 4.74, shows the distribution of amphibole-plagioclase geothermometer calculations from the Basgo, Umla and Taru intrusive rocks plotted against SiO_2 wt% contents of their host rocks. As diagram shows that the temperatures from these intrusive rocks of Leh, Ladakh region around Trans-Himalaya decrease with increasing silica contents of their host rocks.

Diagram shows that all samples from Basgo, Umla and Taru intrusive rocks displaying high temperature for BH (Blundy and Holland's (1990)) as compared to other temperatures of HB1 (Holland and Blundy (1994)) and HB2 (Holland and Blundy (1994)).

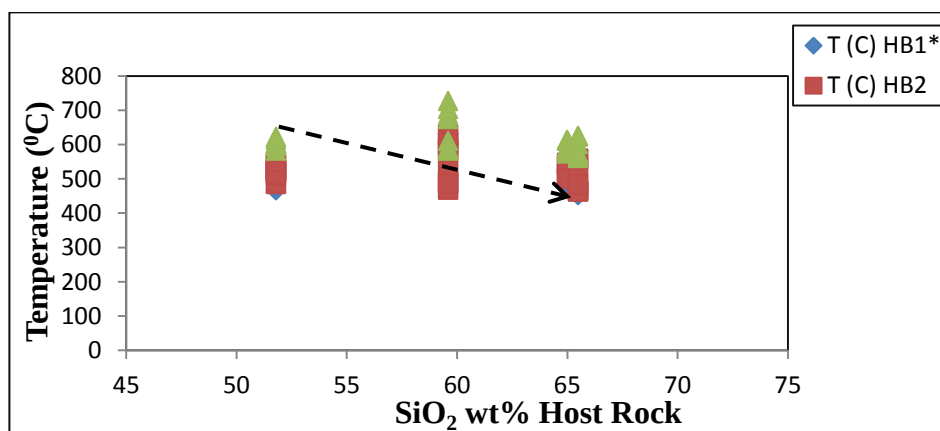


Figure 4.75. Shows the distribution of amphibole-plagioclase geothermometer calculations from the Basgo, Umla and Taru intrusive rocks plotted against SiO_2 wt% contents of their host rocks.

Abbreviations: BH (Blundy and Holland's (1990), HB1 (Holland and Blundy (1994)) and HB2 (Holland and Blundy (1994)).

Figure 4.75 displaying a positive correlation between pressures and temperatures from the Basgo, Umla and Taru intrusive rocks calculated by using the Schmidt's (1992) and Blundy and Holland's (1990) formulations. It shows a steady increase in the pressure from granodiorite to diorite with increase in temperature.

The diorite from the Basgo intrusive rocks showing highest temperatures, whereas the granodiorite from the Umla and Taru intrusive rocks and the monzodiorite from Taru intrusive rocks have the lowest temperatures.

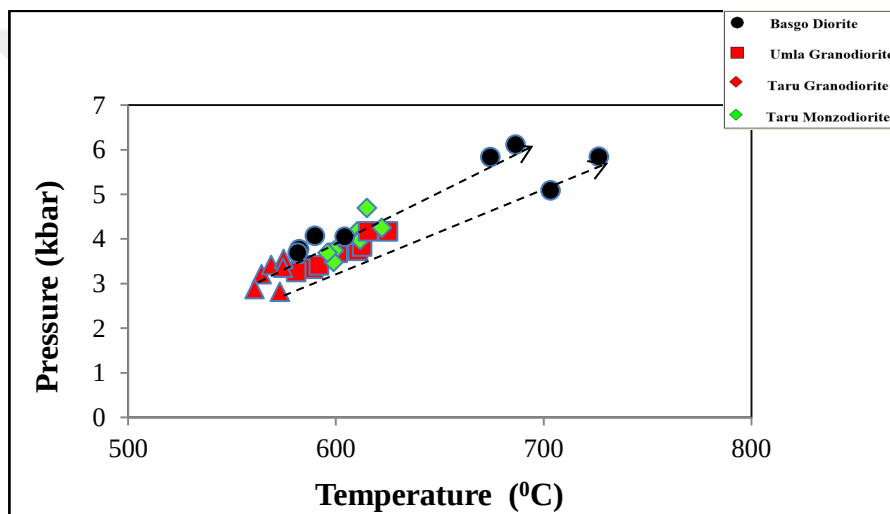


Figure 4.76. Diagram displaying a positive correlation between pressures and temperatures from the Basgo, Umla and Taru intrusive rocks calculated by using the Schmidt's (1992) and Blundy and Holland's (1990) formulations.

In Figure 4.76, the histogram displaying the distribution of crystallization pressure (kbars) by using the Schmidt's (1992) and Anderson (1996) collected from the Leh, Ladakh granitoids of Trans-Himalayan belt. The pressure that calculated by using BH (Blundy and Holland's (1990), showing high percentage of pressure but excepting some of the diorite samples which shows low pressure.

Pressure calculated by using HB1 (Holland and Blundy (1994)) and HB2 (Holland and Blundy (1994) shows low pressure values but in the exceptional case of diorite samples from basgo shows high values of pressure.

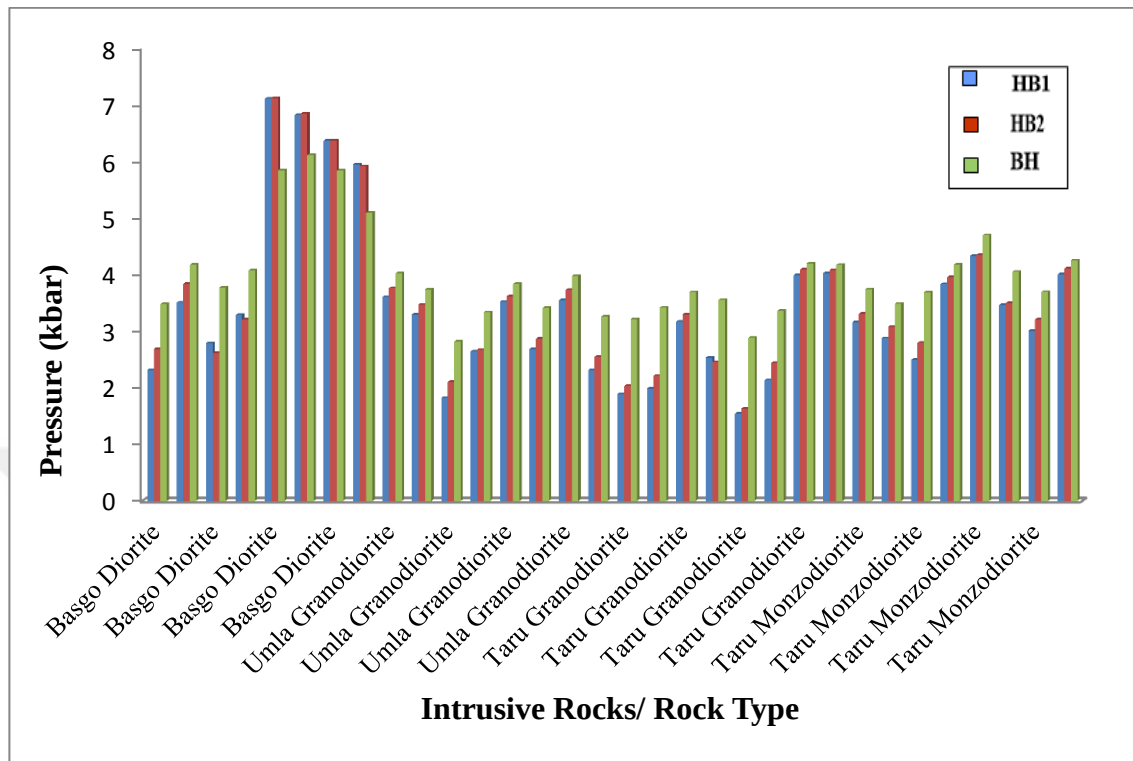
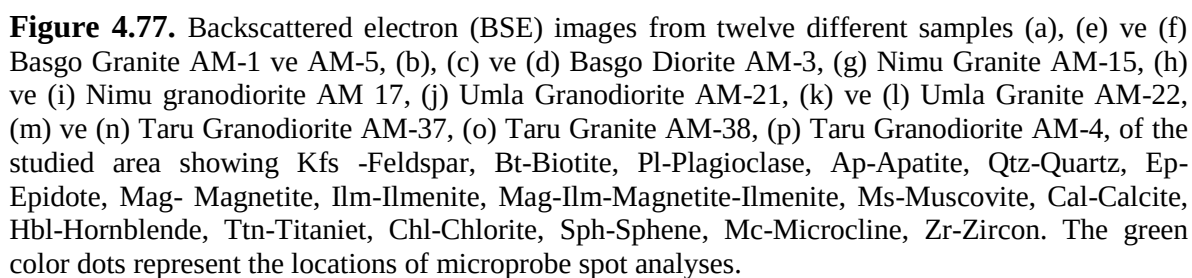


Figure 4.77. Histogram displaying the distribution of crystallization pressure (kbars) by using the Schmidt's (1992) and Anderson (1996) collected from the Leh, Ladakh granitoids of Trans-Himalayan belt. Abbreviations: BH (Blundy and Holland's (1990), HB1 (Holland and Blundy (1994)) and HB2 (Holland and Blundy (1994)).



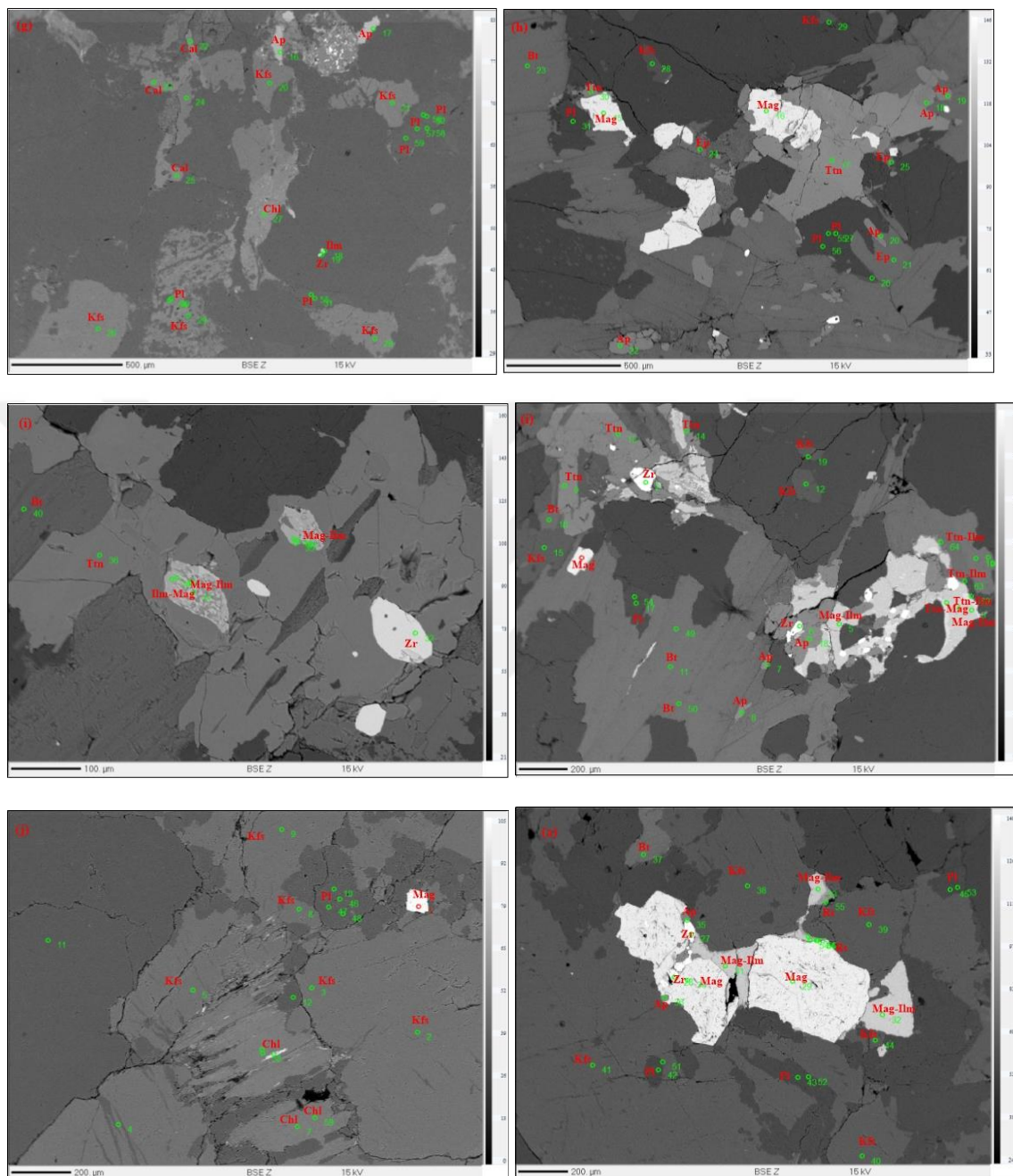


Figure 4.77. continue

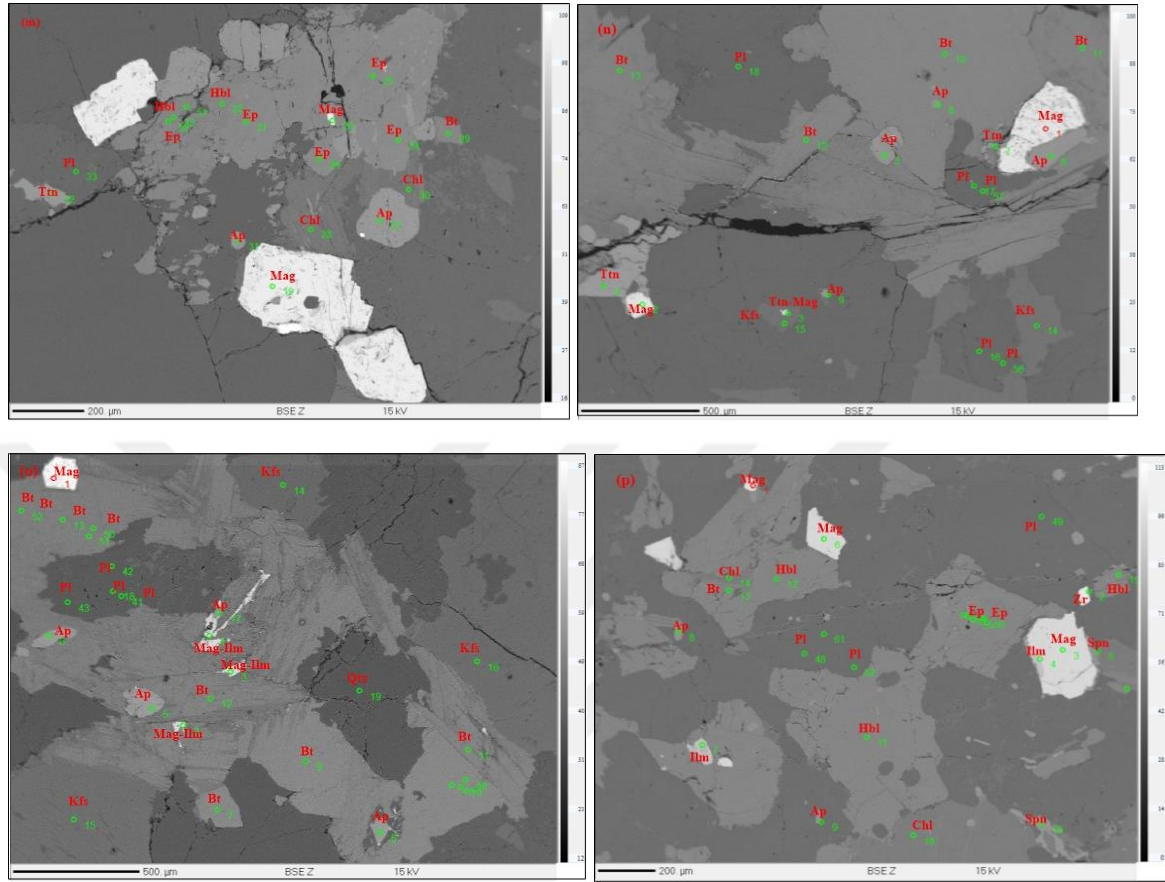
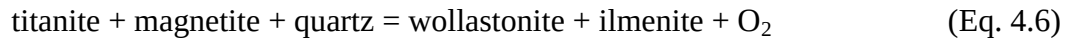


Figure 4.77. continue

4.4.2.3. Oxygen and water fugacities

4.4.2.3(A). Oxygen fugacity

Redox buffer is an assemblage of minerals or compounds that constrains oxygen fugacity as a function of temperature. For the determination of oxygen fugacity (f_{O_2}), at the P and T of crystallisation of granitic rocks is often constrained by subsolidus re-equilibration and/or alteration. During late-stage re-equilibration in granitic plutons, typically loses Ti by magnetite and one or more stages of oxidation-exsolution undergoes by ilmenite. Therefore, the application of ilmenite-magnetite geothermometry cannot be used to ascertain oxygen fugacities during crystallisation of the magmas (Buddington and Lindsley, 1964; Haggerty, 1976).

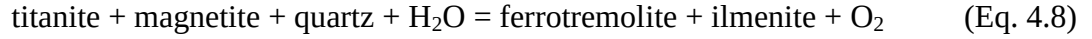


separates an oxidised titanite + magnetite assemblage from a reduced wollastonite + ilmenite assemblage.

By adding SiO_2 , the equilibrium can be written as:



in which hedenbergite and ilmenite represent the reduced assemblages (Wones, 1989). Wones (1989) also suggested that an equilibrium comparable to Equation 4.7, but involving amphibole, can be written:



According to Wones (1989), Equation 4.8 can be used to distinguish relatively oxidised granitoids containing titanite + magnetite + quartz from those that are more reduced and contain amphibole + ilmenite. The temperature dependency of oxygen fugacity (Equations 4.9 and 4.10) can be approximated by:

$$\log f_{\text{O}_2} = \frac{A}{T} + B + \frac{C(P-1)}{T} \quad (\text{Eq. 4.9})$$

using calculated values for A, B and C (Wones, 1989) we get:

$$\log f_{\text{O}_2} = \frac{-30930}{T} + 14.98 + \frac{0.142*(P-1)}{T} \quad (\text{Eq. 4.10})$$

P: pressure (bar)

T: temperature (Kelvin)

To calculate f_{O_2} , Wones (1989) equation (Equation 4.10) has been applied to 12 representative samples from the Basgo, Nimmu, Umla and Taru intrusive rocks. The average pressures and crystallisation temperatures of the plutonics were obtained using the Schmidt (1992) and Holland and Blundy (1990) equations. The estimated Tf_{O_2} conditions for the crystallisation of the Ladakh granitoids are given in Figure 4.77.

The intrusive rocks are crystallized under the conditions between the FMQ (Fayalite- Magnetite-Quartz) buffers and HM (Hematite-Magnetite) (Figure 4.77). The rock units from the Basgo, Nimmu, Umla and Taru intrusive rocks are plotted between the hedenbergite lines and titanite+magnetite+quartz. The Basgo dioritic intrusive rocks have slightly higher f_{O_2} than the other units in the Leh, Ladakh Batholith region from the Trans-Himalayan Belt. 1987).

Many arc-related batholiths crystallise near the experimental Ni-NiO buffer (Czamanske et al., 1981; Speer, 1987). Others, particularly ilmenite series and fayalite-bearing granites (Anderson, 1983; Emslie and Stirling, 1993), crystallise near the quartz-fayalite-magnetite buffer; and a few high f_{O_2} , magnetite series granites (Barth et al., 1995) crystallise a few log units below the hematite magnetite buffer. Thus, the observed range of f_{O_2} in granites spans seven orders of magnitude and this duplicates the range of f_{O_2} measurements for rapidly erupted volcanic rocks (Ewart et al., 1975; Luhr et al., 1984; Carmichael, 1991).

Intrusive rocks commonly record crystallization at oxygen fugacities more oxidizing than the WM (wüstite-magnetite) buffer and more reduced than a log unit or so above the nickel-nickel oxide (NiNiO) buffer. Their oxidizing conditions thus are not far from those of the FMQ (fayalite-magnetite-quartz) redox buffer. Nonetheless, there are systematic differences that correlate with tectonic setting. Intrusive rocks emplaced and erupted in island arcs typically record oxygen fugacities 1 or more log units more oxidizing than those of the NiNiO buffer. In contrast, basalt and gabbro in non-arc settings typically record oxygen fugacities from about those of the FMQ buffer to a log unit or so more were reducing than that buffer.

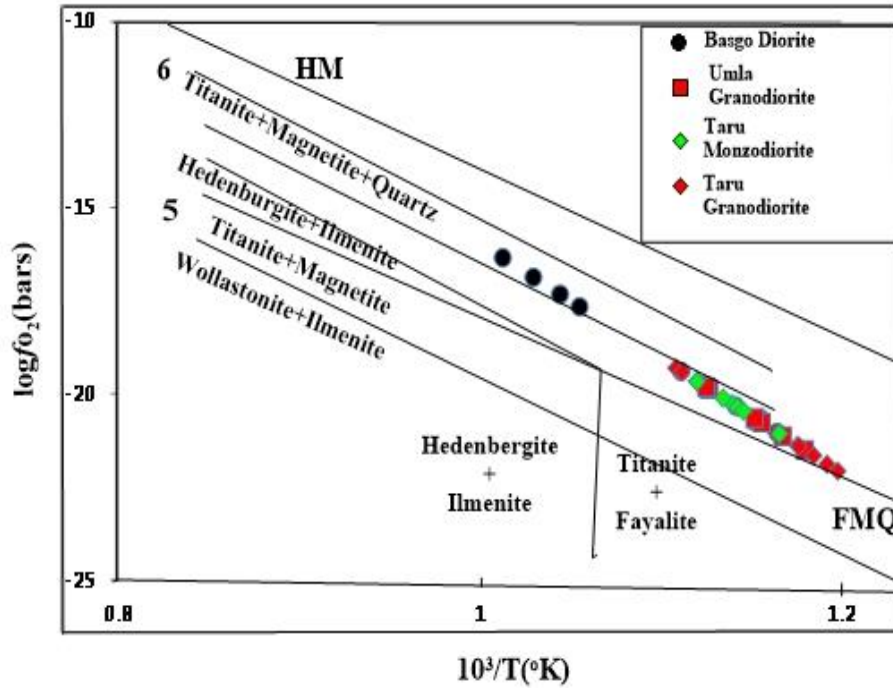


Figure 4.78. Logarithmic plot of f_{O_2} versus temperature $10^3/T(^{\circ}K)$ for the Basgo, Nimmu, Umla and Taru intrusive rocks. Abbreviations: Hematite-Magnetite (HM), Fayalite-Magnetite-Quartz (FMQ) and hed-hedenbergite.

Figure 4.78 shows the logarithmic plot of f_{O_2} versus temperature $T(^{\circ}C)$ for the Basgo, Nimmu, Umla and Taru intrusive rocks assemblages. Oxygen fugacity (f_{O_2}) is positively correlated with temperature (T) in silicate magma and often described as mineral assemblage buffer such as Fayalite-magnetite-quartz (FMQ), Ni-NiO (NNO), Hematite-magnetite (HM) oxygen buffer. The Ni-NiO buffer is widely used to produce more oxidizing conditions in geochemical or petrological experiments. Of particular importance are studies of metal-silicate partitioning, that are carried out to understand the observed budget of moderately and highly siderophile elements in the mantle. Nickel is a key trace element in these studies, because its well-constrained mantle abundance (McDonough and

Sun, 1995) is thought to be a consequence of metal-silicate equilibration during core-mantle segregation in the early Earth (Li and Agee, 1996; Ohtani et al., 1997).

In Figure 4.79, the samples plotted from this study of Ladakh Batholith considering Basgo diorite, Umla granodiorite, Taru granodiorite and Taru monzodiorite all are lying on the Fayalite-Magnetite-Quartz linear segmented line. As compared it from the references like Carmichael (1967, 1991), Bizourd et al. (1980), Novak and Mahood (1986), Mahood (1981), Vogel et al. (1989), as samples are plotted over the logarithmic plot of f_{O_2} versus temperature $T(^{\circ}C)$ that falls in between the field of Fayalite-Magnetite-Quartz (FMQ) and Wustite-Magnetite (WM).

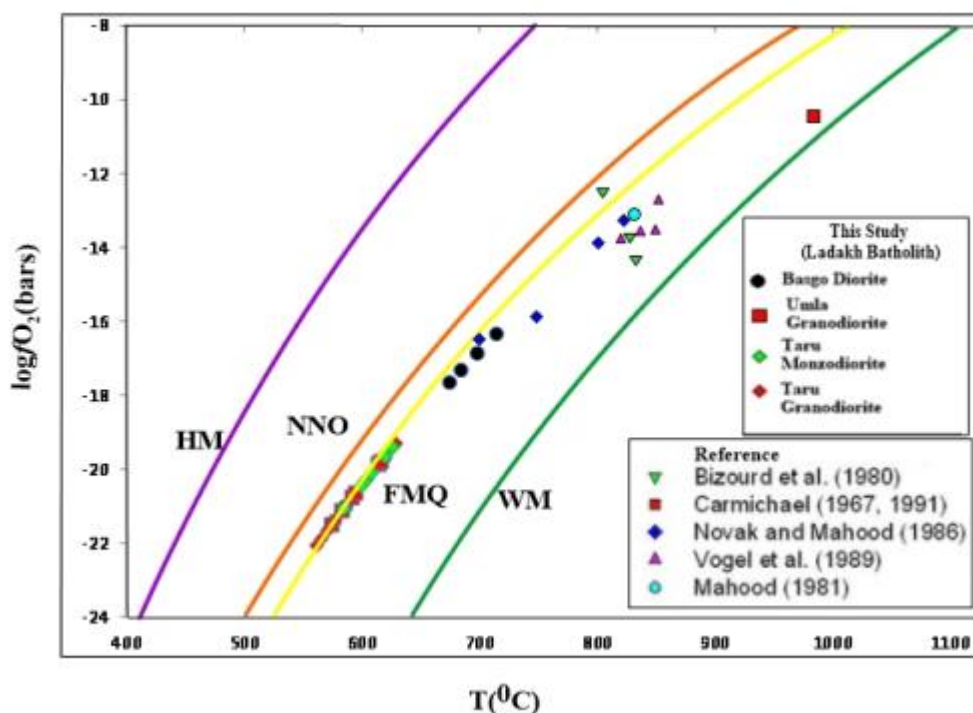


Figure 4.79. Logarithmic plot of f_{O_2} versus temperature $T(^{\circ}C)$ for the Basgo, Nimmu, Umla and Taru intrusive rocks. Abbreviations: Hematite-Magnetite (HM), Fayalite-Magnetite-Quartz (FMQ), Wustite-Magnetite (WM) and Nickel-Nickel Oxide (NNO)

4.4.3. Summary

The mineral phase characteristics and also geothermo-barometry of the Basgo, Nimmu, Umla and Taru intrusive rocks have been summarized in Table 4.5.

Table 4.8. Summary of the geothermo-barometry and features of mineral phase of the intrusive rocks from the Central Anatolian Massif. Pressures (kbars) were computed by the use of the Schmidt's calibration (1992) and T(°C) temperatures were computed by the use of the Blundy and Holland's calibration (1990).

Intrusive Rocks	Basgo	Nimmu	Umla	Taru
Rock Unit	Granite (1), Diorite (2)	Granite (1), Granodiorite (2)	Granite (1), Granodiorite (2)	Granite (1), Granodiorite (2), Monzodiorite (3)
Plagioclase	Mainly andesine and oligoclase (2); andesine, oligoclase and albite (1)	Oligoclase, albite and anorthoclase (1); mainly oligoclase and andesine (2)	Oligoclase and albite (1); andesine and oligoclase (2)	Oligoclase (1); andesine and oligoclase (2,3)
Amphibole	Magnesio- hornblende, edenite (1); magnesio- hornblende, edenite, magnesio- hastingsite, ferro- pargasite (2)	Magnesio- hornblende, edenite (1,2)	Magnesio- hornblende, edenite (1,2)	Magnesio- hornblende, edenite (1,2)
Biotite	Calc-alkaline (metaluminous) (1,2)	Calc-alkaline (metaluminous) (1,2)	Calc-alkaline (metaluminous) (1,2)	Calc-alkaline (metaluminous) (1,2,3)
Pressure (kbar)	2.88-23.84 (2)	-	2.73-3.43 (2)	2.74-3.55 (2); 2.90-3.94 (3)
Temperature (°C)	585-714 (2)	-	574-616 (2)	566-629 (2); 585-626 (3)

4.5. Major Oxides and Trace Element Geochemistry

Introduction

The bulk-rock geochemical analyses (major oxides and trace element) was analysed at Bureau Veritas Mineral Laboratories (Vancouver, Canada). The bulk-rock major oxides and trace element analytical data collected for 41 samples from West side of Leh district around the Ladakh Batholith of Trans Himalayan belt. Major oxides were analysed on fused glass discs by X-Ray Fluorescence spectrometry (XRF). Loss on Ignition (LOI) was computed with high heat to separate moisture or liquid content of rock powder at a temperature of 900°C for >2 hrs. The ICP-MS trace elements that determined were Sc, V,

Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Nd, Pb, Th and U. A subset of representative samples were also analysed for Rb, Sr, Y, Zr, Nb, Cs, Ba. Rare Earth Elements (REE), Hf, Ta, Pb, Th and U by ICP-MS. The results are given in supplementary tables. The analytical data, accuracy and precision of analytical data is given in Appendix. The sets of XRF and ICP-MS data is given in Appendix.

This chapter is characterised into two sections:

4.5.1. The first Section classifies the samples of Ladakh Batholith intrusive rocks on major element contents and examines the major element variation diagrams.

4.5.2. The second Section concentrates on the trace element characteristics, as shown by trace element variation diagrams, REE patterns, multi-element patterns and tectonic discrimination diagrams.

4.4.1. Major Element characterisation of Ladakh Batholith

4.4.1.1. Classification of Intrusive rocks using major element geochemistry

The Ladakh Batholith intrusive rocks have a broad petrological spectrum from biotite amphibole granodiorite, quartz granodiorite to biotite granite. The intrusive rocks from the Ladakh Batholith plotted on the total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) wt% versus SiO_2 wt% diagram after Cox et al. (1976) as shown in (Figure 4.80).

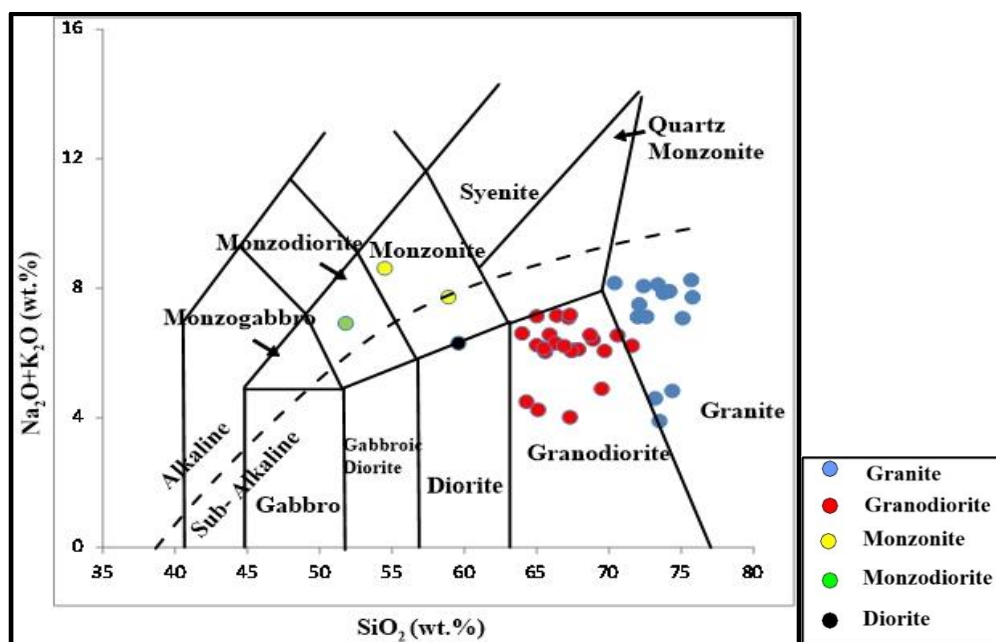


Figure 4.80. The intrusive rocks from the Ladakh Batholith plotted on the total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) versus SiO_2 diagram after Cox et al. (1976). Most of the samples are plotted in the

field of granite and Quartz diorite. But some of the samples are also touches the boundary in and around gabbro, diorite, syeno-diorite.

The whole-rock samples from Ladakh Batholith intrusive rocks that plotted on the total alkali ($\text{Na}_2\text{O}+\text{K}_2\text{O}$) versus SiO_2 diagram after Cox et al. (1976) that falls in the field of granite and quartz diorite. Some of the samples are taking the place in and around gabbro, diorite and syeno-diorite field.

The analytical data collected from the Leh district of Ladakh Batholith region that fall in distinct region of this diagram. The figure shows the collected data from the intrusives rocks of the Basgo, Nimmu, Umla and Taru granites. The diagram after Cox et al. (1976) is displayed in Figure 4.80 to show the compositional differences between the rock types. The Basgo, Nimmu, Umla intrusive rocks, which is made up of granodiorite to granite by covering a wide range of SiO_2 that varies from 65% to 75%. The Taru pluton consists of quartz granodiorite, monzodiorite, granodiorite and granite. Some of the granite samples are falling in and around the field of gabbro and syeno-diorite with the varying concentration of SiO_2 from 50% to 55%.

The intrusive rocks from the Ladakh Batholith have been classified as high K types according to their K_2O and SiO_2 content that plotted on the diagram Peccerillo and Taylor 1976 (Figure 4.81). The below diagram shows the data collected from the four district areas like Basgo, Nimmu, Umla and Taru granites. In Figure 4.81, the plotted samples of Basgo intrusives rocks have the lowest concentration of K_2O (0.94% to 4.77%) and shows a well-defined positive correlation with SiO_2 concentration that varies from 59.6% to 73.5%. The Taru granites shows the highest value of K_2O (1.41% to 4.96%) and showing positive correlation with SiO_2 (65.6% to 75.8%). The rest of the samples that collected from Nimmu and Umla region show intermediate concentration of K_2O that ranges from 1.35% to 4.26% and from 1.58% to 3.67% respectively as compare it to the other samples collected area.

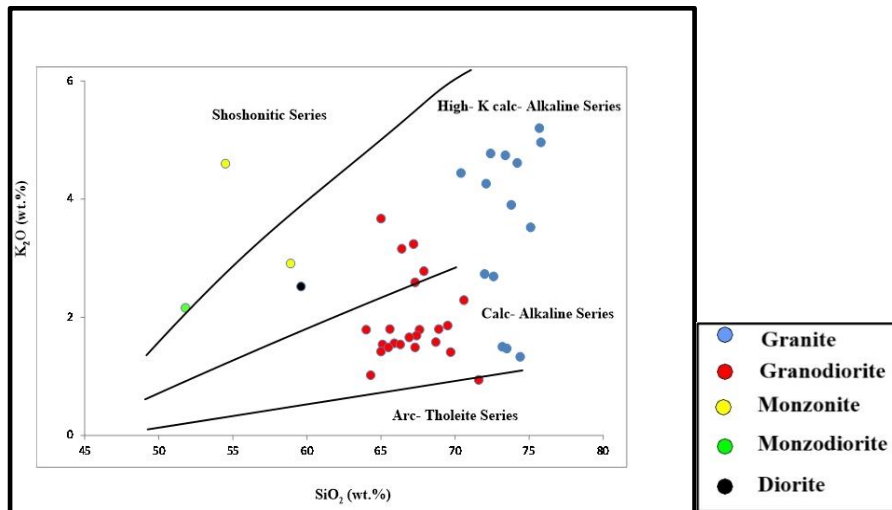


Figure 4.81. The intrusive rocks from the Ladakh Batholith plotted on the K_2O versus SiO_2 diagram Peccerillo and Taylor 1976.

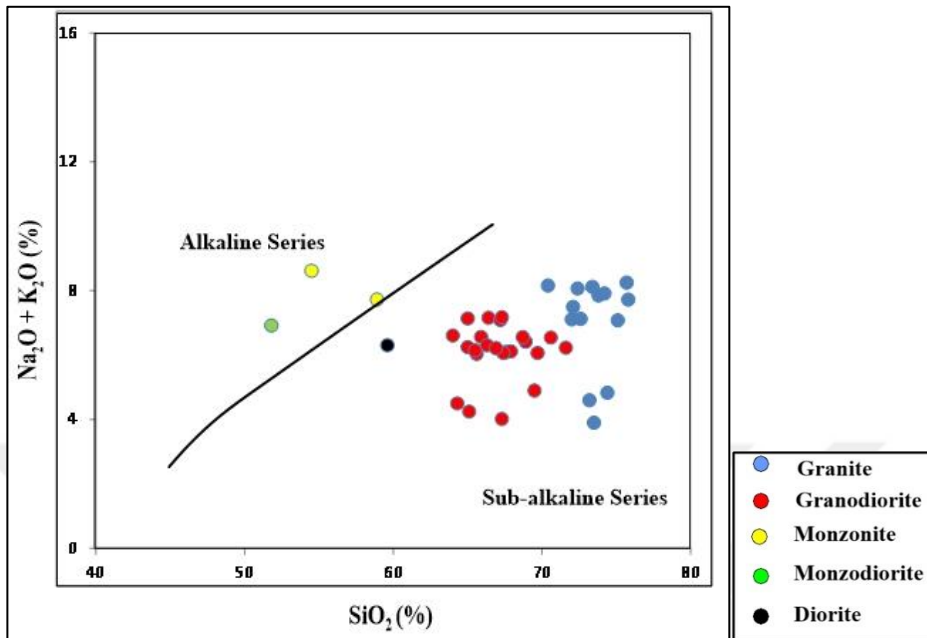


Figure 4.82. shows the intrusive rocks are plotted on the classification of Irvine and Baragar (1971). Diagram shows the plot with both alkaline and subalkaline series.

In addition to that, on the basis of total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$ wt%) versus SiO_2 wt% diagram of Irvine and Baragar (1971) (Figure 4.82). Most of the intrusive rock samples from Basgo, Nimmu, Umla and Taru are fall in the field of subalkaline series. The intrusives plot mainly in the subalkaline field except for the least acidic samples which fall in the alkaline field. But one of the Basgo intrusive rock sample that lie in between the subalkaline and alkaline fields. The concentration of total alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$ wt%) that varies from 3.9% to 8.65% by comparing with highest concentration of SiO_2 (54.5% to 75.8%).

The intrusive rock samples are plotted on the classification of ternary AFM diagram of Irvine and Baragar (1971) (Figure 4.83). It shows the distinction between the tholeiite and calc-alkaline is based on the triangular plot between ($\text{Na}_2\text{O} + \text{K}_2\text{O}$), FeO and MgO. The intrusive rocks from the Ladakh Batholith plot within the calc-alkaline field on the ternary AFM diagram and there is no iron enrichment is observable. The intrusive rocks that plot almost on the A corner of the AFM diagram showing alkali enrichment.

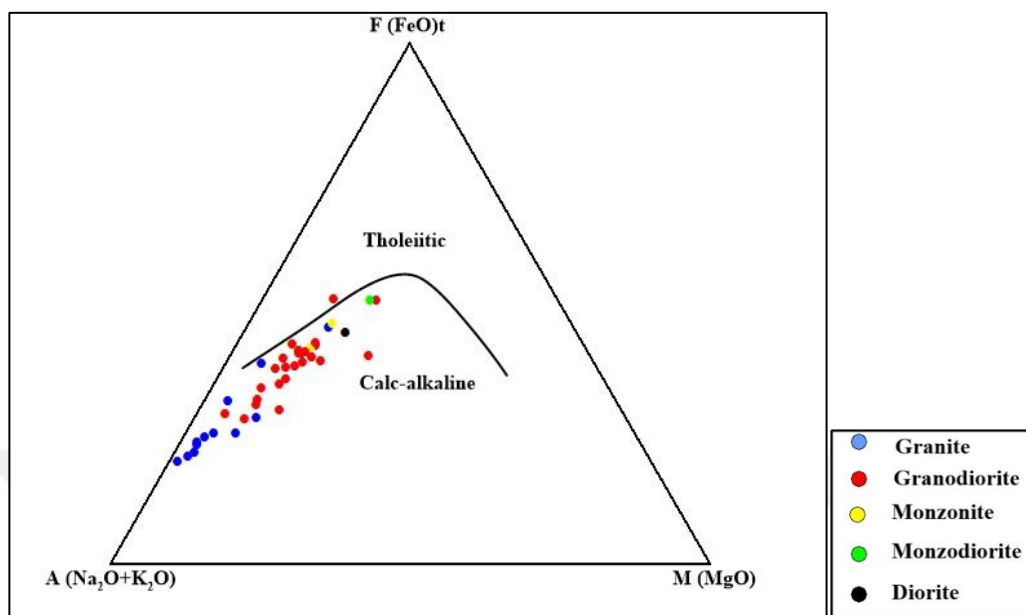


Figure 4.83. shows the intrusive rock samples are plotted on the classification of ternary AFM diagram of Irvine and Baragar (1971). It shows the triangular plot between FeO-($\text{Na}_2\text{O}+\text{K}_2\text{O}$) and MgO.

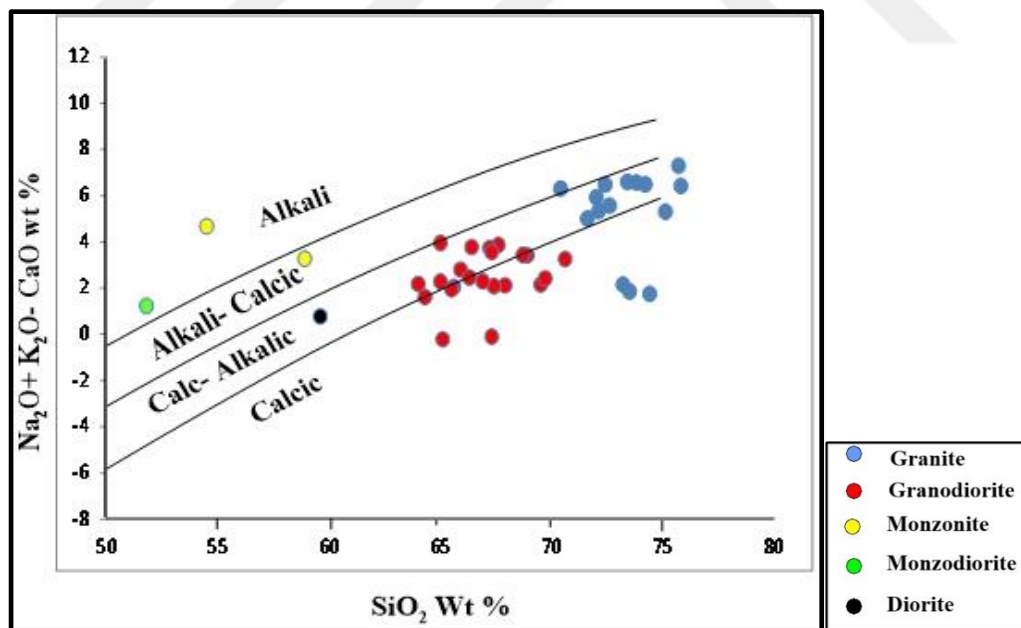


Figure 4.84. shows the intrusive rocks are plotted on the Frost et al. (2001) classification of granitic rocks between ($\text{Na}_2\text{O}+\text{K}_2\text{O}-\text{CaO}$) wt % versus SiO_2 wt%.

In addition to that, the intrusive rocks are plotted on the Frost et al. (2001) classification of granitic rocks between ($\text{Na}_2\text{O}+\text{K}_2\text{O}-\text{CaO}$) wt % versus SiO_2 wt% (Figure 4.84). The diagram shows the four different categories like alkalic, alkali-calcic, calc-

alkalic and calcic. Most of the plotted intrusive rock samples that falls in the field of calc-alkalic and calcic region. It shows most of the samples considering high concentration of SiO_2 (65.6 % to 75.8%) wt % that falls calc-alkalic and calcic region as compare to the rest of the few samples fall in alkalic and alkali-calcic.

In Shand (1951) diagram of alumina saturation of index (ASI) (Figure 4.85), the intrusive rocks from the Ladakh Batholith area around Leh, Ladakh district shows the plotted samples are falls in the field of metaluminous and per-aluminous as well. And most of the samples are touching the margin between metaluminous and per-aluminous. The Nimmu and Umla plutonic rocks are metaluminous except for some of the samples from the Basgo and Taru pluton which are peraluminous (Figure 4.85).

A/CNK values of Ladakh granitoids are ranges from 0.87-1.31, indicates an I-type parentage for most of the samples, whereas some samples shows transformation between I- and S-type granitoids (Figure 4.85). The more mafic rocks have lower A/CNK value, but highly siliceous rocks have high A/CNK values probably indicating that the chemical variation of these granites may be controlled by fractional crystallization processes.

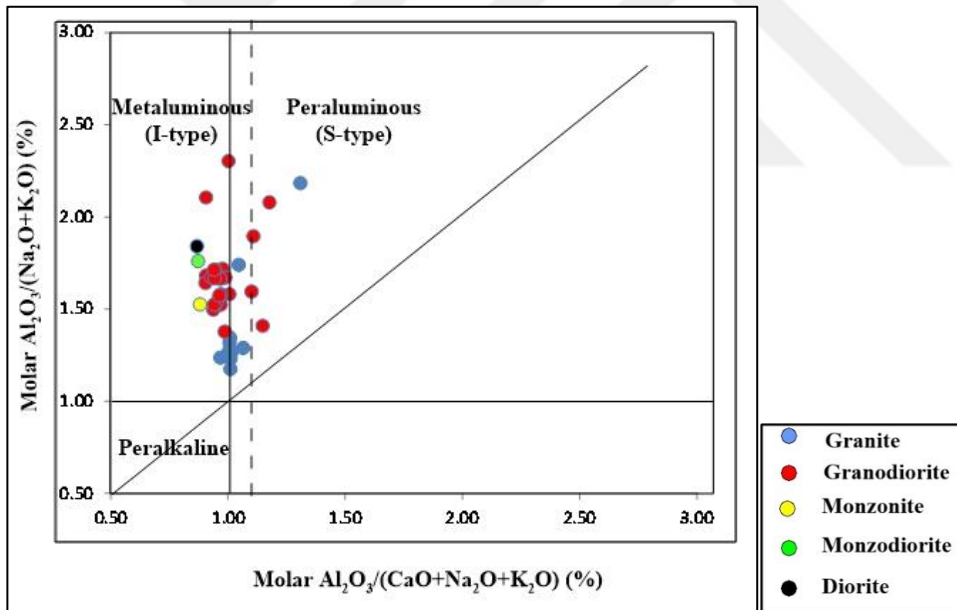


Figure 4.85. shows the alumina saturation diagram of Shand (1951) of the intrusive rock samples from Ladakh Batholith area.

4.4.1.2. Classification of major oxides on the basis of Harker Diagrams

On the Harker's binary diagrams major oxides are plotted against SiO_2 where Al_2O_3 , TiO_2 , Fe_2O_3 , MgO , CaO , Na_2O , P_2O_5 of Ladakh granitoids show moderate to strong negative correlation. The samples from the field area have SiO_2 of 51.8-75.8%. $\text{A/CNK} = 1.0$ -1.1 and $\text{TiO}_2 + \text{FeO} + \text{MgO} = 2.5$ -16.24% (Figure 4.85). The concentration of Fe_2O_3 , Al_2O_3 , MgO , CaO and TiO_2 are usually higher whereas $\text{K}_2\text{O} + \text{Na}_2\text{O}$ wt% is lower. The

intrusive rocks from the Ladakh Batholith are marked on Figure 4.86 with silica as the index of distinction. Silica contents of the intrusive rocks from the Massif ranges from 54.5wt% to 75.8 wt% approximately.

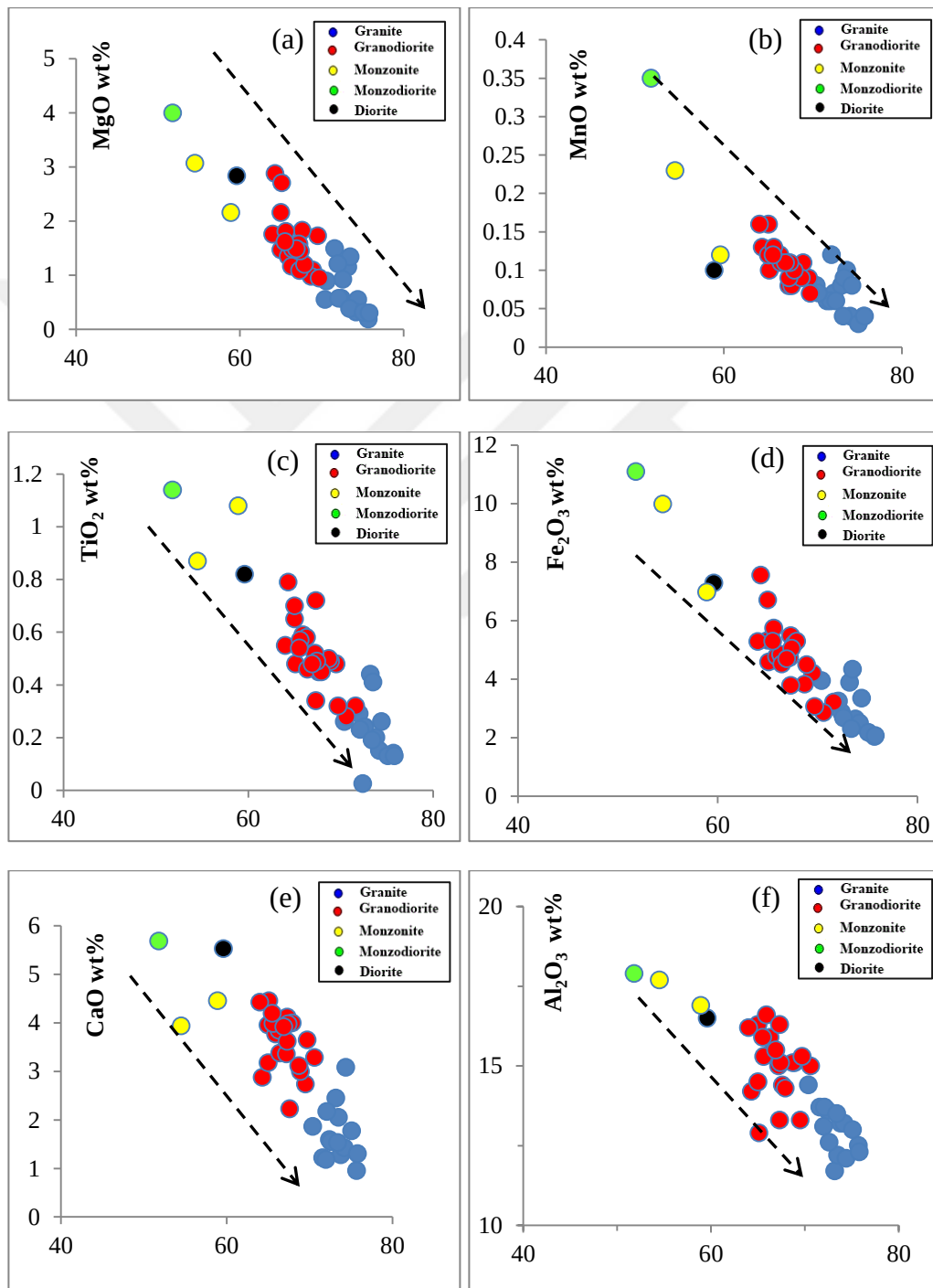


Figure 4.86. shows the Harker variation diagrams of the intrusive rocks from the Ladakh Batholith around Leh, Ladakh district. (Figures numbered from (a) to (i)).

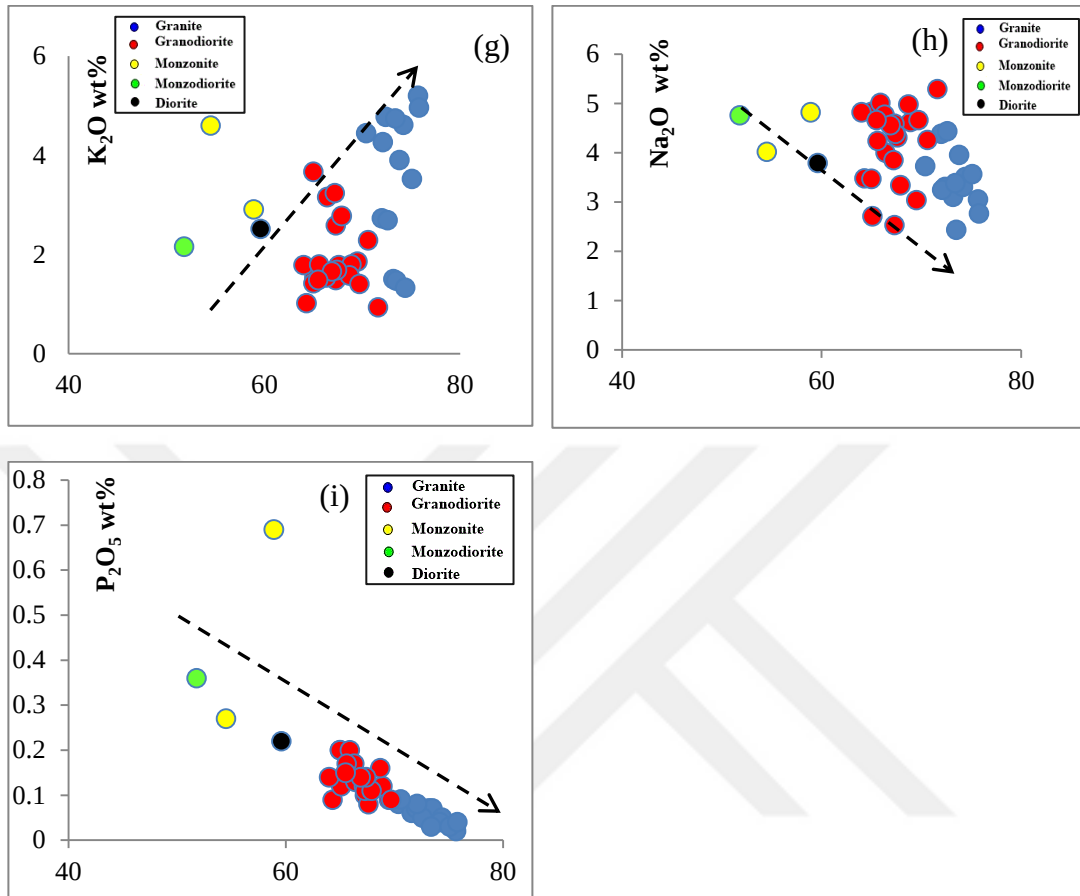


Figure 4.86.continue

The chemical analyses of major element geochemistry reveals that these granitic rocks (granitoids) display a wide range of SiO₂ content (54.50 wt%-75.80 wt%). In contrary to other major oxides are marked against SiO₂ in order to display the pattern of fractionation (Figure 4.86). The oxides of TiO₂ (0.03 wt%-1.14 wt%), MgO (0.30 wt%-2.88 wt%), and Fe₂O₃ (2.03 wt%-7.56 wt%) constituents shows a negative correlation with SiO₂.

The SiO₂ content shows a negative correlation with CaO (0.95 wt%-5.53 wt%) and P₂O₅ (0.02 wt%-0.27 wt%). Apart from this another oxides shows strongly negative trends with SiO₂ are observed for Al₂O₃ (11.70 wt%-17.7 wt%), Na₂O (2.43 wt%-5.29 wt%) and K₂O (0.94 wt%-4.96 wt%). The major oxides of K₂O, Al₂O₃, MgO and Fe₂O₃ shows negative correlation with SiO₂ probably shows the biotite fractionation during crystallization processes. The CaO and TiO₂ shows positive correlation and combined with their negative correlation with SiO₂ most likely display the Sphene fractionation (CaTiSiO₅). The apatite fractionation also indicated by the positive correlation with CaO and P₂O₅ and their negative correlation with SiO₂.

In Harker variation diagrams, K_2O and Rb shows positive correlation against silica in Figure 4.86(g) and Figure 4.86(c) respectively, whereas TiO_2 , Al_2O_3 , Fe_2O_3 , MgO and CaO shows negative correlation with increase of silica, which is similar with their origination through fractional crystallization processes in the analyzed samples.

Ladakh intrusive rocks exhibit a positive correlation between K_2O and SiO_2 probably indicating concentration of K_2O in K-feldspar and biotite. Considering Fe_2O_3 as the differentiation index, its extremely good correlations with TiO_2 , MgO (Figure 4.86 (a,c)) and CaO probably indicate fractionation of biotite and plagioclase.

Depletions in P_2O_5 wt% (Figure 4.86(i)), Sr ppm, Hf ppm, Zr ppm (Figure 4.91(d,i,e)) and TiO_2 wt% (Figure 4.85(c)) against the concentration of SiO_2 wt% can be explained by the fractionation of apatite, plagioclase, zircon and titanite, respectively.

The ratios of Al_2O_3/TiO_2 and CaO/Na_2O in granitic rocks is totally dependent on the composition, temperature, pressure and the ratio of the melt's source rock. The most influential control on the ratio of CaO/Na_2O of the peraluminous granites (Sylvester, 1998) (Figure 4.90(a)). According to Patino-Douce and Johnston (1991), the experiment of melts are exposed on the plagioclase poor natural peliets, the melt has low CaO/Na_2O ratio because CaO is steady as garnet in the remaining part until garnet is absorbed at maximum temperature and Na_2O dissolves in the melt.

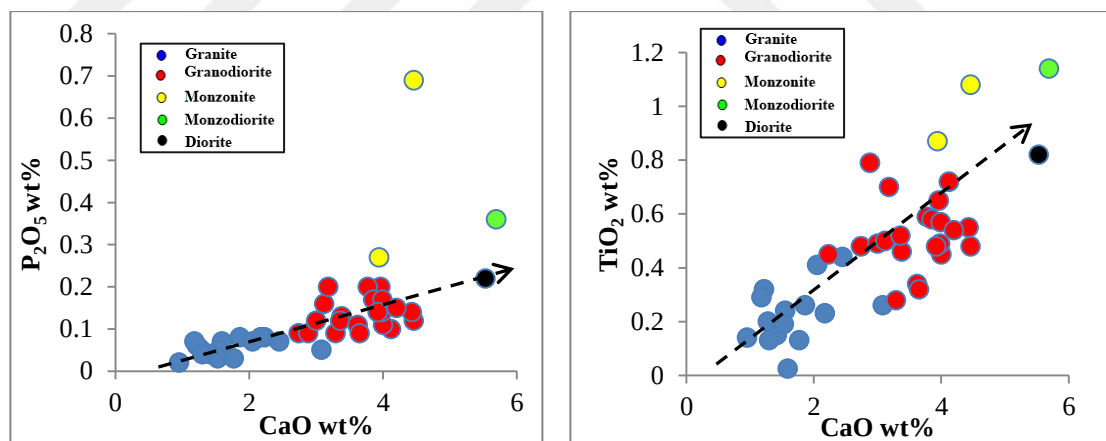


Figure 4.87. shows the Harker variation diagrams between CaO wt % vs P_2O_5 and TiO_2 .

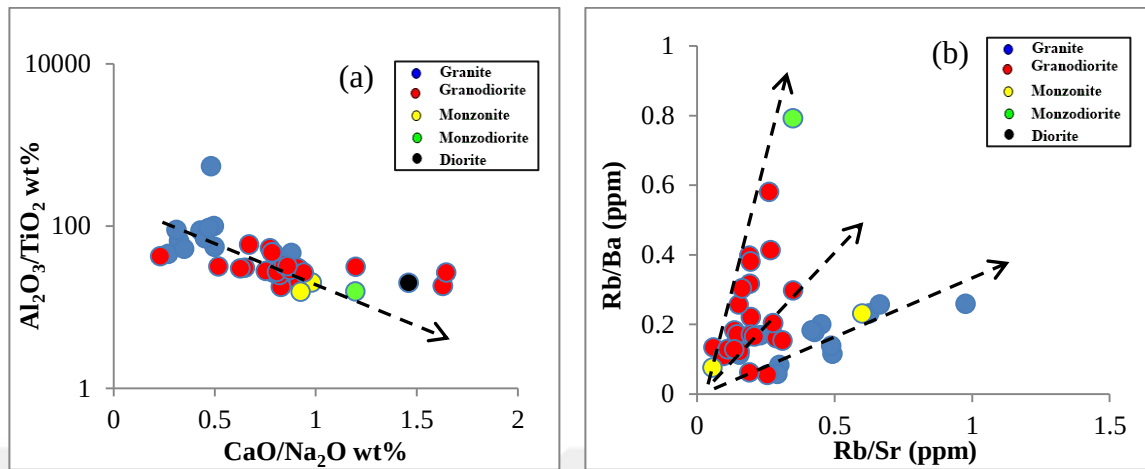


Figure 4.88. (a) Shows the samples are plotted between the ratio $\text{Al}_2\text{O}_3/\text{TiO}_2$ and $\text{CaO}/\text{Na}_2\text{O}$ ratios in granitic rocks. It shows the steep fall of $\text{Al}_2\text{O}_3/\text{TiO}_2$ wt% samples from granite to granodiorite to Monzodiorite with increase in $\text{CaO}/\text{Na}_2\text{O}$ wt%. (b) Figure shows that, the samples are plotted between Rb/Ba versus Rb/Sr diagram of (Sylvester, 1998). It shows the increase in Rb/Ba ratio with increase in Rb/Sr ratio with showing Rb/Sr vs Rb/Ba plot after Patino-Douce and Harris (1998) constraining the granite forming melt to be of clay poor and plagioclase rich composition.

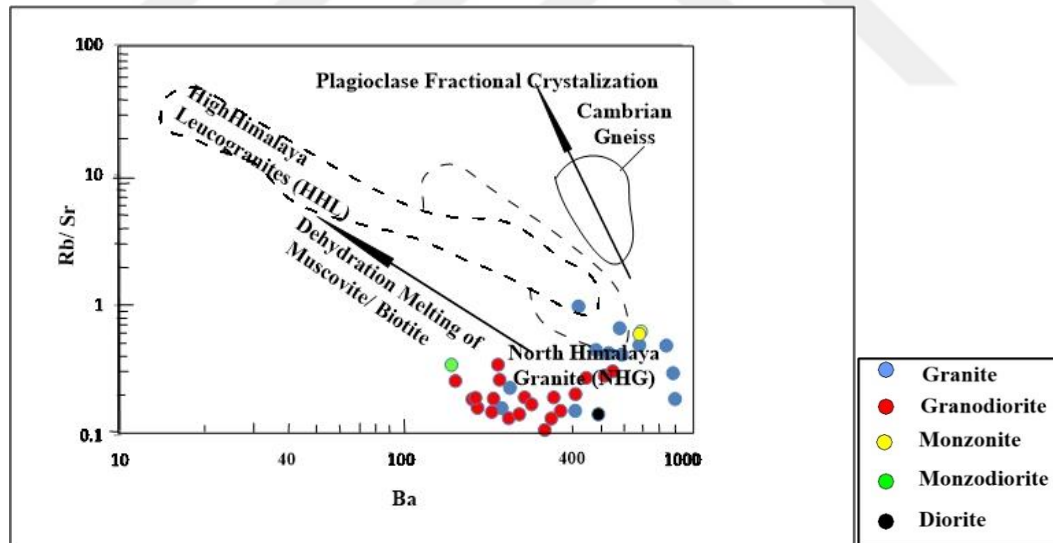


Figure 4.89. shows the sample plotted between Rb/Sr to Ba in which, samples are gathered at North Himalayan Granite (NHG). The plot shows the low concentration of Rb/Sr ratio with increase in the concentration of Ba .

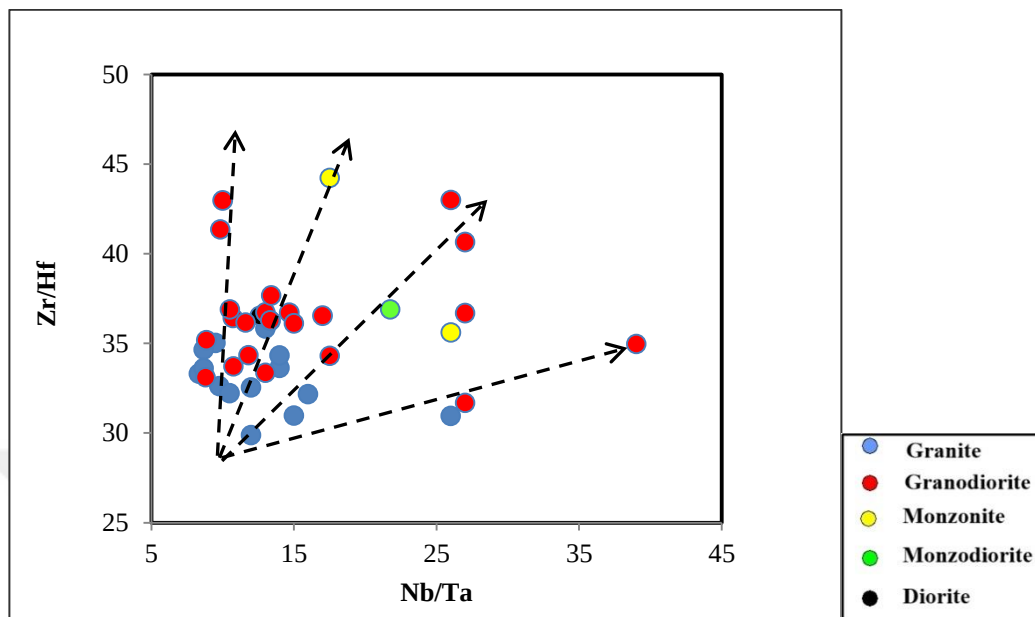


Figure 4.90. shows the samples are plotted between Zr/Hf and Nb/Ta. The plotted arrows shows different variation Zr/Hf ratio with increase in the concentration of Nb/Ta.

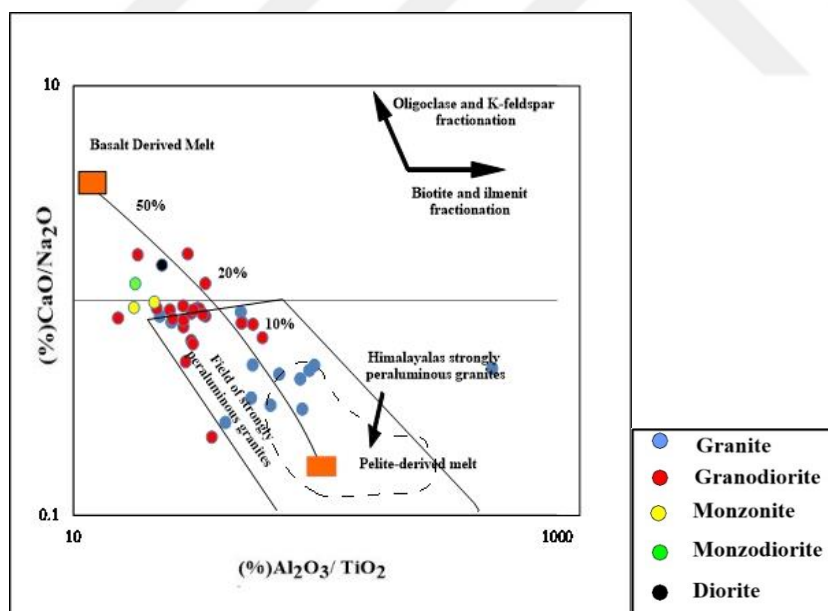


Figure 4.91. shows the samples are plotted between basalt derived melt and pelite derived melt, by showing the field of strongly peraluminous granites on the classification of (Sylvester 1998).

In the plotted samples, the melting investigations of Skjerlie and Johnston (1996) shows that the psammites contains larger amount of plagioclase and hence, the initial melt has lower concentration of both CaO and Na₂O but increases invariantly as plagioclase is preoccupied later, thus with increase in temperature CaO/Na₂O ratio will broadly remains

constant. As a result by (Sylvester, 1998), the psammite derived peraluminous granitic melts have high ratios than the pelite derived melts $\text{CaO}/\text{Na}_2\text{O}$ (0.3). These observations led Sylvester (1998) to suggest that for identification of the source of melts parental to peraluminous granites by building a plot $\text{Al}_2\text{O}_3/\text{TiO}_2$ versus $\text{CaO}/\text{Na}_2\text{O}$ diagram and Rb/Ba versus Rb/Sr (Figure 4.88(a, b)).

4.4.2. Trace element geochemistry characteristics of the plutonics

4.4.2.1. Trace element variation diagrams

The studied Ladakh granitoids of the study area show significant variation in trace element content as shown in Figure 4.91. Trace elements variation of Harker diagrams that plotted against silica are presented as log-normal diagrams for all the plutons in Figure 4.91. Like major element diagrams, the Basgo, Nimmu, Umla and Taru intrusive rocks generally plotted by showing distinctive differentiation trends on most of the diagrams (Figure 4.91).

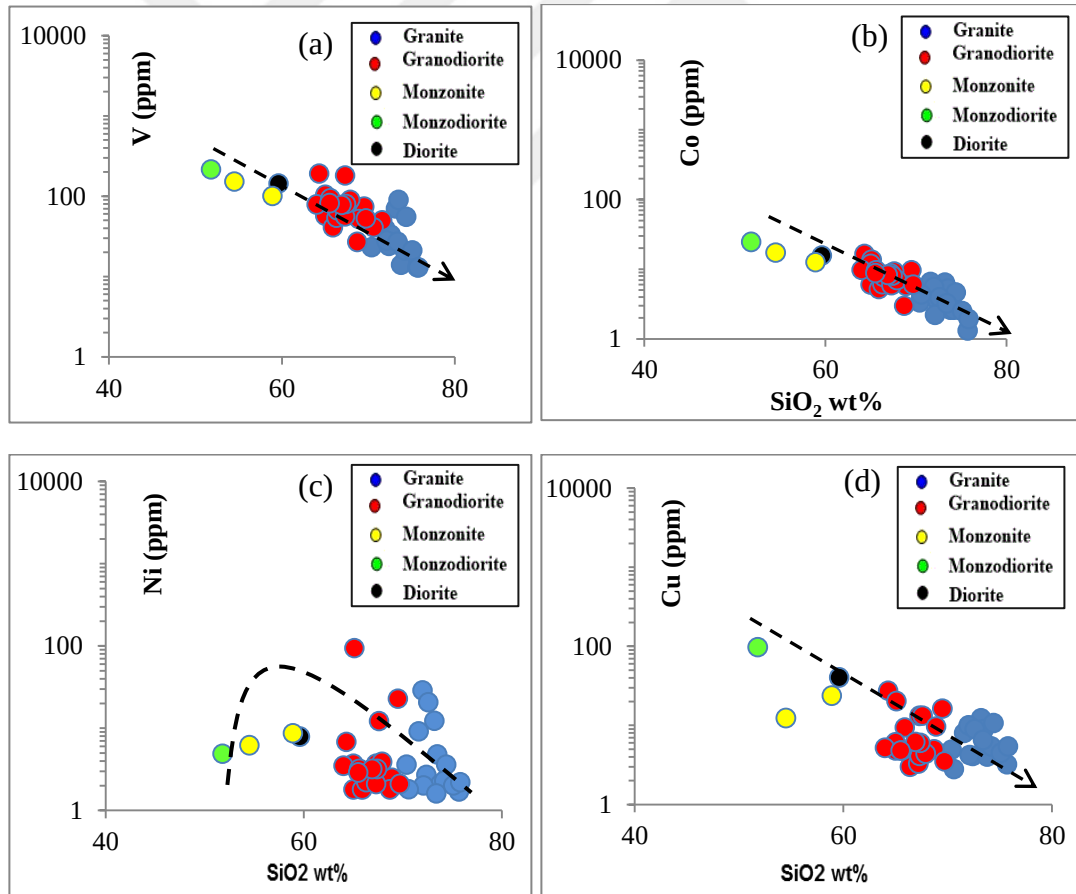


Figure 4.92. shows the variation diagram between trace element versus silica SiO_2 wt % ((a) to (o)) and Zr (ppm) versus Th (ppm) Figure (p).

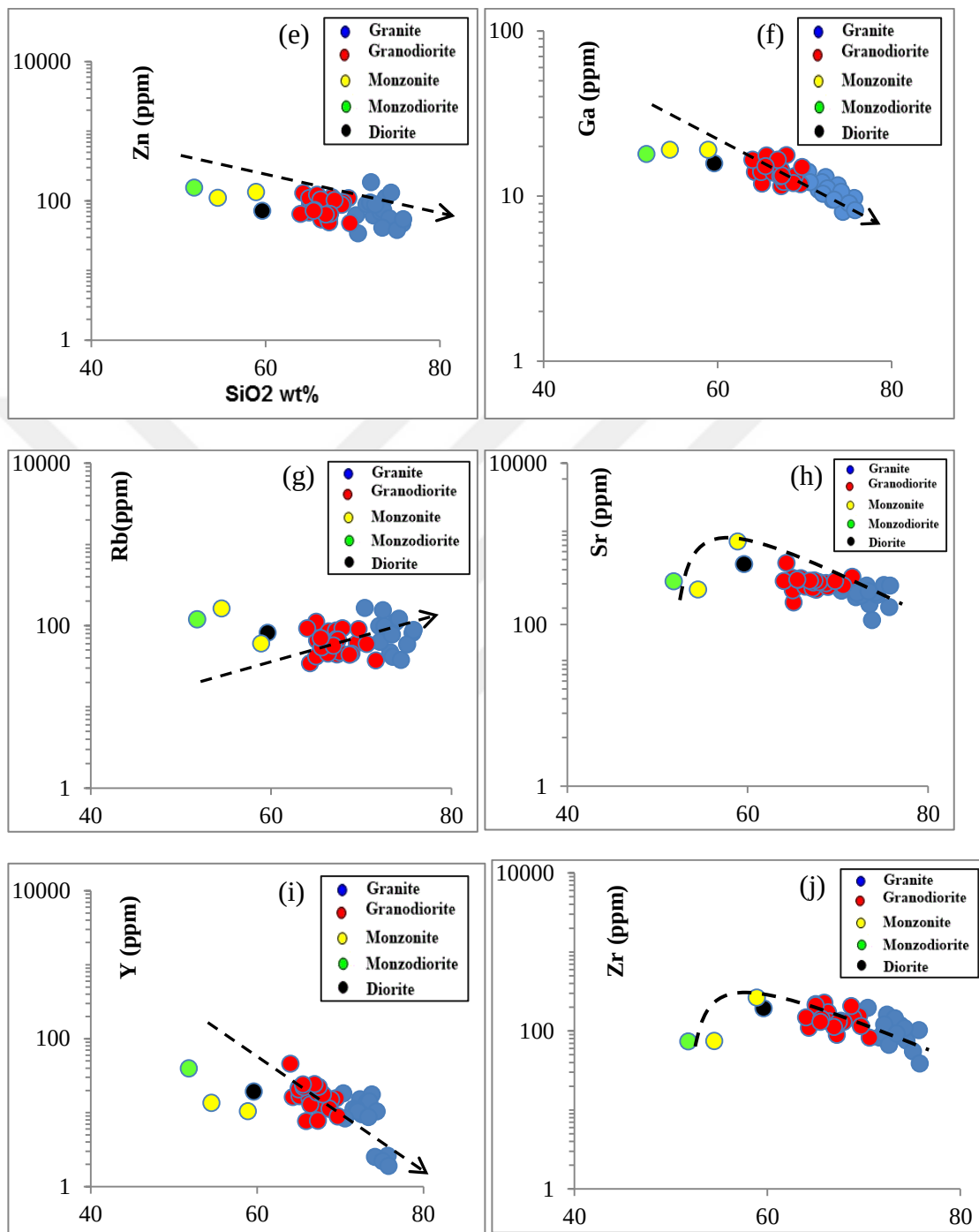


Figure 4.92. continue

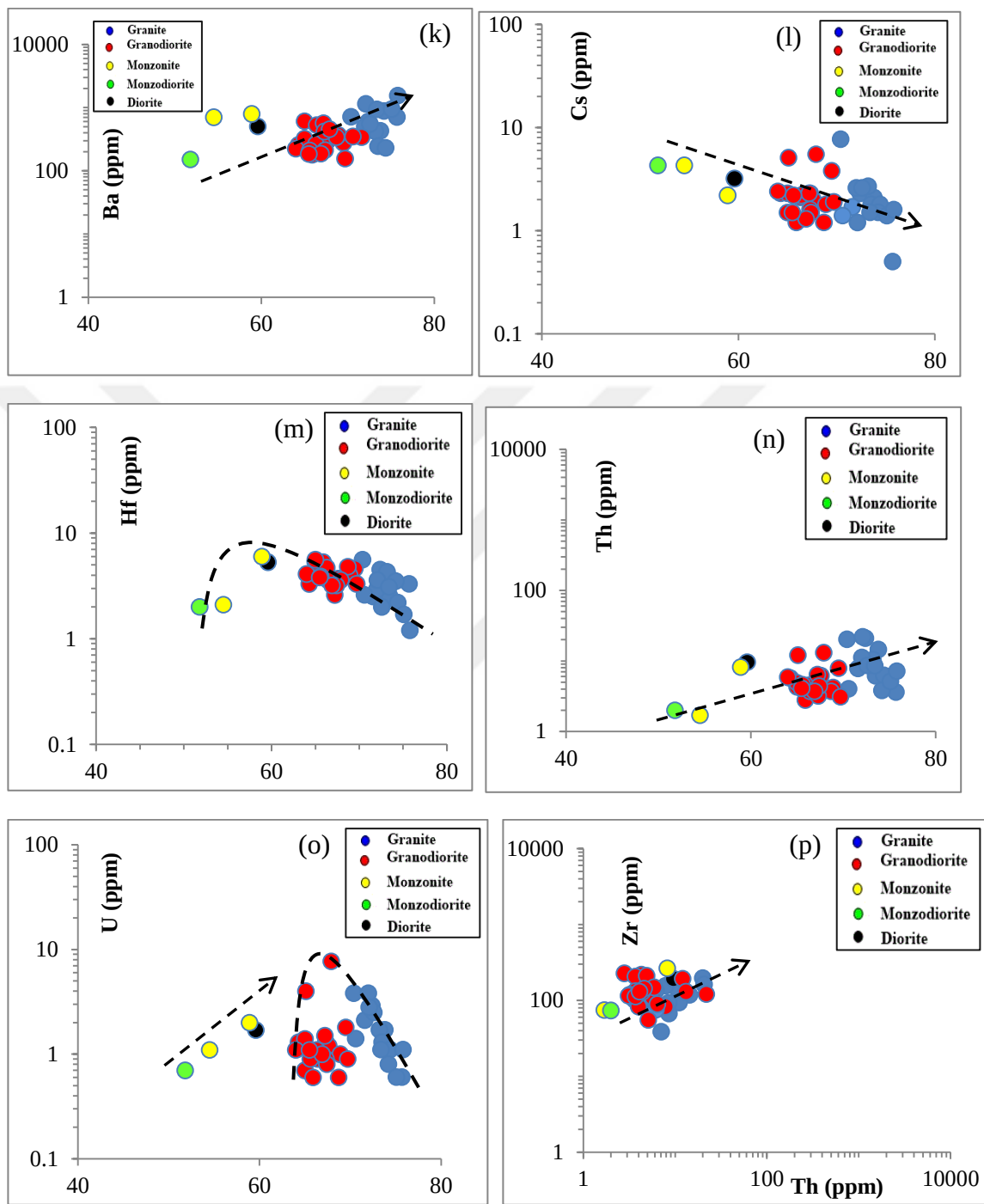


Figure 4.92.continue

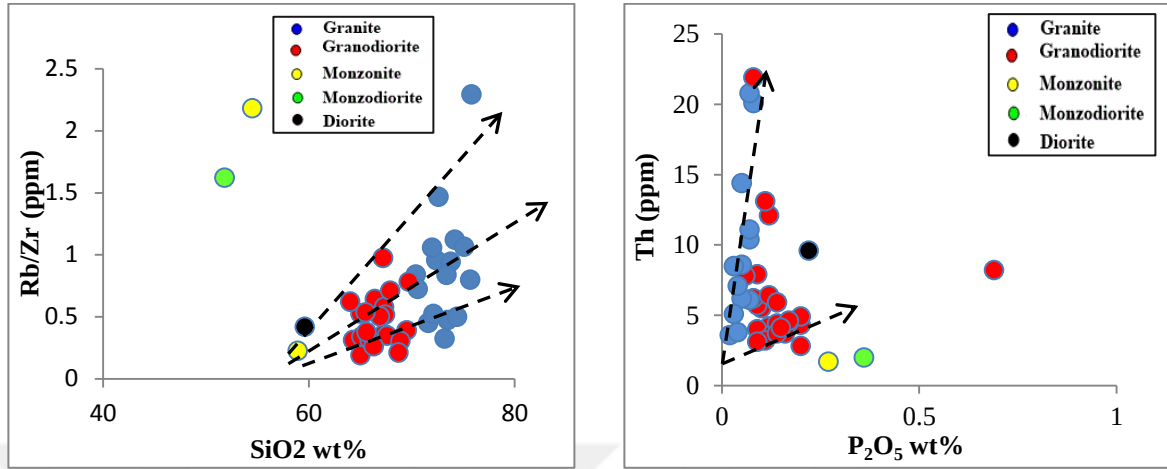


Figure 4.93. shows the variation diagram between Rb/Zr (ppm) versus SiO₂ (wt%) and Th (ppm) versus P₂O₅ (wt%).

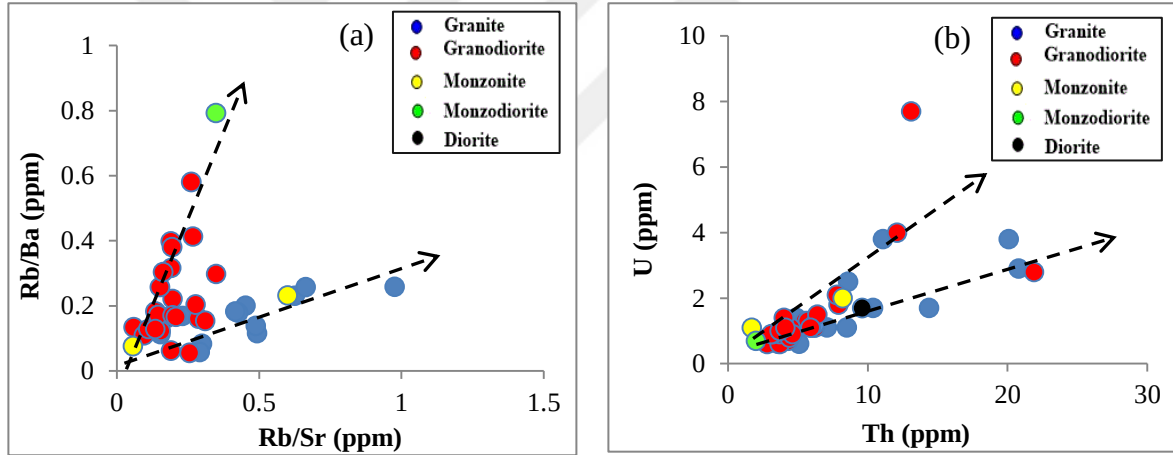


Figure 4.94. (a) shows the variation diagram based on the classification of Sylvester (1998) regarding Rb/Ba(ppm) versus Rb/Sr (ppm). (b) shows the positive correlation of variation diagram between U (ppm) versus Th (ppm).

V, Co, Ni, Cu, Cs, Hf, Zn and Ga have a negative correlation trend with silica as shown in the plotted diagram (Figure 4.92). V, Hf, Co and Zn shows a sharp decline trend with silica whereas Ni and Cu plotting diagram against silica, firstly shows the decline pattern of some samples and after that it shows a constant parallel pattern with silica due to lowest concentration of them.

Important trace elements like Zr, Sr, Rb and trace element ratios like Rb/Sr and Rb/Ba are plotted in the binary diagram (Figure 4.94). Slightly positive trend shown by the Rb against SiO₂ and negative trends are observed between Sr vs SiO₂. Overall Zr shows a negative correlation with SiO₂ and CaO and Sr shows the positive correlation. Zr demonstrates a constant decrease with silica until 65 wt. % and then falls rapidly for all intrusive rocks (Figure 4.92).

Strong negative and positive relationships are observed between Rb/Sr and Eu/Eu* against Sr respectively, indicating K-feldspar-plagioclase fractionation. The Ladakh granitoids are poor in Rb (ranges between 34.5-164.7 ppm; the high silica with high Rb content) and high Sr (113.3-1075.8 ppm). Sr abundances display a well ordered decrease with Eu/Eu*, probably displaying plagioclase dominated fractionation in the Ladakh granitoids.

The discrimination diagrams of elected trace elements against silica are displayed in Figure 4.92. The concentration of Zr and Th are (38.6-227 ppm) and (1.7-20.8 ppm) respectively. The Th shows a slightly positive correlation trend with both SiO₂ and Zr.

The Rb, Ba and Sr shows different trend with SiO₂ and the concentration of Rb, Ba and Sr are varies from (34.5-164.7 ppm), (151-1543 ppm) and (113.3-1075.8 ppm) respectively.

Sr concentration is generally well correlated with silica decreasing linearly with increasing SiO₂. Rb increasing linearly with increasing SiO₂ but shows a great degree of scatter than Sr. Ba generally decreases with increasing SiO₂ but again shows a greater degree of scatter throughout the compositional range. Compatible element like Y (1.9 to 39.8 ppm) decreases linearly with increasing SiO₂ showing scatter similar to Rb. Zr shows appreciable scatter with SiO₂, but the most felsic rock (>75 wt% SiO₂) generally have lower Zr than most of the lower silica granodiorite.

Plotting graph of U against Th (two element incompatible is nearly all phases in the assemblage shown an overall positive correlating trends) (Figure 4.92 (b)).

The intrusive rock samples of Ladakh Batholith region around Leh, Ladakh district shows a strong positive trend of correlation between the Rb/Sr and Rb/Ba ratios and also yield an important details with regards to their melt source rock (Figure 4.92 (a)).

The concentration of Ba, Pb and Nb of research area samples that displayed from 151 to 1543 ppm, 0.9 to 15.4 ppm and 1.2 to 17.5 ppm, respectively. Plotting Rb/Zr (ppm) against SiO₂ (wt%) shows a positive trend but in a scatter pattern.

Trace elements Rb, Sr, Ba are useful indicators for fractionation of the major phases like (e.g. feldspar, amphibole, and biotite) in the source rocks.

On other hand they show low content of incompatible element contents such as LIL (Ba, Sr, Rb) and HFS (Zr, Hf, Nb and Y). On the Harker's binary diagrams important trace elements plotted against SiO₂. Trace elements like Ni, Cr show negative correlation for the intrusive rocks. On the other hand incompatible elements such as Zr, Sr, Ba show slightly negative correlation with SiO₂.

During the cooling and crystallization of granitic melts in the late-stage, a volatile-rich phase such as aplite or pegmatite may be formed and some trace elements remove or mobilize (Hanson, 1978). The Rb seems to have moved from the granitic melt to the fluid

resemble for forming pegmatitic dike. Rb-ion mainly substitutes K-ion, and this net result is reflected by the composition of muscovite, biotite, and K-feldspar. As the mineral/melt partition coefficients (K_d) of Rb in high silica melt are 3.2 for biotite and 1.8 for K-feldspar (Nash and Crecraft, 1985), the high Rb content in pegmatitic dike may result in an abundance of modal muscovite.

As Zr and Th are mainly distributed into zircon, Zr-Th diagram shows positive relation, indicating zircon-fractional crystallization is strong in melt of granitic rocks of study area. It shows slightly decreasing trends of Rb, Ba, Y and Sr as SiO_2 increases, which results from micas, feldspar, and apatite crystallization (Figure 4.92 (p)).

Rb, Sr and Ba display the details of source rocks and unfavorable restriction on the factors overcome during strongly peraluminous granitic melt whereas REEs are primarily controlled by accessory phase behavior (Miller, 1985; Harris and Inger, 1992). The strongly peraluminous granites shows an extended line of increasing Rb/Sr ratio as Rb/Ba ratio increases in the Rb/Sr-Rb/Ba diagram (Figure 4.94 (a)). This means that strongly peraluminous granites with high $\text{CaO}/\text{Na}_2\text{O}$ ratio tend to have lower Rb/Sr and Rb/Ba ratios than those with low $\text{CaO}/\text{Na}_2\text{O}$ ratios (Sylvester, 1998).

The pelite-derived melts will not be particularly higher in Rb and Ba than pelite, because mica and K-feldspar are abundant in the residue, but Sr is similar to contents of pelite because of a low bulk solid/liquid partition coefficient (Miller, 1985). Thus Rb/Ba ratio in pelite-derived melt will be more than about 0.25 (Miller, 1985), and this result coincides with Sylvester's study (Figure 4.94). In the case of psammite-derived melt, the Rb/Sr and Rb/Ba ratios tend to be higher than source, because large amounts of plagioclase for which compatibility is showing in Sr and Ba but incompatibility in Rb elements will be left behind after melting.

However, the ratios of strongly peraluminous melts between Rb/Sr and Rb/Ba are a consequence not only of source configurations other than also for the extents of plagioclase and K-feldspar left behind in the source rocks (Miller, 1985; Harris and Inger, 1992; Sylvester, 1998). The strongly peraluminous granitic rocks are derived from clay-rich, plagioclase-poor meta-sedimentary rocks (Turpin et al., 1990; Patino Douce and Harris, 1998) show considerable difference in the Rb/Sr and Rb/Ba ratios. These can be explained by amount of residual mineral, that is, degrees of partial melting (Harris and Inger, 1992; Williamson et al., 1996).

4.4.3. Rare Earth Element (REE) geochemistry

The rare earth elements (REE) are a group of 15 elements with atomic numbers of 57 to 71 from lanthanum (La) to lutetium (Lu); of which all but Promethium-Pm occur naturally. The REE with lower atomic numbers are generally referred to as the light REE, LREE (La, Ce, Pr, Nd), those with higher atomic numbers as the heavy REE, HREE (Dy, Ho, Er, Tm, Yb, Lu), and with intermediate numbers as the middle REE, MREE (Sm, Eu, Gd, Tb).

The REEs have similar chemical and physical properties because they form stable 3+ ions of similar size. A small number of the REE also exists in oxidation states other than 3+, notably Ce^{4+} and Eu^{2+} . The REEs show differences in their mass and ionic radius due to small but steady decrease in ionic size with increasing atomic number. These small differences in their size and behaviour cause the REEs to become fractionated relative to each other in a number of petrological processes. Thus, the REEs are used in geochemistry to probe the genesis of igneous rocks.

4.4.3.1. Rare Earth Element (REE) abundances in whole-rock of the Ladakh Batholith

The intrusive whole-rock samples were analyzed for the REEs by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Samples plotted in accordance with the increasing silica content of the rock samples are presented on the legend of each diagram. The chondrite normalized REE patterns for the Basgo, Nimmu, Umla and Taru rocks from the complex are shown in Figure 4.94.

The chondrite normalized values of intrusive whole-rock samples were grouped into REE pattern for the intrusive negative rock pattern, positive rock pattern, negative and positive rock pattern.

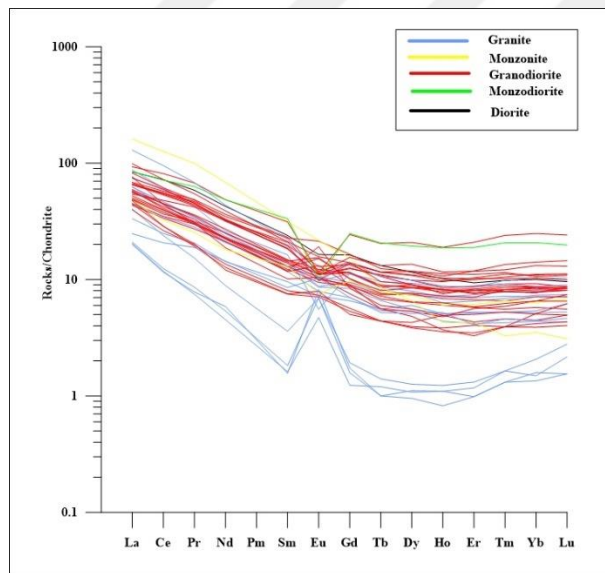


Figure 4.95. shows the chondrite- normalized REE pattern for the intrusive rocks. Normalized components from Sun and McDonough (1995).

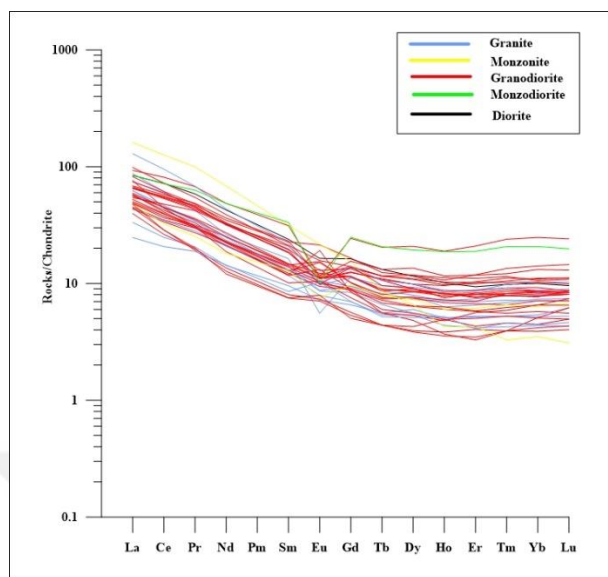


Figure 4.96. shows the revised chondrite- normalized REE pattern for the intrusive rocks. Normalized components from Sun and McDonough (1995).

Chondrite normalized REE pattern for the Ladakh granitoids exhibit enrichment of LREE with variable but predominantly negative Eu anomalies, the Eu/Eu^* varies between $\text{Eu}/\text{Eu}^*=0.35\text{--}4.97$. The more fractionated sample with the lowest iron content exhibits the highest $(\text{La}/\text{Yb})_N$ ratio. The samples with the lowest SiO_2 and the highest total iron contents shows the highest REE contents and it also show high Eu/Eu^* ratio.

They have small to moderate negative Eu anomalies and which is enriched by all LREE. LREE/MREE and MREE/HREE ratios are calculated by using the normalised ratios of $(\text{La}/\text{Eu}^*)_N$ and $(\text{Eu}^*/\text{Yb})_N$ respectively.

In Figure 4.95, Chondrite-normalized REE patterns where samples are usually display same configuration with distinct in abundances. Total REE content in between 20-181 ppm, and LREE enrichment to a certain degree to highly with $(\text{La}/\text{Yb})_N=3.75\text{--}45.95$. Negative Eu anomalies ($\text{Eu}/\text{Eu}^*=0.35\text{--}4.97$) and $(\text{Gd}/\text{Yb})_N=0.83\text{--}4.40$ with moderate HREE fractionation.

$(\text{La}/\text{Yb})_N=3.75\text{--}45.95$ such a large variation can be explained by large discrimination in the degree of incomplete melting (Smedley, 1988) and/or variable depth of melting, implying the absence or varying abundances of garnet in the source (Hanson, 1980) and/or the source was heterogeneous in terms of enrichment and/or a combination of some of the above controlling factors (Ahmad and Tamey, 1994).

REEs patterns such as: Light rare earth elements (LREE) > middle rare earth element (MREE) > high rare earth elements (HREE) showed the result with reflected

source rock patterns with an overall order of abundance. The enrichment of LREEs over HREEs with $(La/Yb)_N=3.75-45.95$ is shown by the chondrite-normalized patterns of REEs while the chondrite normalized value showed low $(Gd/Yb)_N=0.83-4.40$. This was illustrated in the flat HREE pattern. The enrichment of LREE and depletion of HREE shown by the chondrite normalized REE patterns of whole rocks. The REE range from Gd-Lu is considered to be heavy rare earth elements (HREE) and La-Sm is classified as light rare earth elements (LREE).

High $(La/Yb)_N$ ratios 3.75-45.95 shown by Chondrite-normalization, which reflects the highly fractionated REE compositions. $(Gd/Yb)_N$ ratio was calculated to investigate the relative depletion of HREE. The chondrite normalized value shows low $(Gd/Yb)_N$ ratios 0.83-4.40, which is illustrated by the flat HREE pattern. Rare earth element patterns of the rocks are distinguished by the enrichment in the LREE $(La/Yb)_N=3.75-45.95$ relative to the MREE and HREE, with minor to moderate Eu anomalies ($Eu/Eu^*=0.35-4.97$).

The presence of small to moderate negative Eu anomalies indicates that feldspar and plagioclase were fractionating phases. The positive Eu anomalies probably indicate the cumulate plagioclase. In contrast, the granitic samples is discriminated by its low total REE contents and also large positive Eu anomalies, probably reflecting cumulate K-feldspar, as suggested by high K_2O .

The fractionation of REE during melting is function of abundance of phases, that is, the initial liquids may show positive or negative Eu anomalies and light REE enrichment or depletion, which depend upon residue mineralogy (Miller, 1985).

The initial melt having formed these granitic rocks represents weakly depleted content on feldspar after melting source, as mentioned above, and this result agrees with the melt behavior derived from clay-poor, plagioclase-rich quartzo-feldspathic source. And the low to moderate Eu anomalies represent that the melt has relatively high degree of partial melting from the source. While LREEs has narrow compositional gap among each sample in granitic rocks, HREEs show more wide compositional variations which result from zircon fractionation within melt.

In Figure 4.97 shows the chondrite-normalized REE pattern for the intrusive Negative rock pattern (Group 1). The REE range from La-Sm is classified as light rare earth elements and shows the steep fall in LREE rock pattern and Gd-Lu is considered to be heavy rare earth elements (HREE). Total REE content of 47.62-129.21 ppm, and are moderately to highly LREE enrichment, with $(La/Yb)_N=3.75-14.77$. Negative Eu anomalies $(Eu/Eu^*)_N=0.35-0.82$ and $(Gd/Yb)_N=0.97-1.63$ shows moderate HREE fractionation.

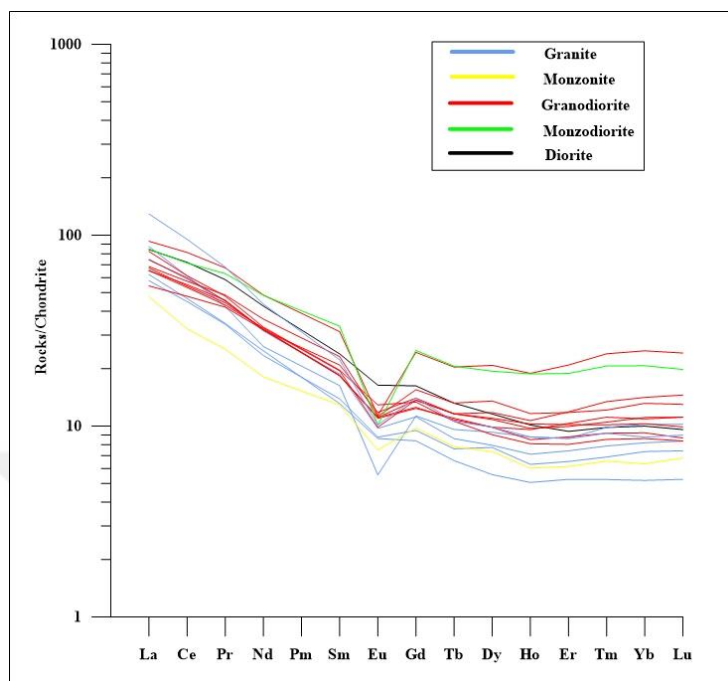


Figure 4.97. shows the chondrite-normalized REE pattern for the intrusive Negative rock pattern (Group 1). Normalized components from Sun and McDonough (1995).

The negative rock pattern (Group 1) considered of Granite, Granodiorite, Monzonite and Monzodiorite rock samples. In Figure 4.97, granite shows high negative Eu anomaly as compared to other rock samples. The enrichment of LREEs over HREEs with $(La/Yb)_N = 3.75-14.77$ shown by chondrite normalized patterns of REEs while the chondrite normalized value showed low $(Gd/Yb)_N = 0.97-1.63$. This was illustrated in the flat HREE pattern. The the enrichment of LREE and depletion of HREE of whole rocks shown by chondrite normalized REE patterns. Chondrite-normalization showed high ratio $(La/Yb)_N = 3.75-14.77$ which reflect highly fractioned REE compositions. $(Gd/Yb)_N$ ratio was calculated to investigate the relative depletion of HREE. The flat HREE pattern is resulted from chondrite normalized values showing low $(Gd/Yb)_N = 0.97-1.63$.

The presence of small negative Eu anomalies indicates that feldspar and plagioclase were fractionating phases. Rocks containing small to moderate REE pattern that contains limited range of LREE/HREE ratio $(La/Lu)_N = 5.11-14.39$. The rock samples in this Negative rock pattern (Group 1) show prominently small negative Eu anomalies $(Eu/Eu^*)_N = 0.35-0.82$, samples suggest only minor amount of feldspar crystallization and high fO_2 .

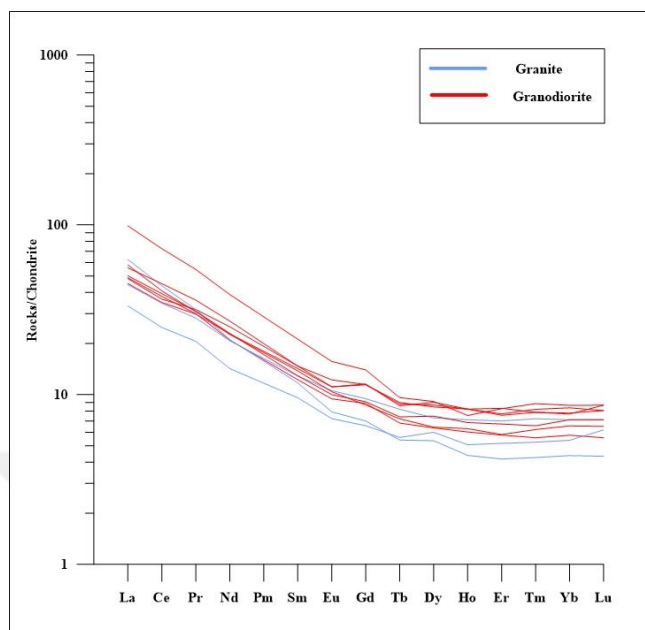


Figure 4.98. shows the chondrite-normalized REE pattern for the intrusives negative rock pattern (Group 2). Normalized components from Sun and McDonough (1995).

In Figure 4.98 shows the Chondrite- normalized REE pattern for the intrusive Negative rock pattern (Group 2). This group of rock samples consists of small negative Eu anomalies. They have total REE content of 33.33-98.73 ppm, and are small to moderately LREE enrichment, with $(La/Yb)_N = 5.39-14.29$. Eu anomalies ($Eu/Eu^* = 0.85-0.95$) and $(Gd/Yb)_N = 1.22-1.62$ with moderate HREE fractionation.

The negative rock pattern (Group 2) considered of Granite and Granodiorite rock samples. In Figure 4.98, granite shows high negative Eu anomaly as compared to granodiorite rock samples. The chondrite normalized patterns of REEs showed enrichment of LREEs over HREEs with $(La/Yb)_N = 5.39-14.29$ while the chondrite normalized value showed low $(Gd/Yb)_N = 1.22-1.62$. Chondrite normalization showed high ratio $(La/Yb)_N = 5.39-14.29$ which reflect highly fractionated REE compositions. $(Gd/Yb)_N$ ratio was calculated to investigate the relative depletion of HREE. The chondrite normalized value shows low $(Gd/Yb)_N = 1.22-1.62$, which is illustrated by the flat HREE pattern.

The Eu anomaly with the presence of small negative values indicates that feldspar and plagioclase were in fractionating phases. The alkali feldspar rich granitic rocks again focus on melting and crystallization models. The large number of rocks in this group with negative Eu anomalies requires that much feldspar is involved in the mineral and melt equilibria during melting and crystallization. Rocks containing small to moderate REE pattern that contains limited range of LREE/HREE ratio $(La/Lu)_N = 5.38-14.43$. The rock samples in this negative rock pattern (Group 2) show a noticeably small negative Eu anomalies ($Eu/Eu^* = 0.85-0.95$) ($Eu < 1$) samples suggest the large negative anomalies in the residual magmas were produced by feldspar crystallization.

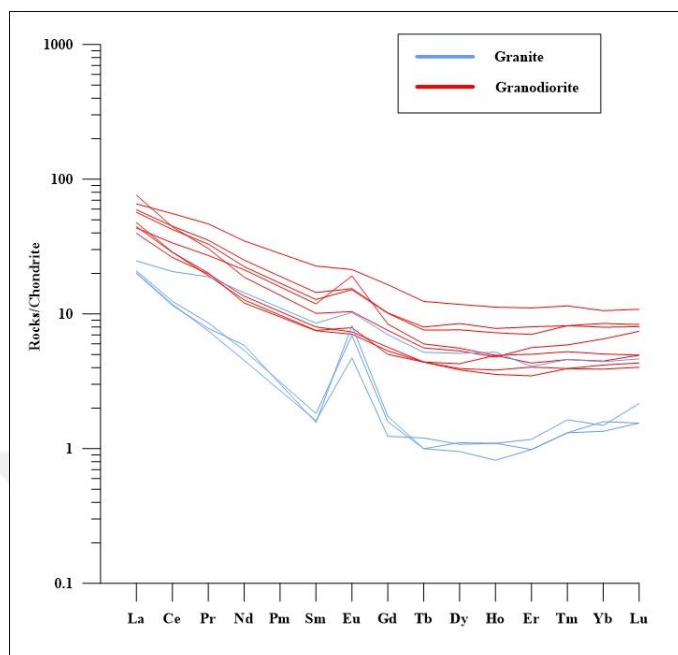


Figure 4.99. shows the Chondrite- normalized REE pattern for the intrusive positive rock pattern (Group 1). Normalized components from Sun and McDonough (1995).

In Figure 4.99, shows the Chondrite- normalized REE pattern for the intrusive positive rock pattern (Group 1). The REE pattern shows the steep fall in LREE in granodiorite as compared to granitic rock pattern and heavy rare earth elements (HREE) is considered as Gd-Lu, in which granodiorite shows the constant pattern of HREE but granite shows simultaneous enrichment and depletion of see saw HREE pattern. Total REE content of 20-76.19 ppm, and are certain extent to highly LREE enrichment, with $(La/Yb)_N = 5.60-15.56$. Eu anomalies ($Eu/Eu^* = 1.07-4.97$) and $(Gd/Yb)_N = 0.83-1.67$ is moderate with HREE fractionation.

The positive rock pattern (Group 1) considered of granite and granodiorite rock samples. In Figure 4.99, the granitic rock samples shows high positive Eu anomaly as compared to granodiorite rock samples. The enrichment of LREEs over HREEs with $(La/Yb)_N = 5.60-15.56$ is shown by chondrite normalized patterns of REEs while the chondrite normalized value showed low $(Gd/Yb)_N = 0.83-1.67$. The chondrite-normalized REE patterns of whole rocks showed the enrichment of LREE and depletion of HREE. Chondrite-normalization showed high ratio $(La/Yb)_N = 5.60-15.56$ which reflect highly fractionated REE compositions. $(Gd/Yb)_N$ ratio was calculated to investigate the relative depletion of HREE. The flat HREE pattern shows low $(Gd/Yb)_N = 0.83-1.67$ from chondrite normalized value.

The positive Eu anomalies indicate the cumulated plagioclase. The rocks with positive Eu anomalies that would presumably represent a large amount of cumulus minerals relative to magma are seldom found in these sequences (e.g. Cullers et al., 1981). Probably

the separations of crystals from magma are incomplete in such viscous magma so that few rocks with enough cumulus feldspar form to develop a positive Eu anomaly.

A melt with a large, negative anomaly mixed with cumulus plagioclase may never produce a rock with a positive anomaly unless the cumulus plagioclase is predominant. In Figure 4.99, shows the steep fall of LREE rock pattern upto Sm and then small amount of enrichment to reach positive Eu anomaly. Then again shows the depletion of rock pattern to Gd, afterwards it shows a flat HREE pattern upto Lu.

Rocks containing small to moderate REE pattern that contains limited range of LREE/HREE ratio $(La/Lu)_N=5.33-13.54$. The rock samples in this positive rock pattern (Group 2) show prominently positive Eu anomalies $(Eu/Eu^*=1.07-4.97)$ ($Eu>1$) samples suggest only major amount of feldspar crystallization.

In Figure 4.100, shows the chondrite-normalized REE pattern for the intrusive Negative rock pattern (Group 2) and Positive rock pattern (Group 1). It shows the granitic and granodioritic rock samples of both negative and positive rock pattern with steep fall of LREE upto Sm and then again shows steep depletion of MREE to Tb and then it shows a constant and regular flat pattern of HREE up to Lu. Total REE content is in between 24.76-98.73 ppm, and LREE enrichment are moderate to high with $(La/Yb)_N=5.39-14.29$. Eu anomalies $(Eu/Eu^*=0.85-1.89)$ and $(Gd/Yb)_N=1.16-1.67$ with moderate HREE fractionation.

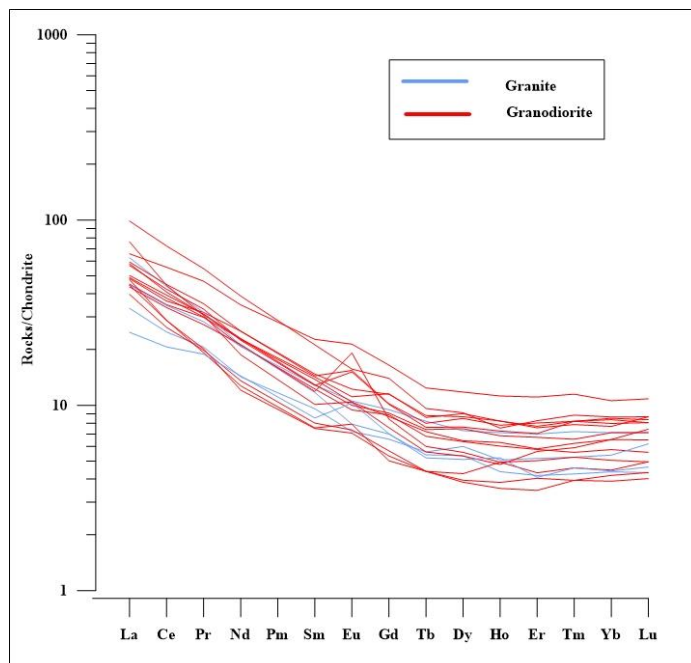


Figure 4.100. shows the rocks/chondrite-normalized REE pattern for the intrusive negative rock pattern (Group 2) and positive rock pattern (Group 1). Normalized components from Sun and McDonough (1995).

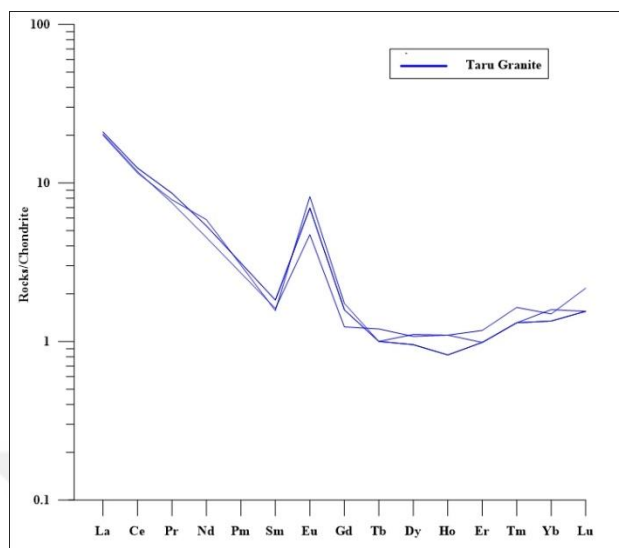


Figure 4.101. shows the rocks/chondrite-normalized REE pattern for the intrusive positive rock pattern (Group 2). Normalized components from Sun and McDonough (1995).

In Figure 4.101, shows the chondrite-normalized REE pattern for the intrusive positive rock pattern (Group 2). It consist of granitic rocks where LREE depletion falls up to Nd and from steep depletion Nd to Sm shows negative anomaly of Sm then increase or enrichment paatern to Eu shows positive anomaly. Total REE content range from 20-20.95 ppm, and having highly LREE enrichment, with $(La/Yb)_N=12.61-15.56$. Eu anomalies $(Eu/Eu^*=3.31-4.97)$ and $(Gd/Yb)_N=0.83-1.18$ with moderate HREE fractionation.

The Positive rock pattern (Group 2) considered of Granite rock samples. In Figure 4.101, the granitic rock samples shows high positive Eu anomaly. The chondrite normalized patterns of REEs showed enrichment of LREEs over HREEs with $(La/Yb)_N=12.61-15.56$. While the chondrite normalized value showed low $(Gd/Yb)_N=0.83-1.18$. The chondrite normalized REE patterns of whole rocks showed the enrichment of LREE and depletion of HREE. Chondrite normalization showed high ratio $(La/Yb)_N=12.61-15.56$ which reflect highly fractioned REE compositions. $(Gd/Yb)_N$ ratio was calculated to investigate the relative depletion of HREE. The chondrite normalized value shows low $(Gd/Yb)_N=0.83-1.18$, which is illustrated by the flat HREE pattern.

The positive Eu anomalies indicate the cumulatic plagioclase. The rocks with positive Eu anomalies that would presumably represent a large amount of cumulus minerals relative to magma are seldom found in these sequences (e.g. Cullers et al., 1981). Probably the separations of crystals from magma are incomplete in such viscous magma so that few rocks with enough cumulus feldspar form to develop a positive Eu anomaly.

4.4.4. Multi-element patterns

4.4.4.1. ORG-normalised diagrams

The oceanic ridge granite (ORG) normalized and chondrite-normalized spider diagrams for intrusive rocks are shown in Figure 4.100, Normalized values are taken from Pearce and Parkinson (1993) has been used for plotting diagrams. Pearce et al. (1984) proposed a spider diagram for granites to classify them on the basis of their tectonic settings. Trace element abundances are normalized to a hypothetical ocean ridge granite (ORG) produced by assuming 75% fractional crystallization of average N-type mid-ocean ridge basaltic magma (MORB) (Pearce et al., 1984).

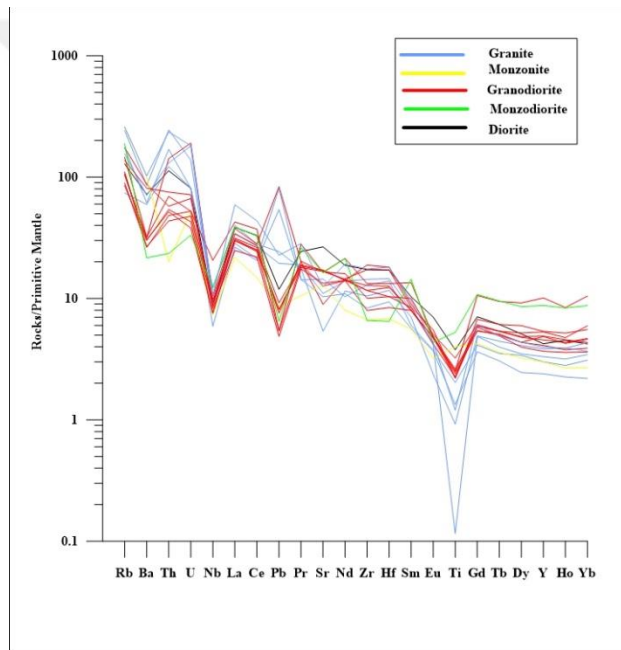


Figure 4.102. shows the rocks/primitive mantle-normalized diagram showing the geochemical properties of the negative intrusive rock pattern (Group 1). Normalized components from Pearce and Parkinson (1993).

Figure 4.102, shows the rocks/primitive mantle-normalized diagram with geochemical characteristics of the negative intrusive rock pattern (Group 1). The rock pattern consists of granite, granodiorite, monzonite and monzodiorite rock type.

Relative to both the ORG and chondrite, the whole granite rock shows the enrichment in Rb, Th. The clearly negative Zr and Y anomalies in ORG-normalized pattern is concluded by the zircon fractionation (Figure 4.102). The chondrite normalized pattern of the whole-rock granites display negative Ba anomalies but having positive Sr anomalies.

Ce has higher concentration than those of Zr and Y. Ce enrichment appear to be a typical geochemical properties of the volcanic arc and syn- collisional granites (Pearce et al., 1984).

Multi-element patterns for the Ladakh granitoids show the enriched characteristics with respect to the primitive mantle (Sun and Mc Donough, 1989), however it also shows depletion of HFSE including Nb, Pb and Ti. Such trace element characteristics are commonly observed in subduction-related magmatism (Saunders et al., 1980; Holm, 1985).

Figure 4.102 shows Sr anomaly shows positive pattern generally in the case of subduction-related magmatism (Holm, 1985), that these are generated in a subduction-related environment by their high Al_2O_3 abundance, predominantly calc-alkaline characteristic and rock association (Brookfield and Andrew-Speed, 1984).

Complementary, multi-element patterns show enrichment of LILE, with distinct negative Pb, Ba, Nb, P and Ti anomalies for both Ladakh granitoids and acidic volcanics. The multi-element pattern of these rocks display similarly enriched LILE and systematic depletion of Pb, Ba, Nb, P and Ti (Figure 4.102) as observed for Ladakh and for most subduction-related volcanics rocks and plutonic rocks (Wood et al., 1979; Briquieu et al., 1984).

The depletion of Nb is typical of the calc-alkaline magmatism from a subduction-zone environment. Samples shows the enrichment in the LIL elements (Rb, Th) and the LREE (Ce) relative to the HFSE (Zr, Hf, Sm, Y, Yb) (Figure 4.102). In addition, Y and Yb have low values relative to the normalizing compositions. There is also a relative enrichment of all elements except Ba in whole granite samples (Figure 4.102).

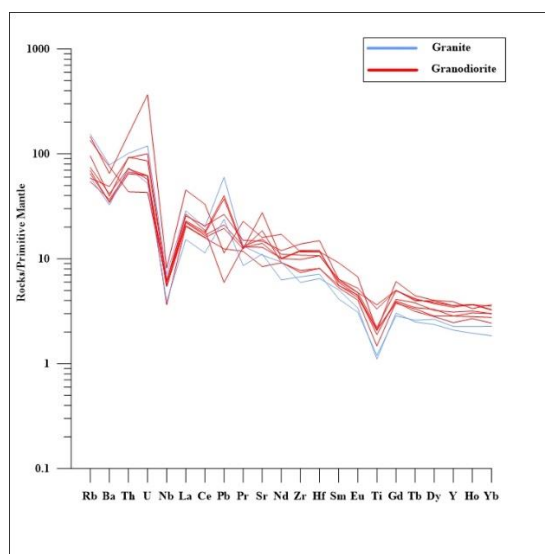


Figure 4.103. shows the rocks/primitive mantle-normalized diagram displaying the geochemical properties of the Negative intrusives rock pattern (Group 2). Normalized components from Pearce and Parkinson (1993).

Figure 4.103, shows the rocks/primitive mantle-normalized diagram displaying the geochemical properties of the negative intrusives rock pattern (Group 2). The plotted samples showing the rock type of granite and granodiorite. The Figure 4.4.14(b) shows the enrichment in Rb, Th and it also shows depletion of HFSE including Nb, Pb and Ti.

The more depletion of Ba displaying the most influential control over the crystallization of alkali feldspar. The enrichment in the LIL elements, and the LREE in comparison to the HFS elements shown by the sample. The patterns of the whole rocks are broadly similar in shape, differing mainly in the absolute abundances of the elements. There are nonetheless some features which are peculiar to particular rock types. For example, the most acidic rocks from the Basgo pluton (Figure 4.102) is more depleted in Ba than the other rock series, resulting in the more control of alkali feldspar. The shapes of the patterns resemble those for the volcanic arc (VAG) and collision granites (syn- and post-COLG) of Pearce et al. (1984). The strong Eu negative anomaly corresponds well to low Sr content, representing that plagioclase composition is relatively depleted.

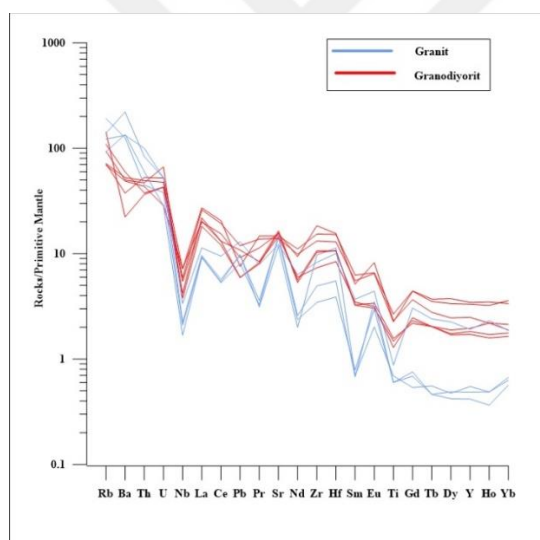


Figure 4.104. shows the rocks/primitive mantle-normalized diagram displaying the geochemical characteristics of the Positive intrusives rock pattern (Group 1). Normalized components from Pearce and Parkinson (1993).

Figure 4.104, shows the rocks/primitive mantle-normalized diagram displaying the geochemical properties of the positive intrusives rock pattern (Group 1). The plotted samples showing the rock type of granite and granodiorite. In Figure 4.104, shows the enrichment in Rb, Th and it also shows depletion of HFSE including Nb, Pb and Ti. Ba shows the depletion in granodiorite and enrichment in granite rock samples.

Pb shows the enrichment in granitic samples and depletion in granodiorite samples. Both granite and granodiorite shows sharp point depletion of Nb, Ce, Pr, Nd, Sm and Ti. The strong Eu positive anomaly corresponds well to enrichment of Sr content, representing that plagioclase composition is relatively enriched.

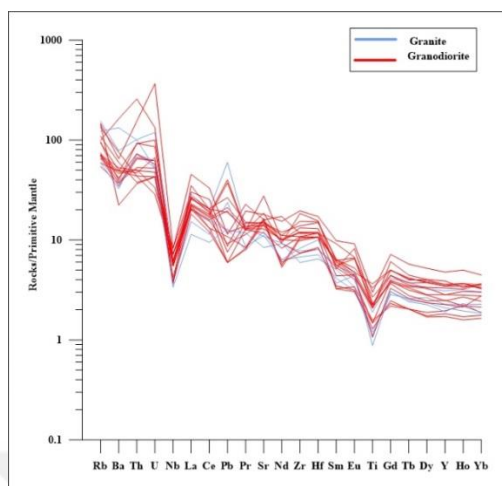


Figure 4.105. shows the rocks/primitive mantle-normalized diagram showing the geochemical characteristics of the Negative (Group 2) and Positive (Group 1) intrusives rock pattern from the complex. Normalized components from Pearce and Parkinson (1993).

Figure 4.105, shows the rocks/primitive mantle-normalized diagram showing the geochemical characteristics of the negative (Group 2) and positive (Group 1) intrusives rock pattern. The multi-element pattern displays the depletion of Nb, Nd, Pb and Ti as compared to the enrichment of Rb, Th, Ba shows the opposite relation with Sr, in which depletion of Ba with the enrichment of Sr. Primordial mantle-normalized spider diagrams (Figure 4.105) are characterized by negative Nb, Sr, Ba, P, Zr and Ti anomalies and relates with high levels of Rb, Th, Nd, U and Sm. The Nb anomaly is succeeded from the magma source, and clearly display a calc-alkaline magmatism in subduction zone environment (Holm, 1985; Lan, 1996; Ahmad, 1998).

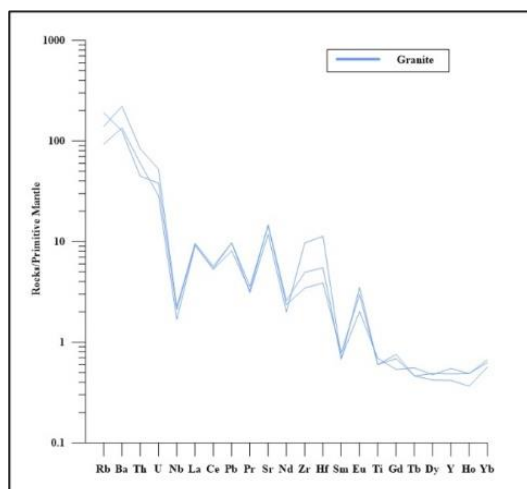


Figure 4.106. shows the rocks/primitive mantle-normalized diagram shows geochemical characteristics of the Positive intrusives rock pattern (Group 2) from the complex. Normalized components from Pearce and Parkinson (1993).

Figure 4.106, shows the geochemical characteristics of the Positive intrusives rock pattern (Group 2). The multi-element pattern of primitive mantle shows the granite rock type, in which depletion of Nb, Ce, Pr, Nd, Sm and Ti. On the other hand Ba, Sr and Eu shows enrichment.

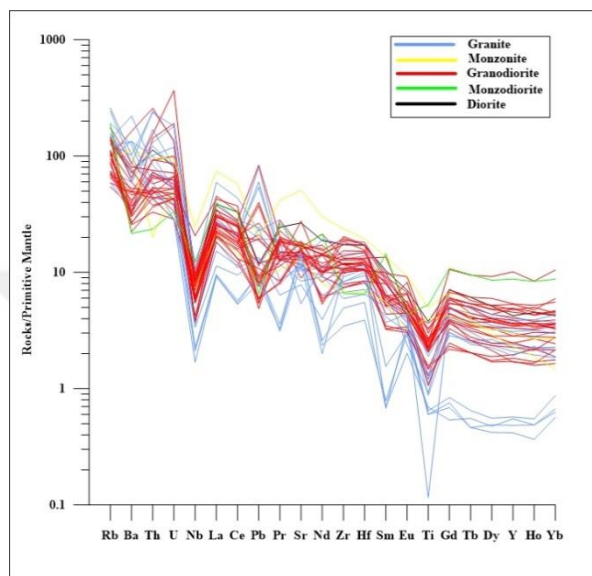


Figure 4.107. shows the geochemical characteristics of the intrusives from the complex. Pearce and Parkinson (1993).

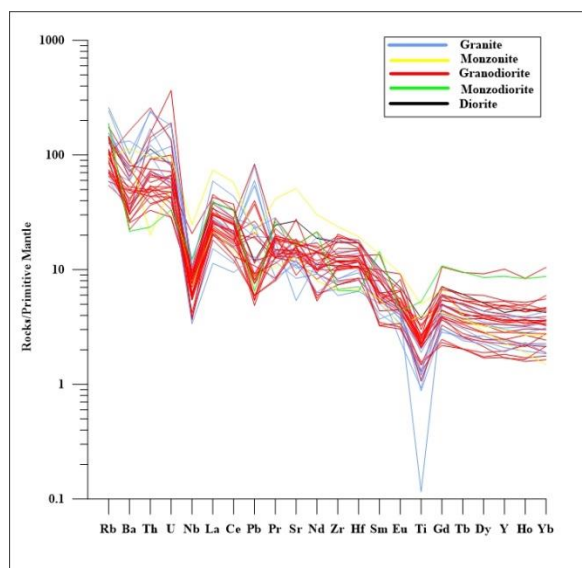


Figure 4.108. shows the rocks/primitive mantle-normalized diagram displaying the geochemical characteristics of the intrusives rocks. Normalized components from Pearce and Parkinson (1993).

4.6. Isotope Geochemistry

4.6.1. Introduction

Radiogenic isotopes are used in geochemistry in two different ways, firstly they were used to determine the age of rocks and minerals. Secondly, they have been used to identify the geological processes and sources in petrogenetic studies. The number of excellent texts that deals with different disciplines like isotope geology or isotope geochemistry (Jager and Hunziker, 1977; Faure, 1986; DePaolo, 1988)

The use of radiogenic isotopes in petrogenesis from over the past two decades is one of the most exciting and fast-moving developments in geochemistry. Radiogenic isotopes are used as a tracer of petrogenetic processes and it has been allowed geochemists to sample the deep interior of the Earth. The main aim of this chapter is to produce petrogenetic models that will provide a brief description about compositional variation in and between Ladakh Batholith regions around Leh area of Trans-Himalayan Belt. Furthermore focus on the Sr and Nd isotope geochemical data for the plutonic rocks.

4.6.2. Radiogenic isotopes in petrogenesis

During subsequent fractionation events, the magma extracted from the source region and the isotopic ratios remain unchanged. This is because the mass difference is so small in any radiogenic isotopes pair in geochemistry (except Helium), so that isotopic pair cannot be fractionated by processes controlled by crystal liquid equilibria. For that reason, during partial melting magma will have the same isotopic character as its source region.

In isotopic geochemistry, some simple observation has led to two important developments. Firstly, distinct source regions can be recognized with their own unique isotopic character and secondly, mixing can be recognized the distinct sources of isotopes. In isotope geology, one of the main quests is to identify the different isotopic reservoirs in the crust and the mantle and to characterize them for as many isotopic systems as it possible.

4.6.3. Role of different isotopic systems in identifying reservoirs and processess

In radiogenic isotopic studies, the elements have different behavior in geology vary greatly in their chemical and physical properties. This variability reflects itself into two ways; firstly, the parent and daughter element may behave in different ways so that the two become fractionated.

The order of incompatibility for elements of interest is:

$$\text{Rb} > \text{Th} > \text{U} > \text{Pb} > (\text{Nd}, \text{Hf}) > (\text{Sr}, \text{Sm}, \text{Lu})$$

These values indicate the extent to which an element is fractionated into the crust relative to the depleted mantle. For example, the concentration of Rb element in the crust is

much more than the depleted mantle but on the other hand, Sr, Sm and Lu are the least concentrated. Alternatively, a parent- daughter element pair may behave coherently and not be fractionated and yet behave in different manner from the parent daughter pair of another isotopic system. For example; the Sm-Nd shows very similar chemical and physical characteristics, and the Rb-Sr system, in which they are strongly fractionated from one another.

During metamorphic or sedimentary processes, Sm and Nd are not significantly fractionated within the continental crust and for that reason preserve the parent/ daughter ratio of their source region. Sm and Nd are much more similar to Lu- Hf but it markedly differ from Rb-Sr, U-Pb and Th-Pb. Due to immobility of Sm and Nd under hydrothermal conditions so for that reason their isotopic composition reflects the actual proportion of rock or magma involved in specific petrological processes. The Sm and Nd shows the disadvantage due to small amount of recycled crust has been mixed with their large portion of a mantle components and it becomes isotopically invisible.

Under hydrothermal conditions, Sr is relatively immobile although Rb is more mobile. As compared to less concentration of Rb, the Sr although reflects closely the original bulk composition of the suites of rocks. Moreover, the Rb-Sr shows extreme differences in incompatibility between parent and daughter elements. The separation of Rb and Sr are easy, that leads to the extreme fractionation between crust and mantle that resulting to the acceleration of strontium isotope in the continental crust relative to mantle. Rb and Sr are further separated in continental crust by remelting, metamorphism and sedimentation, for Sr is portioned into and retained by plagioclase whereas Rb is preferentially partitioned into fluid and melt phase.

4.6.4. Sr-Nd isotope geochemistry

The area that covers the Leh around the Ladakh Batholith region of Trans-Himalayan Belt is a vast matter of contradiction and discussion between worldwide scientists about ages. The samples around Leh area including (Basgo, Umla and Taru) have been collected for the analysis of Sr-Nd isotope geochemistry. The samples that are used for the Sr-Nd isotope analyses are granitoids, mafic enclave and dykes. The analytical calculated values of Sr-Nd isotopes are mentioned in the Appendices 4. Moreover all the diagrams have been made by using isotopical values of Rb-Sr and Sm-Nd are also shown in the Figure 4.109. The calculation that used to calculate the ratios of Nd and Sr including epsilon values are mentioned below:

$$^{87}\text{Sr} = ^{87}\text{Sr}_i + ^{87}\text{Rb} (e^{\lambda t} - 1)$$

Initial measured values for Sr and Nd isotope ratios and Rb, Sr, Sm and Nd concentration of plutonic rocks of Ladakh Batholith region around Leh area of Trans-Himalayan belt of North Western India are listed in the Appendices 4. As gone through the analytical values of initial isotopic ratios as shown in the table that, the plutonic rocks have high initial values of $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios have low initial values.

$^{87}\text{Sr}/^{86}\text{Sr}$ and $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic ratio shows the different diagrams of different source of intrusive rocks along with different rocks suites, these are formed at different tectonic activities as shown in the Figure 4.109. The diagram shows plotted samples from different rock suits, mafic enclaves and dykes are associated with enriched reservoir areas. According to the DePaolo and Wasserburg (1979) and Rollinson (1993), on the basis of concentration of Nd isotope and you can easily separate the old and young crust area. For example; enriched reservoirs (EM 2) upper crust (young crust in which Nd isotope concentration is high) whereas lower crust (old crust in which Nd isotope concentration is less).

Table has been shown in Appendices 4, the plutonic rocks have high initial $^{87}\text{Sr}/^{86}\text{Sr}$ and low initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios.

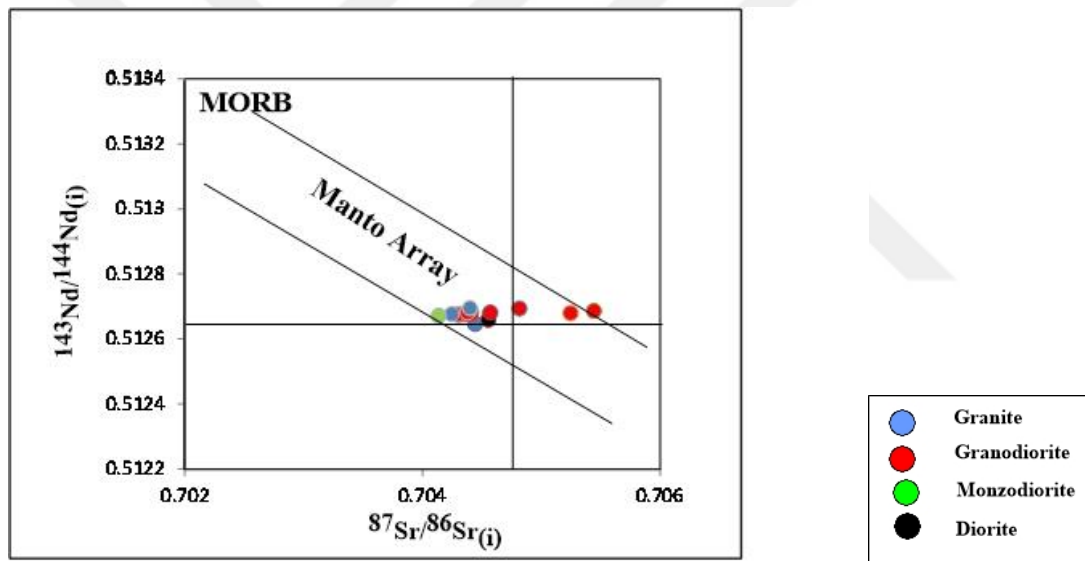


Figure 4.109. Initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios versus initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for the Ladakh intrusive rocks. The mantle array is after DePaolo (1988).

Initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios with initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios for the plutonic rocks in Figure 4.109, together with published data for mantle reservoirs (DePaolo, 1988). As clear out from Figure 4.109, the Ladakh intrusive rocks display within a limited extent for both initial $^{87}\text{Sr}/^{86}\text{Sr}$ (0.70414 to 0.70544) and $^{143}\text{Nd}/^{144}\text{Nd}$ (0.512647 to 0.512695) ratios. They plotted in the low $^{87}\text{Sr}/^{86}\text{Sr}$ and high $^{143}\text{Nd}/^{144}\text{Nd}$ quadrant and some of the granodiorite samples are fall in the quadrant with high $^{87}\text{Sr}/^{86}\text{Sr}$ and high $^{143}\text{Nd}/^{144}\text{Nd}$ in the scaled properties of mantle sources or continental crustal sources with large continental crustal factors.

Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios range between 0.70429 to 0.70544 for the Nimmu, Umla, Taru rock samples showing the granodiorite rock type and 0.70425 and 0.70444 for the Basgo and Taru rock samples showing granite rock type. The granodiorite rock type sample

from the Nimmu, Umla and Taru granitoids shows the highest value pluton (0.70544) of analysed samples for the Ladakh intrusive rocks of study area. The diorite rock type from Basgo area shows moderate analyzed value of measured Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.70455) and the monzodiorite rock type from Taru area shows lowest analyzed value of measured Initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.70414) of analyzed samples for the Ladakh intrusive rocks of the field study area of Trans Himalaya mountain belt.

Initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios range from 0.512674 to 0.512694 for the Nimmu, Umla, Taru rock samples showing the granodiorite rock type and from 0.512647 to 0.512695 for the Basgo and Taru rock samples showing granite rock type. The granite rock type sample from the Basgo and Taru intrusive rocks shows the highest value pluton (0.512695) of analysed samples for the Ladakh intrusive rocks of study area. The diorite rock type from Basgo area shows lowest analyzed value of measured Initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios (0.512659) and the monzodiorite rock type from Taru area shows moderate analyzed value of measured Initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios (0.512671) of analyzed samples for the Ladakh intrusive rocks of the field study area.

The initial $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios provide a clear layout for addressing several petrogenetic aspects for the Ladakh intrusive rocks as shown in Figure 4.109. The main complications to be resolved is whether the different trace element and isotopic characteristics can be related with enrichment of mantle source by the reprocessing of crustal material (e.g. Gill, 1981; Sun and McDonough, 1989) or to fractional crystallisation merged with crustal assimilation (AFC) (e.g. Hildreth and Moorbath, 1988).

During subduction of plates, the process of contamination of mantle source by reprocessing of crustal material describes here as Mantle source enrichment. Subduction of sediment and/or altered oceanic crust releases aqueous fluids and/or siliceous melts into the overlying mantle wedge via a series of dehydration reactions of the hydrous phases. This process results in enrichment in large ion lithophile elements (LILE) in the mantle wedge. The introduction of aqueous fluids and/or siliceous melts lowers the solidus of the peridotites, initiating melting. The mixture of fluids and melts and mantle undergoes partial melting to produce magmas enriched in LILEs.

Mantle source enrichment is well documented in many subduction-related settings (e.g. Gill, 1981; White and Dupre, 1986; McDermott et al., 1993). It is also supported by ^{10}Be anomalies (e.g. Brown et al., 1982; Tera et al., 1986) and high $^{207}\text{Pb}/^{204}\text{Pb}$ ratios in modern volcanic arc basalts (e.g. Kay et al., 1978; White and Dupre, 1986). However, it is less discussed in having a connection with plutonic rocks (e.g. Hill et al., 1986; Von Blanckburg et al., 1992; Tommasini et al., 1995).

Mantle source enrichment is difficult to identify by major and trace element geochemistry in plutonic rocks because all intrusive members, and thus their elemental concentrations, are usually modified by fractional crystallization. Nevertheless, a combination of sensitive isotopic indicators, such as Sr and Nd, which have high contaminant/mantle concentration ratios, with an abundant element such as O (oxygen)

which has approximately equal concentrations in mantle and contaminant, often enables a distinction to be made between source contamination and other processes (e.g. James, 1981).

Mantle source enrichment can be modelled by mixing of two components. A general mixing model first presented by Langmuir et al. (1978) was eventually modified by DePaolo and Wasserburg (1979) for use with the epsilon notation of Nd and Sr. The two-component mixing equation based on the work of Langmuir et al. (1978) is as follows:

$$\varepsilon_m^x = \frac{\left[\varepsilon_a^x X_a F + \varepsilon_b^x X_b (1 - F) \right]}{X_a F + X_b (1 - F)} \dots \dots \dots \text{Eq 4.5.1}$$

Where,

ε_a^x : isotopic parameter of element X in crust

ε_b^x : isotopic parameter of element X in mantle

X_a : element X concentration in crust

X_b : element X concentration in mantle

F : mass fraction of crust in mixture

As per plotted diagram between $\varepsilon\text{Nd}_{(T)}$ and initial measured values of $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios for the Ladakh intrusive rocks as shown in Figure 4.110. The plotted samples are falling in the quadrant of low Sr and high Nd but some of the granodiorite samples are falling in the quadrant of high Sr and high Nd ratios. The epsilon $\text{Nd}_{(t)}$ shows all positive values ranging from 1.68 to 2.62.

Initial $\varepsilon\text{Nd}_{(t)}$ ranges from 2.22 to 2.60 for the Nimmu, Umla, Taru rock samples showing the granodiorite rock type and from 1.68 to 2.62 for the Basgo and Taru rock samples showing granite rock type. The granite rock type sample from the Basgo shows the highest and lowest value of initial $\varepsilon\text{Nd}_{(t)}$ (2.62 and 1.68 respectively) of analysed samples for the Ladakh intrusive rocks of study area.

The diorite rock type from the Basgo area shows lowest analyzed value of measured initial $\varepsilon\text{Nd}_{(t)}$ value of (1.92) and the monzodiorite rock type from Taru area shows moderate analyzed value of measured initial $\varepsilon\text{Nd}_{(t)}$ value of (2.16) of analyzed samples for the Ladakh intrusive rocks of the field study area. The initial $\varepsilon\text{Nd}_{(t)}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios provide a clear framework for mantle source enrichment with several petrogenetic aspects for the Ladakh intrusive rocks as shown in Figure 4.110.

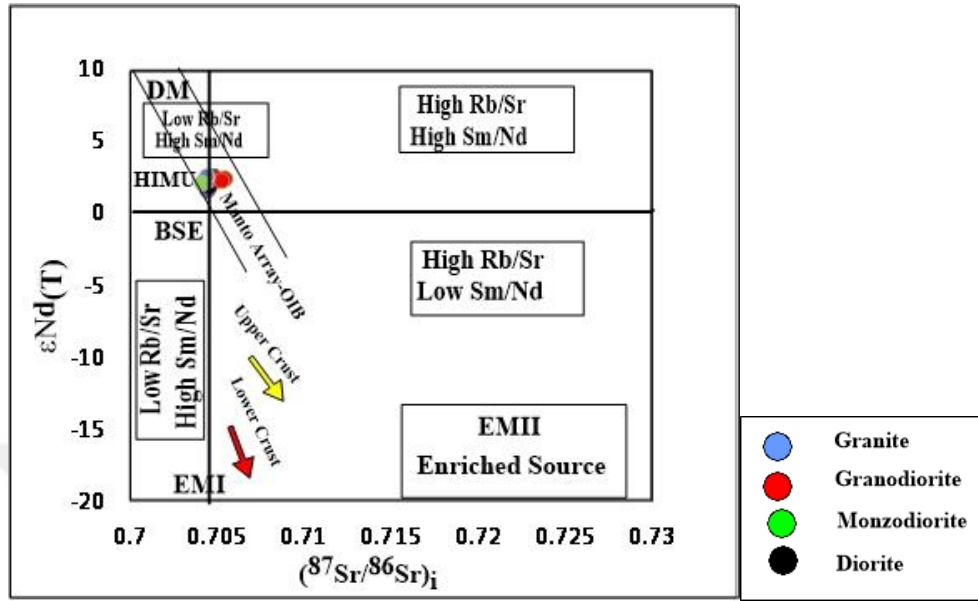


Figure 4.110. $^{87}\text{Sr}/^{86}\text{Sr}$ versus $^{143}\text{Nd}/^{144}\text{Nd}$ isotope diagram (Alici et al., 2002) showing the representative samples from the Leh, Ladakh Batholith region, mantle array from Faure (1986). MORB: mid-ocean ridge basalts; DM: depleted mantle; OIB: ocean island basalts; IAB: island-arc basalts after Zindler and Hart (1986); EMI and EMII represent two types of mantle end-members, respectively (Hou et al., 2011). **(b)** $\epsilon(\text{Nd})_i$ vs $^{87}\text{Sr}/^{86}\text{Sr}_i$ diagram displaying isotopic configurations of magmatic rocks of different ages from the boundary of Asia. Data collected from Searle et al. (1992), Lemennicier (1996), Miller et al. (1999), Rolland et al. (2002), Mahéo et al. (2009).

As shown in the Figure 4.111, which is plotted between $^{143}\text{Nd}/^{144}\text{Nd}$ vs $t_{\text{DM}}(\text{Ga})$ ratios of the Ladakh intrusive rocks displaying against with their ages of mantle extraction.

The Ladakh intrusive rocks and dyke samples that tended in the direction of the low $T_{\text{DM}}(\text{Nd})$ and high $\epsilon_0(\text{Nd})$ end of the notified discriminate ranges, with comparison of low variation in ages of mantle extraction (Figure 4.110 and 4.111). This reflecting that they have gone through with minor crustal assimilation. In variation, Ladakh intrusive rocks and dykes of west of Leh district are scatter towards lower $\epsilon_0(\text{Nd})$ and higher $T_{\text{DM}}(\text{Nd})$.

The figure performed as a local observation of procedure in independent magma-chambers (e.g. assimilation of continental crust, digestion of wall-rocks, magma mixing, involvement of metasomatic fluids, etc.). The isotopic indications of batholith specimen that fitted in the small extent that describe formerly (Schärer et al., 1984; Weinberg and Dunlap, 2001), which was elucidated as proof for the unavailability of crustal component in the evolution of the Ladakh Batholith (Weinberg and Dunlap, 2001).

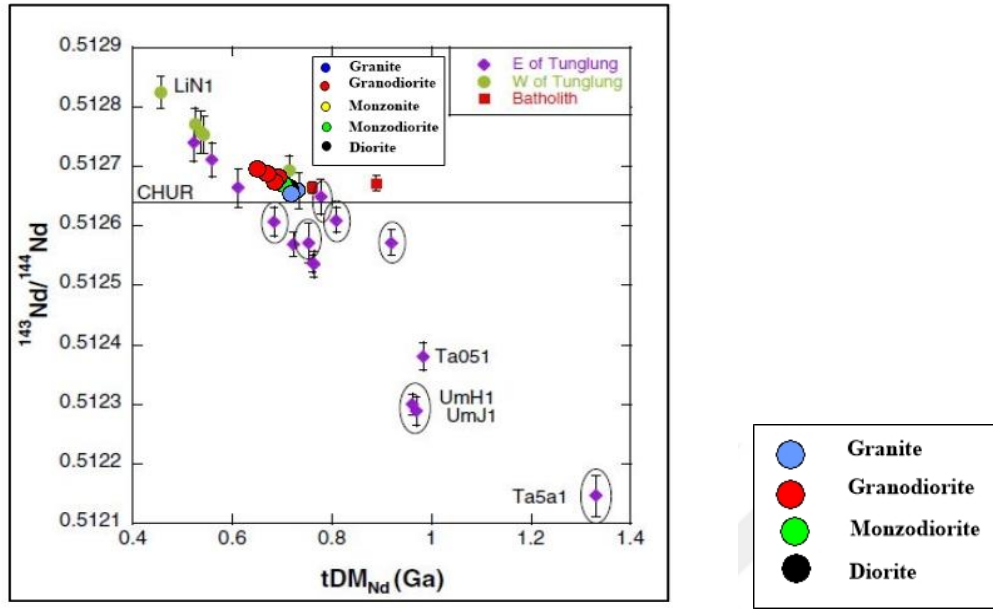


Figure 4.111. shows the $^{143}\text{Nd}/^{144}\text{Nd}$ vs $t_{\text{DMNd}}(\text{Ga})$ ratios of the Ladakh intrusive rocks are displaying against their mantle extraction ages. Collected values from Searle et al. (1992), Lemennicier (1996), Miller et al. (1999), Rolland et al. (2002), Mahéo et al. (2009).

4.6.5. Interpretation of Sr and Nd on the basis of AFC process

The process of assimilation fractional crystallization (AFM) process was first considered by Bowen (1928). He emphasised that assimilation is a complex mixing procedure but has a minimum of three end members, named as the magma, the cumulates and the country rocks.

It is well explained as the contamination by assimilation of wall-rock associates to simultaneous fractional crystallisation. It was modelled by DePaolo (1981). He derived the equations for both isotopic variations and trace element (Equations 4.5.2-4.5.7). He showed that the principle of the effortless blending model, that the concentration in the magma would become different in the supervision of that in the wall-rock, unnecessarily true if fractional crystallisation was also managing.

(a) .General equation applicable to most of the cases:

$$C_m / C_m^0 = F^{-z} + \left(\frac{r}{r-1} \right) \frac{C_a}{z C_m^0} (1 - F^{-z}) \quad (\text{not applicable for } r=1) \quad (\text{Eq. 4.5.2})$$

$$C_m / C_m^0 = 1 + \left(\frac{r}{r-1} \right) \frac{C_a}{C_m^0} \ln F^{-z} \quad (\text{special case } r+D=1 \text{ and } z=0) \quad (\text{Eq. 4.5.3})$$

(b) For the isotopic ratio (ϵ):

$$\frac{\varepsilon_m - \varepsilon_m^0}{\varepsilon_a - \varepsilon_m^0} = 1 - \left(\frac{C_m^0}{C_m} \right) F^{-z} \quad (\text{Eq. 4.5.4})$$

where;

M_m : mass of magma

M_m^0 : mass of original magma

M_c : crystallisation rate (mass/ unit time)

M_a : assimilation rate (mass/ unit time)

C_a : elemental concentration in Wall-rock

C_m : elemental concentration in contaminated magma

C_m^0 : elemental concentration in original magma

D : bulk solid/liquid partition coefficient for the element between the fractionating crystalline phases and the magma

DC_m : elemental concentration in crystallising phases

ε_m : isotopic ratio in the contaminated magma

ε_m^0 : isotopic ratio in the original magma

ε_a : isotopic ratio in wall-rock

$$F = \frac{M_m}{M_m^0} \quad (\text{isotopic ratio in wall-rock}) \quad (\text{Eq. 4.5.5})$$

$$r = \frac{M_a}{M_c} \quad (\text{the ratio of the measure of assimilation to fractional crystallisation}) \quad (\text{Eq. 4.5.6})$$

$$z = \frac{r+D-1}{r-1} \quad (\text{Eq. 4.5.7})$$

4.6.6. Crustal assimilation combined with fractional crystallization or mantle source enrichment

Initial $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios of the Ladakh intrusive rocks are plotted against Rb/Sr (ppm) as shown in (Figure 4.112) to further source enrichment processes or estimation of AFC process in the origination of these intrusive rock types.

In Figure 4.112, radiogenic isotope ratios $^{87}\text{Sr}/^{86}\text{Sr}$ does not display good interpret correlations with Rb/Sr (ppm). If contaminants and parents are different, combined assimilation and fractional crystallisation (AFC) causes enrichment in $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios with increasing Rb/Sr (ppm). If it is not, then AFC display no change in $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios with increase of Rb/Sr (ppm). As shown in Figure 4.112, that the plotted samples are differentiated with the two major groups of rock type such as granodiorite and granite. As plotted Taru granite samples shows that coupled assimilation and fractional crystallization (AFC) display no change in the $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios with increase of Rb/Sr (ppm). On the other hand, the plotted samples from Umla, Taru and Nimmu study area having granodiorite rock type shows the slightly higher concentration of initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and indicating that the contaminants and parents are different, combined assimilation and fractional crystallisation (AFC) display enrichment in initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios with increase of Rb/Sr (ppm).

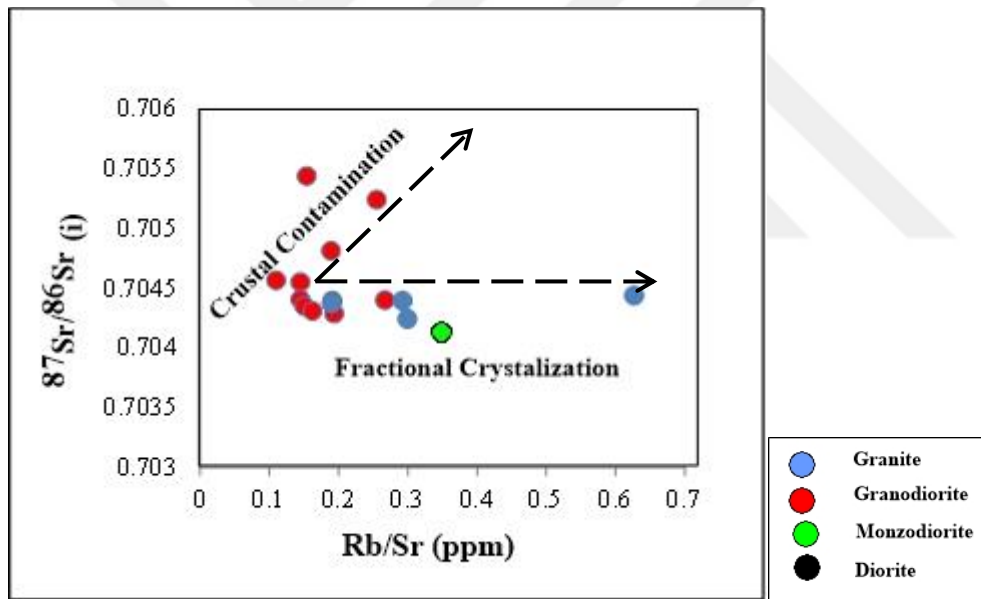


Figure 4.112. shows the $^{87}\text{Sr}/^{86}\text{Sr}$ (i) versus Rb/Sr (ppm) isotope diagram shows the assimilation-fractional crystallization (AFC) and crustal contamination of mantle and shows the metasomatism processes.

Initial $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios of the Ladakh intrusive rocks are plotted against SiO_2 wt% as shown in (Figure 4.113). The plotted sample between initial $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios and SiO_2 wt% and it is showing the scattered pattern of diagram. The two group of rock type mainly granite and granodiorite shows the behavior of combined assimilation and fractional crystallisation (AFC) against silica.

The samples collected from Taru granites displayed no interaction with silica and it indicates that the parental and contaminant magmas of the Taru rock samples have same

$^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios. The granodiorite rock type of other group of samples from Umla, Taru and Nimmu indicate the slightly increase of initial $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios with increase in SiO_2 wt% and it is interpret that the parental magma and contaminants are different with combined assimilation and fractional crystallization.

The granodiorite samples also indicate the constant and no change in initial $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios until nearly about 65 to 67 wt% of silica and then slightly increase with silica.

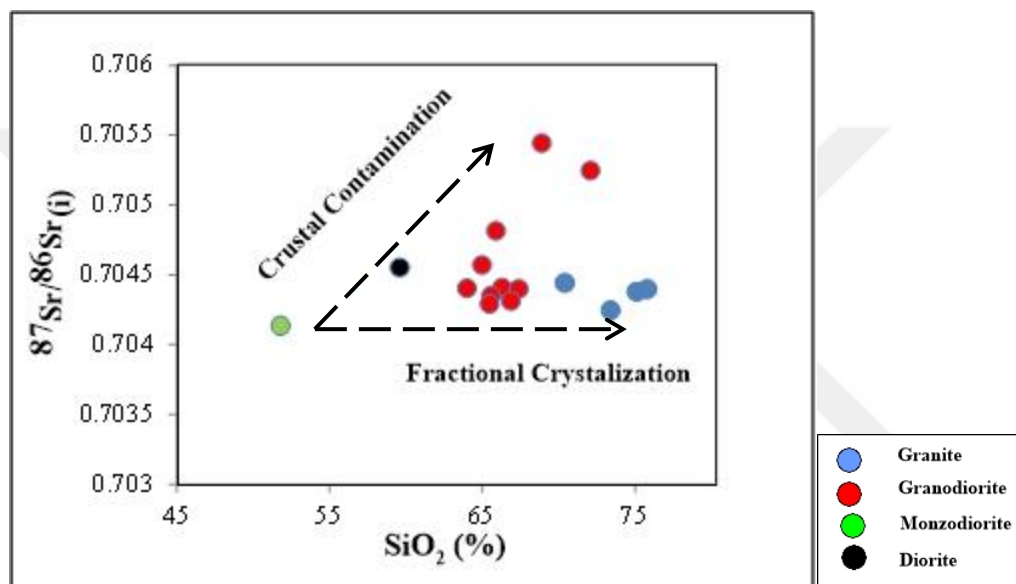


Figure 4.113. shows the $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$ versus SiO_2 wt% isotope diagram shows the assimilation-fractional crystallization (AFC) and crustal contamination of mantle and shows the metasomatism processes.

In Figure 4.114, shows initial $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic ratios with SiO_2 wt% diagram shows Assimilation/ fractional crystallization (AFC) and crustal contamination of mantle and shows the metasomatism processes. The monzodiorite, diorite and granite sample shows slightly decrease in the initial ratio of Nd isotope ratio with increase of SiO_2 wt% and have comparatively low initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios that decreases with increase of silica, displaying the significance of a integrated assimilation and fractional crystallization process in the origination of these intrusive rock types.

The mixed samples from the Umla, Taru and Nimmu rock having a rock type of granite and granodiorite rocks have mainly high initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios, which is nearly remain persistent initial $^{143}\text{Nd}/^{144}\text{Nd}$ ratios with increasing SiO_2 wt%. This may indicate that combined assimilation and fractional crystallisation was a significant process in the origination of these intrusive rock types. The collected samples from the Umla, Taru and Nimmu have converged between 65 to 75 wt% of silica. This is displaying that the parental

magmas of these intrusive rock types are assimilated with the similar contamination and no change in the initial $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic ratios.

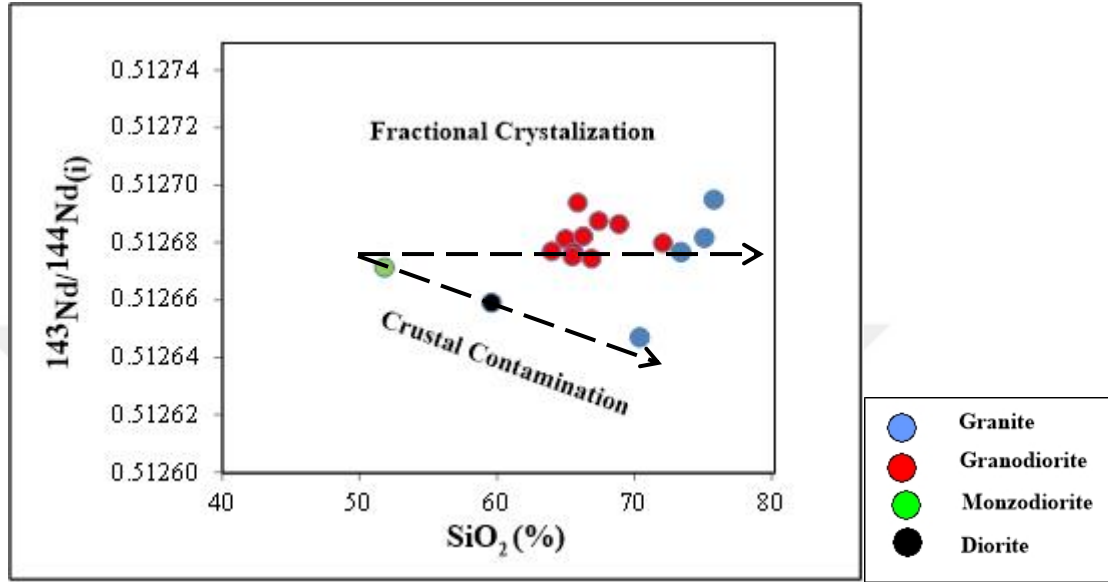


Figure 4.114. shows the $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ versus SiO_2 wt% isotope diagram shows the assimilation/fractional crystallization (AFC) and crustal contamination of mantle and shows the metasomatism processes

Figure 4.115, shows the $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ versus SiO_2 wt% isotope diagram shows the assimilation-fractional crystallization (AFC) and crustal contamination of mantle and shows the metasomatism processes.

Figure 4.115, shows initial $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic ratios with Sm/Nd diagram show the assimilation-fractional crystallization (AFC) and crustal contamination of mantle. The monzodiorite, diorite and granite samples show the decrease in the Sm/Nd ratio with the decrease in the initial $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic ratios of the studied samples. The parent magma and crustal contaminants are different, combined with assimilation and fractional crystallization causes change in initial $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic ratios with Sm/Nd ratio.

On the other side the samples from Umla, Taru and Nimmu intrusives rock area considering two rock type granodiorite and granite shows the slight increase of initial $^{143}\text{Nd}/^{144}\text{Nd}$ isotopic ratios with decrease in Sm/Nd ratio.

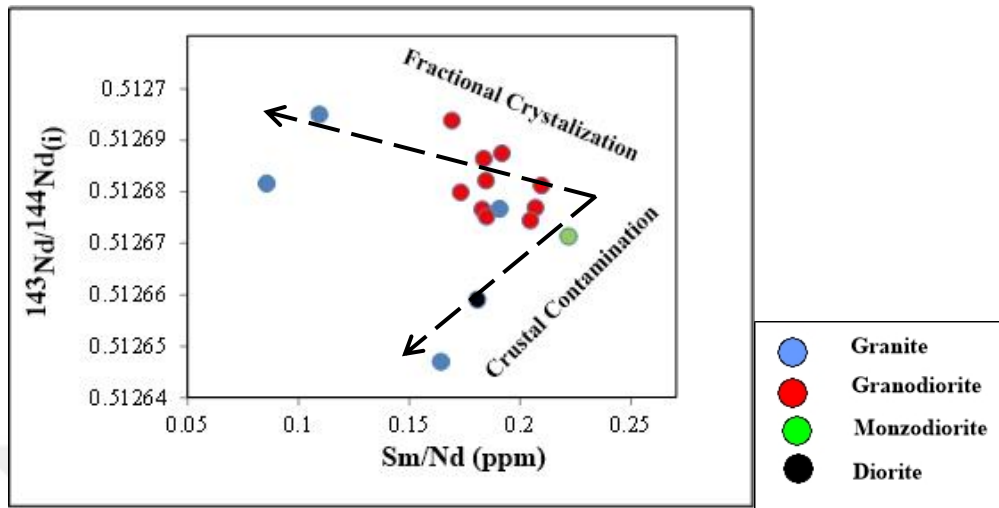


Figure 4.115. shows the $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ versus Sm/Nd (ppm) isotope diagram shows the assimilation-fractional crystallization (AFC) and crustal contamination of mantle and shows the metasomatism processes.

4.6.7. Evidence of Trace element for mantle source enrichment or fractional crystallisation combined with crustal assimilation processes

The variation diagram between Th/Yb and Ta/Yb ratios of the intrusive rocks from the Ladakh Batholith of Trans Himalaya range are plotted against silica to assess the sensitivity of these ratios to AFC (Figure 4.116, 4.117).

The samples are plotted with variation as displaying initial isotope ratios (Sr, Nd) (Figure 4.112- 4.115) for the Ladakh Batholith of Trans-Himalaya region with intrusive rocks furthermore showing with Th/Yb against Ta/Yb (Figure 4.118).

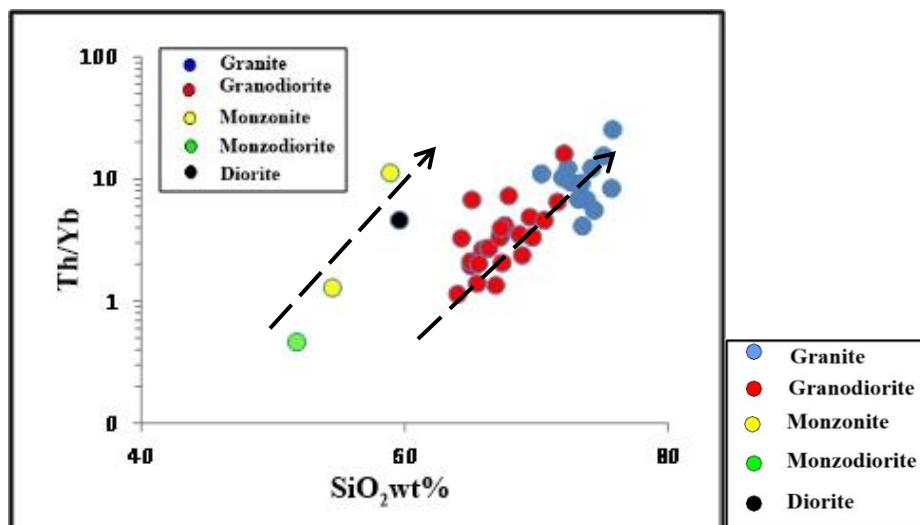


Figure 4.116. shows the plotted samples of Ladakh intrusive rocks between Th/Yb and SiO_2 wt%.

Yb is used as the normalising factor to minimise variations created by partial melting and fractional crystallisation provided that olivine, pyroxenes and feldspars are the dominant crystallising or residual phases (Pearce, 1982). Pearce (1982) demonstrated that the greater mobility of Th in subduction components results in an increase in Th relative to Ta which results in a shift to higher Th/Yb ratios in the mantle wedge above the subduction zone. Assimilation of crust has a similar effect, although assimilation of granulitic crust, which has low Th contents, can cause a shift in the opposite direction (Pearce et al., 1990).

Garnet residues from partial melting will lower Ta/Yb and Th/Yb ratios by similar amounts, and amphibole residues will lower Ta/Yb slightly more than Th/Yb; crystallisation of these phases will have the reverse effect (Pearce et al., 1990), because the partition coefficient of Ta for amphibole in basic compositions (0.25) is five times higher than that of Th (0.05) and the partition coefficients of both Ta and Th are lower than Yb (0.80).

Figure 4.116 shows that the Monzodiorite, Monzonite and Diorite increases Th/Yb ratio with increases in silica having a 60 wt % but as compare to granodiorite and granite samples increase with high silica wt %.for the Ladakh intrusive rocks. The ratio of Th/Yb increases from monzodiorite to granite with increase wt % of silica. The Th/Yb ratio in granite is more as compare to granodiorite.

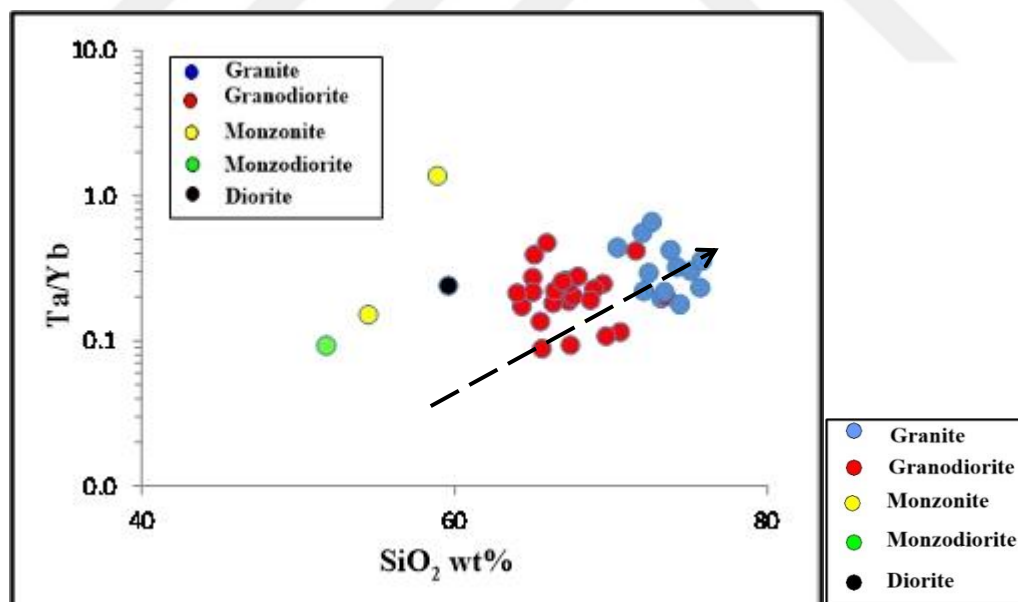


Figure 4.117. shows the plotted samples of Ladakh granitoids between Ta/Yb vs SiO₂ wt%.

In Figure 4.117, the Ta/Yb ratio increases slightly with silica for the monzodiorite to diorite, whereas slightly increase of Ta/Yb ratio from granodiorite to granite with high increase in silica wt %.

The ratio of Th/Yb from the Ladakh intrusive rocks is displayed with Ta/Yb ratio (Figure 4.118). Figure 4.118, showing all intrusive rocks from the Ladakh Batholith are replaced in the direction of higher Th/Yb ratios and forming a pattern that moves related to the mantle metasomatism array. It is suggested that, either it was derived from an enriched mantle source to which a subduction component adjoined or combined crustal contamination with fractional crystallisation or both. Add up to this, both ratios are increasing from the monzodiorite, granodiorite along the granitic rocks.

The elevated high ratio of Ta/Yb of the intrusive rocks could be describe by derivation from a more enriched-mantle source than that of the monzodiorite, diorite, and granodiorite rocks.

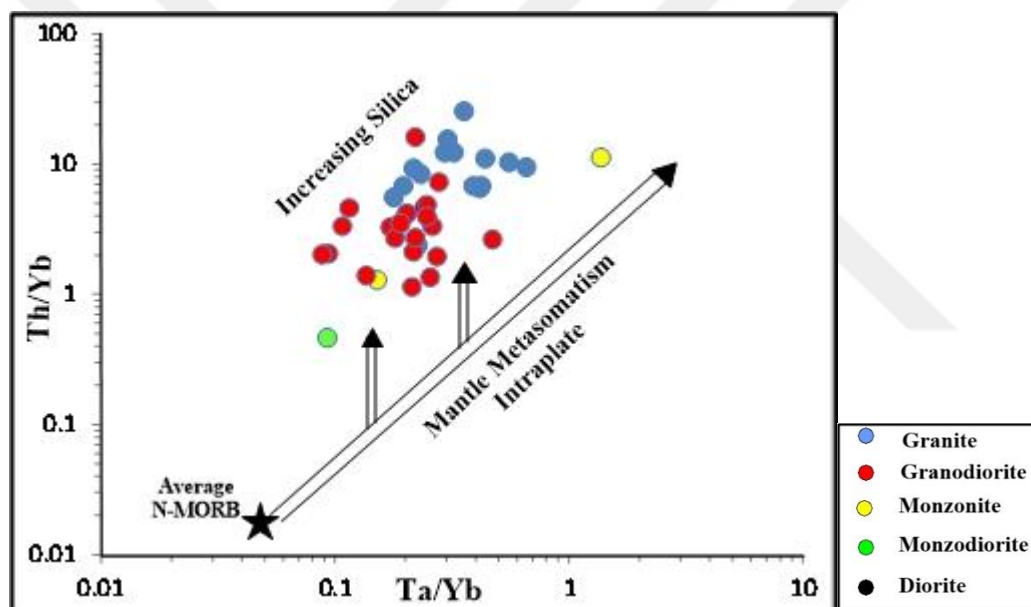


Figure 4.118. shows the variation between Th/Yb and Ta/Yb with increasing silica concentration.

In Figure 4.118, AFC unlikely the single procedure for the origination of the intrusive rocks and do not form patterns from the mantle array to crust. As in the isotope plot (Figure 4.109, 4.126), the parental magmas for the intrusive rocks obliged to be enriched in Sr and Nd isotopic ratios and furthermore in Th.

In Figure 4.118, the granitic rocks are more enhanced in a within-plate component than the other monzodiorite, diorite and granodiorite.

The dissimilarity display by the monzodiorite and monzonite intrusive rocks might be specified that these intrusive rocks are extract from a mantle source have accomplished assimilation and fractional crystallisation throughout the time of arise through continental crust and containing large subduction components. In comparison, the granite and

granodiorite intrusive rocks might be obtained from an additional enriched-mantle source with less integrated crustal assimilation-fractionation in comparison to the monzodiorite and monzonite rocks.

4.6.8. Interpretation of LILEs (Ba, Rb and Sr) fractionation trends for Ladakh Granitoids

In Figure 4.119, shows the variation in the plotted samples between Ladakh intrusive rocks between Ba (ppm) and Rb (ppm). The isotope and trace element geochemical variations between and within the Ladakh intrusive rocks have been explained by the mantle source enrichment and AFC processes (as discussed above). However, in this section the discussion is expanded to determine which phases, if removed from the melt, could cause the observed evolution from the least acidic to the most acidic compositions.

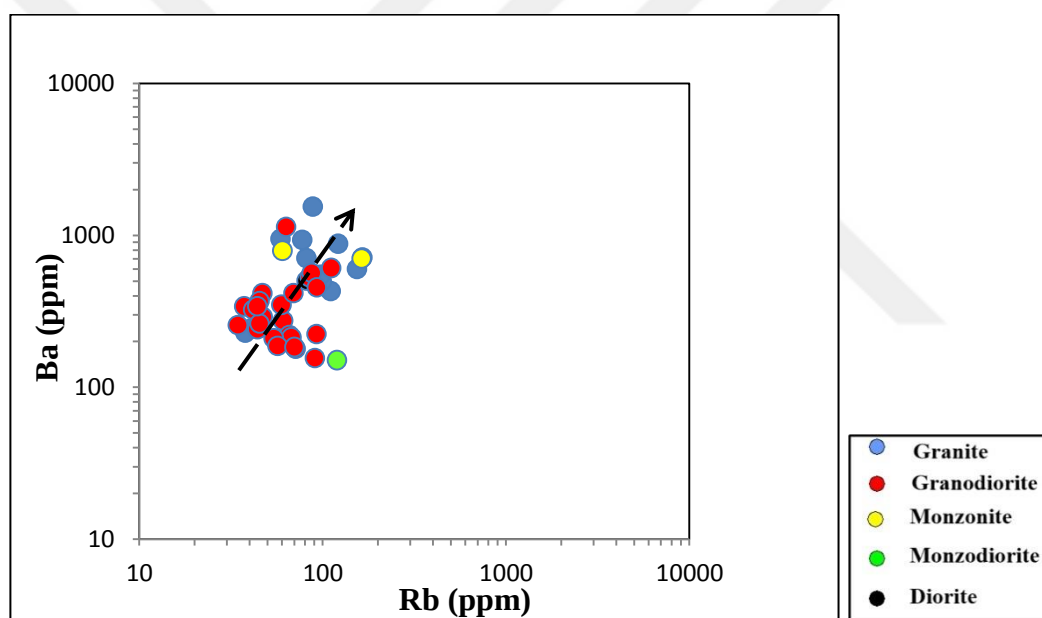


Figure 4.119. shows the variation of plotted samples of Ladakh intrusive rocks between Ba (ppm) and Rb (ppm).

Some authors (e.g. McCarthy and Groves, 1979; Tindle and Pearce, 1981) argued that granites cannot be treated as either pure 'melts' or pure 'cumulates', but should instead be thought of as "crystal mushes". As such, it is unlikely that perfect (Rayleigh) fractional crystallisation would apply to granite crystallisation. Instead, since cumulus- crystals trap interstitial melt, granite crystallisation lies somewhere between the extremes of equilibrium crystallisation and perfect fractional crystallisation.

In spite of these arguments, most authors favour perfect (Rayleigh) fractional crystallisation (e.g. McCarthy and Groves, 1979; Tindle and Pearce, 1981) because crystals are commonly removed from the site of formation after crystallisation and Several attempts at petrogenetic modelling of granite systems have been based on the LILEs (Ba, Rb and Sr)

(e.g. McCarthy and Hasty, 1976; McCarthy and Groves, 1979; Tindle and Pearce, 1981). These elements are useful because they occur only in the major silicate minerals, thus avoiding problems in estimating accessory mineral abundances and behaviour. Changes in LIL element concentrations during fractionation can be examined and modelled more quantitatively by comparing observed and theoretical fractionation vectors on log-log bivariate plots (Figure 4.119, 4.120). Therefore, the LILE data of the Ladakh intrusive rocks are presented as logarithmic plots of Ba against Rb and Ba against Sr (Figure 4.119, 4.120).

In Figure 4.119, the main trends are observed for the Ladakh intrusive rocks trend 1 for the Monzodiorite, Monzonite and Diorite plutonic rocks and trend 2 for the granodiorite and granitic rocks.

In detail, two sub-trends show up in Figures 4.119, for the plutonic rocks: trend 1 (followed by a majority of samples) in which Rb increases with decrease in Ba and trend 2 (followed by the most acidic samples) in which Ba increases and Rb increases. Plagioclase, hornblende, alkali feldspar and biotite could control trend 1 plutonic rocks. These minerals are chosen because they are observed in these rock types. Ba is strongly partitioned into alkali feldspar and biotite, whereas Sr is strongly partitioned into plagioclase and alkali feldspar. Therefore, fractional crystallisation of these minerals results in decrease in Ba and Sr. On the other hand, Rb, Sr and Ba are weakly partitioned into hornblende. Thus, fractionation of this mineral causes enrichment in these elements.

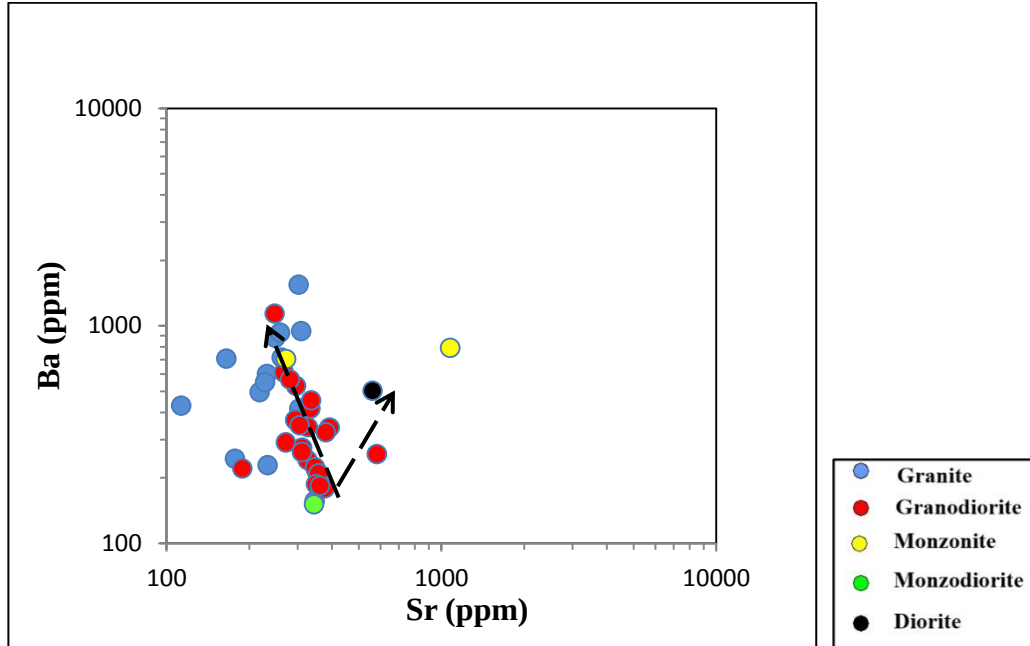


Figure 4.120. shows the variation of plotted samples of Ladakh intrusive rocks between Ba (ppm) and Sr (ppm).

In Figure 4.120, alkali feldspar is a possible candidate in addition to plagioclase and biotite for the most silicic rocks (trend I). Ba is strongly partitioned into biotite and alkali feldspar. Thus, fractional crystallisation of these minerals causes sharp decrease in Ba. On the other hand, Rb is strongly partitioned into biotite. Therefore, fractionation of biotite results in decrease in Rb, whereas Rb is weakly partitioned into plagioclase and alkali feldspar. Thus, fractionation of these minerals causes enrichment in Rb. However, Sr is strongly partitioned into plagioclase and alkali feldspar. Therefore, fractional crystallisation of these minerals results in decrease in Ba and Sr.

4.7. Petrogenesis

4.7.1. Introduction

In this section by using the major oxides and trace element value for the petrogenesis of the intrusive rocks of the Ladakh Batholith is discussed. Normally, the classification of granitic rocks are I-, S-, M- and A-types in according to their protolith (e.g., Chappell and White, 1974; Pitcher 1982, 1993). Linear discrimination in their chemical configurations in I-type granites are commonly indicates more regular than the S-type granites, which is usually shows imperfect associations between SiO_2 with P_2O_5 and Pb, dissimilar from I-type granitoids (Chappell and White, 1992). A negative relation between SiO_2 and P_2O_5 is interpreted as an extended straight line pattern in the Harker diagrams suggested that the Ladakh intrusive rocks are not probably to be S-type granitoids. Normally, granitic rocks of S-type have low Na_2O , CaO values with high Al_2O_3 and A/CNK values (molar $\text{Al}_2\text{O}_3/(\text{CaO}+\text{Na}_2\text{O}+\text{K}_2\text{O}) < 1.1$) as compared to I-type granitoids.

The relatively low Na_2O (2.43-4.98 wt%) and K_2O (0.94-4.96 wt%) and high Al_2O_3 (11.7 to 17.9 wt%) and A/CNK values (0.87 to 1.31) are consistent with the classification of S-type granitoids.

During the emplacement of magma, the Fractional crystallization occurs normally. The accumulation/fractionation of mafic minerals such as hornblende and biotite is due to negative relation between SiO_2 and MgO of the Ladakh intrusive rocks (Figure 4.86).

In Figure 4.92, the fractionation of plagioclase is due to the further demonstration of negative anomalies shown by Eu, Sr and Ba (Wu et al., 2003b). A positive relation between Sr and Ba (Figure 4.92) further displaying the plagioclase fractionation (Li et al., 2007). K-feldspar is not a fractionating mineral and is shown by the weak correlation between Rb and Sr (Figure 4.92).

Detachment of Ti relevant minerals like apatite and (such as ilmenite and titanite) that conducts with the depletion of Nb-Ta-Ti and P, respectively (Wu et al., 2003b). The fractionation of Ti-relevant stages, and the negative relation of P_2O_5 with SiO_2 is compatible with fractionation of apatite is due to the indications of strong depletion of Nb, Ta, Ti of the Ladakh intrusive rocks (Figure 4.86, 4.92)

I-type granites is originated by (1) the fractionation of mafic mineral at an initial level of magmas that obtained from mantle, (2) blending between the mantle and the crustal melts and (3) incomplete melting of mafic crust.

Evolution of mafic magma during the initial stages of fractional crystallization may generate to yield felsic magmas (e.g. Litvinovsky et al., 2002). Despite the fact that low-pressure fractional crystallization of amphibole and feldspars has been experienced the Ladakh intrusive rocks of the study area as mentioned above; there is small verification that these intrusive rocks were evolved by the differentiation of melts that obtained from mantle. Granitoids are evolved by the isolation of such melts that should have model ages that roughly estimated to similar to their age of emplacement (e.g. Sun and Zhou, 2008).

It is highly unlikely that the Ladakh intrusive rocks were outcome of differentiation from mafic magmas because no mafic plutons are recognized in the region. I-type granites are also produced by the blending between mafic magma that obtained from mantle and crustal felsic melts (Chappell, 1996; Yang et al. 2007).

Nevertheless, the homogeneous compositions of the Ladakh intrusive rocks of the study area have relatively and typically formed by the mixing of magma. Discrimination of zircon with varying morphologies due to the rocks that formed by the mixing of magma (Yang et al., 2007). Under polarizing microscopic studies, all euhedral and prismatic with simple oscillatory zoning of zircons are from these rock samples (Figure 4.26), and the samples produce identical properties and generated from a similar place of origin, preferably from blending of felsic and mafic magmas.

The Ladakh intrusive rocks of study area have comparatively steady $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.7041-0.7054), high $\epsilon\text{Nd}(t)$ values (+1.68 to +2.62), and constant trace and REE element trends, incompatible with a evolution by magma mixing.

The values of Nd (T_{DM}) varying between 0.65 to 0.73 Ga, indicating that they were evolved by the melting of older crust. The comparatively low $(^{87}\text{Sr}/^{86}\text{Sr})_i$ ratios and high $\epsilon_0\text{Nd}(t)$ values indicate that their protolith were obtained from a depleted mantle origin. The common source region indicated by Gangdese granitoids that they have shared a similar $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (0.704-0.705) and $\epsilon\text{Nd}(t)$ values (+2 to +4) (Harris et al., 1988).

Decrease concentration of CaO , FeO_t , MgO , TiO_2 , $\text{Na}_2\text{O}+\text{K}_2\text{O}$, Al_2O_3 , Zr, Sr and Ba with increase amount of SiO_2 as indicated by the Fractional crystallization of plagioclase, biotite, K-feldspar and zircon are evidently important for all collected analyzed samples (Figure 4.86). It is obvious that the fractionation of K-feldspar and plagioclase is due to the variations in Rb–Ba and Ba–Sr and the negative relation between SiO_2 and Sr, Eu as well as strongly negative Ba, Sr, P and Ti anomalies (Figure 4.92).

Nevertheless, decrease in the ratios of Zr/Hf and Nb/Ta with increasing SiO_2 ratios for analyzed samples (Figure 4.92), and the different Sr–Nd isotopic configurations for these studied research samples cannot be described the fractional crystallization process by

a closed-system (e.g., Dostal and Chatterjee, 2000). In variation, all these geochemical properties might be the conclusion of heterogeneous origin.

The Ladakh intrusive rock samples are falling in the field of peraluminous rocks and metaluminous rocks that their origins are most probably metasedimentary/metaigneous rocks by showing a first-order of constraint (Kalsbeek et al., 2001). The strongly peraluminous, silica-rich configurations of samples are indicated that the magma can be evolved by (1) the incomplete melting of aluminous-rich metamorphic rocks (e.g., schists and gneisses); (2) under H₂O-rich conditions, the incomplete melting of amphibolites (Ellis and Thompson, 1986) or (3) fractionation of aluminous-poor magma (Zen, 1986). Nevertheless, in contrary to our observations, the out comes from both expression (2) and (3) are normally distinguished by metaluminous, Na- and Sr-rich properties (Zen, 1986; Gaudemer et al., 1988). Under H₂O rich conditions, 2-5 vol.% of melts are usually produced by the anatexis of the high-grade metamorphic rocks (Zen, 1986; Clemens and Vielzeuf, 1987; Patiño-Douce et al., 1990) preferably abundant peraluminous granitic batholith.

In Figure 4.91, The lower CaO/Na₂O ratio from analyzed intrusive rocks samples are drop down in the premises of the orogenic strongly peraluminous granites (Sylvester, 1998), and throughout the length of the mixing line between pelite- and basalt-derived melts most of the Himalayas strongly peraluminous granite samples have been plotted. The samples were obtained from plagioclase-poor and clay-rich origin (e.g., metapelite) whereas other metaluminous rocks were from clay-poor and plagioclase-rich source as such indicated by these characteristics (Chappell and White, 1992; Sylvester, 1998).

The higher ratio of Al₂O₃/TiO₂ for strongly peraluminous granites relative to metaluminous rock indicates that they were produced at high temperature and pressure conditions as compatible with above estimation (Sylvester, 1998). The higher ratio of Al₂O₃/(MgO+FeO_t) but lower CaO/(MgO+FeO_t) ratios than those from the metaigneous rocks have commonly shown by metapelitic-derived melts (Altherr et al., 2000). The ratios of Al₂O₃/(MgO+FeO_t) of peraluminous granite have exhibits almost identical ratio to that of the melt derived from metasedimentary granites, and metaluminous granites has Al₂O₃/(MgO+FeO_t) < 2, identical to those of metabasaltic- and metatonalitic-derived melts. The lower SiO₂ and Al₂O₃/CaO ratio and the higher MgO, FeO_t and TiO₂ contents for metaluminous granite rocks relative to peraluminous granite rocks also need the participation of interposed constituents that are correlated with the metaigneous rocks (Patiño-Douce and Harris, 1998; Anthony, 2005).

In Figure 4.91, the variations of Rb-Sr-Ba of analyzed samples gave an extended straight line of increasing Rb/Sr with Rb/Ba. In conclusion to that, strongly peraluminous granites might be obtained from a clay-rich source. The lower down ratio of Rb/Sr otherwise higher Sr/Ba ratios are exhibited by metaluminous granite, probably representative of heterogeneous origin with elevated degree of plagioclase/clay ratios (Chappell and White, 1992; Jung et al., 2000).

In Figure 4.91, the negative relation corresponded to that of the North Himalayan Granites (NHG)/High Himalayan leucogranites (HHL) as displayed by all analyzed granitic rock samples by showing Rb/Sr vs Ba diagram (e.g., Zhang et al., 2004a,b). In consideration of alkali feldspar is a late crystallization stage verification by petrographic texture as suggested by such trend that peritectic alkali feldspar was included in the reaction. As compared with metaluminous granitic rocks, the peraluminous has lower Ba content and higher Rb/Sr ratio. These displayed that the predecessor magma for peraluminous might be processed under vapour stage-distracted states and that of metaluminous was feasibly formed by H₂O-fluxing (Inger and Harris, 1993; Harris et al., 1995; Koester et al., 2002; Zhang et al., 2004a,b). The muscovite begins to collapsed at ~700 °C, and biotite continuously to collapsed at ~850 °C under fluid absent conditions (~5 kbar; Le Breton and Thompson, 1988; Thompson, 1996; Patiño-Douce and Harris, 1998; Vielzeuf and Schmidt, 2001).

The melt and disappearance of Epidote/zoisite will take place at ~750–800 °C at ~10 kbar, 150-200 °C, which is less than that of amphibole (~920 °C; Lambert and Wyllie, 1972; Patiño-Douce et al., 1990; Vielzeuf and Schmidt, 2001). Besides of this, in existence of feldspar and quartz, the melting of Al-poor rocks could produce metaluminous, Na- and Sr-rich melts, and peraluminous and K-rich melt generally generated from an Al-rich source at 0.1-1.0 Gpa (Zen, 1986; Patiño-Douce et al., 1990; Miller, 1995). From above collective rough calculation of melting states, it is probably that mica-rich metapelitic origin is primarily the dehydration of metabasaltic origin can be allocated to the collapse of epidote/zoisite and dehydrated by the collapse of muscovite.

4.7.2. Tectonic Significance and discrimination diagrams

The two groups of incompatible elements such as Large ion lithophile elements (LILE) and high field strength elements (HFSE) that can be used as measured of the tectonic settings and the magmatic processes for the generation of granitic rocks. The large ionic radii elements of previous group that includes e.g., K, Rb, Sr, Ba and Cs, whereas the higher valencies elements of final which includes Zr, Th, U, Ta, REE etc.

The abundance of the HFS Niobium element can be used to discriminate between tectonic settings of magmas which is liable for the generation of within plate granites and volcanic-arc granites (Pearce and Gale, 1979). The volcanic-arc granites with abundance amount of Nb is noticeably lesser than that in within plate granites across the complete range of SiO₂. The Ladakh intrusive rocks of studied samples show volcanic arc magmatic setting.

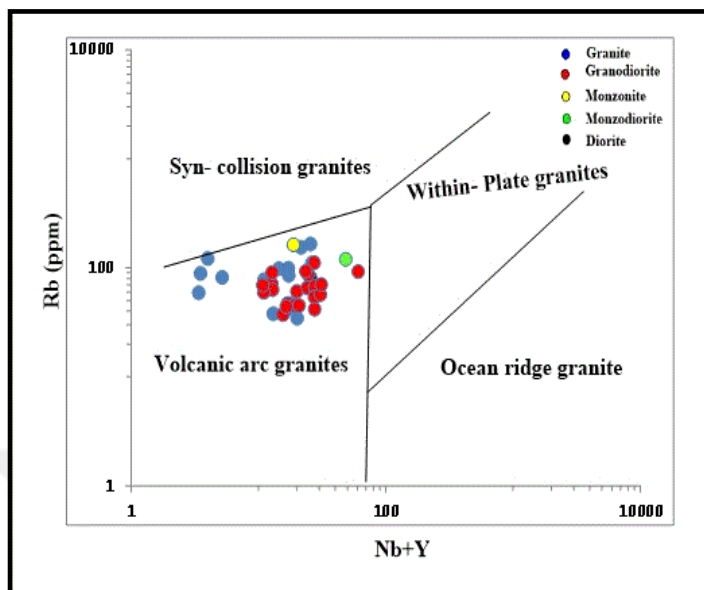


Figure 4.121. shows the variation diagram between Rb (ppm) versus Nb+Y (ppm) given by Pearce et al. (1984).

In the the plot of Rb (ppm) with (Y+ Nb) ppm of tectonic discrimination diagram (Figure 4.121, most of the samples of sub alkaline and calc-alkaline are plotted in the field of Volcanic Arc Granites (VAG) as described by the Pearce et al. (1984). In contrast, two of the samples are plotted in the field of syn-collision granites and within-plate granites respectively. As shown in the above diagram the concentration of Rb (ppm) in calc-alkaline and sub-alkaline is much more than Nb+Y (ppm) (Figure 4.121).

4.7.3. Origin of Post-orogenic with possible mechanism of melting

The melting of crust is based on the temperature and the thickness of the crust. The generation of granitic melts where thickened crust is influenced by (a) shears or thrusts by major crust (e.g., Barbarin, 1996), (b) the over-thickened crust produces in situ radiogenic heating and (c) underplated magma in a post-collisional setting produces conductive heating (e.g. Wang et al. 2007).

The study area of the Ladakh intrusive rocks considering Nb and Ti negative anomalies are identical to those of syn-collisional granites in continental margins, displaying that these intrusive rocks are generate in a syn-collisional environment (Pearce et al., 1984). In contrast to the Nb vs Y diagram, plotted samples are drop down in volcanic arc and syn-collisional granites (Figure 4.122), although the Rb vs. Y+Nb diagram they drop down in volcanic arc granitic rocks (Figure 4.121).

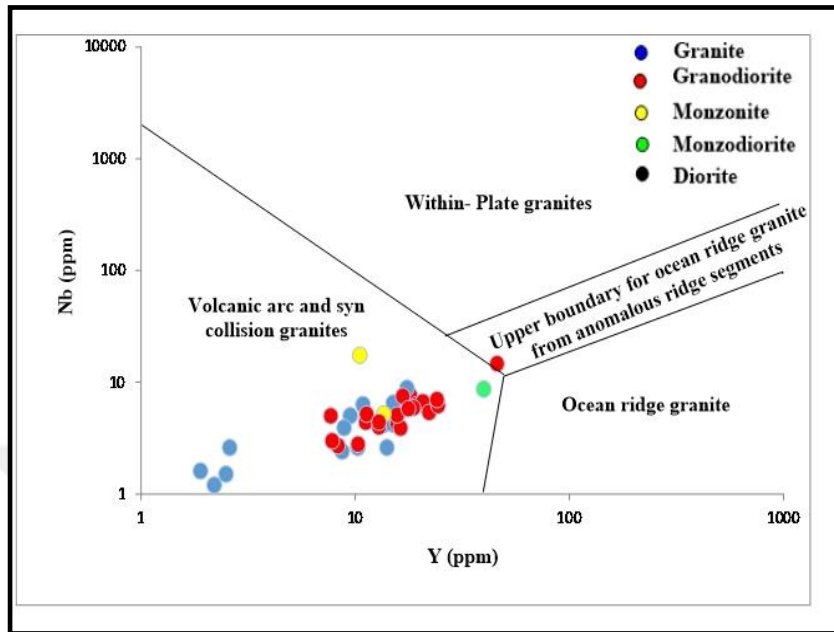


Figure 4.122. shows the variation diagram between Nb (ppm) versus Y (ppm) given by Pearce et al. (1984).

The intrusive rock samples from the complex are marked on the discrimination diagrams of Pearce et al. (1984) (Figure 4.122). In the diagram Nb (ppm) vs Y (ppm) Figure 4.122, the sub-alkaline and the calc-alkaline rock samples are drop down into the VAG (volcanic arc granite) and syn-COLG (syn-collisional granites) fields. One of the samples is fall into the field of upper boundary for ocean ridge granite from anomalous ridge segments.

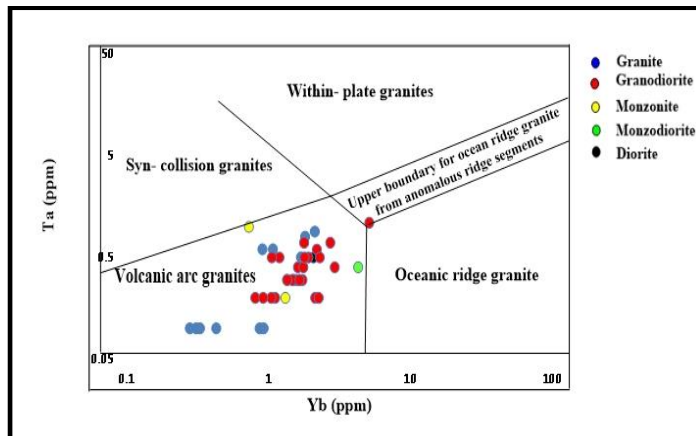


Figure 4.123. shows the variation diagram between Ta (ppm) versus Yb (ppm) given by Pearce et al. (1984).

In the Ta (ppm) against Yb (ppm) discrimination diagram (Figure 4.123) most of the sub alkaline and calc-alkaline samples are plotted in the field of Volcanic Arc Granites

(VAG) as described by the Pearce et al. (1984). But one of the plot that touches the common boundary of VAG, ORG and upper boundary for ORG from anomalous ridge segments. And one of the samples touches the common boundary of VAG and syn-COLG fields as shown in Figure 4.123.

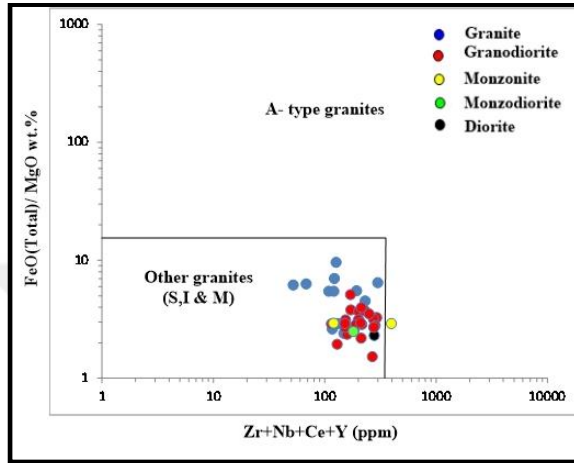


Figure 4.124. shows the variation diagram between FeO_T/MgO wt% versus Zr+Nb+Ce+Y (ppm) given by Whalen et al. (1987).

In the FeO_T/MgO wt% against (Zr+Nb+Ce+Y) (ppm) discrimination diagram (Figure 4.124) most of the sub alkaline and calc-alkaline samples are plotted in the field of S and I type granites as described by the Whalen et al. (1987). The calc-alkaline rock samples show, I-type metaluminous hornblende+biotite-bearing granodiorite as shown in Figure 4.124. The peraluminous S-type granites are meta-sedimentary rocks showing the fractionation of muscovite. All the samples are calc-alkaline and sub-alkaline that shows the concentration of FeO_T/MgO wt% is lower as compare to (Zr+Nb+Ce+Y) (ppm) as shown in the Figure 4.124.

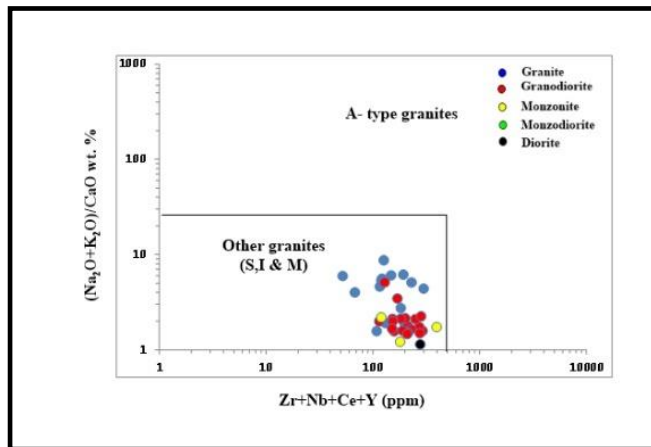


Figure 4.125. shows the variation diagram between $(\text{Na}_2\text{O}+\text{K}_2\text{O})/\text{CaO}$ versus Zr+Nb+Ce+Y (ppm) given by Whalen et al. (1984).

Figure 4.125 shows the variation diagram between $(\text{Na}_2\text{O}+\text{K}_2\text{O})/\text{CaO}$ versus $(\text{Zr}+\text{Nb}+\text{Ce}+\text{Y})$ given by Whalen et al. (1984). This also shows the discrimination between A-, S- and I-type granites. All sub alkaline and calc-alkaline rocks samples are plotted in the field of S- and I-type granites showing the concentration of $(\text{Zr}+\text{Nb}+\text{Ce}+\text{Y})$ is much higher than the $(\text{Na}_2\text{O}+\text{K}_2\text{O})/\text{CaO}$ ratio. The samples with hornblende+biotite-bearing granodiorite show I-type metaluminous composition. On the other hand, S-type granites are thought to originate by melting (or possibly by ultrametamorphism) of a pre-existing metasedimentary or sedimentary source rock. These are peraluminous granites [i.e. they have molecular $\text{Al}_2\text{O}_3 > (\text{Na}_2\text{O}+\text{K}_2\text{O})$]. Since many sedimentary rocks are enriched in Al_2O_3 as a result of their constituents having been exposed to chemical weathering near the Earth's surface (particularly rocks such as shales that contain clay minerals), melting of these rocks is a simple way of achieving the peraluminous condition. S-type granite, has muscovite and biotite and is depleted in sodium but enriched in aluminum Figure (4.125).

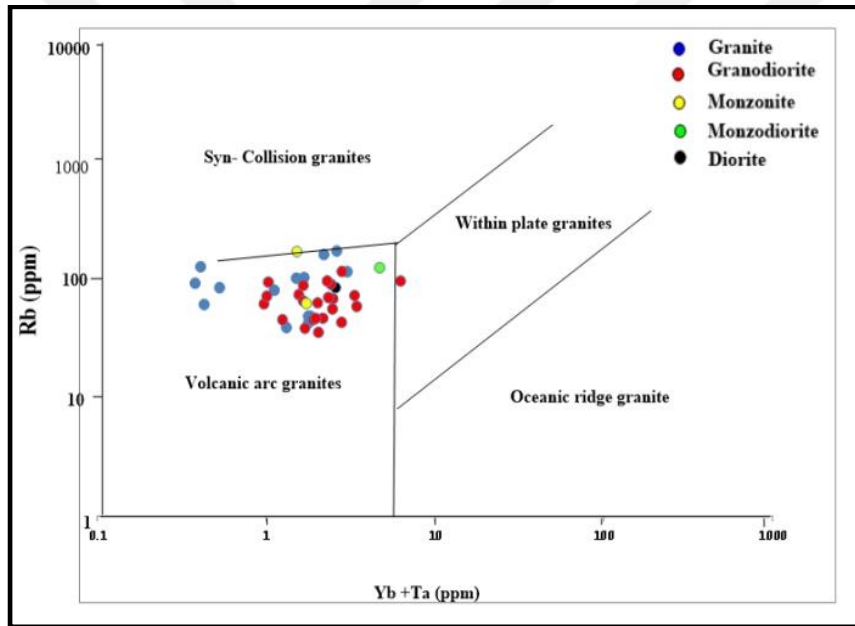


Figure 4.126. shows the variation diagram between Rb (ppm) versus Yb+Ta (ppm) given by Eby et al. (1992).

Geochemical diversity in granitic rocks is ultimately managed by the compositions of the source region. Further, contrasting source regions area reflection of the geotectonic environment (continental vs. Oceanic) (Bowden, 1984). In sequence to understand the source and geotectonic environment of the intrusive rocks of present study area, the average sample/ORG data of Eastern KAB is compared with Volcanic Arc Granites (VAG) of continental type (Chile) and VAG of oceanic type (Troodos) on an extended plot for granitic rocks of Pearce (1984). The positive Rb, Th and Ce and negative Ba, Nb and Zr anomalies of these granitoids display a pattern similar to VAG of continental type rather than oceanic type (Thompson, 1982).

Figure 4.126 shows the variation diagram between Rb (ppm) versus Yb+Ta (ppm) given by Eby et al. (1992). It shows that all samples are fall into volcanic arc granites.

Understanding the granite magmatism in the present study area is unfavorable for evaluating the tectono-magmatic origination of the SSZ and Eastern Karakoram. The existence of two contrasting granitoid suites (I- and S-type) within the Eastern KAB has been suggested by the previous workers (Srimal, 1987; Chandra, 1999; Upadhyay, 2002).



5. CONCLUSIONS

This chapter summarizes the general characteristics from the previous chapters that covering field, petrography, geochemical studies and isotope geochemistry of Ladakh granitoids along the north eastern part of Leh region has following characteristics with the features of petrogenetic significance and may lead to the following results:

- ✓ The Ladakh intrusive rocks of the study area can be distributed into four different villages are The Basgo, Nimu, Umla and Taru intrusive rocks of Leh- Ladakh district (Jammu & Kashmir) India. The Ladakh Batholith is covered by Indus-Tsangpo Suture Zone towards south and Shyok Suture Zone towards north.
- ✓ These rocks are generally divided into monzodiorite, monzonite, diorite, granodiorite and granites. The main minerals of these rocks are plagioclase, K-feldspar, quartz, biotite and amphibole. The accessory minerals are sphene, apatite, zircon, monazite and opaque minerals. Sericitization, clayification, chloritization and sossuritization are alteration types.
- ✓ The plagioclase contents of these intrusive rocks vary between $An_{(55-99)}$ while the K-feldspar contents vary between $Or_{(85-99)}$. Biotites are generally compounds of annite. Amphiboles are composed of edenite, magnesio-hornblende and hastingsite.
- ✓ The geothermobarometer results of intrusive rocks show crystallization temperatures ranging from 452 to 628 ° C, with varying pressure values ranging from 2.3-3.9 kbar. There is decrease in temperature-pressure-depth (13.7-12.8 km in the south; 9.9-8.1 km in the north) was observed as it moved from the suture zone in the south (Indus-Tsangpo Suture Zone) towards north suture zone (Shyok Suture Zone).
- ✓ The total alkaline (Na_2O+K_2O)% values of the intrusive masses, ranging from monzodiorite to granite, vary between 3.9% - 8.65%, while the SiO_2 values range between 54.5% and 75.8%. A/CNK(0.87 to 1.31) ratios refer to I-type source for most of the intrusive rock samples. The values of some samples indicate the transition between I- and S-type granitoids.
- ✓ In Harker variation diagrams, K_2O and Rb showed a positive correlation against silica, while TiO_2 , Al_2O_3 , Fe_2O_3 , MgO and CaO showed a negative correlation with the increase of silica. The positive correlation between K_2O and SiO_2 indicates K_2O content in K-feldspar and biotite.
- ✓ In trace element harker diagrams, increasing SiO_2 versus V, Ni, Co, Cu, Zn, Ga, Y decreased; Rb, Ba, Th values increase.
- ✓ In the multi-element diagrams created according to the primitive mantle, it shows enrichment by LIL elements. However, depletion is observed for HFSE, including Nb and Ti. Trace element as such characteristics are generally observed in subduction-related magmatisms.
- ✓ Total REE contents of Ladakh intrusive rocks vary between 20-181 ppm while $(La/Yb)_N = 3.75-45.95$ shows with varying rates of LREE in terms of medium-high enrichment.

- ✓ Negative Eu anomalies ($\text{Eu}/\text{Eu}^*=0.35-4.97$) and $(\text{Gd}/\text{Yb})_N=0.83-4.40$ shows differentiation with moderate HREE. In addition to this, all rock-chondrite-normalized REE patterns shows enrichment in LREE but showing depletion in HREE.
- ✓ Sr and Nd isotopic analytical values of Ladakh Batholith samples show values in the range of $^{87}\text{Sr}/^{86}\text{Sr}_{(i)}$ (0.70414-0.70544) and $^{143}\text{Nd}/^{144}\text{Nd}_{(i)}$ (0.512647- 0.512695). In the $\text{Sr}_{(i)}$ - $\text{Nd}_{(i)}$ diagram, samples are located in the low Sr and high Nd area, while some granodiorite samples are located in the area representing the high Sr and high Nd. It has $\epsilon\text{Nd}_{(t)}$ values ranging from 1.68 to 2.62.
- ✓ Ladakh intrusive rocks are generally located in the volcanic arc area in tectonic discrimination diagrams.
- ✓ Field, mineralogy-petrography, mineral-rock and isotope geochemistry show that fractional crystallization and magma mixing / mingling processes are effective in the formation and development of Ladakh intrusive rocks.

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7. APPENDICES

APPENDICES-1. MINERAL CHEMISTRY (PLAGIOCLASE, K-FELDSPAR, BIOTITE AND AMPHIBOLE)

Table 1. EPMA analysis of Plagioclase mineral, samples that collected from Leh region of Ladakh Batholith around the Trans-Himalayan Belt (India)

Sample No.	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	1	2	3	4	5	6	7	8	9	10	11	12
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO₂	67.77	76.75	64.66	61.58	61.86	62.81	65.40	68.14	63.85	65.04	63.52	66.25
TiO₂	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.02	0.00	0.00	0.00
Al₂O₃	22.32	16.61	22.64	24.50	24.22	24.08	21.86	19.88	22.41	22.15	23.09	21.36
Cr₂O₃	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.08	0.07	0.15	0.06	0.13	0.13	0.05	0.01	0.14	0.03	0.15	0.06
MnO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.01	0.05	0.00	0.00
MgO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	2.91	1.24	4.00	6.12	5.92	5.43	2.99	1.71	3.80	3.31	4.48	2.88
BaO	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00
Na₂O	10.89	9.15	9.99	9.15	9.15	9.28	10.82	10.78	10.26	10.78	10.03	10.81
K₂O	0.20	0.05	0.30	0.10	0.16	0.18	0.21	0.07	0.14	0.08	0.23	0.06
An	12.74	6.97	17.81	26.86	26.12	24.21	13.11	8.03	16.86	14.44	19.55	12.80
Ab	86.19	92.72	80.58	72.61	73.04	74.83	85.78	91.58	82.39	85.16	79.24	86.88
Or	1.06	0.31	1.61	0.52	0.84	0.97	1.11	0.39	0.75	0.40	1.22	0.33

Table 1. (Continue)

Sample No.	AM1	AM3	AM3	AM3	AM3	AM3	AM3	AM3	AM3	AM3	AM3	AM3
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Rock Type	Granite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite
Point analysis	13	1	2	3	4	5	6	7	8	9	10	11
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO₂	62.15	60.51	58.65	62.23	62.57	60.01	60.01	59.52	56.01	57.16	61.49	60.02
TiO₂	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al₂O₃	23.89	24.73	25.70	23.97	23.73	25.55	24.62	25.42	27.24	26.42	23.70	24.84
Cr₂O₃	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.04	0.00	0.01	0.00	0.02
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.10	0.17	0.09	0.11	0.16	0.28	0.14	0.11	0.13	0.10	0.10	0.13
MnO	0.05	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.01	0.01
MgO	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.00
CaO	5.47	7.01	7.76	5.63	5.44	7.79	6.48	7.35	10.08	8.84	5.57	7.04
BaO	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00
Na₂O	9.42	8.14	7.64	8.98	9.35	7.78	8.25	8.21	6.49	7.06	9.07	8.22
K₂O	0.19	0.22	0.12	0.12	0.16	0.14	0.17	0.11	0.06	0.09	0.17	0.12
An	24.06	31.87	35.73	25.57	24.11	35.35	29.97	32.90	46.05	40.68	25.10	31.91
Ab	74.96	66.96	63.62	73.76	75.04	63.90	69.10	66.50	53.62	58.82	73.96	67.43
Or	0.98	1.17	0.65	0.67	0.84	0.75	0.93	0.60	0.33	0.50	0.93	0.66

Table 1. (Continue)

Sample No.	AM3	AM5	AM5	AM5	AM5	AM5	AM5	AM5	AM5	AM5	AM5	AM5
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Rock Type	Diorite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	12	1	2	3	4	5	6	7	8	9	10	11
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO ₂	59.68	63.46	71.36	60.00	61.32	57.68	64.98	65.65	72.27	59.18	61.53	62.84
TiO ₂	0.05	0.02	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Al ₂ O ₃	24.79	24.74	21.00	24.58	23.67	25.42	22.62	21.54	19.97	25.74	23.77	22.87
Cr ₂ O ₃	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00
Fe ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.08	0.31	0.05	0.89	0.19	0.22	0.17	0.13	0.11	0.10	0.13	0.50
MnO	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.03	0.00	0.00	0.01	0.02
MgO	0.01	0.19	0.00	0.29	0.02	0.00	0.00	0.01	0.00	0.04	0.02	0.19
CaO	6.99	4.37	1.23	6.97	5.81	8.27	4.33	3.59	0.28	7.02	5.12	3.14
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.05	0.02	0.03	0.03
Na ₂ O	8.24	8.27	11.86	8.35	8.61	7.36	9.63	10.15	12.40	7.77	9.53	9.72
K ₂ O	0.12	1.15	0.14	0.13	0.23	0.12	0.42	0.10	0.09	0.59	0.17	0.96
An	31.74	21.10	5.36	31.34	26.83	38.06	19.45	16.28	1.22	32.22	22.68	14.34
Ab	67.62	72.29	93.90	67.97	71.93	61.31	78.32	83.21	98.31	64.56	76.42	80.45
Or	0.64	6.60	0.73	0.69	1.24	0.63	2.24	0.51	0.46	3.22	0.90	5.21

Table 1. (Continue)

Sample No.	AM5	AM5	AM5	AM5	AM5	AM15	AM15	AM15	AM15	AM15	AM15	AM15
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	12	13	14	15	16	1	2	3	4	5	6	7
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO ₂	61.48	58.94	62.18	68.57	66.59	67.33	71.99	70.54	73.01	68.14	65.74	67.98
TiO ₂	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.03	0.00
Al ₂ O ₃	23.95	25.33	23.00	19.37	20.83	21.92	20.54	19.87	20.81	23.44	21.39	19.92
Cr ₂ O ₃	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00
Fe ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.20	0.34	0.62	0.08	0.01	0.06	0.02	0.07	0.03	0.00	0.00	0.02
MnO	0.02	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.05	0.00
MgO	0.01	0.02	0.13	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.04
CaO	5.55	7.16	4.33	2.69	1.87	2.58	0.20	0.18	0.26	2.95	2.53	0.22
BaO	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.14	0.00	0.01	0.00	0.04
Na ₂ O	9.03	7.93	9.45	9.59	11.48	11.05	12.71	10.48	12.51	11.15	11.17	12.40
K ₂ O	0.30	0.36	0.46	0.13	0.04	0.13	0.04	2.72	0.15	0.10	0.11	0.28
An	24.95	32.63	19.70	13.30	8.24	11.35	0.88	0.80	1.13	12.68	11.06	0.95
Ab	73.47	65.42	77.81	85.93	91.56	87.97	98.92	84.74	98.08	86.82	88.36	97.60
Or	1.58	1.95	2.49	0.77	0.19	0.69	0.20	14.46	0.79	0.50	0.58	1.45

Table 1. (Continue)

Sample No.	AM15	AM15	AM15	AM15	AM15	AM15	AM15	AM15	AM15	AM17	AM17	AM17
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	G.Diorite	G.Diorite	G.Diorite
Point analysis	8	9	10	11	12	13	14	15	16	1	2	3
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO₂	68.39	67.33	67.93	68.82	68.17	64.84	65.46	64.39	65.51	62.17	62.35	62.71
TiO₂	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.02	0.00	0.02	0.03	0.03
Al₂O₃	19.61	20.18	20.07	19.41	19.71	21.70	21.41	21.78	21.37	23.94	23.62	23.83
Cr₂O₃	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.00	0.05	0.00	0.05	0.02	0.03	0.05	0.01	0.09	0.09	0.14	0.25
MnO	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00
CaO	0.25	0.38	0.25	0.11	0.32	2.51	2.32	2.99	2.47	5.56	5.46	5.63
BaO	0.00	0.10	0.05	0.03	0.07	0.00	0.08	0.00	0.08	0.03	0.00	0.00
Na₂O	12.45	12.06	12.22	12.44	12.38	10.94	11.17	10.59	10.98	9.38	9.29	9.14
K₂O	0.08	0.49	0.27	0.46	0.18	0.33	0.28	0.14	0.09	0.11	0.17	0.20
An	1.11	1.65	1.10	0.49	1.41	11.06	10.14	13.40	11.01	24.51	24.30	25.12
Ab	98.46	95.79	97.47	97.14	97.65	87.19	88.40	85.88	88.52	74.90	74.78	73.83
Or	0.43	2.56	1.43	2.37	0.94	1.75	1.46	0.72	0.47	0.58	0.92	1.05

Table 1. (Continue)

Sample No.	AM17	AM17	AM17	AM17	AM17	AM17	AM17	AM17	AM17	AM17	AM17	AM19
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Rock Type	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite
Point analysis	4	5	6	7	8	9	10	11	12	13	14	1
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO₂	62.19	60.64	62.22	61.54	61.38	60.64	61.77	62.07	61.50	61.73	61.46	61.76
TiO₂	0.00	0.02	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02
Al₂O₃	23.67	24.94	24.26	24.29	24.00	24.19	23.77	23.51	24.03	23.60	23.70	23.80
Cr₂O₃	0.01	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.03	0.03	0.00	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.21	0.06	0.11	0.18	0.09	0.08	0.09	0.08	0.18	0.15	0.22	0.13
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.04	0.01
MgO	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.01
CaO	5.37	6.90	5.65	6.10	5.68	6.12	5.13	5.43	5.66	5.51	5.49	6.05
BaO	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00
Na₂O	9.30	8.37	9.12	8.80	9.14	8.85	9.24	9.12	9.16	9.17	9.30	8.82
K₂O	0.21	0.14	0.16	0.24	0.13	0.09	0.29	0.22	0.12	0.20	0.18	0.16
An	23.90	31.06	25.29	27.35	25.37	27.50	23.11	24.48	25.27	24.66	24.38	27.27
Ab	74.97	68.19	73.88	71.35	73.95	71.99	75.33	74.35	74.08	74.29	74.68	71.87
Or	1.13	0.75	0.83	1.29	0.68	0.50	1.57	1.17	0.65	1.05	0.95	0.85

Table 1. (Continue)

Sample No.	AM19	AM19	AM19	AM19	AM19	AM21	AM21	AM22	AM22	AM22	AM22	AM22
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	Granite	Granite	Granite	Granite	Granite
Point analysis	2	3	4	5	6	1	2	1	2	3	4	5
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO ₂	60.46	62.57	61.67	61.31	60.61	62.52	63.45	64.96	67.26	66.32	67.34	67.57
TiO ₂	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.01
Al ₂ O ₃	23.42	23.92	23.88	23.84	23.37	23.72	22.90	22.28	22.03	22.75	21.72	20.67
Cr ₂ O ₃	0.00	0.03	0.04	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Fe ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.03	0.09	0.14	0.00	0.10	0.09	0.15	0.10	0.02	0.07	0.06	0.03
MnO	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00
MgO	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.02	0.08	0.00	0.00
CaO	5.96	5.83	6.02	5.85	5.92	4.85	4.43	3.74	2.95	3.45	2.41	1.51
BaO	0.00	0.00	0.00	0.02	0.04	0.03	0.01	0.00	0.00	0.00	0.00	0.00
Na ₂ O	8.71	8.84	8.62	8.75	8.77	9.70	9.92	10.14	10.49	10.04	11.08	11.79
K ₂ O	0.17	0.20	0.28	0.13	0.22	0.08	0.13	0.17	0.09	0.17	0.07	0.08
An	27.19	26.44	27.44	26.78	26.85	21.54	19.65	16.78	13.37	15.83	10.69	6.60
Ab	71.92	72.49	71.04	72.49	71.96	78.02	79.64	82.32	86.15	83.26	88.95	93.01
Or	0.90	1.07	1.53	0.73	1.19	0.44	0.71	0.89	0.49	0.91	0.36	0.39

Table 1. (Continue)

Sample No.	AM22	AM22	AM22	AM22	AM22	AM22	AM22	AM22	AM24	AM24	AM24	AM24
Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	6	7	8	9	10	11	12	13	1	2	3	4
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO₂	64.07	64.51	67.47	65.81	79.37	68.48	66.34	67.83	62.27	61.25	60.94	61.19
TiO₂	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Al₂O₃	22.26	21.81	20.27	21.30	13.34	19.59	20.94	19.82	24.22	24.06	23.63	23.74
Cr₂O₃	0.01	0.01	0.04	0.00	0.01	0.02	0.00	0.00	0.24	0.00	0.00	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.04	0.08	0.09	0.04	0.01	0.04	0.02	0.00	0.24	0.18	0.15	0.09
MnO	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.06	0.00	0.00	0.00
MgO	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00
CaO	3.67	3.23	1.12	3.08	1.86	0.31	2.19	1.37	5.99	6.37	6.11	5.91
BaO	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Na₂O	10.34	10.53	12.12	10.53	6.77	12.36	11.41	11.55	8.47	8.32	8.53	8.60
K₂O	0.14	0.14	0.04	0.12	0.07	0.10	0.07	0.06	0.29	0.40	0.22	0.28
An	16.29	14.39	4.83	13.82	13.10	1.36	9.54	6.14	27.65	29.07	28.01	27.11
Ab	82.98	84.87	94.95	85.55	86.35	98.10	90.10	93.56	70.77	68.76	70.77	71.37
Or	0.72	0.75	0.21	0.63	0.55	0.54	0.36	0.30	1.58	2.17	1.22	1.52

Table 1. (Continue)

Sample No.	AM24	AM24	AM24	AM24	AM37	AM37	AM37	AM37	AM37	AM37	AM37	AM37
Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	Granite	Granite	Granite	Granite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite
Point analysis	5	6	7	8	1	2	3	4	5	6	7	8
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO₂	62.14	61.23	60.71	62.21	61.46	61.52	61.54	61.95	61.82	60.99	61.67	61.81
TiO₂	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Al₂O₃	24.04	23.66	23.44	23.90	24.18	24.27	23.95	23.93	23.82	24.60	23.94	24.10
Cr₂O₃	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.03
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.07	0.13	0.09	0.08	0.10	0.17	0.05	0.11	0.21	0.14	0.09	0.11
MnO	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.01	0.00	0.01	0.02	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
CaO	5.90	5.80	5.92	5.91	6.18	6.01	5.88	5.53	5.67	6.47	5.71	5.75
BaO	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.01	0.03
Na₂O	8.87	8.65	8.57	8.65	8.89	9.03	9.01	9.21	8.91	8.48	9.13	9.05
K₂O	0.15	0.15	0.25	0.18	0.24	0.16	0.07	0.19	0.34	0.22	0.15	0.16
An	26.69	26.80	27.26	27.16	27.39	26.66	26.41	24.67	25.53	29.31	25.47	25.78
Ab	72.53	72.36	71.36	71.87	71.33	72.49	73.23	74.30	72.63	69.49	73.74	73.38
Or	0.79	0.85	1.38	0.97	1.28	0.85	0.36	1.02	1.85	1.20	0.79	0.84

Table 1. (Continue)

Sample No.	AM38	AM38	AM38	AM38	AM38	AM38	AM38	AM38	AM38	AM38	AM41	AM41
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	1	2	3	4	5	6	7	8	9	10	1	2
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO₂	62.62	63.61	63.17	61.94	61.49	63.96	61.71	62.43	62.90	63.30	61.42	61.67
TiO₂	0.02	0.00	0.13	0.02	0.00	0.01	0.00	0.00	0.05	0.02	0.00	0.00
Al₂O₃	23.55	23.47	23.47	23.27	23.50	22.31	23.61	23.30	22.73	22.53	23.82	24.18
Cr₂O₃	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.22	0.14	0.22	0.20	0.15	0.24	0.10	0.08	0.19	0.26	0.23	0.18
MnO	0.00	0.00	0.01	0.02	0.00	0.02	0.00	0.00	0.03	0.02	0.03	0.00
MgO	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.03	0.01
CaO	4.81	4.76	5.03	5.23	5.39	3.55	5.20	4.84	4.10	3.97	5.75	6.10
BaO	0.04	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.03	0.00	0.00
Na₂O	9.40	9.39	9.54	9.34	9.28	10.60	9.24	9.53	10.06	10.11	8.80	8.83
K₂O	0.23	0.27	0.07	0.24	0.27	0.13	0.24	0.16	0.17	0.15	0.13	0.21
An	21.76	21.57	22.47	23.33	23.98	15.52	23.42	21.74	18.23	17.67	26.34	27.33
Ab	76.98	76.99	77.15	75.42	74.62	83.79	75.29	77.43	80.87	81.52	72.97	71.53
Or	1.26	1.44	0.37	1.25	1.40	0.69	1.29	0.83	0.90	0.81	0.69	1.14

Table 1. (Continue)

Sample No.	AM41	AM41	AM41	AM41	AM41	AM41	AM41	AM41	AM41	AM41	AM41	AM41
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	3	4	5	6	7	8	9	10	11	12	13	14
Mineral	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg	Plg
SiO₂	61.99	61.71	61.95	61.83	61.37	61.63	61.64	60.79	61.57	60.84	61.29	61.07
TiO₂	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.04	0.01	0.00
Al₂O₃	24.42	23.97	24.00	24.64	24.34	24.18	24.01	24.38	24.24	23.83	24.01	24.01
Cr₂O₃	0.00	0.04	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.04	0.00	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.16	0.21	0.13	0.31	0.16	0.12	0.16	0.21	0.11	0.15	0.20	0.21
MnO	0.02	0.02	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
CaO	5.96	5.98	6.01	6.16	6.11	6.19	5.89	6.15	6.29	5.95	5.75	5.94
BaO	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.02	0.00	0.00
Na₂O	8.73	8.81	8.87	8.73	8.64	8.71	8.89	8.75	8.83	8.69	8.97	9.00
K₂O	0.23	0.24	0.29	0.15	0.14	0.21	0.30	0.24	0.19	0.27	0.20	0.10
An	27.05	26.92	26.83	27.83	27.88	27.86	26.38	27.63	27.96	27.04	25.88	26.58
Ab	71.73	71.82	71.65	71.38	71.37	70.99	72.03	71.09	71.02	71.50	73.02	72.90
Or	1.22	1.26	1.52	0.80	0.75	1.15	1.59	1.28	1.02	1.46	1.09	0.52

Table 1. (Continue)

Sample No.	AM41
Pluton/Area	Taru
Rock Type	Granite
Point analysis	15
Mineral	Plg
SiO₂	61.42
TiO₂	0.00
Al₂O₃	24.25
Cr₂O₃	0.00
Fe₂O₃	0.00
FeO	0.31
MnO	0.03
MgO	0.00
CaO	5.72
BaO	0.03
Na₂O	8.97
K₂O	0.16
An	25.82
Ab	73.30
Or	0.88

Table 2. EPMA analysis of K-Feldspar mineral, samples that collected from Leh region of Ladakh Batholith around the Trans-Himalayan Belt (India)

Sample No.	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1	AM1
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	1	2	3	4	5	6	7	8	9	10	11	12
Mineral	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs
SiO₂	65.37	64.77	65.59	66.00	65.80	65.19	65.31	64.90	65.41	65.17	65.51	65.39
TiO₂	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al₂O₃	18.01	18.20	18.03	18.33	18.26	18.20	18.30	18.13	18.14	18.17	18.07	18.16
Cr₂O₃	0.03	0.01	0.01	0.00	0.00	0.02	0.03	0.03	0.02	0.00	0.00	0.02
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.70	0.53	0.08	0.08	0.06	0.12	0.14	0.07	0.13	0.03	0.04	0.11
MnO	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.04
MgO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
BaO	0.06	0.57	0.02	0.03	0.02	0.15	0.05	0.01	0.04	0.10	0.02	0.08
Na₂O	0.84	0.64	1.12	0.86	0.90	1.05	0.88	0.41	0.75	0.98	0.69	1.01
K₂O	15.55	15.57	15.29	15.53	15.35	14.69	15.31	16.28	15.64	15.31	15.72	15.23
An	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00
Ab	7.61	5.88	9.99	7.79	8.19	9.81	8.06	3.70	6.82	8.82	6.28	9.19
Or	92.39	94.12	90.01	92.21	91.81	90.19	91.94	96.30	93.18	91.18	93.64	90.81

Table 2. (Continue)

Sample No.	AM1	AM1	AM3	AM3	AM3	AM3	AM3	AM3	AM3	AM3	AM3	AM15
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Nimu
Rock Type	Granite	Granite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Granite
Point analysis	13	14	1	2	3	4	5	6	7	8	9	1
Mineral	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs
SiO ₂	65.35	65.07	65.25	65.13	64.64	65.58	64.72	65.21	65.26	64.68	64.71	65.95
TiO ₂	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Al ₂ O ₃	18.20	18.26	18.13	18.22	18.40	18.47	18.13	17.95	18.19	18.77	18.25	18.25
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.02	0.00	0.00	0.00	0.03
Fe ₂ O ₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.06	0.10	0.08	0.05	0.06	0.07	0.12	0.13	0.15	0.00	0.03	0.00
MnO	0.01	0.00	0.02	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.01	0.00
CaO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.15	0.04	0.00
BaO	0.04	0.03	0.32	0.34	0.56	0.37	0.50	0.13	0.35	1.23	0.21	0.00
Na ₂ O	0.73	0.80	0.83	0.83	0.98	0.45	0.69	0.41	0.66	0.91	0.39	0.26
K ₂ O	15.73	15.58	15.38	15.34	15.06	15.26	15.49	15.84	15.80	14.89	15.88	16.04
An	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.74	0.19	0.00
Ab	6.60	7.21	7.57	7.56	9.03	4.33	6.36	3.81	5.93	8.43	3.63	2.41
Or	93.40	92.79	92.43	92.44	90.95	95.67	93.64	96.19	94.07	90.83	96.18	97.59

Table 2. (Continue)

Sample No.	AM15	AM15	AM15	AM15	AM15	AM15	AM15	AM15	AM15	AM15	AM15	AM15
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	2	3	4	5	6	7	8	9	10	11	12	13
Mineral	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs
SiO₂	64.81	64.93	65.68	64.88	66.59	64.83	64.83	66.74	66.44	65.56	65.69	68.51
TiO₂	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00
Al₂O₃	18.16	18.16	18.33	18.24	18.42	18.36	18.05	18.58	17.93	18.47	18.47	19.33
Cr₂O₃	0.00	0.00	0.04	0.02	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.00	0.09	0.06	0.09	0.00	0.08	0.06	0.01	0.15	0.11	0.02	0.00
MnO	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00
MgO	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	0.00	0.00	0.01	0.03	0.00	0.00	0.02	0.00	0.00	0.07	0.00	0.00
BaO	0.20	0.13	0.05	0.13	0.07	1.03	0.07	0.48	0.15	0.43	0.00	0.47
Na₂O	0.86	0.72	0.77	1.22	1.62	0.78	0.45	0.54	0.48	0.93	0.65	0.23
K₂O	15.40	15.56	15.36	15.05	13.55	15.10	16.03	16.07	15.74	15.19	15.78	14.87
An	0.00	0.00	0.06	0.16	0.02	0.00	0.12	0.00	0.00	0.33	0.00	0.00
Ab	7.80	6.61	7.07	10.93	15.36	7.31	4.04	4.87	4.40	8.52	5.85	2.29
Or	92.20	93.39	92.87	88.90	84.62	92.69	95.84	95.13	95.60	91.15	94.15	97.71

Table 2. (Continue)

Sample No.	AM15	AM15	AM15	AM15	AM17	AM17	AM17	AM17	AM19	AM19	AM19	AM19
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Rock Type	Granite	Granite	Granite	Granite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite
Point analysis	14	15	16	17	1	2	3	4	1	2	3	4
Mineral	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs
SiO₂	66.59	67.08	65.87	65.66	65.78	65.24	65.13	65.38	64.45	64.18	65.67	64.48
TiO₂	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.06	0.00
Al₂O₃	18.57	18.96	18.38	18.37	18.34	18.19	18.07	18.26	17.91	17.86	18.06	17.93
Cr₂O₃	0.00	0.01	0.01	0.05	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.07	0.00	0.18	0.13	0.30	0.06	0.04	0.30	0.05	0.08	0.02	0.06
MnO	0.04	0.02	0.04	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.01	0.00	0.00
CaO	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.29	0.52	0.47	0.24	0.04	0.41	0.51	0.20	0.51	0.66	0.54	0.47
Na₂O	0.99	0.48	0.65	0.80	0.05	0.73	0.59	0.06	0.72	0.76	0.42	0.69
K₂O	14.90	15.57	15.50	15.53	16.52	15.36	15.46	16.40	15.50	15.31	15.68	15.61
An	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ab	9.17	4.44	5.98	7.23	0.48	6.70	5.52	0.52	6.57	6.97	3.88	6.27
Or	90.83	95.56	93.95	92.77	99.52	93.30	94.48	99.48	93.43	93.03	96.12	93.73

Table 2. (Continue)

Sample No.	AM19	AM19	AM19	AM19	AM19	AM19	AM19	AM19	AM19	AM19	AM21	AM21
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Umla	Umla
Rock Type	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite
Point analysis	5	6	7	8	9	10	11	12	13	14	1	2
Mineral	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs
SiO₂	64.68	64.47	64.37	64.52	64.15	63.80	63.74	63.56	64.25	64.13	65.00	64.16
TiO₂	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02
Al₂O₃	18.16	17.97	17.93	17.95	17.96	17.72	17.86	17.60	17.78	17.69	18.04	18.32
Cr₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.15	0.22	0.00	0.02	0.03	0.06	0.18	0.02	0.03	0.18	0.06	0.06
MnO	0.00	0.03	0.00	0.05	0.00	0.03	0.00	0.00	0.00	0.00	0.01	0.00
MgO	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
BaO	0.59	0.59	0.64	0.63	0.61	0.55	0.70	0.41	0.53	0.55	0.09	0.67
Na₂O	0.80	0.75	0.78	0.52	0.59	0.86	0.75	0.36	0.36	0.31	0.68	0.81
K₂O	15.78	15.58	15.37	15.87	15.59	15.30	15.35	16.06	16.13	16.05	15.76	15.35
An	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Ab	7.12	6.77	7.13	4.78	5.47	7.83	6.88	3.29	3.29	2.84	6.11	7.46
Or	92.88	93.23	92.87	95.22	94.53	92.17	93.12	96.71	96.71	97.02	93.89	92.54

Table 2. (Continue)

Sample No.	AM21	AM21	AM21	AM21	AM21	AM22	AM22	AM22	AM22	AM22	AM22	AM22
Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	3	4	5	6	7	1	2	3	4	5	6	7
Mineral	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs
SiO₂	64.36	64.20	64.80	63.51	64.40	65.24	65.47	66.07	65.69	65.14	65.04	65.77
TiO₂	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02	0.00
Al₂O₃	17.97	17.72	18.09	18.74	18.30	18.17	18.13	18.43	18.26	18.06	18.24	18.24
Cr₂O₃	0.03	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.10	0.06	0.05	0.04	0.04	0.09	0.00	0.12	0.09	0.12	0.10	0.03
MnO	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
CaO	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.42	0.37	0.39	0.52	0.65	0.17	0.17	0.18	0.18	0.17	0.29	0.11
Na₂O	0.82	0.54	0.77	0.47	0.90	0.74	0.46	0.74	0.31	0.85	0.80	0.59
K₂O	15.40	15.38	15.58	15.48	15.20	15.63	15.93	15.30	15.85	15.28	15.39	15.60
An	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ab	7.51	5.02	6.99	4.44	8.22	6.74	4.22	6.87	2.92	7.79	7.34	5.42
Or	92.49	94.98	93.01	95.45	91.78	93.26	95.78	93.13	97.08	92.21	92.66	94.58

Table 2. (Continue)

Sample No.	AM22	AM22	AM22	AM22	AM22	AM22	AM24	AM24	AM24	AM24	AM24	AM24
Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite	G.Diorite
Point analysis	8	9	10	11	12	13	1	2	3	4	5	6
Mineral	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs
SiO₂	65.63	66.35	65.02	65.14	64.68	64.88	65.77	64.15	64.97	65.41	65.93	65.53
TiO₂	0.02	0.00	0.00	0.02	0.00	0.05	0.01	0.00	0.01	0.02	0.00	0.02
Al₂O₃	18.52	18.29	18.08	18.25	18.14	18.13	18.03	17.74	17.95	17.92	18.02	18.03
Cr₂O₃	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.08	0.06	0.08	0.07	0.06	0.04	0.04	0.04	0.13	0.00	0.02	0.00
MnO	0.03	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
MgO	0.01	0.00	0.00	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
CaO	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
BaO	0.56	0.18	0.18	0.25	0.31	0.36	0.21	0.28	0.21	0.38	0.31	0.26
Na₂O	0.34	0.80	0.89	0.97	0.93	0.50	0.69	0.53	0.72	1.17	0.31	1.26
K₂O	16.07	15.36	15.42	15.26	15.22	15.72	15.65	15.63	15.72	14.84	15.99	14.88
An	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00
Ab	3.09	7.36	8.04	8.79	8.50	4.62	6.30	4.93	6.54	10.68	2.88	11.44
Or	96.91	92.64	91.96	91.13	91.50	95.38	93.70	95.07	93.46	89.14	97.12	88.56

Table 2. (Continue)

Sample No.	AM37	AM37	AM38	AM38	AM38	AM38	AM38	AM38	AM38	AM38	AM38
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	G.Diorite	G.Diorite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	1	2	1	2	3	4	5	6	7	8	9
Mineral	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs	Kfs
SiO₂	65.08	65.11	64.99	64.75	64.31	64.84	64.66	65.01	65.32	65.86	64.99
TiO₂	0.00	0.04	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.00	0.05
Al₂O₃	18.10	18.13	18.27	18.28	18.23	18.17	18.21	18.10	18.11	18.55	18.18
Cr₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01
Fe₂O₃	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	0.05	0.05	0.11	0.09	0.09	0.04	0.11	0.10	0.09	0.07	0.39
MnO	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.01
MgO	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00
CaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.22	0.09	0.39	0.34	0.28	0.31	0.33	0.41	0.35	0.37	0.44
Na₂O	0.61	0.49	0.86	0.71	0.94	0.89	0.84	0.61	0.81	1.33	0.69
K₂O	16.06	15.97	15.21	15.59	15.19	15.37	15.08	15.62	15.25	14.79	15.50
An	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ab	5.47	4.47	7.87	6.46	8.57	8.12	7.76	5.56	7.49	12.01	6.33
Or	94.53	95.53	92.13	93.54	91.43	91.88	92.24	94.44	92.51	87.99	93.67

Table 3. EPMA analysis of Biotite mineral, samples that collected from Leh region of Ladakh Batholith around the Trans-Himalayan Belt (India)

Sample No.	AM1	AM1	AM1	AM1	AM1	AM1	AM1
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Rock Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite
Point analysis	1	2	3	4	5	6	7
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	37.46	36.65	35.98	37.21	37.23	36.91	36.82
TiO₂	3.53	3.64	3.69	2.83	3.72	3.66	3.07
Al₂O₃	14.44	14.07	13.93	13.52	13.91	14.03	13.77
FeO	19.84	20.72	20.18	19.88	20.65	20.51	20.44
MnO	1.18	0.79	0.80	0.63	0.70	0.67	0.76
MgO	10.62	10.18	9.99	11.13	10.55	10.09	10.64
CaO	0.01	0.04	0.00	0.00	0.03	0.03	0.00
Na₂O	0.06	0.12	0.09	0.06	0.07	0.10	0.07
K₂O	9.67	9.33	9.27	9.56	9.38	9.59	9.06
Cl	0.03	0.05	0.05	0.03	0.03	0.02	0.03
F	0.67	0.70	0.66	0.78	0.66	0.63	0.72
Si	5.67	5.64	5.63	5.74	5.67	5.67	5.70
Al iv	2.33	2.36	2.37	2.26	2.33	2.33	2.30
Al T	2.57	2.55	2.57	2.46	2.50	2.54	2.51
Al vi	0.24	0.19	0.20	0.20	0.17	0.21	0.21
Ti	0.40	0.42	0.43	0.33	0.43	0.42	0.36
Fe(ii)	2.51	2.67	2.64	2.57	2.63	2.64	2.65
Mn	0.15	0.10	0.11	0.08	0.09	0.09	0.10
Mg	2.39	2.33	2.33	2.56	2.40	2.31	2.46
Ca	0.00	0.01	0.00	0.00	0.01	0.00	0.00
Na	0.02	0.03	0.03	0.02	0.02	0.03	0.02
K	1.87	1.83	1.85	1.88	1.82	1.88	1.79
Cl	0.01	0.01	0.01	0.01	0.01	0.01	0.01
F	0.32	0.34	0.32	0.38	0.32	0.31	0.35
Total	15.58	15.59	15.58	15.64	15.57	15.59	15.59
Fe/Fe+Mg	0.51	0.53	0.53	0.50	0.52	0.53	0.52

Table 3. (Continue)

Sample No.	AM1	AM1	AM3	AM3	AM3	AM3	AM3
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Rock Type	Granite	Granite	Diorite	Diorite	Diorite	Diorite	Diorite
Point analysis	8	9	1	2	3	4	5
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	37.39	37.38	36.77	36.82	37.57	36.89	36.14
TiO₂	3.53	3.30	2.73	2.46	1.72	2.65	2.77
Al₂O₃	13.78	14.09	14.28	14.73	15.68	14.81	14.68
FeO	19.68	19.88	20.00	19.84	19.30	19.77	19.92
MnO	0.71	0.71	0.32	0.37	0.34	0.37	0.33
MgO	11.09	10.85	11.06	11.16	11.61	10.99	11.61
CaO	0.04	0.00	0.10	0.14	0.09	0.23	0.31
Na₂O	0.12	0.10	0.26	0.14	0.11	0.13	0.17
K₂O	9.38	9.63	8.40	8.62	8.80	9.07	7.63
Cl	0.04	0.03	0.09	0.07	0.08	0.08	0.08
F	0.75	0.69	0.00	0.00	0.00	0.00	0.01
Si	5.70	5.70	5.69	5.67	5.70	5.66	5.60
Al iv	2.30	2.30	2.31	2.33	2.30	2.34	2.40
Al T	2.48	2.53	2.60	2.68	2.80	2.68	2.68
Al vi	0.18	0.23	0.29	0.35	0.50	0.34	0.27
Ti	0.41	0.38	0.32	0.29	0.20	0.31	0.32
Fe(ii)	2.51	2.54	2.59	2.56	2.45	2.54	2.58
Mn	0.09	0.09	0.04	0.05	0.04	0.05	0.04
Mg	2.52	2.47	2.55	2.56	2.62	2.51	2.68
Ca	0.01	0.00	0.02	0.02	0.01	0.04	0.05
Na	0.04	0.03	0.08	0.04	0.03	0.04	0.05
K	1.82	1.87	1.66	1.69	1.70	1.78	1.51
Cl	0.01	0.01	0.02	0.02	0.02	0.02	0.02
F	0.36	0.33	0.00	0.00	0.00	0.00	0.00
Total	15.58	15.60	15.55	15.56	15.56	15.59	15.51
Fe/Fe+Mg	0.50	0.51	0.50	0.50	0.48	0.50	0.49

Table 3. (Continue)

Sample No.	AM3	AM3	AM3	AM3	AM3	AM3	AM17
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Nimu
Rock Type	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite	Granodiorite
Point analysis	6	7	8	9	10	11	1
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	35.93	36.32	35.72	36.80	37.14	37.11	37.68
TiO₂	3.33	2.14	2.90	2.62	2.52	2.16	1.94
Al₂O₃	13.91	15.13	14.34	14.69	14.70	14.89	15.31
FeO	19.64	19.48	19.90	19.46	19.78	19.54	17.81
MnO	0.34	0.40	0.32	0.37	0.39	0.30	0.77
MgO	11.29	10.70	10.08	11.09	11.14	11.16	11.57
CaO	0.25	0.37	0.24	0.05	0.28	0.11	0.04
Na₂O	0.36	0.14	0.17	0.12	0.15	0.17	0.04
K₂O	7.05	8.15	8.78	8.92	8.52	8.49	9.17
Cl	0.06	0.07	0.08	0.09	0.08	0.07	0.08
F	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Si	5.64	5.67	5.65	5.68	5.69	5.72	5.75
Al iv	2.36	2.33	2.35	2.32	2.31	2.28	2.25
Al T	2.57	2.78	2.67	2.67	2.66	2.70	2.75
Al vi	0.21	0.45	0.32	0.35	0.35	0.42	0.51
Ti	0.39	0.25	0.35	0.30	0.29	0.25	0.22
Fe(ii)	2.58	2.54	2.63	2.51	2.54	2.52	2.27
Mn	0.04	0.05	0.04	0.05	0.05	0.04	0.10
Mg	2.64	2.49	2.38	2.55	2.55	2.56	2.63
Ca	0.04	0.06	0.04	0.01	0.05	0.02	0.01
Na	0.11	0.04	0.05	0.03	0.05	0.05	0.01
K	1.41	1.62	1.77	1.76	1.67	1.67	1.78
Cl	0.02	0.02	0.02	0.02	0.02	0.02	0.02
F	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Total	15.43	15.51	15.57	15.56	15.53	15.53	15.54
Fe/Fe+Mg	0.49	0.51	0.53	0.50	0.50	0.50	0.46

Table 3. (Continue)

Sample No.	AM17	AM17	AM17	AM17	AM17	AM17	AM17
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	2	3	4	5	6	7	8
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	36.77	37.50	37.10	37.36	37.71	37.18	38.04
TiO₂	2.65	2.31	2.22	2.03	1.83	2.33	2.22
Al₂O₃	15.10	15.68	15.29	15.88	15.80	15.39	15.36
FeO	18.56	18.84	18.81	18.19	18.31	19.13	17.97
MnO	0.68	0.71	0.77	0.71	0.65	0.73	0.70
MgO	10.90	11.15	11.12	11.30	11.84	11.26	11.37
CaO	0.09	0.00	0.14	0.00	0.00	0.05	0.05
Na₂O	0.07	0.06	0.09	0.06	0.05	0.05	0.07
K₂O	9.24	9.65	8.49	9.49	9.52	9.29	9.00
Cl	0.05	0.04	0.05	0.04	0.07	0.04	0.07
F	0.00	0.02	0.00	0.00	0.00	0.01	0.00
Si	5.67	5.67	5.70	5.68	5.69	5.66	5.77
Al iv	2.33	2.33	2.30	2.32	2.31	2.34	2.23
Al T	2.74	2.80	2.77	2.85	2.81	2.76	2.75
Al vi	0.42	0.47	0.47	0.53	0.50	0.42	0.51
Ti	0.31	0.26	0.26	0.23	0.21	0.27	0.25
Fe(ii)	2.39	2.38	2.42	2.31	2.31	2.43	2.28
Mn	0.09	0.09	0.10	0.09	0.08	0.09	0.09
Mg	2.51	2.52	2.55	2.56	2.66	2.56	2.57
Ca	0.01	0.00	0.02	0.00	0.00	0.01	0.01
Na	0.02	0.02	0.03	0.02	0.02	0.01	0.02
K	1.82	1.86	1.66	1.84	1.83	1.80	1.74
Cl	0.01	0.01	0.01	0.01	0.02	0.01	0.02
F	0.00	0.01	0.00	0.00	0.00	0.01	0.00
TOTAL	15.56	15.60	15.50	15.59	15.61	15.60	15.48
Fe/Fe+Mg	0.49	0.49	0.49	0.47	0.46	0.49	0.47

Table 3. (Continue)

Sample No.	AM17	AM17	AM19	AM19	AM19	AM19	AM19
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	9	10	1	2	3	4	5
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	38.08	37.84	36.42	36.04	36.33	36.47	36.24
TiO₂	1.46	1.28	2.15	2.13	2.85	2.11	2.29
Al₂O₃	16.70	16.99	14.41	15.03	14.85	15.36	14.86
FeO	17.33	17.66	18.46	17.79	18.15	17.51	17.78
MnO	0.68	0.64	1.64	1.65	1.44	1.66	1.73
MgO	11.91	12.06	10.87	10.56	10.41	10.96	10.65
CaO	0.04	0.10	0.12	0.21	0.07	0.11	0.25
Na₂O	0.05	0.05	0.10	0.13	0.11	0.11	0.12
K₂O	9.14	8.67	9.11	9.03	8.98	9.17	8.93
Cl	0.07	0.05	0.07	0.09	0.06	0.05	0.08
F	0.00	0.00	0.05	0.05	0.00	0.00	0.01
Si	5.71	5.68	5.70	5.66	5.67	5.66	5.67
Al iv	2.29	2.32	2.30	2.34	2.33	2.34	2.33
Al T	2.95	3.00	2.66	2.78	2.73	2.81	2.74
Al vi	0.66	0.68	0.35	0.44	0.39	0.47	0.41
Ti	0.16	0.14	0.25	0.25	0.33	0.25	0.27
Fe(ii)	2.17	2.21	2.41	2.34	2.37	2.27	2.33
Mn	0.09	0.08	0.22	0.22	0.19	0.22	0.23
Mg	2.66	2.70	2.53	2.47	2.42	2.53	2.48
Ca	0.01	0.02	0.02	0.04	0.01	0.02	0.04
Na	0.01	0.02	0.03	0.04	0.03	0.03	0.03
K	1.75	1.66	1.82	1.81	1.79	1.82	1.78
Cl	0.02	0.01	0.02	0.02	0.02	0.01	0.02
F	0.00	0.00	0.02	0.03	0.00	0.00	0.00
TOTAL	15.52	15.51	15.64	15.61	15.54	15.61	15.59
Fe/Fe+Mg	0.45	0.45	0.49	0.49	0.49	0.47	0.48

Table 3. (Continue)

Sample No.	AM19	AM19	AM19	AM19	AM19	AM19	AM19
Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	6	7	8	9	10	11	12
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	37.41	36.74	36.34	37.23	37.17	36.82	37.38
TiO₂	2.81	2.35	1.99	2.79	2.77	2.02	2.63
Al₂O₃	14.95	14.89	14.63	15.41	15.23	15.14	15.46
FeO	18.16	18.56	18.25	17.91	17.88	18.04	17.72
MnO	1.58	1.51	1.52	1.56	1.58	1.72	1.41
MgO	10.80	10.70	10.83	10.89	10.75	10.79	10.96
CaO	0.03	0.23	0.31	0.00	0.02	0.11	0.00
Na₂O	0.10	0.10	0.13	0.12	0.11	0.12	0.09
K₂O	9.24	8.62	8.28	9.15	9.28	8.77	9.55
Cl	0.07	0.10	0.07	0.06	0.09	0.06	0.09
F	0.00	0.00	0.02	0.05	0.02	0.02	0.04
Si	5.71	5.69	5.71	5.67	5.68	5.71	5.69
Al iv	2.29	2.31	2.29	2.33	2.32	2.29	2.31
Al T	2.69	2.72	2.71	2.77	2.75	2.77	2.77
Al vi	0.40	0.41	0.42	0.44	0.43	0.47	0.46
Ti	0.32	0.27	0.23	0.32	0.32	0.24	0.30
Fe(ii)	2.32	2.40	2.40	2.28	2.29	2.34	2.25
Mn	0.20	0.20	0.20	0.20	0.20	0.23	0.18
Mg	2.46	2.47	2.54	2.47	2.45	2.49	2.49
Ca	0.00	0.04	0.05	0.00	0.00	0.02	0.00
Na	0.03	0.03	0.04	0.04	0.03	0.04	0.03
K	1.80	1.70	1.66	1.78	1.81	1.73	1.85
Cl	0.02	0.03	0.02	0.02	0.02	0.02	0.02
F	0.00	0.00	0.01	0.02	0.01	0.01	0.02
TOTAL	15.53	15.53	15.54	15.53	15.53	15.55	15.56
Fe/Fe+Mg	0.49	0.49	0.49	0.48	0.48	0.48	0.48

Table 3. (Continue)

Sample No.	AM19	AM21	AM21	AM21	AM21	AM21	AM21
Pluton/Area	Nimu	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	13	1	2	3	4	5	6
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	37.35	37.37	36.60	37.44	37.36	37.69	37.13
TiO₂	2.72	3.43	3.00	1.53	2.53	2.70	2.54
Al₂O₃	15.18	15.08	15.26	15.98	15.37	15.88	15.52
FeO	18.01	18.01	18.04	17.89	17.07	17.53	17.67
MnO	1.46	0.58	0.54	0.59	0.56	0.61	0.65
MgO	10.80	10.82	11.02	11.92	11.29	11.51	11.38
CaO	0.00	0.00	0.01	0.01	0.05	0.02	0.02
Na₂O	0.09	0.06	0.06	0.08	0.09	0.07	0.08
K₂O	9.30	9.62	9.39	9.54	9.09	9.65	9.39
Cl	0.05	0.05	0.07	0.06	0.07	0.07	0.07
F	0.00	0.00	0.00	0.03	0.00	0.00	0.03
Si	5.70	5.69	5.64	5.69	5.74	5.67	5.67
Al iv	2.30	2.31	2.36	2.31	2.26	2.33	2.33
Al T	2.73	2.71	2.77	2.86	2.78	2.82	2.80
Al vi	0.43	0.40	0.41	0.55	0.52	0.49	0.47
Ti	0.31	0.39	0.35	0.17	0.29	0.31	0.29
Fe(ii)	2.30	2.29	2.32	2.27	2.19	2.21	2.26
Mn	0.19	0.07	0.07	0.08	0.07	0.08	0.08
Mg	2.46	2.46	2.53	2.70	2.58	2.58	2.59
Ca	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Na	0.03	0.02	0.02	0.02	0.03	0.02	0.02
K	1.81	1.87	1.84	1.85	1.78	1.85	1.83
Cl	0.01	0.01	0.02	0.01	0.02	0.02	0.02
F	0.00	0.00	0.00	0.01	0.00	0.00	0.02
TOTAL	15.53	15.50	15.55	15.64	15.48	15.54	15.55
Fe/Fe+Mg	0.48	0.48	0.48	0.46	0.46	0.46	0.47

Table 3. (Continue)

Sample No.	AM21	AM21	AM21	AM21	AM21	AM21	AM21
Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	7	8	9	10	11	12	13
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	37.40	37.40	37.13	37.67	37.07	36.95	37.61
TiO₂	2.03	2.26	3.09	2.97	2.78	2.67	2.77
Al₂O₃	16.00	15.93	15.10	15.43	15.44	15.66	16.32
FeO	17.15	17.25	17.89	18.05	18.44	18.40	17.10
MnO	0.48	0.54	0.58	0.62	0.59	0.56	0.48
MgO	11.95	11.35	10.83	11.05	11.18	11.24	11.45
CaO	0.01	0.04	0.01	0.00	0.00	0.01	0.00
Na₂O	0.08	0.08	0.03	0.09	0.14	0.11	0.07
K₂O	9.25	9.48	9.63	9.61	9.47	9.50	9.76
Cl	0.07	0.06	0.06	0.06	0.08	0.06	0.06
F	0.11	0.03	0.02	0.06	0.02	0.00	0.00
Si	5.68	5.70	5.70	5.70	5.65	5.63	5.65
Al iv	2.32	2.30	2.30	2.30	2.35	2.37	2.35
Al T	2.87	2.86	2.73	2.75	2.77	2.81	2.89
Al vi	0.55	0.56	0.43	0.45	0.42	0.44	0.54
Ti	0.23	0.26	0.36	0.34	0.32	0.31	0.31
Fe(ii)	2.18	2.20	2.30	2.28	2.35	2.34	2.15
Mn	0.06	0.07	0.07	0.08	0.08	0.07	0.06
Mg	2.71	2.58	2.48	2.49	2.54	2.55	2.57
Ca	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Na	0.02	0.02	0.01	0.03	0.04	0.03	0.02
K	1.79	1.84	1.88	1.85	1.84	1.85	1.87
Cl	0.02	0.01	0.01	0.01	0.02	0.01	0.02
F	0.05	0.02	0.01	0.03	0.01	0.00	0.00
TOTAL	15.55	15.54	15.52	15.52	15.58	15.59	15.53
Fe/Fe+Mg	0.45	0.46	0.48	0.48	0.48	0.48	0.46

Table 3. (Continue)

Sample No.	AM21	AM21	AM22	AM22	AM22	AM22	AM24
Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	G.diorite	G.diorite	Granite	Granite	Granite	Granite	G.diorite
Point analysis	14	15	1	2	3	4	1
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	37.64	37.47	37.12	37.53	38.13	38.14	37.58
TiO₂	2.58	2.75	1.34	3.05	3.02	2.69	1.93
Al₂O₃	15.95	15.99	15.60	13.88	14.91	14.52	15.24
FeO	17.56	17.20	18.25	18.04	17.82	17.48	19.12
MnO	0.51	0.58	0.51	0.61	0.52	0.48	0.67
MgO	11.42	11.26	12.57	12.33	11.62	12.16	11.38
CaO	0.00	0.00	0.07	0.21	0.03	0.18	0.02
Na₂O	0.09	0.08	0.07	0.09	0.09	0.09	0.07
K₂O	9.51	9.73	8.73	8.87	9.23	8.50	9.57
Cl	0.07	0.04	0.06	0.05	0.04	0.05	0.09
F	0.06	0.02	0.41	0.50	0.42	0.56	0.00
Si	5.68	5.67	5.67	5.73	5.75	5.79	5.71
Al iv	2.32	2.33	2.33	2.27	2.25	2.21	2.29
Al T	2.84	2.85	2.81	2.50	2.65	2.60	2.73
Al vi	0.52	0.53	0.48	0.22	0.40	0.39	0.44
Ti	0.29	0.31	0.15	0.35	0.34	0.31	0.22
Fe(ii)	2.22	2.18	2.33	2.30	2.25	2.22	2.43
Mn	0.07	0.07	0.07	0.08	0.07	0.06	0.09
Mg	2.57	2.54	2.86	2.80	2.61	2.75	2.58
Ca	0.00	0.00	0.01	0.03	0.01	0.03	0.00
Na	0.03	0.02	0.02	0.03	0.03	0.03	0.02
K	1.83	1.88	1.70	1.73	1.78	1.65	1.86
Cl	0.02	0.01	0.02	0.01	0.01	0.01	0.02
F	0.03	0.01	0.20	0.24	0.20	0.27	0.00
TOTAL	15.53	15.53	15.62	15.55	15.48	15.43	15.63
Fe/Fe+Mg	0.46	0.46	0.45	0.45	0.46	0.45	0.49

Table 3. (Continue)

Sample No.	AM24	AM24	AM24	AM24	AM24	AM24	AM24
Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	2	3	4	5	6	7	8
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	37.57	37.22	36.81	36.74	36.84	36.76	37.28
TiO₂	1.92	3.42	3.52	3.16	3.20	1.97	3.75
Al₂O₃	15.53	14.54	14.44	13.95	14.12	14.52	14.39
FeO	18.44	19.44	19.28	19.70	19.48	18.91	19.33
MnO	0.69	0.75	0.79	0.58	0.75	0.62	0.73
MgO	11.14	10.86	10.46	11.03	10.79	11.31	10.83
CaO	0.01	0.04	0.00	0.11	0.09	0.23	0.00
Na₂O	0.07	0.11	0.05	0.12	0.11	0.17	0.09
K₂O	9.55	9.41	9.52	8.90	9.17	8.51	9.45
Cl	0.09	0.08	0.09	0.13	0.09	0.12	0.08
F	0.03	0.00	0.00	0.04	0.00	0.00	0.03
Si	5.73	5.66	5.66	5.68	5.68	5.73	5.67
Al iv	2.27	2.34	2.34	2.32	2.32	2.27	2.33
Al T	2.79	2.61	2.62	2.54	2.57	2.67	2.58
Al vi	0.52	0.27	0.28	0.22	0.25	0.39	0.24
Ti	0.22	0.39	0.41	0.37	0.37	0.23	0.43
Fe(ii)	2.35	2.47	2.48	2.55	2.51	2.46	2.46
Mn	0.09	0.10	0.10	0.08	0.10	0.08	0.09
Mg	2.53	2.46	2.40	2.54	2.48	2.62	2.45
Ca	0.00	0.01	0.00	0.02	0.01	0.04	0.00
Na	0.02	0.03	0.01	0.04	0.03	0.05	0.03
K	1.86	1.83	1.87	1.76	1.81	1.69	1.83
Cl	0.02	0.02	0.02	0.03	0.02	0.03	0.02
F	0.02	0.00	0.00	0.02	0.00	0.00	0.01
TOTAL	15.59	15.56	15.55	15.56	15.57	15.57	15.53
Fe/Fe+Mg	0.48	0.50	0.51	0.50	0.50	0.48	0.50

Table 3. (Continue)

Sample No.	AM24	AM37	AM37	AM37	AM37	AM37	AM37
Pluton/Area	Umla	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	9	1	2	3	4	5	6
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	36.49	37.54	37.15	37.86	36.77	37.59	36.86
TiO₂	3.13	3.23	2.68	3.06	2.33	2.43	2.42
Al₂O₃	14.15	14.61	14.87	14.81	15.13	14.96	15.09
FeO	19.16	18.73	18.35	18.65	18.80	18.15	19.43
MnO	0.66	0.61	0.66	0.56	0.61	0.71	0.63
MgO	10.73	11.29	11.23	11.54	11.33	11.85	11.19
CaO	0.02	0.00	0.02	0.01	0.00	0.03	0.03
Na₂O	0.06	0.09	0.13	0.10	0.11	0.05	0.09
K₂O	9.61	9.59	9.30	9.17	9.61	9.64	9.16
Cl	0.10	0.12	0.13	0.11	0.10	0.11	0.10
F	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Si	5.67	5.69	5.70	5.71	5.65	5.70	5.65
Al iv	2.33	2.31	2.30	2.29	2.35	2.30	2.35
Al T	2.59	2.61	2.69	2.63	2.74	2.68	2.73
Al vi	0.26	0.30	0.39	0.35	0.39	0.38	0.37
Ti	0.37	0.37	0.31	0.35	0.27	0.28	0.28
Fe(ii)	2.49	2.38	2.35	2.35	2.41	2.30	2.49
Mn	0.09	0.08	0.09	0.07	0.08	0.09	0.08
Mg	2.49	2.55	2.57	2.60	2.60	2.68	2.56
Ca	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Na	0.02	0.03	0.04	0.03	0.03	0.01	0.03
K	1.91	1.85	1.82	1.77	1.88	1.86	1.79
Cl	0.03	0.03	0.03	0.03	0.03	0.03	0.03
F	0.00	0.00	0.00	0.00	0.00	0.02	0.00
TOTAL	15.62	15.56	15.56	15.51	15.66	15.61	15.61
Fe/Fe+Mg	0.50	0.48	0.48	0.48	0.48	0.46	0.49

Table 3. (Continue)

Sample No.	AM37	AM37	AM37	AM37	AM38	AM38	AM38
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	7	8	9	10	1	2	3
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO ₂	37.07	37.06	36.91	37.31	37.10	37.05	37.37
TiO ₂	2.48	2.88	2.81	1.73	3.56	3.78	3.53
Al ₂ O ₃	15.12	14.62	14.82	15.43	14.91	15.02	15.18
FeO	19.31	19.16	18.70	18.62	18.67	18.41	18.37
MnO	0.64	0.79	0.66	0.62	0.47	0.40	0.46
MgO	11.03	11.45	11.36	11.86	10.58	10.34	10.86
CaO	0.00	0.10	0.01	0.00	0.01	0.05	0.00
Na ₂ O	0.06	0.07	0.09	0.08	0.09	0.08	0.10
K ₂ O	9.63	8.78	9.16	9.28	9.30	9.14	9.29
Cl	0.11	0.10	0.11	0.13	0.12	0.06	0.07
F	0.00	0.00	0.00	0.03	0.13	0.00	0.08
Si	5.66	5.67	5.66	5.68	5.67	5.68	5.67
Al iv	2.34	2.33	2.34	2.32	2.33	2.32	2.33
Al T	2.72	2.63	2.68	2.77	2.69	2.71	2.72
Al vi	0.38	0.30	0.34	0.46	0.36	0.39	0.39
Ti	0.29	0.33	0.32	0.20	0.41	0.44	0.40
Fe(ii)	2.47	2.45	2.40	2.37	2.39	2.36	2.33
Mn	0.08	0.10	0.09	0.08	0.06	0.05	0.06
Mg	2.51	2.61	2.60	2.69	2.41	2.36	2.46
Ca	0.00	0.02	0.00	0.00	0.00	0.01	0.00
Na	0.02	0.02	0.03	0.02	0.03	0.02	0.03
K	1.88	1.71	1.79	1.80	1.81	1.79	1.80
Cl	0.03	0.02	0.03	0.03	0.03	0.02	0.02
F	0.00	0.00	0.00	0.01	0.06	0.00	0.04
TOTAL	15.62	15.54	15.57	15.63	15.48	15.42	15.47
Fe/Fe+Mg	0.50	0.48	0.48	0.47	0.50	0.50	0.49

Table 3. (Continue)

Sample No.	AM38	AM38	AM38	AM38	AM38	AM38	AM38
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	4	5	6	7	8	9	10
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	36.89	34.98	36.75	36.72	36.52	37.71	35.93
TiO₂	3.21	3.42	3.29	3.60	3.37	3.37	3.56
Al₂O₃	14.43	14.94	14.88	14.45	14.50	14.75	13.80
FeO	18.93	19.55	19.53	18.55	17.86	18.55	18.81
MnO	0.47	0.58	0.54	0.44	0.44	0.51	0.45
MgO	10.96	11.67	10.77	11.27	10.94	11.42	10.54
CaO	0.17	0.21	0.01	0.09	0.01	0.08	0.35
Na₂O	0.12	0.11	0.04	0.12	0.09	0.08	0.15
K₂O	8.02	7.68	9.45	9.04	9.22	9.02	7.59
Cl	0.10	0.09	0.09	0.06	0.08	0.08	0.11
F	0.14	0.06	0.11	0.08	0.12	0.12	0.07
Si	5.71	5.46	5.62	5.65	5.68	5.70	5.69
Al iv	2.29	2.54	2.38	2.35	2.32	2.30	2.31
Al T	2.63	2.75	2.68	2.62	2.66	2.63	2.58
Al vi	0.34	0.20	0.31	0.26	0.34	0.33	0.27
Ti	0.37	0.40	0.38	0.42	0.39	0.38	0.42
Fe(ii)	2.45	2.55	2.50	2.38	2.32	2.35	2.49
Mn	0.06	0.08	0.07	0.06	0.06	0.07	0.06
Mg	2.53	2.71	2.46	2.58	2.54	2.57	2.49
Ca	0.03	0.04	0.00	0.01	0.00	0.01	0.06
Na	0.04	0.03	0.01	0.03	0.03	0.02	0.05
K	1.58	1.53	1.84	1.77	1.83	1.74	1.53
Cl	0.03	0.02	0.02	0.02	0.02	0.02	0.03
F	0.07	0.03	0.05	0.04	0.06	0.06	0.03
TOTAL	15.40	15.54	15.57	15.52	15.51	15.47	15.37
Fe/Fe+Mg	0.49	0.48	0.50	0.48	0.48	0.48	0.50

Table 3. (Continue)

Sample No.	AM38	AM38	AM38	AM38	AM38	AM38	AM38
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	11	12	13	14	15	16	17
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	38.05	37.56	36.96	36.47	36.71	37.33	37.62
TiO₂	2.93	3.36	3.33	3.30	3.79	3.28	2.90
Al₂O₃	15.55	15.34	14.96	14.46	14.68	15.21	15.88
FeO	18.12	18.68	18.94	18.91	19.04	18.88	18.40
MnO	0.37	0.50	0.54	0.52	0.45	0.47	0.37
MgO	11.38	10.92	10.79	10.86	10.62	10.65	11.18
CaO	0.03	0.00	0.00	0.18	0.00	0.01	0.07
Na₂O	0.08	0.09	0.08	0.11	0.05	0.08	0.05
K₂O	9.19	9.58	9.47	8.76	9.59	9.48	8.96
Cl	0.07	0.06	0.08	0.09	0.05	0.09	0.07
F	0.01	0.08	0.10	0.04	0.08	0.11	0.01
Si	5.72	5.66	5.65	5.66	5.63	5.67	5.67
Al iv	2.28	2.34	2.35	2.34	2.37	2.33	2.33
Al T	2.75	2.73	2.69	2.64	2.65	2.72	2.82
Al vi	0.47	0.39	0.34	0.30	0.29	0.40	0.49
Ti	0.33	0.38	0.38	0.39	0.44	0.38	0.33
Fe(ii)	2.28	2.36	2.42	2.45	2.44	2.40	2.32
Mn	0.05	0.06	0.07	0.07	0.06	0.06	0.05
Mg	2.55	2.46	2.46	2.51	2.43	2.41	2.51
Ca	0.00	0.00	0.00	0.03	0.00	0.00	0.01
Na	0.02	0.03	0.02	0.03	0.02	0.02	0.01
K	1.76	1.84	1.85	1.73	1.88	1.84	1.72
Cl	0.02	0.02	0.02	0.02	0.01	0.02	0.02
F	0.00	0.04	0.05	0.02	0.04	0.05	0.00
TOTAL	15.46	15.52	15.54	15.51	15.54	15.51	15.45
Fe/Fe+Mg	0.47	0.49	0.50	0.49	0.50	0.50	0.48

Table 3. (Continue)

Sample No.	AM41	AM41	AM41	AM41	AM41	AM41	AM41
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	M.diorite	M.diorite	M.diorite	M.diorite	M.diorite	M.diorite	M.diorite
Point analysis	1	2	3	4	5	6	7
Mineral	Bt	Bt	Bt	Bt	Bt	Bt	Bt
SiO₂	37.25	37.58	37.03	37.16	36.85	37.44	37.01
TiO₂	2.07	2.26	3.68	3.17	1.68	3.13	2.43
Al₂O₃	15.17	15.49	14.28	14.31	15.36	14.48	14.54
FeO	18.10	18.51	18.71	18.95	18.26	19.11	18.71
MnO	0.69	0.66	0.72	0.72	0.66	0.71	0.73
MgO	11.50	11.36	10.86	10.99	11.99	11.18	10.83
CaO	0.08	0.02	0.01	0.01	0.04	0.05	0.00
Na₂O	0.08	0.10	0.09	0.07	0.06	0.08	0.08
K₂O	9.70	9.71	9.26	9.32	9.16	9.45	9.30
Cl	0.06	0.09	0.08	0.08	0.09	0.11	0.08
F	0.11	0.11	0.12	0.05	0.23	0.10	0.15
Si	5.70	5.69	5.68	5.70	5.67	5.69	5.74
Al iv	2.30	2.31	2.32	2.30	2.33	2.31	2.26
Al T	2.74	2.76	2.58	2.59	2.78	2.60	2.66
Al vi	0.44	0.45	0.27	0.29	0.45	0.29	0.40
Ti	0.24	0.26	0.42	0.37	0.19	0.36	0.28
Fe(ii)	2.32	2.34	2.40	2.43	2.35	2.43	2.43
Mn	0.09	0.08	0.09	0.09	0.09	0.09	0.10
Mg	2.63	2.56	2.48	2.51	2.75	2.53	2.50
Ca	0.01	0.00	0.00	0.00	0.01	0.01	0.00
Na	0.02	0.03	0.03	0.02	0.02	0.02	0.02
K	1.89	1.88	1.81	1.82	1.80	1.83	1.84
Cl	0.02	0.02	0.02	0.02	0.02	0.03	0.02
F	0.05	0.05	0.06	0.02	0.11	0.05	0.07
TOTAL	15.64	15.61	15.51	15.55	15.64	15.56	15.57
Fe/Fe+Mg	0.47	0.48	0.49	0.49	0.46	0.49	0.49

Table 3. (Continue)

Sample No.	AM41	AM41	AM41
Pluton/Area	Taru	Taru	Taru
Rock Type	M.diorite	M.diorite	M.diorite
Point analysis	8	9	10
Mineral	Bt	Bt	Bt
SiO₂	37.18	36.68	37.59
TiO₂	3.47	3.11	1.90
Al₂O₃	14.68	14.28	15.33
FeO	18.75	18.65	17.70
MnO	0.66	0.56	0.61
MgO	10.57	10.80	11.63
CaO	0.00	0.00	0.17
Na₂O	0.07	0.10	0.11
K₂O	9.39	9.39	8.48
Cl	0.07	0.10	0.08
F	0.06	0.04	0.09
Si	5.69	5.70	5.76
Al iv	2.31	2.30	2.24
Al T	2.65	2.61	2.77
Al vi	0.34	0.31	0.53
Ti	0.40	0.36	0.22
Fe(ii)	2.40	2.42	2.27
Mn	0.09	0.07	0.08
Mg	2.41	2.50	2.66
Ca	0.00	0.00	0.03
Na	0.02	0.03	0.03
K	1.83	1.86	1.66
Cl	0.02	0.03	0.02
F	0.03	0.02	0.04
TOTAL	15.50	15.56	15.47
Fe/Fe+Mg	0.50	0.49	0.46

Table 4. EPMA analysis of amphibole data based on 23 Oxygen and pressure calculation based on the formula Schmidt 1992.

Sample No.	AM3	AM3	AM3	AM3	AM3	AM3
Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Rock Type	Diorite	Diorite	Diorite	Diorite	Diorite	Diorite
Point analysis	1	2	3	4	5	6
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	46.74	45.98	46.46	46.03	41.54	42.54
TiO ₂	1.04	1.24	0.95	1.26	1.73	1.39
Al ₂ O ₃	7.02	7.69	7.33	7.61	10.73	10.37
Cr ₂ O ₃	0.01	0.01	0.01	0.02	0.00	0.03
FeO	16.35	16.53	16.91	16.72	19.33	19.20
MnO	0.55	0.51	0.57	0.62	0.49	0.55
MgO	11.89	11.47	11.53	11.32	8.85	9.22
CaO	11.81	11.78	12.11	11.87	11.89	12.00
Na ₂ O	1.10	1.23	0.98	1.14	1.40	1.41
K ₂ O	0.73	0.84	0.73	0.76	1.02	0.78
Si	6.99	6.90	6.93	6.90	6.36	6.45
Al (iv)	1.01	1.10	1.07	1.10	1.64	1.55
Total (Si + Al (iv))	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.23	0.26	0.22	0.24	0.29	0.30
Ti	0.12	0.14	0.11	0.14	0.20	0.16
Cr	0.00	0.00	0.00	0.00	0.00	0.00
Fe(iii)	0.09	0.04	0.22	0.09	0.34	0.36
Fe(ii)	1.95	2.04	1.89	2.00	2.14	2.07
Mn	0.07	0.06	0.07	0.08	0.06	0.07
Mg	2.65	2.57	2.56	2.53	2.02	2.08
Ca	1.89	1.89	1.93	1.91	1.95	1.95
C + B	7.00	7.00	7.00	7.00	7.00	7.00
Na ***	0.32	0.36	0.28	0.33	0.42	0.42
K	0.14	0.16	0.14	0.14	0.20	0.15
TOTAL	15.46	15.52	15.42	15.48	15.61	15.57
A site (Na+K)	0.46	0.52	0.42	0.48	0.61	0.57
T/S	1.00	1.00	1.00	1.00	0.99	0.99
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.95	0.98	0.90	0.96	0.86	0.85
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.05	0.02	0.10	0.04	0.14	0.15
Mg/(Mg+Fe ²⁺)	0.58	0.56	0.58	0.56	0.49	0.50
Fe ³⁺ /(Fe ³⁺ + [6]Al)	0.29	0.13	0.51	0.28	0.53	0.55
Mineral (calcic)	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Hastingsite	Magnesio-hastingsite
(Ca+Na)B	2.21	2.25	2.22	2.24	2.36	2.36

Table 4. (Continue)

Sample No.	AM3	AM3	AM24	AM24	AM24	AM24	AM24
Pluton/Area	Basgo	Basgo	Umla	Umla	Umla	Umla	Umla
Rock Type	Diorite	Diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	7	8	1	2	3	4	5
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	43.16	43.37	45.29	45.45	46.86	46.19	45.52
TiO ₂	1.22	1.40	1.42	1.69	1.26	1.00	1.48
Al ₂ O ₃	9.87	9.38	7.49	7.18	6.39	6.82	7.34
Cr ₂ O ₃	0.00	0.03	0.01	0.00	0.00	0.02	0.00
FeO	18.68	17.48	16.47	15.99	15.20	16.54	16.87
MnO	0.51	0.49	0.95	0.96	0.93	0.92	0.94
MgO	9.65	10.24	11.23	11.36	12.57	11.60	11.32
CaO	11.94	11.93	11.51	11.66	11.75	11.87	11.69
Na ₂ O	1.30	1.24	1.31	1.29	1.22	1.16	1.36
K ₂ O	0.98	1.03	0.86	0.83	0.69	0.71	0.83
Si	6.54	6.60	6.87	6.90	7.02	6.95	6.86
Al (iv)	1.46	1.40	1.13	1.10	0.98	1.05	1.14
Total (Si + Al (iv))	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.31	0.28	0.21	0.18	0.15	0.17	0.16
Ti	0.14	0.16	0.16	0.19	0.14	0.11	0.17
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe(iii)	0.30	0.23	0.04	0.00	0.07	0.18	0.09
Fe(ii)	2.07	1.99	2.05	2.03	1.84	1.91	2.03
Mn	0.07	0.06	0.12	0.12	0.12	0.12	0.12
Mg	2.18	2.32	2.54	2.57	2.81	2.60	2.54
Ca	1.94	1.95	1.87	1.90	1.89	1.91	1.89
C + B	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Na ***	0.38	0.37	0.39	0.38	0.35	0.34	0.40
K	0.19	0.20	0.17	0.16	0.13	0.14	0.16
TOTAL	15.57	15.57	15.55	15.54	15.49	15.47	15.56
A site (Na+K)	0.57	0.57	0.55	0.54	0.49	0.47	0.56
T/S	0.99	1.00	1.00	1.00	1.00	1.00	1.00
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.87	0.90	0.98	1.01	0.96	0.92	0.96
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.13	0.10	0.02	-0.01	0.04	0.08	0.04
Mg/(Mg+Fe ²⁺)	0.51	0.54	0.55	0.56	0.60	0.58	0.56
Fe ³⁺ /(Fe ³⁺ +6[Al])	0.49	0.45	0.15	0.00	0.31	0.52	0.37
Mineral (calcic)	Edenite	Edenite	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende
(Ca+Na)B	2.32	2.31	2.26	2.28	2.24	2.25	2.28

Table 4. (Continue)

Sample No.	AM24	AM24	AM24	AM24	AM24	AM37	AM37
Pluton/Area	Umla	Umla	Umla	Umla	Umla	Taru	Taru
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	6	7	8	9	10	1	2
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	46.28	45.59	46.79	45.40	47.00	47.30	46.90
TiO ₂	1.27	1.53	1.28	1.43	0.79	0.79	0.68
Al ₂ O ₃	6.93	7.49	6.84	7.64	7.16	6.88	7.03
Cr ₂ O ₃	0.00	0.00	0.02	0.00	0.00	0.00	0.01
FeO	16.54	16.69	16.06	16.83	16.43	15.80	16.33
MnO	0.93	0.82	0.88	0.91	0.96	0.85	0.79
MgO	11.61	11.44	11.90	11.41	12.14	12.23	11.87
CaO	11.68	11.52	11.73	11.72	12.00	11.64	11.57
Na ₂ O	1.19	1.33	1.24	1.33	1.18	1.22	1.12
K ₂ O	0.79	0.90	0.76	0.88	0.69	0.56	0.69
Si	6.95	6.87	7.00	6.82	6.94	7.05	7.03
Al (iv)	1.05	1.13	1.00	1.18	1.06	0.95	0.97
Total (Si + Al (iv))	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.18	0.20	0.20	0.17	0.19	0.26	0.27
Ti	0.14	0.17	0.14	0.16	0.09	0.09	0.08
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe(iii)	0.08	0.03	0.00	0.13	0.22	0.05	0.10
Fe(ii)	2.00	2.07	2.00	1.98	1.81	1.92	1.95
Mn	0.12	0.10	0.11	0.12	0.12	0.11	0.10
Mg	2.60	2.57	2.65	2.55	2.67	2.72	2.65
Ca	1.88	1.86	1.88	1.89	1.90	1.86	1.86
C + B	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Na ***	0.35	0.39	0.36	0.39	0.34	0.35	0.32
K	0.15	0.17	0.15	0.17	0.13	0.11	0.13
TOTAL	15.50	15.56	15.51	15.56	15.47	15.46	15.46
A site (Na+K)	0.50	0.56	0.51	0.56	0.47	0.46	0.46
T/S	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.96	0.99	1.00	0.94	0.89	0.97	0.95
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.04	0.01	0.00	0.06	0.11	0.03	0.05
Mg/(Mg+Fe ²⁺)	0.57	0.55	0.57	0.56	0.60	0.59	0.58
Fe ³⁺ /(Fe ³⁺ + [6]Al)	0.31	0.14	0.02	0.44	0.54	0.17	0.27
Mineral (calcic)	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende
(Ca+Na)B	2.22	2.25	2.24	2.27	2.24	2.21	2.18

Table 4. (Continue)

Sample No.	AM37	AM37	AM37	AM37	AM37	AM37	AM37
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
Point analysis	3	4	5	6	7	8	9
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	46.02	46.46	47.57	47.49	45.13	45.14	45.76
TiO ₂	1.53	0.91	0.73	0.62	1.67	1.78	1.47
Al ₂ O ₃	7.22	7.11	6.59	7.03	7.75	7.74	7.44
Cr ₂ O ₃	0.00	0.06	0.02	0.00	0.03	0.00	0.01
FeO	16.77	16.38	16.33	16.68	17.39	17.19	16.69
MnO	0.86	0.77	0.82	0.86	0.94	0.93	1.02
MgO	11.45	11.61	12.22	12.02	10.88	11.05	11.39
CaO	11.58	11.72	11.78	11.64	11.41	11.59	11.80
Na ₂ O	1.24	1.17	1.13	1.18	1.34	1.31	1.20
K ₂ O	0.72	0.64	0.60	0.64	0.89	0.82	0.82
Si	6.91	6.98	7.06	7.03	6.82	6.80	6.86
Al (iv)	1.09	1.02	0.94	0.97	1.18	1.20	1.14
Total (Si + Al (iv))	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.19	0.24	0.21	0.26	0.20	0.17	0.17
Ti	0.17	0.10	0.08	0.07	0.19	0.20	0.17
Cr	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Fe(iii)	0.06	0.10	0.13	0.11	0.04	0.10	0.13
Fe(ii)	2.05	1.96	1.90	1.95	2.15	2.07	1.96
Mn	0.11	0.10	0.10	0.11	0.12	0.12	0.13
Mg	2.56	2.60	2.70	2.65	2.45	2.48	2.54
Ca	1.86	1.89	1.87	1.85	1.85	1.87	1.89
C + B	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Na ***	0.36	0.34	0.32	0.34	0.39	0.38	0.35
K	0.14	0.12	0.11	0.12	0.17	0.16	0.16
TOTAL	15.50	15.46	15.44	15.46	15.56	15.54	15.51
A site (Na+K)	0.50	0.46	0.44	0.46	0.56	0.54	0.51
T/S	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	0.97	0.95	0.94	0.95	0.98	0.96	0.94
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	0.03	0.05	0.06	0.05	0.02	0.04	0.06
Mg/(Mg+Fe ²⁺)	0.56	0.57	0.59	0.58	0.53	0.55	0.56
Fe ³⁺ /(Fe ³⁺ +6[Al])	0.24	0.28	0.37	0.30	0.18	0.36	0.43
Mineral (calcic)	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende
(Ca+Na)B	2.22	2.23	2.20	2.19	2.24	2.25	2.24

Table 4. (Continue)

Sample No.	AM41	AM41	AM41	AM41	AM41	AM41	AM41
Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru	Taru
Rock Type	M.diorite	M.diorite	M.diorite	M.diorite	M.diorite	M.diorite	M.diorite
Point analysis	1	2	3	4	5	6	7
Mineral	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl	Hbl
SiO ₂	45.87	46.21	46.09	45.48	45.29	45.79	46.06
TiO ₂	1.60	1.42	1.04	1.42	1.26	1.07	1.35
Al ₂ O ₃	7.24	7.01	7.18	7.71	8.25	7.57	7.20
Cr ₂ O ₃	0.05	0.00	0.00	0.01	0.00	0.04	0.00
FeO	16.23	16.79	16.29	17.05	15.94	17.02	16.40
MnO	1.02	1.00	0.91	0.98	1.00	0.95	0.94
MgO	11.25	11.32	11.14	10.92	11.42	11.03	11.34
CaO	11.66	11.61	11.45	11.64	11.96	11.89	11.67
Na ₂ O	1.29	1.22	1.15	1.33	1.29	1.04	1.26
K ₂ O	0.82	0.78	0.78	0.90	0.87	0.79	0.82
Si	6.92	6.95	7.01	6.86	6.80	6.88	6.95
Al (iv)	1.08	1.05	0.99	1.14	1.20	1.12	1.05
Total (Si + Al (iv))	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Al (vi)	0.21	0.19	0.29	0.23	0.25	0.23	0.22
Ti	0.18	0.16	0.12	0.16	0.14	0.12	0.15
Cr	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Fe(iii)	0.00	0.03	0.00	0.03	0.12	0.19	0.00
Fe(ii)	2.05	2.08	2.07	2.12	1.88	1.95	2.07
Mn	0.13	0.13	0.12	0.13	0.13	0.12	0.12
Mg	2.53	2.54	2.52	2.46	2.55	2.47	2.55
Ca	1.88	1.87	1.86	1.88	1.92	1.91	1.88
C + B	6.99	7.00	6.99	7.00	7.00	7.00	7.00
Na ***	0.38	0.35	0.34	0.39	0.38	0.30	0.37
K	0.16	0.15	0.15	0.17	0.17	0.15	0.16
TOTAL	15.52	15.50	15.48	15.56	15.54	15.45	15.52
A site (Na+K)	0.54	0.50	0.49	0.56	0.54	0.45	0.53
T/S	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe ²⁺ /(Fe ²⁺ +Fe ³⁺)	1.02	0.99	1.02	0.99	0.94	0.91	1.00
Fe ³⁺ /(Fe ³⁺ +Fe ²⁺)	-0.02	0.01	-0.02	0.01	0.06	0.09	0.00
Mg/(Mg+Fe ²⁺)	0.55	0.55	0.55	0.54	0.58	0.56	0.55
Fe ³⁺ /(Fe ³⁺ +6[Al])	0.00	0.14	0.00	0.11	0.32	0.46	0.00
Mineral (calcic)	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende	Magnesio-hornblende
(Ca+Na)B	12.95	12.82	12.61	12.97	13.26	12.93	12.93

Table 4. (Continue)

Sample No.	AM41
Pluton/Area	Taru
Rock Type	M.diorite
Point analysis	8
Mineral	Hbl
SiO₂	44.94
TiO₂	1.49
Al₂O₃	7.75
Cr₂O₃	0.00
FeO	16.82
MnO	1.00
MgO	10.77
CaO	11.74
Na₂O	1.35
K₂O	0.93
Si	6.83
Al (iv)	1.17
Total (Si + Al (iv))	8.00
Al (vi)	0.21
Ti	0.17
Cr	0.00
Fe(iii)	0.04
Fe(ii)	2.10
Mn	0.13
Mg	2.44
Ca	1.91
C + B	7.00
Na ***	0.40
K	0.18
TOTAL	15.58
A site (Na+K)	0.58
T/S	1.00
Fe²⁺/(Fe²⁺+Fe³⁺)	0.98
Fe³⁺/(Fe³⁺+Fe²⁺)	0.02
Mg/(Mg+Fe²⁺)	0.54
Fe³⁺/(Fe³⁺+6Al)	0.16
Mineral (calcic)	Magnesio-hornblende
(Ca+Na)B	13.08

APPENDICES-2. GEOCHEMISTRY (MAJOR OXIDES AND CIPW NORM)**Table 5.** Major oxides and CIPW norm analysis of the samples collected from the Leh region of Ladakh Batholith around the Trans-Himalaya Belt, (India)

Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Sample No.	AM1	AM2	AM3	AM4	AM5	AM6	AM7
Rock Type	Granite	Granite	Diorite	Granite	Granite	G.diorite	G.diorite
SiO₂	70.40	72.40	59.60	73.80	73.20	69.50	67.30
Al₂O₃	14.40	13.60	16.50	13.20	11.70	13.30	13.30
Fe₂O₃	3.94	2.86	7.29	2.63	3.88	4.21	5.49
CaO	1.86	1.59	5.53	1.28	2.45	2.74	4.12
MgO	0.55	0.57	2.84	0.43	1.15	1.73	1.30
Na₂O	3.72	3.30	3.79	3.95	3.10	3.04	2.53
K₂O	4.44	4.77	2.52	3.90	1.50	1.86	1.49
MnO	0.08	0.07	0.12	0.10	0.08	0.09	0.08
TiO₂	0.26	0.03	0.82	0.20	0.44	0.48	0.72
P₂O₅	0.08	0.07	0.22	0.05	0.07	0.09	0.10
Cr₂O₃	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total (LOI Free)	99.74	99.27	99.24	99.55	97.58	97.05	96.44
LOI	-0.38	-0.29	0.14	-0.39	1.41	2.08	2.72
CIPW norm.(%)							
Qtz	27.19	30.89	13.62	32.66	42.66	36.50	36.40
Plg	40.18	35.35	52.64	39.45	37.93	38.73	41.19
Or	26.24	28.19	14.89	23.05	8.86	10.99	8.81
Cm	0.28	0.28	0.00	0.27	0.69	1.52	0.27
Di	0.00	0.00	2.37	0.00	0.00	0.00	0.00
Hyp	1.37	1.42	5.97	1.07	2.86	4.31	3.24
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt	0.17	0.00	0.00	0.09	0.35	0.38	0.63
Ilm	0.17	0.06	0.26	0.21	0.17	0.19	0.17
Mag	0.00	0.14	0.00	0.00	0.00	0.00	0.00
Hem	3.94	2.76	7.29	2.63	3.88	4.21	5.49
Ap	0.19	0.16	0.51	0.12	0.16	0.21	0.23
Spn	0.00	0.00	1.68	0.00	0.00	0.00	0.00

Table 5. (Continue)

Pluton/Area	Basgo	Basgo	Basgo	Nimu	Nimu	Nimu	Nimu
Sample No.	AM8	AM9	AM10	AM11	AM12	AM13	AM14
Rock Type	G.diorite	G.diorite	Granite	Granite	G.diorite	G.diorite	Granite
SiO ₂	64.30	71.60	73.50	74.40	67.60	65.10	72.00
Al ₂ O ₃	14.20	13.70	12.20	12.10	14.40	12.90	13.10
Fe ₂ O ₃	7.56	3.22	4.33	3.34	5.20	4.59	3.23
CaO	2.88	1.22	2.05	3.08	2.23	4.46	1.18
MgO	2.88	1.49	1.34	0.55	1.83	2.71	1.21
Na ₂ O	3.48	5.29	2.43	3.50	4.31	2.71	4.38
K ₂ O	1.02	0.94	1.47	1.33	1.79	1.54	2.73
MnO	0.13	0.06	0.09	0.08	0.08	0.10	0.06
TiO ₂	0.79	0.32	0.41	0.26	0.45	0.48	0.29
P ₂ O ₅	0.09	0.06	0.07	0.05	0.08	0.12	0.07
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.03	0.01
Total (LOI Free)	97.34	97.91	97.90	98.70	97.98	94.74	98.26
LOI	2.08	1.03	1.40	0.68	1.39	4.56	1.03
CIPW norm.(%)							
Qtz	29.94	32.57	47.55	42.01	28.40	30.80	31.94
Plg	43.15	50.42	30.27	42.99	47.01	41.42	42.46
Or	6.03	5.56	8.69	7.86	10.58	9.10	16.13
Cm	2.35	1.91	3.05	0.00	1.51	0.00	0.96
Di	0.00	0.00	0.00	0.77	0.00	1.23	0.00
Hyp	7.17	3.71	3.34	1.01	4.56	6.18	3.01
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt	0.64	0.25	0.31	0.00	0.36	0.00	0.22
Ilm	0.28	0.13	0.19	0.17	0.17	0.21	0.13
Mag	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hem	7.56	3.22	4.33	3.34	5.20	4.59	3.23
Ap	0.21	0.14	0.16	0.12	0.19	0.28	0.16
Spn	0.00	0.00	0.00	0.42	0.00	0.90	0.00

Table 5. (Continue)

Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Umla
Sample No.	AM15	AM16	AM17	AM18	AM19	AM20	AM21
Rock Type	Granite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
SiO ₂	72.60	68.90	65.00	65.90	72.10	66.30	68.70
Al ₂ O ₃	12.60	15.10	16.30	16.60	13.70	15.90	15.10
Fe ₂ O ₃	2.67	4.50	5.33	4.78	3.24	4.85	3.83
CaO	1.55	3.00	3.96	3.77	2.17	3.85	3.12
MgO	0.92	1.10	1.47	1.35	0.57	1.17	0.98
Na ₂ O	4.43	4.62	4.83	5.01	3.24	4.77	4.98
K ₂ O	2.69	1.80	1.42	1.56	4.26	1.54	1.58
MnO	0.06	0.11	0.12	0.12	0.12	0.12	0.09
TiO ₂	0.24	0.49	0.65	0.59	0.23	0.58	0.50
P ₂ O ₅	0.05	0.12	0.20	0.20	0.08	0.17	0.16
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total (LOI Free)	97.82	99.75	99.29	99.89	99.72	99.26	99.05
LOI	1.23	-0.18	-0.02	-0.01	-0.16	-0.22	-0.10
CIPW norm.(%)							
Qtz	32.16	27.41	21.36	21.26	31.68	23.27	26.05
Plg	44.04	53.19	59.21	59.79	37.66	57.79	56.32
Or	15.90	10.64	8.39	9.22	25.18	9.10	9.34
Cm	0.00	0.38	0.10	0.29	0.00	0.00	0.00
Di	0.17	0.00	0.00	0.00	0.00	0.00	0.00
Hyp	2.21	2.74	3.66	3.36	1.42	2.91	2.44
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt	0.00	0.37	0.51	0.45	0.09	0.28	0.33
Ilm	0.13	0.24	0.26	0.26	0.26	0.26	0.19
Mag	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hem	2.67	4.50	5.33	4.78	3.24	4.85	3.83
Ap	0.12	0.28	0.46	0.46	0.19	0.39	0.37
Spn	0.42	0.00	0.00	0.00	0.00	0.40	0.18

Table 5. (Continue)

Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Sample No.	AM22	AM23	AM24	AM25	AM26	AM27	AM28
Rock Type	Granite	G.diorite	G.diorite	Monzonite	G.diorite	G.diorite	G.diorite
SiO ₂	75.70	70.60	65.00	54.50	66.40	67.20	67.30
Al ₂ O ₃	12.50	15.00	14.50	17.70	15.40	15.00	16.30
Fe ₂ O ₃	2.03	2.86	6.71	9.99	4.52	4.74	3.79
CaO	0.95	3.29	3.18	3.94	3.38	3.36	3.62
MgO	0.19	0.89	2.16	3.07	1.49	1.58	1.09
Na ₂ O	3.05	4.26	3.47	4.02	4.00	3.85	4.59
K ₂ O	5.20	2.29	3.67	4.60	3.16	3.24	2.59
MnO	0.04	0.07	0.16	0.23	0.11	0.11	0.09
TiO ₂	0.14	0.28	0.70	0.87	0.46	0.52	0.34
P ₂ O ₅	0.02	0.09	0.20	0.27	0.13	0.12	0.11
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total (LOI Free)	99.83	99.64	99.76	99.20	99.06	99.73	99.83
LOI	-0.22	0.15	0.12	0.51	0.07	0.12	0.06
CIPW norm.(%)							
Qtz	35.80	29.08	21.59	1.50	22.20	23.58	21.84
Plg	30.39	51.09	42.51	50.68	48.58	46.65	55.06
Or	30.73	13.53	21.69	27.18	18.67	19.15	15.31
Cm	0.17	0.00	0.00	0.00	0.00	0.00	0.00
Di	0.00	0.00	0.00	0.00	0.01	0.33	0.15
Hyp	0.47	2.22	5.38	7.65	3.71	3.78	2.65
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt	0.09	0.00	0.14	0.29	0.00	0.00	0.00
Ilm	0.09	0.15	0.34	0.49	0.24	0.24	0.19
Mag	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hem	2.03	2.86	6.71	9.99	4.52	4.74	3.79
Ap	0.05	0.21	0.46	0.63	0.30	0.28	0.25
Spn	0.00	0.49	0.93	0.79	0.82	0.97	0.59

Table 5. (Continue)

Pluton/Area	Umla	Umla	Taru	Taru	Taru	Taru	Taru
Sample No.	AM29	AM30	AM31	AM32	AM33	AM34	AM35
Rock Type	Monzonite	G.diorite	Granite	G.diorite	G.diorite	G.diorite	G.diorite
SiO ₂	58.90	67.90	74.20	69.70	64.00	67.40	65.60
Al ₂ O ₃	16.90	14.30	13.20	15.30	16.20	15.10	15.30
Fe ₂ O ₃	6.98	5.30	2.49	3.07	5.29	5.06	5.75
CaO	4.46	4.00	1.42	3.65	4.43	3.98	3.99
MgO	2.16	1.20	0.32	0.95	1.76	1.45	1.81
Na ₂ O	4.82	3.34	3.30	4.66	4.82	4.38	4.24
K ₂ O	2.91	2.78	4.61	1.41	1.79	1.69	1.80
MnO	0.10	0.10	0.04	0.07	0.16	0.11	0.13
TiO ₂	1.08	0.45	0.15	0.32	0.55	0.49	0.57
P ₂ O ₅	0.69	0.11	0.04	0.09	0.14	0.14	0.17
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total (LOI Free)	99.01	99.49	99.78	99.23	99.15	99.81	99.37
LOI	0.22	0.08	-0.19	0.20	0.05	-0.10	0.11
CIPW norm.(%)							
Qtz	9.27	28.50	33.95	28.40	18.21	25.65	23.56
Plg	56.67	44.08	34.71	56.10	58.07	53.61	53.28
Or	17.20	16.43	27.24	8.33	10.58	9.99	10.64
Cm	0.00	0.00	0.30	0.00	0.00	0.00	0.00
Di	0.00	1.66	0.00	0.01	1.94	0.78	0.00
Hyp	5.38	2.22	0.80	2.36	3.48	3.25	4.51
Ol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rt	0.47	0.00	0.10	0.00	0.00	0.00	0.05
Ilm	0.21	0.21	0.09	0.15	0.34	0.24	0.28
Mag	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hem	6.98	5.30	2.49	3.07	5.29	5.06	5.75
Ap	1.60	0.25	0.09	0.21	0.32	0.32	0.39
Spn	1.22	0.83	0.00	0.59	0.91	0.90	0.91

Table 5. (Continue)

Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru
Sample No.	AM36	AM37	AM38	AM39	AM40	AM41
Rock Type	G.diorite	G.diorite	Granite	Granite	Granite	M.diorite
SiO ₂	66.90	65.50	73.40	75.10	75.80	51.80
Al ₂ O ₃	15.50	15.90	13.50	13.00	12.30	17.90
Fe ₂ O ₃	4.70	5.30	2.30	2.17	2.06	11.10
CaO	3.92	4.20	1.53	1.77	1.30	5.69
MgO	1.49	1.62	0.38	0.31	0.30	4.00
Na ₂ O	4.56	4.66	3.38	3.56	2.76	4.76
K ₂ O	1.66	1.49	4.74	3.52	4.96	2.16
MnO	0.11	0.12	0.04	0.03	0.04	0.35
TiO ₂	0.48	0.54	0.19	0.13	0.13	1.14
P ₂ O ₅	0.14	0.15	0.03	0.03	0.04	0.36
Cr ₂ O ₃	0.01	0.01	0.01	0.01	0.01	0.01
Total (LOI Free)	99.47	99.49	99.50	99.63	99.70	99.27
LOI	0.03	-0.09	-0.21	-0.37	-0.13	0.46
CIPW norm.(%)						
Qtz	24.15	22.09	31.84	36.75	37.64	0.00
Plg	55.51	57.50	35.99	38.71	29.54	61.37
Or	9.81	8.81	28.01	20.80	29.31	12.76
Cm	0.00	0.00	0.10	0.19	0.12	0.00
Di	0.29	0.30	0.00	0.00	0.00	1.70
Hyp	3.58	3.90	0.95	0.77	0.75	8.30
Ol	0.00	0.00	0.00	0.00	0.00	0.61
Rt	0.00	0.00	0.14	0.10	0.08	0.00
Ilm	0.24	0.26	0.09	0.06	0.09	0.75
Mag	0.00	0.00	0.00	0.00	0.00	0.00
Hem	4.70	5.30	2.30	2.17	2.06	11.10
Ap	0.32	0.35	0.07	0.07	0.09	0.83
Spn	0.87	0.99	0.00	0.00	0.00	1.83

APPENDICES-3. GEOCHEMISTRY (TRACE ELEMENT)**Table 6.** Trace element analysis of the samples collected from the Leh region of Ladakh Batholith around the Trans-Himalaya Belt, (India)

Pluton/Area	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo	Basgo
Sample No.	AM1	AM2	AM3	AM4	AM5	AM6	AM7
Rock Type	Granite	Granite	Diorite	Granite	Granite	G.diorite	G.diorite
V	23.00	24.00	144.00	14.00	70.00	74.00	181.00
Co	3.30	3.50	15.70	2.60	6.40	9.70	8.30
Ni	3.60	2.70	7.90	2.10	12.30	22.90	3.70
Cu	4.90	4.10	40.50	4.00	12.30	16.30	13.20
Zn	62.00	61.00	72.00	110.00	69.00	110.00	56.00
Ga	14.00	13.00	15.80	11.60	9.50	11.80	11.50
Rb	164.70	154.10	81.60	110.60	46.90	60.80	44.10
Ba	713.00	599.00	503.00	428.00	416.00	275.00	241.00
Th	20.10	20.80	9.60	14.40	10.40	7.90	5.50
U	3.80	2.90	1.70	1.70	1.70	1.80	1.30
Nb	7.60	6.50	6.30	8.80	4.20	4.30	3.90
La	40.70	23.60	26.50	27.50	18.20	17.60	15.20
Ce	77.40	47.90	58.60	49.80	36.50	36.60	29.70
Pb	4.20	3.60	2.20	4.50	10.00	4.90	3.90
Pr	7.83	5.21	6.73	4.87	3.93	4.14	3.65
Sr	263.00	232.00	561.90	113.30	304.80	310.90	325.70
Nd	26.00	18.80	25.40	15.60	14.00	16.20	15.00
Zr	196.10	161.20	193.70	117.40	144.60	155.10	121.20
Hf	5.60	4.50	5.30	3.60	4.30	4.60	3.30
Sm	4.27	3.60	4.59	3.13	2.67	2.83	2.83
Eu	0.73	0.70	1.18	0.40	0.63	0.80	0.88
Ti	1558.29	149.84	4914.61	1198.69	2637.11	2876.85	4315.27
Gd	3.64	2.90	4.21	2.93	2.46	2.96	2.97
Tb	0.53	0.43	0.66	0.48	0.38	0.45	0.44
Dy	3.21	2.58	3.76	3.02	2.51	2.75	2.82
Y	18.10	15.10	19.30	17.50	13.70	15.70	16.30
Ho	0.64	0.52	0.74	0.64	0.46	0.60	0.60
Yb	1.82	1.70	2.08	2.13	1.53	1.62	1.60
Er	1.83	1.58	2.00	1.84	1.39	1.77	1.61
Tm	0.28	0.24	0.30	0.30	0.21	0.24	0.24
Lu	0.29	0.27	0.31	0.33	0.24	0.26	0.28
(La/Yb)n	14.77	9.17	8.41	8.53	7.85	7.17	6.27
(Gd/Yb)n	1.61	1.37	1.63	1.10	1.29	1.47	1.49
Eu/Eu*	0.56	0.65	0.82	0.40	0.75	0.85	0.93

Table 6. (Continue)

Pluton/Area	Basgo	Basgo	Basgo	Nimu	Nimu	Nimu	Nimu
Sample No.	AM8	AM9	AM10	AM11	AM12	AM13	AM14
Rock Type	G.diorite	G.diorite	Granite	Granite	G.diorite	G.diorite	Granite
V	191.00	50.00	90.00	55.00	79.00	70.00	39.00
Co	16.60	6.50	5.20	4.60	9.30	13.70	5.50
Ni	6.80	9.10	4.80	3.60	12.20	94.00	28.80
Cu	27.50	8.00	8.90	10.70	13.30	20.30	10.00
Zn	130.00	89.00	74.00	131.00	113.00	91.00	94.00
Ga	14.00	10.90	9.90	8.00	12.20	11.90	12.10
Rb	34.50	37.30	41.10	37.80	47.00	65.80	98.80
Ba	257.00	341.00	244.00	228.00	291.00	221.00	494.00
Th	5.70	7.80	6.10	6.20	6.20	12.10	11.10
U	1.30	2.10	1.30	1.10	1.20	4.00	3.80
Nb	3.90	4.40	2.60	2.80	4.00	7.50	6.30
La	14.20	15.40	14.00	10.50	15.80	25.90	19.60
Ce	28.40	30.80	28.10	20.20	32.00	49.90	37.90
Pb	3.60	6.90	2.30	4.40	7.40	15.40	14.90
Pr	3.43	3.45	3.25	2.37	3.57	5.52	3.97
Sr	582.30	391.70	177.80	233.70	271.80	188.70	218.40
Nd	13.60	12.50	12.40	8.50	13.70	19.70	14.80
Zr	110.10	82.80	86.60	75.50	134.30	193.00	93.40
Hf	3.30	2.50	2.50	2.20	3.70	5.30	2.90
Sm	2.73	2.35	2.47	1.84	2.48	3.77	2.52
Eu	0.80	0.68	0.76	0.52	0.72	0.93	0.62
Ti	4734.81	1917.90	2457.31	1558.29	2697.04	2876.85	1738.09
Gd	2.99	2.30	2.45	1.70	2.35	3.46	2.17
Tb	0.43	0.34	0.41	0.28	0.37	0.53	0.33
Dy	2.93	2.07	2.37	1.95	2.43	2.93	1.81
Y	16.30	11.20	14.10	10.30	12.90	16.70	10.90
Ho	0.60	0.44	0.52	0.37	0.50	0.59	0.37
Yb	1.74	1.20	1.48	1.12	1.48	1.79	1.08
Er	1.64	1.23	1.49	1.10	1.43	1.71	1.12
Tm	0.25	0.17	0.22	0.16	0.20	0.26	0.16
Lu	0.26	0.18	0.23	0.20	0.23	0.27	0.17
(La/Yb)n	5.39	8.47	6.25	6.19	7.05	9.55	11.98
(Gd/Yb)n	1.38	1.54	1.33	1.22	1.28	1.55	1.61
Eu/Eu*	0.86	0.89	0.95	0.89	0.91	0.78	0.80

Table 6. (Continue)

Pluton/Area	Nimu	Nimu	Nimu	Nimu	Nimu	Nimu	Umla
Sample No.	AM15	AM16	AM17	AM18	AM19	AM20	AM21
Rock Type	Granite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite	G.diorite
V	33.00	52.00	57.00	41.00	28.00	54.00	27.00
Co	3.90	5.80	6.00	5.20	2.20	6.10	3.00
Ni	20.70	2.50	1.80	1.80	2.00	2.20	1.80
Cu	8.90	9.70	4.80	9.40	4.20	4.50	5.00
Zn	88.00	95.00	110.00	123.00	184.00	105.00	88.00
Ga	11.10	13.20	14.80	15.00	10.30	14.50	12.00
Rb	97.70	45.30	41.80	71.30	63.10	45.20	44.00
Ba	548.00	369.00	324.00	179.00	1138.00	263.00	342.00
Th	8.60	4.20	4.30	2.80	21.90	4.50	3.70
U	2.50	1.00	0.70	0.60	2.80	1.10	0.60
Nb	5.00	4.20	5.90	5.00	2.60	5.10	5.20
La	19.70	17.90	20.70	16.50	24.00	18.70	13.70
Ce	35.60	34.40	45.20	32.30	36.10	36.50	27.40
Pb	11.10	2.20	1.60	1.60	3.50	1.40	1.70
Pr	3.65	3.80	5.37	3.46	3.52	4.06	3.13
Sr	228.70	293.90	379.70	376.20	247.30	311.00	326.60
Nd	12.60	13.40	20.80	13.30	11.20	15.00	12.70
Zr	66.60	147.60	219.20	227.80	121.00	171.80	206.40
Hf	2.00	4.00	5.30	5.30	3.60	4.70	4.80
Sm	2.25	2.46	4.36	2.25	1.94	2.77	2.28
Eu	0.57	1.09	1.54	0.95	0.75	1.11	1.38
Ti	1438.42	2936.78	3895.73	3536.12	1378.49	3476.19	2996.71
Gd	1.81	2.62	4.27	2.32	1.96	2.64	2.18
Tb	0.27	0.38	0.62	0.28	0.28	0.40	0.30
Dy	1.74	2.48	3.83	1.57	1.73	2.76	1.81
Y	9.50	15.10	21.70	7.70	10.30	15.70	11.30
Ho	0.32	0.53	0.82	0.27	0.35	0.57	0.36
Yb	0.91	1.77	2.20	1.06	1.36	1.66	1.05
Er	0.89	1.50	2.36	0.70	1.20	1.71	1.07
Tm	0.13	0.25	0.35	0.12	0.18	0.25	0.16
Lu	0.14	0.27	0.35	0.20	0.24	0.26	0.16
(La/Yb)n	14.29	6.68	6.21	10.28	11.65	7.44	8.62
(Gd/Yb)n	1.60	1.19	1.56	1.76	1.16	1.28	1.67
Eu/Eu*	0.85	1.32	1.09	1.28	1.18	1.25	1.89

Table 6. (Continue)

Pluton/Area	Umla	Umla	Umla	Umla	Umla	Umla	Umla
Sample No.	AM22	AM23	AM24	AM25	AM26	AM27	AM28
Rock Type	Granite	G.diorite	G.diorite	Monzonite	G.diorite	G.diorite	G.diorite
V	13.00	41.00	104.00	152.00	67.00	77.00	56.00
Co	1.30	4.30	12.00	17.30	7.80	8.70	5.90
Ni	1.70	1.80	3.70	6.20	2.30	2.60	2.10
Cu	3.20	2.80	6.10	12.40	3.00	3.30	4.10
Zn	47.00	34.00	68.00	111.00	54.00	53.00	49.00
Ga	9.70	12.10	14.00	19.10	13.90	13.20	14.40
Rb	81.50	59.60	111.40	163.20	85.10	87.20	69.20
Ba	704.00	349.00	610.00	704.00	529.00	566.00	417.00
Th	3.60	4.00	4.90	1.70	3.70	6.40	3.20
U	0.60	1.40	1.40	1.10	0.90	1.50	0.90
Nb	2.60	2.70	6.70	5.20	4.40	5.90	3.00
La	12.70	12.50	20.50	15.00	18.30	17.10	15.00
Ce	19.40	21.40	44.80	26.30	33.20	38.90	23.40
Pb	2.50	1.10	1.50	1.60	1.10	0.90	1.10
Pr	1.76	2.28	5.25	2.91	3.55	4.83	2.21
Sr	165.30	304.90	267.40	272.00	296.20	281.10	333.60
Nd	5.30	8.10	19.00	10.80	13.50	19.10	7.60
Zr	102.10	82.40	211.00	74.80	132.20	89.30	119.20
Hf	3.30	2.60	5.60	2.10	3.60	2.60	3.30
Sm	0.69	1.54	4.01	2.48	2.65	3.53	1.45
Eu	0.50	0.53	0.85	0.54	0.75	0.79	0.57
Ti	839.08	1678.16	4195.40	5214.28	2756.98	3116.58	2037.77
Gd	0.50	1.47	3.63	2.53	2.25	3.21	1.30
Tb	0.07	0.22	0.58	0.39	0.36	0.55	0.22
Dy	0.41	1.28	3.52	2.39	2.09	3.20	1.25
Y	2.60	8.30	20.70	13.60	12.90	18.70	7.80
Ho	0.09	0.28	0.71	0.44	0.46	0.62	0.26
Yb	0.43	0.87	2.31	1.32	1.36	1.92	0.81
Er	0.28	0.86	2.12	1.31	1.24	1.87	0.74
Tm	0.05	0.12	0.32	0.20	0.19	0.28	0.12
Lu	0.09	0.14	0.36	0.22	0.21	0.28	0.13
(La/Yb)n	19.50	9.49	5.86	7.50	8.89	5.88	12.23
(Gd/Yb)n	0.93	1.36	1.26	1.54	1.33	1.34	1.29
Eu/Eu*	2.51	1.07	0.68	0.66	0.93	0.71	1.26

Table 6. (Continue)

Pluton/Area	Umla	Umla	Taru	Taru	Taru	Taru	Taru
Sample No.	AM29	AM30	AM31	AM32	AM33	AM34	AM35
Rock Type	Monzonite	G.diorite	Granite	G.diorite	G.diorite	G.diorite	G.diorite
V	101.00	90.00	21.00	53.00	79.00	80.00	94.00
Co	12.60	7.00	2.60	6.00	9.80	8.10	9.70
Ni	8.70	3.90	2.30	2.10	3.50	3.20	3.20
Cu	23.80	4.40	5.40	3.50	5.20	6.00	4.80
Zn	134.00	103.00	56.00	48.00	65.00	65.00	74.00
Ga	19.10	17.70	10.60	15.00	16.60	13.30	17.60
Rb	60.30	92.80	121.50	90.60	92.60	67.50	54.10
Ba	792.00	455.00	878.00	156.00	224.00	213.00	210.00
Th	8.20	13.10	3.80	3.10	5.90	4.40	4.60
U	2.00	7.70	0.80	0.90	1.10	0.80	0.90
Nb	17.50	5.80	1.50	3.90	14.70	5.40	5.40
La	50.80	31.10	6.40	14.00	29.30	20.60	21.20
Ce	102.50	58.80	9.60	23.30	66.10	43.30	44.00
Pb	3.70	2.10	1.80	2.00	1.00	1.50	1.00
Pr	11.47	6.28	0.86	2.32	7.76	4.95	5.09
Sr	1075.80	335.80	248.90	346.40	346.70	352.60	357.60
Nd	40.80	23.20	2.70	7.20	29.00	19.50	19.30
Zr	265.40	130.20	108.40	115.40	148.60	130.10	143.10
Hf	6.00	3.60	3.50	3.30	4.10	3.20	3.90
Sm	6.04	4.07	0.31	1.44	6.00	3.74	3.53
Eu	1.56	1.13	0.34	0.51	0.82	0.71	0.80
Ti	6472.90	2697.04	899.01	1917.90	3296.39	2936.78	3416.25
Gd	4.00	3.62	0.32	1.38	6.31	3.55	3.25
Tb	0.43	0.48	0.06	0.22	1.02	0.58	0.54
Dy	2.14	2.96	0.35	1.39	6.77	3.57	3.21
Y	10.50	17.70	2.50	8.90	46.00	22.30	22.10
Ho	0.31	0.55	0.08	0.36	1.38	0.75	0.70
Yb	0.73	1.80	0.31	0.93	5.16	2.14	2.27
Er	0.91	1.76	0.25	0.92	4.45	2.17	2.20
Tm	0.10	0.27	0.05	0.14	0.73	0.31	0.34
Lu	0.10	0.28	0.07	0.16	0.78	0.32	0.36
(La/Yb)n	45.95	11.41	13.63	9.94	3.75	6.36	6.17
(Gd/Yb)n	4.40	1.62	0.83	1.19	0.98	1.33	1.15
Eu/Eu*	0.92	0.89	3.31	1.10	0.41	0.59	0.72

Table 6. (Continue)

Pluton/Area	Taru	Taru	Taru	Taru	Taru	Taru
Sample No.	AM36	AM37	AM38	AM39	AM40	AM41
Rock Type	G.diorite	G.diorite	Granite	Granite	Granite	M.diorite
V	78.00	82.00	27.00	21.00	13.00	216.00
Co	8.30	8.80	3.20	2.50	1.90	24.70
Ni	3.20	2.90	1.60	2.00	2.20	4.90
Cu	6.20	4.80	6.50	4.50	5.40	97.30
Zn	64.00	72.00	41.00	38.00	54.00	155.00
Ga	16.60	15.20	9.50	9.00	8.20	18.00
Rb	56.80	70.10	77.50	58.80	88.50	119.70
Ba	187.00	184.00	929.00	944.00	1543.00	151.00
Th	3.70	4.10	8.50	5.10	7.10	2.00
U	1.00	1.10	1.10	0.60	1.10	0.70
Nb	6.20	7.00	2.40	1.20	1.60	8.70
La	21.60	23.40	7.80	6.30	6.60	26.70
Ce	46.70	48.60	16.80	9.40	10.10	58.10
Pb	1.40	1.70	2.40	1.50	1.80	1.20
Pr	5.59	5.21	2.17	0.90	0.99	7.24
Sr	349.50	361.40	258.90	309.50	302.80	343.80
Nd	21.70	19.10	8.60	3.50	3.20	28.90
Zr	112.60	130.40	92.60	55.30	38.60	73.80
Hf	3.20	3.80	3.10	1.70	1.20	2.00
Sm	4.44	3.53	1.64	0.30	0.35	6.41
Eu	0.81	0.80	0.74	0.59	0.50	0.73
Ti	2876.85	3236.45	1138.75	779.15	779.15	6832.51
Gd	4.02	3.54	1.82	0.45	0.41	6.45
Tb	0.66	0.58	0.26	0.05	0.05	1.03
Dy	4.40	3.83	1.66	0.36	0.31	6.31
Y	24.40	24.10	8.70	2.20	1.90	39.80
Ho	0.85	0.78	0.38	0.08	0.06	1.37
Yb	2.74	2.94	0.92	0.33	0.28	4.31
Er	2.51	2.53	0.87	0.21	0.21	4.02
Tm	0.37	0.41	0.14	0.04	0.04	0.63
Lu	0.42	0.47	0.15	0.05	0.05	0.64
(La/Yb)n	5.21	5.26	5.60	12.61	15.56	4.09
(Gd/Yb)n	1.18	0.97	1.59	1.10	1.18	1.20
Eu/Eu*	0.58	0.69	1.32	4.97	4.08	0.35

APPENDICES 4. ISOTOPE GEOCHEMISTRY (Rb-Sr AND Sm-Nd ISOTOPICAL DATA)**Table 7.** Rb-Sr isotopic data of Ladakh batholith granitic rocks of Leh region, from the Trans-Himalayan belt, North- Western India

Sample No.	Rock Type	SiO ₂ Wt%	Rb (ppm)	Sr (ppm)	Rb/Sr (ppm)	⁸⁷ Sr/ ⁸⁶ Sr (measure)	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr/ ⁸⁶ Sr (initial)
AM-1	Basgo Granite	70.4	164.7	263	0.626236	0.705988	1.812952	0.704443
AM-3	Basgo Diorite	59.6	81.6	561.9	0.145222	0.704911	0.420416	0.704553
AM-16	Nimu Granodiorite	68.9	45.3	293.9	0.154134	0.705822	0.446218	0.705442
AM-17	Nimu Granodiorite	65	41.8	379.7	0.110087	0.704842	0.318702	0.70457
AM-18	Nimu Granodiorite	65.9	71.3	376.2	0.189527	0.705283	0.54868	0.704815
AM-19	Nimu Granodiorite	72.1	63.1	247.3	0.255156	0.705875	0.738676	0.705245
AM-20	Nimu Granodiorite	66.3	45.2	311	0.145338	0.704766	0.420752	0.704407
AM-33	Taru Granodiorite	64	92.6	346.7	0.26709	0.705063	0.773225	0.704404
AM-34	Taru Granodiorite	67.4	67.5	352.6	0.191435	0.70487	0.554204	0.704398
AM-35	Taru Granodiorite	65.6	54.1	357.6	0.151286	0.704725	0.437974	0.704352
AM-36	Taru Granodiorite	66.9	56.8	349.5	0.162518	0.704713	0.470489	0.704312
AM-37	Taru Granodiorite	65.5	70.1	361.4	0.193968	0.70477	0.561537	0.704291
AM-38	Taru Granite	73.4	77.5	258.9	0.299343	0.704985	0.866599	0.704246
AM-39	Taru Granite	75.1	58.8	309.5	0.189984	0.704848	0.550003	0.704379
AM-40	Taru Granite	75.8	88.5	302.8	0.292272	0.70512	0.846128	0.704399
AM-41	Taru Monzodiorite	51.8	119.7	343.8	0.348168	0.704995	1.007945	0.704136

Table 8. Sm-Nd isotopic data of Ladakh batholith granitic rocks of Leh region, from the Trans-Himalayan belt, North- Western India

Sample No.	Rock Type	SiO ₂ wt%	Sm (ppm)	Nd (ppm)	Sm/Nd (ppm)	¹⁴³ Nd/ ¹⁴⁴ Nd (measured)	¹⁴⁷ Sm/ ¹⁴⁴ Nd	¹⁴³ Nd / ¹⁴⁴ Nd (T) initial	EpsilonNd (initial)
AM-1	Basgo Granite	70.4	4.27	26	0.164231	0.512686	0.099343	0.512647	1.7
AM-3	Basgo Diorite	59.6	4.59	25.4	0.180709	0.512702	0.109311	0.512659	1.9
AM-16	Nimu Granodiorite	68.9	2.46	13.4	0.183582	0.51273	0.111049	0.512686	2.5
AM-17	Nimu Granodiorite	65	4.36	20.8	0.209615	0.512731	0.126796	0.512681	2.3
AM-18	Nimu Granodiorite	65.9	2.25	13.3	0.169173	0.512734	0.102333	0.512694	2.6
AM-19	Nimu Granodiorite	72.1	1.94	11.2	0.173214	0.512721	0.104777	0.51268	2.3
AM-20	Nimu Granodiorite	66.3	2.77	15	0.184667	0.512726	0.111705	0.512682	2.4
AM-33	Taru Granodiorite	64	6	29	0.206897	0.512726	0.125152	0.512677	2.3
AM-34	Taru Granodiorite	67.4	3.74	19.5	0.191795	0.512733	0.116017	0.512687	2.5
AM-35	Taru Granodiorite	65.6	3.53	19.3	0.182902	0.51272	0.110637	0.512677	2.3
AM-36	Taru Granodiorite	66.9	4.44	21.7	0.204608	0.512723	0.123768	0.512674	2.2
AM-37	Taru Granodiorite	65.5	3.53	19.1	0.184817	0.512719	0.111796	0.512675	2.2
AM-38	Taru Granite	73.4	1.64	8.6	0.190698	0.512722	0.115353	0.512677	2.3
AM-39	Taru Granite	75.1	0.3	3.5	0.085714	0.512702	0.051849	0.512682	2.4
AM-40	Taru Granite	75.8	0.35	3.2	0.109375	0.512721	0.066161	0.512695	2.6
AM-41	Taru Monzodiorite	51.8	6.41	28.9	0.221799	0.512724	0.134166	0.512671	2.2

RESUME

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AWARDS

Awards	Year
Two year membership as a grant has been awarded by the Geochemical Society, Organizers of Goldschmidt 2018 (Boston- USA)	2018-2019
Grant has been awarded by the Geochemical Society, Organizers of Goldschmidt 2018 (Boston- USA)	2018
Young Scientist Travel Award by European Geosciences Union Assembly (EGU) (Vienna-Austria)	2015

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