3.1 Location and Accessibility of the Area

The eastern part of the Himalayan Mountain Belt, commonly known as Eastern Himalaya lies mostly in Sikkim, Bhutan and Arunachal Pradesh, where Arunachal Himalaya occupies the eastern most part of Himalayan Mountain belt. There are four major rivers Kameng, Subansiri, Siang and Lohit draining the Arunachal Pradesh which divides the region in four geological corridors (Fig. 3.1) according to their catchments areas. The study area lies in the west Kameng district of Kameng corridor, a part of western Arunachal Himalaya comprised of west Kameng and Tawang districts. The west Kameng district constitutes an important geological section in western Arunachal Himalaya and composed of Higher and the Lesser Himalayan rocks, which are separated by Main Central Thrust (MCT). It is bordered by Tethys Himalaya in the north and Sub-Himalayan ranges in the south, whereas Main Boundary Thrust (MBT) forms its southern limit. It is bounded by Bhutan in west, in the north by Tibet, in the east by east Kameng and Siang districts and in the south by Assam state. The study area is highly mountainous with altitudes ranging from 2,000 m to 4,000 m. It lies between latitude 27°10’ to 27°30’ N and longitude 92°05’ and 92°30’ E. The west Kameng district of western Arunachal Himalaya is well connected to Guwahati by road and flights. Bomdila is 320 km far from Guwahati where bus services of Arunachal Pradesh and Assam State Transport Corporation are playing to Bomdila from Tezpur via Bhalukpong – Tipi – Tengavally - Rupa. Tawang is 170 kms far from Bomdila and can be reached by bus from Bomdila (10 hours drive) via crossing the Se La pass. The nearest railway station is Bhalukpong (100 kms) and airport is Tezpur (160 kms). However, except some valley regions and few towns, major part of the study area is inaccessible and tracking is the only way to access.
3.2 Physiography

Arunachal Pradesh is characteristically rugged terrain which is highly inaccessible with dense forests and poor road communications. There are four physiographic segments (Kumar, 1997; Kesari, 2010) of Arunachal Pradesh with distinct stratigraphy and structures.

3.2.1 Himalayan Range

The northern most part of Arunachal Himalaya, also known as Tethyan or Tibetan Himalayan Range, extends from the border of Bhutan to the Dibang and Lohit valleys and terminating against the Tidding-Tutting suture. This range is comprised of high grade schist and gneisses of the Sela Group, Proterozoic metasediments of Lumla Formation and a part of Tethyan sequences.

Higher Himalaya is bounded by the Tethyan Himalaya in north and the Lesser Himalaya in south, where Dirang or Main Central Thrust defines its southern limit. Higher Himalaya is characterized by high relief (~6000 m) and rugged topography,
where high grade Palaeoproterozoic gneiss, schist and Tertiary leucogranite are among the major lithounits. Kangto (7,090 m) and Gorichen (6,538 m) are the highest peaks in the Higher Himalaya of Arunachal Pradesh.

Lesser Himalaya, bounded between Dirang or Main Central Thrust in north and Main Boundary Thrust in south is characterized by moderate relief (2500 m - 4000 m) and comprised of low grade Palaeoproterozoic metasediments and gneisses. However, mafic rocks in the form of Abor volcanics and as mafic intrusive dykes are also present.

The Sub-Himalaya or the foothill fore-deep is represented by 1700 m – 2000 m high narrow (10-20 km wide) hill range, which is characterized by well defined ‘Dun’ type valleys.

3.2.2 Trans-Himalayan Range

Trans-Himalayan range is represented by Mishmi Hills, which form the eastern most part of Arunachal Pradesh, where the Himalayan Range abuts against Mishmi Hills along Tidding-Tutting Suture. The general elevation of the Trans-Himalaya Range is between 2500 m and 6000 m. It is equivalent of Ladakh Range lying north of the Indus Tsangpo Suture.

3.2.3 Naga-Patkoi Range

The Naga-Patkoi hill range attains medium height (2780 m), moderate relief and comprised of Tertiary sequence of Assam and southeastern Arunachal Pradesh. These hills are the northern continuation of ENE-WSW trending Arakan-Yoma mountain chain.

3.2.4 Brahmaputra Plain

Brahmaputra plain lying between Himalayan Range to the north and the Shillong Plateau-Naga-Patkoi range to the south, and commonly filled by post-Siwalik Quaternary sediments. The valley is characterized by three to four levels of terraces.
3.3 Drainage

The Tawang region is drained by the Tawang Chu, Nyamjang Chu (both of which drain into Bhutan) and their tributaries. The Bomdila area in northeastern Himalaya is occupied by Bhareli or Kameng River catchments. Geographically the boundary of Bomdila watershed is situated between latitudes 27°0'41.09"-27°32'15.03"N and longitudes of 91°59'38.85"-92°47'59.83"E. The drainage area covers an area of 6492 km sq (Fig. 3.2) and shows four orders of streams forming dendritic drainage pattern. The elevation of the watershed varies from 451 m to 2920 m above mean sea level. The order of river system is in a disequilibrium state of channels due to tectonic and climatic perturbation. All the major rivers draining the western Arunachal Pradesh are the tributaries of Brahmaputra River. The rivers of the western Arunachal Himalaya are also Neotectonically active (Srivastava and Mishra, 2008).
3.4 People

The people of Arunachal Pradesh are predominantly tribals, under the scheduled of India forming 65% of total population. There are 26 main tribes and numerous sub-tribes, each with a specific geographic distribution and distinct linguistic, cultural and social identities. Most of the tribal groups are ethnically similar, having derived from original common stock but their geographical isolation from each other has brought amongst them certain distinctive characteristics in language, dress and customs. Nearly 80% of people have main occupation of agriculture. Large forested areas still remain in Arunachal, in part because of its low human population density (13 km$^{-2}$, compared to a national average of 324 km$^{-2}$; Government of India, 2003). Nevertheless, Arunachal’s decadal (1991–2001) growth rate is 26% higher than the national average of 21% (Government of India, 2003). Tawang and Kameng (7,422 km$^2$) districts have a human population density of 16 km$^{-2}$ and 10 km$^{-2}$ respectively (Government of India, 2003). The Buddhist Monpa tribe is the main ethnic group in Tawang with a considerable presence of the Indian Army in the district, whereas in west Kameng district people belong to the Monpa, Sherdukpen, Bugun, Aka, and Miji tribes (Choudhury, 1996). People in the low-lying valleys cultivate rice. Other crops include barley, wheat, millet, maize and buckwheat. Livestock include yak, cattle, the semi-wild mithun Bos frontalis, and their hybrids, in addition to sheep and horses. Milk products such as butter and cheese from yak, cattle and their hybrids form an important source of income. Lossar is one of the important festivals; however festivals are connected with ritualistic gaiety either to thank God for his providence or to pray for good harvests.

3.5 Climate, Flora and Fauna

The lower belts of Arunachal Pradesh experience hot and humid climate. The maximum temperature is 40º C (during summer), whereas during winters temperature ranges from 15º C to 21º C. During the monsoon the temperature in this region is in between 22º C and 30º C. The areas around middle belt of Arunachal Pradesh are cooler and experience microthermal climate. Moreover, Arunachal Pradesh possesses alpine type climate in the higher altitudes and witnesses snowfall during winters.
Arunachal Pradesh experiences heavy rainfall during May to September each year. The rainfall commonly varies between 80 cm and 450 cm with an average of about 300 cm.

Arunachal falls within the Eastern Himalaya global biodiversity hotspot (Myers et al., 2000) and is also among the 200 globally important eco-regions (Olson and Dinerstein, 1998). It harbours the world’s northernmost tropical rainforests and is estimated to contain nearly 50% of the total flowering plant species in India (Rao and Hajra, 1986; Whitmore, 1998; Procter et al., 1998). Out of about a thousand species of orchids in India over 500 are found in Arunachal alone. Some of the orchids are rare and classified as endangered. Arunachal Pradesh Forest Development Corporation has established an Orchid Research and Development Station at Tipi and two orchid conservation sanctuaries at Sessa and Dirang in west Kameng district.

The wild life of Arunachal is equally rich and diversified. Elephants and tigers abound especially in the grassy foothills and the leopard and jungle cat are quite common. The red pandas, musk deer and yak are found in the higher ranges. The *Mithun* (Bos Frontaills) exists both in wild and semi-domestic form and has religious significance. Mishra et al (2006) report results of recent mammal surveys in the western Arunachal Pradesh. A total of 35 mammal species (including 12 carnivores, 10 ungulates and 5 primates) were recorded, of which 13 are categorized as Endangered or Vulnerable on International Union for Conservation of Nature (IUCN) Red List. Snow leopard, musk deer and tiger are some of them. Arunachal has a wide altitudinal range (100 m – 7,090 m), and is also a happy home of great Indian Hornbill, the extraordinary bird with an inordinately large beak.

3.6 Regional Geology

3.6.1 Geology and Tectonics of Arunachal Pradesh

The Himalaya extends for about 2400 km long and about 270 km wide from east at Namche Barwa to the west at Nanga Parbat, which can be divided into western, central and eastern segments along its strike, where eastern Himalaya (Sikkim, Bhutan and Arunachal Himalaya) constitutes about the one forth of the Himalayan mountain belt (Fig. 3.3). The eastern part of Himalaya is mostly present in the Arunachal Pradesh in northeastern region of India and possesses geology and stratigraphic more akin to
central Himalayan sequences except rate of crustal shortening (Yin et al., 2010). Eastern Himalaya is comprised of large thrust duplex with the folded MCT as roof fault.


Figure 3.3 Geological map of the Himalayan mountain belt (after Valdiya, 2010) showing the distribution of Higher and Lesser Himalayan crystalline sheet and metadesiments spreading across the strike of Himalaya from west to east.

Tethyan Himalayan sequences are not exposed in the Arunachal Pradesh but can be traced to the further north in southeast Tibet as immensely deformed and folded lithounits of Triassic to Cretaceous age (Pan et al., 2004; Aikman et al., 2008, Yin et al., 2010). Greater Himalayan Crystalline Complex is mainly represented by Se La Group of rocks which are well exposed in and around Se La Pass region in western Arunachal Himalaya and at Subansiri valley section. The Higher Himalayan Crystallines in Arunachal Pradesh has been divided between Taliha and Galensiniak
Formations, where Taliha Formation is comprised of medium to high grade gneisses, migmatites, schists and quartzites, however, high grade gneisses, calc-silicates, schists and marbles are the major constituting lithounits of Galensiniak Formation (Kumar, 1997; Kesari, 2010). Se La Group has been considered equivalent of the Central Crystallines of western, central, Darjeeling Himalaya and Thimpu Group of Bhutan Himalaya, representing Early Paleoproterozoic Sequences (Jangpangi, 1978; Anon, 1984; Wang, 1986). The high grade metamorphics and associated lithounits of Se La Group are profusely intruded by dykes and sills of Tertiary two-mica (± tourmaline) leucogranites (Kumar, 1997; Yin et al., 2006; Kumar and Pathak, 2008, 2009), related to Himalayan orogeny. Main Central Thrust (or Dirang Thrust) places Greater Himalayan Crystalline Complex over Lesser Himalayan Sequences.

The lithounits constituting the Lesser Himalaya are Proterozoic low grade metasediments and intrusive granite and granite-gneises which have been grouped in several Groups and Formations with different local names in Bhutan, western and eastern Arunachal Himalaya. Conventionally in Kameng district of western Arunachal Himalaya, the Lesser Himalayan lithounits have been grouped in Palaeoproterozoic Bomdila Group and Salari Group (augen gneisses and granite with interlayered phyllites carbonaceous shale) (Dikshitulu et al., 1995) and Mesoproterozoic to Neoproterozoic Rupa and Dirang Group (quartzite and phyllite below and carbonate above) (Yin et al., 2010). The older gneisses, granites and interlayered rocks have been considered as thrust sheet equivalent to the Lesser Himalayan crystalline thrust sheets of Himachal Pradesh, Kumaun, and Nepal Himalaya (Table 1.1). The Bome thrust places the Lesser Himalayan sequences over the Permian Gondwana Sequence (Kumar, 1997; Yin, 2006, Yin et al., 2010). The rocks of Lower Gondwana Group are exposed in discontinuous patches over a roughly E-W trending belt extending from Bhutan border in west to the north of Pasighat in the east (Kumar, 1997; Nayak et al., 2009; Kesari, 2010). The Main Boundary Thrust places the Permian Gondwana Sequence over Tertiary strata of Sub-Himalaya, where Sub Himalaya occurs as linear belt from Bhutan in the west to Roing in the Dibang valley in the east where it ends against the Roing fault. Siwalik has been subdivided in to Dafla Formation (Lower Siwalik), Subansiri Formation (Middle Siwalik) and Kinim Formation (Upper Siwalik), where Tipi thrust places Miocene Dafla Formation over the Pliocene Subansiri and Peistocene Kinim Formations (Kumar, 1997). The southern limit of Sub-Himalaya is defined by
the Main Frontal Thrust which separate it to the southern quaternary Brahmaputra plain and cratonic regions. The Main Frontal Thrust zone consists of a series of *en echelon* folds that branch off obliquely from the main Himalayan Range front toward the Indian craton (Shillong Plateau) (Yin et al., 2010).

The Arunachal Himalaya may be divided further into the eastern and western domains separated by the Siang window, shown as Siang Corridor in figure 3.1, directly south of the eastern Himalayan syntaxis (Singh and Chowdhary, 1990; Singh, 1993; Acharyya, 1998; Burg et al., 1998; Ding et al., 2001; Zeitler et al., 2001; Yin et al., 2010). The Siang window is defined by a closed trace of the Main Boundary Thrust that places Lesser Himalayan strata over Cretaceous-Palaeogene strata (Kumar, 1997). Regional features such as the Main Central Thrust, Bome Thrust (Upper Main Boundary Thrust, Yin et al., 2010), and the Indus-Tsango suture all make sharp U-turns around the window (Kumar, 1997; Yin et al., 2010; Kesari et al., 2010). In the eastern Himalaya, east of the Siang window, the Cretaceous-Tertiary Gangdese Batholith thrusts over the Greater Himalayan Crystalline complex, omitting the entire section of the Tethyan Himalayan sequences (Gururajan and Chowdhary, 2003). This relationship is in sharp contrast to that in southeast Tibet, where the Gangdese Batholith thrusts over the Tethyan Himalayan Sequence or mélangé complex in the Indus-Tsango suture zone (e.g. Yin et al., 1994, 1999; Harrison et al., 2000). In places, the Greater Himalayan Crystalline Complex also thrusts over Quaternary sediments, omitting the Lesser Himalayan Sequences that commonly seen in the rest of the Himalaya (Gururajan and Chowdhery, 2003 and Yin, 2006).

**3.6.2 Geology and Field Relationship in the Study Area**

Greater Himalayan Crystalline Complex and Lesser Himalayan sequences are well exposed in western Arunachal Himalaya along Sessa – Bomdila – Dirang -Se La - Tawang transect, where Main Central Thrust, also locally known as Dirang Thrust, is the main structural feature (Fig. 3.4). The Lesser Himalayan Sequences, which are comprised of Bomdila, Salari and Rupa Groups, as the major integral geological constituents of western Arunachal Himalaya.
Bomdila Group represents the oldest Palaeoproterozoic Group, which has been sub-divided into four Formations viz. 1) Khetabari Formation, 2) Tenga Formation, 3) Dedza Formation, and 4) Bomdila Gneiss. The low grade of metasediments comprising sericite-quartz phyllite, garnetiferrous phyllite and schist, carbonaceous phyllite, quartzite, minor carbonate, chert and amphibolite, well exposed around Khetabari in the Lower Subansiri district constitute the Khetabari Formation. However, this Formation is not well exposed in west Kameng district except Kiriphum village. The metasediments consisting of green phyllite, quartzite, and metavolcanics are mostly exposed in and around Tenga valley in west Kameng district originally described as Tenga Formation by Das et al (1975). Its equivalent Formations in east Kameng and Subansiri districts have been sub-divided into Lower and Upper Members. A thick succession of dominantly carbonate rock lying unconformably over the Tenga Formation in Dedza locality of Tenga valley is known as Deza Formation. The Dedza Formation has been correlated with the Buxa Group of Lesser Himalaya in Bhutan and Menga Formation of Subansiri valley on the basis of lithology and stromatolites (Acharyya, 1980). A vast stretch of area in the west Kameng district is extensively occupied by augen gneisses of Bomdila Group, which are best exposed around Nachiphu, Tenga and Dahung valley, in and around Bomdila, Chakkoo, between Bomdila and Dirang and Bomdila-But and Kiriphum localities. The Ziro gneiss exposed in Ziro valley of lower Subansiri district considered as the eastern extension of
batholithic augen gneiss of Bomdila Group. Kumar (1997), Kumar and Pathak (2009, 2010), and Singh (2010) have considered it as felsic bodies intrusive into the metasediments of Bomdila Group (Khetaabari and Tenga Formations), where the intrusive nature of gneiss is well exposed in Ziro valley in east Kameng district (Singh, 2012; Kesari, 2010 and references therein).

The carbonaceous black shale, arenites and quartzite of But and Salari villages along with the intrusive hornblende-biotite granite are the major constituting lithounits of the Salari Group (Dikshitulu et al., 1995; Kumar and Pathak, 2009, 2010; Singh, 2010), where the intrusive relation is inferred from the presence of angular to subangular carbonaceous country rock xenolith in Salari granite and up doming of the overlying metasediments. Salari Group of rocks occupies the axial trace of a regionally refolded antiform structure (Fig. 3.4) named as a Salari antiform by Srinivasan (2001).

Rupa Group which is consisted of lower quartzite and phyllite and upper carbonate members represent the youngest non-fossiliferous Lesser Himalayan unit, which has been assigned younger than 950 Ma based on detrital zircon chronology (Yin et al., 2006). Yin et al., (2006) considered Rupa Group lying unconformably over the Bomdila granite gneisses, where as Bhushan et al., (1991) considered a tectonic contact between Rupa and Bomdila Groups.

3.7 Granitoids in Western Arunachal Himalaya

3.7.1 Sela Group

Sela Group is well exposed between Sapper and Tawang with its tectonic contacts with Bomdila Group along MCT, which can be recognized as quartzite marker beds of Dirang Formation near Ramacamp (Yin et al., 2006). The constituting rocks are interbedded, low to high-grade biotite-rich metapelites and gneisses, which are, at places, intruded by Tertiary leucogranites and pegmatites (TLG). The gneissic rocks are represented by Hb-Bt granite gneiss (HBGGn) near Sapper, Bt-granite gneiss (± Gt ± Tur) in and around Se La and Bt-Ms gneiss (± Hb ± Gt ± Tur) (TGN) in Tawang area, elsewhere described as migmatite (e.g. Dikshitulu and Raju, 1997; Bhattacharjee and Nandy, 2007).
HBGGn has limited exposure beyond MCT in and around Sapper and Nyukmadong localities in the form of small gneissic patches with in high-grade metasediments of Se La Group. It is a medium to coarse grained, mesocratic and magnetite bearing, but at places exhibits migmatite-like (sensu lato) layered structure (Fig. 3.5a). Locally it is also sheared in nature (Fig. 3.5b). This felsic lithounit most likely represents Palaeoproterozoic felsic magmatic event (~2300 Ma – 2100 Ma;
Kumar, 1997), which have been later affected by Pan-African thermal event, as evident from a reset whole-rock Rb-Sr age of 481 ± 23 Ma (Dikshitulu et al., 1995; Acharyya, 1995). Bt-granite gneiss is a medium to fine grained, mesocratic rocks, characterized by banded gneissic texture, and is found closely associated with biotite-rich layered metapelites.

Figure 3.6 Granite gneiss from Tawang region, Se La Group, Higher Himalaya (a) figure showing the gneissic to migmatitic nature of TGN with well developed quartzofeldspathic augens, shearing is also present, (b) migmatized TGN with ptygmatically folded leucocratic neosome, (c) extensional boudinage structure developed in TGN.
Figure 3.7 Tourmaline bearing Leucogranite TLG in Se La Group of Higher Himalaya (a) dykes of leucogranite intruding the metasediments of Se La Group, (b) close view of two-mica leucogranite and tourmaline nodules bearing pagmatite. Note the magmatic flowage structure in granite near the pegmatite-granite contact, (c) massive outcrop of leucogranite in contact with the biotite-rich metapelite, (d) sill-like massive intrusion of leucogranite into the metapelites (base of the photograph is equal to 9 m).

TGN is mesocratic, medium to fine grained, at places streaky in nature whereas medium to coarse grained augen gneissic variety with sheared character is also observed (Fig. 3.6a). It is best exposed in and around Bomdir, Sheru, Lhou and Tawang localities. It is magnetite-free and sometimes magnetite-bearing, but contains more mafic minerals and garnet as compared to HBGGn (Fig. 3.6b). It has no marked augens but the leucocratic bands sometimes form extensional pinch and swell structures (Fig. 3.6c).

All these gneissic bodies are discordantly intruded by TLG, Himalayan felsic magmatic phases (29±7 Ma, Bhalla et al., 1989; 23-20 Ma, Yin et al., 2006), which are comprised of tourmaline-rich, tourmaline-poor and pegmatite varieties. It intrudes the high-grade metasedimentary and gneissic rocks in the form of dykes and sills (Fig. 3.7a) of few meters to kilometer in scale. TLG is medium to coarse grained,
equigranular, and hololeucocratic ($M' < 15$) to leucocratic ($M' = 15 - 35$) in nature. The pegmatite phase of TLG with abundant tourmaline nodules intrudes tourmaline-poor phase of TLG (Fig. 3.7b). At places, magmatic fabric as flowage structure is developed in the latter close to the intrusive contact of pegmatite (Fig. 3.7b). Occasional gneissic texture is developed in TLG close to the major shear zones of MCT. The leucocratic felsic (TLG) melt generated elsewhere are also found emplaced along the foliation plane of older granite gneisses (HBGGn, TGN and Bt-granite gneiss), with mafic segregation and clots (biotite-rich) along the margins of felsic layers, resulting in the development of migmatite-like and lit-par-lit structures. It is commonly associated with biotite-rich metasediments (Fig. 3.7c, d).

### 3.7.2 Bomdila Group

Bomdila Group is comprised of metasediments (quartzites, arenites, black shale and slate) and Palaeoproterozoic (1914±23 Ma, Dikshitulu et al., 1995; 1743±4 Ma, Yin et al., 2008; 1752±23 Ma, Present work) Ms-Bt ($\pm$Tur) GGn of batholithic dimension and mafic intrusives. GGn is mesocratic, dominantly comprised of feldspar, quartz, biotite and muscovite, where biotite is greater than the muscovite, however a leucocratic variety of GGn is also present ($Ms > Bt$) mostly in the south to Bomdila town between Dedja and Sessa localities and in northeast to Bomdila town in and around Kiriphum and Nafra localities. Originally GGn is a porphyritic granite where the tabular and euhedral phenocrysts of K-feldspar are randomly oriented (Fig. 3.8a) in a relatively fine grained non foliated mesocratic ground mass. However change in the shape and size of phenocrysts and effect of deformation resulting in development of foliation into groundmass which can be seen at several places (Fig. 3.8b). The shape of the phenocrysts is varying from tabular to round to elliptical where as size is now the function of degree of deformation. The undeformed to less deformed outcrops are coarse grained where as grain size reduction has been observed in deformed GGn (Figs. 3.9a, b, 3.10a, b, and 3.11a, b).

The mesocratic variant of GGn is non-foliated to foliated and megacryst-bearing porphyritic granite gneiss, where the alignment of micaceous mineral and enveloping around feldspar phenocrysts giving rise to augen-like gneissic structure. The early formed mafic minerals mostly comprised of biotite are present as mafic
segregates (Fig. 3.9a). The GGn present in and around the Bomdila proper is characterized by tourmaline as accessory phase mostly present as clusters of tourmaline nodules (Fig. 3.10a) and as independent crystal impregnated into the groundmass. Structural fabrics such as S-C-planes caused by ductile shearing of rocks have also been identified in the GGn outcrops near to shear zone from Bomdila - Dirang road (Fig. 3.10b). At places megacryst-free variety of GGn are also present, where the phenocryst-free nature has been attained to GGn by intense ductile deformation leading to grain size reduction and mylonitization of GGn. (Fig. 3.11a, b). Frequency of augens in GGn increases gradually while moving away from its contact as consequence of decrease in degree of mylonitization away from shear zones. The GGn and metasediments are interbedded and they are best exposed in and around Bomdila, Rupa, Dirang, Tenga, Chakoo, and Kiriphum localities. The lenticular to tabular metapelitic xenoliths of varying length (10 cm to 35 cm) are very common in to GGn mostly in and around Tenga and Ninemile localities (Fig. 3.12a). Along Ninemile-Salari road the sharp contact between metasediments of Bomdila Group and GGn has been observed (Figs. 3.12b, 3.13a) whereas same contact near Ninemile locality is characterized by development of cms thick quartzofeldspathic veins along the sharp contact (Fig. 3.12b) and mylonitic nature of GGn, which may be resulted by later deformational activities where felsic melt squeezed out from metapelitic protolith heated and partially melted due to crushing and shearing effects. A gradational contact of GGn with metasediments of Bomdila group has been observed from the Tenga where the insitu friezing of GGn melt along the foliation or bedding of metasediments has been identified (Fig. 3.13b). The leucocratic GGn is characterized by less abundance of biotite over muscovite and present in both as deformed to weekly deformed or undeformed nature (Fig. 3.14a, b). The leucocratic GGn are well exposed along Salari - Nfra transect in and around Kiriphum locality found associated with the mesocratic augen variety of GGn. It is also present in the southern part of the study area at Jamiri - Sessa transect (Fig. 3.15a) found in sharp contact with the arenaceous metasediment of Bomdila Group (3.15b), where a baking effect has been observed over metasediment resulting in compactness and massiveness into metasediments. A grain size variation away from this contact has been observed where GGn is characterized by fine grained nature near contact. In Shergaon locality of Bomdila proper both mesocratic and leucocratic variants of GGn are present in close association.
Figure 3.8 field photographs of GGn showing (a) primary undeformed nature of GGn where randomly oriented tabular phenocrysts of feldspar are characterized by sharp and straight crystal boundaries, (b) GGn characterized by subhedral to euhedral phenocrysts of K-feldspar of varying sizes, giving porphyritic texture, however the groundmass is relatively fine grained and foliated.
Figure 3.9 (a) Deformed GGn characterized by foliations well defined by the alignment of micaeous minerals. The coarse phanocrysts are of elliptical shaped giving augen-like structure. Note the melanocratic mafic segregate in GGn parallel to the foliations, in the left side of the picture and (b) GGn is characterized by abundant feldspar phenocrysts of varying shape and sizes.
Figure 3.10 (a) Porphyritic GGn with tourmaline clusters, where tourmaline crystal are characterized by dark colour and nodular form, and (b) highly deformed GGn showing structural fabrics (S-C fabric) pertaining to ductile deformation.
Figure 3.11(a) Streaky gneiss, a variety of GGn characterized by banded nature, where quartzofeldspathic material has flowed giving rise to mylonitic structure, (b) intense grain size reduction in GGn due to pulverization and strain softening in ductile environment resulting in typical mylonite.
Figure 3.12 (a) Undigested metasedimentary or pelitic xenolith hosted in GGN near Tenga, which is showing sharp contact with its host and aligned parallel to major foliation, (b) sharp contact between metasedimentary and GGN where quartzofeldspathic vein (1.5cm) is remarking the contact near Nine Mile locality (see text for description).
Figure 3.13 (a) Cold intrusive showing sharp contact between GGn and mylonitized metasediments of Chiliphum Formation of Bomdila Group near Tenga, (b) intrusion of feldspar phenocryst bearing GGn melt into the metasediments of Bomdila Group along major foliation planes or bedding (?) frized insitu and showing gradational intrusive contact.
Figure 3.14 (a) Leucocratic GGu present at the northeastern part of Bomdila near Kiriphum village, characterized by multi stage of deformation evident by its intense foliated and crenulated nature, it is in association with (b) leucocratic GGu representing the evolved fraction of GGu with less degree of deformation, which is foliated, where foliation is defined by the alignment of mica.
Figure 3.15 (a) Leucocratic variant of GGn present on Dirang-Sessa section, less deformed to undeformed and medium grained in nature representing the evolved fraction of GGn melt, (b) sharp contact of leucocratic GGn with quart-arenite of Bomdila Group south of the Zero point on Sessa-Dirang road. The country rock is highly silicified, hard and compact (base of the photograph is equal to 15 m).
Figure 3.16 (a & b) Quartzofeldspathic pegmatites of varying shape, sizes and thickness intruding the metasediments of Bomdila Group very close to the intrusive contact between metasediments and GGn. These pegmatites are tourmaline bearing and are representing the late magmatic activity of GGn. Base of the photograph is 12 m in (a) and 9 m in (b).
Figure 3.17 (a) Quartzo-feldspathic veins and pegmatite representing the late magmatic event of GGn found intruding the GGn itself, and (b) a thick quartzofeldspathic pegmatite intruding GGn near Tenga (on Bomdila-Dirang road) hosting abundant of tourmaline nodules varying in size from 2 mm to 5 mm.
At most places, the contact between GGn and metasediments are characterized by presence of intrusive pegmatites of various sizes (Fig. 3.16a, b). Sometimes these pegmatites intrude the adjacent metasediments while several others (1-2 m thick) are found intruding the GGn (Figs. 3.17a, b). The intruding pegmatites are highly quartzofeldspathic in nature with fragment patches of coarse tourmaline nodules (Fig. 3.17b). The arenaceous sediments of Bomdila Group on Rupa-Bomdila road are showing features related to intrusion of GGn. Here the sediments are baked, highly silicified and have abundant dark patches of radiating tourmaline nodules akin to hornfels-like texture (Fig. 3.18). The abundance of these patches in metasediment is continuously decreasing as moving away from the contact aureole of GGn. GGn has been considered as potential provenance to Mesoproterozoic basins, now forming the metasediments of Dirang, Rupa and equivalent Formations.

### 3.7.3 Salari Group

Salari Group is comprised of low-grade metasediments and intrusive granite, where metasediments (black shales and quartz arenites) are well exposed in between But and Salari villages and composed of thinly bedded black shale, phyllite and grey
arkose, which are intruded by a stock-like hbl-bt (±cpx) granite (HBG) body of Mesoproterozoic age (1536 ± 60 Ma, Dikshitulu et al., 1995; 1749 ± 22 Ma, present work). Salari and But villages are situated in very dense forest covers with rugged topography and high relief features. The field mapping of the intrusive relation of HBG with country-rocks was quite difficult. Therefore field relation and aerial expansion of HBG have been established and demarcated with the help of Google image and field data. It has been observed that HBG is exposed as a very small intrusive body between the metasediments of Bomdila Group, and combining the field observation and reproduced images as figure 3.19 it can be inferred that only the apical part of the HBG is exposed.

Figure 3.19 Google image of the Salari village used to demarcate the field boundaries of intrusive HBG with metasediments. HBG is exposed only as a thin lense or small intrusive body between the metasediments of Bomdila Group. Limit of GGn body is also shown.

HBG has a sharp intrusive contact with the country-rocks (Fig. 3.20a) clearly depicted from the presence of abundant country-rock xenoliths of shale and phyllite within it, best exposed along a road cut near Salari village (Figs. 3.20b, c). Some rounded to elliptical microgranular (magmatic) enclaves (~10 cm size across) are also found hosted in HBG. These enclaves are melanocratic and magmatic in nature and bear medium to fine grained rounded to subrounded felsic phenocrysts (Figs. 3.21a, b). HBG is undeformed to weakly-foliated, medium to coarse grained, leucocratic to mesocratic and equigranular in texture (Fig. 3.21c). However, relatively more leucocratic and fine-grained nature of HBG can be observed near its contact with country-rocks of Salari Group (Fig. 3.20a).
Figure 3.20 Intrusive nature of HBG shown by (a) sharp intrusive contact between HBG and overlying metasediments where HBG exhibits relatively leucocratic nature near intrusive contact, base of the photograph is equal to 25m, (b and c) abundant and irregular shaped country rock (shale) xenoliths of various sizes are engulfed in HBG demonstrating the intrusive shallow-level nature of HBG. Note the leucocratic nature of HBG near intrusive contact in (a) and (c).
Figure 3.21 (a and b) Rounded to elliptical mafic magmatic microgranular enclaves containing felsic phenocrysts hosted in HBG, (c) Hard and compact nature of massive mesocratic non foliated and fresh nature of HBG.

3.8 Sample and Locations

Detailed fieldwork in the west Kameng and Tawang district of western Arunachal Himalaya has been carried out where the felsic magmatic lithounits have been mapped all along the various planned and possible traverses and the field data such as shape, size, mineralogy, texture, type of enclave and contact relationship have been documented. The locations of samples have been marked on the Google image of the mapped study area as shown in figure 3.22. An intensive magnetic susceptibility mapping has been conducted on smooth and fresh granitoid surfaces. Magnetic
susceptibility values ($\times 10^{-3}$ SI unit) of granitoids are shown on geological map all along the undertaken traverses (Fig. 3.23). Based on close textural, mineralogical, lithological and magnetic susceptibility variations more than 150 fresh and representative rock samples were collected for further investigations. The GPS locations with sample descriptions have been summarized in the appendix-1.

![Figure 3.22 Google image of the Kameng corridor of western Arunachal Himalya with the GPS locations from where samples and geological field data have been collected. The yellow line is the international boundary between India and Bhutan.](image)

3.9 Magnetic Susceptibility (MS) and Granite Series

MS measurements have been performed along various traverses (Sessa-Bomdila-Senge-Sela-Tawang and Bomdila-Salari-Nafra) on HBGGn, TGN, TLG, GGn and HBG felsic magmatic lithounits of western Arunachal Himalaya. The average MS values ($\times 10^{-3}$ SI) of various lithotypes are given in table 3.1, as well as over the geological map (Fig. 3.23). Range of MS values for each felsic magmatic lithotype from different localities and traverses is shown on figures 3.24a, b.
Figure 3.23 The geological map of the study area showing the average magnetic susceptibility of the granitoids at various studied locations.

Most of average MS values for GGn, TGN, TLG, and HBG vary between 0.05 and 0.50×10^{-3} SI. MS value of 3×10^{-3} SI has been used to discriminate between magnetite (>3×10^{-3} SI) and ilmenite (≤3×10^{-3} SI) series granitoids of Japan (Ishihara, 1977, 1990). In the present investigation only a few MS values of studied felsic lithounits have exceeded 0.50×10^{-3} SI (Fig. 3.24a, b), and hence a MS-value of 0.50×10^{-3} SI has been chosen as division between magnetite (>0.50×10^{-3} SI) and ilmenite (≤0.50×10^{-3} SI) series respectively corresponding to oxidized type and reduced type granite series, as similarly employed elsewhere (e.g. Hart et al., 2004). The average MS-values less than 0.50×10^{-3} SI can be further grouped into moderately to strongly reduced, ilmenite series granites.
### Table 3.1: Magnetic susceptibility (MS) values (in × 10⁻³ SI unit) of felsic lithounits of western Arunachal Himalaya measured in various localities.

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Lithounits</th>
<th>Locality/Transect</th>
<th>Average Magnetic Susceptibility (MS) values (×10⁻³ SI unit)</th>
<th>Inferred granite series</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hbl-Bt granite gneiss (HBGGn)</td>
<td>Sapper</td>
<td>4.75(5), 2.82 (23), 15.423(10), 27.27(7)</td>
<td>Magnetite-series</td>
</tr>
<tr>
<td>2</td>
<td>Bt-Ms granite (TLG)</td>
<td>Sapper</td>
<td>0.224(15), 1.700(9),</td>
<td>Ilmenite to Magnetite series</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nyukmadong</td>
<td>0.042(11), 0.114(6),</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Senge</td>
<td>0.065(35), 1.272(6), 0.109(12), 0.105(8), 0.115(6), 0.089 (9)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Tawang gneiss (TGN)</td>
<td>Tawang</td>
<td>0.263(4), 0.289(7), 0.162(5), 0.325(11), 0.235(3), 13.136(8), 0.326(6), 10.260 (9), 3.680(5), 0.225(6)</td>
<td>Magnetite to Ilmenite-series</td>
</tr>
<tr>
<td>4</td>
<td>Ms-Bt granite gneiss (GGn)</td>
<td>Sessa-Jamiri</td>
<td>0.670(4), 0.690(6), 0.198(5), 0.098(6), 0.125(12), 0.234(8), 0.126(5), 0.105(8), 0.112(3), 0.123(7), 0.127(5), 0.112(8)</td>
<td>Ilmenite-series</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jamiri-Tenga</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tenga-Rupa</td>
<td>0.171(20), 0.119(24), 0.188(23), 0.158(27), 0.162(22), 0.181(9), 0.065(8), 0.136(27), 0.149(15)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rupa-Bomdila-NineMile</td>
<td>0.160(18), 0.168(9), 0.139(13), 0.103(9), 0.111(12), 0.104(12), 0.106(15), 0.200(24), 0.086(26), 0.243(11), 0.109(11), 0.136(27), 0.180(41), 0.151(4), 0.128(17)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>NineMile-Munna</td>
<td>0.160(23), 0.119(11), 0.088(12), 0.123(15), 0.131(19), 0.076(6), 0.160(23)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Salari-Nafra</td>
<td>0.068(3), 0.680(3), 0.085(4), 0.100(6),</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Hb-Bt granite (HBG)</td>
<td>Salari-But</td>
<td>0.076(8), 0.146(30), 0.156(16), 0.247(5), 0.386(6), 0.124(8), 0.076(6), 0.100(13), 0.199(5), 0.199(8)</td>
<td>Ilmenite-series</td>
</tr>
</tbody>
</table>

Numbers given in parantheses represent number of MS-measurements. MS-value 0.5×10⁻³ SI has been considered as division between ilmenite (reduced-type) and magnetite (oxidized-type) series.

HBGGn is a magnetite-bearing, peraluminous (S-type) granite, but records very high MS values ranging between 2.82 and 27.3×10⁻³ SI, which relate to moderately and strongly oxidized, magnetite series (>0.50×10⁻³ SI) granites. TGN is magnetite-free peraluminous (S-type) granite, and measures MS values between 0.162 and 13.14×10⁻³ SI. About 43% of MS values of TGN correspond to magnetite series and 57% to ilmenite series granites. Ilmenite series granite commonly predominates over magnetite series granite in syn-tectonic environment (Ishihara et al., 2002). TLG is magnetite-free, highly peraluminous (S-type) but exhibits two distinct MS distribution patterns, one associated with high MS values (>0.5×10⁻³ SI) tourmaline-rich, moderately oxidized, magnetite series TLG and another with low MS values (≤0.5×10⁻³ SI) relating to tourmaline-poor, highly reduced, ilmenite series TLG. GGn is magnetite-
free, peralumious (S-type) granite. MS of GGn has been measured on forty fresh outcrops along various transects because of its large aerial exposure. GGn shows MS variations ranging from $0.065$ to $0.690 \times 10^{-3}$ SI, with a maximum frequency distribution in the MS class $0.10$-$0.30 \times 10^{-3}$ SI, which represent moderately to strongly reduced, ilmenite series granites. GGn has recorded relatively lower MS values near the contact of GGn with phyllite and quartzite, which led to strongly reducing nature of GGn close to the tectonic and intrusive contacts.

![Graph showing magnetic susceptibility variations of felsic magmatic lithounits of western Arunachal Himalaya along (a) Sessa-Bomdila-Tawang, and (b) Ninemile-Salari-Nafr transects. Symbols are (○) GGn, (∆) HBG, (+) TLG, (□) HBGGn, and (♦) TGN).](image)

Figure 3.24 Magnetic susceptibility variations of felsic magmatic lithounits of western Arunachal Himalaya along (a) Sessa-Bomdila-Tawang, and (b) Ninemile-Salari-Nafr transects. Symbols are (○) GGn, (∆) HBG, (+) TLG, (□) HBGGn, and (♦) TGN).