# PETROGRAPHIC AND GEOCHEMICAL STUDY OF GRANITOID OF SINDHUDURG, MAHARASHTRA

A Dissertation Report for
GEO-651: Dissertation
Credits:16
Submitted in partial fulfilment of
Masters in Science
In
Applied Geology
By

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**GOA UNIVERSITY**
**May 2024**

SEOAS, GOA UNIVERSITY
TALEIGAO PLATEAU GOA

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## DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "**PETROGRAPHIC AND GEOCHEMICAL STUDY OF GRANITOID OF SINDHUDURG, MAHARASHTRA**" is based on the results of investigations carried out by me in the at the Masters of Science in the Discipline MSc. Applied Geology at the School of Earth Ocean and Atmospheric Sciences, Goa University.
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# COMPLETION CERTIFICATE

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**LIST OF ABBREVATION**

%- Percentage

MALI - Modified alkali Lime index

AI -Alkali index

A- Aluminium molar value

N- Sodium molar value

C- calcium molar value

Fe- Iron

K- Potassium

mm- millimetre

cm- centimetre

Q- Quartz

P-Plagioclase

F-ferroan

M- magnesian

Y-Yttrium

Nb-Niobium

Rb-Rubidium

Sr-Stronium

Ta-Tantalum

# CHAPTER I : INTRODUCTION

Granitoid is a Plutonic felsic Igneous rock having a composition range from Quartz-Plagioclase-Alkali Feldspar ,which is formed in continental crust setting during orogeny process such as continental-arc subduction or Collision of sialic mass and Granitoid are also formed when the crust undergoes some thermal disturbance or Anatexis. They are large massive irregular bodies formed beneath the earth's crust which get exposed on earth's surface when the crust undergoes tectonic disturbances and Erosion and weathering processes of the crust. The size of such granitic bodies varies from a few metres to hundreds to thousand kilometres , also they occur in the form of dykes and sills. Granitoid rocks are medium to coarse grain size indicating slow cooling and Also there are volatile involved during its formation. Plagioclase ranges from $An_{10}$ to $An_{93}$ during the early dominant phase. Quartz and Alkali Feldspar are late and are more in Alkaline rock, there are some mafic minerals such as Biotite, Muscovite and Hornblende.

Granites exhibit textures that are entirely determined by size, shape, and reciprocal relationships.They are essentially medium to coarse, meaning that the minerals are visible to the unaided eye; this texture is known as phaneritic. The granites exhibit colour variety, ranging from pink to grey.The chemical makeup and cooling history of molten granites reveal a variety of textures. The rock has distinct crystal sizes that point to two phases of magma cooling: first, the huge crystal cooled slowly, and then the fine-grained crystals cooled quickly. Phenocryst is the term for the larger grain, while groundmass minerals is the term for the smaller grain. Because of their mutual association with crystals, these grains have a texture known as porphyritic texture.

## 1.1 CLASSIFICATION OF GRANITES

Both Peacock's (1931) alkali-lime index and Shand's (1951) subdivision into 'peraluminous', 'metaluminous' and 'peralkaline' are still used as indicators of the major element characteristics of granites and have led to the commonly-held (though somewhat simplistic) assumptions that 'calc-alkaline' granites are the products of volcanic arc magmatism, that 'alkaline' and 'peralkaline' magmas are associated with within plate settings and that 'peraluminous' granites result from the anatexis of sedimentary rocks, mainly during continent collision. Building on previous work by La Roche (1978), Debon & Le Fort (1982) produced a series of "characteristic minerals" diagrams that include the tectonic context information present in both the chemical and mineralogical categories. It has also been extended from its original genetic concept to a tectonic indicator, where S-type granites are assumed to be the result of continent collision and I-type granites to be the result of cordilleran and post-orogenic uplift regimes (e.g. Beckinsale, 1979; Pitcher, 1983). This division of granites into S-type and I-type is documented in Chappell & White, 1974; White & Chappell, 1977. A-type (Collins et al., 1982) and M-type (White, 1979) granites were classified to include the granites of anorogenic and oceanic arc settings, respectively, in accordance with this shift in emphasis.By extending the latter, one can also include the Coleman & Peterman (1975) oceanic plagiogranite group, which includes the sodic granites of ophiolite complexes thought to have originated at mid-ocean ridges.

**1,1.1 MINERALOGICAL CLASSIFICATION**

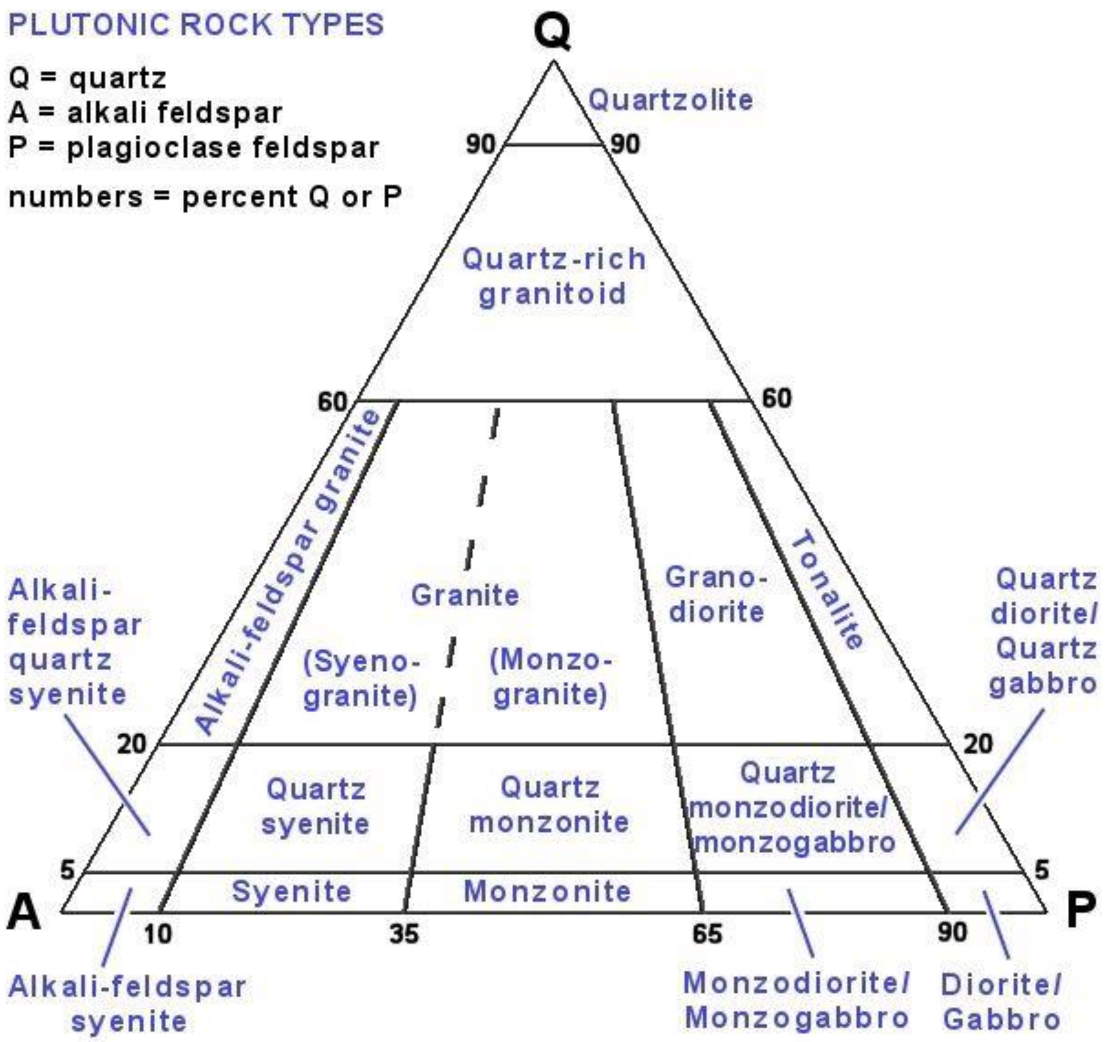



Figure 1.: IUGS CLASSFICATION

Granitoids are categorised according to their modal abundances of quartz, plagioclase, and alkali feldspar in the conventional IUGS petrographic scheme. Many different types of granitoid are accounted for by the IUGS classification, which is based on variations in the feldspar compositions and abundances. It is genuinely non-genetic, affordable, and easy to use. The IUGS classification has the benefit of being easily applied in the field for the majority of rocks. According to IUGS (Figure 1), the four granite domains that make up the mineralogical categorization of granites are tonalite, granodiorite, granite (monzogranite and syenogranite), and alkali feldspar granites.

### 1.1.2, S-I-A-M CLASSIFICATION

#### I-type

It was initially suggested by Chappell and White (1974) that igneous protoliths are the source of I-type granites. Elevated levels of $Na_2O$ and moderate levels of $Al_2O_3$ are present. Silica is saturated in I-type granites, although aluminium is undersaturated. The chemical makeup of the original magma is reflected in its petrographic characteristics. Plagioclase, potassium feldspar, and quartz are the main major minerals found in I-type granites. Zone formation and albite twinning are observed in Plagioclase. Tartan twinning in microcline, Carlsbad twinning, and perthite textures are all possible in potassium feldspar. There is very little granophyric texture in potassium feldspar and quartz. Comparatively speaking, S-type granite colour index equivalents have more quartz than I-type granites do.

In granites classified as I-type, biotite is the most prevalent minor mineral. S-type granite never contains the common I-type granite mineral hornblende. Accessory minerals in I-type granites are zircon, apatite, titanite (sphene), and allanite. Zircon and apatite can occur in both I- and S-type granites, whereas titanite (sphene) and allanite are considered diagnostic accessory minerals for I-type granites.

Compared to S-type granites, I-type granites are higher in silica, calcium, and sodium but lower in potassium and aluminium. Metaluminous to slightly peraluminous is the usual state of I-type granites. Rubidium/strontium (Rb/Sr) ratios are lower in I-type granites than in S-type granites. I- and S-type granites can be distinguished from one another using the initial strontium isotopic ratios ($^{87}Sr/^{86}Sr$)i, where I-type granites have lower starting strontium isotopic ratios than S-type granites.

**S-type granites**

Granites of the S-type group were first suggested in 2001. S-type granitoids, which are formed from sedimentary protoliths and have comparatively low $Na_2O$ content and high $Al_2O_3$ content.A particular set of mineralogical, geochemical, textural, and isotopic traits identify them. S-type granites have an ASI index more than 1.1, indicating an oversaturation of aluminium.Quartz, plagioclase feldspar, and alkali-feldspar are the main major minerals found in S-type granites. As a result, S-type granites lack feldspathoids and are over-saturated in silica (containing quartz). Cordierite, muscovite, garnet, and sillimanite are examples of minor minerals. In line with the higher ASI index of S-type granites, the biotite compositions of these granites are more aluminous than those of I-type granites. Zircon, apatite, tourmaline, monazite, and xenotime are examples of accessory minerals that are frequently found in S-type granites. As an accessory mineral, monazite is thought to be diagnostic for S-type granites, while allanite is diagnostic for I-type granites. Ilmenite is more likely than magnetite to be the oxide mineral found in S-type granites. Lower sodium and calcium levels and higher silica and aluminium levels are two of the main elemental properties of S-type granites. Magnesium predominates over iron in S-type granites. S-type granites are invariably peraluminous, or have a ratio of more than one between the total amount of alkali (including calcium) and aluminium. S-type granites have low strontium content and high potassium, rubidium, and lead concentrations.

**M-type granite**

White coined the name "M-type granite" in 1979. It was then proposed to refer to granites that were unmistakably generated from crystallised mafic magmas, which are often derived from the mantle, as M-type or mantle-derived granite. These are uncommon because fractional crystallisation presents a challenge in converting basalt to granite.

**A-type granites**

In 1979, Loiselle and Wones coined the term "A-type granite." Because these granites lack orogenic or transitional tectonic fabric and have a low water content, the "A" stands for Anorogenic or Anhydrous. The A-type granites are primarily formed at regional post-orogeny uplift or collapse, or within continental intraplate rifting or uplifting. They could form either after orogeny is over, or they could form in anorogenic conditions, which are very different from orogeny.Granites of the A-type often have a peralkaline composition. These rocks are frequently found to include minerals such as the sodic pyroxene, aegerine, and the sodic amphiboles, riebeckite and arfvedsonite. Elevated silica, alkalis, zirconium, niobium, gallium, yttrium, and cerium are among the chemical properties of A-type granites. Furthermore, they are frequently rather Fe-rich, which might lead to the occurrence of fayalitic olivine.The source for A-type granites could be dry granulite left over from the loss of wet magma during orogenies.

### 1.1.3 Geochemical classification based on

1. **Alumina saturation index (ASI) :**

Shand established the alumina saturation index (ASI) in 1943. Based on the molar ratios of Al2O3/($CaO$+$Na_2O$+$K_2O$) ("A/CNK"), alumina saturation classes are determined. Based on their chemical makeup, granites can be classified as peralkaline, metaluminous, or peraluminous using the ratio $Al_2O_3$/($Na_2O$ + $K_2O$ + $CaO$).

## 2. Fe-number

Fe-number The ratio of iron (Fe) to magnesium (Mg) in a rock is indicated by this index. $FeO/(FeO + MgO)$ is the ratio of iron (Fe) to magnesium (Mg) in a rock.There are two types of granites: ferroan ($FeO/(FeO + MgO) > 0.5$) and magnesian ($FeO/(FeO + MgO) < 0.5$). Grouping: Magnesian Granite: $FeO/(FeO + MgO) < 0.5$ .This suggests that magnesium is more abundant than iron.$FeO/(FeO + MgO) > 0.5$ in ferrean granite denotes a higher iron content than magnesium.

Beginning and Petrogenesis: aids in comprehending the origin and creation process of the granite magma..

The sorts of minerals that are present in granite are influenced by the mineral composition. Mineral Assemblage of granite is Influences by the types of minerals present in the granite. Magnesian granites may contain more ferromagnesian minerals like biotite and hornblende, while ferroan granites may have higher concentrations of iron-bearing oxides like magnetite.

1. **Peraluminous:** If $Al_2O_3 > (Na_2O + K_2O + CaO)$ or $Al_2O_3/(Na_2O + K_2O + CaO) > 1.1$, rock will probably have muscovite and may have garnet; it will be corundum normative.
2. **Metaluminous:** If $Al_2O_3 < (Na2O + K_2O + CaO)$ but $Al2O_3 > (Na_2O + K_2O)$ or $Al_2O_3/(Na_2O + K_2O + CaO) > 1.0$; rock may have hornblende.
3. **Peralkaline:** If $Al_2O_3 < (Na_2O + K_2O)$ or $Al_2O_3/(Na_2O + K_2O + CaO) << 1.0$; rock will probably have a lot of K-feldspar in the norm, probably a feldspathoid or very little, if any quartz.

## 3. Modified alkali-lime index (MALI)

The Alkali-Lime classification of Peacock et al. (1931) forms the basis of our scheme's secondary level. The alkali lime index, or the SiO level at which Na + K + O in a suite of lavas equaled CaO, was used by Peacock to divide volcanic suites into four sections. The alkali-lime index ranges from 56 to 61, which corresponds to calc-alkalic suites; 51 to 56 indicates alkali-calcic suites; and 61 to 61 indicates alkalic suites. Despite being frequently used, this approach is difficult to apply, with the exception of silica values close to the junction. We expand to a larger range of silica concentrations and, by adding the variable $Na_2O$ + $K_2O$-CaO, we decrease the three variables required for the classification ($SiO_3$, CaO, and $Na_2O$ + $K_2O$) to two. This variable is known as the modified alkali-lime index, or MALI. The modified alkali-lime index for a certain suite rises as the weight percentage of $SiO_2$ increases; in the case when MALI = 0-0, the silica content is equal to Peacock's alkali-lime index (1931).

## 4. Trace element discrimination diagram

In order to describe the tectonic setting of granitic rocks, Pearce et al. (1984) developed a geochemical approach. Within-plate granites, ocean ridge granites, volcanic arc granites, and collisional granites are the four main tectonic settings that may be distinguished geochemically using more than 600 analyses. Nb vs. Y, Ta vs. Y, Rb vs. (Y + Nb), and Rb vs. (Y + Ta) were the top discriminators. The tectonic setting of granitic rocks, the tectonic setting of which has not been preserved, can be ascertained by the use of this widely used technique.

The tectonic environment plays a secondary role in the trace element compositions of granitoids, which are determined by the melt's crystallisation history and sources. For instance, the origin of post-collisional granitoids varies according to the nature of the crust that thickened during orogenesis. Additionally, according to Liégeois et al. (1998), these granitoids are closely linked to mafic magmas, which have the potential to mix or mingle with the melt component that is obtained from the crust. Consequently, this tectonic group plots over the range of fields indicated by Pearce et al. (1984), indicating that the group's chemical composition is impacted by a variety of source components.

## 1.2 REGIONAL GEOLOGY

Dharwar craton, a Precambrian greenstone-granite terrain, is the rigorously studied area of the Indian Shield. This shield is mostly made up of gneisses, granites, dyke swarms, and Archaean greenstone belts. Over this shield are undulating Proterozoic basins such as the Kaladgi and Bhima basins (Pichamuthu and Srinivasan, 1983; 1984; Radhakrishna and Naqvi, 1986). A variety of volcano-sedimentary sequences developed at various times between 3.5(?) and 2.6 Ga make up the greenstone belts (6SB).

Referred to the Peninsular Gneisses (PG), these gneisses encircle and devour the greenstone belts. Regardless of genesis, metamorphic processes, or chronology, gneissic-structured quartzo-feldspathic rocks are included in the name "PG." The Dharwar schists described by Bruce Foote are also referred to as the "greenstone belt" in this context (1888). However, other researchers have pointed out that the name "greenstone belt" is insufficient to describe the supracrustal rocks of the Indian Archaean, which are basically schistose and metamorphic in nature.

It was suggested (Chadwick et al., 1981) to refer to the Archaean volcano-sedimentary sequence of India as supracrustals or supracrustal associations, but the older name "schist belts" seems more fitting since it highlights the schistose nature of the succession (Radhakrishna and Naqvi, 1986). The high-grade granulite terrain in the southern portion of the Dharwar Craton is connected to the terrain dominated by schist belts via a transition zone (Allen et al., 1983). Proterozoic sedimentary basins include the Kaladgi and Bhima basins as important components (Radhakrishna, et al. 1987). Swami Nath and Ramakrishnan et.al (1981) observed variations in the degree of regional metamorphism (inside the craton), specifically the low-pressure type in the eastern area and intermediate pressure type in the western block of the Dharwar Craton.

The investigation finds a strong lineament with significant fracturing, brecciation, and silicification in the Metaconglomerate-Quartzite Member that trends NNW-SSE from Malvan to Nivti in the north. It also observes another significant lineament extending NNW-SSE from Maldi Ln to Kalsa in the south. There is shearing in the Kaladgi sandstone near Maldi and Vadachapat, and there is a vertical displacement in the laterite cap near Chaphekhol. South of Achra, there is evidence of lateritization and heavy soil in a north-south trending lineament with an easterly convexity. Shearing and silicification in foundation rocks and river terraces characterise an east-west oriented, dark-toned linear structure that stretches from Ghumbra to Chaphekhol. A NW-SW lineament controlling box meander of the Karli River is exposed, with a gabbro body exposed south of this lineament. Geophysical observations reveal more direct evidence of tectonic activity related to West Coast faulting in the area.

Situated east of Closepet Granite, the Dharwar Batholith is a sequence of parallel plutonic bands. The Age: Gneisses with granitic to granodioritic composition, 2750–2710 years old. It differs from the Peninsular Gneisses in that it is older (the granitic gneisses of the Dharwar Batholith are Late Archaean, whereas the Peninsular Gneisses are Early Archaean). The belts are wedge-shaped, primarily composed of mixtures of granites and diorites, with steep granitic dyke intrusions. The Bangalore Granite and the granite of the Hosekote region in the Kolar Schist Belt are examples of the plutonic bodies of the Dharwar Batholith.The characteristics of the late Archaean magmatic and tectonic events in the Dharwar craton have been proposed to be best described by a compressive rising mantle plume beneath an advanced Archaean crust. The heat from the plume can promote metamorphism, inverse diapirism, and soften the crust. The massive amounts of juvenile magmas that deposited in the craton approximately 2500 Ma are thought to have been produced by melting of the plume.

## 1.3 STUDY AREA

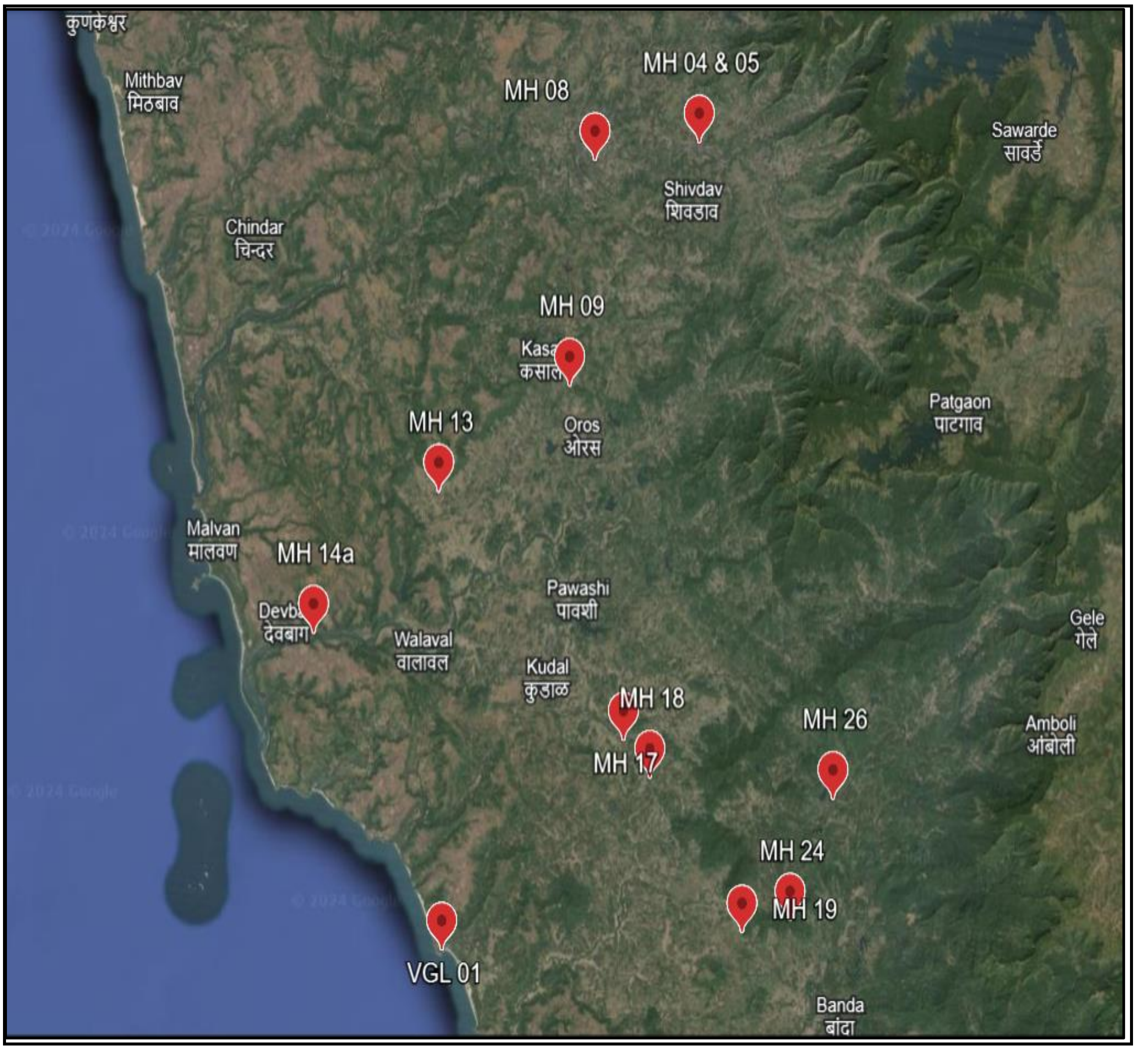



Figure 1.1 : study area map plotted using Google earth

## 1.3.1 FIELD OBSERVATION

Spot 1 was along the highway were the rock was in form of Batholith which was showing vertical alignment of biotite and the rock overall was appearing whitesh which can be due to high amount of felsic minerals.

Figure 1.2: the rock was showing alignment of the dark colour minerals

Spot 2 was also a batholith which was moderately appear pinkish, can be due to presence of K-rich minerals. The rock was highly weathered also there was explosive used to blast the terrain in that area.

Figure 1.3: the rock was blasted at spot 2

Spot 3 was a batholith which was cut for transportation which was covered with vegetation. The rock was showing faulting which was identified based on the displacement on both side of cross cutting. Also there there  slicken slide that indicates is a smoothly polished surface caused by frictional movement between rocks along a fault.

Figure 1.4: Spot 3 Slicken slide identified on the broken sample

At Spot 4, rock was exposed on the bank of a dry stream which was showing Porphyritic texture in hand. The phenocryst was made up of pinkish can be K-rich feldspar with mafic groundmass. The rock was the based on the sream which was effected by weather due to water during rains and heat of sunlight.

Figure 1.5: spot 4 granitoid exposed at a dry stream

The rock at spot 5 was highly deformed and the rock was having lens or eye shaped felsic grains surrounded by fine grain. The texture was identified as Augen Gneiss.

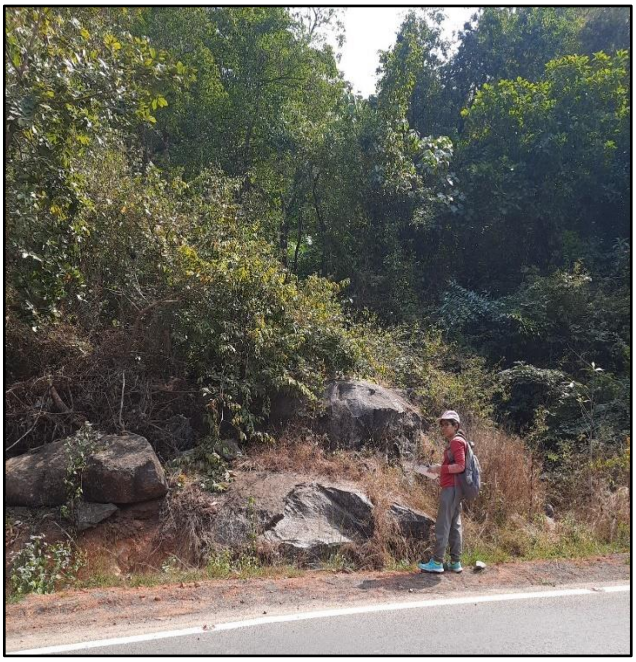


Figure 1.6: Augen Gneiss exposed as boulders

Spot 6 was a headland which was having parallel joint set. Also there were intruded in the country rock in that are (Hornblende schist). The rock was coarse to medium grain size. It appears as white rock indicate felsic mineral abundance.

Figure 1.7: (a) Joint set were noted in the granitoid terrain (b) intrusion of felsic magma into hornblende schist

Spot 7 was a hilly terrain where the rock was in also having some tors. The rock was a coarse-grained granitoid having grain size 2-3cm. the rock was appearing Grey. The rock was having vegetation along the area. Also, there were quartz veins intruded in granitoids.

Figure 1.8: The granitoid was covered with vegetation

On Spot 8 the granitoid was in form of intrusion and in form of veins the thickness varies from 0.5 cm to few meters. The rock is appearing grey. The rock was undergoing deformation.

Figure 1.9: spot 8 (a) rock exposed in form of intrusion (b) and in form of veins

Spot 9 was a batholith exposed along forest which was appearing Reddish could have high k-feldspar. There was medium to coarse grained. the granitoid exposed at this spot was young compared undeformed.

Figure 1.10: spot 9 batholith exposed in a forest area covered with vegetation

Spot 10 was bank of river gad which was highly deformed and weathered due to the action of water and sunlight. It appeared white in colour with purple grains embedded in it. The terrain was a large batholith body exposed due to weathering of overlying layer due action of water.

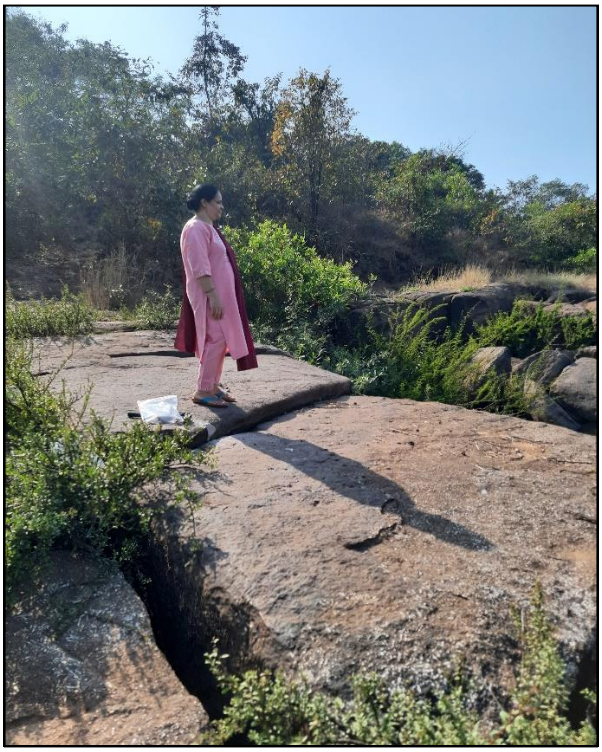


Figure 1.11: spot 10 weathered terrain along the river

Spot 11 the rock was undergoing deformation. The rock was showing contact between two types of chemically varying granite rock. The phenocryst of k-feldspar was 2-4cm in size. The rock was overall grey in colour.

Figure 1.12: contact between two different granite showing slight variation in composition (b)Porphyritic texture was visible clearly

**1.3.2 Inference Based on Field visit**

The study aimed to understand the petrography and geochemical study of granitoids of Sindhudurg. The petrography was carried out in parts of Sindhudurg where the rocks were showing variation from Pinkish to grey to white granite which was clearly observed in hand specimen, this was due to change in mineralogically and chemically. The hand samples was collected was showing variation in feldspar contain from Potassic to sodic composition and quartz contain were varying some 45-60%. The quartz contain is high in MH-19 (figure 4.7 & figure 4.16 a & b). MH 9 is a Potassic rock which can be noted based on both thin section and figure 4.12 (a & b) and hand specimen (figure 4.3).MH 14a is a Gneissic rock which have lens shaped clast (figure 4.4).Remaining all the rock that is MH 4, MH 17, MH 18 , MH 24 and MH 26 all are Grey granite (Figure 4.1;figure 4.5, figure 4.6: figure 4.8 and figure 4.9 respectively.)

## 1.4. OBJECTIVE

1. To study and understand the granitoid geochemistry
2. To comprehend the origins of the granitiod and their magma sources

# CHAPTER II : LITERATURE REVIEW

Geologists have been fascinated with granite, a feature of the continental crust, for many years because it provides information about tectonic, magmatic, and geochemical processes on Earth. In order to clarify granite's diversity, origin, and classification, this review synthesises both classic and modern studies, focusing on both Indian and worldwide viewpoints.

Granite is the most common intrusive igneous rock in the Earth's continental crust. It is characterized by a coarse-grained texture and a mineral composition dominated by feldspar and quartz. The formation of granite requires specific geological conditions, including high temperatures (at least 600°C), high pressures (5-10 km depth), slow cooling, water content, and a felsic (silica-rich) composition. they typically forms through the melting of pre-existing rocks, such as sedimentary or metamorphic rocks, deep within the Earth's crust. This molten material, called magma, rises towards the surface and slowly cools and crystallizes, forming the large mineral crystals that give granite its distinctive appearance.Granite deposits are widely distributed around the world, often associated with areas of high tectonic activity like mountain ranges and volcanic regions. The geochemistry of granite can provide insights into the tectonic settings and processes involved in its formation. For example, the $SiO_2$ vs. $Na_2O+K_2O$ plot can be used to classify different types of granites, such as Na-granitoids and K-granitoids, based on their alkali content and other geochemical characteristics. Overall, the formation and distribution of granite is closely linked to the complex geological processes that shape the Earth's continental crust over long timescales.

## 2.1 Occurrences of granitoids worldwide

Granite is a common batholith terrain exposed worldwide. Numerous granite blocks have been documented from various locations, including the Abuja Batholith in

Northern Nigeria (Goodenough et al. 2014), Solli Hill in North Central Nigeria (Ferré et al. 1998), and the Obudu Hills in Southeast Nigeria (Ekwueme & Kröner 2006). The most obvious indication of late Precambrian tectono-magmatic activity, which added considerable materials to the crust, is found in older granites. Numerous research (Lehmann, 1982, 1987; Štemprok, 1990; Taylor & Wall, 1992, 1993; Linnen et al., 1995, 1996; Audétat et al., 1998, 2000; Chen et al., 2000) have been conducted on the behaviour and metallogeny of tin in granitoid magmas and magmatic hydrothermal fluids.In southern China, the Qitianling granitic stock is situated in the centre of the Nanling granitic magma intrusive belt. With a tin content of 26–45 ppm, it is a member of the stanniferous granite family (Zheng & Jia, 2001; Wang et al., 2003).

A-Type granites can form in a variety of geodynamic conditions, such as marine and continental habitats, as well as other terrestrial planetary bodies. They are not directly linked to orogenic events. They define Earth's "Within Plate" terranes of stable crustal blocks, not with standing their geological range (Bonin, 2007; Bonin et al., 2002). The search for a comprehensive petrogenetic model is made more difficult by their diverse mineralogical and geochemical properties, as well as their dynamic tectonic settings. There are five stages of magma generation from an enriched source—a hotspot, mantle plume, or partial melting of an enriched lithology—melt occurring at high temperature granulite facies, beneath an Archean craton, facilitating the liberation of HFS, incompatible, and volatile elements from metal- and volatile-bearing phases; a high degree of fractionation, which may vary depending on the initial HFS element composition, the scale of the fractionating magma, and the F ± B composition of the evolving granite; the exsolution and accumulation of a magmatically derived F- and Cl-rich hydrothermal fluid in the granite cupola; and a mineralizing precipitation event, either because of a change in the composition of the granite.

Based on the tectonic discrimination diagrams of Pearce et al. (1984), the Lachlan S and I-type granites can be classified as post-COLG or VAG, and the A-type granites as WPG. This trio is a part of a process of tectonic switching that involves repeated subduction advance and retreat within a single geodynamic setting (Collins 2002a). It suggests that while the three varieties of granite are created from the same source materials, they are produced in systematically varying amounts due to continuing lithospheric extension. S-type granites originated when the arc moved beneath a metasedimentary crust that had thickened, while I-type granites formed as the arc went outboard, resulting in their location as proximal back-arc or inter-arc rift.

## 2.2 Occurrences of granitoids in India

Grainoids that make up the northern block of the Western Dharwar Craton (WDC) have been field-examined, mapped, and interpreted using petrological, geochemical, and Sm-Nd isotopic data. The region is contained within a 225 km long and 40 km wide transect corridor that runs from East of Gadag to the coast of Goa. Five massive plutons with batholithic size and two stock-like masses make up the rocks, which make up 43% of the corridor lithology. These fall into one of the following categories: Anmod Ghat trondhjemite (AGT), Chandranath granite (CNG), Dudhsagar granite (DSG), Ramnagar migmatite (RNM), Ramnagar granite gneiss (RNGn), Ramanagar porphyritic granite (RNPG), Annigeri-Majjigudda granite (AMG), and Hatalgeri-Naregal migmatite (HNM).

The best Anmod Ghat Trondhjemite outcrops can be found in the NH4A road cuttings, which start at the border between Karnataka and Goa and go for about 12 km in the direction of Molem. The rock has a consistent ash grey hue and mild to moderate foliation, but no obvious banding. Shear planes overlap with the foliation. The rock is peraluminous nature, magnesian-rich and characterized by low alumina, high Na2O/K2O (1.45 to 11.01), Sr and Sr/Ba (1.48), low Rb/Sr (0.18), Zr and REE. The tonalite-trondhjemite character of the rock is reflected in the ternary discrimination plots of CaONa2O-K2O and Ab-An-Or (Fig.9A) and binary plot of Na2O vs K2O. Moderate LREE enrichment and the absence or presence of very weak Eu anomalies characterize the chondrite normalized REE pattern of the rock.

Chandranath Granite encloses about half of this 270 km2 ellipsoidal granite body. The analysed samples show limited variation being mostly in the range of granodiorite. It is relatively aluminous, significantly low in Na2O/K2O, Sr/Ba and high in Rb, Ba, Zr, Th, Rb/Sr and REE. Distinct LREE enrichment and HREE depletion and very weak negative Eu anomaly characterize the chondrite normalized REE patterns of the rock.

Annigeri-Majjigudda Granite (AMG) is a sporadically exposed granitoid occupying about 980 km2 area, separating the Dharwar and Gadag Supracrustal belts.It is buff white to ash grey coloured, medium to coarse grained rock, containing sporadically distributed megacrysts of K-feldpsar..

Hatalgeri-Naregal Migmatite (HNM) occupies an area of about 460 km2 of the transect corridor, lying to the east of the Gadag belt. Representative exposures of this granitoid are found in the quarries SE of Gadag, between Hatalgeri and Sambapura and N and SW of Naregal. It is typically a polyphase migmatiteshowing rude to moderate banding. It consists of at least three different phases. The oldest are the mafic palaeosomes which also include rare enclaves of olivine-bearing ultramafite with mantle signatures and garnet-clinopyroxene bearing metasedimentary enclave with deep crustal signatures. The dominant felsic palaeosome of the rock is the light to medium grey coloured tonalite/trondhjemite-monzogranite. The predominant younger felsic phase of the rock is a coarse-grained granodiorite-granite. There is considerable interaction between the mafic palaeosome and the felsic phases of the rock to produce a range of hybrid compositions.

Dudhsagar Granite is a coarse grained, ash grey coloured rock showing weak to moderate foliation related to shearing and preferred orientation of feldspar megacrysts parallel to foliation. It is an inequigranular rock with grains measuring 1 to 13 mm across dominating over smaller grains. Feldspars tend to be subhedral and lath-shaped. Myrmekite is noted.A plot of modal data for QAP indicates that it lies in the range of monzogranite-granodiorite.a low alumina and high-K granite with Na2O: K2O = 0.85 to 1.23 . It ranges from granodiorite to adamellite in terms of K2O vs Na2O plots, granodiorite to quartz-monzonite in the ternary Cao-Na2O-K2O discrimination plot and granite to adamellite in normative An-Ab-Or ternary plot. Low Sr, Zr, Sr/Ba and high Rb/Sr and Fe/(Fe+Mg) are among the distinguishing chemical characteristics. Low SREE content and weak to strong negative Eu anomaly (the latter in respect of the sample containing 27% plagioclase, 13% K-feldspar) distinguish the chondrite normalized REE patterns of the rock.

Ramnagar Granitoids (RNG) covers an area of about 60 km2 in the center of RNG. It is a typical polyphase gneiss consisting of at least four different phases, which may be broadly separated as mafic dioritic palaeosomes, felsic tonalitic palaeosomes, felsic neosomes (granodiorite-granite) and pegmatite-aplite

A wide variety of rock types and mineral compositions define the geologically significant Dharwar area of Sindhudurg district in Maharashtra. This region's common granitoids are important to understanding the region's geological past. Granitoids are rich in quartz and feldspar and are intrusive igneous rocks. Their mineral composition varies based on the conditions of their particular development. Granites, granitic gneisses, and tonalites are among the Archean and Dharwar rocks that are frequently linked to granitoids in the Sindhudurg district. These rocks have a complicated history of production, deformation, and metamorphism that illustrates the region's tectonic evolution throughout geological time periods.

## 2.3 Occurrence in Sindhudurg, Maharashtra

Granitoids in the Sindhudurg district's Dharwar area are crucial markers of the geological processes that have sculpted the region. They offer insights into the tectonic processes that followed, which shaped the region's geological evolution, as well as the deep-seated magmatic activity that took place during the formation of the Earth's crust. The intricate interaction of geological forces that have contributed to the development and modification of the Earth's crust in this region is highlighted by the discovery of granitoids in the Dharwar section of Sindhudurg district.The presence of granitoids in the Dharwar portion of Sindhudurg district highlights the complex interplay of geological forces that have contributed to the formation and modification of the Earth's crust in this area.

# CHAPTER III : METHODOLOGY

## I.MEGASCOPIC AND MICROSCOPIC ANALYSIS

Study of Hand specimen and Thin section under NIKON E200/INFINITY Polarising microscope and Identification of minerals and the texture and interpretation based on the observation.

## II. GEOCHEMICAL ANALYSIS

1. Powdering the samples

The process for turning a rock sample into powder depends on the specific requirements for the analysis and the type of rock itself. Here's a general outline of two common methods:

. Crushing and Grinding:

1. Safety First: Wear safety glasses, gloves, and a dust mask when handling rock and powder.
2. Initial Crushing: a jaw crusher or a hammer and mortar to break the rock into smaller pieces. For some very hard rocks, a tungsten carbide mortar and pestle might be needed.
3. Grinding: Once you have smaller fragments, use a grinder mill like a ball mill or a disc mill to achieve a finer powder. These mills use grinding media (balls or discs) to pulverize the rock. The grinding time and the type of grinding media will affect the final particle size.

(2) **XRF**

An X-ray fluorescence (XRF) spectrometer is an x-ray instrument used for routine, relatively non-destructive chemical analyses of rocks, minerals, sediments and fluids. It works on wavelength-dispersive spectroscopic principles that are similar to an electron microprobe. However, an XRF cannot generally make analyses at the small spot sizes typical of EPMA work (2-5 microns), so it is typically used for bulk analyses of larger fractions of geological materials. The relative ease and low cost of sample preparation, and the stability and ease of use of x-ray spectrometers make this one of the most widely used methods for analysis of major and trace elements in rocks, minerals, and sediment.

**Sample Preparation: Making Pressed Pellets**

Pressing a sample leads to a pressed pellet with a defined density thus ensuring reproducible sample preparation. For X-ray fluorescence analysis, it is important that the pellet is also mechanically stable because when being introduced into the analytical instrument, the sample is subjected to evacuation and then aeration after the measurement.

High stability is required so that the sample does not break during these procedures. A few materials display this stability which can be increased by pressing in aluminium cups or rings. However, mixing with a binder is obligatory for most materials.

**1**) Grinding and Mixing

First, a grinder or mill is used to ground the solid rock sample into a fine powder. This guarantees improved packing and a constant particle size during pressing. The sample that has been powdered may occasionally be combined with a binder or grinding aid. This makes the pellet more robust and enhances the binding of the particles.

**2)** Pressing

Next, the ground sample—with or without binder—is put into a cylindrical die composed of steel or another appropriate material. Powder is compressed into a solid disc-shaped pellet using a hydraulic press that applies tremendous pressure (15–40 tonnes) to the die. The sample material determines the optimal pressure.

**3)** Analysis

For XRF analysis, the pressed pellet is now prepared. X-rays are used by XRF equipment to excite the atoms in the pellet, resulting in the emission of fluorescence radiation with distinct energies.The XRF device determines the elemental composition of the rock sample by examining the X-ray energy and intensities that are emitted.

**Principle**:

The analysis of major and trace elements in geological materials by x-ray fluorescence is made possible by the behaviour of atoms when they interact with radiation. When materials are excited with high-energy, short wavelength radiation (e.g., X-rays), they can become ionised. If the energy of the radiation is sufficient to dislodge a tightly-held inner electron, the atom becomes unstable and an outer electron replaces the missing inner electron. When this happens, energy is released due to the decreased binding energy of the inner electron orbital compared with an outer one. The emitted radiation is of lower energy than the primary incident X-rays and is termed fluorescent radiation. Because the energy of the emitted photon is characteristic of a transition between specific electron orbitals in a particular element, the resulting fluorescent X-rays can be used to detect the abundances of elements that are present in the sample.

1. X-ray Excitation: An X-ray source irradiates the sample with high-energy X-rays. These X-rays interact with the electrons in the atoms of the sample.

2. Inner Shell Electron Ejection: If the energy of the incident X-ray is high enough, it can knock out an electron from an inner shell of an atom in the sample. This creates a vacancy or hole in the inner electron shell.

3. Outer Shell Electron Transition: An electron from an outer shell of the atom moves down to fill the vacancy in the inner shell. This transition releases energy in the form of a fluorescent X-ray.

4. Characteristic X-ray Emission: The energy of the emitted fluorescent X-ray is characteristic of the element from which it originated. Each element has a unique set of energy levels for its electrons, so the energy of the fluorescent X-ray will be specific to that element.

5. X-ray Detection and Analysis: The emitted fluorescent X-rays are detected by a detector in the XRF spectrometer. The detector measures the energy and intensity of the X-rays. This information is then used to identify and quantify the elements present in the sample.X-ray Excitation: An X-ray source irradiates the sample with high-energy X-rays. These X-rays interact with the electrons in the atoms of the sample.

**WORKING**

The analysis of major and trace elements in geological materials by XRF is made possible by the behaviour of atoms when they interact with X-radiation. An XRF spectrometer works because if a sample is illuminated by an intense X-ray beam, known as the incident beam, some of the energy is scattered, but some is also absorbed within the sample in a manner that depends on its chemistry. The incident X-ray beam is typically produced from a Rh target, although W, Mo, Cr and others can also be used, depending on the application.

When this primary X-ray beam illuminates the sample, it is said to be excited. The excited sample in turn emits X-rays along a spectrum of wavelengths characteristic of the types of atoms present in the sample.The atoms in the sample absorb X-ray energy by ionizing, ejecting electrons from the lower (usually K and L) energy levels.The ejected electrons are replaced by electrons from an outer, higher energy orbital. When this happens, energy is released due to the decreased binding energy of the inner electron orbital compared with an outer one. This energy release is in the form of emission of characteristic X-rays indicating the type of atom present. If a sample has many elements present, as is typical for most minerals and rocks, the use of a Wavelength Dispersive Spectrometer much like that in an EPMA allows the separation of a complex emitted X-ray spectrum into characteristic wavelengths for each element present. Various types of detectors (gas flow proportional and scintillation) are used to measure the intensity of the emitted beam. The flow counter is commonly used for measuring long wavelength (>0.15 nm) X-rays that are typical of K spectra from elements lighter than Zn. The scintillation detector is commonly used to analyse shorter wavelengths in the X-ray spectrum (K spectra of elements from Nb to I; L spectra of Th and U). X-rays of intermediate wavelength (K spectra produced from Zn to Zr and L spectra from Ba and the rare earth elements) are generally measured by using both detectors in tandem. The intensity of the energy measured by these detectors is proportional to the abundance of the element in the sample. The exact value of this proportionality for each element is derived by comparison to mineral or rock standards whose composition is known from prior analyses by other techniques.

# CHAPTER 4: RESULT AND DISCUSSION

## 1.1 STUDY OF HAND SPECIMEN

### 1. MH 04

The given specimens consist of minerals like K-feldspar which is the phenocryst mineral having a grain size varying from 2-5 cm, showing a pinkish appearance of the mineral having groundmass minerals like Quartz, biotite. The rock has less than 40% of Quartz and it was identified based on its vitreous lustre along with accessory minerals like Biotite showing pearly lustre and elongated grains. The whole rock appears grey due to present of mafic mineral content, that is biotite. The overall minerals are randomly originated and the rock is comprise of crystals, reflecting to its Holocrystalline nature and the rock have Inequigranular grain size. The Mutual relationship between phenocryst and groundmass that is large grain are surrounded by small groundmass minerals reflect to inequiagranular texture called as Porphyritic texture. The rock is having colour index Leucocratic.The rock is a Grey Granite.

Figure 4.1: k-feldspar porphyry in grey granite

**2. <u>MH 09</u>**

The hand specimen is a Coarse grained rock which is composed of K-feldspar identified based on its pinkish appearance. The rock is showing Phaneritic nature as the grain are visible in naked eyes. The Quartz content is less than 45% along with accessory minerals like Biotite.The grains are randomly originated and they have Irregular boundaries. The grain size is medium to coarse grained that is 2-5 cm size of k-feldspar, 1-2 cm for Quartz and this variation in grain size implying to Inquigranular texture that is large grain phenocryst surrounded by groundmass minerals like Quartz and Biotite implying to Porphyritic Texture. The rock is showing more felsic minerals and the colour index is leucocratic. The rock is a Potaasic granite.

Figure 4.2:Potassic granite with hornblende accessory

**3. <u>MH 14a</u>**

The rock is a medium to coarse grained rock having augen shaped of quartz and feldspar surrounded by biotite giving rise to Augen texture. The augen texture reflect to the metamorphism that is rock has recrystallination. The rock is a Gneissic rock reflecting to high temperature and high pressure. The size of the augen is 5-6cm. The colour index is leucocratic in nature as it is dominated by felsic minerals more than mafic minerals. The rock is a Augen gneiss.

Figure 4.3:Quartz forming Augen shaped in a Augen gneiss

**4. MH 17**

The rock is a medium to coarse grained, fully crystal rock indicating to a Holocrystalline nature of rock. The phenocryst size varies from 2-5 cm for k-Feldspar followed by Quartz size from 2-4 mm and Biotite is having 2-3 mm size.The quartz content in this rock is less than 50%. The grain are randomly oriented. Based on the variation in grain size the rock is inequigranular in nature having Inequigranular texture. The larger grains of phenocryst are surrounded by small grains of groundmass minerals forming a porphyritic texture. The rock is showing leucocratic colour index.The rock is a Grey Granite.

Figure 4.4: Microcline porphyry in grey granite

**5. MH 18**

The rock is a coarse grained, having more of pinkish appearance indicating presence of K-feldspar having less than 50% of Quartz with fine grained Biotite groundmass. The whole rock is consist of crystals implying to Holocrystalline nature. The grains wer anhedral to subhedra. The rock is showing inequigranular mineral with randomly originated minerals. The larger grains of K-rich feldspar is surrounded by small groundmass of Quartz and Biotite referring to Porphyritic texture also there were cluster of phenocryst together forming glemorporphyritic texture. The rock is having colour index upto 30 % that is leucocratic.The rock is a Grey granite.

Figure 4.5: Grey granite having k-Feldspar porphyry

**6. MH 19**

The sample is of a coarse grained rock reflecting to Phaneritic nature with size of the minerals varying from 5mm- 2cm. The rock consists of more Felsic minerals like quartz, up to 65% followed by Feldspar compared to mafic minerals like biotite. This implies that the colour index is leucrocratic as there are more felsic minerals. The rock has 60% of quartz reflecting to crystallized for high Silica-rich magma.the rock comprise of minerals like microcline, quartz and biotite . The size of mineral varies that is for inequigarnular grain size of grain implying to inequigranular texture, that is porphyritric texture , the phenocryst of microcline and quartz and groundmass of biotite.The rock is showing vertical lineation of biotite. The rock is a White granite.

Figure 4.6:White granite having porphyry of microcline

**7. MH 24**

Handspecimen is a coarse grained rock having porphyry of feldspar and quartz encircling around by biotite and hornblende. The rock comprised of minerals like feldspar having size varying from 2-5 cm , quartz having size approximately 2-3 cm and biotite and hornblende having size from 0.5-1cm. Due to variation in grain size, the rock forms an inequigranular texture that is porphyritic texture ,the phenocryst mineral that is feldspar and Quartz surrounded by groundmass minerals like Biotite and Hornblende.The colour index is leucocratic, as the rock is more dominant with felsic minerals. It comprise of 60% Quartz. The rock is a Grey granite.

Figure 4.7: coarse grained Grey granite

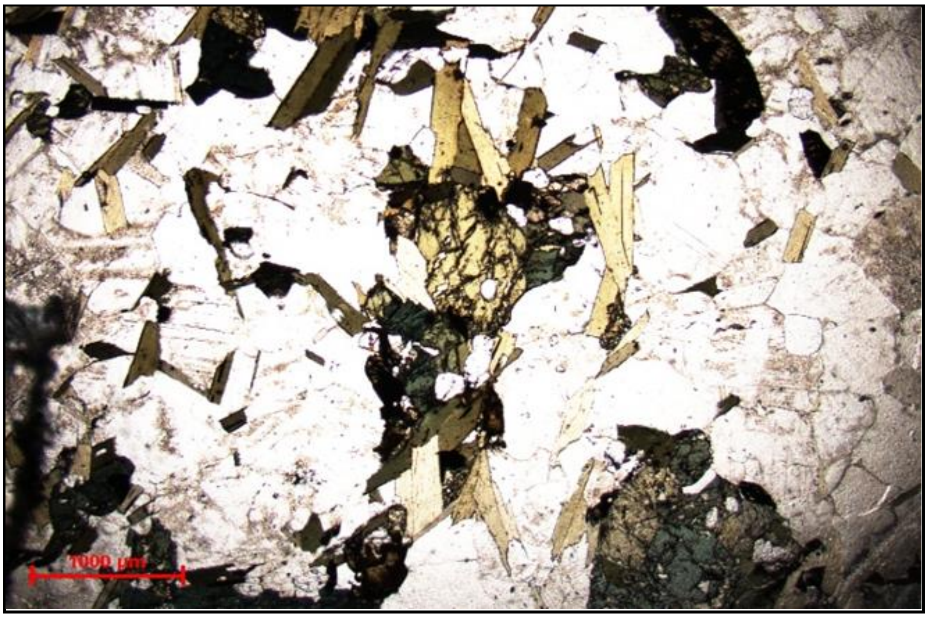
**8. MH 26**

The rock is a medium grained rock which made up of crystal indicating to Holocrystalline nature. Minerals like microcline are present in the form of phenocryst, along with quartz, along with groundmass minerals like biotite are identified based on their pearly lustre. The Microcline is is approximately 2cm in size and Quartz size is approximately 0.5-1cm and biotite is less than 0.5 mm. The rock is showing Inequigranular texture that is the phenocryst of Microcline is surrounded by groundmass of Biotite and also with Quartz. The crystals grains in the rock was randomly orienated. The colour index for this rock is leucocratic.it has quartz contain upto 50%.. The rock is Grey granite.

Figure 4.8: Grey granite

## 1.2 PETROGRAPHIC STUDY

### 1. MH 04



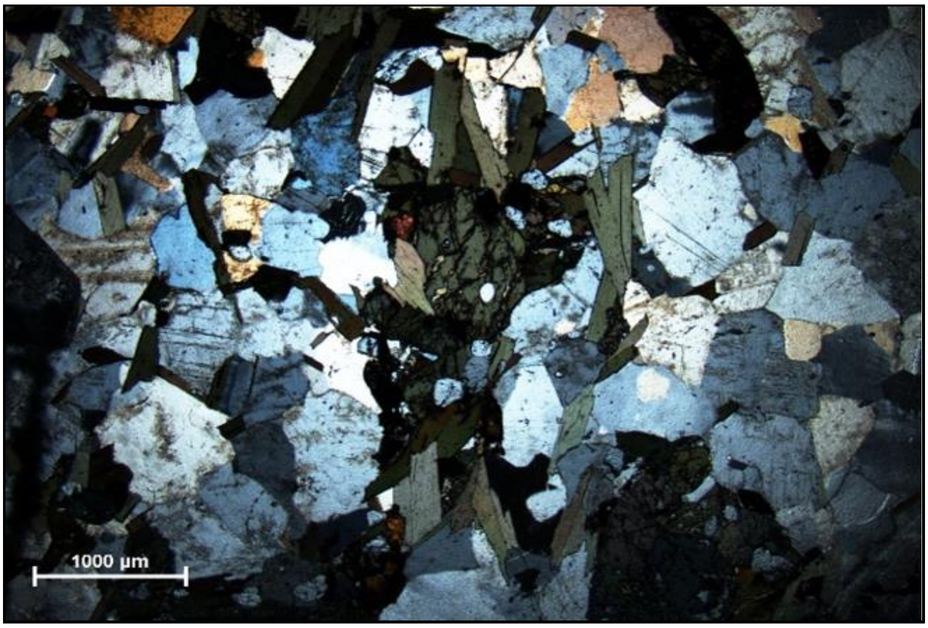




Figure 4.9: Hornblende surrounded by biotite grains in (a) plane polarized light and (b) cross polarized.

The section comprises of mineral like Microcline, Quartz, Plagioclase along with accessory minerals such as Biotite and Hornblende.The microcline and plagioclase grains are subhedral in shape.The rock comprise of 45-55% quartz and the grains are Anhedral. The rock is having variation in grain size of the rock forming inequigranular texture. The phenocryst minerals are of microcline and quartz and groundmass minerals are hornblende and biotite forming a prophyritic texture. The texture refers to two stage of mineral formation.The Hornblende grains are irregular,surrounded by elongated grains of biotite and they are randomly orientaed shown in Figure 4.10(a and b).The rock is a Grey granite.

**2.** **<u>MH 08</u>**

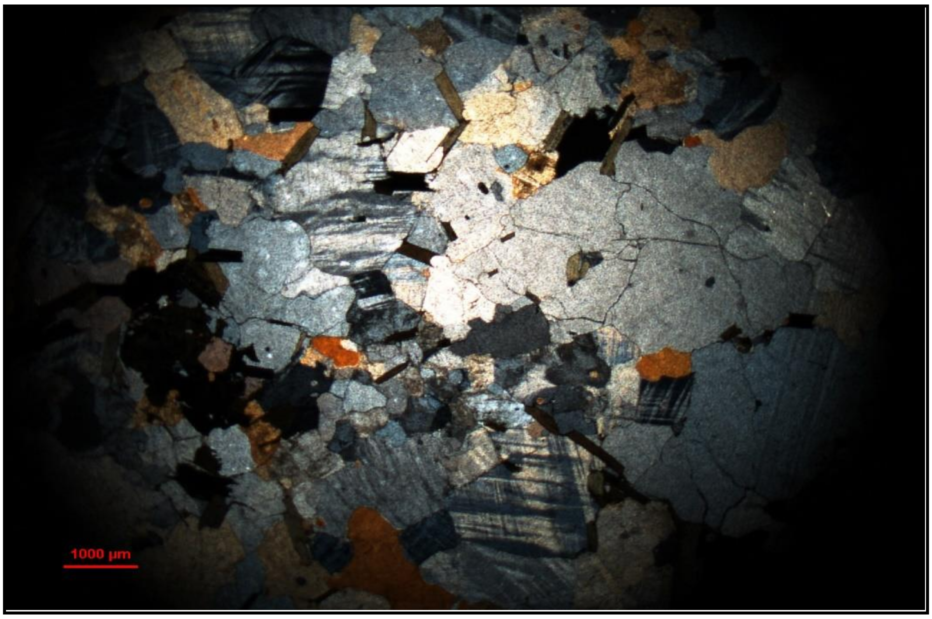



Figure 4.10: Deformed grains of microcline (a) plane polarised (b) cross polarised

The section consists of minerals such as Microcline, Quartz, Plagioclase with accessory minerals like Biotite. The rock overall made of crystals implying to Holocrystalline nature of rock. The grains are subhedral and various in size that is microcline vary from 2-3mm-, quartz varying from 2-4mm having inclusion and the biotite is 1-2 mm in size.The microcline are dominant mineral and the grains are highly deformed.The rock is showing irregular grain size referring to ineqiuganular texture, where phenocryst of are microcline and quartz groundmass mineral of biotite indicating two stage of mineral crystallization.The rock is showing perthite texture in microcline. The rock is a Grey gramite.

**3. MH 09**

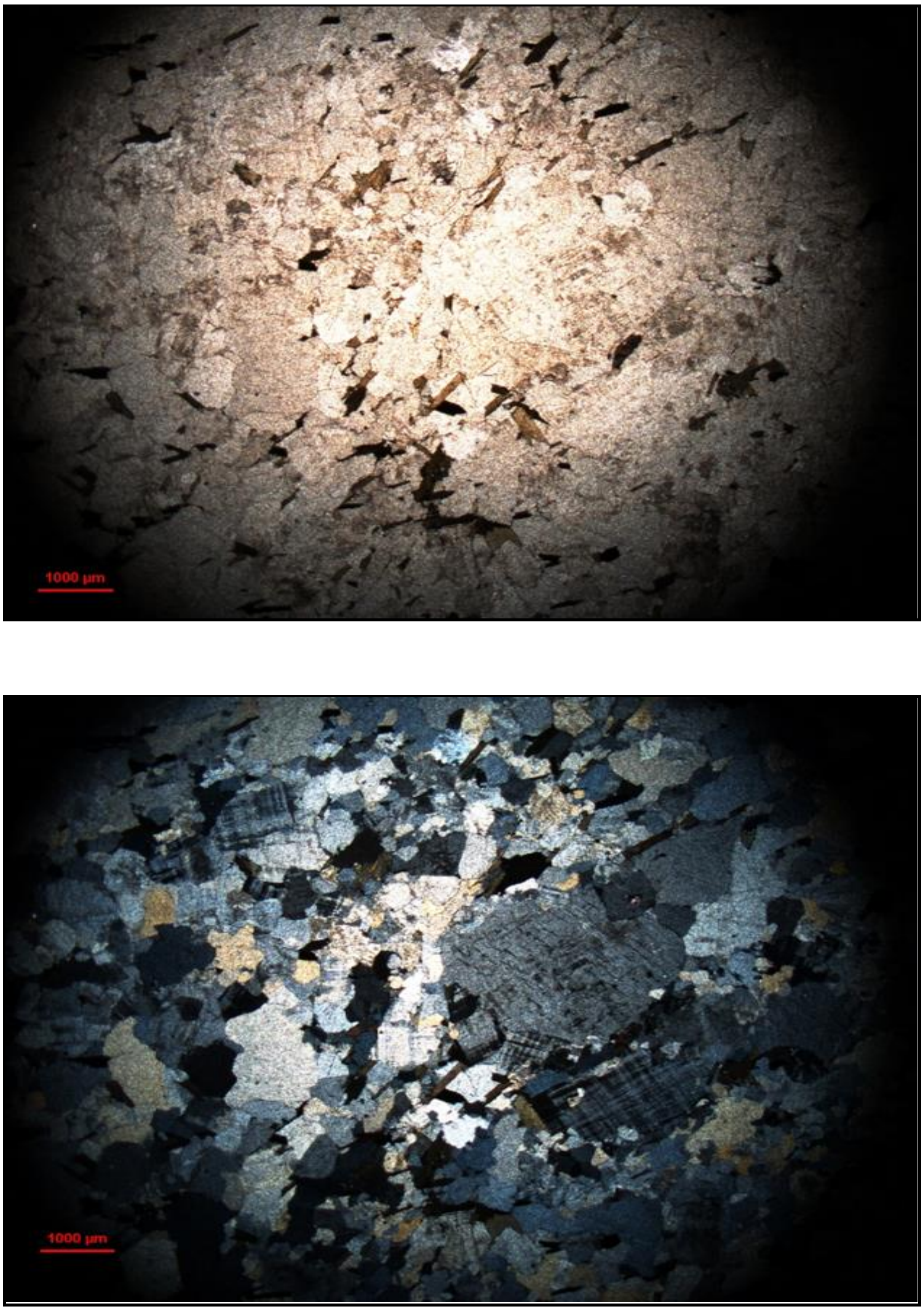



Figure 4.11: Porphyritic texture under (a) plane polarised (b) cross polarised

The rock consists of minerals such as Microcline,Plagioclase, Quartz and accessory minerals like Biotite. The rock is Holocrystalline in nature and the grains are subhedral. The rock is dominated by microcline, which is 2-4mm in size, as well as plagioclase, which is similar in size to microcline, and quartz, which ranges in size from 2-3mm.

The biotite is varying from 1-2mm in size and are randomly oriented . The is showing multiple twinning. Also there was perthite texture observed.Due to unequal grain sizes, the rock have resulted in inequigranular texture. Porphyritic texture was observed were phenocryst minerals were plagiocalse, microcline showing cross hatching,which was was surrounded with biotite minerals grains. The rock is Poatssic granite.

4. **MH 14a**

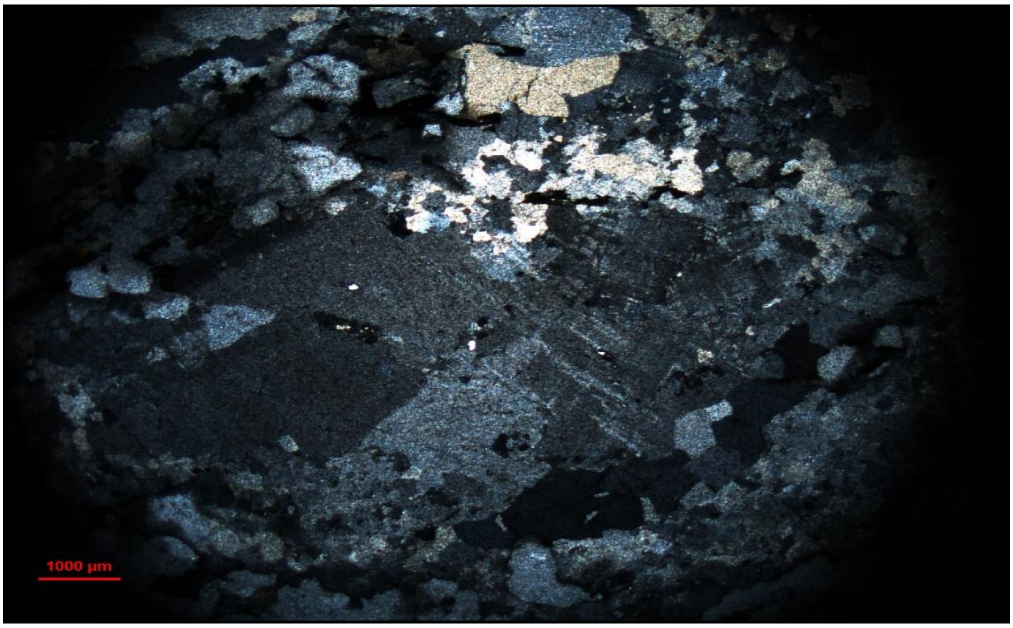
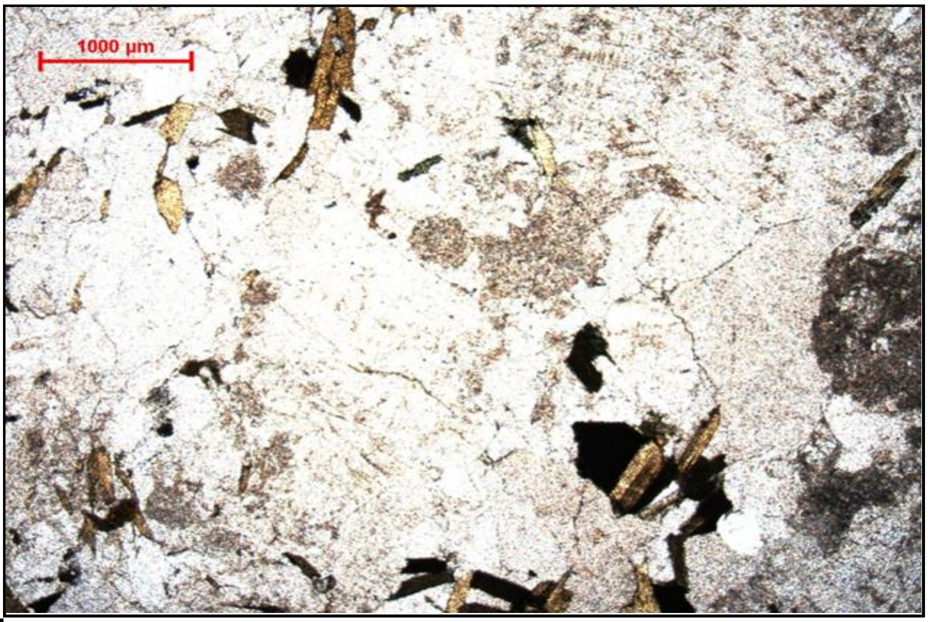



Figure 4.12:Augen shaped (a) plane polarised (b) cross polarised

The section comprised of Quartz,Microcline,Plagioclase with accessory like Biotite and Hornblende.The rock consist of crystal implying to Holocrystalline nature and the rock is showing inequigranular texture as it have inequigranular size.The overall grains are subhedral to Anhedral.Quartz is the dominent mineral followed by microcline and plagioclase.The hornblende are randomly orienated and irregular in shape and the biotite are elonagted and randomly orienated.The quartz are showing Myrmekite texture where it was observed that the quartz are formation bulb shaped intergrowth.The feldspar are highly deformed.The rock is Augen Gneiss.

## 5. MH 17



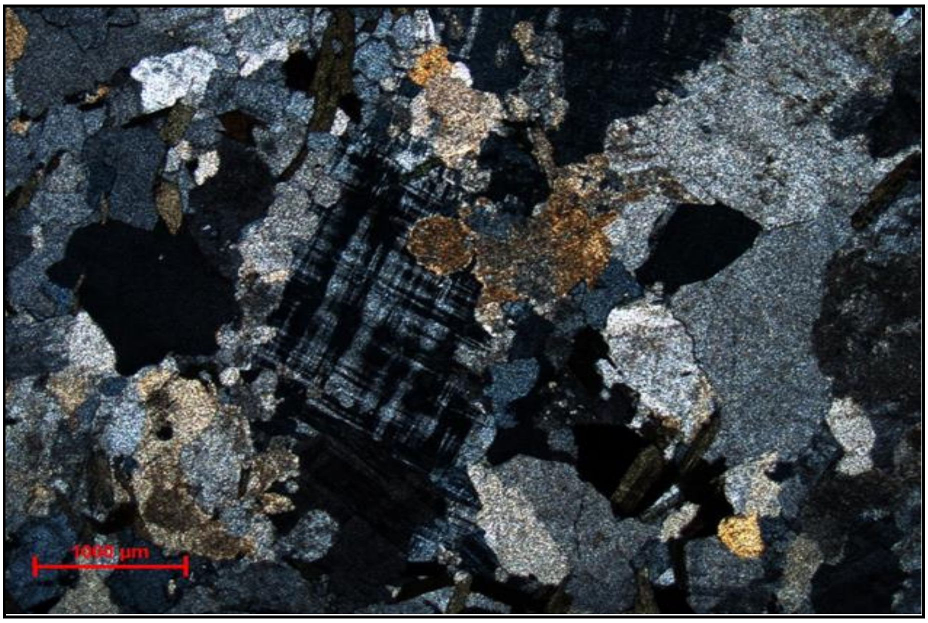




Figure 4.13: Deformed grains showing porphyritic texture under (a) plane polarised (b) cross polarised

The rock have minerals such as Microcline,Quartz and Plagioclase with accesory minerals such as Biotite and opaques.The rock is composed of crystals so its indicating

Holocrystalline nature of rock the grains are sunhedrel.The biotite are randomly orinented and are the grains are around 1-2mm.The grains due to inequigranular size of grain,they are formation inequigranular texture.Porphyritic texture is observed in which Microcline is the phenocryst minerals surrounded by groundmass minerals like biotite. There are inclusion present in phenocryst. Also Myrmikitic texture is observed in which Quartz bulb shaped intergrowth is noted. Also the quartzwase showing bulging and recrystallization in some portion referring to Bulging recrystallisation . Based on mineral the rock is concluded to be Grey granite.

**6.** **<u>MH 18</u>**


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Figure 4.14 : Porphyritic texture (a) plane polarised (b) cross polarised

The rock is composed of minerals like Microcline,Quartz and plagioclase, with accessory minerals as Biotite and opaques. The rock is made up of crystals, referring to the holocrystalline nature of the rock. The grains are randomly oriented, and the grain shape varies from subhedral to anhedral. The quartz grains are highly deformed and irregular, showing bulging, and small grains are recrystallized at boundaries, referring to bulging recrystallization in quartz. The biotite grains are randomly oriented, and their sizes vary from 1-2mm. The unequal size of grain in the section resulting in inequigranular texture that is the phenocryst of Plagioclase and Microcline is surrounded by groundmass minerals of biotite and recrystallized quartz. Also Myrmikitic texture was observed identified based on the bulb like appearance of quartz in feldspar.The rock is a Grey granite.

## 7. <u>MH 19</u>



Figure 4.15: Deformed garins of Quartz and microcline (a) plane polarised (b) cross polarised

The rock has minerals like Microcline,Orthoclase,Quartz,Plagiclase wth accessory like Hornblende and Biotite.The rock comprised of crystal implies to Holocrystalline nature of rock. The grains are randomly orienated and grains are having subhedral to Anhedral grain boundaries. Due to inquigranular size of grains, they are forming inequigranular texture that is Porphyritic texture where phenocryst is plagioclase,microcline and at some portion orthoclase and groundmass minerals are hornclende and biotite. Also there was perthite texture observed. The hornblende was surrounded by biotite grains.the plagiocalse was showing deformation twin. The rock is a White granite.

**8. <u>MH 24</u>**

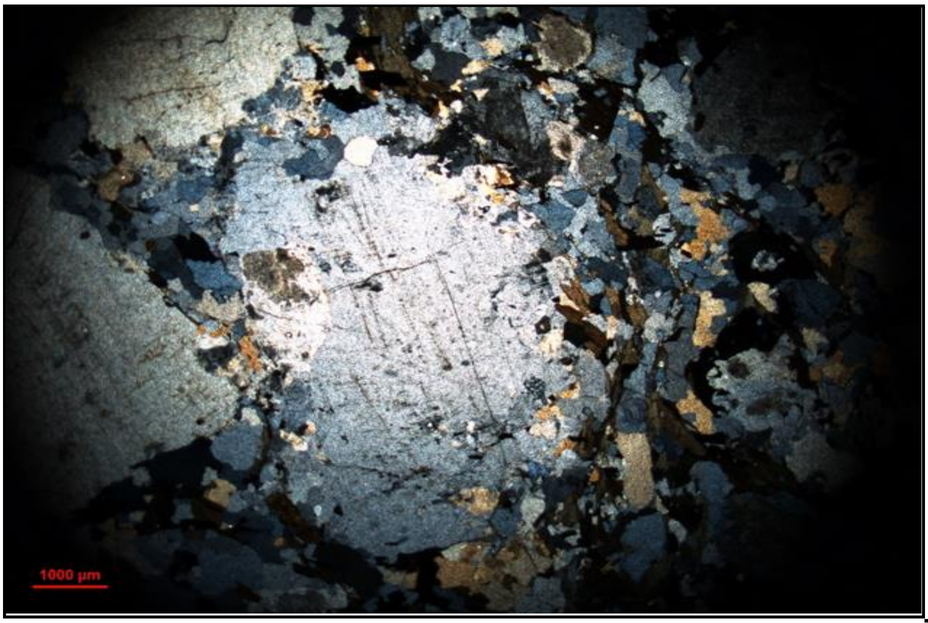
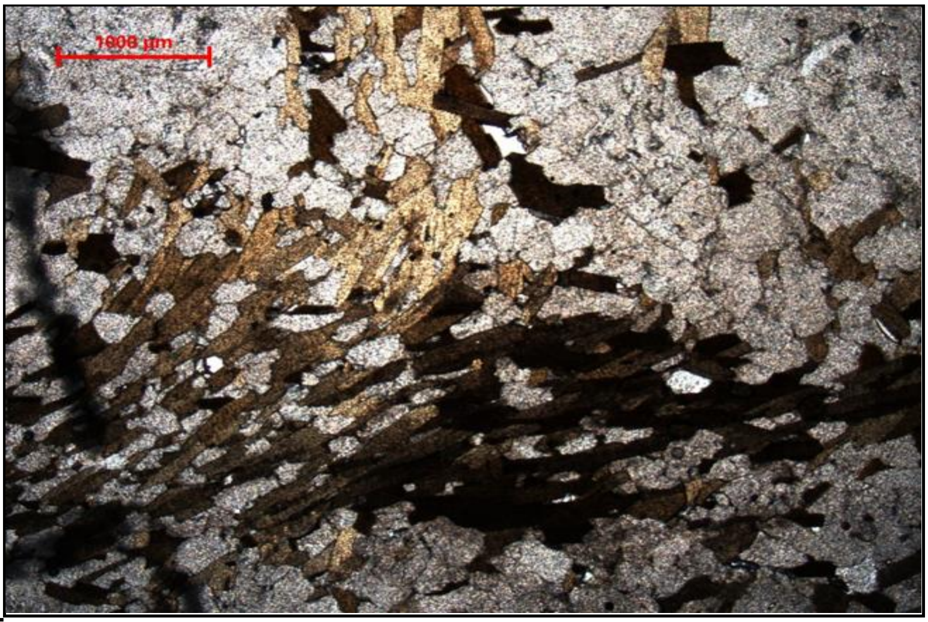



Figure 4.16 : Porphyritic texture under cross polarised

Minerals such as Microcline,Orthoclase,Quartz, Plagiclase along with accessory minerals with acccesory mineral namely, Biotite and Hornblende. The grains are irregular or are not having definate boundaries refering to Anhedral shape.The whole rock is comprised of crystal indicating to Holocrysatalline nature. The rock is showing Inequigranular grain size which have resulted in formation of inequigranular texture.Porphyritic texture is observed where the phenocryst are orthoclase, quartz and microcline with groundmass minerals such as hornblende and biotite. There were clast of phenocryst such texture is referred as Glomeroporphyritic texture.The quartz are showing Myrmikitic texture that is intergrowth of quartz in form of bulb in feldspar. The rock is Grey granite.

**9. MH 26**



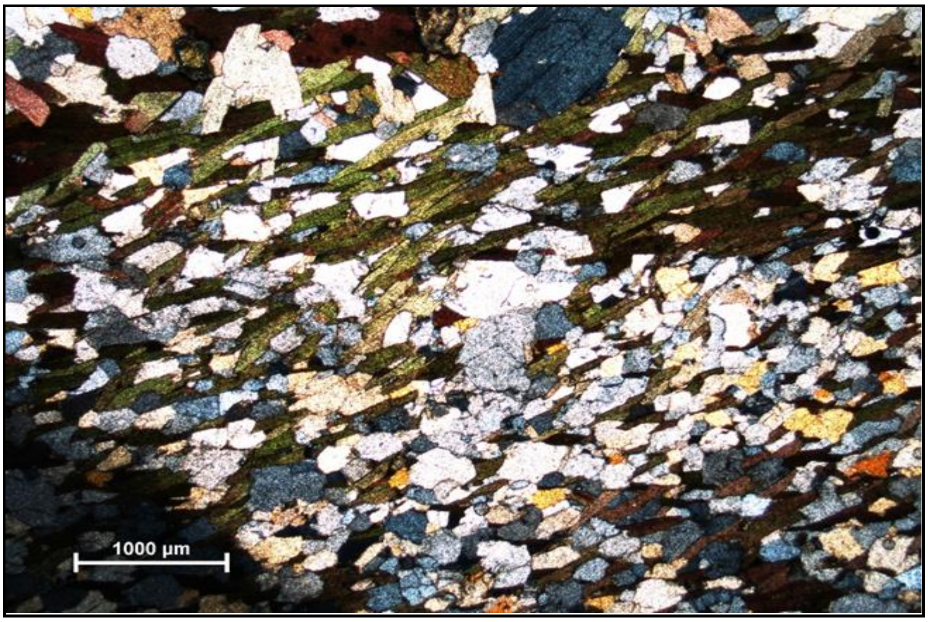



Figure 4.17 : Gneissic texture formation under (a) plane polarised (b) cross polarised

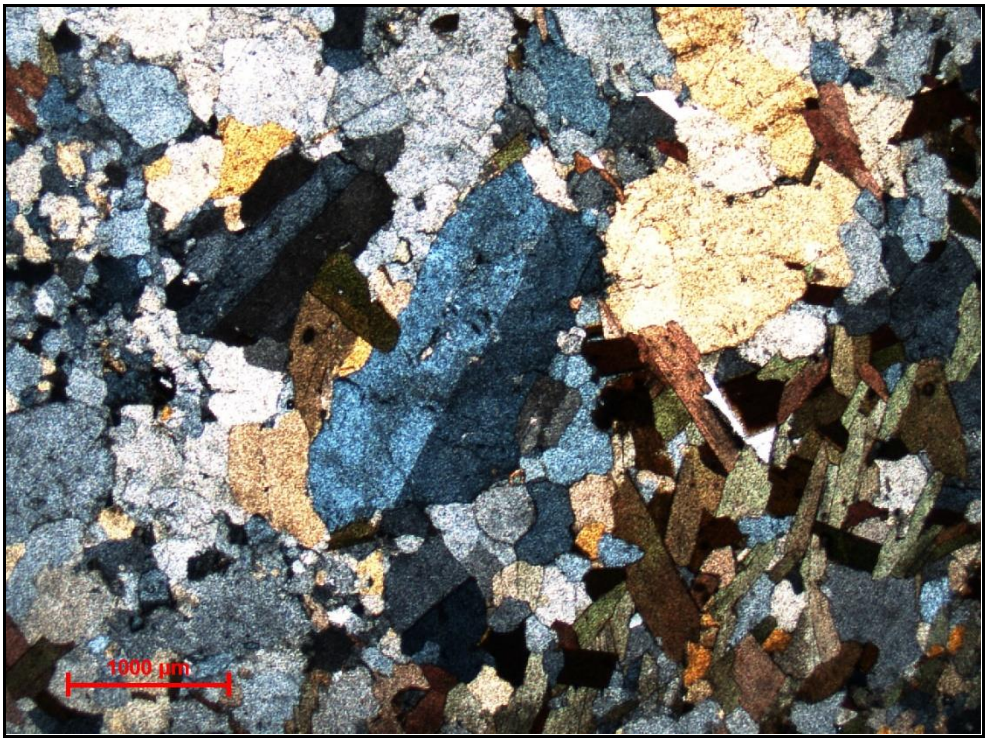



Figure 4.18 : Porphyritic texture under Cross polorized light

The rock include minerals such as Quartz, Plagioclase,Microcline with Accesory minerals that is the Biotite. The grains are subhedral to anhedral. The rock is made of crystals, implying to Holocrystalline nature. The rock shows alignment of quartz and biotite, indicating that the rock is going through metamorphism forming a gneissic texture. The quartz is showing worm like orienation indicating to Myrmikite texture. Also there grains are inequigranular forming inequigranular texture. Porphyritic texture is observed where phenocryst various from plagiocalse to microcline at some places and groundmass as biotite. The biotite is having inclusion in form Biotite Halos and there are opaques presents. The rock is a Grey granite.

**Inference Based on study of thin section**

All the samples in the thin section are Coarse grained, Holocrystalline showing inequigranular grain size with Subhedrel to Anhedral grain boundaries. Various minerals were identified in thin sections namely, Microcline, Orthoclase, Plagiocalse,Quartz, Biotite and Hornblende. There were orientation of biotite noted in one of the sampled location where the rock was showing Gneissic texture indicating to metamorphism of the rock. Due to inquigranular size of the minerals, there was formation of Porphyritic texture which can be possible that there was two stages of mineral formation in the rock. Also there was inclusion in form of opaques and alteration. Deformation is noted in the quartz where it has recrystallized in form of Bulges to form Bulge Recrystallization. The hornblende grains were surrounded by biotite. The biotite mineral was present in all the rock samples but hornblende was absent in few sample. Based on the thin section study, it can br imply that MH 14a has undergone metamorphism showing augen shape (figure 4.13) and also MH 26 is form Gneissic texture at small scale which is noted in figure 4.18 (a & b).

2. G**<u>eochemical studies and Inference Based on Geochemical data</u>**

HARKER PLOT FOR MAJOR ELEMENTS DESCRIBING THE TREND

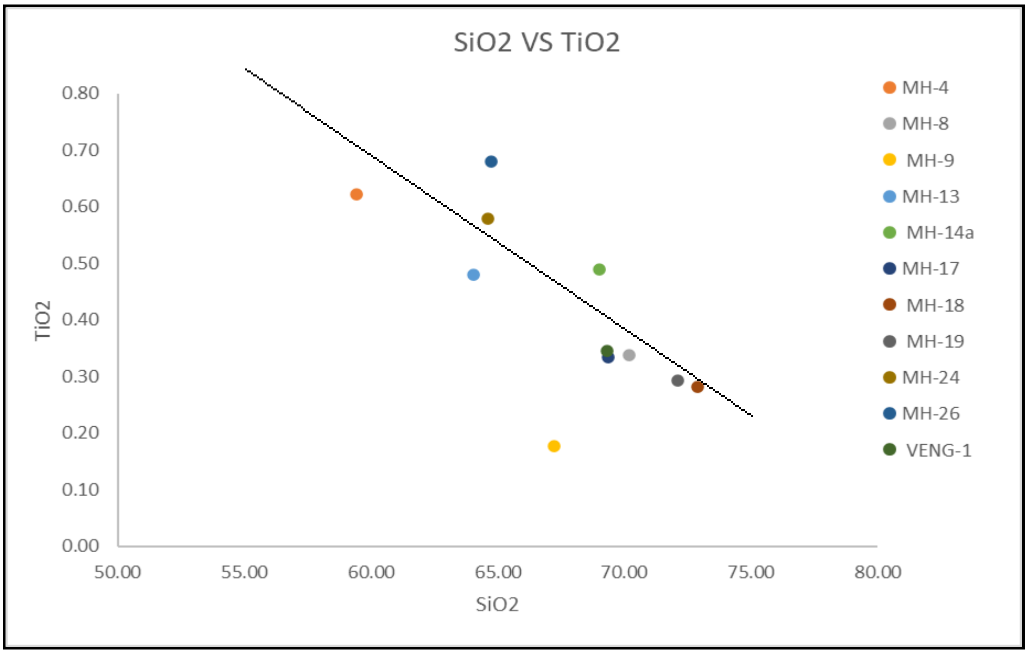



Figure 4.19: $SiO_2$ vs $TiO_2$ relationship exhibiting magmatic trends for the studied sample shows negative trend with increase in $SiO_2$

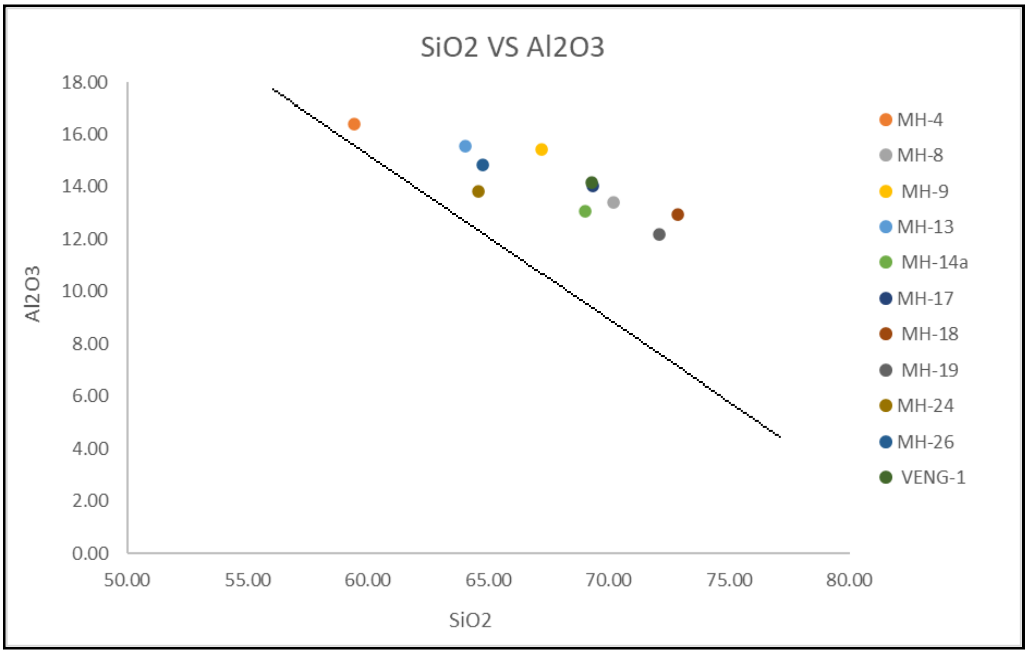


Figure 4.20: $SiO_2$ vs $Al_2O_3$ relationship exhibiting magmatic trends for the studied sample shows negative trend with increase in SiO2

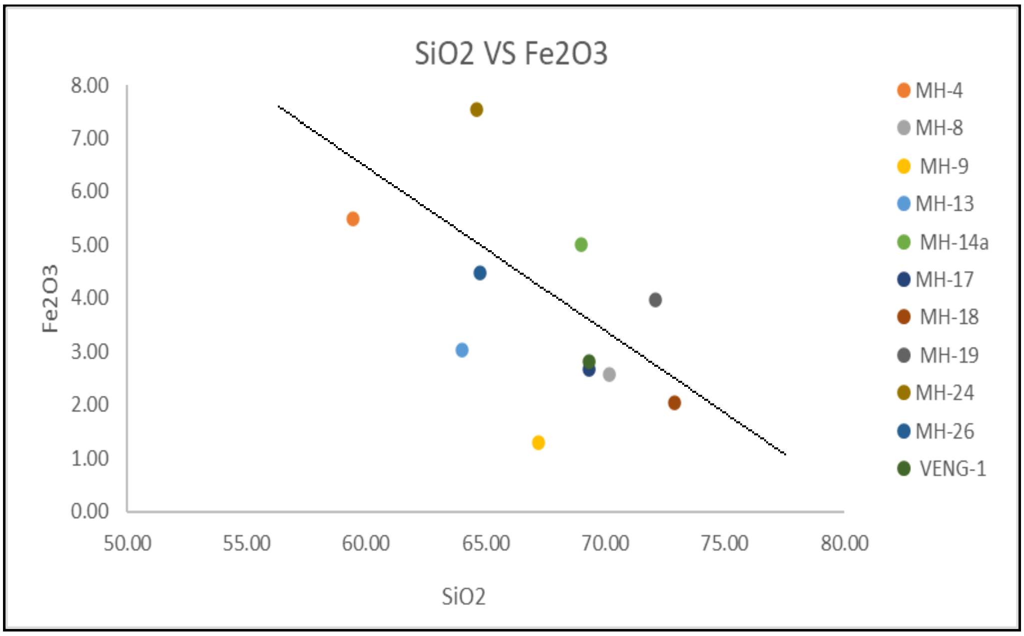



Figure 4.21: $SiO_2$ vs $Fe_2O_3$ relationship exhibiting magmatic trends for the studied sample shows negative trend with increase in $SiO_2$

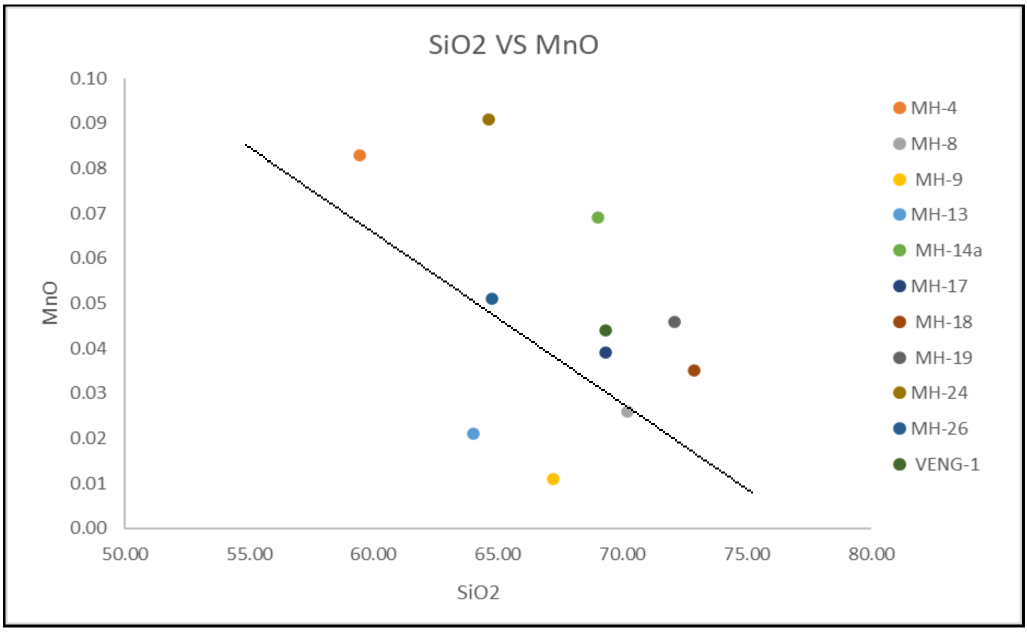



Figure 4.22: $SiO_2$ vs MnO relationship exhibiting magmatic trends for the studied sample shows negative trend with increase in SiO2

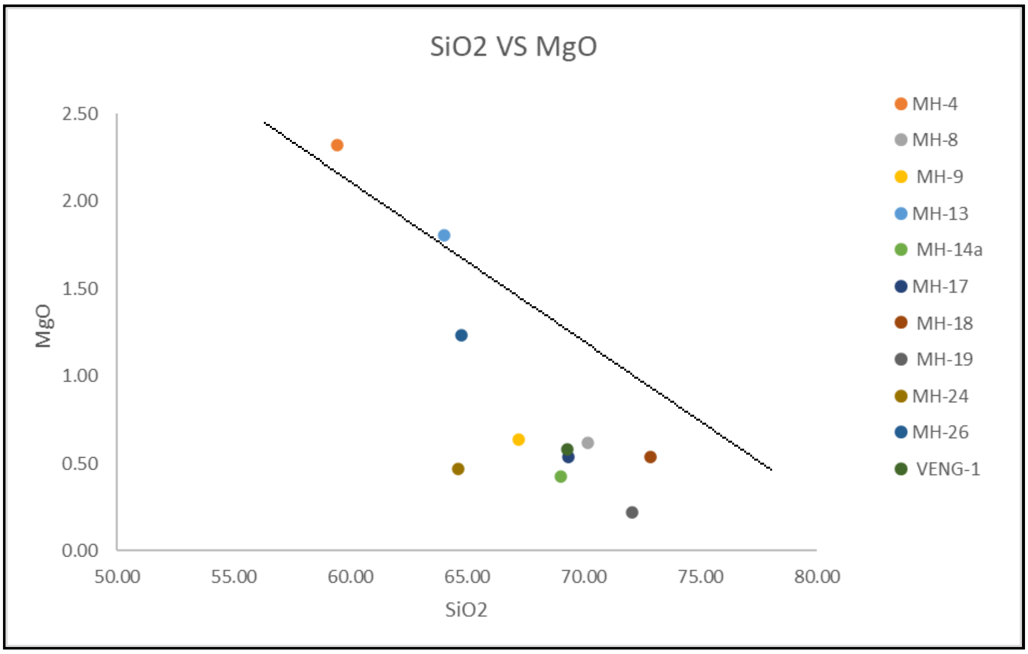



Figure 4.23 : $SiO_2$ vs MgO relationship exhibiting magmatic trends for the studied sample shows negative trend with increase in SiO2

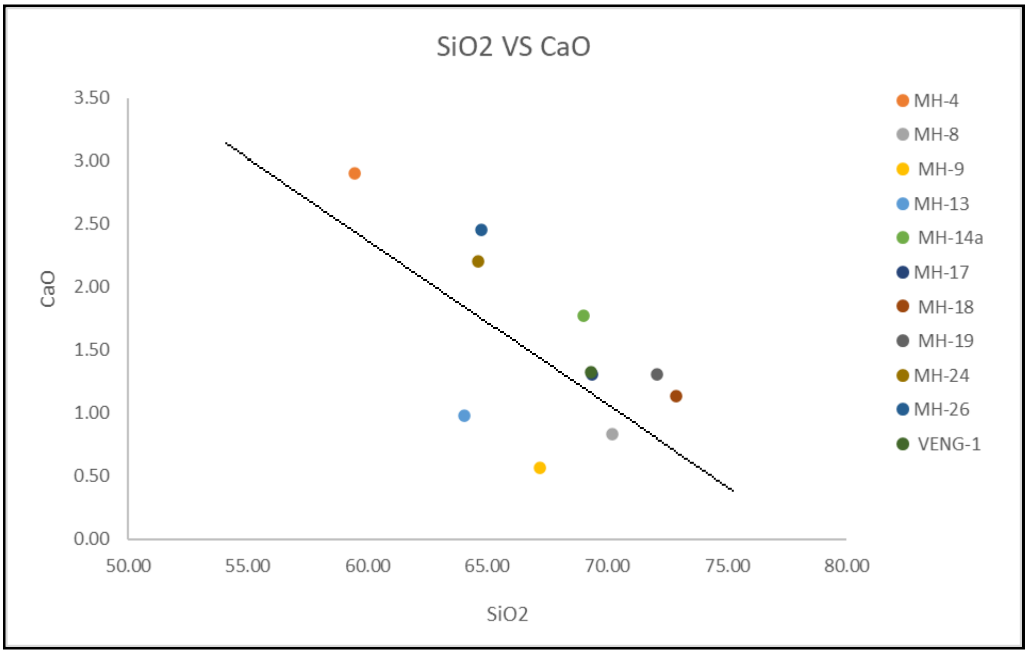



Figure 4.24: $SiO_2$ vs CaO relationship exhibiting magmatic trends for the studied sample shows negative trend with increase in $SiO_2$

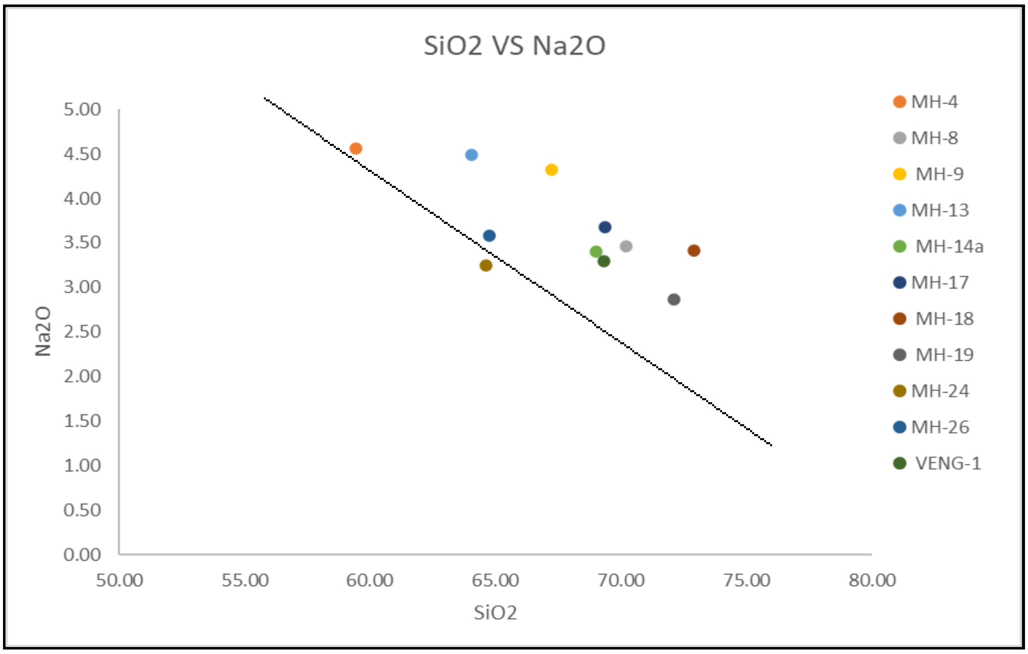



Figure 4.25: $SiO_2$ vs $Na_2O$ relationship exhibiting magmatic trends for the studied sample shows negative trend with increase in SiO2

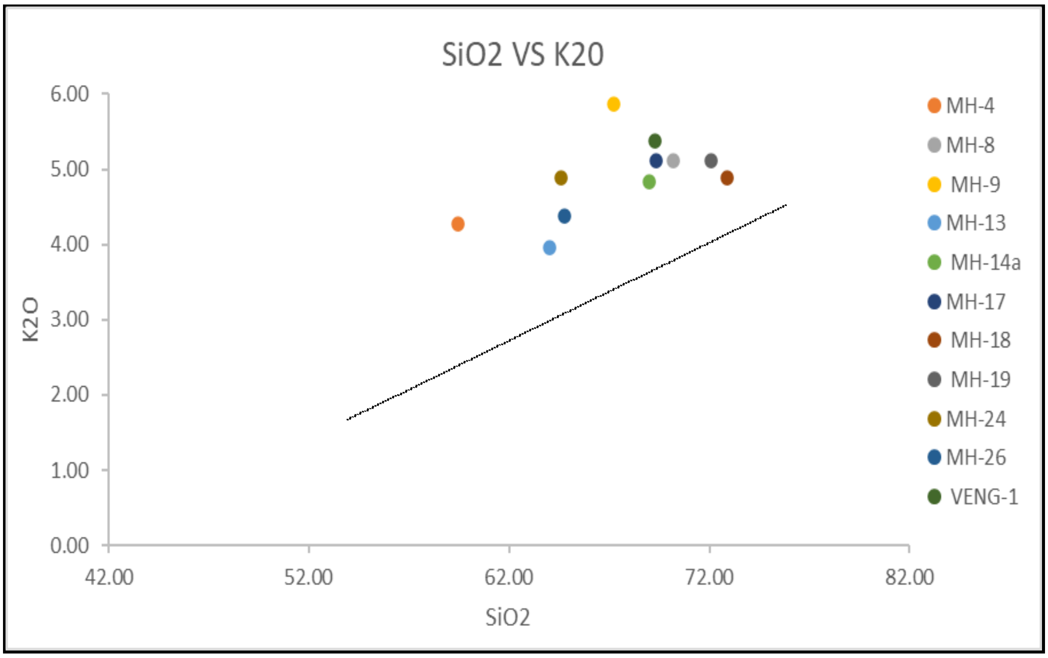



Figure 4.26 : $SiO_2$ vs $K_2O$ relationship exhibiting magmatic trends for the studied sample shows positive trend with increase in $SiO_2$

**Harker- type Binary Diagram**

All the granite are siliceous with $SiO_2$ values ranging from 59.44 - 72-89%, in which potassic granite is 67.21%, and Gneissic rock is having composition of 64.75-69.01%. Higher $SiO_2$ values indicate that the rock has formed from magma which has undergone more differentiation process. Major elements Harker plots demonstrate all the oxides values showing a negative correlation which has been studied and seen in (figure 4.20: figure 4.21; figure 4.22; figure 4.23; figure 4.24; figure 4.26) where there is an increase in $SiO_2$ concentration but a decrease in concentration of $TiO_2$, MgO, MnO, $P_2O_5$, CaO, $Al_2O_3$ and $Na_2O$ except $SiO_2$ vs $K_2O$ plot (figure 4.27) shows increased in $K_2O$ with the increase in $SiO_2$ showing a positive trend.

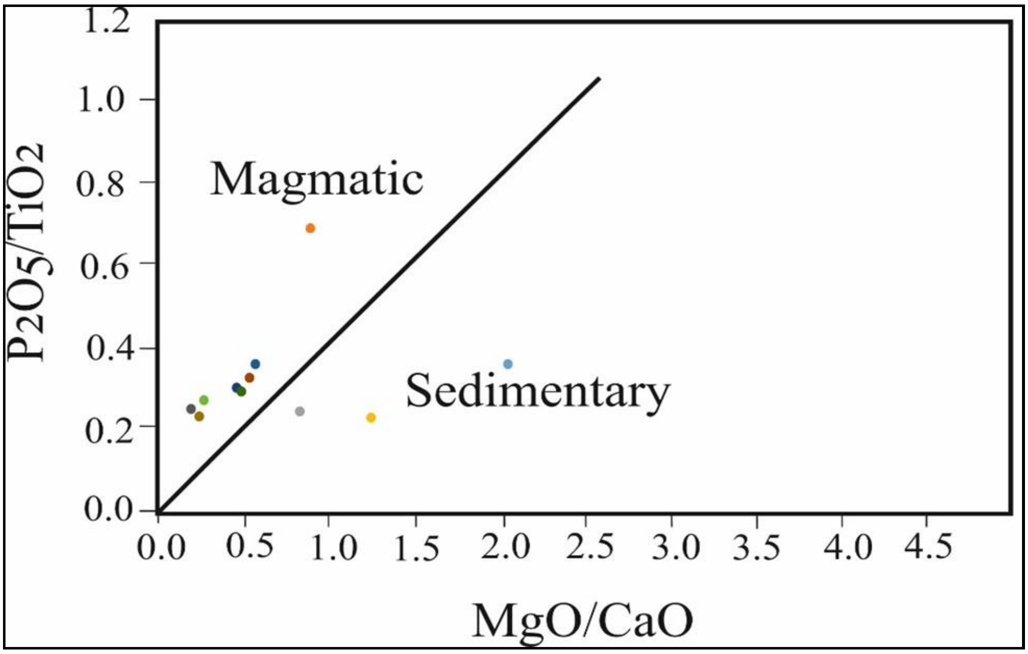



Figure 4.27: Major element discrimination diagram MgO/CaO VS $P_2O5/TiO_2$ Werner, C.D. (1987) showing the source of magma for the formation of granitoid

Major element discrimination diagram MgO/CaO VS $P_2O5/TiO_2$ plot by Werner, C.D. (1987) gives a brief idea about whether the rock is originated from and magmatic source or from a Sedimentary source. MH-13, MH-9 and MH-8 have some relation with sedimentary source and the other granitoid samples are plotted in a magmatic field.

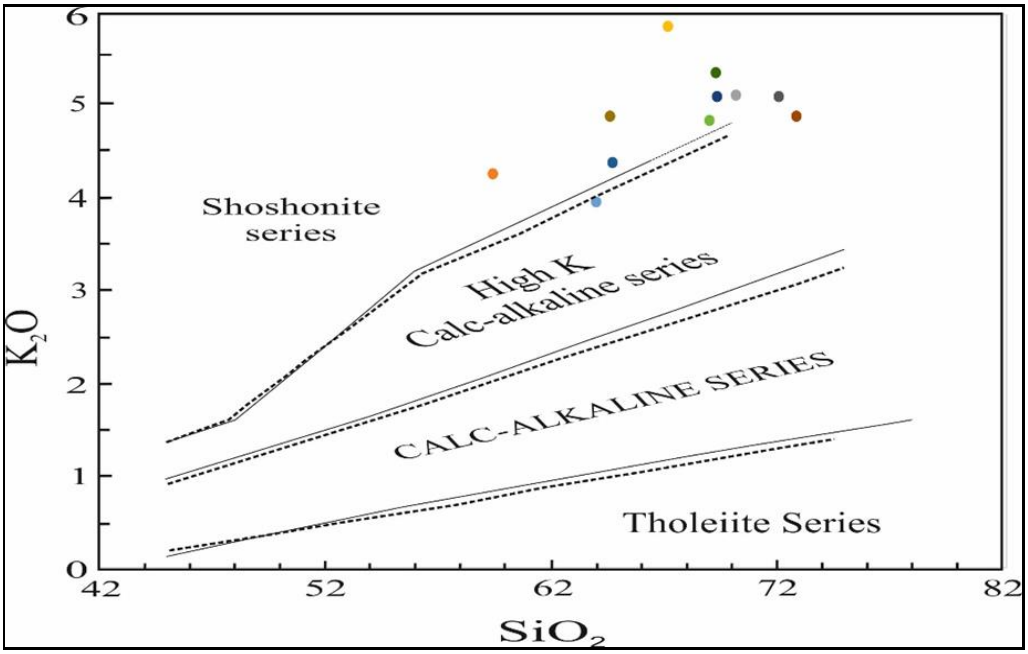



Figure 4.28: $SiO_2$ vs $K_2O$ relationship in which the sample show high k-calc-alkaline to schistose series

The $SiO_2$ vs $K_2O$ shows that all the granitiods are plotted in the shoshonite series except MH 13 which is plotted into High-k Calic-alkali Series. The shoshonite series contain are more K-rich source when compared with High-k calic alkali series, this indicates that all the granitoids have form from mantle source which have undergoing magma differentiation. Such concentration is mostly found in continental margin setting which is seen in Figure 2.29. The K-rich granite are formed from Post-collisional margin setting. High potassic Feldspar content are characteristic feature for Post collisional setting. Most of the Archaean sodic granitoids to transitional granitoids shows transition with elevated K-content.

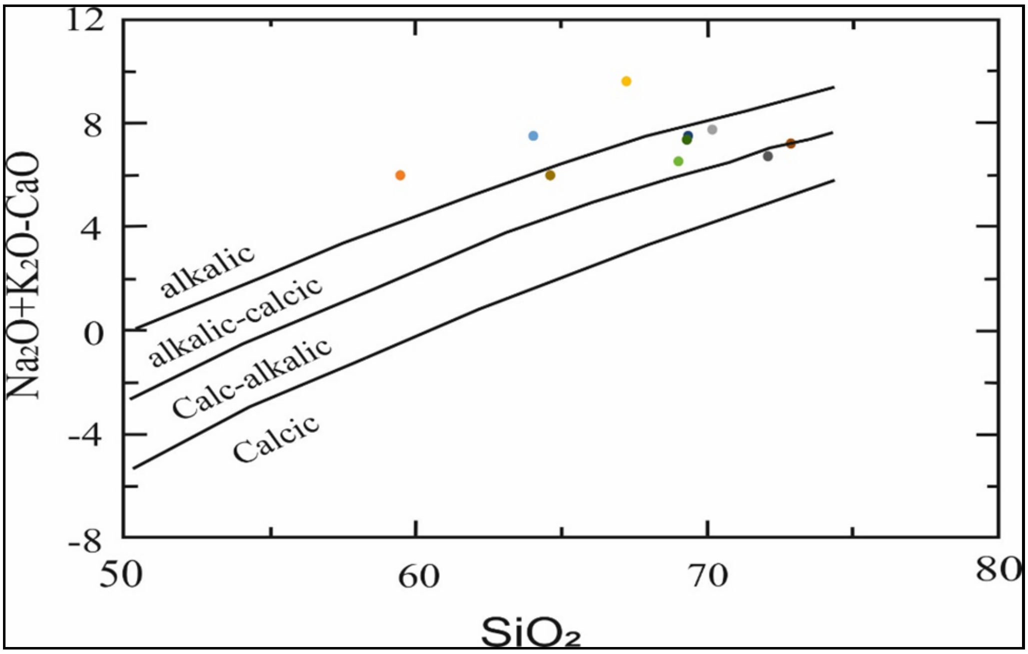



Figure 4.29: $SiO_2$ vs MALI -index diagram (after Frost et al.) showing a calcic to alkalic character

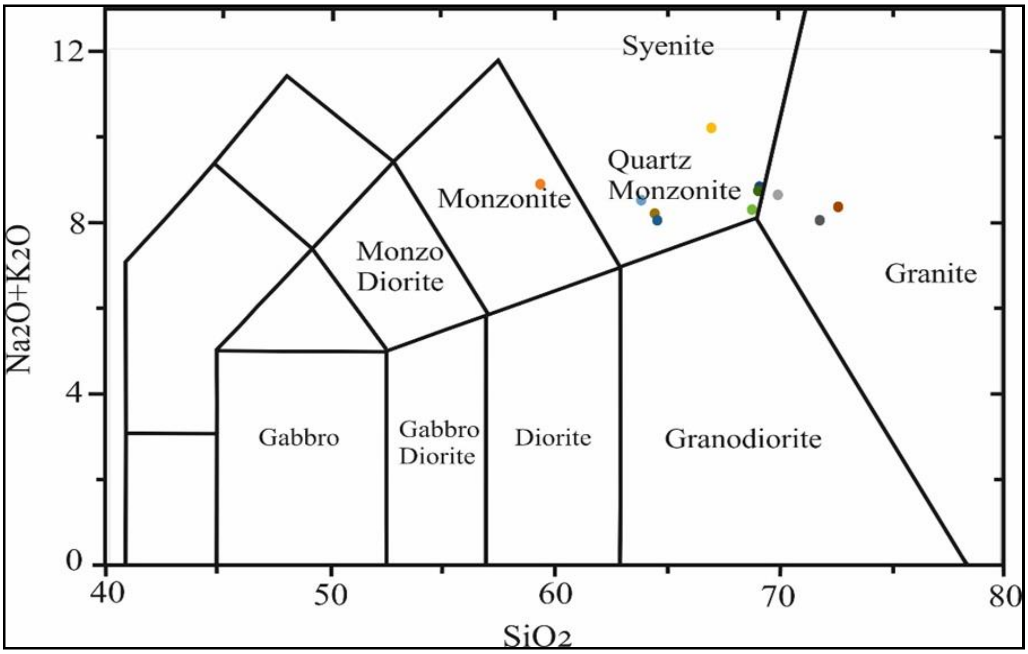



Figure 4.30 : $SiO_2$ VS ($Na_2O$ + $K_2O$) classification diagram for rocks by after Middelmost (1994)

Plot for $SiO_2$ vs ($Na_2O$+$K_2O$) classification diagram (Figure 4.31) after Middelmost (1994) for granitoids shows that MH-18, MH-19 and MH-8 is plotted in Granite, MH-4 for plotting in Monzonite and rest all where plotting in Quartz monzonite. This is based on the Alkali index implies that the rock is Na-rich or K-rich source, having similar alkali index composition as the field they are plot field. It refers to geochemical and tectonic setting of granites.

$SiO_2$ vs Modified alkali lime index ($Na_2O$+$K_2O$-CaO) plots gives more details about the presences of alkali minerals, MH 9, MH 13 and MH 4 are plotted in alkali field, MH 18 is plotted in calic-alkali field and rest are plotted in alkali-calic.

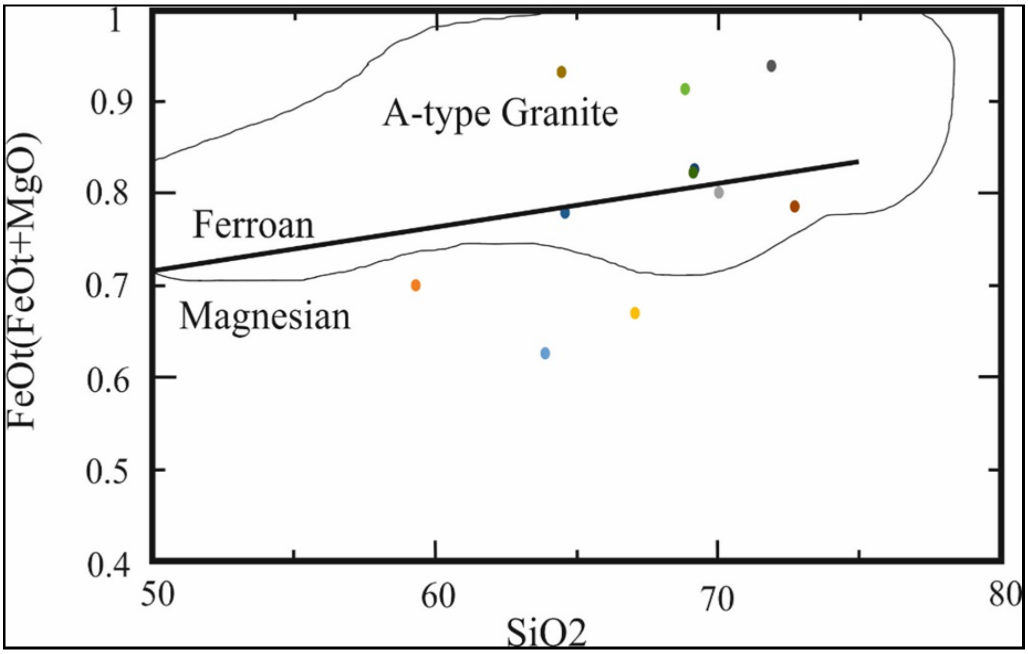



Figure 4.31: $SiO_2$ VS Ferroan index (Frost et al.2001) showing nature of the sample

The $SiO_2$ vs $FeO^t$ ($FeO^t$+MgO) reflect the present Fe and Mg content in the granite. MH-19, MH-17, VENG-1, MH-14a, and MH24 show Fe content this reflects the tectonic setting of the granite in which it is crustal melting events and MH18, MH 8, MH 26, MH 9, MH 13, MH 4 are plotted in Mg, it content reflects granites associated with magmas that originate from the mantle as shown in figure 4.32.

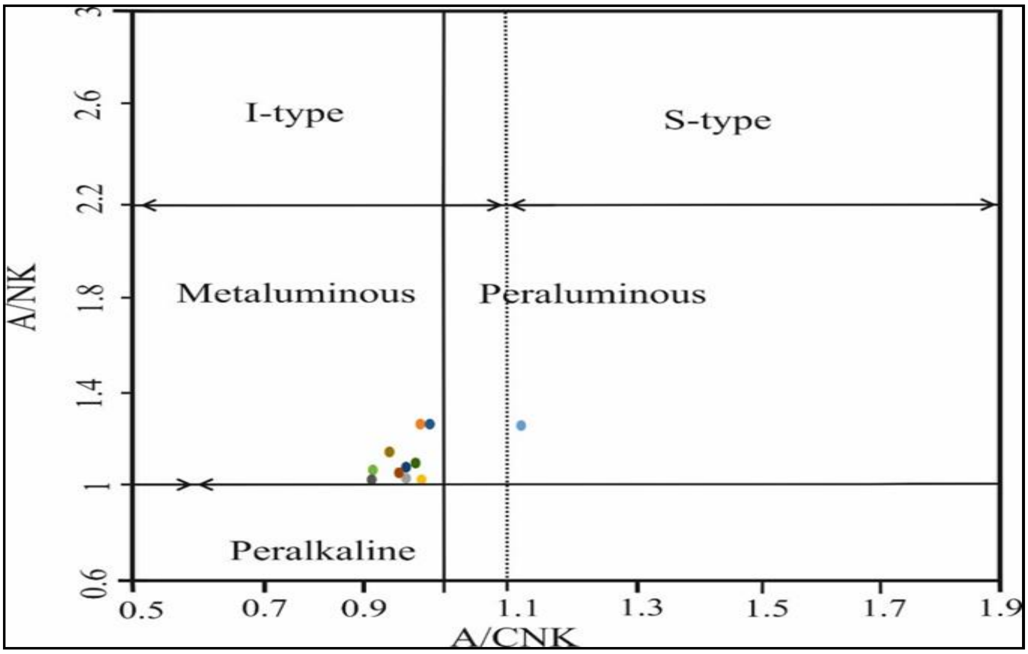



Figure 4.32: Molar A/CNK VS A/NK diagram showing the metaluminous to peraluminous nature of the studied sample

On A/CNK vs A/NK plot the granitoid are Metaluminous and are plotted in I-type field except for MH 13 which is plotted in Peraluminous field and is a S-type of granitoid. The metaluminous ($Al_2O_3$ < ($Na_2O$ + $K_2O$ + CaO) but Al2O3 > ($Na_2O$ + $K_2O$)) nature indicate that the rock from form Igneous origin and it comprised of high alkali index or alkali minerals, it also indicate the presence of minerals like Hornblende. Peraluminous ($Al_2O_3$ > ($Na_2O$ + $K_2O$ + CaO) or $Al_2O_3$/($Na_2O$ + $K_2O$ + CaO) ) nature indicates that the rock has more Al2O3 than alkali minerals it consists of minerals like muscovite.

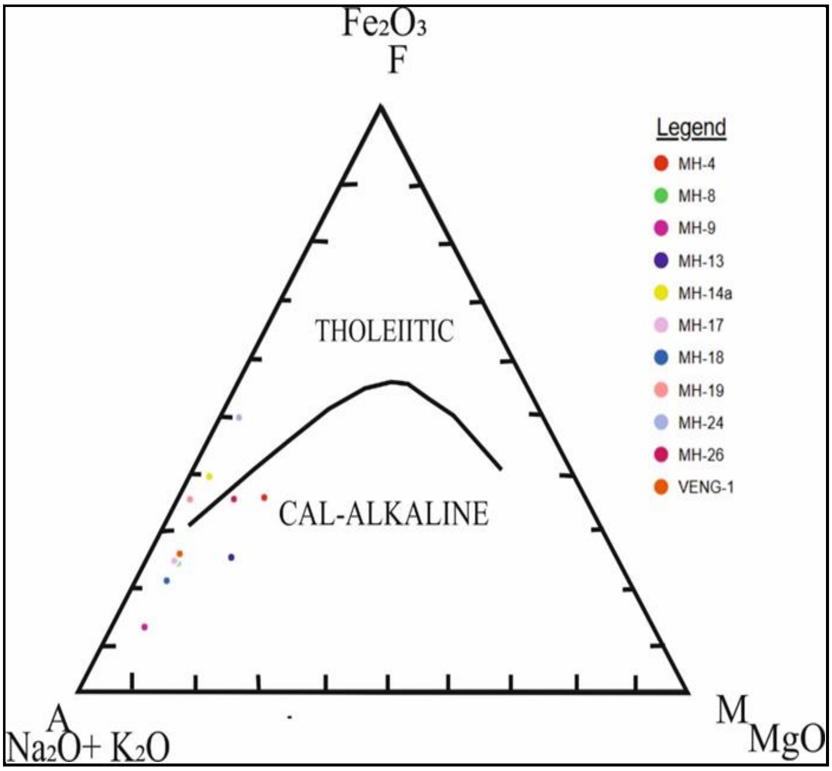



Figure 4.33:AFM diagram (Irvine and Baragar, 1971) indicating the calic -alkaline to tholeiitic trend

Based on the study of AFM Plot ($Fe_2O_3$; ($Na_2O$+$K_2O$); MgO) by Irvine and Baragar et al.1971) the showing affinity from Cal-alkaline to Tholeiitic composition.MH 24, MH14a MH 19 are plotted in tholeiitic field where else remaining sample fall in Cal-alkaline field (Figure 4.33).

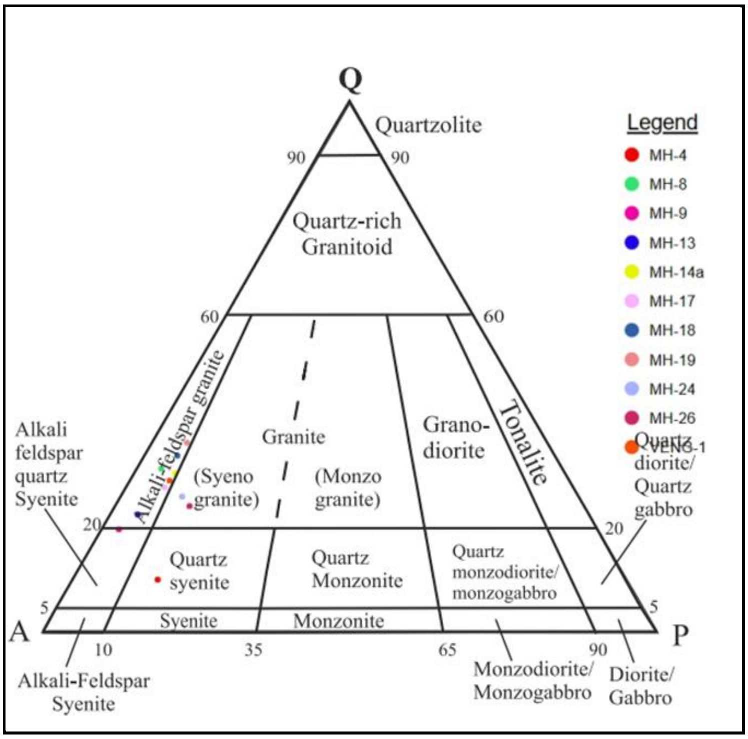



Figure 4.34: QAP showing diagram with the sample plot with the normative values from the study area

Based on the normative values calculated. Most of the granitoid were plotted in Alkali-feldspar granite. except MH 24 and MH 26 were plotted in Granite (Syenogenite) and VENG-1 is plotted in Quartz syenite (figure 4.27).

# CHAPTER V: CONCLUSION

Based on the study carried out the on the granitoids of Sindhudurg is shows variation in geology of granitoid is noted. there are two types of granitoids observed in that area. The rock are Holocrystalline, medium to coarse grained which was consist of minerals like Plagioclase, Quartz with variation of alkali feldspar from microcline to orthoclase dominence., Biotite was present in all granitoids in the study area and there was variation in Hornblende.the quartz was showing Bulging recrystallisation in most of the specimens.

The rock ranges from metaluminous, plotted in I-type protolith for most of the sample to peraluminous which was plotting in S-type field. I-type calc-alkaline magma source is from within a continental volcanic arc. This magma was most likely produced by partial melting of hydrated lower crustal rocks.

All the rock samples are showing Cal-alkaline to Tholeiitic affinity. Also the rocks is showing $SiO_2$ content 59.44- 72.89%, Ferroan to magnesian variation reflecting to source from crustal to mantle origin this reflect to evolution of magma over time. The eock shows composition from Shoshonite series tp High-k Calic-alkali Series. The mali value for Sindhudurg granitoids ranges from Alkalic to alkalic-calaic to calc-alkalic. The rocks are result of remelting of I-type and S-type which formed A-type of granitoid, such rock are formed in post collisional setting.Post-collisional granitoids are typically metaluminous, meaning they have a balanced composition of aluminum ($Al_2O_3$) and silica ($SiO_2$).They belong to the I-type suite, which indicates a magmatic origin related to subduction or collisional processes

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