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Petrography And Engineering Behavior Of Gabbro-Norites; A Case Study From Dasu Dam Site, Northern Pakistan

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Abstract

The study area comprised the rocks of the Kamila amphibolite belt, which constitutes the southern portion of the Kohistan Island Arc. Field examinations and microscopic analysis of the representative samples divulge that the area comprises the two major lithologies, i.e. hornblende gabbro-norite and altered gabbro-norite. Altered gabbro-norite exhibit porphyritic texture and the grains are subhedral. Plagioclase (66-75%) is the common essential mineral of altered gabbro-norite while muscovite (3-4%), quartz (7-12%), epidote (10%), clino-zoisite (1%) and garnet (3-5%) are accessory phases. Hornblende gabbro-norite is medium to coarse-grained, containing plagioclase (22-47%), ortho-pyroxene (12-16%) and clino-pyroxene (13-20%) as essential minerals whereas amphibole (9-20%), muscovite (1-15%), quartz (7-11%) and a few opaque minerals are found as accessory phases. The mechanical properties of the investigated samples are also part of this study. These properties include unconfined compressive strength, unconfined tensile strength, water absorption, specific gravity and shear strength. The unconfined compressive strength of altered gabbro-norite is 133.76 MPa and unconfined tensile strength is 15.2 MPa whereas unconfined compressive strength of gabbro-norites is 79.92-106.4 MPa and unconfined tensile strength ranges from 15.2 to 31.92MPa. Both rock types can be used as dimension stone and construction materials because both have high strength values. Comparison of the rock strength with their petrographic features reveals that grain shape and size, mineralogical composition, alteration products and micro-fractures have remarkable impacts on the engineering behavior of the studied rocks.

Keywords: *Gabbro-norite; Kamila amphibolite belt; Kohistan island arc; mechanical properties; petrography.*

Introduction

The spectacular Himalayas are well known for their overwhelming peaks and majestic physiography. The investigated area falls in Dasu, district of Kohistan which is the part of the Kohistan island arc (K.I.A). Various types of geological features of the K.I.A attracted many global geoscientists to dig out the details of the area. However detailed physico-mechanical data on the rocks along the Dasu area is still lacking. This study aims to give an account of petrographic features and physico-mechanical characteristics of the rocks along the Dasu area. In addition to this, mechanical properties will be correlated petrographic data as grain size and shape, fabric, type of grain contact, mineralogy and degree of weathering affects the mechanical properties (Ahmed and Sajid, 2022). Fresh igneous and metamorphic rocks depicts high strength and excellent elastic deformation properties whereas the increase in grain size in igneous rocks negatively impacts strength (Sajid et al., 2016).

Regional Geology And Tectonics

Three distinct tectonic domains, i.e. the Eurasian plate in north, K.I.A and the Indian plate in south constitutes northern Pakistan. Sea floor spreading, continental drift and sub-sequent collisional created the gigantic Himalayas (Sajid et al., 2018). The K.I.A is the product of intra-oceanic subduction if Neo-Tythes during Cretaceous displaying lowermost crustal and adjacent mantle rocks (Ali et al., 2020; Hussain et al., 2020). Main Mantle Thrust (MMT) separates Indian plate from K.I.A whereas Main Karakorum Thrust (MKT) marks the northern edge of K.I.A (Ali et al., 2020). Meta volcanics, meta sediments and plutonic rocks constitutes K.I.A. The Spat and Jijal complexes depict the upper mantle portion of the K.I.A whereas amphibolite facies of Kamila represents the lower to middle crustal rocks of K.I.A (Hussain et al., 2020). Three stages of rocks can be found in K.I.A i.e. stage 1 rocks are subduction related and mainly composed of tonalite, gabbro and diorite. Stage 2 rocks are diorites, granites and leucogranites whereas stage 3 rocks are aplite-pegmatites (Jagoutz et al., 2018).

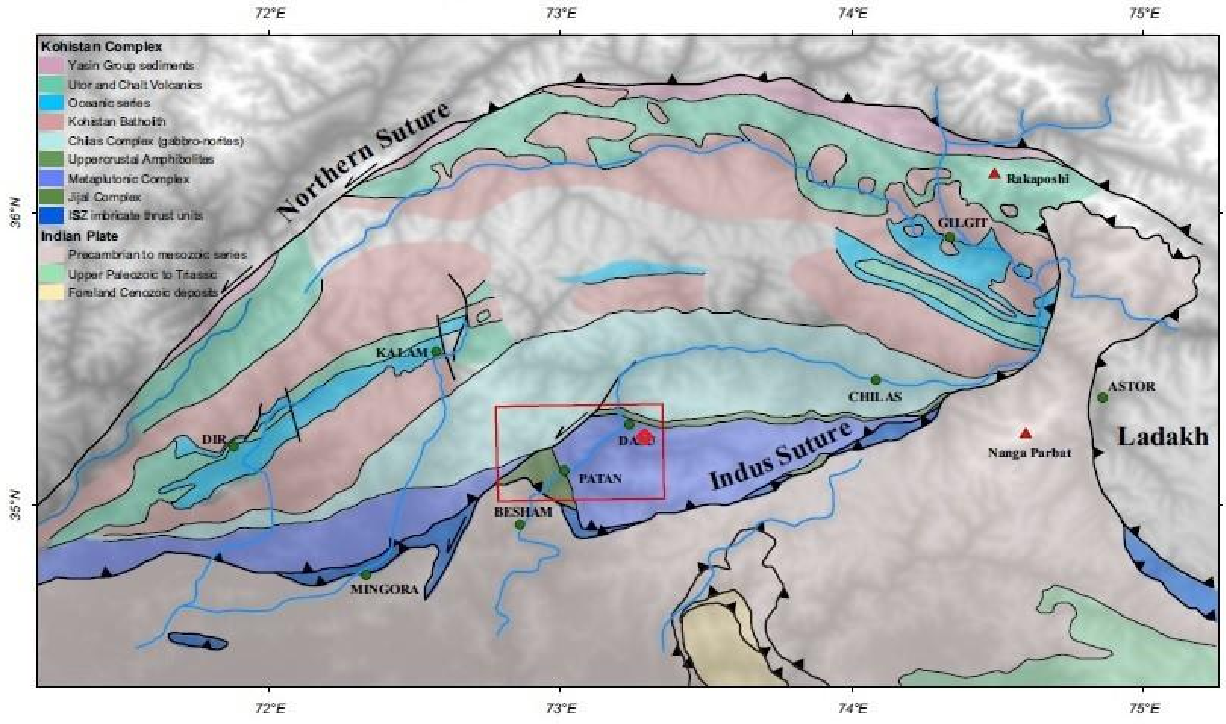

Fig. 1 Geological map of northern Pakistan. The red spot in square box shows location of studied samples (After Dipietro and Pogue, 2004).

Methodology

Detailed fieldwork was carried out along the study area. During field work different geological features were observed. Six core rock samples were collected to determine the strength and petrographic analysis. Ten thin sections were prepared in the Department of Geology, University of

Peshawar, Pakistan. According to ASTM standards, six cylindrical rock core samples were collected by drilling from the outcrop to determine the rocks' mechanical properties along the study area. Later on, these core samples were dried at 90-100°C to remove the moisture content. Then these samples were tested for unconfined compressive strength and unconfined tensile strength using the universal testing machine at the Material Testing Laboratory, Department of Mining Engineering, University of Engineering and Technology, Peshawar. Mohr's circle diagram is used to estimate the values of cohesion (c) and angle of internal friction (θ).

Field Features

Studied igneous rocks are part of the Kamila amphibolite belt, predominantly composed of meta-volcanic and meta-plutonic rocks. The studied rocks constitutes Gabbro-norite and altered gabbro-norites which are medium to coarse-grained. Small-scale s and z type folds and faults are also observed (Figure 2).

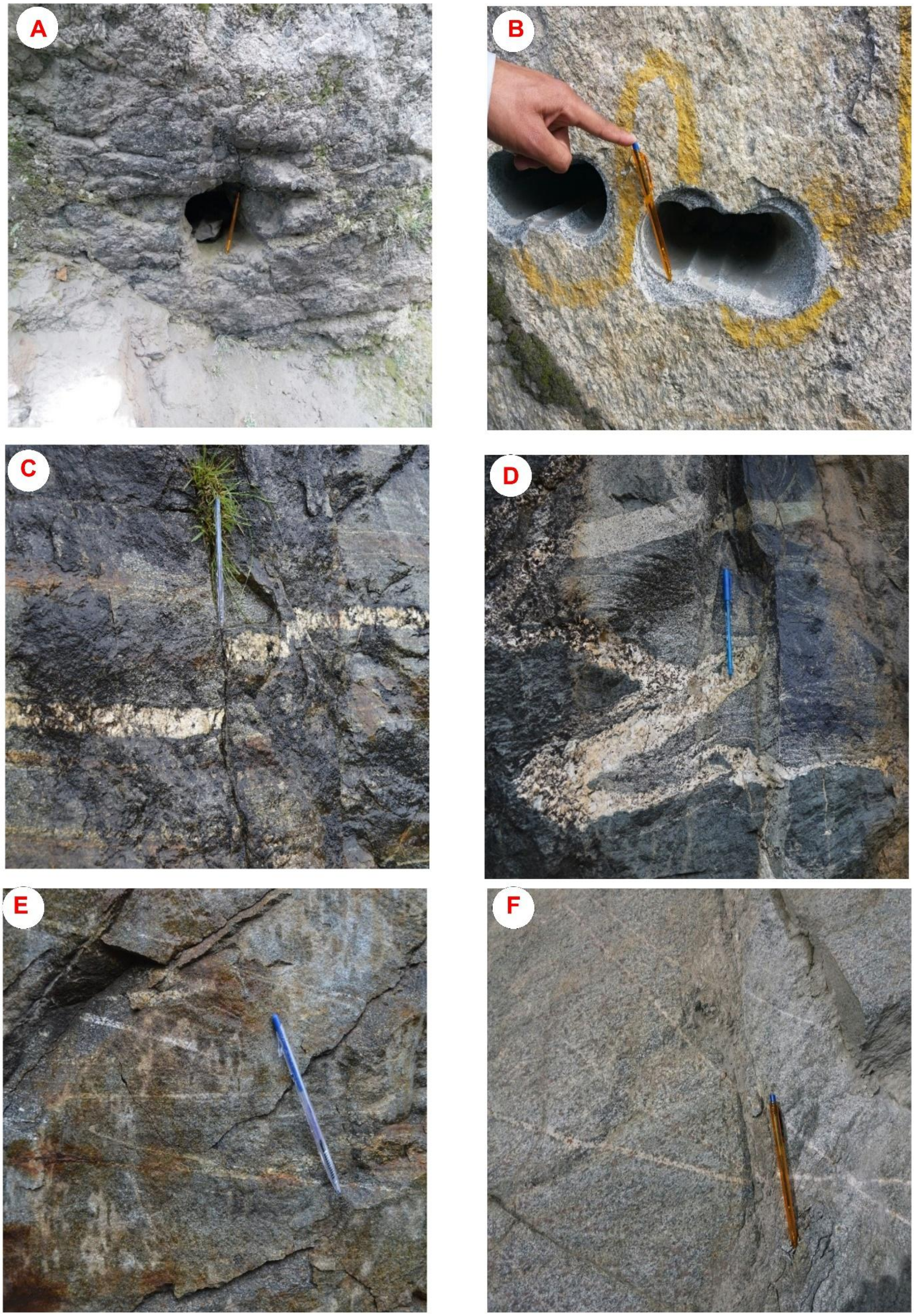
A
B
C
D
E
F

Fig. 2 (a) Field photographs showing medium to fine grained gabbro-norite; **(b)** samples cored from the outcrop; **(c)** small scale fault **(d)** z type folding **(e)** Fractures with s and z-type folding **(f)** Quartz veins showing cross-cutting relationship in hornblende gabbro-norite.

Petrography

Petrographic features includes textures, grain size, identification of minerals and modal mineralogical composition. For this purpose ten representative rock-thin sections were prepared. Petrographic investigation led to categorizing of the studied rocks into altered gabbro-norites and hornblende gabbro-norites.

Altered Gabbro-Norites

Microscopic examinations suggest that plagioclase is the most abundant mineral in the rocks ranging from 66 to 75% (Table 1). It is subhedral, coarse-grained and depicts polysynthetic twinning (Figure 4f). Plagioclase is mainly altered into clays, clino-zoisite, epidote and micas. A Considerable amount of quartz is also observed showing undoluse extinction. Garnet is also there as poikilioblasts. Epidote grains are subhedral and show zoning (Figure 4b). Mineral grains other than plagioclase are fine to medium-grained.

Hornblende Gabbro-Norites

Plagioclase, ortho-pyroxene, clino-pyroxene and hornblende occurs as essential minerals, whereas quartz, muscovite, actinolite, biotite and opaques occur as accessory minerals in these rocks. In these rocks plagioclase is most common ranges from 21% to 45%, mostly fine to medium grained and subhedral to euhedral (Figure 5.B, b). Ortho-pyroxene ranges from 12% to 16%, subhedral and medium to coarse-grained (Figure 5.A. a, b, c). Few ortho-pyroxene grains altered to chlorite and quartz showing symplectic intergrowth. Ore minerals occurs as inclusions in ortho-pyroxene grains (Figure 5-b). Some grains of ortho-pyroxene show extensive chloritization such that chlorite leaves behind only relics of ortho-pyroxene. The modal abundance of clino-pyroxene is 9-20%, medium to coarse-grained. Few grains are converted into chlorite and amphibole at the margins (Figure 5-d). Some of grains mostly altered into amphibole and clino-pyroxene occurs as relics like ortho-pyroxene. Both ortho-pyroxene and clino-pyroxene exhibit irregular fractures. Amphibole occurs as medium to coarse grained, subhedral and subequigranular. It ranges from 9 to 20%. Few amphibole grains contain ortho-pyroxene and tiny grains of opaque minerals as inclusions. Chloritization is a remarkable feature of the amphibole (Figure 5.A., b, d).

Table. 1 Modal mineralogical composition of the studied rock samples from Dasu dam site.

Sample No	Plg	Opx	Cpx	Qtz	Amp	Mus	Bt	Epi	Zst	Grt	Cly	Ore
Altered Gabbro-Norites												
G1a	66.6	0	0	11.8	0	3.8	0	10.6	1	5	1.2	0
G1b	74.8	0	0	6.8	0	3	0	10.2	0.8	3.4	0.4	0.2
Hornblende Gabbro-Norites												
G2a	22.4	15.4	13.4	10.4	15	14.8	0	0.2	0	0.4	0	8
G2b	21.6	16.4	13.8	8.6	20.2	12.6	0	0	0	0	0	6.6

G3a	27.6	12.8	13.2	15.2	18	8.2	0	0	0	0	0	5
G3b	25.4	12	16	10.8	19.2	8	0	0	0	1.6	0	7
G4a	31.6	15	19.6	7.6	9	11.2	1.6	0	0	1	0	2.8
G4b	31.2	12.6	17	10.6	12.2	7.8	3	0.4	0	0	0	5.2
G5a	44.6	12.6	13.2	8.6	13.6	1.8	0	0	0	0	0	6.2
G5b	43.8	12	14.2	9.4	12.6	1.6	0	0	0	0	0	6.4

Qtz= Quartz, Plg= Plagioclase, Opx= Ortho-pyroxene, Cpx= Cpx-pyroxene, Amp= Amphibole, Mus= Muscovite, Bt= Biotite, Epi= Epidote, Zst= Zoisite, Grt= Garnet, Cly=Clay.

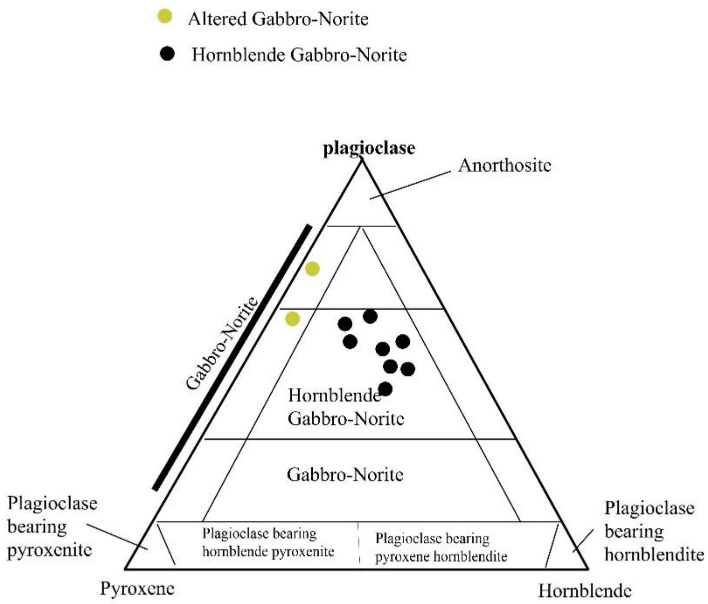

Fig. 3 Modal composition of the studied rocks plotted on the IUGS classification diagram (from Le Maitre, 2002).

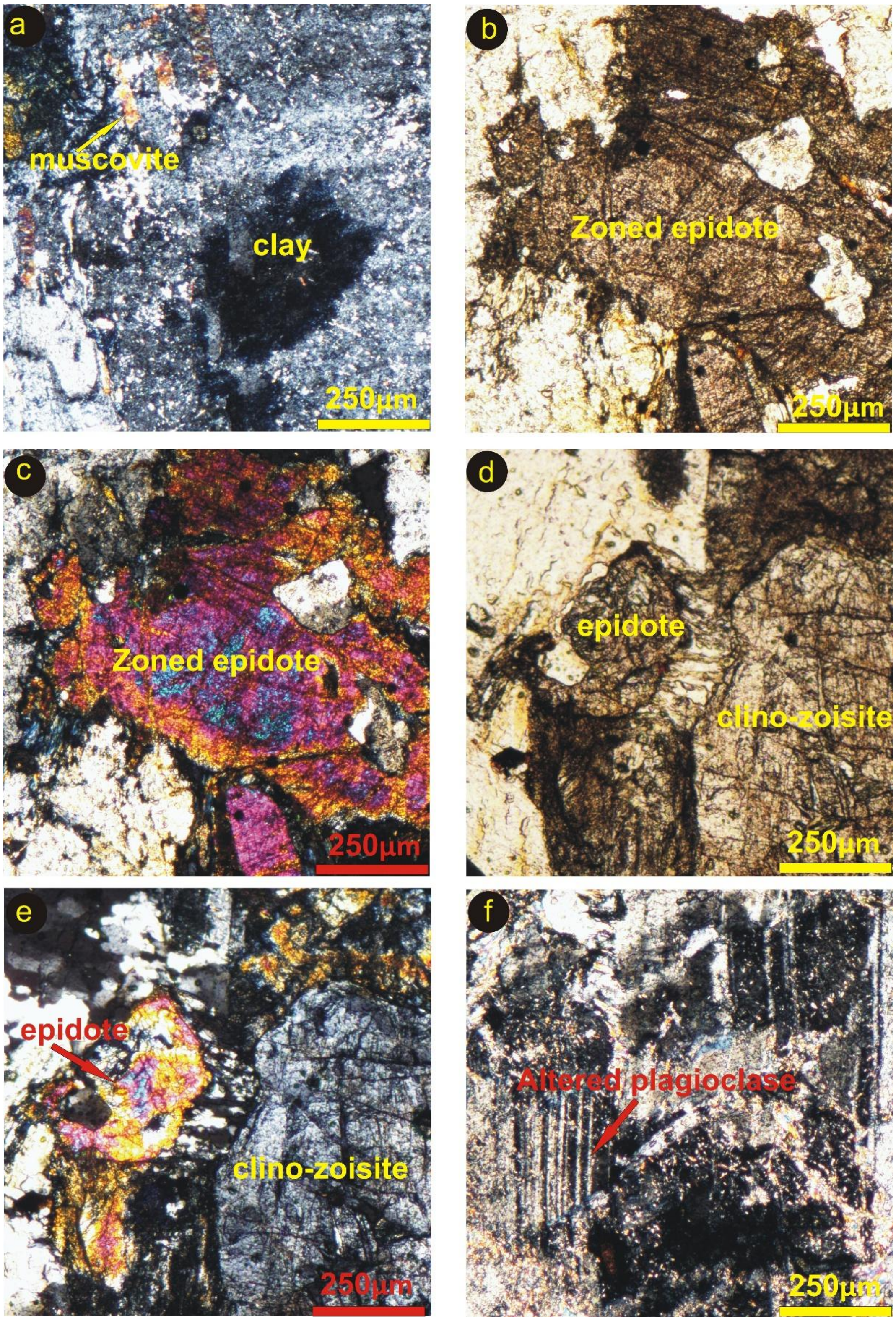

Fig. 4 Microphotographs of altered gabbro-norites showing **(a)** microphotograph showing clays and muscovite in fine grained matrix; **(b)** zoned epidote (PPL); **(c)** zoned epidote (XPL) **(d)** epidote and clino-zoisite (XPL) **(e)** epidote and clino-zoisite (PPL); **(f)** plagioclase alter to sericite.

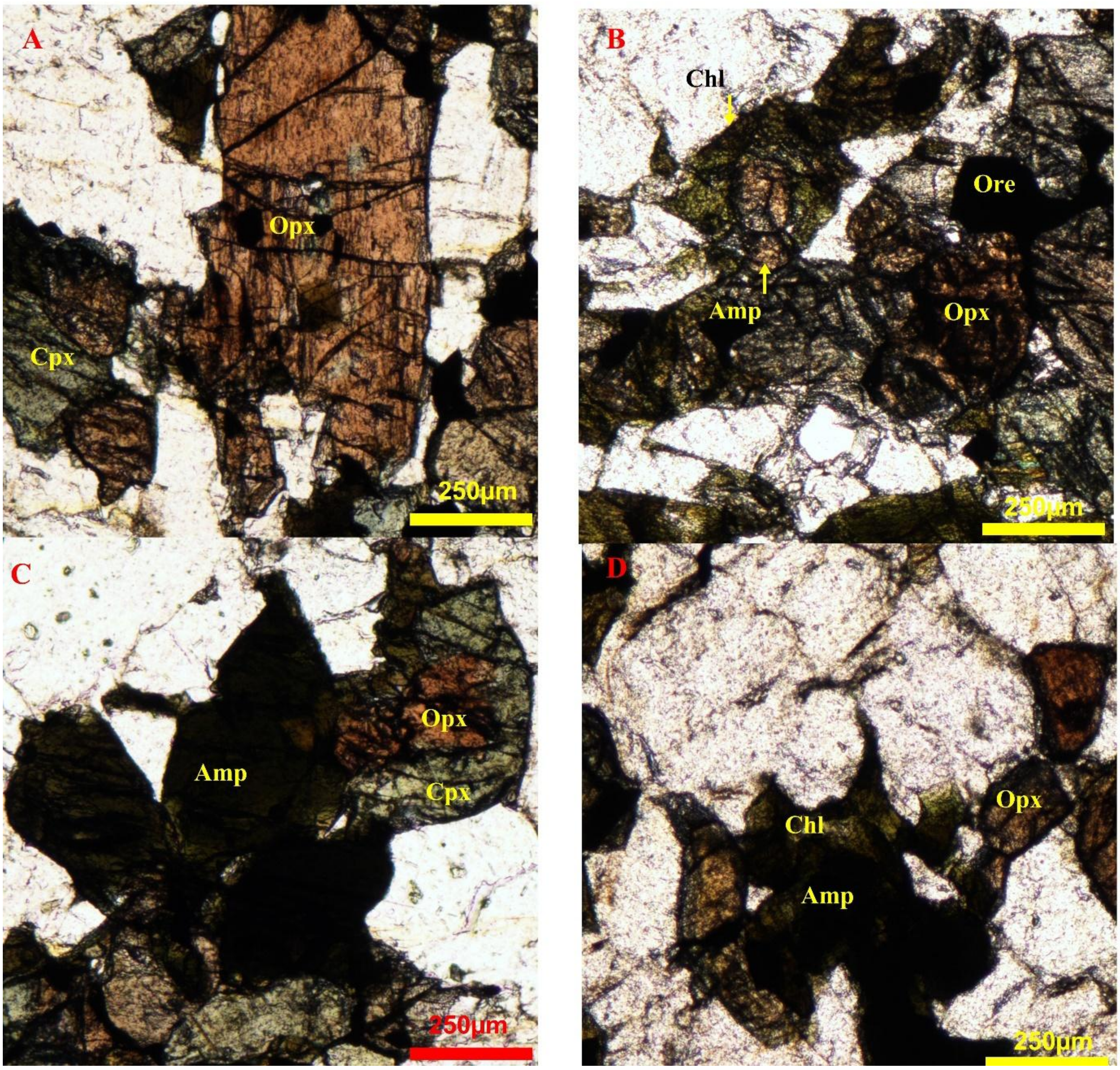

Fig. 5.A (PPL) Microphotographs of altered gabbro-norites showing **(a)** amphibole containing ores and clino-pyroxene (cpx); **(b)** amphibole altered to chlorite, ortho-pyroxene (Opx) **(c)** amphibole, ortho-pyroxene altered to clino-pyroxene **(d)** amphibole altered to chlorite, ortho-pyroxene.

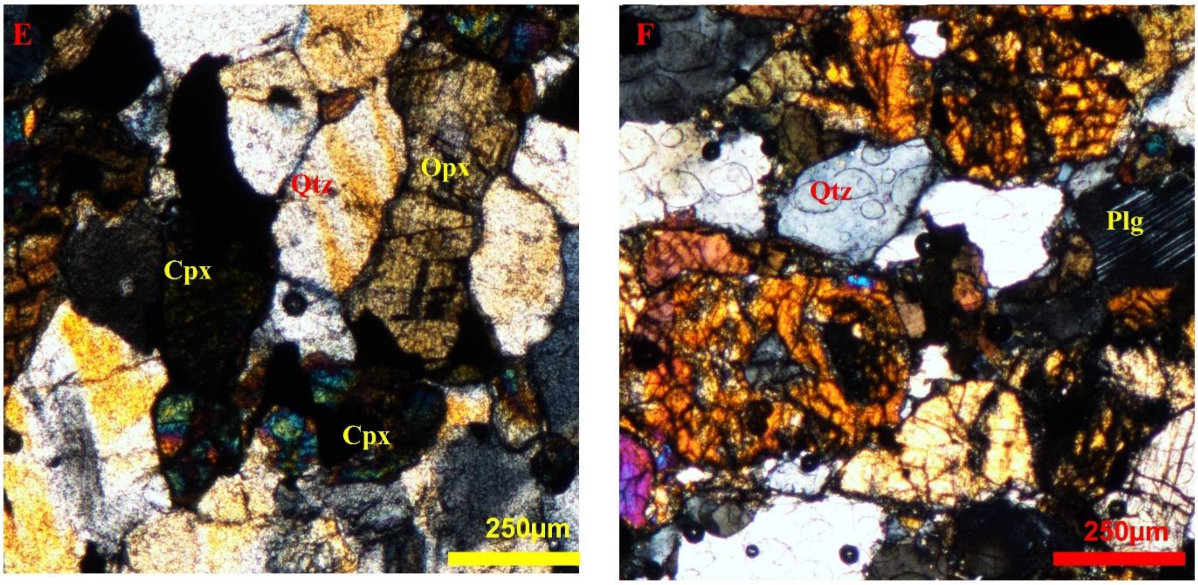

Fig.5.B (XPL) (E) ortho-pyroxene, clino-pyroxene and quartz **(F)** quartz, hornblende (Hbd) and plagioclase (plg)

Physico-Mechanical Properties

Strength

Unconfined compressive strength (U.C.S) and uniaxial tensile strength (U.T.S) of the petrographically analyzed samples of altered gabbro-norites and hornblende gabbro-norites were calculated in the laboratory. Six core samples were drilled from the outcrop. The cylindrical samples were prepared according to ASTM standards.

Unconfined Compressive Strength (U.C.S) (ASTM D-3829)

Also known as uniaxial compression test (U.C.T) or uniaxial compressive strength. One core sample of altered gabbro-norite and five specimens of gabbro-norite were investigated for U.C.S. The U.C.S values of hornblende gabbro-norites show moderate variations (69.92-106.4 MPa) (Table 2). In contrast U.C.S value of altered gabbro-norite is 133.76 MPa (Table 2).

Unconfined Tensile Strength (U.T.S)

There are two principal methods to calculate U.T.S i.e. direct method and indirect method. For this study indirect method also known as Brazilian method (ASTM, 1986) was utilized as it is much simpler and inexpensive than the former one. U.T.S values of the samples are much lower than their U.C.S values (Table 2).

Water Absorption (ASTM C-127)

It is defined as the amount of water that rock can absorb. Rocks exposed to the surface have more chances to absorb water, which trigger the rate and degree of weathering. Mechanical failure may occur due to consistent hydration and dehydration (Bell, 2007). Water absorption values of the investigated samples are 0.3 for both varieties.

Specific Gravity (ASTM C-127)

The specific gravity of the altered gabbro-norites and hornblende gabbro-norites are 2.9 and 2.79 respectively. Tendering of rocks due to water absorption is dependent on rock origin. Swelling of rocks has a negative impact on density and strength and it is very significant in controlling the engineering behavior of rocks

.

Table. 2 Results of UCS and UTS, UTS to UTS ratio, values of shear strength.

Sample No	U.C.S (MPa)	ISRM rating	U.T.S (MPa)	U.C.S:U.T.S	Cohesion (C) (MPa)	Angle of Internal Friction (θ)	C:U.T.S
				Altered gabbro-norites			
G1	133.76	High	15.2	8.8	22.527	53°	1.48
				Gabbro-norites			
G2	80.56	Medium	31.92	2.52381	25.33	26°	0.79
G3	88.16	Medium	15.2	5.8	18.3	45°	1.20
G4	92.72	Medium	22.8	4.06667	22.98	37°	1.01
G5	106.4	High	21.28	5	23.77	42°	1.12
G6	79.92	Medium	22.8	3.50526	19.96	31°	0.88

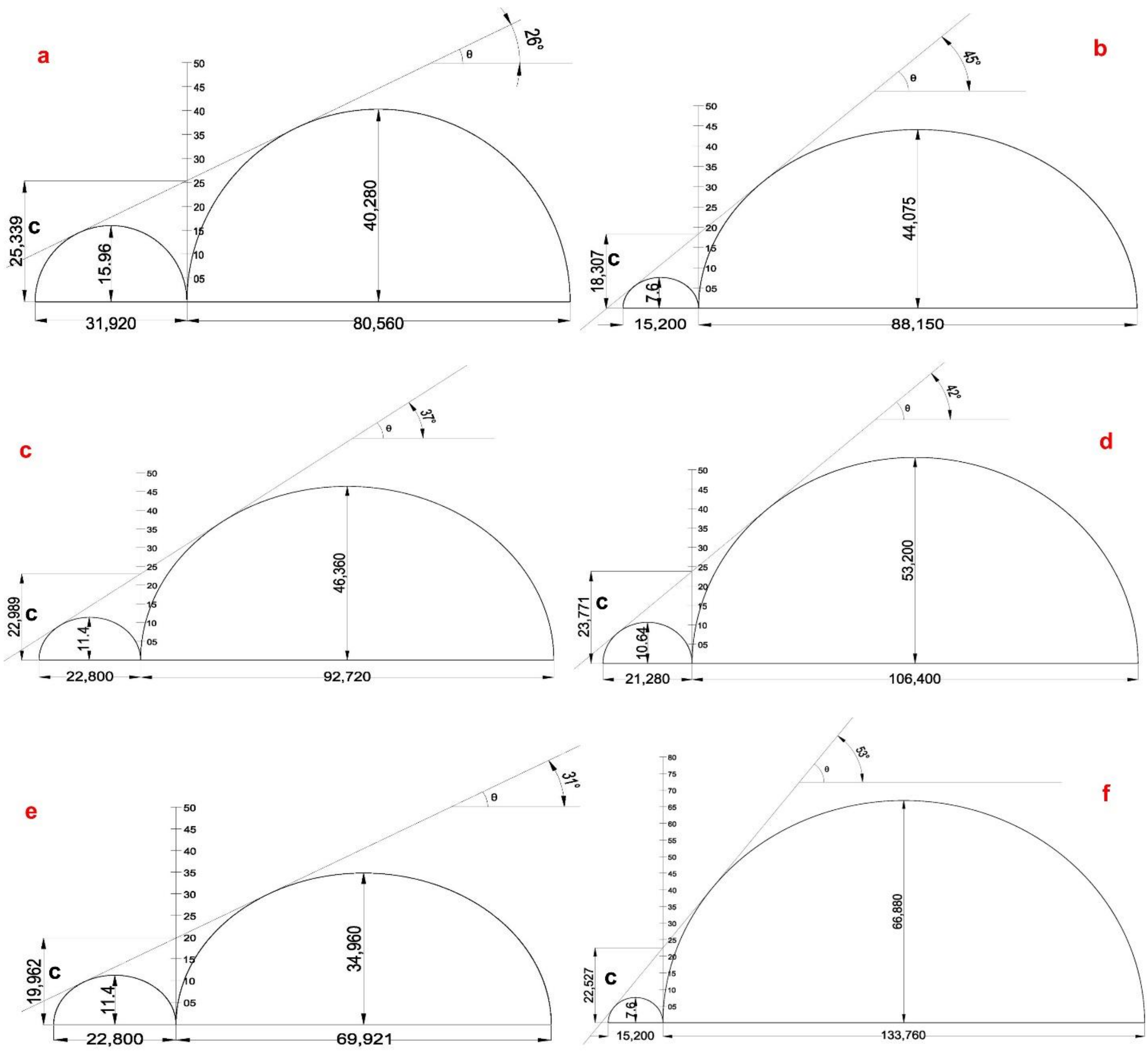

Fig. 6 Measurement of shear strength from U.C.S and U.T.S through Mohr's circle diagram.

Discussions

U.C.S is eight times more than the U.T.S of rocks (Brady and Brown, 2004), whereas Farmer (1983) proposed this ratio to 10:1. But the current study does not support the statement. The U.C.S to U.T.S ratio is less than 8 for the hornblende gabbro-norites where it is 8.8 for the altered gabbro-norite. Similarly the cohesion to UTS ratio also falls below the required range (=2) for both rock types. There may be two possible reasons for this (i) U.C.S values are underestimated (ii) U.T.S values are overestimated. But these values are genuine suggesting to extend the lower limits of U.C.S to U.T.S and cohesion to U.T.S ratios. However limited amount of data presented here hinders for the suggestion to extend the lower limits. The engineering attitude of rocks mainly relies on the petrographic features of the rocks (Sajid et al., 2016). Rock strength can be influenced by the twinning planes, cleavages, micro-fractures and interlocking pattern of grains. Microscopic to mesoscopic veins, mineral alteration, foliations, lineations and mineral alignment act as discontinuity and have significant impact on mechanical properties of rocks (Ali et al., 2020). In general coarse grained rocks have less strength as compared to fine grained varieties. Additionally idioblastic or equigranular rocks are more susceptible for fragmentation and wearing as compared to those with the large grain size range (Lindqvist et al., 2007).

Rocks with subhedral to anhedral mineral grains have more strength than rocks with euhedral grains (Lindqvist et al., 2007). As in xenoblastic texture, the grain boundaries are irregular, giving more strength to the rock (Åkesson et al., 2003). Similarly weathering and alteration products of minerals also play a vital role in the mechanical behavior of rocks. Generally, clays are the most common alteration product of plutonic rocks and make the rock more durable (Ahmed and Sajid., 2022).

Metamorphic textures also contribute in rock strength. Aligned micas and clays strongly influence the mechanical behavior of rocks as compared to those which have other aligned minerals. Irregularly aligned sheet silicates have less cogent impact as aligned micas act as discontinuity along which rupture can easily initiate and propagate (Sajid et al., 2009). Strength of rocks increases when applied stresses are parallel to pervasive slip layers and vice versa (Ali et al., 2020).

Compositionally the investigated hornblende gabbro-norites and altered gabbro-norites are identical i.e. both are mafic. Hence both rock types are expected to have comparable strength and will fall in similar rock categories according to Hoek and Brown (1997). But the investigated samples depict a remarkable difference between the strength values of genetically identical rock types. Mineralogical variations, degree of weathering and textures may be the reasons for this difference.

As the altered gabbro-norites are fine to coarse-grained and hornblende gabbro-norites are medium to coarse-grained. That's why the former shows higher strength as compared to later. Further altered gabbro-norites have subhedral grains of plagioclase while on the other hand hornblende gabbro-norites have subhedral to euhedral plagioclase grains. Both the rock

types have considerable amount of muscovite which is randomly oriented and hence has no prominent effect on strength.
The presence of epidote, clino-zoisite and a considerable amount of quartz and the complete absence of pyroxene in altered gabbro-norites, has probably given higher strength of the altered gabbro-norites. Conversely, the hornblende gabbro-norites contains high temperature phases i.e. clino and ortho-pyroxene which are much sensitive for chemical weathering (Sajid et al., 2016). Furthermore both (clino and ortho-pyroxene) have irregular fractures. All these factors may contribute to the lower strength of the gabbro-norites.

Conclusions

Above discussion can be concluded as

- Hornblende gabbro-norite and gabbro-norites have low water absorption, high strength and specific gravity. So both are suitable for constructional material and dimension stones.
- The U.C.S to U.T.S ratio of the altered gabbro-norite follow the recommended range, whereas this ratio falls below the lower limit of the required range for the gabbro-norites.
- The mechanical strength of the altered gabbro-norite is higher than the gabbro-norite. Detailed observations suggest that, the texture and mineralogical variations are responsible for this difference in strength.

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