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Petrography, geochemistry and physico-mechanical properties of dolerite from Oghi (Mansehra), Khyber Pakhtunkhwa, Pakistan

Muhammad Ismaeel[1], Muhammad Naveed Anjum[1*], Waqas Ahmed[2], Amjad Hussain[3] and Muhammad Sajid[1]

[1]Department of Geology, University of Peshawar, Pakistan
[2]National Centre of Excellence in Geology, University of Peshawar
[3]School of Earth Resources China University of Geoscience Wuhan ,China
**Correspondence author's email: naveed_geo@uop.edu.pk*
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Abstract

Dolerite dykes having excellent exposures around Maira Chanser and Jodan Khatta areas of District Masehra are studied in terms of their suitability for aggregates and dimension stone using a combination of petrographic, geotechnical and geochemical characteristics. Petrographically, these rocks, known as black granites in commercial market, are fine to medium-grained having ophitic to sub-ophitic texture. Plagioclase and clinopyroxene occurs as the major mineral phases, whereas opaques, quartz, biotite, amphibole, olivine, apatite, chlorite, orthopyroxene and epidote constitute minor to accessory phases. Geochemically, these dolerites show sub-alkalic, metaluminous, tholeiitic to alkalic basalt character and fall in gabbroic category. These rocks have relatively high TiO_2 contents and are ferroan in nature. The geotechnical properties such as unconfined compressive strength (32702psi-34965psi), unconfined tensile strength (485psi - 535psi), specific gravity (3.109 and 3.169), water absorption (0.14% - 0.61%), loss Angeles abrasion (17.34% - 17.36%), soundness (13.86 - 14.31), and flexural test values (30.065 N/mm^2 - 30.066 N/mm^2) show their suitability for construction work as aggregate for concrete and light foundation loads as well as indoor and outdoor dimension stones. The strength properties of all the studied samples have inverse ratio with the plagioclase content which is more probably due to perfect cleavage pattern of the plagioclase. The samples from Jodan Khatta show a relatively small grain size and fractured nature and demonstrate slightly weak mechanical properties as compared to Maira Chanser dolerite. Similarly, the Jodan Khatta samples show more alteration along their grain boundaries which have also affected their grain to grain relationship and thus have lower down their strength values. Moreover, their relatively fine-grained nature has also contributed to higher extent of alteration. The study confirms that mineralogical and textural variations have an important control on mechanical properties of the studied rocks.

Keywords: Dolerite, Petrography, District Mansehra, Mechanical properties, Aggregate, Dimension stone.

1. Introduction

Black dimensional stones are known as "black granites" in commercial market because of their strength and textural similarities to granitic rocks. Petrologically, these rocks are classified as gabbros, norites, diorites, dolerites (also known as diabase), basalts and anorthosites.

Dolerite is commonly used as concrete aggregate in sub-base material as well as dimension stone, due to its fine- grained texture, strong interlocking crystals and high toughness values (Arnold, 2010). The price of black dimensional stone in the international market generally in the range of 900-2,400 US$/m3. Among these, the dolerites of Uruguay (900 to 1,700 US$/$m^3$) and China (1,000 to 2,000 US$/$m^3$), gabbro/norite of the South Africa, (2,000 US$/$m^3$) and the iridescent norite of India (2,400 US$/$m^3$) are the notable ones. Generally, the price value of black stones depends on the intensity of black color and size of tile.

These rocks are usually found as smaller, relatively shallow intrusive bodies such as dykes, sills or as small boss and laccoliths intruded in country rocks (Bell, 2007). In Pakistan, basic intrusions are widespread in Pre-Permian sections between Khairabad thrust and Main Mental Thrust (MMT) including those of the Malka, the Ambela and the Othla areas (Pogue et al., 1992b). These rocks are quarried locally from Othla area and the study area of District Mansehra for use as dimension stone owing to its black iridescent color (Fig. 3-B). The study area includes Maira Chanser and Jodan Khatta deposits that lie between N

34°26′.744″ and E 072°58′.00″ and N 34°25′.296″ and E 072°54′.806″ respectively at an elevation of 3366 feet. In order to perform a feasibility study of any rock type, the petrographic analysis provides important insights about its mechanical behavior under stress by studying its grain size, grain shape, fabric, grain boundaries, mineralogical composition and weathering (Irfan, 1996). In case of a typical fresh igneous rock, texture and the mineralogy collectively reflect the strength and elastic deformation characteristics. The mechanical properties essential for determining rock suitability, include unconfined compressive strength (UCS), unconfined tensile strength (UTS), water absorption (WA), and specific gravity (Sp gr.), Loss Angeles abrasion (LA), soundness and flexture. The aim of this study is to evaluate dolerites, from selected areas of Hazara Division Pakistan, for their suitability as dimension stone as well as aggregate using the techniques of petrography, geochemistry and engineering properties.

2. Geology of the area

The Indo-Pakistan and Asian plates are directly in contact along the Indus-Tsangpo Suture Zone (ITS) in India and Nepal (Gansser, 1980), but are separated from one another by the rocks of the Kohistan arc sequence in NW Pakistan (Fig. 1). The area under investigation is a part of a well-known Mansehra granite, which stratigraphically belongs to Hazara Granitic Complex of Indian plate (Shams and Ahmed, 1968). Rocks of Hazara area including Hazara Complex lies in the southwest section of the Nanga Parbat that forms the eastern portion of northern edge of the Indo-Pakistan plate (Fig. 2). These rocks consist of Precambrian basement rocks that are unconformably overlain by metasediments of Phanerozoic time. The basement sediments are dominated by Precambrian metapelites and metapsammites, mainly the Abbottabad and Tanawal formations. In Cambrian time, these rocks were interrupted by porphyritic and coarse grained granites of Mansehra area. More than half of the Mansehra District is occupied by granitic rocks of varying types having different ages and that is why all granitic rock types have been grouped together into the Hazara granitic complex (Shams and Ahmed, 1968). Stratigraphically, the Hazara granitic complex is further sub-divided into Older granites and gneisses, Susalgali granitic gneiss, Mansehra granite, Andalusite granites and associated minor acid bodies, Younger tourmaline granites, dolerites and meta-dolerites (intruded in the older lithologies), Pre-granite metamorphic rocks (includes Hazara schistose group and Pelitic schistose-quartzite with meta-conglomerate bands.

Mineralogicaly, the Mansehra granite consists of variable amount of quartz, feldspar and micas and is not homogeneous in nature. It is intruded by dolerite dykes and sills at several places, mostly in the areas along Oghi-Darband road (study area). The dolerite dyke series are composed of dozens of parallel dykes with an average of about 100 meters length and 30 meters width. Petrographic observations and chemical analysis reveal the presence of supposedly similar basic intrusions between Khairabad thrust of Attock-Cherat Ranges and Main Mantle Thrust Zone (MMTZ) including those of Malka area and Othla areas. The Malka area dykes are considered to have intruded during Permian rifting of the northern portion of the Indian plate (Majid et al., 1991). Sajid (2012) has classified dykes of the Othla area into unaltered dolerites and altered mafic dykes. These basic intrusions are being mined locally, especially in the study area of District Mansehra, while in areas around Malka, Othla and Attock, these dykes/sills are smaller in size and are relatively more weathered and hence, not suitable to be used as aggregate and dimension stone. The dykes of Oghi-Darband areas are being quarried for dimension stones, since the early 1990s owing to their deep black color and granular texture and shimmering effect in light, enhancing its esthetic value.

Igneous activity within the Peshawar Plain Alkaline Igneous Province (PPAIP), which includes the Malka dolerites, has already been related to extensional tectonics within the NW Indo-Pakistan plate margin (Kempe and Jan, 1970; Rafiq, 1988). The Rb/Sr isochron data from Koga nephiline syenite within the Peshawar plain alkaline igneous province (PPAIP) of Peshawar Basin shows the time of rifting around 297-315 Ma. (Le Bas et al., 1987). The continental rifts are generally considered the zones of localized extension showing a broad spectrum of magma composition ranging from alkaline nature in major continental rift zones and transitional basaltic nature in areas of major crustal extension (Wilson, 1989; Bailey, 1983).

3. Materials and methods

A total of 19 fresh/less altered samples (including two block size and 4 tabular ones for tile making) were collected, from Maira Chanser and Jodan Khatta quarries (Fig. 3). Two representatives block sized samples, each having a volume of one cubic feet, were used for the extraction of six cylindrical cores (three from each bulk sample). After extraction of cylindrical cores from the block samples, the left over material were also crushed to obtain aggregates of appropriate sizes. Both the aggregates and the cores were then subjected to standard physical and mechanical tests for ascertaining their geomechanical characteristics at the National Centre of Excellence in Geology, University of Peshawar. A total of nineteen thin sections were prepared (including one from each core sample) for detailed petrographic investigation at the Department of Geology, University of Peshawar. Tiles were prepared for flexure test. Seven representative samples were analyzed at the Geoscience Advance Research Laboratories (Geological Survey of Pakistan) Islamabad for major element oxides through XRF (RIGAKU XRF-3370E) using pressed pellets. A set of international standards was alternately processed with each batch of five samples to monitor the precision and accuracy of the machine.

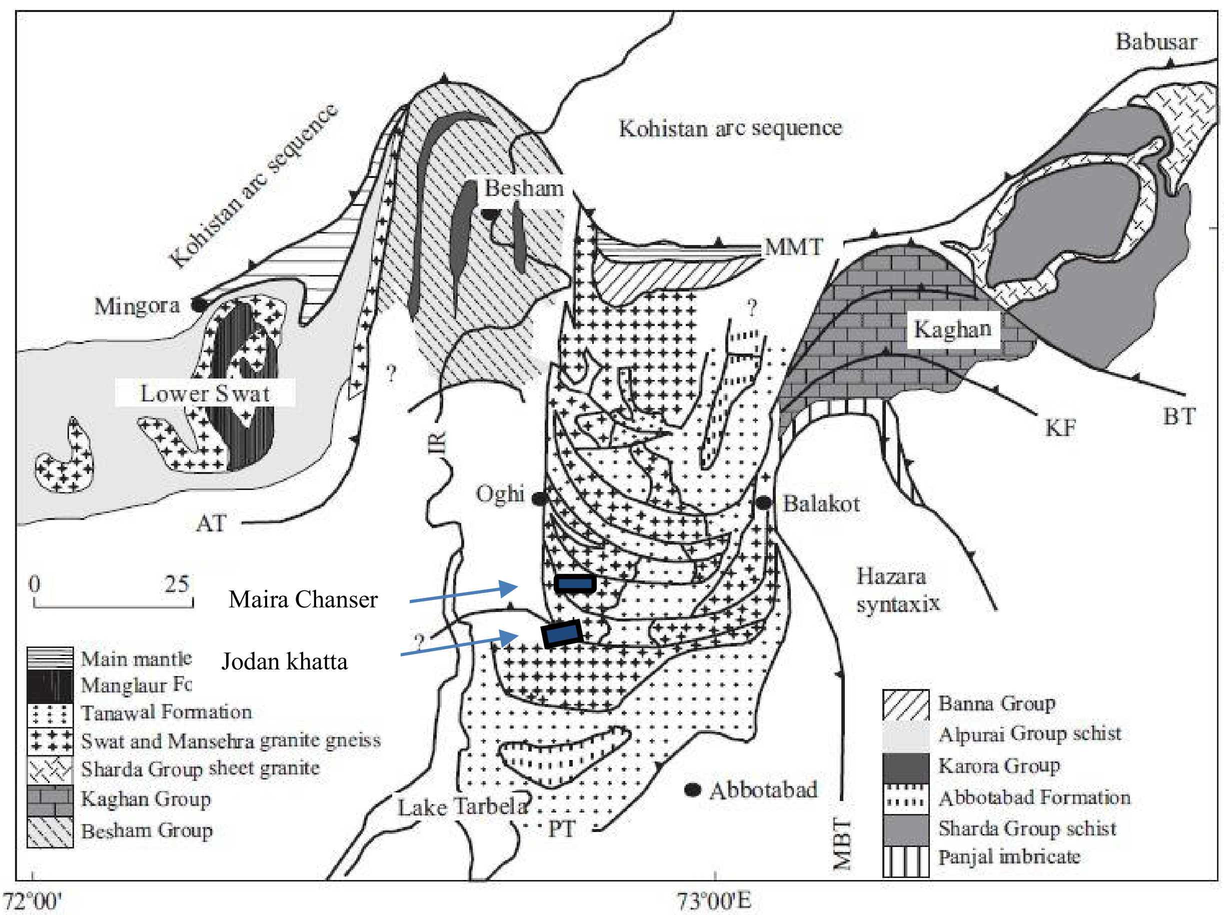

Fig. 1. Geological map of the study area, south of the Main Mantle Thrust (MMT) between the Swat and Kaghan valleys (Treloar and Rex, 1990). A T. Alpurai thrust; BSZ. Balakot shear zone; BT. Batal thrust; IR. Indus River; KF. Khannian fault; MBT. Main boundary thrust; MMT. Main mantle thrust; PJ. Panjal thrust; TSZ. Thakot shear zone.

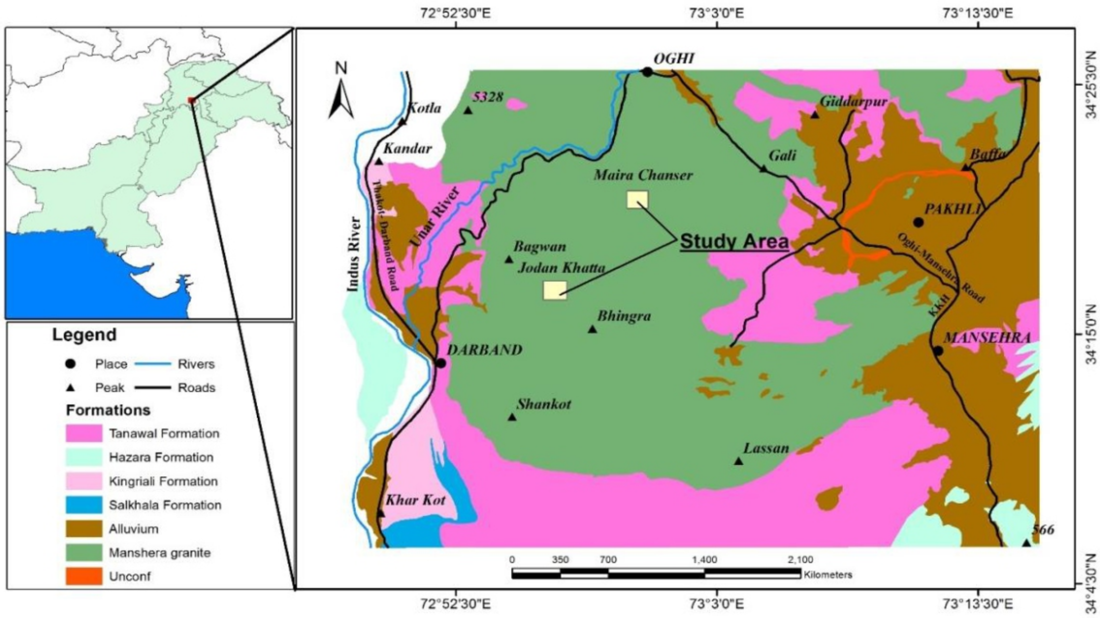

Fig. 2. Geological map of Hazara area showing various stratigraphic units (Calkins et al., 1975). Boxes in the map show the study areas.

4. Petrography

Megascopically, the studied mafic rocks are massive looking/huge in size and their color varies from greenish black to black. Petrographically, these dolerites are fine to medium-grained with plagioclase and clinopyroxene as the dominant minerals. Modal mineralogy shows that they are more or less uniform in mineral contents and consist of plagioclase (45-50 % volume), clinopyroxene (30 to 35% volume), quartz (1-7% volume), biotite (3-5% volume), amphibole (1-2% volume) and accessory amounts of olivine, garnet, apatite, chlorite orthopyroxene, epidote and opaque ores (Table1, Fig. 4).

Texturally, these rocks are sub ophitic to ophitic and rarely porphyritic (Fig. 4C). The plagioclase laths are randomly oriented and some grains show dusty appearance under plane light due to partial alteration to clays and sericite, most commonly along the cleavage planes. Majority of the plagioclase shows characteristic twinning (Fig. 4A). Clinopyroxene is the second most abundant mineral in these rocks where it is found either as aggregate or as discrete grains distributed throughout the matrix (Fig. 4C). Clinopyroxene (Augite) grains (Fig. 4B) have relatively coarse size and irregular shape with anhedral to subhedral nature. These grains are also found in the form of phenocryst which imparts porphyritic texture to these rocks (Fig. 4D).

5. Major elements geochemistry

The major element compositions of 07 samples from both locations (Maira Chanser and Jodan Khatta) were selected for their geochemical characterization (Table 2). The chemical analysis reveals that these dolerites display a narrow spectrum of SiO_2 content (47.67-49.51 wt. %). In igneous rocks, in order to see the mutual relationship and to identify leading process, e.g. fractionation, correlation binary variation diagrams are constructed between SiO_2 and other major oxides. Their TiO_2 (1.45-2.59 wt. %), Fe_2O_3 (11.82-15.36 wt. %), Al_2O_3 (14.03-14.70 wt. %), Na_2O (1.37-1.69 wt. %), K_2O (0.30-0.82 wt. %), P_2O_5 (0.09-0.41 wt. %), MnO (0.17-0.21 wt. %) contents display negative correlation against SiO_2 whereas MgO (6.80-7.71 wt. %), CaO (9.90-12.56 wt. %) contents show a positive trend with SiO_2 (Fig.6.3). According to the classification diagram of Cox et al. (1979) (Fig.5A) the studied rocks lie in the field of Gabbro and shows subalkaline nature.

Similarly, AFM (Fig. 5B) diagram (Na_2O+K_2O-FeOt-MgO) shows that these rocks are tholeitic basalt to alkalic basalt. The Fe number ranges from 0.61-0.69 and hence the studied dolerites can be classified as ferroan.

Fig. 3. Field photographs (A) Dolerite dyke within Mansehra Granite showing their sharp contact. (B) A showing massive character of quarried block of dolerite.

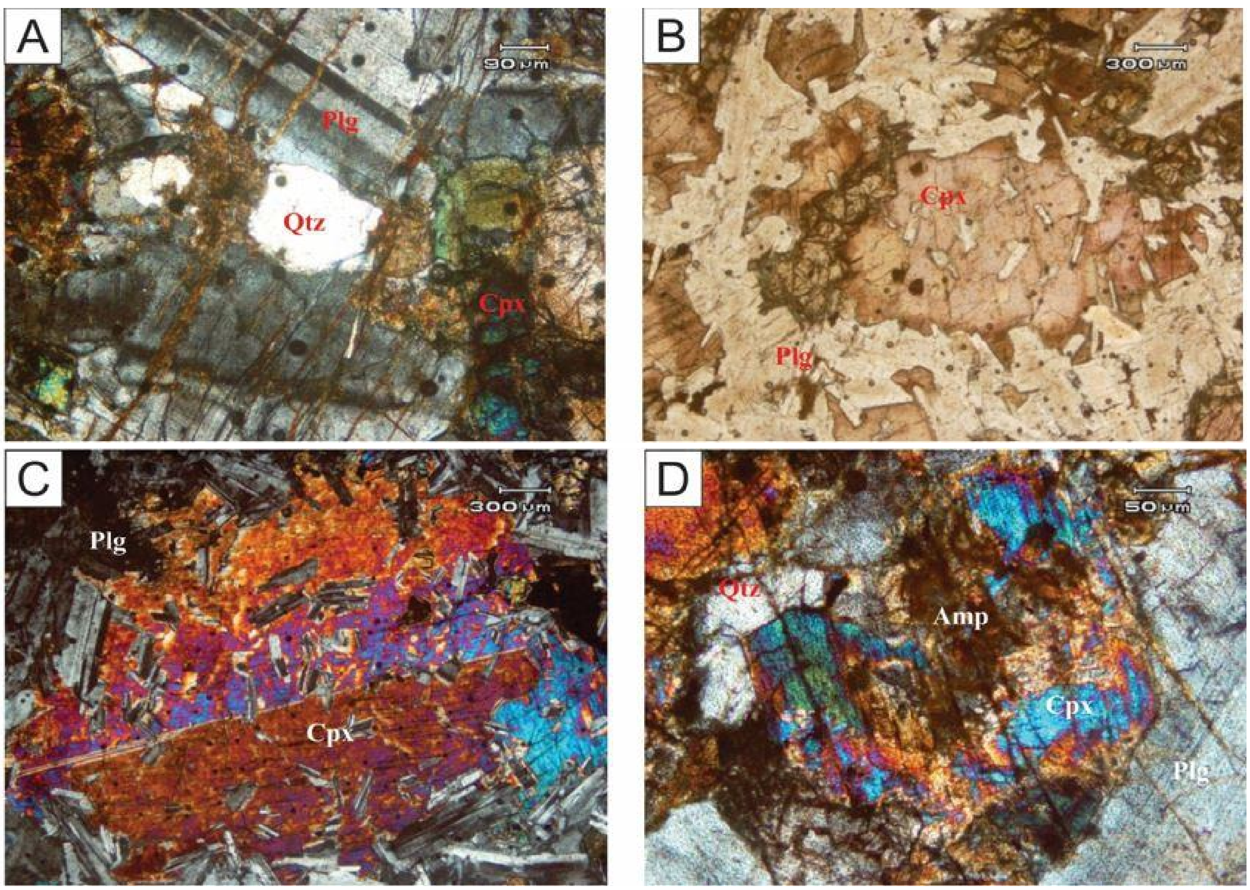

Fig. 4. Photomicrographs showing, (A, XPL) plagioclase grain showing albite polysynthetic twining, quartz inclusion also visible, (B, PPL) showing ophitic texture, where clinopyroxene phenocryst is enclosed by tiny laths of plagioclase. Plagioclase laths show slightly dusty appearance due to alteration to clays and sericite, (C, XPL) Sub-ophitic texture where single twinned clinopyroxene grain is partly enclosed by plagioclase laths. (D, XPL), grains of clinopyroxene partially altering to amphibole. Intergranular fractures are also observable.

Table 1. Showing modal mineralogy of the studied rocks.

	S. No.	Sample	Plg	Cpx	Opq	Biot	Olv	Apt	Qtz	Chl	Amp	Opx	Epi
MAIRA CHANSER	1	M1	54	28	6	..	..	..	6	2	2	2	..
	2	M2	55	36	2	1	1	1	2	1	1	...	1
	3	M3	60	31	6	..	..	..	2	1	1	..	..
	4	M4	57	33	3	1	..	1	2	..	..	..	..
	5	M5	56	33	3	1	..	1	2	2	..	..	..
	6	M6	59	33	4	1	..	1	5	..	..	..	..
	7	M7	54	31	5	1	3	1	4	1	..	..	..
	8	M8	61	26	5	1	..	1	5	1		..	..
	9	M9	55	28	7	1	..	..	7	1	..	..	1
	10	M10	57	25	7	1	1	..	7	1	1	..	..
ODAN KHATTA	11	J1	63	30	2	1	..	1	..	1	1	..	..
	12	J2	62	28	3	1	..	1	1	3	1	..	..
	13	J3	58	32	5	1	1	1	..	1	..	1	..
	14	J4	61	29	2	1	..	1	1	1	..	2	2
	15	J5	67	27	1	1	..	1	1	1	1	..	..
	16	J6	65	27	2	1	1	..	1	1	..	2	..
	17	J7	63	26	2	2	1	1	1	2	1	..	1
	18	J8	63	28	3	2	..	..	2	..	..	2	..
	19	J9	58	31	2	5	..	1	2	1	..	...	..

*Abbreviations: Plg= Plagioclase, Cpx= Clinopyroxene, Opq= Opaques, Biot=Biotite, Olv=Olivine, Grt=Garnet, Apt= Apatite, Qtz= Quartz, Amp=Amphibole, Opx= Orthopyroxene, Epi=Epidote

Table 2. Major oxides geochemistry (wt. %) of dolerites from the study area.

Samples	M-5	M-7	M-9	J-5	J-7	J-9	J10
SiO_2	47.67	49.51	47.78	49.42	49.51	48.65	47.7
TiO_2	2.59	1.67	2.53	1.45	1.46	2.07	2.5
Al_2O_3	14.7	14.62	14.54	14.03	14.09	14.58	14.5
Fe_2O_3*	15.36	11.82	15.28	12.75	13.05	13.43	15.25
MnO	0.2	0.17	0.21	12.75	0.19	0.18	0.2
MgO	6.8	7.71	6.83	7.36	7.27	7.24	6.86
CaO	9.9	12.5	10	12.5	12.5	11.3	9.9
Na_2O	1.57	1.37	1.61	1.59	1.42	1.67	1.71
K_2O	0.82	0.4	0.8	0.3	0.27	0.59	0.7
P_2O_5	0.39	0.12	0.41	0.09	0.1	0.26	0.37
LOI	0	0.06	0.03	0.13	0.13	0.02	0.02
Total	100	100	99.9	99.99	99.99	100	99.89
FeO/MgO	2.26	1.53	2.24	1.73	1.80	1.85	2.22
Fe_2O_3/Fe_2O_3+MgO	0.69	0.61	0.69	0.63	0.64	0.65	0.69

Note: Fe_2O_3 is calculated as FeOt

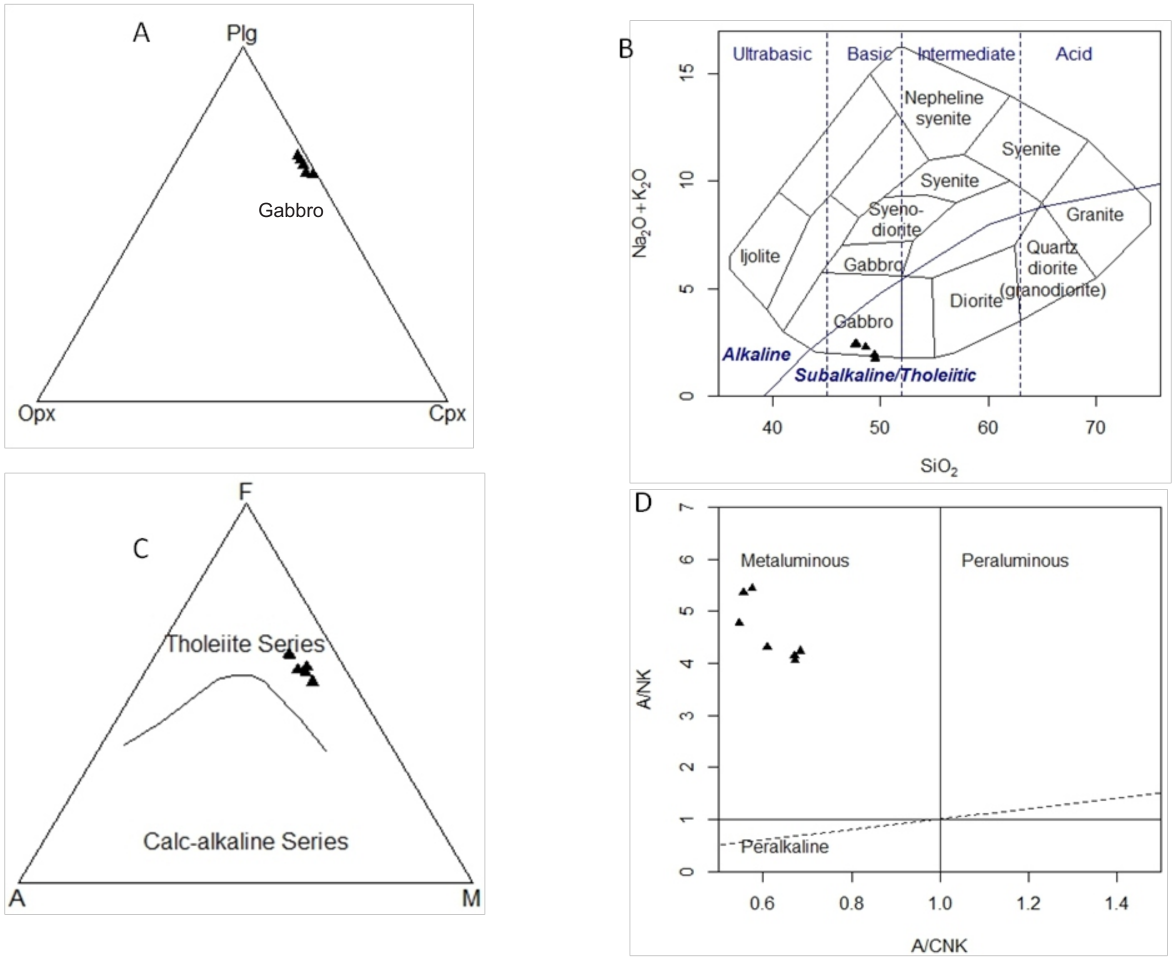

Fig. 5. (A) Modal composition of the studied dolerites plotted on the IUGS classification diagram (from Le Maitre, 2002). (B) Nomenclature of normal igneous rocks (after Cox et al, 1979). (C) AFM plot (after Irvine and Baragar, 1971). (D) Molecular Al_2O_3/(CaO+Na_2O+K_2O) versus Al_2O_3/(Na_2O+K_2O) diagram (Shand, 1943)

6. Evaluation of Physico-mechanical properties

The results of the physical and mechanical properties are listed in the Table 3 compressive strength (Designation 39/C 39M–03) values ranges from 34536- 35230psi (mean 30.34965 psi) and from 32405-32940psi (mean = 32702 psi) for the samples collected from Maira Chanser and Jodan Khatta areas respectively. The Overall Mean value is about 3383psi. According to the (Table 3) Tensile strength values ranges from 439–550psi for the samples with a mean value of 510psi. The estimated water absorption values (Water absorption; Designation C 121 – 90) are 0.06-0.95% (average value = 0.037 %). The total loss % (Loss Angeles Abrasion; ASTM C 131 – 03) for the aggregate of Maira Chanser is 17.34% and for the sample of Jodan Khatta aggregate is 17.36%. Specific gravity values (Designation, C 127 – 0) of the studied samples are in the range of 3.03–3.08 (average = 3.05). During soundness test [ASTM C 88 – 99a] the aggregate sample is repeatedly submerged in a saturated sodium sulfate solution followed by oven drying. The degree of unsoundness is expressed by the reduction in particle size after a specified number of cycles. Loss % for the samples of Maira Chanser is from (0.67-8.33; Table 4). Flexural test results show the values of 30.068N/mm^2, 30.067N/mm^2 and 30.065N/mm^2 of three different tiles from Maira Chanser (average = 30.066 N/mm^2) while that Jodan Khatta tiles shows the values of 30.066 N/mm^2, 30.065 N/mm^2, 30.064 N/mm^2 (average = 30.065 N/mm^2) [ASTM C 880 – 98].

Table 3. Showing geomechanical properties.

Property	M-5	M-7	M-9	J-5	J-7	J-9
Water Absorption (%)	0.25	0.12	0.06	0.95	0.57	0.31
Specific gravity	3.263	3.246	3.228	3.171	3.169	3.168
Tensile strength (Psi)	520	537	550	439	495	520
Compressive strength (Psi)	34536	35130	35230	32405	32760	32940
Tensile Strength (Psi)/Tensile strength	66.42	65.42	64.06	73.82	66.18	63.35

Table 4. Showing the results of soundness.

Group Name	area	Sieve No. (in)	Weight of sample before test (gm)	Sieves used to determine loss (in)	Weight of sample after test (gm)	Loss % (Result of soundness)
A	Jodan Khatta	2 ½ 2.00	2003.35 3013.7	1 ¼	4980	0.73
B		3/4 1.00	495.2 1006.80	5/8 (16mm)	1470	2.13
C		3/8 1/2	330.7 670.6	5/16 (8mm)	970	3.12
D		4	300	5	275	8.33
E	Maira Chanser	2 ½ 2.00	2001.35 3010.7	1 ¼	4978	0.67
F		3/4 1.00	492 1005.80	5/8 (16mm)	1467	2.05
G		3/8 1/2	333.08 671.5	5/16 (8mm)	973	3.14
H		4	300	5	276	8

7. Discussion

The dykes and sills of dolerite show greenish black to black color. In the study area, these rocks have cut across the rocks of Cambrian Mansehra granite. Field observations show that these dolerites are of two types i.e., weathered and compact. The weathered dolerites while exposure to weathering for a long period of time has altered their color and physio-mechanical properties. The compact dolerites are being mined for their use as dimension stone and civil work. No age difference is discernable between the two verities. On the basis of petrography, the un-weathered dolerite can be further classified into fresh and slightly-weathered varieties. These rocks are characterized by brecciation and jointing at places whereby facilitating the recovery of blocks without any blasting. Petrographically, these rocks are mainly composed of plagioclase, clinopyroxene as the essential minerals whereas orthopyroxene, opaques, quartz, garnet, biotite, chlorite, apatite and amphibole are forming minor to trace phases. Under thin sections, they show ophitic to sub-ophitic texture in which a larger grain of clinopyroxene encloses subhedral to anhedral laths of plagioclase (Fig. 4B). Main alteration products are clays, sericite and chlorite. The samples of dolerite from Maira Chanser and Jodan Khatta areas show a slight mineralogical (Table 1) and textural dissimilarities which have affected their physico-mechanical properties to a certain degree, e.g. the rocks of Maira Chanser have relatively lower plagioclase content as compared to Jodan Khatta which results in decrease of Loss Angeles abrasion values and hence have better mechanical strength as compared to the samples of Jodan Khatta (Table 3).

7.1. Suitability of studied rocks as dimension stones

The results of different investigated physical and mechanical tests are presented in Table 3. The igneous rocks having water absorption values less than 1% by weight can be used as a dimension or building stone because such a rock possesses significantly high resistance to weathering (Blyth and Freitas, 1974). The water absorption values range from 0.06-0.61% with a mean value of 0.037% that shows their suitability as a dimension stone. This difference may be because of the difference in the extent of fracturing.

Among the aggregate characteristics, the Loss Angeles abrasion (LA) values for coarse aggregate from Maira Chanser and Jodan Khatta areas are 17.34% and 17.36%, respectively that shows good toughness value as the maximum allowed value ranges up to 40% (ASTM C 131-03). During the soundness determination of the aggregates, no considerable change in volume of the aggregate is observed, i.e. 0.67-8.33% against the permissible limit (ASTM-88) in the range of 9-20. It is, therefore, exhibited that the aggregate will cause no deleteriousness to the concrete in the form of pop-outs or extensive surface cracking (due to changes in weathering conditions). The specific gravity values (3.245 and 3.169) for the two areas also show their suitability for construction purposes as well as a dimension stone. Similarly, the flexure test values (1.9467 and 1.9466 tons for Maira Chanser and Jodan Khatta areas respectively) also lie in the permissible limit as suggested by ASTM C 880-98.

7.2. Relationship between Petrographic and mechanical properties

Mechanical properties are controlled by petrographic and textural features of the rock (Sajid et al., 2016). The data of six core samples show a narrow range of variations in the values of strength, Loss Angeles abrasion, soundness, water absorption, specific gravity and flexural tests. The samples belonging to Maira Chanser have relatively lower plagioclase content (55% by volume, Table 1), and hence higher strength values (Table 3) as compared to the samples of Jodan Khatta (62.6 %). This relationship may be because of the perfect cleavage (twining) of plagioclase that apparently decreases the coherence of the rock. Similar, observations have also been made by previous workers (Gunsallus and Kulhawy, 1984; Tugrul and Zarif, 1999). The replacement of clinopyroxene by amphibole and chlorite in dolerite partly destroys their interlocking texture and hence may enhance the Loss Angeles abrasion values as well. Similarly, relatively high amount of ores and quartz may have contributed to the high strength values of MC (Tables 1 and 3).

Mean grain size is an important textural characteristic that influences the quality of aggregates. Most researchers have found that mechanical strength increases as the mean grain size decreases (Olsson, 1974; Brattli, 1992; Tugrul and Zarif, 1999). However, the present study shows deviation from this generalization and therefore, the dolerite of Jodan Khatta which are although fine to medium-grained but still show slightly lower UCS and UTS values, in comparison to the dolerite of Maira Chanser area which are medium-grained. Generally, the smaller grain size has more surface area exposure to weathering conditions and therefore, the rock alteration rate may be high which could affect the strength and durability of the rocks. Hence, the fine-grained variety from Jodan Khatta area shows more alteration and is, therefore, imparting lower strength and durability values as compared to Maira Chanser dolerite. (Avg. UCS = 32702 versus 34965 psi, avg. UTS = 485 versus 535 psi), (soundness 3.58 verses 3.47 % loss). Moreover, there is less variation in the grain size of fine-grained samples (JK) and therefore, their lower strength may also be because of the greater uniformity in their grain size as compared to medium-grained samples (MC). This is in accordance with the Lindqvist et al. (2007) interpretation that, it is not only the grain size but also the grain size distribution that is important, with the effect that a relatively large grain size range results in a higher strength and better resistance to fragmentation and wearing as compared to a more equigranular or idiomorphic rock.

In order to see the mutual relationship among different physical and petrographic values, various binary correlation diagrams are used. According to Figure 6A-B, negative correlation exists which exhibits that an increase in water absorption values lowers uniaxial compressive strength (UCS) and uniaxial tensile strength values.

Properties of these dolerite rocks are also compared to those studied in different parts of the world (Table 6). From this Table, it can be seen that density, water absorption, unconfined compressive strength and flexural strength values are in a close range which proves its high-quality nature. Petrographic and major oxide geochemical data demonstrate that these dolerites are of similar nature to those studied by Majid et al., 1991 (Malka area lower Swat) and by Sajid (2009; Utla area Swabi).

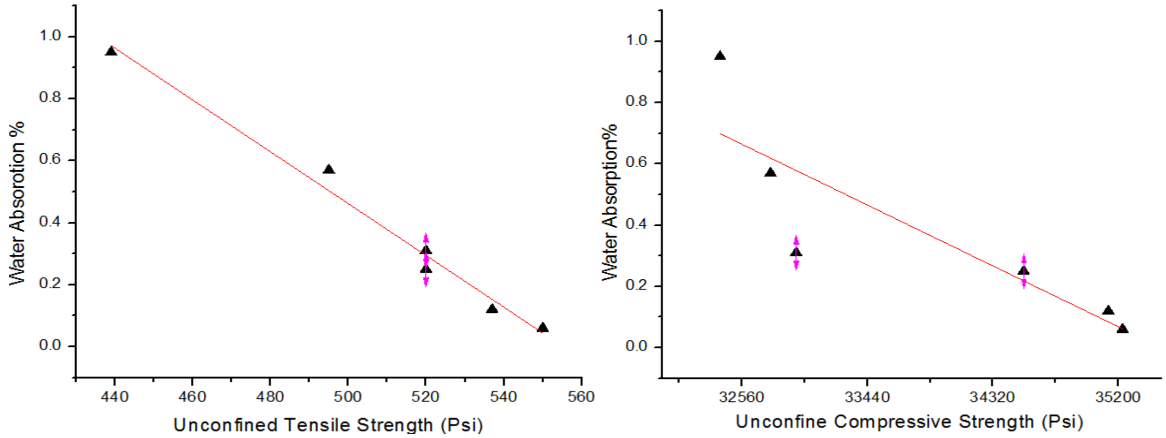

Fig. 9. (A) Relationship between unconfined compressive strength and water absorption (B). Relationship between unconfined tensile strength and water absorption.

Table 5. Major oxide geochemistry of the studied dolerite as compared to those of Malka (Lower Swat) and Utla (Swabi) dolerites (after Majid et al., 1991 and Sajid, 2009).

Major Oxides	Oghi (Mansehra) (Present Study)	Malka (Lower Swat) (Majid et al., 1991)	Utla (Swabi) (Sajid, 2009)
SiO_2	48.75	47.44	50.73
TiO_2	1.96	3.32	4.33
Al_2O_3	14.42	12.87	16.68
Fe_2O_3	13.61	3.13	4.87
MnO	0.19	0.19	1.22
MgO	7.20	8.15	7.26
CaO	11.47	11.63	11.31
Na_2O	1.54	2.79	2.64
K_2O	0.53	0.70	0.76
P_2O_5	0.22	0.10	0.53
LOI	………	………	0.02

Table 6. Comparison of mechanical properties of black dimension stones (Source Borner and Hill, 2010) with the study area.

Sample	Origin	Lithology	Density	UCS*	Flexture*	WA (%)
Impala	S. Africa	Gabbro/Norite	2.8-3.0	221-261	22-26	0.08-.32
Nero Assoluto	Zimbabwe	Gabbro/Norite	3.0-3.1	240-2252	24-29	0.12-0.16
Preto Absoluto	Brazil	Basalt	3.1	210	34	0.05
Star Galaxy	India	Gabbro/Norite	2.8-2.9	183-203	19-20	0.08-0.12
Ebony Black	Sweden	Dolorite	3.1-3.3	294	25	.10
Absolute Black	Uruguay	Dolorite	3.0	367-400	46-53	.01
Shanxi Black	China	Dolorite	3	350	------	.33
Absolute Black	Uruguay	Dolorite	3.0	266-286	31-36	.02
Black	Pakistan	Dolorite	3.05	236	30	.037

* N/mm^3

8. Conclusion

The studied rocks along Oghi-Darband road are fine to medium grained dolerites with characteristic ophitic to sub-ophitic texture. Geochemically, these rocks are mafic in nature and fall in the gabbroic compositional field showing a similar composition to that of sub-alkalic and tholeiitic basalt of ferroan character. The strength properties of all studied samples have inverse ratio with the plagioclase content which implies that cleavage do affect the strength properties of the rock. The samples of Jodan Khatta samples have a relatively small grain size and fractured nature and thats why show slightly weak mechanical strength as compared to the dolerite from Maira Chanser. Similarly, the Jodan Khatta samples exhibit more altered nature along their grain boundaries which also have affected their grain to grain relationship and have thus lowered down their strength values. Moreover, their relatively fine-grained nature has also contributed to higher extent of alteration. Based on petrography, geomechanical properties, and their mutual relationship, these dolerites are classified as high strength rocks and are, therefore, considered suitable for their use as dimension stone and aggregate in the construction of railway tracks, bridges, roads, canals, drainages, large scale tunnels and dams etc.

Author's Contribution

M. Ismaeel, Naveed Anjum and Waqas Ahamed, proposed the main concept and involved in write up. Amjad, assisted in establishing petrology diagrams. Ismaeel and Naveed also collected field data. Ismaeel performed the laboratory work. Muhammad Sajid, did technical review before submission.

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