

Petrography and mechanical properties of the Mansehra granite, Hazara, Pakistan

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ABSTRACT: *Rocks of granitic composition occur in the area around Mansehra (Hazara), Pakistan. These rocks are mostly used as building/ construction materials. In order to study the petrography of these rocks in detail and determine their geotechnical properties, representative samples were collected from different parts of the area. Detailed studies reveal that, compared to granitic rocks from elsewhere in northern Pakistan, the investigated rocks have very low values of compressive strength. This could be due to their older age, coarser texture, unevenness in grain size, deformed/ metamorphosed character and weathered/ altered nature. Therefore, they cannot be recommended for use in the construction of large-scale engineering structures such as tunnels and dams. However, the compressive strength values and Cs/Ts ratios of the studied rocks are high enough for their use as building stones in the construction of railway tracks, bridges, roads, canals, drainages and embankments.*

INTRODUCTION

Effective utilization of a building/ construction material demands an adequate knowledge of its mechanical properties. However, the mechanical properties of most of the rocks, which occur in different areas of northern Pakistan and used as building stones, are not previously determined. That is why the amount of published material, which describes the geotechnical properties of these rocks, is rather limited. Din et al. (1993) have determined shear strength and triaxial strength of various types of rocks used as building materials in northern Pakistan. Khan et al. (1990) also investigated the compressive strength of some of the rocks commonly occurring in the Northwest Frontier Province (NWFP) of Pakistan.

Granitic rocks and their metamorphosed equivalents are among the different lithological types widely occurring and mostly used as building stones in northern Pakistan. In addition to other parts of NWFP, rocks of granitic composition also occur in the Mansehra district. Although being used as a building stone, data on the mechanical properties of the Mansehra granite are currently lacking. The present work was undertaken to study the petrography of these rocks in detail, determine their geotechnical properties, relate the geotechnical properties with mineralogical composition and textural characteristics, and assess their quality for use as a building/ construction material.

The mechanical properties, which are determined and described as part of the

present investigation, include compressive strength, tensile strength, water-absorption and specific gravity. All these properties are compared with the American standards of testing materials, which are used as standard reference.

REGIONAL GEOLOGY AND TECTONIC FRAMEWORK

The Indo-Pakistan and Asian plates are directly in contact along the Indus-Tsangbo 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 Kohistan sequence was sutured to the Asian plate along the Northern, or Shyok, suture at about 100 Ma (Coward et al., 1986; Treloar et al., 1989) well before the onset of Himalayan collision. The Himalayan collision in northern Pakistan was thus between the Kohistan sequence and the Indo-pakistan plate along the Main Mantle Thrust (MMT). It is generally believed (e.g. Treloar et al., 1989) that following its collision in the early Tertiary, the Kohistan arc was thrust southwards onto the Indo-Pakistan plate. The Swat valley, Hazara and adjoining parts of northern Pakistan, therefore, consist of three major tectonostratigraphic units. From north to south (Fig. 1), these are (1) the Kohistan island arc, (2) the Main Mantle Thrust melange group and (3) the Indo-Pakistan plate sequence. The rocks studied during the present investigation belong to the Indo-Pakistan plate sequence.

In northern Pakistan, the northernmost part of the Indo-Pakistan plate has assumed the shape of a loop, known as the Nanga Parbat-Haramosh massif, consisting of Precambrian gneisses intruded by early Cambrian granitoids (Chamberlain et al., 1989). Rocks of the Hazara region lying southwest of the Nanga Parbat and

constituting the eastern part of the northern edge of the Indo-Pakistan crust in northern Pakistan (Fig. 1) consist of Precambrian basement overlain unconformably by Phanerozoic metasediments. The basement rocks of the Hazara area, like their northeastern counterparts in the Nanga Parbat region, were intruded during the Cambrian by the coarse-grained Mansehra porphyritic granites (Le Fort et al., 1980; Shams, 1983) (Figs.1, 2).

APPROACH AND METHODOLOGY

As mentioned above, the present research work is concerned with petrographic study and mechanical properties of granitic rocks from different localities in the Mansehra district (Figs.1,2). Block samples were collected from three localities, i.e. the areas around Mansehra, Baffa and Susilgali (Fig.2). Each of the collected block samples was 2-2.5 feet long, 1-0.5 feet wide, and ~0.5 foot thick. The idea of selecting different localities was to get a wide range of representative samples differing in colour, mineralogy, texture and /or structure, thus providing a good opportunity to relate the mechanical properties of the rocks with their mineralogical and structural characteristics. The collected samples were processed for their petrographic study and determination of their geotechnical properties. Two small chips from each block sample were cut and made into thin sections for petrographic observations.

Samples used for determining the different mechanical properties of the rocks were prepared by using core drill machine, diamond-cut saw, grinder lab and surface grinder. Cylindrical cores were prepared by a thin wall bit of tungsten carbide attached to core barrel. Water was admitted through a swivel in the core barrel to clear drill cuttings and cool the bit. The cores obtained by this

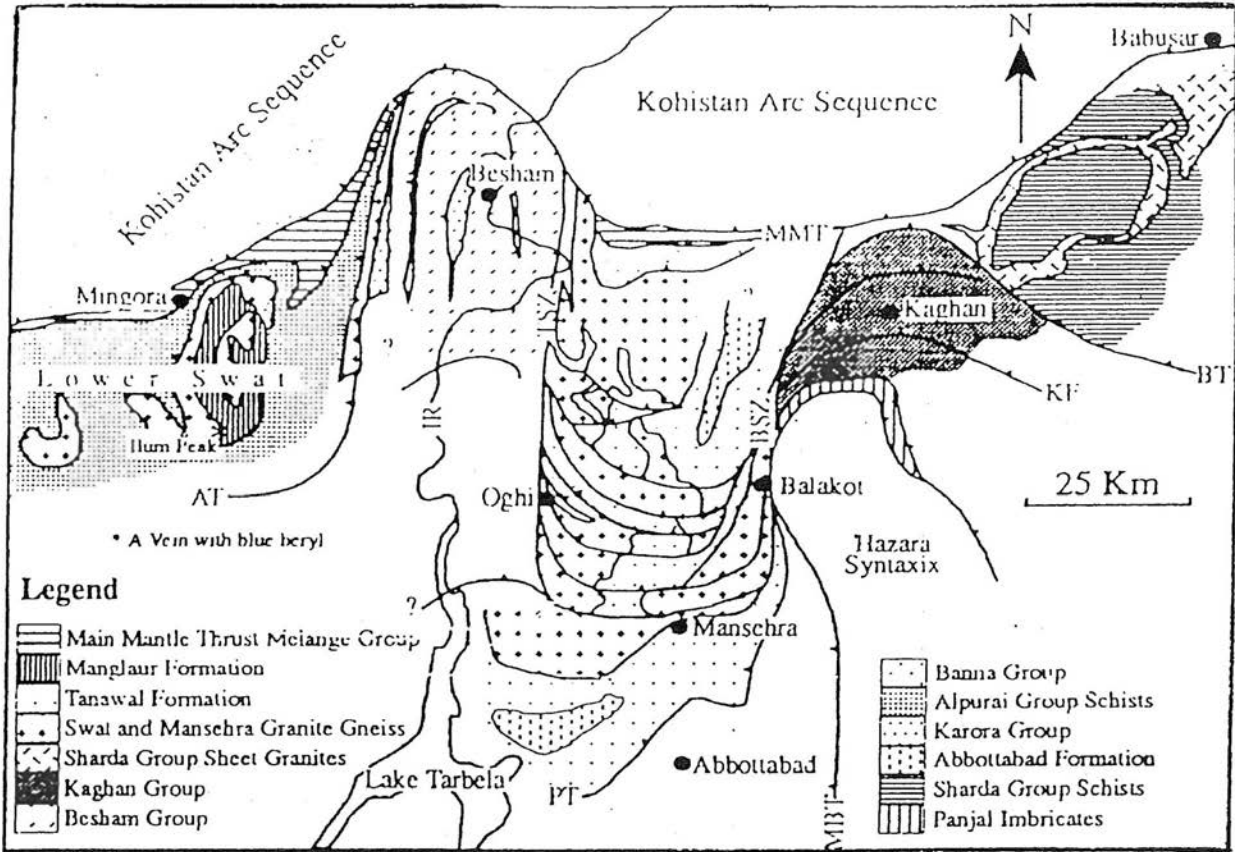


Fig. 1. Geological map of the area south of the Main Mantle Thrust between the Swat and Kaghan valleys (redrawn from Treloar & Rex, 1990). Abbreviations: AT = Alpurai Thust; BSZ = Balakot Shear Zone; BT = Batal Thrust; IR = Indus River; KF = Khannian Fault; MBT = Main Boundary Thrust; MMT = Main Mantle Thrust; PT = Panjal Thrust; TSZ = Thakot Shear Zone.

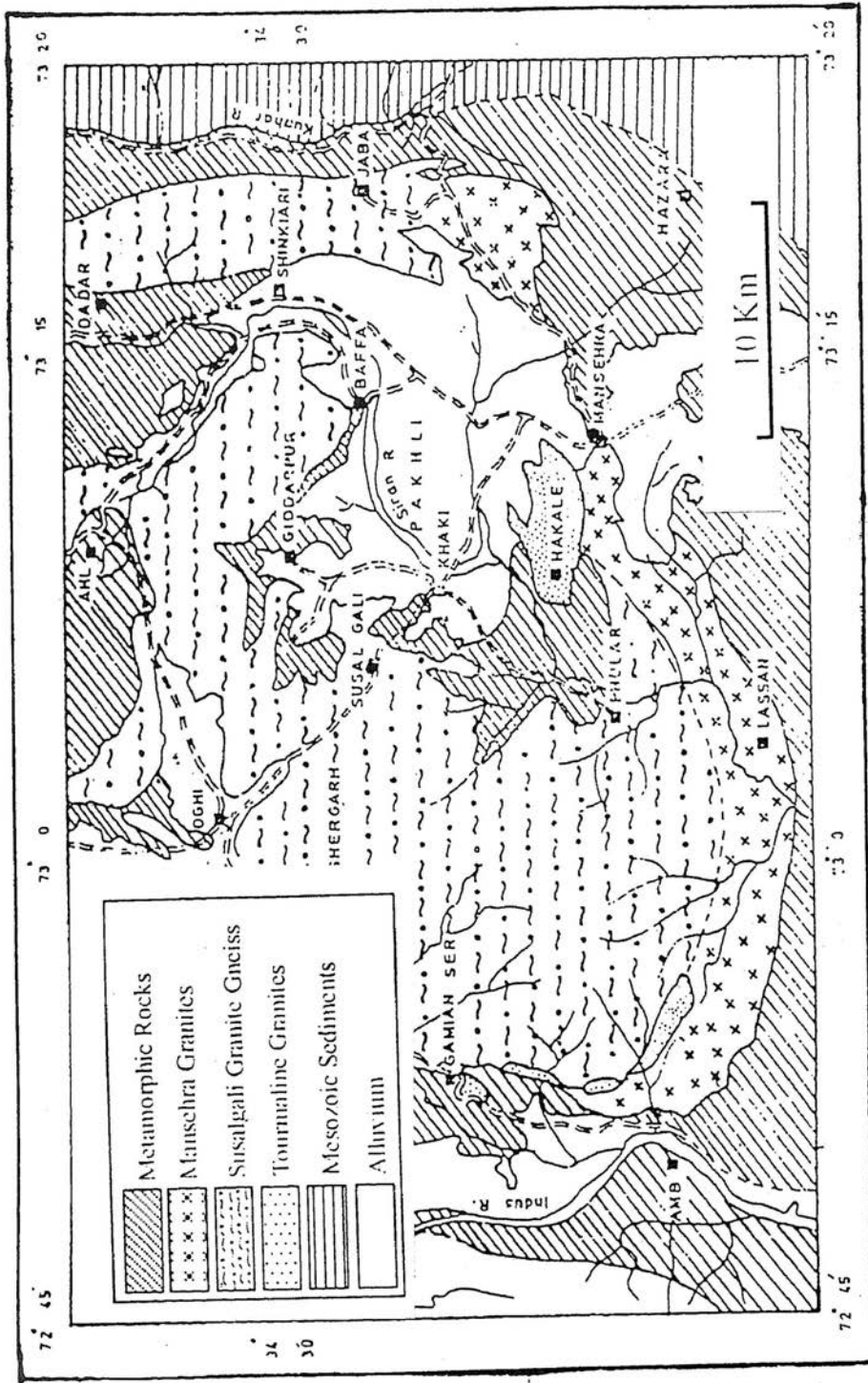


Fig. 2. Geological map of the study area (after Shams, 1967).

process were sawed with an abrasive blade where water was used as coolant. The smoothness and flatness of the core ends were obtained to a satisfactory degree by the use of lapping machine. In core preparation, the faces of the cores were kept exactly at right angles to the core axis and are flat and smooth.

Portions from each of the block samples were used for the preparation of samples for carrying out water absorption test and determination of specific gravity.

PETROGRAPHY

Megascopic Features

The granite that crops out in the vicinity of the Mansehra town is whitish grey in colour. It is coarse to very coarse grained and strongly porphyritic. The rather large phenocrysts of alkali feldspar are readily distinguishable in hand specimen. Diagonal fractures occur and are clearly visible in the core samples that are prepared for a detailed study of the engineering properties of the rock.

The granite from the Baffa area is blackish to dirty white in colour, coarse grained with a larger proportion of dark-coloured minerals, mainly biotite. Unlike the sample from Mansehra, it is homogeneous in texture. However, like the Mansehra sample, the sample from this locality also displays fractures.

Granite from the Susilgali area is coarse-grained, and grey to dark grey and dirty white in colour. The brownish black flakes of biotite are readily recognizable in hand specimen. The grains of feldspar are distinguished by their dull white appearance whereas those of quartz stand out due to their diagnostic vitreous lustre. Gneissose structure is well developed. Both augen and banding

structures can be seen in hand specimen. Locally, the granitic rocks in this area are intensively sheared. The studied sample is moderately weathered. The rusty brown colour on weathered surface is due to leaching of some of the iron-bearing minerals, e.g. biotite.

Mineralogy and Microscopic Features

As mentioned above, the sample from Mansehra displays a typical porphyritic texture. It is essentially composed of perthitic alkali feldspar (30%), quartz (30%), plagioclase (20%), and mica (15%) including bitotite, muscovite and sericite. The alkali feldspar and plagioclase mainly occur as phenocrysts. Locally, the grains of plagioclase show alteration to sericite and epidote. Some of the plagioclase grains display concentric zoning. A typical myrmekitic texture is also observed close to the grains of perthitic alkali feldspar. Some of the phenocrysts of alkali feldspar are fractured. Biotite and muscovite mostly occur in close association. In some cases, muscovite appears to have formed later than and at the expense of biotite as it, with or without sericite, occurs along fractures, margins and/or edges of biotite. Conchoidal fractures are seen in quartz grain. Trace amounts of magnetite and carbonate also occur in the thin sections of the Mansehra granite.

Microscopic study shows that the Baffa granite principally consists of alkali feldspar (30%), quartz (30%), plagioclase (15%) and micas (biotite, muscovite and sericite) (17%). On the basis of the studied thin sections, the texture of the Baffa granite can best be described as equigranular to subporphyritic. In some cases, two or more grains of the perthitic alkali feldspar are intergrown. Some of the feldspar phenocrysts are fractured and the fractures are healed with sericite.

In terms of modal composition, the Baffa granite is almost similar to the granite from Mansehra. However, its plagioclase abundance is slightly less and mica content a little more than the Mansehra samples. Conchoidal fractures are observed in quartz grains. Because of some deformation, the quartz grains exhibit wavy extinction. Trace amounts of other minerals including chlorite, carbonate and epidote, also occur in the sample representing the Baffa area. The degree of deformation seems to be greater than the Mansehra granite.

The Susilgali granite is porphyritic to subporphyritic in texture. Its essential minerals are feldspar (29%), quartz (28%), plagioclase (15%), and mica (biotite + muscovite + sericite) (22%). The rock also contains vermicular intergrowth between quartz and feldspar. Some of the plagioclase grains display Carlsbad twinning. At places, the quartz and feldspar grains are lenticular in shape. The growth of muscovite at a stage later than biotite is also indicated by its crosscutting relationship with the latter.

Compared to the samples from Baffa and Mansehra, the Susilgali granite is highly deformed and locally contains fractures, joints and other features indicative of ductile as well as brittle deformation. The ductile deformation is in some cases manifested by kinking of cleavages in grains of biotite.

EVALUATION OF MECHANICAL PROPERTIES

Among the mechanical properties of rocks, the compressive strength, tensile strength, specific gravity and water absorption tests are of greater importance. The mechanical properties of rocks govern their behaviour in response to applied load. The most important mechanical properties that must be

investigated, when designing foundations, structures and underground openings are hardness, durability, elasticity and strength of the rock used.

Strength of a material is its ability to resist externally applied load. The strength of rocks depends on quantitative and qualitative mineral composition and texture. It can be determined either experimentally by means of laboratory testing of the rock specimen or by its testing in situ. Laboratory tests are more accurate, cheaper, easier to carry out and intellectually more satisfactory than field tests. The tests performed during the present study include a) compressive strength, b) tensile strength, c) specific gravity and d) water absorption.

Compressive Strength

Compressive strength (C_s) = P/A . Where $A = \pi/4 \times D^2$, P = applied load at failure, A = cross sectional area of the specimen, D = diameter of the specimen. The compressive strengths are tested according to the method of the American standard for testing material. Two types of compressive tests are generally used: (1) uniaxial compressive strength and (2) triaxial compressive strength.

The method used during the current investigation for the determination of compressive strength in the laboratory is uniaxial compressive strength. Uniaxial strength of a rock is determined, when load is applied in one direction. Since the samples are obtained normally as cylindrical core of various diameters, the load is applied along the axis of the cylinder. The uniaxial compressive strength is given by maximum stress level at which the material fails by crushing. For best results, the length of the specimen should be at least twice its diameter.

Tensile Strength

Tensile strength of a rock is its resistance to failure in tension. It can be determined by direct or indirect method. We used the indirect or Brazilian method for the determination of tensile strength of the studied specimens. The tensile strength (T_s) is given by $T_s = 2P/(3.14 \times D \times L)$, where P = Load at failure, D = Diameter of the specimen, L = Length of the specimen. The behaviour of the compressive and tensile strength is influenced to some extent by the test conditions. The most important of these is the length/diameter or cylinderness ratio (Dhir & Sanghar, 1973).

Water Absorption

It refers to the quantity of water that can be absorbed by a rock. During 1982, the American Standard for Testing Material (ASTM) recommended that at least three specimens should be used for such a test. First the sample is dried at 105-110° C overnight, cooled and weighed as W_1 . The same sample is then kept in distilled water for ten days. This wet sample is then weighed as W_2 . The amount of water absorbed, if any, by the specimen is calculated as $(W_2 - W_1/W_2) \times 100$.

Most of the rocks are weakened by the addition of water through absorption. Pressure is developed called pre-water pressure that influences the strength of the rock. Greater the water content, the greater will be the loss in the strength of the rock.

Specific Gravity

It is the ratio between weight of a sample and weight of an equal volume of distilled water. The specific gravity of a sample is equal to $W_1/(W_1 - W_2)$, where W_1 = weight of the sample in air, W_2 = weight of the same sample while immersed in water. The specific gravity of the investigated samples was determined by using a Jolly spring balance.

RESULTS AND DISCUSSION

Compressive Strength

Results of the compressive strength test on the samples collected from different localities are given in Table 1. Variation in the values of compressive strength is limited. They range from 1595 Psi to 1725 Psi. On the basis of these values, the granitic rocks of the Mansehra, Baffa and Susilgali areas can be classified as having moderate strength. These can thus be used as building stones in the construction of railway tracks, bridges, roads, canals, drainages and embankments. However, they cannot be recommended for use in the construction of such large-scale engineering structures as tunnels and dams.

Comparison of the data listed in Table 1 with that on granitic rocks from elsewhere in NWFP (cf. Din et al., 1993) shows that the compressive strength values of the presently investigated samples are very low. As outlined below, this sharp contrast in compressive strength of the studied samples

TABLE 1. VALUES OF COMPRESSIVE STRENGTH, TENSILE STRENGTH, WATER ABSORPTION AND SPECIFIC GRAVITY

S.No.	Location	Compressive Strength (Psi)	Tensile Strength (Psi)	Compressive Strength/ Tensile Strength	Water Absorption (%)	Specific Gravity
1	Susilgali	1647.2	197.63	8.33	0.989	2.720
2	Mansehra	1725.5	429.2	4.20	0.381	2.718
3	Baffa	1595.0	240.0	6.64	1.162	2.743

with rocks having broadly similar mineralogical compositions could be a result of a complex interplay of a number of factors. These include 1) age, 2) texture and structure, 3) type and degree of metamorphism, 4) nature and amount of deformation and 5) degree of weathering/altertaion.

As the rocks under discussion are older than the granites investigated by Din et al. (1993), their low strength values are partly because of the age factor. However, the difference in strength between the presently studied rocks and those representing the Peshawar Alkaline Igneous Province is too large to be due to a difference in age alone. The low values of compressive strength of the studied samples could also due to their texture. As mentioned in the section on petrography, the rocks under discussion are rather coarse grained and mostly porphyritic. This coarseness and very strong unevenness in grain size must have a significant impact on the strength of the rocks. Furthermore, the investigated rocks are metamorphosed and display textural/structural features indicative of both brittle and ductile deformation. These phenomena could also have lowered the strength of the studied samples.

Tensile Strength

The tensile strength varies from a minimum value of 198 Psi for the Susilgali sample to a maximum value of 429 Psi for the sample from Mansehra whereas the sample representing the Baffa area gives an intermediate value (240 Psi) (Table 1). Comparison between the values of compressive and tensile strengths reveals that the Susilgali sample has the highest (8.33), the Mansehra sample has the lowest (4.2) while the Baffa sample exhibits an intermediate (6.64) C_s/T_s ratio (Table 1). As the values of compressive strength for the

investigated samples are more are less same, the relatively large variation in the C_s/T_s ratios is mainly due to difference in the values of tensile strength. This is also manifested by a strong negative correlation between C_s/T_s ratios and tensile strength (Table 1).

According to Annon (1979), rocks with C_s/T_s ratios falling in the range of 1-10 can be successfully utilised for building and/ construction purposes. This shows that all the investigated samples belong to the category of materials regarded suitable for use in building/ construction schemes.

Water Absorption

In general, all the studied samples are compact and show no water absorption problem. The amount of water absorbed by them ranges from 0.38 % to 1.16 %. The data show that the samples from Mansehra and Baffa have absorbed, respectively, the least (0.38 %) and most amounts of water whereas the intermediate value of water absorption (0.99 %) is yielded by the Susilgali sample (Table 1).

Comparison of the data listed in Table 1 suggests a strong negative correlation between compressive strength and water absorption values. Such a decrease in the amount of water absorbed with rising compressive strength is normal and to be expected.

Specific Gravity

The specific gravity ranges from 2.718 for the Mansehra sample to 2.743 for the sample from the Baffa area (Table 1). In terms of specific gravity, the Susilgali (specific gravity = 2.720) and Mansehra samples are almost identical. As apparent from the data, the amount of variation in the specific gravity of the studied samples is negligibly small.

CONCLUSIONS

The following broad conclusions can be drawn from the discussion given above:

- Compared to granitic rocks from elsewhere in northern Pakistan, the rocks under discussion have very low values of compressive strength. This could be due to their older age, coarser texture, unevenness in grain size, deformed/metamorphosed character and weathered/ altered nature.
- The compressive strength values and Cs/Ts ratios of the granitic rocks from the Mansehra and adjoining areas are high enough for their use as building stones in the construction of railway tracks, bridges, roads, canals, drainages and embankments. However, they cannot be recommended for use in the construction of large-scale engineering structures such as tunnels and dams.

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