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COMPRESSIVE STRENGTH OF A PORPHYRITIC HORNBLENDE MICROGRANODIORITE FROM KAMPUNG KAPA, SABAH, EAST MALAYSIA

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ABSTRACT : *Laboratory tests show a porphyritic hornblende microgranodiorite from Kampung Kapa in Sabah to have mean dry, and saturated, unit weights of 25.54, and 25.80, kN/m^3, as well as mean dry, and saturated, densities of 2,604, and 2,631, kg/m^3, respectively. The rock material has a mean effective porosity of 2.66%, with its solid mineral grains having a specific gravity of 2.70. Compression tests on prismatic specimens with height to breadth ratios of 2.5 yield a mean uniaxial compressive strength of 111.30 MPa (or 16,143 lb/in^2), whilst similar tests on specimens with lower height to breadth ratios yield higher values of strength. Point load tests yield a strength index [Is($_{50}$)] of 9.92 MPa; this value determined from extrapolation of the log-log plots of the loads at failure versus the squares of the equivalent core diameters of several blocks of different sizes that were tested. The point load strength index is thus related to the uniaxial compressive strength by a multiplication factor of 11.2.*

INTRODUCTION

Standard geological descriptions and classification fulfill an important role in the appraisal of rock material for engineering purposes, though such qualitative data often needs to be confirmed and augmented by quantitative data that allows a more precise description. Several laboratory testing procedures have therefore, been formalized to determine relevant quantitative data; the most commonly determined parameter being the uniaxial compressive strength (Lama and Vutukuri, 1979; ISRM, 1979).

The uniaxial compressive strength is usually determined through loading of a cylindrical or prismatic specimen to failure in a compression machine; the strength (Co) given by Co = Fc/A, where Fc is the applied compressive load at failure and A the cross-sectional area of the specimen. Although the concept of the test is deceptively simple, there are several factors that significantly affect the test results, including the flatness of the bearing surfaces, the shape and size of the specimen, the rate of loading and the alignment of the swivel head (Lama and Vutukuri, 1978). The effects of these factors cannot be eliminated, though they can be minimized through adoption of standard testing procedures as described in Lama and Vutukuri (1978) or ISRM (1981).

The uniaxial compressive strength can also be estimated from the point load test which has gained widespread acceptance as an index test for the strength classification of rock material (ISRM, 1985). Little or no specimen preparation is needed for this test which involves the splitting of rock specimens by application of a concentrated load through a pair of spherically truncated, conical platens. The specimens can be in the form of cores (the diametral and axial tests), cut blocks (the block test), or irregular lumps (the irregular lump test). Where specimens with shapes other than cores are tested, both shape and size correction factors are needed; the shape factor being based on the minimum cross-section area of the tested specimen and the calculation of an "equivalent core diameter". The size correction factor, however, is best determined from the log-log plots of the loads at failure versus the squares of the equivalent core diameters of a range of specimen sizes as this then allows interpolation or extrapolation of the load corresponding to a standard diameter of 50 mm (ISRM, 1985).

In this paper are presented and discussed, the results of uniaxial compression, and point load, tests that have been carried out to determine the strength of a porphyritic hornblende microgranodiorite that outcrops close to Kampung Kapa in northwest Sabah, East Malaysia.

SAMPLING SITE - GEOLOGICAL SETTING

The igneous rocks of Sabah are varied in composition and origin with 3 main periods of igneous activity having been identified. The earliest period gave rise to granodiorite, tonalite, trondhjemite and granite intrusions that are associated with pre-Triassic basement rocks, whilst the second period is represented by the basic-ultrabasic rocks, spilite and basalt association, related to the Upper Cretaceous Chert-Spilite Formation. The third period occurred in Late Miocene to Quaternary times and is represented by post-orogenic intrusives and extrusives occurring at Gunung Kinabalu and in the Semporna Peninsula (Anon., 1995).

To the east of Tamparuli in northwest Sabah are found acidic igneous rocks that intrude into turbidite sedimentary rocks of the Eocene to Oligocene, Crocker Formation (Kamaludin, 1981). These igneous rocks occur in the form of dykes or small stocks and are likely to be related to the Gunung Kinabalu massif which was emplaced some 9 million years ago in the Late Miocene (Jacobson, 1970). At a quarry near Kampung Kapa (Fig. 1), the acidic igneous bedrock occurs in the form of a steeply dipping to vertical, dyke that trends 150° and is some 80 to 140 m wide. As a part of a larger study on the geotechnical properties of the rock materials of Malaysia, a large block of some 0.1 m^3 in size was collected at the quarry for subsequent laboratory investigations.

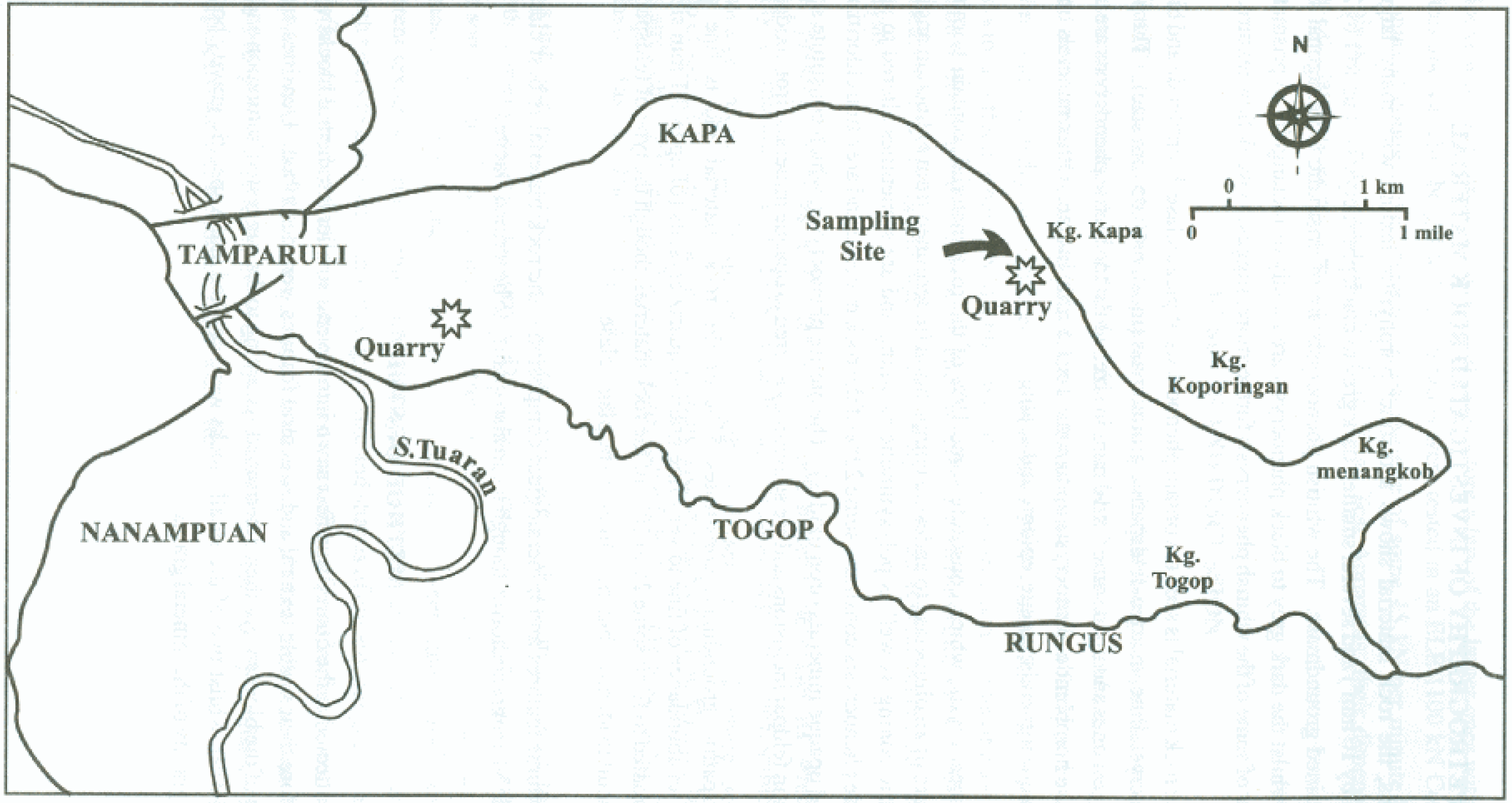

Fig. 1 : Location Map

PETROGRAPHY OF INVESTIGATED ROCK MATERIAL

In hand specimens, the rock material shows a distinct porphyritic texture with many large, whitish phenocrysts (of up to 5 by 10 mm^2) and several smaller, dark grey to black phenocrysts (of up to 1 by 2 mm^2) set in a light grey, fine grained groundmass. The whitish phenocrysts are of prismatic to hexagonal shapes and show distinct zoning, whilst the dark grey to black phenocrysts are mostly of rectangular to prismatic shapes. An indistinct alignment of some of the whitish phenocrysts furthermore, suggests a weak flow texture.

In thin sections, the rock material is seen to contain phenocrysts of plagioclase, hornblende and biotite set in a fine grained to cryptocrystalline, quartzo-feldspathic groundmass (mostly < 0.05 mm size),. The plagioclase phenocrysts are the largest ones and up to some 5 x 10 mm^2 in size, whilst the biotite phenocrysts are up to about 1 x 2 mm^2 in size and the hornblende phenocrysts up to some 1 x 1.5 mm^2 in size. Other minerals occurring as accessories include opaque minerals, calcite, epidote and apatite.

The plagioclase phenocrysts, which constitute some 19% of the rock material, contain hornblende and biotite inclusions and are of an oligoclase to andesine composition (determined from extinction angles). They show normal, concentric zoning as well as polysynthetic twinning and are sometimes altered to sericite and calcite. The hornblende phenocrysts constitute some 22% of the rock material and are often chloritized, as well as altered to calcite and opaque minerals (iron oxides). The biotite phenocrysts, which constitute some 6% of the rock material, contain feldpar inclusions and are sometimes altered to opaque minerals (iron oxides).

The quartzo-feldspathic groundmass constitutes 51% of the rock material and is fine grained to cryptocrystalline with an abundance of fine to very fine grained quartz crystals (of up to 0.1 mm size). These quartz crystals are estimated to form some 25 to 30% of the rock material, though the type of feldspar present in the groundmass is difficult to identify, but most likely to be plagioclase.

In view of the textural features and mineralogical composition, the rock material is best classified as a Porphyritic Hornblende Microgranodiorite, though it can also qualify to be termed Dacite.

METHOD OF STUDY

The large block collected at the quarry was first sawn into several smaller tetrahedral blocks whose sides were finely ground before their visible textural and structural features were described. Densities, unit weights and porosities of some of the blocks were then determined according to the suggested 'saturation and buoyancy technique' of ISRM (1979), whilst two of the small blocks were crushed and a specific gravity bottle used to determine the specific gravity of the mineral grains.

The blocks were then air-dried for several days before a few of the larger ones with approximately square cross-sections and variable height to breadth ratios were tested in an ELE 1100 kN Compression Machine to determine uniaxial compressive strengths; a loading rate of some 15 kN per minute being employed. The remaining blocks were tested with an ELE Point Load Test Apparatus; their dimensions having been first measured to calculate 'equivalent core diameters'.

RESULTS AND DISCUSSION

From Table 1, it can be seen that the porphyritic hornblende micro-granodiorite shows a fairly narrow range of dry and saturated densities from 2,588 to 2,651 kg/m^3, with mean dry, and saturated, densities of 2,604, and 2,631, kg/m^3, respectively. Unit weights of the rock material also show a fairly narrow range from 25.381 to 26.002 kN/m^3, with mean dry, and saturated, unit weights of 25.541, and 25.802, kN/m^3, respectively. The rock material has a mean effective porosity of 2.66%, with its solid mineral particles having a specific gravity of 2.698. In comparison with published data on other igneous bedrock materials (Lama and Vutukuri, 1978), the effective porosity appears to be rather high, though this is probably due to the several mineral alterations that have affected the phenocrysts.

As the "presence of pores in the fabric of a rock material decreases its' strength and increases its deformability" (Lama and Vutukuri, 1978), it can be expected that the porphyritic hornblende microgranodiorite will not show a very high uniaxial compressive strength. This is seen in Table 2, where specimens with a height to breadth ratio of some 2.5 yield a mean uniaxial compressive strength of 111.30 MPa (or 16,142 lbf/in^2). In terms of proposed strength classifications of rock materials, as the ISRM (1981) classification, the tested rock material would be classified as one of high strength or very strong.

There is unfortunately, little data with which to compare the determined strength for most published work has dealt with coarser grained granoidiorites. Dayre and Giraud (1986) for instance, quote uniaxial compressive strengths of some 135 to 170 MPa, and tensile strengths of 7 to 13 MPa, for equigranular, medium grained (0.2 - 5.0 mm) granodiorites from France. Comparisons of strength between igneous rocks of similar compositions, but of different textures, is furthermore, misleading for their strength characteristics are mainly governed by texture, which refers to the relative amounts, grain size and shapes of constituent grains, as well as the manner of interlocking (Merriam *et al,* 1970). For a fine grained granodiorite from California with an average grain size of 0.5 to 1 mm, Merriam *et al* (1970) have quoted a tensile strength of 1,060 lbf/in^2 (or some 7.4 MPa) and a uniaxial compressive strength of 15,100 lbf/in^2 (or some 104 MPa); a value closely similar to that determined for the investigated porphyritic hornblende microgranodiorite.

Merriam, R., Rieke III, H.H. and Kim, Y.C. (1970): Tensile strength related to mineralogy and texture of some granitic rocks. *Engng. Geol.*, No. 4, p. 155-160.

Sample Number	Dry Density (kg/cu.m.)	Dry Unit Weight (kN/cu.m)	Porosity (%)	Satursted Density (kg/cu.m.)	Saturated Unit Weight (kN/cu.m.)
Grd 1	2,622	25.719	2.89	2,651	26.002
Grd 11	2,610	25.600	2.43	2,635	25.838
Grd 12	2,589	25.837	2.90	2,618	25.672
Grd x	2,597	25.472	2.15	2,619	25.682
Grd y	2,619	25.687	2.54	2,645	25.936
Grd 1a	2,588	25.381	3.07	2,619	25.682
Mean	2,604	25.541	2.66	2,631	25.802

Table 1 : Unit Weight, Dentsity and Porosity

Table 2 : Uniaxial Compressive Strength

Sample Number	Length (L) (mm)	Breadth (B) (mm)	Height (H) (mm)	Ratio (H)/(B)	Uniaxial Compressive Strength		Mode of Failure (after Hawkes & Mellor, 1970)
					(Ibf/sq.in.)	(MPa)	
GD 11	35.8	35.3	83.0		2.416,068	110.782	Shear (2 sets)
GD 12	34.5	33.7	83.0	2.5	16,217	111.814	Shear (2 sets)
Mean					16,143	111.298	
G 5	32.1	30.2	49.2	1.6	18,702	128.943	Shear (2 sets)
G 6	33.7	30.4	48.8	1.6	22,631	156.038	Shear (2 sets)
G 7	32.8	30.9	47.4	1.5	21,006	146.026	Shear (2 sets)
G 8	32.3	31.0	50.5	1.6	18,831	129.831	Shear (2 sets)

Table 3 : Results of Point Load Tests

Sample Number	Equivalent Core Diameter (s.q.mm.)	Load at Failure (lbf)	Load at Failure (kN)
G 1	1,833	4,100	18.00
G 3	1,207	3,200	14.00
G 9	1,722	4,000	14.00
G 21	595	1,500	6.50
G 22	506	1,150	5.13
G a	717	1,500	7.00
G b	924	2,600	11.50
G c	789	2,000	9.00
G d	912	2,000	9.00
G e	780	2,100	9.40
G f	599	1,800	8.00
G g	767	1,900	8.50
G h	712	1,800	8.00
G i	514	1,400	6.00
G k	750	2,100	9.00
G m	565	1,400	6.00
G n	797	1,800	8.00

In Table 2, a number of higher uniaxial compressive strengths are also listed, though they have been determined from specimens with height to breadth ratios of about 1.5. This feature is unexpected for all published work, including Lama and Vutukuri (1978), has shown that there is an increase in compressive strength with a decrease in the height to breadth ratios of tested cylindrical or prismatic specimens. This influence of sample shape has thus led to the recommendation that uniaxial compression tests be carried out on rock cores or prismatic specimens with height to breadth ratios of between 2.5 and 3 (Lama and Vutukuri, 1978; ISRM, 1981).

Point load tests on different sized blocks of the porphyritic hornblende microgranodiorite have yielded a range of loads at failure that can be correlated with calculated 'equivalent core diameters' (Table 3). When the loads at failure and the squared values of the equivalent core diameters are plotted on double log paper (Fig. 2), a linear relationship is seen which allows for extrapolation of the load corresponding to the square of the standard diameter of 50 mm (ISRM, 1985). A regression analysis of the plotted data yields a gradient of 42.5° and a y-axis intercept of 1.29 kN for the linear relationship. As the extrapolated load at failure corresponding to the standard diameter of 50 mm is 24.80 kN, the point load strength index [$Is_{(50)}$] is calculated to be 9.92 MPa.

The point load strength index [$Is_{(50)}$] can be seen to be related to the uniaxial compressive strength by a multiplication factor of 11.2; a value that is much lower than the multiplication factors of between 20 and 25 that have been used by other workers for the similar general relationship (ISRM, 1985). Forster (1983) furthermore, has pointed out that the ratio of the uniaxial compressive strength to the point load strength index varies not only with rock type and weathering grade, but is also considerably influenced by any anisotropy in the rock material. The weak flow texture of the investigated porphyritic hornblende microgranodiorite therefore, probably gives rise to an anisotropic rock material and results in the somewhat low value of the uniaxial compressive strength.

CONCLUSION

Arising from the above discussion, it is concluded that the porphyritic hornblende microgranodiorite shows mean dry, and saturated, unit weights of 25.54, and 25.80, kN/m^3, and mean dry, and saturated, densities of 2,604, and 2,631, kg/m^3, respectively. The rock material has a mean effective porosity of 2.66%, with its solid mineral grains having a specific gravity of 2.70. Compression tests on prismatic specimens with height to breadth ratios of 2.5 yield a mean uniaxial compressive strength of 111.30 MPa (or 16,143 lb/in^2), though similar tests on specimens with lower height to breadth ratios yield higher values of strength. Point load tests yield a strength index [Is($_{50}$] of 9.92 MPa; this value determined from extrapolation of the log-log plots of the loads at failure versus the squares of the equivalent core diameters of several blocks of different sizes that were tested. The point load strength index is thus related to the uniaxial compressive strength by a multiplication factor of 11.2.

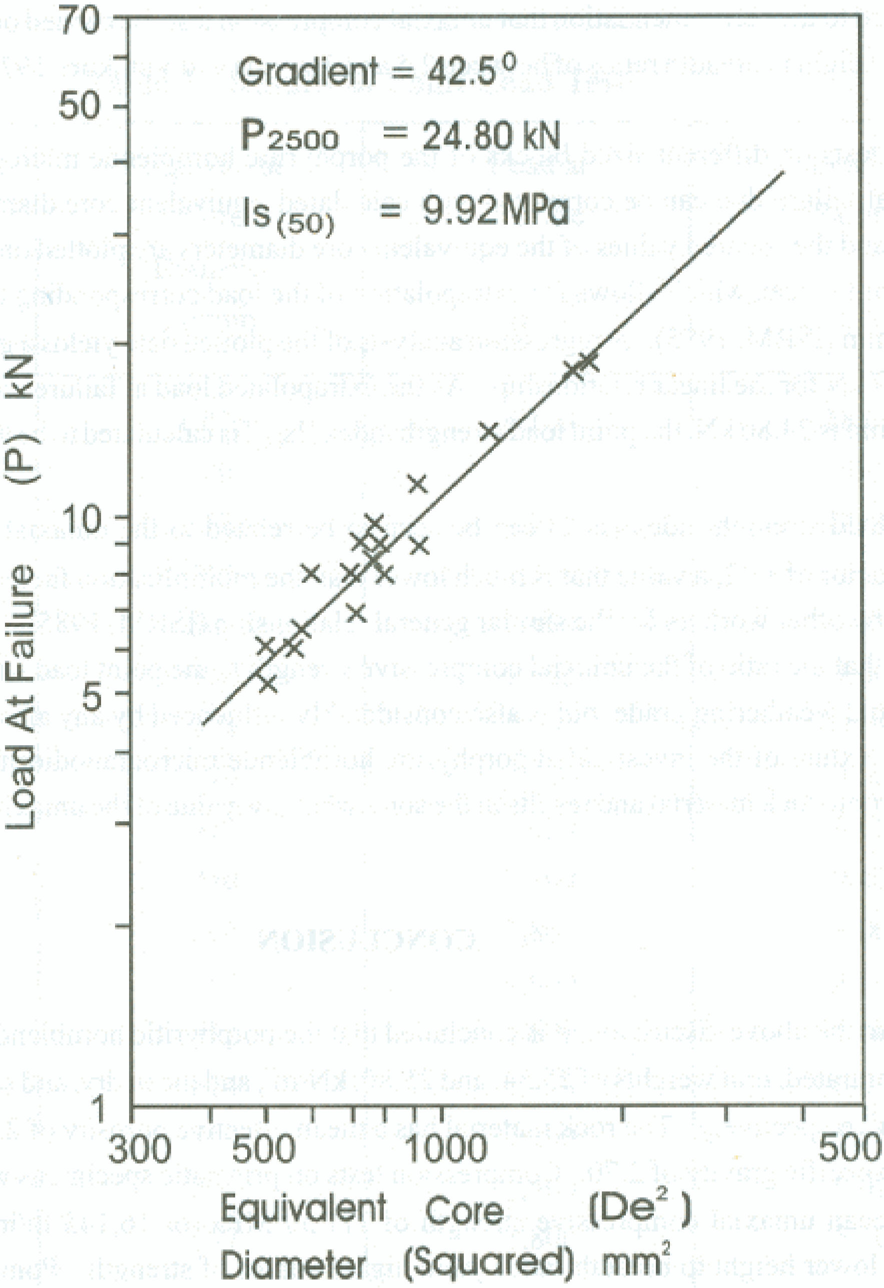

Fig. 2 : Log-Log Plots Of Load At Failure (P) In Versus Squares Of Equivalent Core Diameters (De^2) In mm^2

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