Appraisal of Engineering Geological Parameters of Rocks in and Around Mines - A Case Study

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Abstract

An endeavor has been made to assess the engineering geological attributes of the various types of granitic rocks of Malanjkhand area. In general, the engineering attributes are dependent variables which are controlled by the independent variables, such as chemical and mineralogical parameters. Hence, the authors have attempted to establish relationship, if any, existing between them. Based on the data obtained through field and laboratory investigations, the areas comprising rocks of high compressive strength and tensile strength have been demarcated on the iso - compressive strength and iso - tensile strength maps. The compressive strength decreases from west to east direction, the grey non-porphyritic granite showing the highest compressive strength, while granitic gneiss and pinkish grey granite show the least. In case of tensile strength, there is a general increase from north to south, the least being in the granodiorite and highest in non-porphyritic grey granite. Hence, the benches of the mine can be developed with ease in the east-west direction. It is also obvious from structural map that the frequencies of north-south shear joints are abundant in mine area. Thus, it is easier to mine in north-south direction then in east-west direction and east-west, oriented benches/slopes are suitable for hauling ore as well as mine waste. These slopes/benches appear to be much stable than any other orientation.

Introduction

The study area is well known for its Precambrian porphyry copper deposit. Geologically, this deposit belongs to the rocks of Precambrian age. Thus, considering the economical and geological importance, the authors have chosen the area for the present studies. A preliminary attempt has been made to study the engineering and physical parameters of the various textural types of granites of Malanjkhand area, to understand their engineering behavior and to make recommendations on the stability of the slopes and open faces of rocks.

Considering the vast extent of the rocks of granitic composition constituting the Indian shield, the research work pertaining to their engineering behavior is very scanty. Much work does not exist in literature on the studies of engineering geological properties of granites. Among the works, the mention may be made of works by Balakrishna (1967) on the physical properties of rocks, Lundborg (1967) on the strength - size relationship of granites, Wawarshik and Brace (1971) on the post failure behavior of a granite and diabase, Merrium *et al.* (1970) on the tensile strength related to mineralogy and texture of some granitic rocks and by Vaya and Vikram (1983) on the mineralogical parameters in granite sawing.

Geological Aspects

Regionally, the study area belongs to "Precambrian" terrain, the well-known porphyry copper deposit of Central India. The lower basement complex comprises the various textural types of granitic rocks constitute the older member, while the basal part of Chilpi Ghat Group constituting the younger division. The granitic terrain represents both pink and

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grey types, which are both porphyritic and non-porphyritic in nature and includes gneissic and granodioritic types (Fig.1, 2 and Table. 1). The relationship between these members is not very clear, because they invariably grade one into the other. Further, these members are also intruded by a series of doleritic dykes and quartz veins, which are appreciably mineralized.

Sample Preparation

In general, the rocks are mechanically heterogeneous and their properties vary at different locations. Hence, every care has been taken to sample the rocks specially to make it as representative as possible. In all 36 samples have been selected from various types of granitic and basic rocks for different tests following Obert *et al.* (1946), Robertson (1955), Everling (1964), Bieniawaski (1975), Vojki and Kevari (1978), Jaeger (1979), Odonera and Kumara (1980), Farmer (1983), ISRM (1972, 1978, 1981), ISI (1986) for strength testing, Lundborg (1967), Merrium *et al.* (1970), Pitaeu (1971), Geol. Soc. London (1977), Hallbour *et al.* (1978) for petrological description and geological factors significant to slope stability; Krynine and Judd (1957), Miller (1965), Deer and Miller (1966), Bernaix (1969), Bell (1981) for determining engineering properties and Colback *et al.* (1965) for understanding the influence of moisture content on the strength of rocks.

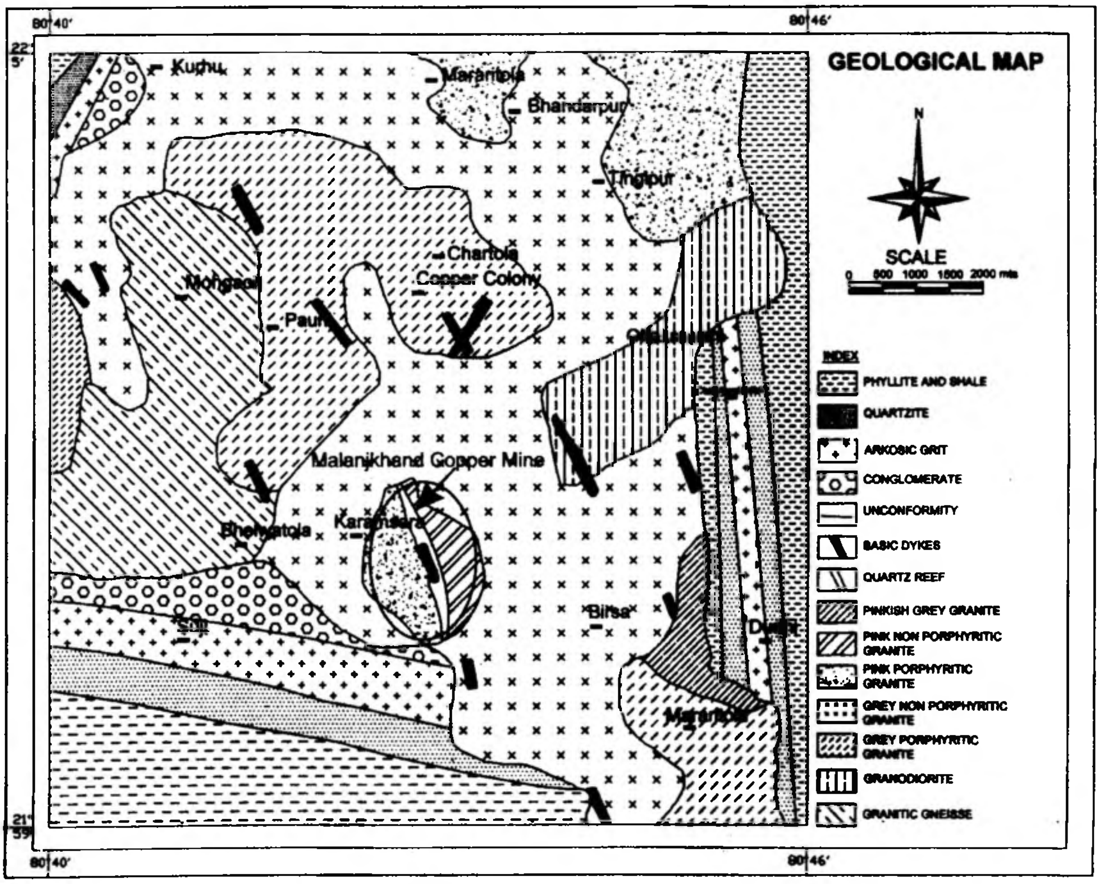

Figure. 1 Geological map of the study area

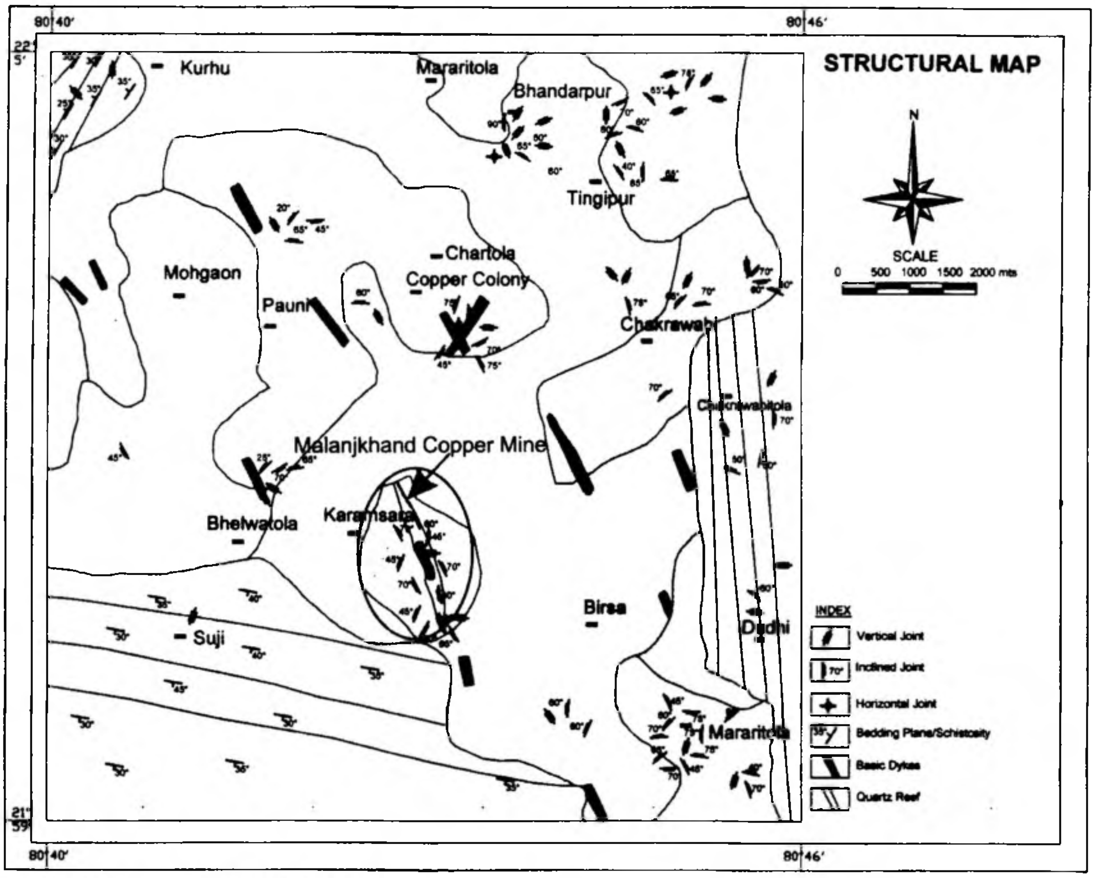

Figure. 2 Structural map of the area

Table-1. Generalized geological succession of Malanjkhand and surrounding area

Quaternary	Pleistocene Palaeocene	-Laterites and Bauxite Deccan Trap Basalt
	-----Unconformity-----	
Proterozoic	Chilpi Group	-Pegmatite, Quartz vein -Quartz, Biotite gneiss -Sericite & Mica schist -Phyllite -Crystalline Limestone -Mica schist -Orthoquartzite & Grit conglomerate
	-----Unconformity-----	
Archaean Basement Complex	Younger Metamorphics	-Pegmatite, Quartz veins -Malanjkhand Granodiorite -Pipardhar Grandiorite
	Older Metamorphics	-Amphibolite schist -Biotite gneiss -Hornblende gneiss

Engineering and Physical Parameters

The various physico-mechanical parameters determined are presented in Table - 2. Further, in order to understand the relationship among the engineering properties of different rock types, a series of histograms and graphic curves have been developed.

Fig. 3a depicts an increase in compressive strength from NPP to PGG and from GD to GG. Whereas, NPP, PG and GD have appreciably lower compressive strength. The sudden drop in compressive strength is probably due to compositional and grain size variation, specially the presence of phenocrysts of orthoclase feldspar, which are very sensitive to chemical alteration. Fig. 3b shows a decrease in shear strength from PG to GD, followed by a sudden rise at NGG and then decrease upto GG. In this case, besides compositional variation, orientations of foliation planes have also influenced the shear strength largely. Fig. 3c shows that the NPP, NGG and PPG have higher tensile strength compared to other rock types. On the other hand, due to compositional variation, high-grade metamorphism, and orientation of foliation planes with respect to applying load, the PG and GG show a rapid decrease in tensile strength. Fig. 3d and e are showing variation in physical properties such as porosity and density. NPP, PGG and GD depict the maximum porosity, while the least porosities are observed in GG, and PG fig 3d. The rocks, which show intermediate porosity, are NGG and PPG. In general, the constituting minerals influence the densities of different rocks. Hence, the rocks comprising heavier minerals such as PPG and GG show high densities compared to other rock types. Except NGG, there is a progressive increase in densities at both ends such as at PGG and GG fig 3e.

Table-2. Engineering properites of rocks around Malanjkhand area.

Rock Type	Sample Tested	Density	Porosity	Compressive Strength	Tensile Strength	Single Shear Test	Double Shear Test
Formula Used				$S_C = \frac{\text{Load}}{\text{Area}}$	$S_t = \frac{2W}{dl}$	$S_{SS} = \frac{W}{A}$	$S_{DS} = \frac{W}{2A}$
Units		gm/cm^3	%	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2
Nonporphyritic Pink Granite (NPP)	4	2.732	0.68	813	159	355	–
Pinkish Grey Granite (PGG)	4	2.727	0.19	1234	120	370	–
Porphyritic Pink Granite (PG)	4	2.738	0.587	1935	147	–	311
Granodiorite (GD)	3	2.70	0.59	1260	145	–	198
Non porphiritic Grey Granite (NPG)	3	2.656	0.31	1779	191	311	–
Pink Prophyritic Granite (PPG)	5	2.761	0.40	1896	178	–	214
Dolerite (DL)	5	3.010	0.62	465	226	–	301
Gneissic Granite (GG)	6	2.786	0.18	1912	132	–	175

Abbreviation : d-diameter of specimen, L-length of specimen, A-cross sectional area, W-ioad applied, S_c- compressive strength, S_t - tensile strength, S_{ss} - single strength, S_{DS} - double shear strength

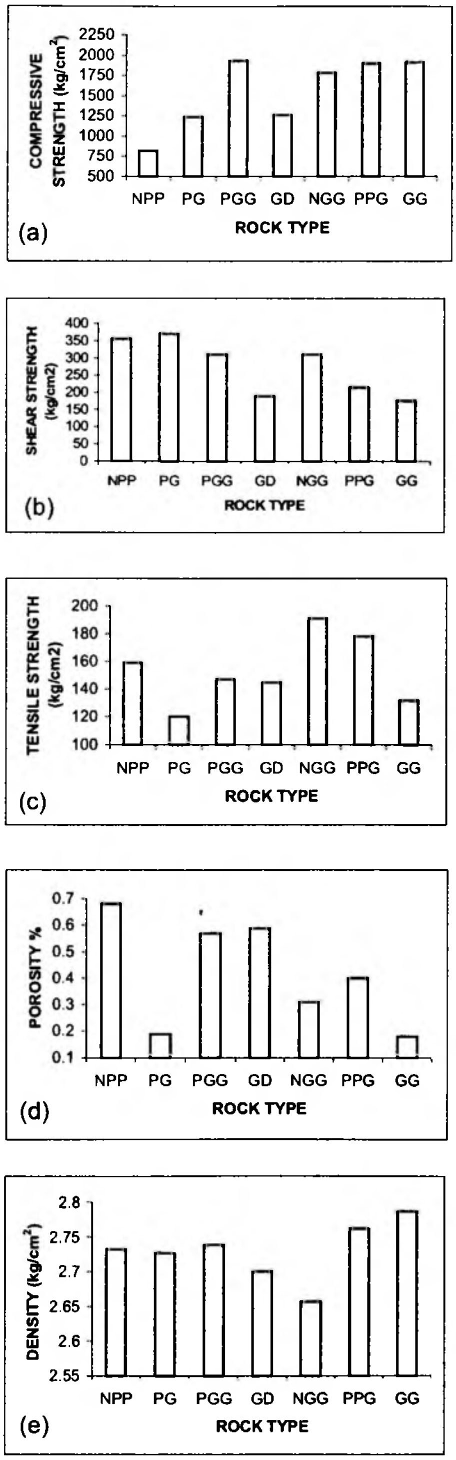

Figure 3a,b,c,d,e

Relationship among Engineering, Physical, Chemical, Mineralogical and Petrographic Parameters

The variation in the physical and engineering parameters displayed by the different varieties of granites can be explained by the change in chemical, mineralogical, and petrographic parameters in the rocks.

In order to explore, whether any relationships exist between physical and engineering parameters, the compressive strength, shear strength and tensile strength data are plotted against the porosity and specific gravity. Fig. 4a shows a gradual decrease of compressive strength with an increase in porosity, Fig.4b do not show any relationship between porosity and shear strength as the points plotted show a wide scattering, Fig. 4c shows an increase of tensile strength up to 0.3% porosity and then a gradual decrease with increase in porosity.

Fig. 5a is a plot of shear strength versus compressive strength. The compressive strength increases with consequent decrease in shearing strength. The tensile strength shows an increase up to a point with resulting increase in compressive strength fig. 5b and then it decreases. Fig. 5c shows a similar relationship on tensile strength versus shear strength graph. Fig. 5b and 5c show an increase in elastic limit up to a point and beyond that point the elastic limit decreases.

It is well established that various physical and engineering parameters are dependent variables, but these are controlled by the independent variables, such as, composition (chemical, mineralogical) and petrographic characteristics. The independent variables taken into consideration are such as SiO_2, MnO, H_2O, mineralogical parameters, total modal quartz percentage, total feldspar percentage, total ferromagnesian mineral percentage, quartz/feldspar ratio, felsic/mafic index, and weathering potential index.

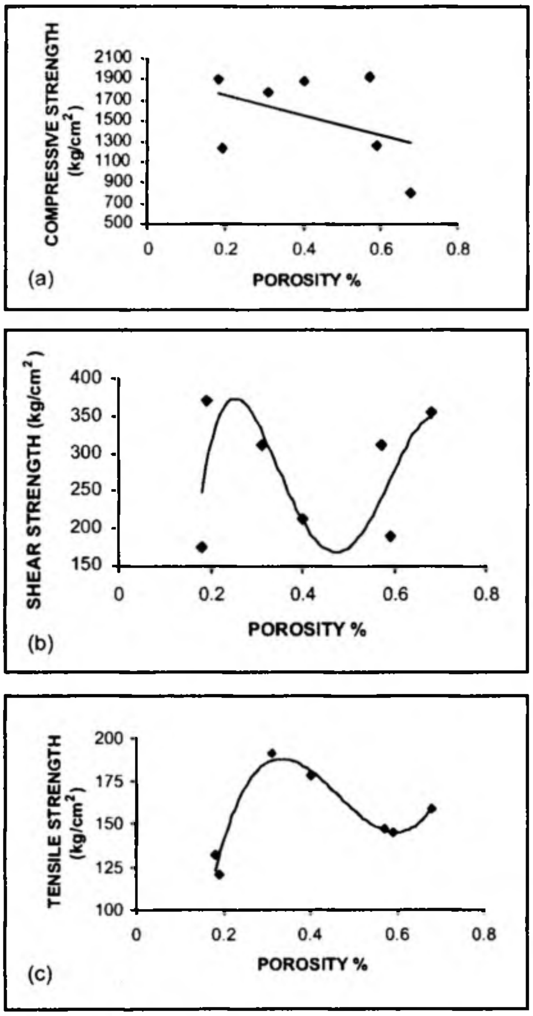

Figure 4a,b,c

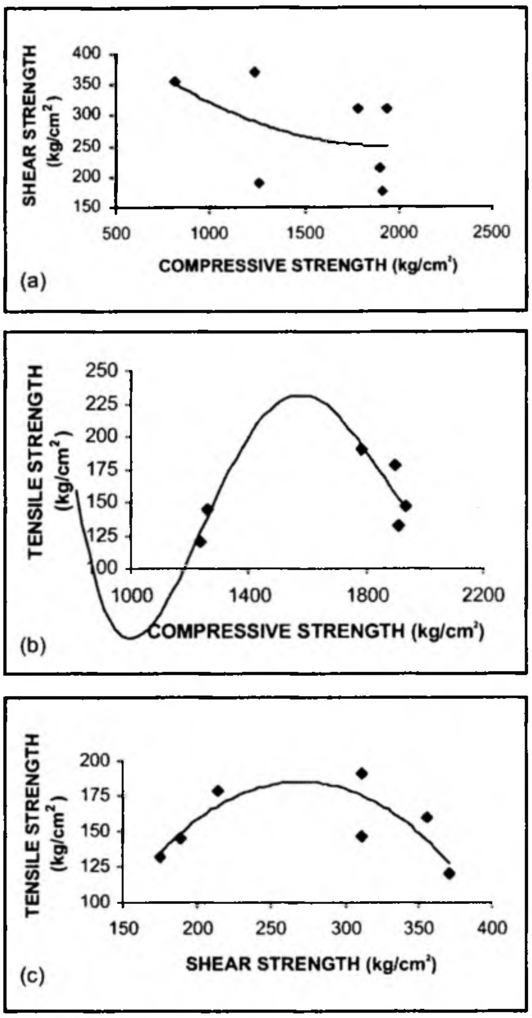

Figure 5a,b,c

Fig. 6a compressive strength versus SiO_2 graph shows a decrease in compressive strength with increase in SiO_2 (i.e. at 68%) and then a decrease in compressive strength with increase in SiO_2 content (i.e. at 72%). The SiO_2 % is calculated based on the total silica, which includes both free and combined SiO_2, associated as silicates in different rocks. The combined SiO_2 is colloidal in nature and heals up the interstices and planes of weakness in the rock. Thus, combined SiO_2 increases the compressive strength, while free silica decreases the same. As a result, there is a drop in compressive strength (i.e. about 1450 kg/cm2) with a consequent increase in silica percentage. The increase in silica percentage increases the interlocking character, which ultimately enhance the friction between shear surfaces. Fig. 6b shear strength versus SiO_2% graph shows a gradual increase in shear strength with resulting increase in SiO_2. Fig. 6c tensile strength versus SiO_2 graph shows a slight increase in tensile strength with continuous increase in SiO_2.

The fig. 7a shows an increase of crushing strength with increase of MnO, while fig. 7b shows that the shear strength decreases

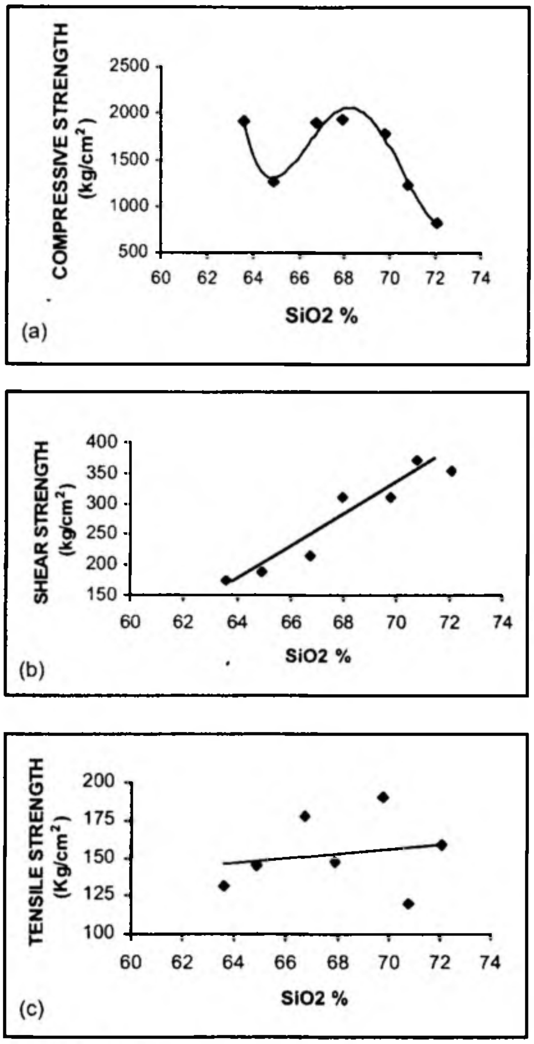

Figure 6a,b,c

sharply with consequent increase in MnO content. Fig. 7c shows constant level increase in tensile strength with continual increase in MnO. In case of compressive strength, the introduction of MnO has influenced significantly the textural (interlocking) characteristics in varieties of granites and found to be enhancing the strength, whereas by the process of leaching and alteration, it has dropped down the shearing and tensile strength.

In fig. 8a, b and c the engineering strengths are plotted against H_2O percentage where water is found to be associated in different rocks as natural moisture content. All the three plots show a gradual decrease in engineering strength as water content increases.

Fig. 9a and b show the plots of porosity versus the MnO and H_2O percentage, the porosity decrease in different varieties of granitic rocks with an increase in MnO and H_2O%. This is because of leaching of MnO, which fills up the void spaces, and thus the resulting decrease

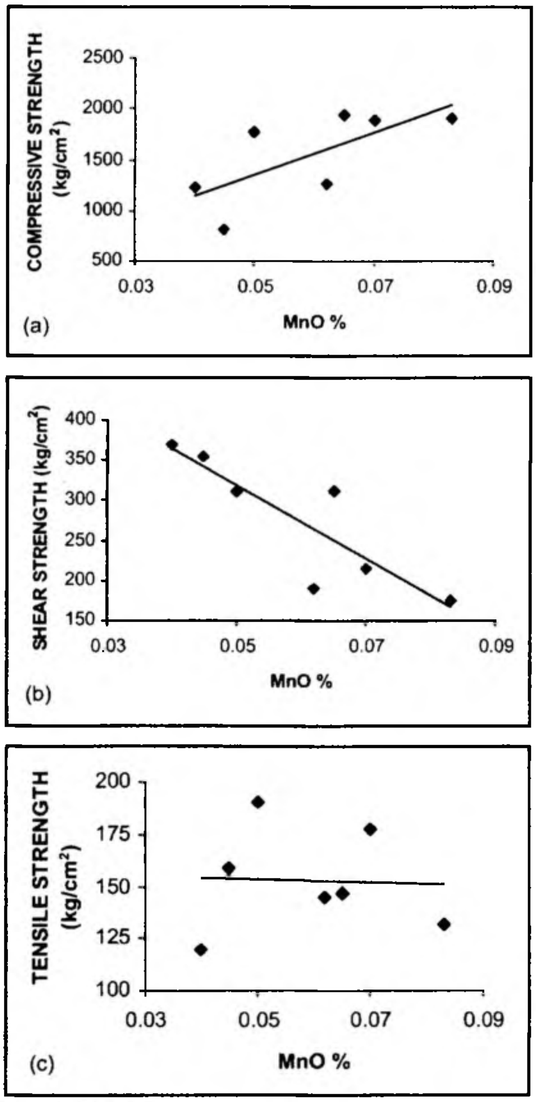

Figure 7a,b,c

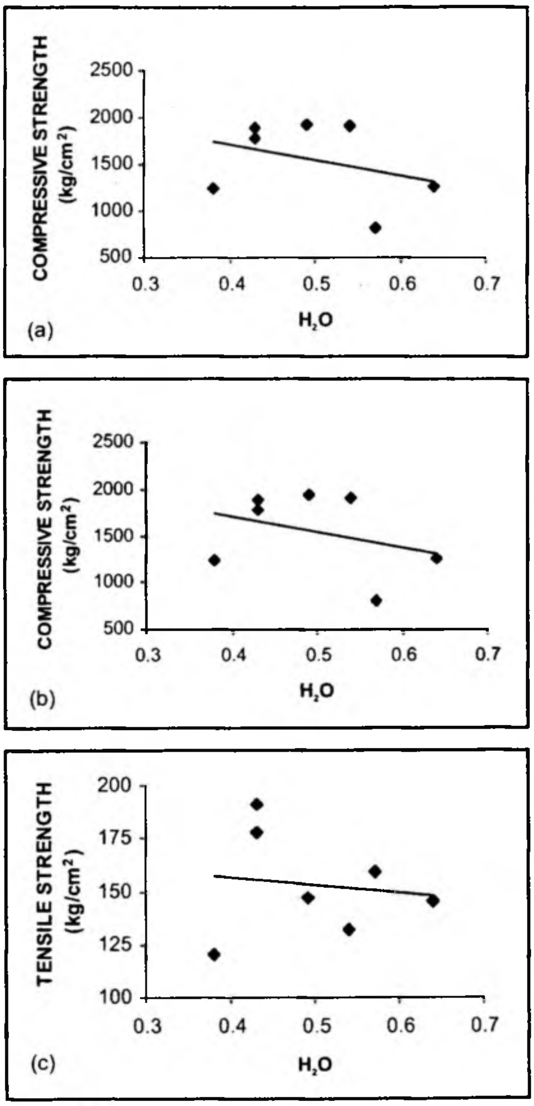

Figure 8a,b,c

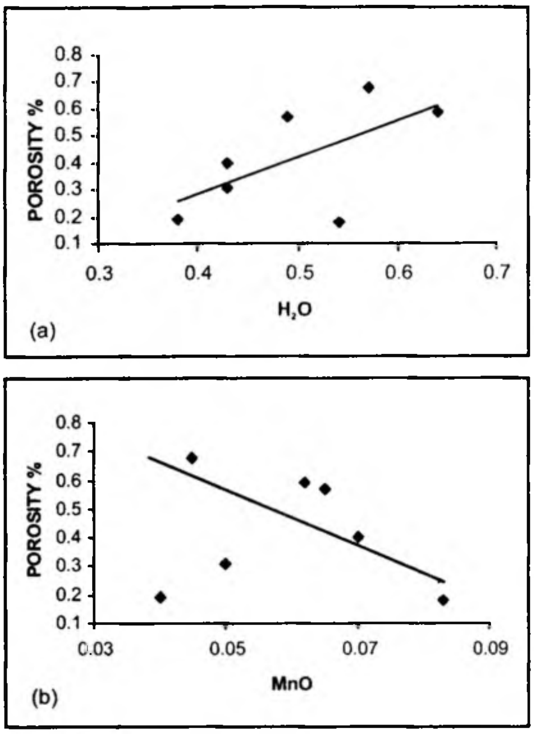

Figure 9a,b

in porosities. Similar phenomenon is also observed in case of H_2O.

In fig. 10a, b and c the engineering strengths are plotted against quartz content. Compressive and tensile strength decrease with increase of quartz content fig. 10a and c. The shear strength increases with increase in quartz content fig. 10b. The increase in quartz content imparts toughness and rigidity to the rocks and hence resulting increases in shearing strength, while compressive and tensile strengths have significantly decreased, since the quartz is brittle in nature.

Fig. 11a, b and c are showing plots of strength data against modal feldspars. The modal feldspars include both potash feldspar and plagioclase. Fig. 11a and b show uniform decrease in compressive and shear strength with consequent increase in modal feldspar. Fig. 11c shows an increase in tensile strength with an increase in total modal feldspar. In general, the presence of total modal feldspar has been found significantly reducing the shear and compressive strength.

Fig. 12a, b and c show plots depicting strength data against total modal ferromagnesian minerals. Fig. 12a shows a gradual increase of compressive strength with increase in ferromagnesian mineral content, while fig. 12b and c show a peak shear strength at 20%

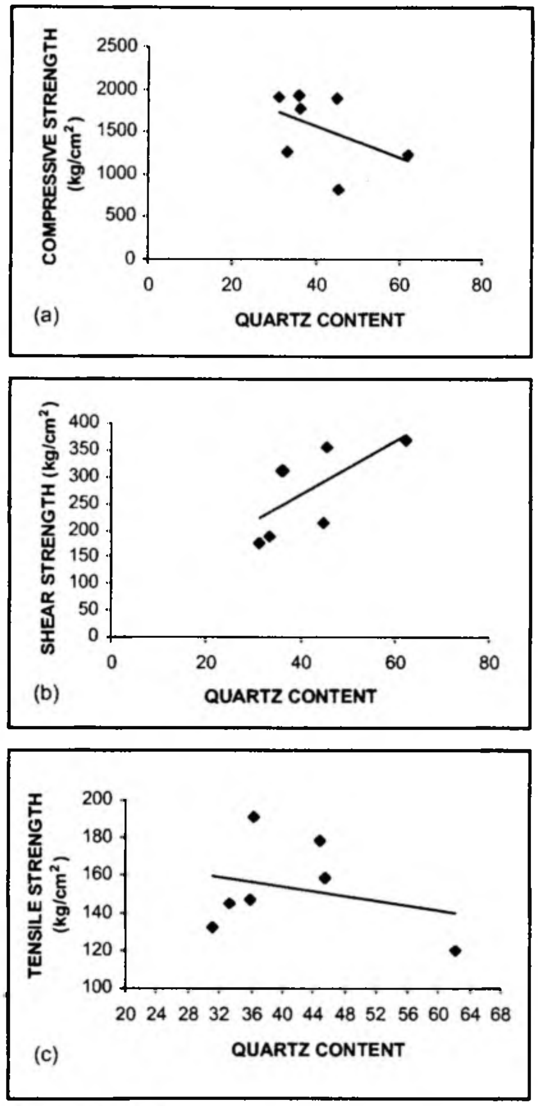

Figure 10a,b,c

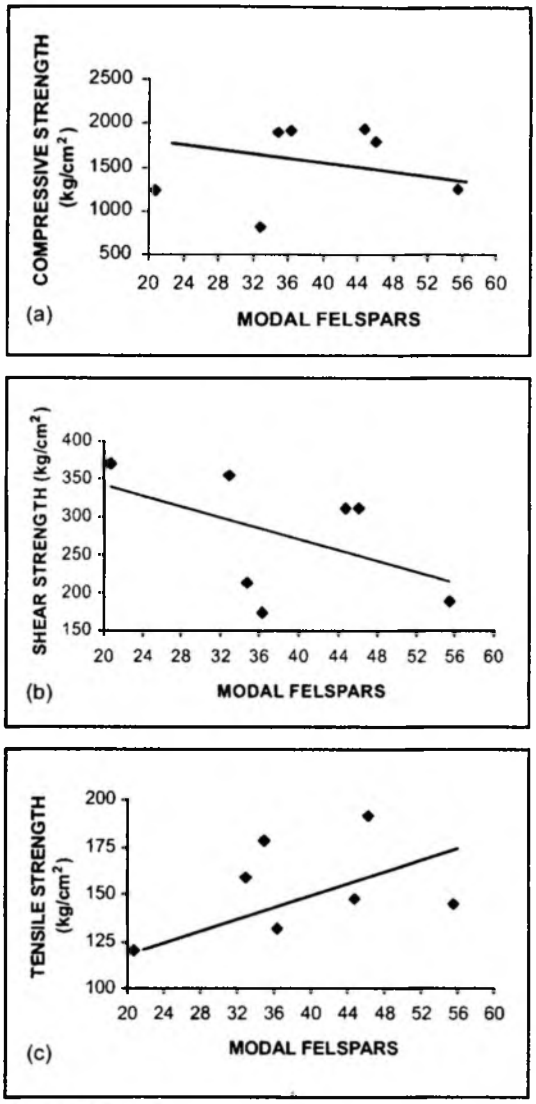

Figure 11a,b,c

ferromagnesian minerals (i.e. about 300 kg/cm^2 stress level) and a peak tensile strength at 22% ferromagnesian minerals (i.e. about 160 kg/cm^2 stress level) respectively. Practically, both shear and tensile strength decrease constantly as the level of stresses are increased further.

The ferromagnesian minerals include mainly biotite with minor amount of epidote, sphene. Since micas are characterized by a well-developed basal cleavage, the shearing and tensile strength decrease with increase in ferromagnesian mineral content. Though, the increase of compressive strength with respect to increase of ferromagnesian minerals looks anomalous, it may be attributed to the orientation of platy and flaky minerals in the rocks, with respect to the applying of load especially during the determination of compressive strength. If the load at the time of testing was at right angle to the plane of mica or in the plane of cleavage, in the first instance, there will be an increase while in a later case; there will be a drastic decrease in compressive strength.

In order to understand the effect of petrological parameters over strength of varieties of granites, the following relationship have been developed, such as quartz/feldspar ratio, salic/famic mineral ratio and weathering potential ratio (Rieche, 1943). The data calculated are presented in the form of various plots (Fig. 11, 12 and 13).

The fig. 13a, b and c show the plot of engineering strength versus quartz/feldspar ratio. Fig. 13a and c show a gradual decrease in compressive and tensile strength with increase of quartz/feldspar ratio, while fig 13b, shows a gradual increase in shear strength with increase of quartz/feldspar ratio.

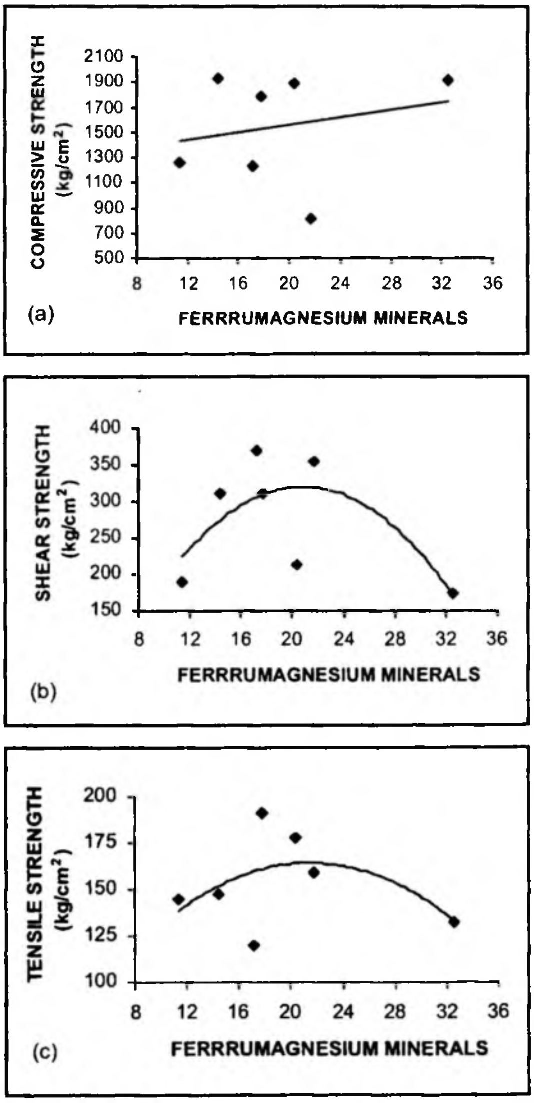

Figure 12a,b,c

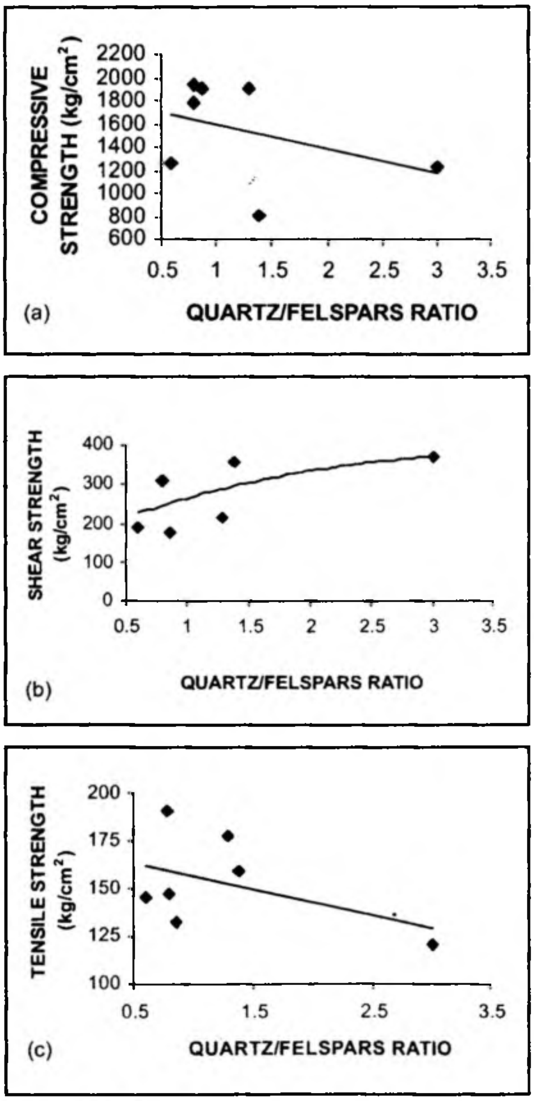

Figure 13a,b,c

When the engineering parameters are plotted against felsic/mafic ratio, the following observations have been noted. Fig. 14a shows a gradual decrease in compressive strength with an increase in felsic/mafic ratio while fig. 14b and c show a constant level increase in shearing and tensile strength with the increase in felsic/mafic ratio. The felsic minerals taken into account are quartz and feldspars, while the mafic minerals comprise biotite, epidote, and sphene. Hence, the increase of felsic and mafic minerals develop the planes of weakness in the rocks, which ultimately decreases the compressive strength and influence shearing and tensile strength significantly.

The other important petrographic parameter namely weathering potential index has been computed for the six varieties of granites. The data calculated on engineering strengths are plotted against weathering potential index. Fig. 15a shows an increase while fig.15b and c

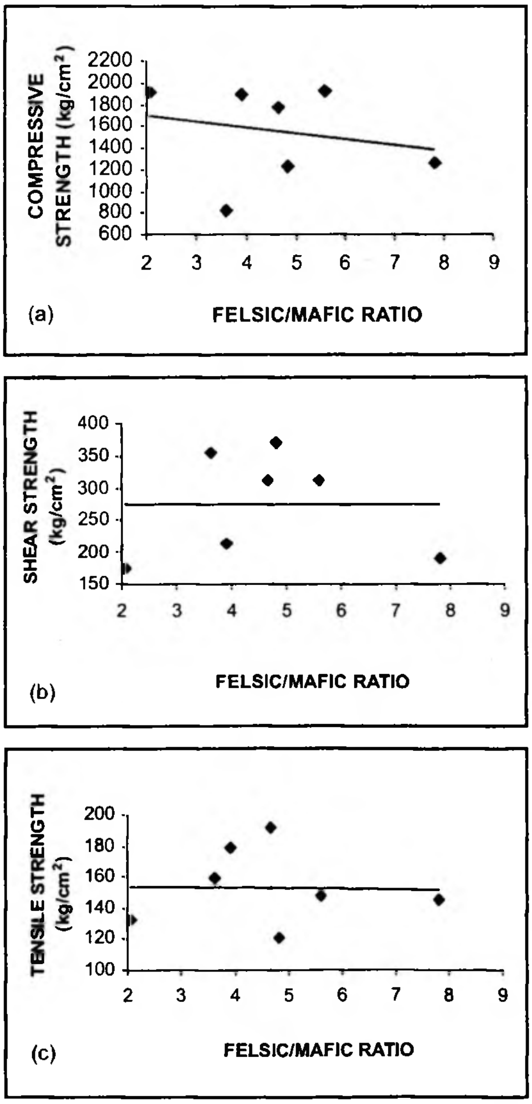

Figure 14a,b,c

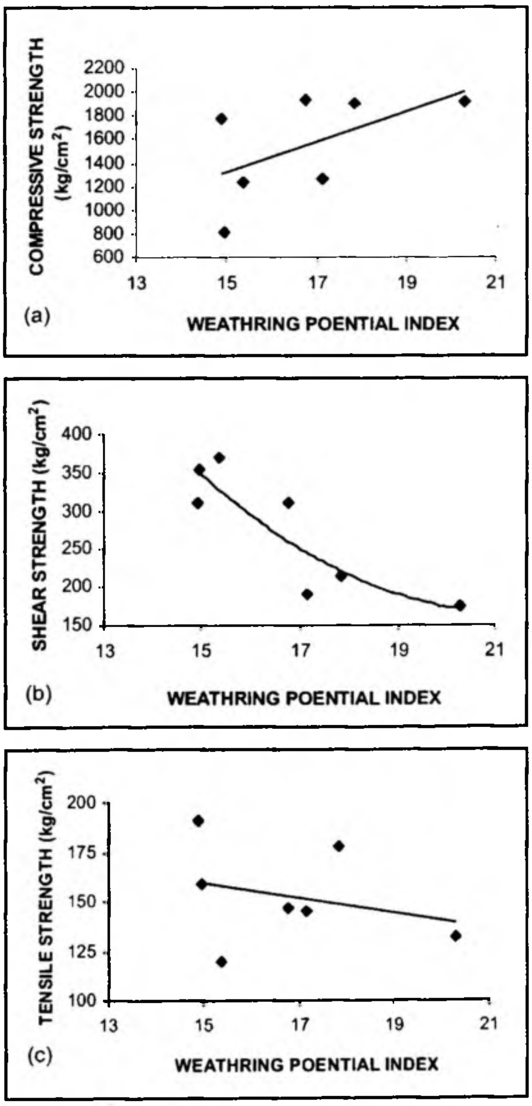

Figure 15a,b,c

show gradual decrease in engineering strength with consequent increase in weathering potential index.

In order to demarcate the areas comprising rocks of high compressive strength and high tensile strength, iso-compressive strength and iso-tensile strength maps have been prepared on a contour interval of 100 and 10 kg/cm^2 respectively (Fig. 16 a and b). The iso-compressive strength map prepared at contour interval of 100 kg/ cm^2 (Fig. 1 and 16a). This shows a general increase from west to east direction, the grey non-porphyritic granite having the highest compressive strength, granitic gneiss and pinkish-grey granite having the least. The iso-tensile strength map prepared (Fig. 1 and 16b) shows a general increase of tensile strength from north to south, the least being in the granodiorite and highest in non-

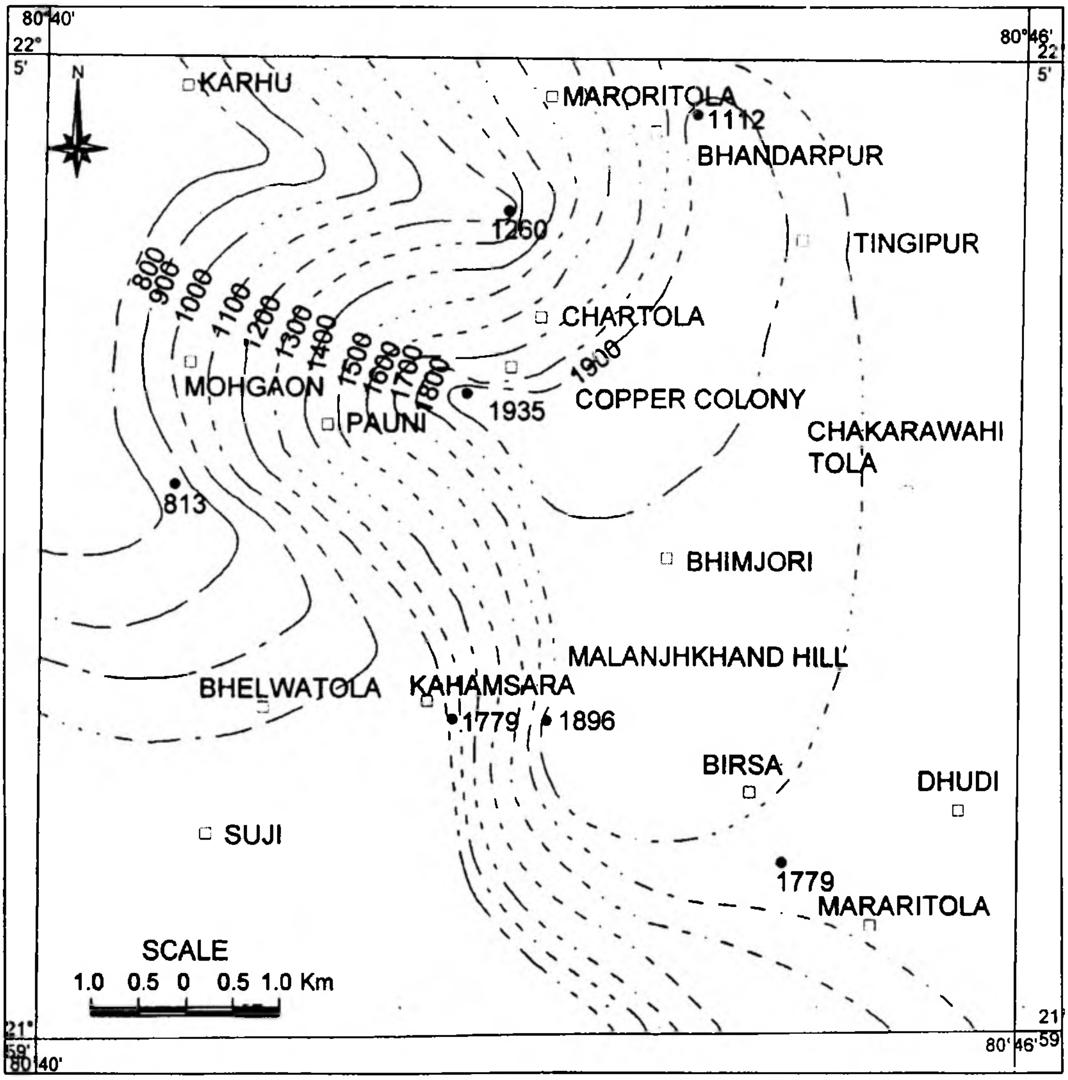

Figure 16a Iso-compressive Strength Map

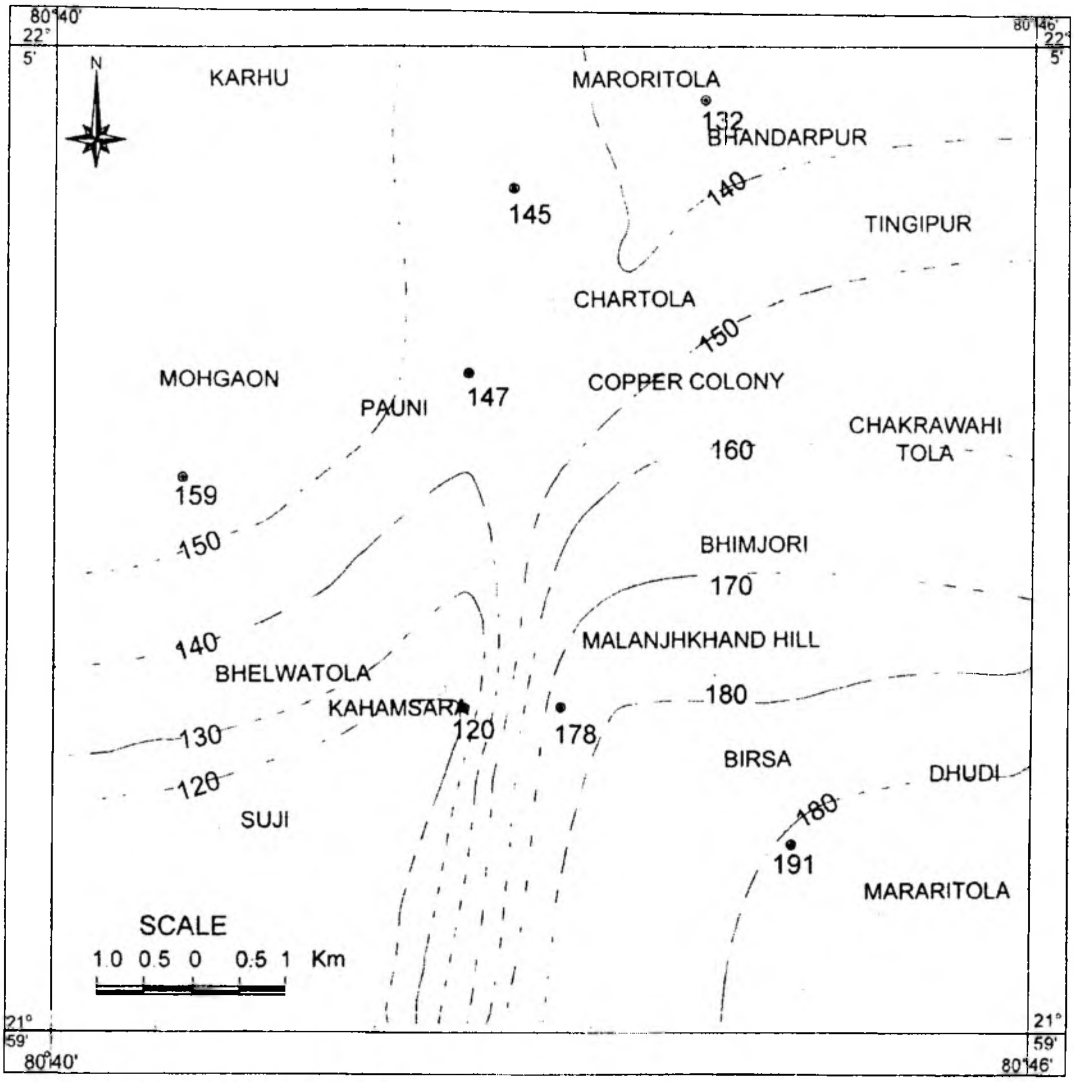

Figure 16b Iso-tensile Strength Map

porphyritic grey granites. Hence, the benches can be developed with ease in the east-west direction. The map (fig. 2) further indicates that the frequencies of north-south shear joints are abundant in the mine area. The iso-compressive strength map also shows a similar relationship with tensile strength. The iso-strength maps, geological, structural maps, chemical/ mineralogical and other engineering parameter point out that it is easier to mine in a north-south direction then east-west direction and east-west oriented benches/slopes for hauling ore as well as mine waste. These slopes/ benches appear to be much stable than any other orientation.

Summary and Conclusions

The following conclusions have been drawn on the basis of analysis and studies conducted on different varieties of granites of Malanjkhand area:-

An increase in compressive strength from granodioritic to grey porphyritic granites on the one hand while a gradual decrease from granite gneiss to granodioritic and from grey porphyritic to pinkish grey granites on the other hand. The shear strength shows an initial increase from granitic gneiss to non-porphyritic grey granite, followed by a decrease from porphyritic grey granite and from non-porphyritic grey granite to pinkish-grey granites, which show an increase. The tensile strength shows an increase from granitic gneiss to pink-porphyritic and a decrease from pink-porphyritic to pinkish-grey granite.

Physical parameter namely porosity, it is maximum in granodiorite and porphyritic-grey granite; while the least porosity is seen in granitic gneiss whereas intermediate porosities in non-porphyritic-grey, porphyritic pink and pinkish-grey granites. Density is highest in granitic gneiss and least in pink porphyritic granite. However, the progressive increase in specific gravity is noted from granodiorite to grey non-porphyritic granite. In order to demarcate the areas, comprising rocks of high compressive strength and high tensile strength for determining the stability of mines/slopes in and around Malanjkhand mining area, the iso-compressive strength and iso-tensile strength maps have been prepared and the areas of varying stability have been demarcated. The compressive strength decreases from west to east direction, the grey non-porphyritic granite showing the highest compressive strength, while granitic gneiss and pinkish grey granite show the least. In case of tensile strength, there is a general increase from north to south, the least being in the granodiorite and highest in non-porphyritic grey granite. Hence, the benches of the mine can be developed with ease in the east-west direction. It is also obvious from structural map that the frequencies of north-south shear joints are abundant in mine area. Thus, it is easier to mine in north-south direction then in east-west direction and east-west, oriented benches/slopes are suitable for hauling ore as well as mine waste. These slopes/benches appear to be much stable than any other orientation.

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