Determination of the effects of mineralogy on the point load compressive strength of rock

Mahdi Askaripour[1], Ali Saeidi[2], Alain Rouleau[3], Patrick Mercier-Langevin[4]

[1] Researcher, PhD candidate, Department of Applied Sciences, University of Quebec at Chicoutimi, Chicoutimi G7H 2B1, Canada

[2] Professor, PhD, Department of Applied Sciences, University of Quebec at Chicoutimi, Chicoutimi G7H 2B1, Canada

[3] Professor, PhD, Department of Applied Sciences, University of Quebec at Chicoutimi, Chicoutimi G7H 2B1, Canada

[4] Research Geoscinetist, PhD, Geological Survey of Canada, Quebec City, QC G1K 9A9, Canada

ABSTRACT

Rock forming minerals are of great importance understanding the instability of a rock. While the rock instability has been the main subject of many studies, the relation between rock forming minerals and geomechanical parameters of rock remained unknown. This research study aims to investigate the effect of rock forming minerals on the point load test (PLT) of the rock. In the laboratory, rock specimens from four boreholes with different lithologies are tested to obtain their axial and diametrical PLT. Correspondingly, the mineral of rock specimens is analyzed in thin section study. Here, the thin section results of specimens are coupled with all units of boreholes to assign the obtained minerals to all lithologies of boreholes. As there are many minerals in the database, the principal component analysis (PCA) is applied to reveal the significant minerals and then, the data reduction is carried out. The principal component regression (PCR) is performed to evaluate the effect of minerals on axial and diametrical PLT of the rock. Comparison of PCR results of diametrical and axial PLT highlights the effect of major rock minerals, metamorphic minerals and sheets minerals on PLT. Quartz, feldspar, amphibole, plagioclase, and epidote have shown a positive effect on axial and diametrical PLT of the rock. On the other side, chlorite and white mica have represented a negative effect on axial and diametrical PLT of rock. Moreover, the effect of anisotropy of rock and grain size have shown a negative effect on diametrical PLT of the rock.

RÉSUMÉ

Les minéraux formant des roches sont d'une grande importance pour comprendre l'instabilité de celle-ci. Alors que leurs instabilité a été le principal sujet de nombreuses études, la relation entre les minéraux formant la roche et les paramètres géomécaniques est restée inconnue. Cette étude vise à étudier l'effet des minéraux formant la roche sur le test de charge ponctuelle (PLT) de la roche. En laboratoire, des spécimens de roche provenant de quatre forages avec différentes lithologies sont testés pour obtenir leur PLT axial et diamétral. De même, le minéral des spécimens de roche est analysé dans une étude en coupe mince. Ici, les résultats des coupes minces des spécimens sont couplés à toutes les unités de forages pour attribuer les minéraux obtenus à toutes les lithologies des forages. Comme la base de données contient de nombreux minéraux, l'analyse en composantes principales (PCA) est appliquée pour révéler les minéraux importants, puis la réduction des données est effectuée. La régression en composantes principales (PCR) est effectuée pour évaluer l'effet des minéraux sur le PLT axial et diamétral de la roche. La comparaison des résultats de PCR du PLT diamétral et axial met en évidence l'effet des principaux minéraux de roche, des minéraux métamorphiques et des minéraux en feuilles sur le PLT. Le quartz, le feldspath, l'amphibole, le plagioclase et l'épidote ont montré un effet positif sur le PLT axial et diamétral de la roche. De l'autre côté, le chlorite et le mica blanc ont représenté un effet négatif sur le PLT axial et diamétral de la roche. De plus, l'effet de l'anisotropie de la roche et la granulométrie ont montré un effet négatif sur le PLT diamétral de la roche.

1 INTRODUCTION

The strength and mechanical properties of a rock with its petrophysical properties are significant parameters when considering rock failure, drilling of wells and constriction of reservoirs. (Worthington, 1991). Mechanical properties refer to the strength characteristics of rock. The strength of the rock is dependent on primarily on its mineral composition and constitution (Bell et all, 1999). The rock mass contains planes of weakness, making it mechanically anisotropic. Rock anisotropy affects the underground stability and surface excavations, rock cutting and other engineering applications in civil, mining, geological and petroleum engineering (Hoek, 1964; Ulusay and Gökçeo_glu, 1997).

The several parameters that influences the strength and deformability of rocks can be divided into two categories: the nature and condition of the rock itself (e.g. mineralogy, texture, porosity density, in-situ stresses) and factors related to sample preparation and testing methods (Tugrul and Zarif 1999; Gupta and Rao 2000; Tugrul 2004; Sousa et al. 2005; Tercan and Ozcelik 2006). These properties on the physical and mechanical properties of rock have been investigated for many years, and studies have indicated that there is a close relationship between these parameters. Textural characteristics, such as grain size, grain distribution and grain orientation could influence rock strength (Akesson et al. 2003; Hecht et al. 2005). Several authors have studied the effect of the degree of weathering and porosity in the mechanical behavior of the rocks (Hudec 1998; Tugrul 2004; Aydin and Basu 2005). It is indicated that the increase in the degree of weathering and porosity have a negative effect on the mechanical strength of rocks (Steiger et al. 2011).

Mineralogical composition also affects rock strength by the inherent characteristics of each mineral (Karaca and Onargan 2008; Basu et al. 2012). Quartz is one of the most important minerals in granites, since it is always present (quartz can be absent or be present in a low amount in dark magmatic rocks), and its characteristics can influence the rock's mechanical behavior. The hardness of the quartz has a major contribution to the strength of the rock. Lindqvist et al. (2007) studied the effects of mineral composition, grain size, porosity and micro-fissures on rock mechanics properties. Meriam et al. (1970) investigated and clearly stated the relationship between the tensile strength and the percentage of quartz. Higher percentage of quartz has higher strength of rocks. In contrast of presence of feldspar, the strength of rocks seems decreased. Johansson et al (2011) confirmed that mineral composition, grain size, shape and lamination are the most significant factors influencing rock mechanics properties. He also summarized the different characteristics of various mineral composition and structure porosity as well as their effects on rock mechanics properties. Tugrul and Zarif (1999) recognized that the physical and mechanics properties of rock are functions of mineral composition and structure. Prikryl (2001) concluded that the uniaxial compressive strength (UCS) of granite is closely related to its grain size. The studies cited above do not normally incorporate detailed information concerning the other minerals composition of rock. This lack of information about the mineralogy, especially about the minerals of felsic and mafic rocks, could make it difficult to investigate the mechanical behavior of the rock. Subsequently, even with the same mineralogical composition, the mechanical properties of the rock may vary. Therefore the research on mineral composition of rock, structure and rock mechanics, especially the relationships among them are needed. Although a number of studies have been conducted on the relationship between petrographic and mechanical properties, the majority of work has been conducted on mineralogical composition of mafic and felsic rocks.

Our ongoing investigation are aimed to approach effect of mineralogy of mafic and felsic rock on point load compressive strength of rock. This present study reports data on core samples collected from different boreholes in the Westwood Mine, Abitibi area. The Westwood Mine was selected due to its unique features in terms of different lithologies with different minerals, an increasing degree of metamorphism of rock by increasing depth of excavation and reports of rock mass failure in term of the rockburst. Thin section studies, geotechnical logging data were performed and then, these results were assigned to lithologies of selected boreholes in order to have large database of mineralogy of the rock. The axial and diametrical point load compressive strength (PLT) was under taken in each meter of boreholes. To clarify the role of each mineral as well as effect of foliation on axial and diametrical PLT the principal component analysis (PCA) and principal component regression (PCR) carried out.

2 METHODOLOGY

Figure 1 presents the methodology and sequential steps that we use to assess the effect of the mineral composition of the rock on the point load compressive strength of rock mass.

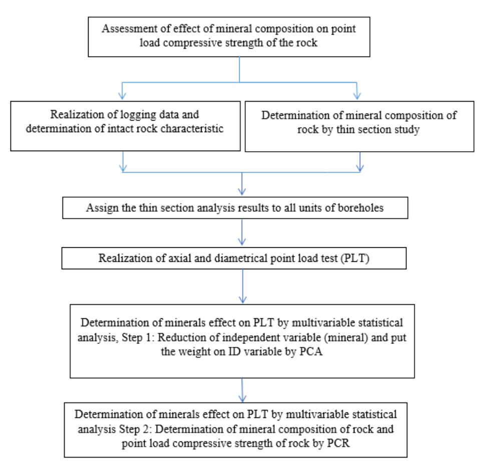


Figure 1. The methodology used to evaluate the effect of rock mineral composition on point load compressive strength of the rock

2.1 Geology of site and rock tested

The sampling area is situated in the Doyon property (Westwood Mine), 2.5 kilometers east of the former Doyon gold mine in the Bousquet Township, approximately 40 kilometers east of Rouyn-Noranda and 80 kilometers west of Val d'Or in northwestern Québec, Canada. This area is approximately 420 km northwest of Montreal (Figure 1). The Westwood Project is held 100% by IAMGOLD. This deposit is one of the most important gold discoveries of recent years in Canada and it has been in production since March 2013.

At the Westwood Mine, the units are often thin and interleaved, creating or generating differential strength in rock over short distances. In order to understand the impact of rock quality on the geomechanical parameters of rock, it is essential to know the different lithology of the Westwood deposit which are intersected by the Bousquet fault. The geology of this deposit is complex and it comprises 16 lithological units passing from mafic (fragile-ductile unit) to felsic (fragile unit) with 6 different types of alteration, all intersected by dykes and veins of variable composition (Yergeau 2015a). The Westwood mine is part of the Doyon-Bousquet-Laronde mining camp, which is located within the Southern Volcanic Zone of the Abitibi sub-province. Zone 2 of the Westwood deposit is hosted in felsic volcanic rock with sub-vertical to steeply south dipping schistosity. Schistocity is heterogeneous and varies in intensity from moderate to strong. East–west anastomosing high-strain corridors are observed throughout the property. Three mineralised corridors comprise the deposit and are stratabound and vertically stacked with respect to the original volcanic stratigraphy. In the lower portion of the stratigraphy, the Zone 2 Extension forms the deepest and northernmost part of the deposit. The North Conidor is found in the central portion and the Westwood-Warrenmac Corridor is located in the southern part of the deposit, in the upper units of the Bousquet Formation. In this study, Zone 2 Extension corridor will be studied. The geological map of the Westwood mine, is presented in Figure 2.

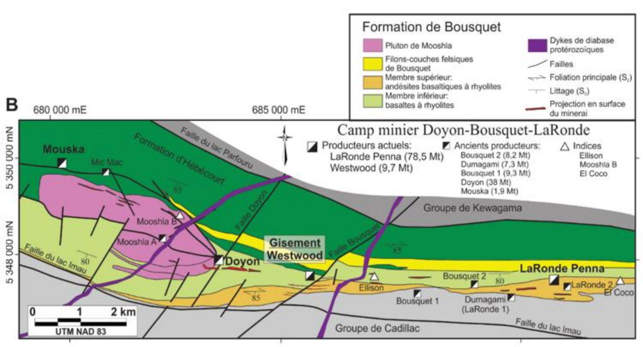


Figure 2. Simplified geological map of Westwood deposit and three main corridors (Modified by Mercier-Langevin, P et al., 2009)

2.2 Determination of mineralogy of rock as a function of depth at the Westwood Mine

As mentioned before, degree of rock mass metamorphism and mineralogy of the rock can influence the behavior of rock mass in underground excavations, since the mineralogy and texture of the rock is modified (Abioye, 2015). As the first objective of the thesis, mineralogy of rock samples should be evaluated. For this purpose, the samples will be taken from different depths of the Westwood Mine to be subjected to petrographic and mineralogy analysis. In fact, by applying thin section analysis on the samples, the grain size, texture and composition of the rock would be determined. Moreover, microanalysis (e.g., microprobe, mineral mapping, etc.) would be employed to better identify some minerals, and to image textures versus mineral assemblages versus foliation(s) to provide a clearer understanding over the state and severity of metamorphism. By obtaining the results, degree of rock mass metamorphism at the Westwood Mine will be determined.

2.3 Assessment of point load compressive strength of rock (PLT test)

The point load test (PLT) is an attractive alternative to the UCS because it can provide similar data at a lower cost. According to the shape of the sample, four types of PLT are distinguished. These type are axial test, diametrical test, prismatic test and test on an irregular sample. The point load test allows the determination of the uncorrected point load strength index (Is). It must be corrected to the standard equivalent diameter (De) of 50 mm. If the core being tested is "near" 50 mm in diameter, the correction is not necessary. The procedure for size correction can be obtained graphically or mathematically as outlined by the ISRM procedures. The value for the Is50 (in psi) is determined by the following equation:

$$Is_{50} = \frac{P}{D_e^2} \quad [1]$$

Where P is load (lbf) and D_e^2 is the equivalent core diameter (in).

In this study, the axial and diametrical point load test were carried out for each meter of mentioned boreholes in Table 1. It means two tests were done in each meter of borehole as axial and diametrical test. Totally, 1466 point load test were done as axial and diametrical test. The number of axial and diametrical applied test on each borehole and their point load index are presented in Figure 6.

2.4 Assessment of borehole logging data

The geotechnical core logging process has been developed to record mechanical and structural properties of the rock mass. The scope of geotechnical core logging is to get an appreciation of the rock conditions and apply these understandings to mine design. The core logging method developed requires the core to be grouped into logging intervals that are unique geotechnical domains or designs regions within a particular rock type. The geotechnical domains are assessed by grouping together rock which represents similar geotechnical characteristics and which will behave uniformly in an excavation or the fixed interval method is applied.

In order to assess the geotechnical core logging, several boreholes from different depths and units were selected and the fixed interval domain logging data (3 meters) was chosen. When the length of each boreholes is grouped into this domains, each relevant parameter required for geotechnical evaluation were logged. These parameters includes discontinuity condition, foliation intensity and foliation orientation, rock quality designation (RQD) and core recovery.

Meanwhile the geotechnical core logging was taken, a designed rock mass characteristic chart will be carried out (Figure 3). This chart is deigned in order to assess the properties of rock such as color, roughness, acid reaction and the other parameters. The important part of this chart is determination of observable minerals of each unit of boreholes. This part (observable minerals) will be assigned to mineralogy of the rock which is obtained from thin section studies. Then, it able us to have the mineralogy of all unit of boreholes.

Hole ID :	R19018-18			
From:	0			
To:	1.65			
Homogeneity :	Folié			
Unit	3.3.0			
Colour:	Gray to white gray			
Hardness :	4			
Magnetism (0-5):	0			
Acid reaction (Y/N):	No			
Grain size:	aphanitic < 0.125mm			
Schistosity (0-5):	4			
Altération	3			
Métamorphisme	0			
Observable mineral:	(No/Mineral/Porphyre)	%:	Orientation:	Granulométrie
Quartz	No			
Feldspaths	No			
Sericite	Mineral	20	Schistosity	aph
Muscovite	No			
Chlorite	No			
Biotite	No			
Epidote	No			
Amphiboles	No			
Grenat	No			
Kyanite	No			
Sulfures	Mineral	1	Alteration	0,5 to 2mm
Texture :	Schistose			

Figure 3. Proposed rock characteristic chart

2.5 Assign thin section analysis results to all units of boreholes

As mentioned before, the rock characteristic charts able us to determine information about the texture of rock in each unit of borehole as well as observable minerals of the each unit. As the length of each boreholes is too high, the thin section studies could not be applied for each meter of boreholes where the point load compressive strength of rock are applied. The reasons is that the cost of thin section study is high and if the thin section study wanted to be applied for each meter of boreholes, we needed 800 samples for this test.

In order to overcome this challenge, we assigned the results of rock characteristic chart with results of thin section study for each unit of boreholes. As mentioned, samples for thin section studies were collected from different depths and boreholes of study area. So, how we could determine the rock mineralogy of borehole (Table 1) that they did not have any thin section study from them? Figure 5 presents the proposed methodology by authors to overcome this challenge. In the first step, we considered result of thin section for sample number N and then, it compared to each observable minerals from proposed chart (Figure 4). If the both results were similar, the thin section was assigned to whole relevant unit of boreholes. If not, we tried the other thin section studies result. By doing this methodology, mineralogy of rocks is determined for all units and all boreholes mentioned in Figure 4. Now, we can apply PLT test for each meter of boreholes because the mineralogy of all boreholes were determined.

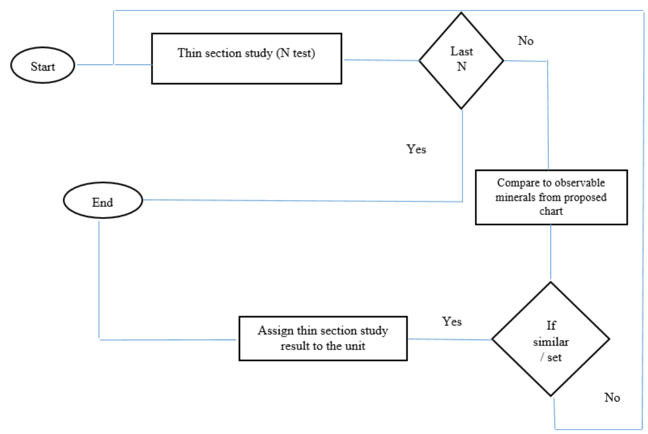


Figure 4. Schematic of novel methodology for determination of mineralogy of rock

2.6 Determination of effect of rock minerals on PLT by multivariable statistical analysis

The literature review has identified the lack of quantitative assessment on effect of minerals on strength of rock. In keep with objective of this article, the effect of rock mineralogy on axial and diametrical point load compressive strength of rock is carried out using multivariable statistical analysis. The term "multivariate statistics" is used to include all statistics where there are more than two variables analyzed simultaneously. Multivariable statistical analysis is used as the problem of effect of minerals on point load compressive strength of rock is multi-dimensional and related more than one minerals. Bivariate analyses of strength of rock is unable to account the complexity of the problem and capture the "whole picture". Therefore, its use can not be appropriate.

Regarding to different methods of multivariable statistical analysis, the two appropriate methods were selected as principal component analysis (PCA) and principal component regression (PCR). The purpose of choosing PCA methods is as followed: Extraction of most significant minerals among several minerals of database and finding effect of rock mineralogy on axial and diametrical point load compressive strength of rock. These methods are explained in the next sections. Figure 5 illustrates simply how these methods are used in this study.

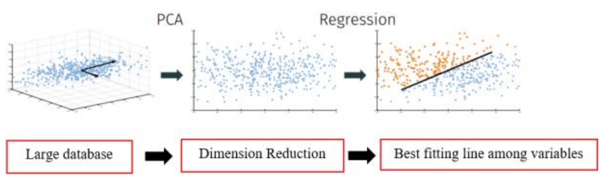


Figure 5. Simple schematic of applied multivariable statistical method

2.6.1 *Step 1: Reduction of independent variable (mineral) and put the weight on ID variable by PCA*

Large datasets are increasingly widespread in many disciplines. In order to interpret such datasets, methods are required to reduce their dimensionality in an interpretable way, such that most of the information in the data is preserved. Many techniques have been developed for this purpose, but principal component analysis (PCA) is one of the oldest and most widely used technique. PCA of a data matrix extracts the dominant patterns in the matrix in terms of a complementary set of score and loading plots. In other words, principle component analysis is a multivariate statistic technique applied to a single set of variables where researchers are interested in discovering the underlying correlations among them (Tabachnick and Fidell., 1996). The underlying correlations among variables are often referred to as factors or components. PCA frequently used in physchological and social sicences studies, has been seen applied in the filed of mining enegineering (Morissette et al., 2011)

In this study, principal component analysis is used to explore the pattern among variables to identify significant variables so that a subsequent data reduction is possible. The database is classified into the two main groups; felsic rocks and mafic rocks.

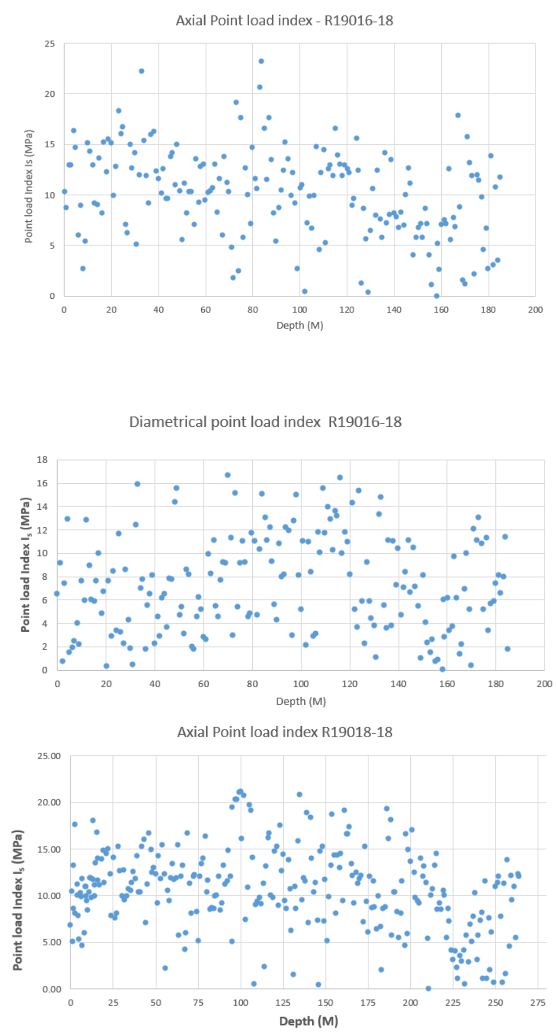
2.6.1 Step 2: *Determination of mineral composition of rock and point load compressive strength of rock by PCR*

Principal component regression (PCR) is a multivariable statistical analysis method in order to determine the quantitative relationship between more variables. In other word, PCR is the method of combining linear regression with principal component analysis. As mentioned before, the principal component analysis can gather highly correlated independent variables into a principal component, and all principal components are independent of each other, so that all it does is to transform a set of correlated variables to a set of uncorrelated principal components. Then we built the regression equations with a set of uncorrelated principal components and get the 'best' equation according to the principle of the maximum adjusted R^2 and minimum standard error of estimate. At last, the 'best' equation is transformed into the general linear regression equation.

3 RESULTS AND DISCUSSION

3.1 Point load compressive strength of rock data

Previously mentioned that point load compressive strength of the rock was selected as indicator of strength of rock. Both tests, axial and diametrical tests, was applied for each meter of borehole. Figure 6 presents the value of point load index test for each borehole.



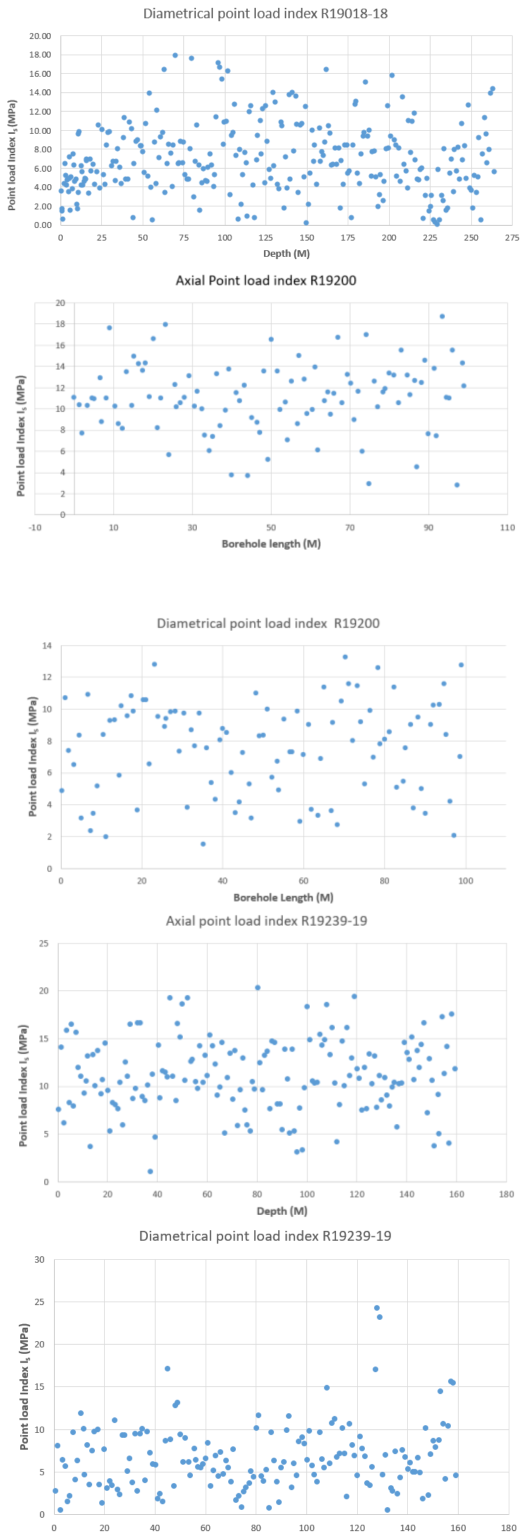


Figure 6. Axial and diametrical point load index for each borehole

3.2 Multivariable statistical analysis

In order to assess the minerals affecting point load index, the most significant minerals have to be identified within the database. At this point, it is important to separate between independent variables and outcome variables (dependent variables). Tabachnick and Fidell (1996) defined independent variables (IV) as the differing conditions to which researchers expose subjects, or characteristics the subjects themselves bring, into the research situation. To maintain simplicity, a total of 10 variables were considered as dependent variables. There variable are minerals of the rock. It is important to determine the correlation between variables. As mentioned, principal component analysis is the first technique used in this study to achieve this objective. Once significant predictor variables are determined, regression modelling is then used to determine the relationship between the dependent variable and independent variables. So, the principal component regression is secondly used to determine the effect of independent variables on independent variable. Note that the rocks in the large database are classified into the felsic and mafic rocks. Subsequence, the effect of minerals on felsic and mafic rocks were evaluated

3.2.1 Step 1: Reduction of independent variable (mineral) and put the weight on ID variable by principal component analysis (PCA)

In this study, PCA is used to explore the pattern among variables to identify and distinguish 'noise' variables so that a subsequent data reduction is possible. Following data preparation, a simple run of PCA was carried out without varimax rotation technique. Nine variables were used in this run: quartz, chlorite, carbonate, sericite, feldspar, epidote, white mica, amphibole and biotite. The extracted component and their associated eigenvalues and variance are shown in Figure7 and 8. Figure 7 belongs to felsic rock and Figure 8 belongs to mafic rocks. Eigenvalue for a component indicates the variance of the data along the new feature axes.

Total Variance Explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.095	20.947	20.947	2.095	20.947	20.947	2.025	20.249	20.249
2	1.822	18.215	39.162	1.822	18.215	39.162	1.785	17.852	38.101
3	1.634	16.341	55.503	1.634	16.341	55.503	1.521	15.207	53.307
4	1.244	12.439	67.943	1.244	12.439	67.943	1.464	14.635	67.943
5	.961	9.611	77.553						
6	.737	7.367	84.921						
7	.648	6.479	91.400						
8	.473	4.731	96.131						
9	.302	3.024	99.155						
10	.084	.845	100.000						

Extraction Method: Principal Component Analysis.

Figure 7. Eigenvalue and total variance of extracted components for felsic rocks

Total Variance Explained

Component	Initial Eigenvalues Total	% of Variance	Cumulative %	Extraction Sums of Squared Loadings Total	% of Variance	Cumulative %
1	2.105	21.048	21.048	2.105	21.048	21.048
2	1.815	18.146	39.194	1.815	18.146	39.194
3	1.622	16.215	55.409	1.622	16.215	55.409
4	1.250	12.504	67.914	1.250	12.504	67.914
5	.955	9.550	77.464			
6	.736	7.358	84.822			
7	.655	6.550	91.372			
8	.474	4.744	96.116			
9	.296	2.957	99.073			
10	.093	.927	100.000			

Extraction Method: Principal Component Analysis.

Figure 8. Eigenvalue and total variance of extracted components for mafic rocks

Latent Root Criterion (or Eigenvalue criterion) specifies that factors with an eigenvalue greater than 1 should be retained for interpretation (Meyers et al., 2006). Based on this criterion, four components should be retained for interpretation. The four factors account for a total of 67% of the total variance in the data set, which is considered to be acceptable according to the recommended value of between 50 to 75% (Tabachnick & Fidell 1996). One should be cautious when interpreting total variance accounted for by the extracted factors. Total variance can be interpreted as all variation introduced by all variables in the data set, variance accounted for measuring the amount of variation 'captured' by the extracted correlation among variables (called component or factor).

Figure 9 and 10 represents the factor loading matrix without rotation technique for felsic and mafic rocks. For interpretation and extraction of significant mineral, a minimum loading number cut-off of 0.32 is considered.

Component Matrix[a]

	Component 1	2	3	4
Q	.917	.085	-.250	-.069
Chl	-.284	-.181	.276	-.039
Ser	-.427	.133	-.193	.138
Epi	.414	.018	.289	-.197
Amp	.002	.759	.288	.299
Felds	-.249	.726	.008	-.045
Plagioclase2	.082	.532	.391	.232
Biotite2	.147	-.074	.122	-.144
Whitrmica	-.141	-.165	-.642	.221
Carb	.292	.278	.127	-.314

Extraction Method: Principal Component Analysis.

a. 4 components extracted.

Figure 9. Factor loading number for felsic rock

One should be cautious when interpreting total variance accounted for by the extracted factors. Total variance can be interpreted as all variation introduced by all variables in the data set, variance accounted for measuring the amount of variation 'captured' by the extracted correlation among variables (called component or factor). In Figure 9, principal component 1 is positively correlated with quartz and epidote, and negatively correlated with sericite. This positive loading number for quartz and epidote confirms the statistical similarities among them. The negative weak correlation of sericite to component 1 suggests that there is an inverse relationship between sericite and point load index. Principal component 2 is well represented with amphibole, feldspar and plagioclase. The positive loading number for amphibole, feldspar and plagioclase confirms that these minerals will play an important role in our statistical analysis since. Principal component 3 is well represented with white mica and plagioclase. Principal component 4 has weak correlation with all variables meanwhile its eigenvalue is more than mentioned criterion. It seems that this component could not capture the effect of variables. So, as mentioned before, the main scope of using PCA was decreasing the number of variables. It seems that some variable could be considered as outlier variable. First, the garnet mineral was removed from future study because it had a constant value. Ten, if the minimum cut off be 0.32, principal component 1 suggests that quartz, epidote and sericite are statistically all closely correlated with rock other and can be used to represent effect of them on compressive strength of rock. From principal component 2 amphibole, feldspar and plagioclase are extracted since all three variables are statistically similar. The white mica is determined from the principal component 3. In summary, quartz, epidote, sericite, amphibole, feldspar, plagioclase and white mica are selected as the significant variables for felsic rock and the rest of variables are removed from future study.

In figure 10, the factor loading matrix of mafic rocks was extracted. It seems that principal component 1 is positively correlated with quartz, feldspar and epidote, and negatively correlated with chlorite and white mica. Principal component 2 is well represented with amphibole, feldspar and quartz. Principal component 3 is well represented with epidote and amphibole and principal component 4 has a correlation with plagioclase. It seems that the extracted variables are same as the felsic rock but chlorite is selected instead of the sericite.

	Component 1	2	3	4
Q	.814	.417	-.042	-.158
Chl	-.532	-.395	.150	-.056
Carb	-.222	.210	.123	-.290
Ser	-.191	-.083	.023	.077
Epi	.515	-.184	.565	-.070
Amp	.220	.797	.505	.249
Felds	.412	.674	.168	.012
Plagioclase2	.154	.513	.307	.381
Biotite2	.197	-.218	-.199	-.089
Whitr mica	-.365	-.198	-.642	-.150

Extraction Method: Principal Component Analysis.

a. 4 components extracted.

Figure 10. Factor loading matrix for mafic rocks

In order to have proper component score, after removing outlier variables, the PCA is run again with Varimax rotation technique. The reason is that when the Varimax rotation technique able to maximizes the sum of the variance of the squared loadings, where loadings means correlations between variables and factors. Subsequence, the score loading factor and weighting factors will be better than PCA without rotation. The weighting component factors will be applied in PCR.

So, the PCA was carried out with varimax rotation technique. Seven variables were used in this run belongs to felsic rock: quartz, epidote, sericite, amphibole, feldspar, plagioclase and white mica. The variables belongs to mafic rocks are quartz, epidote, chlorite, amphibole, feldspar, plagioclase and white mica. Figure 11 represent factor loading matrix for felsic rock with Varimax rotation technique. Principal component 1 is positively correlated with quartz and epidote, and negatively correlated with sericite. This positive loading number for quartz and epidote confirms the statistical similarities among them. The negative weak correlation of sericite to component 1 suggests that there is an inverse relationship between sericite and point load index. Principal component 2 is well represented with amphibole, feldspar and plagioclase. The positive loading number for amphibole, feldspar and plagioclase confirms that these minerals will play an important role in our statistical analysis since. Principal component 3 is well represented with white mica and plagioclase.

Rotated Component Matrix[a]

	Component		
	1	2	3
Q	.902	-.090	.045
Ser	-.182	-.458	.108
Epi	-.145	.137	.636
Amp	-.077	.884	.184
Felds	.597	-.206	.717
Whitr mica	-.727	.009	-.297
Plagioclase2	-.001	.666	-.029

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Figure 11. Factor loading matrix with Varimax rotation for felsic rock

Figure 12 represent factor loading matrix for mafic rocks with Varimax rotation technique. Principal component 1 is positively correlated with quartz and epidote, and negatively correlated with chlorite. This positive loading number for quartz and epidote confirms the statistical similarities among them. The negative weak correlation of sericite to component 1 suggests that there is an inverse relationship between chlorite and point load index. Principal component 2 is well represented with amphibole, feldspar and plagioclase. The positive loading number for amphibole, feldspar and plagioclase confirms that these minerals will play an important role in our statistical analysis since. Principal component 3 is well represented with white mica and plagioclase.

Rotated Component Matrix[a]

	Component		
	1	2	3
Q	.880	-.119	.180
Chl	-.657	.021	.062
Epi	.693	-.094	.129
Amp	-.180	.749	.378
Felds	.314	.501	.221
Plagioclase2	.069	.867	-.230
Whitr mica	.188	.031	-.687

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Figure 12. Factor loading matrix with Varimax rotation for mafic rock

As we expected, the most significant minerals of database and their factor loading were determined for felsic and mafic rocks. These extracted weighting factor will be used in PCR. In the next step the results of PCR will be explained.

3.2.2 Determination of minerals effect on PLT by multivariable statistical analysis; Step 2: Determination of mineral composition of rock and point load compressive strength of rock by PCR

Principal component regression (PCR) is a multivariable statistical analysis method in order to determine the quantitative relationship between more variables. Because of page number limitation, the final results of PCR are presented here.

For felsic rocks, two equation are extracted as:

$$Y_{AXIAL} = 0.51\ (Q) - 0.32\ (SER) + 0.2\ (EPI) + 0.31\ (AMP) + 0.11\ (FELDS) + 0.43\ (PLAGIO) - 0.22\ (WM) \quad [2]$$

$$Y_{DIAMETRICAL} = 0.38\ (Q) - 0.39\ (Ser) + 0.17\ (Epi) + 0.3\ (Amp) + 0.1\ (Felds) + 0.31\ (Plagio) - 0.34 (WM) \quad [3]$$

In both equation, increasing the amount of quartz could enhance the point load index. Also, amphibole behaves same as quartz. But sericite and white mica have negative effect on point load index. According to geology view, the white mica and quartz are sheet minerals and these minerals could decrease the point load index. Note that the minerals that had negative effect on the axial test, represented a more negative effect on diametrical tests due to the strong effect of schistosity. As mentioned before, degree of schistosity of tested samples was between 70º to 90º. So, when the schistosity of rocks is closed to perpendicular to force load, it could be broken easier.

For mafic rocks, two equation are extracted as:

Y_{AXIAL} = 0.41 (Q) – 0.42(Chl) +0.18 (Epi) + 0.44 (Amp) +0.18(Felds) +0.39(Plagio) – 0.215(WM) [4]

$Y_{DIAMETRICAL}$ = 0.25 (Q) – 0.48(Chl) +0.08 (Epi) + 0.37 (Amp) +0.09 (Felds) +0.24 (Plagio) – 0.38(WM) [5]

As it seems, again quartz has possitively effect on poin load index as wll as amphibile. Minerals that had negative effect on the axial test, represented a more negative effect on diametrical tests due to the strong effect of schistosity. We can conclude that initial minerals of rock help to have stronger rocks than the secondary minerals.

As future study, the effect of minerals on rockburst intensity will be evaluated. We expect that stronger minerals such as quartz or amphibole could increase the rockburst intensity. The reason is that if we do not consider the other parameters which can effect on the rockburst intensity, such as effect of faults or magnitude of in-situ stresses, the stronger minerals helps to rock to store more elastic energy and so, the rockburst intensity increases as well. The obtained results from this study will be compared to seismicity recorded data of Westwood Mine in order to select the best rockburst prediction criterion

5. CONCLUSION

The metamorphic rocks consist of different minerals which can affect on behavior of rock in underground excavation. These effect also can increase or decrease the rockburst intensity. In this study, the effect of metamorphic rock minerals were evaluated on point load index. This index considered as the strength of rock. Multivariable statistical analysis, PCA and PCR, were used in order to decrease the number of variables and fit the best line among the variables. Based on the obtained results from these two methods, quartz plagioclase and amphibole had positive effect on point load index whereas, sericite, chlorite and white mica had negative effect on point load index. Also, the effect of schisotsity on point load index also evaluated.

REFERENCES

Akesson UA, Stigh J, Lindqvist JE, Goransson M (2003) The influence of foliation on the fragility of granitic rocks, image
analysis and quantitative microscopy. Eng Geol 68:275–288

Aydin A, Basu A (2005) The Schmidt hammer in rock material characterization. Eng Geol 81:1–14

Bell, FG., Lindsay P (1999)., The petrography and geomechanical properties of somes sandstones from the newspaper member of the Natal group near Durban, South Africa, Eng Geol 53, pp. 57-81

Ceryan S, Tudes S, Ceryan N (2008a) A new quantitative weathering classification for igneous rocks. Environ Geol 67(1):97–104

Gupta AS, Rao KS (2000) Weathering effects on the strength and deformational behaviour of crystalline rocks under uniaxial compression state. Eng Geol 56:257–274

Hecht CA, Bonsch C, Bauch E (2005) Relations of rock structure and composition to petrophysical and geomechanical rock properties: examples from Permocarboniferous Red-Beds. Rock Mech Rock Eng 38(3):197–216

Hudec P (1998) Rock properties and physical processes of rapid weathering and deterioration. In: Moore DP, Hungr O (eds) Proceedings of 8th International Congress of IAEG, vol 1. Balkema, Rotterdam, pp 341–355

ISRM. International Society of Rock Mechanics Commission on Testing Methods, Suggested Method for Determining Point Load Strength, Int. J. Rock Mech. Min. Sci. and Geomech. Abstr. 22, 1985, pp.51-60.

Johansson E. Technological properties of rock aggregates. Luleå: Luleå University of Technology; 2011.

Lindqvist JE, Åkesson U, Malaga K. Microstructure and functional properties of rock materials. Mater Charact 2007;58(11–12):1183–8.

Meriam, R., Herman, H.R. III., and Kim, Y.C, 1970, Tensile Strength Related to Mineralogy and Texture of Some Granitic Rocks, Geology, pp 155-160 108

Meyers, LS, Gamst, G,Guarino, AJ 2006, *Applied Multivariate Research - Design and Interpretation*, Sage Publications, California, USA.

Prikryl R. Some microstructural aspects of strength variation in rocks. Int J Rock Mech Min Sci 2001;38(5):671–82. Sachpazis CI., (1990)., Correlation Schmidt hardness with compressive strength and Young's moduluds of carbonate rock. ,Bull Ing Assoc Eng Geol., 42., pp. 75-83

Sousa LMO, Sua´rez del Rı´o LM, Calleja L, Ruiz de Argandon˜a V, Rey AR (2005) Influence of microfractures and porosity on the physico-mechanics properties and weathering of ornamental granites. Eng Geol 77:153–168

Tabachnick, BG & Fidell, LS 1996, *Using multivariate statistics*, 3th ed. edn, HarperCollins College Publishers, New York, NY.

Tercan AE, Ozcelik Y (2006) Canonical ridge correlation of mechanical and engineering index properties. Int J Rock Mech Min Sci 43(1):58–65

Tugrul A, Zarif IH (1999) Correlation of mineralogical and textural characteristics with engineering properties of selected granitic rocks from Turkey. Eng Geol 51(4):303–317

Worthingtopn, Pf., (1991) the firection of petrographysics : a five year perspective. Log analysis Mar-Apr: 57-62

Yergeau, D. (2015a). Géologie du gisement synvolcanique aurifère atypique Westwood, Abitibi, Québec, Université du Québec, Institut national de la recherche scientifique.