

Mechanical and Petrological Properties of Gercus Formation in Dukan Area, Kurdistan of Iraq

● **Dr. Younis Mustafa Alshkane**¹ - Lecturer ●
Dr. Hyam Saleh Daoud² - Assist. Prof.
Dr. Kamal Ahmad Rashed¹ - Assist. Prof.

¹University of Sulaimani, College of Engineering, Department of Civil Engineering

²University of Sulaimani, College of Engineering, Department of Irrigation

Received : 02/07/2017 / Accepted : 07/01/2018

DOI Link: <https://doi.org/10.17656/sjes.10065>

Abstract

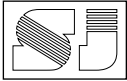


The mechanical properties of Gercus Formation in Iraq such as Uniaxial Compressive Strength (UCS), Tensile Strength (TS), Point Load Strength and Young's Modulus (E) are very crucial to design structures in or on the Formation. Unfortunately, there is no information about these mechanical properties as well as about predicting these properties using non-destructive tests such as the ultrasonic pulse velocity (UPV). The aim of this study is to evaluate these mechanical properties for Gercus Formation and to develop the correlation equations to find the mechanical properties from simple indirect tests such as point load test (PLT) and non-destructive test (UPV). Fifty one core samples (75mm diameter and 150 mm height) were collected from Gercus formation at Surqawshan Dam Project in Iraq and prepared for physical and mechanical testing. The obtained results showed that the mechanical properties of the Gercus Formation can be obtained using non-destructive test (UPV) whereas the point load test is not a good choice to predict the mechanical properties of the formation. Furthermore, the petrological properties of Gercus Formation have been studied macroscopic and microscopic by thin sections. Based on the petrological analysis, the collected samples were classified in white dolomitic limestone, gray shale, red silty sandstone and red clayey sandstone.

Keywords: Gercus Formation, Young's Modulus, Pulse Velocity, Tensile Strength, Point Load Strength, Uniaxial Compressive Strength, Petrological Properties.

1- Introduction

The primary type section of Gercus Formation was first described in the Gercus region (Figure. 1, P), in the South-East Turkey by Maxon in 1936 (Bellen *et al.*, 1959). In Iraq, a supplementary type section was described by Wetzel in Duhok area (Figure. 1, S). The formation consists of red and purple shales, mudstones, sandy and gritty marls, pebbly sandstones and conglomerates. Sometimes, the lenses of gypsum and halite are observed near the top of the formation. The thickness of the formation reaches 850 m. In the Shaikhan and Zawita anticlines the formation consists mainly of red clastic, carbonate and rare conglomerate beds with two beds of gypsum in the upper part of the formation (Majid *et al.*, 2015). The thickness of the formation decreases towards the SE; near the Iranian border along the Sirwan River, usually less than 100 m thick. In other successions in northeastern Iraq the formation consists of brown clastics and limestone in the Demir Dagh area (Ditmar and Iraqi-Soviet Team, 1971). In the Derbendikhan anticline (Jassim *et al.*, 1975) the thickness of this formation is 300 m on the NE limb and 50 m along the SW limb. The age Middle Eocene is considered by some researchers for Gercus Formation (Bellen *et al.*, 1959, Ditmar and Iraqi-Soviet Team, 1971, Jassim *et al.*, 1975). According to (Al-Rawi, 1980, Al-Qayim and Al-Shaibani, 1994, Ameen, 1998) these deposits represent fluvio-deltaic facies of the Middle Late Eocene age. Related to the depositional environment the Gercus Formation was deposited along the NE margin of the Middle Eocene basin representing red molasse sequence that was derived from uplifted areas in the N and NE (Jassim and Goff, 2006). Mechanical and petrological properties are very important for the design of structures in or on rock masses as well as for strength classification



of rocks used in buildings. The determination of the mechanical properties of intact rock often requires very sophisticated test setup and careful specimen preparation according to the standard test procedures (ISRM 1981). Also, the results are greatly sensitive to the style of loading. Consequently, a test procedure that would use small segments of the core with minimal sample preparation to determine the required properties indirectly has always been demanded (Ulusay *et al.*, 2001). Indirect test methods such as Schmidt hammer, ultrasonic pulse velocity (UPV), point load index (PLI), and Brazilian Tensile Strength tests (BT) are widely used because they are simple, more economical, less time-consuming, and easily adaptable to the field conditions [Aksay *et al.*, 2011].

There are many researches about the correlation between direct and indirect methods of intact rock. Vasconcelos *et al.* (2008) used UPV to evaluate the physical and mechanical properties of granite rock samples and they found that there is a reasonable linear relationship of UPV with each of Young's modulus (E) and UCS. Khandelwel (2013) found a linear relationships between UPV and UCS, TS, punch shear, density, slake durability index, Young's modulus, PLI, and Schemidt hammer rebound number using intact rock samples of igneous, sedimentary, and metamorphic rocks collected from different location of India. Nazir *et al.* (2013) proposed a power correlation between BT and UCS using 20 samples of dry limestone. Kaya and Karaman (2016) correlated UCS with PLI using linear equation and they concluded that the geological origin of the rock has the greatest influence on the relationship between UCS and PLI which indicates the necessity of the current study. Armaghani *et al.* (2016) developed an empirical equation to predict UCS of sandstone samples from UPV, Schmidt hammer, porosity, and PLI using multiple regression analysis by hybrid ICA-ANN model. Momeni *et al.* (2015) revealed about 85 models with different level of reliability to predict UCS from indirect tests; but these models should be used with caution since the nature of rock materials is complex and may vary from point to another point for similar rock block. Kallu and Roghanchi (2015) correlated the direct compression strength with indirect compression strength for basalt and rhyolite rock types using only 10 UCS samples. They found that the uniaxial compression strength has the best correlation with the splitting tensile strength using the regression analysis. However, this may not be true for some sedimentary rocks and heterogeneous formation such as Gercus

formation in Iraq. Logically, the best relationship should be between UPV and modulus of elasticity since the transition of the produced wave depends on elastic properties. Furthermore, according to the literature review, there is no any study about the mechanical properties of Gercus Formation in Iraq. Also, the literature review revealed that most of the studies were to predict UCS from indirect tests such as UPV and PLI.

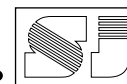
This study is primarily focused on the mechanical properties using direct methods and developing correlations between the direct and indirect compression test methods for sedimentary rock samples obtained from Gercus Formation at Surqawshan dam in Iraq. A number of tests, such as, point load index (PLI), splitting tensile strength (Brazilian Test), and Ultrasonic Pulse Velocity test, were conducted on core samples. Also, the petrological properties of Gercus Formation have been studied.

2- Materials and Methods

Seventeen homogeneous core rocks were collected from Gercus Formation at Surqawshan dam in Iraq and from each core three air dry samples were prepared for the following tests: UCS, PLI, and splitting tensile strength. The samples prepared for UCS were also used to conduct the Ultrasonic Pulse velocity test before breaking samples in the UCS test. It should be noted that all attempts were made to obtain good quality samples. Also, thin sections were prepared to study the Petrological properties of Gercus Formation under binocular microscope. The sample ends were ground down using the Rock Grinder according to ISRM (1981).

2-1- Uniaxial Compressive Strength (UCS) test

The UCS tests were conducted for the Gercus Formation at Surqawshan dam site using the Control Machine Compression servo-controlled. Axial load was applied at a displacement rate of 0.002 mm/sec. The axial displacement was measured by a dial gauge with a precision of ± 0.002 mm. The procedures for testing and calculation of tests were performed according to the suggested methods in International Society of Rock Mechanics [ISRM,1981, Bieniawski & Bernede, 1979]. The diameter of cylindrical samples was 75 mm. The height to diameter ratio of the rock samples (Figure 2) was kept as 2. The results are presented in the table 1.



2-2- Ultrasonic pulse velocity (UPV) test

Ultrasonic pulse velocity (UPV) testing is a reliable and very useful nondestructive method for obtaining the geomechanical properties of rock (e.g. the modulus of elasticity and the compressive strength). The velocity of ultrasonic pulses traveling in a intact rock depends on the elastic and density of the rock materials. The quality of some materials is occasionally related to their elastic modulus, so that measurement of ultrasonic pulse velocity in such materials can often be used to indicate their quality as well as to determine the modulus of elasticity (Ulusay *et al.*, 2001). The ultrasonic pulse velocity test was conducted on 17 prepared UCS samples according to ISRM (1981) and the direction of waves was identical with the direction of loading. The obtained results are presented in the Table 1.

2-3- Point load index (PLI) test

The point load test is an index that can be used to predict UCS of intact rock. Franklin (1985) has suggested a procedure for testing and results calculation. This can be done on three types of samples: diametrical core, axial core, and lumps. In this study, the diametrical cone test was chosen to perform the test on selected samples. The testing device was used to load a cylindrical sample by a pair of spherically truncated conical platens that have an opening angle of 60°. The point load testing was conducted according to the ASTM. The point load reading for each sample is the average of ten readings obtained from ten specimens of the same sample. The point load testing and calculation of results are presented in the Table 2.

2-4- Splitting tensile strength (Brazilian) test

The Brazilian test, known as indirect tensile strength (ISRM 1981), was used to estimate the uniaxial tensile strength of prepared intact rock samples. A disc-shaped rock sample was loaded diametrical as a strip load. The rate of loading was about 200 N/sec so that the failure in the rock samples occurs within 15-30 sec (ISRM 1981). The table 3 shows the results of Tensile Strength.

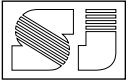
2-5- Petrological analysis

According to the macroscopic and microscopic analyses of collected samples and prepared thin sections the samples are classified in four types of rocks (Figure 2): white dolomitic limestone (B1-1

to B2-1), gray shale (B3-1 to B8-1), red silty sandstone (B9-1 to B12-1) and red clayey sandstone B13-1 to B17-1). The first type of white dolomitic limestone (Figure 3, thin sections B and D) represents mudstone microfacies consisting mostly of micrite (microcrystalline calcite) that was compacted mechanically deposited lime mud (Folk, 1959). This lime mud is formed in place or by accumulation of fine grained preexisting carbonate material and by lithification, it became micrite cement. The white spots in above mentioned thin sections represent the crystals of dolomite formed by dolomitization processes of microcrystalline calcite. The second type is represented by gray shale (Figure 4, A and B) consisting mostly of silt. They break into thin chips with roughly parallel tops and bottoms during tread hammer or under pressure of uniaxial compressive strength test. The particles of silt are quartz or feldspars without any percent of calcite due to no-interaction with hydrochloric acid. The third type identified as red silty sandstone (Figure 5, A and B). This type of rock consists mostly of sand particles (Quartz, Feldspar) ranging in size between 75 μm and 2.25 mm (Figure 5, B). The size of sand grains according to (ASTM) classification of soil is 0.075-4.75 mm. The percent of sand is 50-60% with moderately sorted, low sphericity and angular shape. The type of contact between grains is generally grain/non-grain contacts (black lines) with very little grains showing point contact (white lines). The fourth type is red clayey sandstone (Figure 5, C and D). It consists of particles of sand with size 75-250 μm with very well sorted, high sphericity and subangular shape.

The most contact between grains is of point type and grain/non-grain contacts (white lines and black lines). The amount of sand in this type rock varying between 70-75% the rest is clay minerals. The particles of sand, especially quartz, originate from weathered its parent rocks, most commonly granite. These particles and their shapes reflect material composition, formation of grains and release from the mineral matrix (Margolis and Krinsley, 1974). The shape and size of quartz grains are strongly affected by their solidification during formation when magma crystallizes and igneous rocks are formed (Smalley, 1966). Later, these features can change significantly by chemical and mechanical weathering.

The size and shape of particles (sphericity, roundness, ellipticity, angularity, smoothness and roughness) play a major role in mechanical and physical behavior of granular soils such as



stiffness, strength, internal friction angle, density and packing. Many of the recent researches on this subject have shown that the particle shape play an important role in mechanical soils behavior (Santamarina, and Cho, 2004, Dodds, 2003, Bowman *et al.*, 2001, Ashmawy *et al.*, 2003, Frye and Marone, 2002).

For the third and fourth type of rocks, the angular and subangular shape of sand grains increases the energy required for dilation and therefor the internal friction angle between grains increases due to the particle's interlocking as a result these types have a reasonable value of UCS.

3- Results and Discussion

Figure 6 presents the axial stress-strain relationships results of 17 rock samples that were tested under uniaxial compression test. The Young's modulus (E) was computed using the tangent modulus at 50% of the failure stress from the axial stress- strain curve (ISRM 1981). The range of UCS obtained approximately between 28.00 to 194.34 MPa while the range of modulus of elasticity obtained roughly between 2.63 to 46.11 GPa . Also, the UCS and modulus of elasticity results are presented in Table 1.

The results of UPV are presented in Table 1. It can be seen that as the UPV increases the UCS and modulus of elasticity increase. The range of UPV is roughly between 0.31 to 5.79 km/sec.

Table 2 presents the point load strength index $I_{s(50)}$ results for 17 cylindrical rock samples. The range of $I_{s(50)}$ is between 3.28 to 17.17 MPa. The Brazilian indirect tensile strength test was performed on 17 rock samples according to the procedure adopted in (ISRM 1981). The results are presented in Table 3. The range of tensile strength was between 2.79 to 12.51 MPa.

3-1- Correlations between the direct and indirect methods

In this study, different correlations have been proposed for Gercus Formation by correlating direct and indirect test methods. Simple regression was used to develop the correlations between the direct test results, such as UCS and modulus of elasticity, and indirect test results such as UPV and PLI. Also the tensile strength from Brazilian indirect test was correlated with UPV and PLI. It should be noted that the best correlation equation was chosen based on the value of the coefficient of determination (R^2). The correlation equations are shown in Figures (7 and 8). The developed correlations are presented in Table 4.

It can be seen that the modulus of elasticity (E) has the best correlation with the UPV and followed by UCS and TS, whereas the UCS and E have a poor correlation with point load strength index ($I_{s(50)}$), this is because the rocks of Gercus Formation have micro cracks that make the rock fail quickly under concentrate load such as in point load test; therefore, the indirect PLT should not be used to predict the UCS and E of Gercus Formation. However, it may be used to predict the tensile strength of the rocks in the formation.

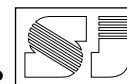
In this study it is not recommended to use PLI to predict the UCS and E of Gercus Formation but prediction of these values can be easily predicted by using the UPV and the correlation equation that were given in Table 4.

Recently, Kaya and Karaman (2016) concluded that there is no single value of the ratio between UCS and predicted UCS from indirect test that is applicable to all rock classes which indicates the necessity of this study since there is no any study about prediction of strength and deformability properties of Gercus Formation from indirect tests such as UPV. Therefore, the correlations developed in Table 4 to predict UCS and E from UPV compared with the correlations from literature using the laboratory results. Table 5 presents the results of comparison. It can be seen that the correlations developed by literature may not reasonable predict the UCS and E because their value depend on the geological origion of the rock samples (Kaya and Karaman, 2016). Also the coefficients of determination and the root mean square error are presented in table 5. it can be seen that the root mean square error in this study is less than the other.

4- Conclusions

In this study an attempt was made to provide the mechanical and petrological properties such as strength and deformability for Gercus Formation and from the study the following conclusion can be drawn:

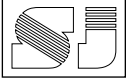
- 1- The range of UPV is roughly between 0.31 to 5.79 km/sec for Gercus Formation. The lower limit was recorded for Gray shale whereas the upper limit was recorded for red clayey sandstone.
- 2- The range of UCS was from 28.00 (red claystone) to 194.34 MPa (gray shale) while the range of modulus of elasticity obtained roughly between 2.63-46.11 GPa, for red clayey sandstone and dolomitic limestone, respectively.



- 3- The range of tensile strength obtained between 2.79 to 12.51 MPa., for red clayey sandstone and gray shale, respectively.
- 4- The modulus of elasticity has a best correlation with UPV for Gercus Formation since the coefficient of correlation (R) is 0.97 which represents 97% of the data.
- 5- There is a poor correlation (R=0.32) between the UCS and E with point load test since the intact rock in the Gercus Formation has a micro cracks. However, there is an acceptable correlation (R=0.83) between TS and PLI.
- 6- The point load test may not be a good choice to predict the strength and deformation of clastic sedimentary rock such as Gercus Formation rocks.
- 7- The angular and subangular shape of sand grains increases the energy required for dilation and therefore the internal friction angle between grains increases due to the particle's interlocking as a result the red silty sandstone and red clayey sandstone have a reasonable values of UCS.
- 7- Bellen, R. C. Van, Dunnington, H. V., Wetzel, W., and Morton, D. M., (1959), *Lexique stratigraphique international, Asie, Fasc., 10a*, Iraq: Center Natl. Recherche Sci., Paris, p. 333.
- 8- Bieniawski, Z. T. & Bernede, M. J. (1979), Suggested methods for determining the uniaxial compressive strength and deformability of rock materials: Part 1. Suggested method for determination of the uniaxial compressive strength of rock materials. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, vol.16, No.2, pp. 138-140.
- 9- Bowman, E.T., Soga, K., and Drummond, W. (2001), Particle shape characterization using Fourier descriptor analysis. *Géotechnique*, vo. 51, No.6, pp. 545-554.
- 10- Ditmar, V. and Iraqi-Soviet Team, (1971), Geological conditions and hydrocarbon prospects of the Republic of Iraq (Northern and Central parts). Manuscript report, INOC Library, Baghdad.
- 11- Dodds J.S. (2003), Particle Shape and Stiffness - Effects on Soil Behavior, MSc Thesis, Georgia Institute of Technology, Atlanta, p. 173.
- 12- Folk, R.L. (1959): Practical petrographical classification of limestones. - *Amer. Ass. Petrol. Geol. Bull.*, vol.43, pp.1-38
- 13- Franklin, J. A. (1985), Suggested method for determining point load strength. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, vol 22, No. 2, pp. 51-60.
- 14- Frye, K. M. and Marone, C. (2002), The effect of particle dimensionality on granular friction in laboratory shear zones, *Geophysical Research Letters*, vol. 29, No. 19, pp. 221- 224.
- 15- ISRM (1981), Rock Characterization, Testing and monitoring. ISRM Suggested Methods. Pergamon Press.
- 16- Jassim, S. Z., Al-Shaibani, S. K. and Ajina, T. M., (1975), Possible Middle Eocene block movement in Derbendikhan area , northeast Iraq, *jour. Geol. Soc. Iraq*, special issue, pp. 139-145.
- 17- Jassim, S. Z., and., Goff, J. C., (2006), *Geology of Iraq*. Dolin Prague and Moravian Museum. Brno, Czech Republic, p. 341.
- 18- Kallu, Raj, and Pedram Roghanchi, (2015) Correlations between direct and indirect strength test methods. *International Journal of Mining Science and Technology* 25, No. 3, pp. 355-360.
- 19- Kaya, Ayberk, and Kadir Karaman, (2016), Utilizing the strength conversion factor in the estimation of uniaxial compressive strength from the point load index. *Bulletin of Engineering Geology and the Environment* 75, No. 1, pp.. 341-357.

References

- 1- Aksoy CO, Ozacar V, Demirel N, Ozer SC, Safak S., (2011), Determination of instantaneous breaking rate by geological strength index, block punch index, and power of impact hammer for various rock mass conditions. *J Tunnel Undergr Space Technol*; vol. 26, No. 4, pp.534-40.
- 2- Al-Qayim, B. and Al-Shaibani, S. K., (1994), Bimodal tidal depositional system of the Gercus Formation, Shaqlawa area northeast Iraq, *Iraqi geol. Jour.*, vol. 27, No. 2, pp.75-95.
- 3- Al-Rawi, Y. T., (1980), Petrology and sedimentology of the Gercus red bed Formation (Eocene) northeast Iraq, *Iraqi jour. Sci.*, vol.21, pp. 132-188.
- 4- Ameen, B. M., (1998), Sedimentological study Gercus Formation in Northeast Iraq. Unpubl. M.Sc. Thesis, Univ. of Baghdad. p.103 .
- 5- Armaghani, Danial Jahed, Mohd For Mohd Amin, Saffet Yagiz, Roohollah Shirani Faradonbeh, and Rini Asnida Abdullah, (2016) Prediction of the uniaxial compressive strength of sandstone using various modeling techniques. *International Journal of Rock Mechanics and Mining Sciences* vol. 85, pp.174-186.
- 6- Ashmawy, A.K., Sukumaran, B., and Vinh Hoang, V. (2003). Evaluating the influence of particle shape on liquefaction behavior using discrete element modelling. *Annual International Society of Offshore and Polar Engineering Conference*, Hawaii, USA, PCW-05.



- 20- Khandelwal, Manoj, (2013), "Correlating P-wave velocity with the physico-mechanical properties of different rocks." Pure and Applied Geophysics vol.170, no. 4, pp. 507-514.
- 21- Majid A. Kadhum¹ and Habib R. Habib, (2015), Mineralogy of Palygorskite-Rich Claystone in Gercus Formation, Dohuk Governorate, Northern Iraq. Iraqi Bulletin of Geology and Mining, vol.11, No.2, pp. 75-91.
- 22- Margolis, S. V. and Krinsley, D. H. (1974), Processes of formation and environmental occurrence of microfeatures on detrital quartz grains. American Journal of Science, vo. 274, No.5, pp. 449-464.
- 23- Momeni, Ehsan, Ramli Nazir, Danial Jahed Armaghani, and Edy Tonnizam Mohamad, (2015) Prediction of unconfined compressive strength of rocks: a review paper. Jurnal Teknologi vol., 77, no. 11.
- 24- Nazir, Ramli, Ehsan Momeni, Danial Jahed Armaghani, and M. F. Mohd Amin, (2013) Correlation between unconfined compressive strength and indirect tensile strength of limestone rock samples. Electr J Geotech Eng vol., 18, pp. 1737-1746.
- 25- Santamarina, J.C. and Cho, G.C. (2004), Soil Behavior: The Role of Particle Shape, Proc. Skempton Conf., March, London.
- 26- Smalley, I.J. (1966), Formation of quartz sand, Nature, vol. 211, pp. 173-174.
- 27- Ulusay R, Gokceoglu C, Sulukcu S., (2001) Draft ISRM suggested method for determining block punch strength index (BPI). Int J Rock Mech Min Sci. vol. 38, No.8, pp.1113-20.
- 28- Vasconcelos, G., P. B. Lourenço, C. A. S. Alves, and J. Pamplona, (2008) Ultrasonic evaluation of the physical and mechanical properties of granites. Ultrasonics vol. 48, No. 5, pp. 453-466.

الخصائص الميكانيكية والبتروولوجية لتكوين جركس في منطقة دوكان بكوردستان العراق

د. يونس مصطفى الشبخاني¹ - مدرس

د. هيام صالح داود² - استاذ مساعد

د. كمال أحمد رشيد¹ - استاذ مساعد

¹ جامعة السليمانية - كلية الهندسة - قسم الهندسة المدنية

² جامعة السليمانية - كلية الهندسة - قسم هندسة الري

المستخلص:

ان الخصائص الميكانيكية لتكوين جركس في العراق مثل الضغط الأحادي المحور، ضغط الشد، ضغط الحمل النقطي وكذلك معامل يونغ مهمة جدا لتصميم الهياكل داخل أو على هذا التكوين. لسوء الحظ لا توجد معلومات حول الخصائص الألفة الذكر وكذلك حول علاقات الترابط لإيجاد هذه الخصائص باستخدام اختبارات غير مدمرة مثل سرعة النبض بالموجات فوق الصوتية. الهدف من هذه الدراسة هو تقييم الخواص الميكانيكية المذكورة لتكوين جركس وتطوير معادلات الارتباط لإيجاد الخواص الميكانيكية بالاعتماد على التجارب المختبرية البسيطة مثل تجربة الضغط النقطي والتجربة الغير مدمرة (سرعة النبض بالموجات فوق الصوتية). تم جمع وتحضير ودراسة إحدى وخمسون نموذجا اسطوانيا (قطر 75 مم وارتفاع 150 مم) من مشروع سد سورقاوشان شمال العراق. النتائج التي تم الوصول إليها تشير إلى أنه يمكن الحصول على الخصائص الميكانيكية لتكوين جركس باستخدام سرعة النبض بالموجات فوق الصوتية بينما لا يمكن الاعتماد على تجربة الضغط النقطي لحساب هذه الخصائص لأنها لم تعط نتائج جيدة. كذلك تمت دراسة الخصائص البتروولوجية لهذا التكوين في الحقل وفي المختبر اعتمادا على المقاطع الرقيقة. بناءا على التحليل البتروولوجي تم تصنيف النماذج المدروسة إلى: الصخر الكلسي الدولوميتي الأبيض، الطين الصفائحي رمادي اللون، الصخر الرملي السيلتي الأحمر والصخر الرملي الطيني الأحمر.

الكلمات المفتاحية: تكوين جركس، معامل يونغ، سرعة النبض، ضغط الشد، الحمل النقطي، الضغط الأحادي، الخصائص البتروولوجية.

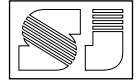


Figure 1: Locations of Primary (P) and Supplementary (S) Sections of Gercus Formation. (<http://www.earth.google.com>)



Figure 2: Prepared samples for compressive strength. (by researchers)

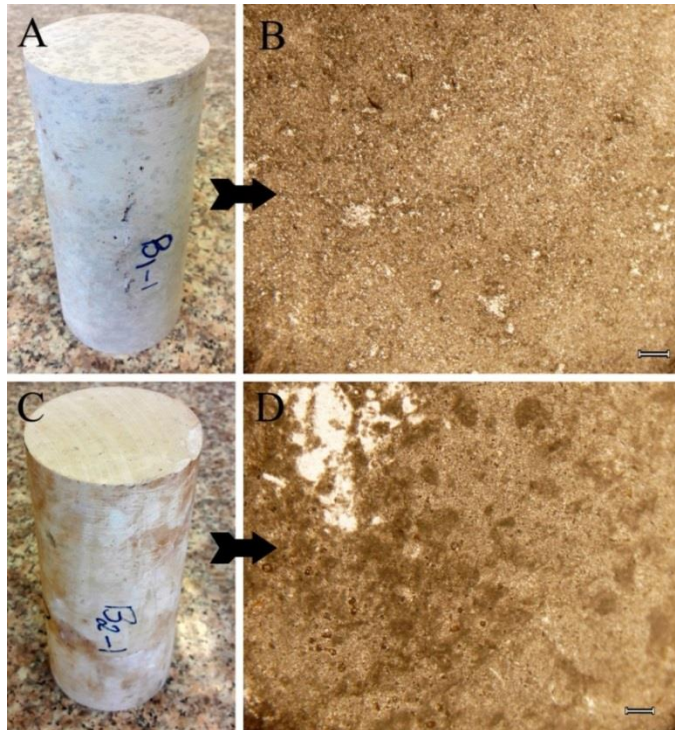
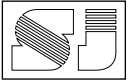


Figure 3: Thin sections (B, D) of white dolomitic limestone. Both samples B1-1 and B2-1 are composed of dolomitic limestone with cement type micrite without fossils or probably the fossils are destroyed by dolomitization processes. The bar scale is 250 μm (by researchers).

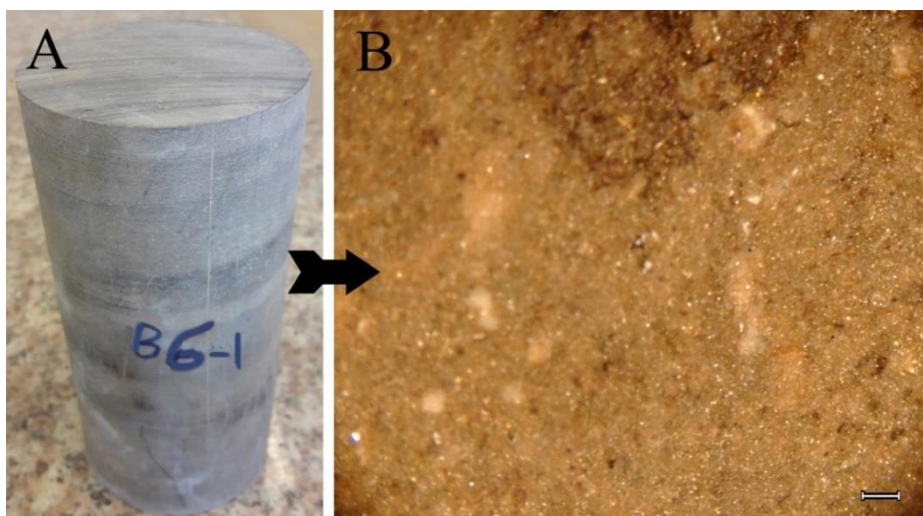


Figure 4: Thin sections of gray shale (B6-1). The bar scale is 250 μm . (by researchers)

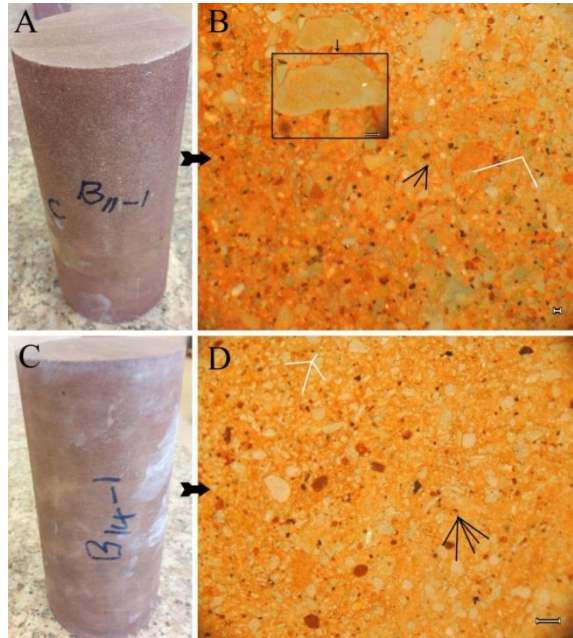
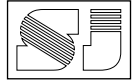


Figure 5: Thin sections of red silty sandstone (B11-1) and red clayey sandstone (B14-1).

Black lines indicate the grain/non-grain contacts and the white lines indicate the point contact. The bar scale is 250 µm. (by researchers)

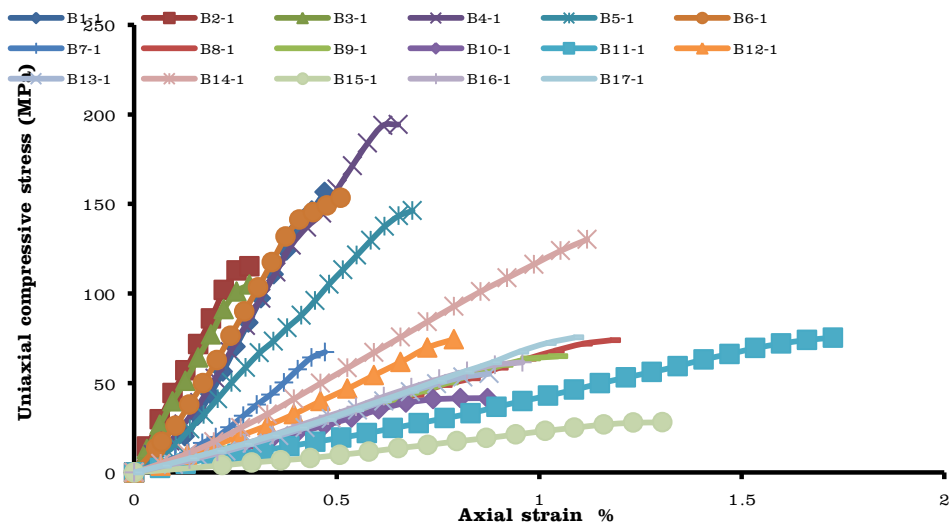


Figure 6: Axial stress-strain for rock samples. (by researchers)

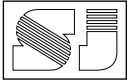
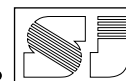


Table 1: The results of Ultrasonic pulse Velocity, UCS, and Modulus of Elasticity. (by researchers)

Sample No.		Ultrasonic Velocity of Longitudinal Wave. V_p (km/s)	Uniaxial Compressive Strength (MPa)	Modulus of Elasticity GPa
White Dolomitic limestone	B1-1	5.68	156.58	41.820
	B2-1	4.77	115.00	46.110
Gray shale	B3-1	4.71	104.88	41.380
	B4-1	5.79	194.34	38.260
	B5-1	4.55	146.22	23.940
	B6-1	5.38	153.40	40.440
	B7-1	4.27	67.30	18.950
	B8-1	2.28	73.87	7.160
Red silty sandstone	B9-1	2.07	64.87	7.230
	B10-1	2.33	41.55	6.200
	B11-1	1.64	75.31	5.070
	B12-1	2.49	74.45	10.480
Red clayey sandstone	B13-1	1.90	55.17	7.360
	B14-1	2.54	130.15	12.730
	B15-1	0.31	28.00	2.630
	B16-1	2.27	61.54	7.550
	B17-1	1.72	75.39	7.590

Table 2: The results of Point Load Strength. (by researchers)

Sample No.		Point Load reading (KN)	Point Load strength Index I_s (MPa)	Point Load strength Index $I_{s(50)}$ (MPa)
White Dolomitic limestone	B1-2	23.49	14.68	13.28
	B2-2	14.56	8.25	7.63
Gray shale	B3-2	17.42	12.72	11.11
	B4-2	7.45	3.68	3.51
	B5-2	15.61	14.33	11.89
	B6-2	20.41	18.74	15.55
	B7-2	25.24	20.03	17.17
	B8-2	8.15	7.86	6.45
Red silty sandstone	B9-2	7.09	4.66	4.17
	B10-2	5.96	3.60	3.28
	B11-2	8.22	4.45	4.15
	B12-2	8.41	5.67	5.04
Red clayey sandstone	B13-2	11.88	12.20	9.87
	B14-2	11.70	9.55	8.13
	B15-2	7.56	7.38	6.04
	B16-2	9.38	7.24	6.24
	B17-2	4.10	5.42	4.14

**Table 3: The results of Tensile Strength.** (by researchers)

Sample No.	Load reading KN	Tensile stress MPa
White Dolomitic limestone	B1-3	38.40
	B2-3	27.83
Gray shale	B3-3	31.50
	B4-3	24.10
	B5-3	30.00
	B6-3	33.95
	B7-3	53.00
	B8-3	20.20
Red silty sandstone	B9-3	26.30
	B10-3	33.20
	B11-3	20.30
Red clayey sandstone	B12-3	19.10
	B13-3	26.50
	B14-3	34.20
	B15-3	11.50
	B16-3	23.00
B17-3	24.60	

Table 3: Developed correlations between direct and indirect tests. (by researchers)

Correlation	Coefficient of determination (R^2)	Correlation coefficient (R)	Description
$E = 22.5332 * e^{0.5094UPV}$	0.94	0.97	E in GPa and UPV in km/sec
$UCS = 23.52 * UPV + 19.51$	0.71	0.84	UCS in MPa and UPV in km/sec
$TS = 3.9419e^{0.158UPV}$	0.50	0.71	TS in MPa and UPV in km/sec
$TS = 0.485 * I_{s(50)} + 3.0755$	0.69	0.83	TS in MPa and $I_{s(50)}$
$E = 1.8217 * I_{s(50)} + 4.36$	0.25	0.50	E in GPa and $I_{s(50)}$
$UCS = 3.3803 * I_{s(50)} + 67.81$	0.10	0.32	UCS in MPa and $I_{s(50)}$

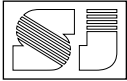
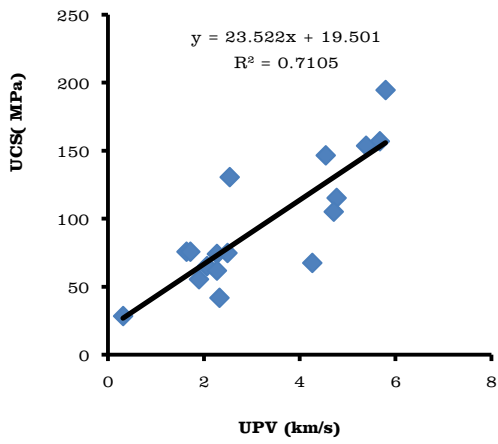
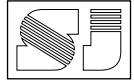
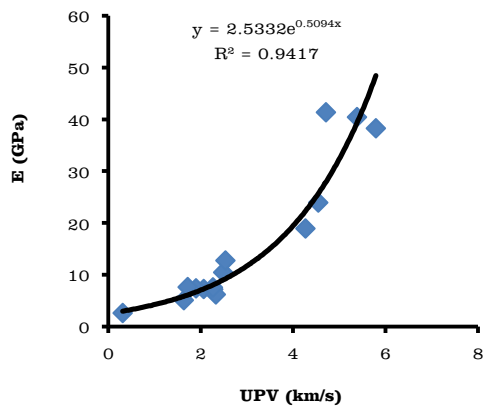


Table 4: Laboratory tests results and Predicted UCS using correlation equations. (by researchers)

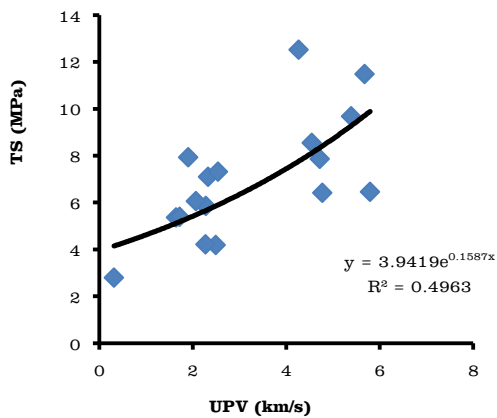
Measured			Predicted							
			This study		Vasconcelos et al. (2008)		Khandelwel (2012)		Kallu and Roghanchi (2015)	
UPV (km/sec)	UCS (MPa)	E (GPa)	UCS (MPa)	E (GPa)	UCS (MPa)	E (GPa)	UCS (MPa)	E (GPa)	UCS (MPa)	E (GPa)
5.676	156.58	41.82	153.01	45.54	194.71	84.97	152.48	107.64	397.27	73.80
4.769	115.00	46.11	131.68	28.70	157.80	66.95	122.55	89.50	176.52	44.19
4.713	104.88	41.38	130.37	27.90	155.52	65.84	120.71	88.39	167.92	42.82
5.794	194.34	38.26	155.78	48.35	199.49	87.31	156.36	109.99	441.29	78.87
4.547	146.22	23.94	126.45	25.63	148.75	62.53	115.22	85.06	144.69	38.97
5.385	153.40	40.44	146.16	39.26	182.84	79.18	142.86	101.81	306.08	62.59
4.267	67.30	18.95	119.87	22.23	137.37	56.98	105.99	79.46	112.67	33.27
2.276	73.87	7.16	73.03	8.07	56.31	17.40	40.26	39.63	18.98	10.79
2.066	64.87	7.23	68.09	7.25	47.76	13.23	33.33	35.43	15.73	9.58
2.328	41.55	6.20	74.26	8.29	58.44	18.45	42.00	40.68	19.89	11.11
1.640	75.31	5.07	58.09	5.84	30.46	4.78	19.31	26.93	10.75	7.53
2.492	74.45	10.48	78.11	9.01	65.11	21.70	47.40	43.96	23.02	12.19
1.901	55.17	7.36	64.22	6.67	41.07	9.96	27.91	32.14	13.58	8.73
2.538	130.15	12.73	79.19	9.22	66.97	22.61	48.91	44.87	23.99	12.51
0.314	28.00	2.63	26.88	2.97	-23.55	-21.58	-24.48	0.39	3.28	3.56
2.271	61.54	7.55	72.91	8.05	56.10	17.30	40.10	39.53	18.89	10.76
1.719	75.39	7.59	59.93	6.08	33.64	6.34	21.89	28.49	11.53	7.87
The coefficient of determination (R^2)			0.71	0.85	0.45	0.86	0.37	0.86	-0.46	0.83
Root Mean Square Error (RMSE)			24.3	6.1	37.0	25.4	37.4	43.7	104.1	14.7



(a)

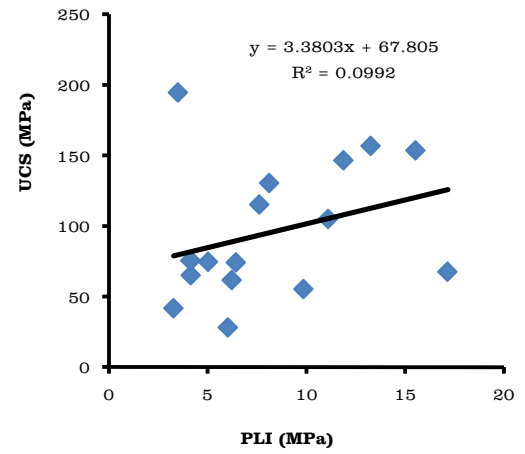


(b)

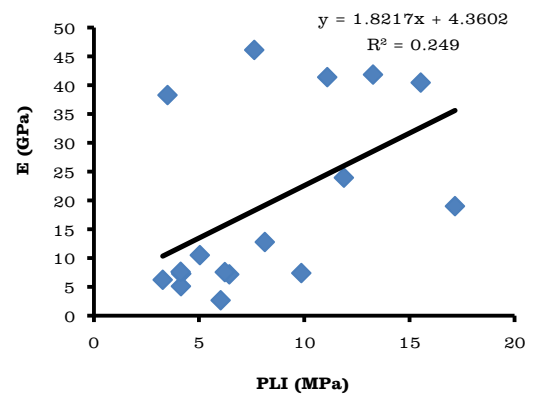


(c)

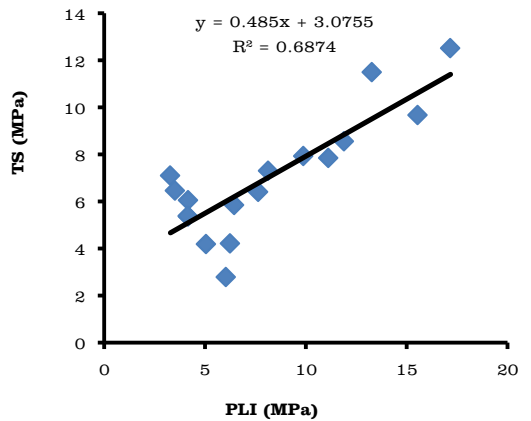
Figure 7: (a) Correlation between UPV and UCS, (b) Correlation between UPV and modulus of elasticity, and (c) Correlation between UPV and Tensile Strength. (by researchers)



(a)



(b)



(c)

Figure 8: (a) Correlation between PLI and UCS, (b) Correlation between PLI and modulus of elasticity, and (c) Correlation between PLI and Tensile Strength. (by researchers)