

Unconfined Compressive Strength of Vermont Rock

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State of Vermont

Agency of Transportation

Construction and Materials Bureau

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INTRODUCTION

One of the parameters considered during the design process for bridges includes the unconfined compressive strength (UCS) of rock supporting their foundations. On many projects, the Agency will test rock cores to acquire this information. In some instances, rock cores may not be available and therefore this information is not known and our engineers are left to look up typical values published in text books or presented in professional papers. The Vermont Agency of Transportation (VTrans) has been conducting UCS testing since 2007 and it became apparent that a cataloging of test values could be of great benefit to our engineers for estimating purposes. The purpose of this analysis was to provide an “in house” reference document that accurately reflects the average UCS of rocks found in Vermont. Accurate UCS values of rock within Vermont will be a useful tool for VTrans engineering staff, in regards to estimating compressive strengths for designs of structures. Currently VTrans engineering staff use published values of compressive strength of rock for design purposes of structures such as bridge footings, abutments, and piers when site specific test results are not available. Those published values reflect strengths from rocks that may contain differing and varying mineralogies, as well as having been formed under and subjected to different geologic processes than those in Vermont. Using published values of compressive strength may lead to over design of projects resulting in increased project costs.

The UCS data obtained from the testing of rock cores is also used to calculate the Modulus of Elasticity (Young’s Modulus). Young’s Modulus is a measurement of the force needed to stretch or compress a material. The higher the Young’s Modulus, the stiffer the material is.

GEOLOGY

The bedrock of Vermont consists of north-south trending belts of metamorphic, sedimentary, and meta-sedimentary rocks, with scattered igneous intrusions in the northeastern section of the state as well as a few scattered intrusions in the southeastern section of the state. A generalized geologic map of Vermont is shown in Figure 1.

The lithology of the bedrock within Vermont is highly variable. Some of the more common metamorphic rocks found within the state include slate, phyllite, schist, gneiss, amphibolite, marble, hornfels, greenschist, greenstone, serpentinite, granulite, and quartzite.

Igneous rocks found within the state include granite, granodiorite, diorite, quartz-monzonite, tonalite, andesite, and basalt.

Sedimentary rocks found within the state include shale, siltstone, limestone, dolostone, conglomerates, and sandstones. The sedimentary rocks within Vermont are not true sedimentary rocks, meaning that they have undergone at least some form of low grade metamorphism. However, in some cases, the degree of metamorphism has not been great enough to turn these sedimentary rocks into true metamorphic rocks. Hence, geologists in the Northeast commonly refer to these sedimentary rocks as “meta-sedimentary”.

The majority of rocks within Vermont have undergone extensive tectonic deformation caused by at most three orogenic (mountain building) events, meaning that the rocks are highly fractured and folded. The presence of the discontinuities caused by these orogenic events can reduce the unconfined compressive strength of the rock mass. Discontinuities within rock masses include foliation, jointing, cleavage, healed fractures, veins, faults, and folds.

Experimental work by others has been performed in order to understand the effect of orientation of structures within rock cores on the compressive strength of the rock. Nasser et al. (Nasser et al. *Anisotropic strength and deformational behavior of Himalayan schists* / International Journal of Rock Mechanics & Mining Sciences 40 (2003) p. 3-23) has shown that the UCS of schistose rock cores is highest when the stress is applied perpendicular to the structures. This implies that the steeper the angle of the structure, the lower the UCS will be.

METHODOLOGY

The procedure for selecting and testing rock core samples to determine UCS is beyond the scope of this paper. The document detailing the process of selecting and testing rock core samples to determine UCS (VT-AOT-MRD 58-12) is attached as Appendix A.

A list of past projects that rock core testing has been performed for was created. From this list information such as project number, sample number, rock type, diameter of sample rock core, length of sample rock core, UCS, and Young's Modulus was compiled within a spreadsheet. Photographs of the rock core samples were analyzed in order to determine if the rock core broke along a pre-existing structure within the rock or if it was free of pre-existing discontinuities (Figure 2). The presence of discontinuities were also noted in the spreadsheet.

The rock core samples were then sorted by lithology and the average UCS was calculated, as well as average Young's Modulus values. Charts were then made showing average UCS by lithology, as well as charts showing average Young's Modulus by lithology.

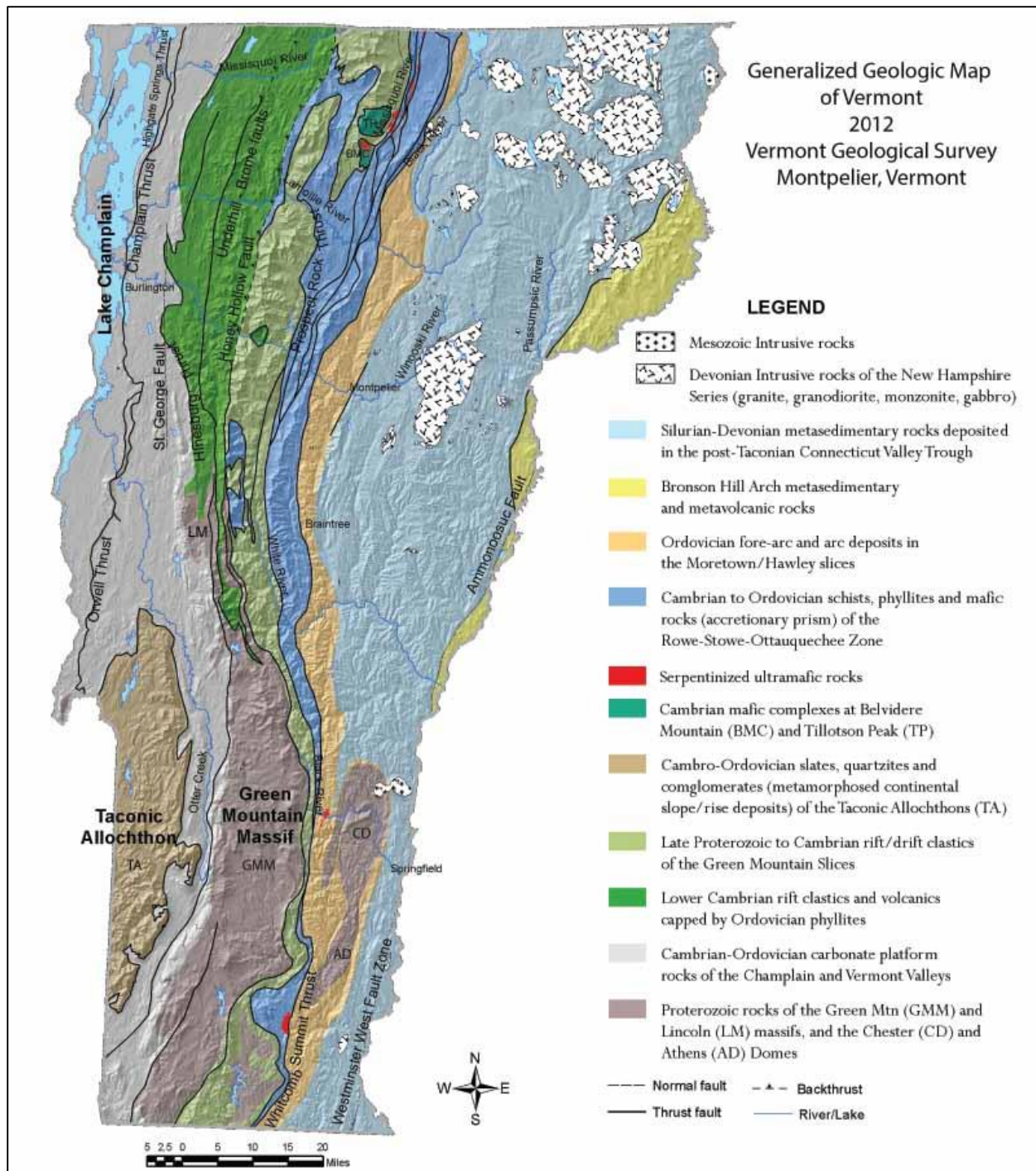


Figure 1: Generalized Geologic Map of Vermont

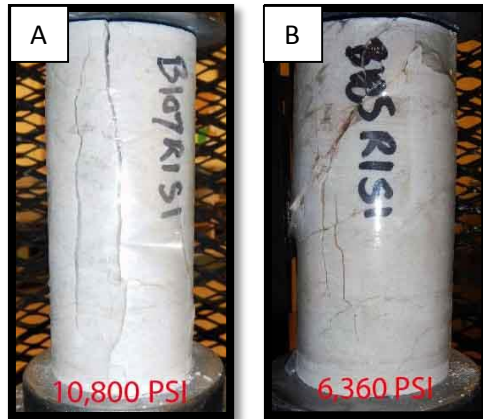


Figure 2: These rock cores tested in the VTrans laboratory are of marble (from the same source). Compressive strengths of the rock cores were 10,800 psi and 6,360 psi respectively. The rock core depicted in (A) contained no discontinuities. Core (B) contained a discontinuity which cut across the core at about 45°. Notice that core (B) failed along the existing discontinuity. The force applied to this core was not transmitted uniformly through the core length resulting in a lower UCS value.

RESULTS

A total of 162 rock cores were tested for UCS from 2007 to 2015. 106 rock cores were classified as metamorphic, 25 rock cores were classified as meta-sedimentary / sedimentary, 14 rock cores were classified as igneous, and 17 rock cores were classified as metamorphic & meta-sedimentary / sedimentary. A chart depicting the number of rock cores tested sorted by lithology and rock type is presented as Figure 3.

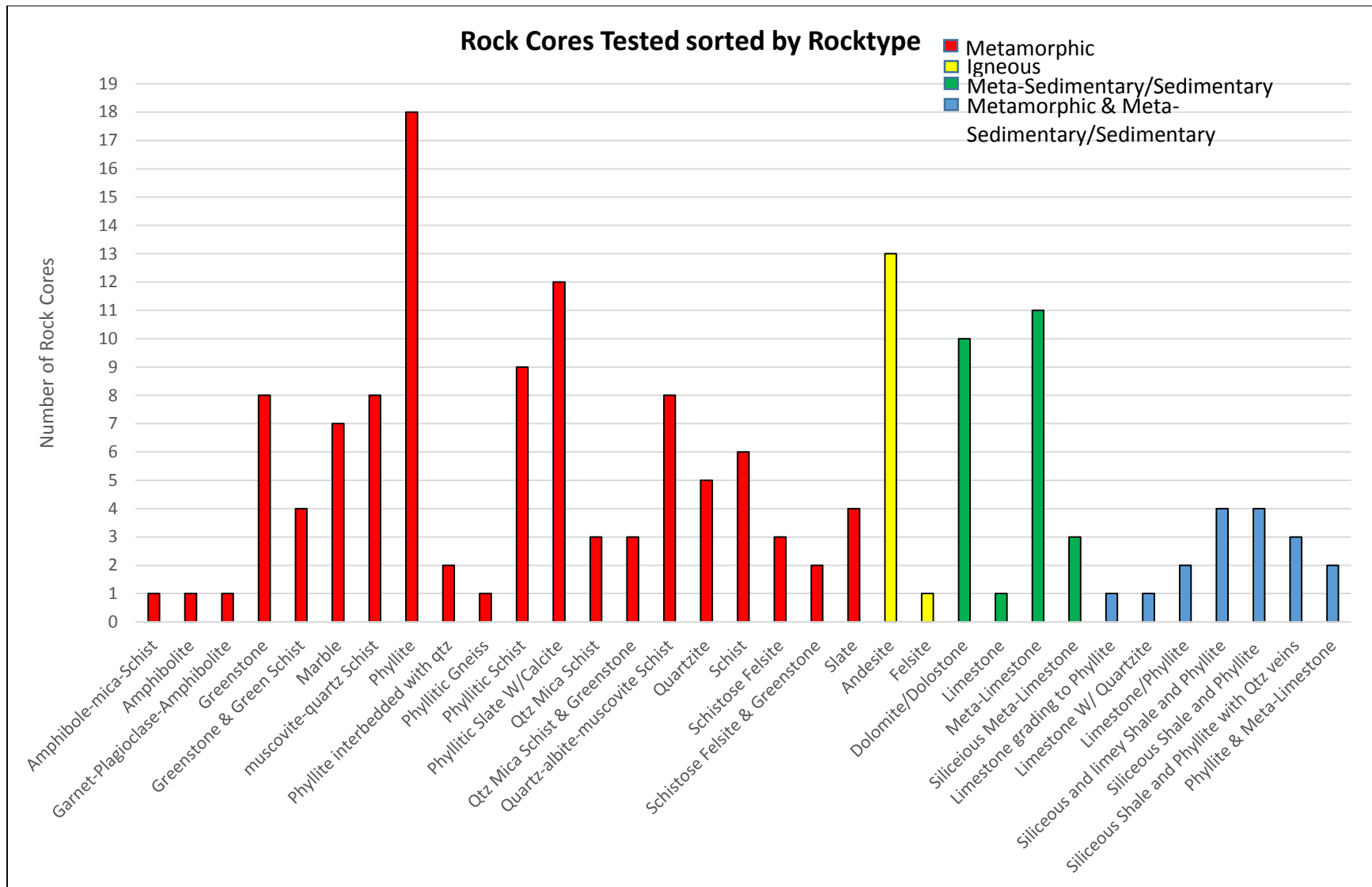


Figure 3: The number of rock cores tested sorted by lithology and rock type. Note the majority of samples tested are metamorphic. The samples represented by the blue color represent rock cores with a dual lithology. They are composed of both metamorphic and meta-sedimentary/sedimentary rocks.

The following charts depict average UCS sorted by lithology. The first chart (Figure 4) consists of average UCS values of all lithologies, including rock cores that did break along pre-existing discontinuities. Some lithologies of rock cores that were tested only failed along pre-existing discontinuities.

The second chart (Figure 5) consists of average UCS values of lithologies that did not break along pre-existing discontinuities. These values better reflect actual rock strength.

The third chart (Figure 6) compares the average UCS of rock cores that broke along pre-existing discontinuities with the average UCS of rock cores that did not.

The fourth chart (Figure 7) shows the average UCS for rock cores with a simplified lithology. UCS values for rock cores with differing mineralogies but having the same rock name classification were grouped together. This was done in order to provide a simpler and more easily used chart to look up average UCS values.

The fifth chart (Figure 8) shows the average Young's Modulus values for rock cores with a simplified lithology.

All the data that was analyzed can be found in an excel file in the following link:

<file:///Z:/Highways/ConstructionMaterials/GeotechEngineering/Geology/UCS%20of%20Rock%20Cores/UCS%20Rock%20Master%20List.xlsx>

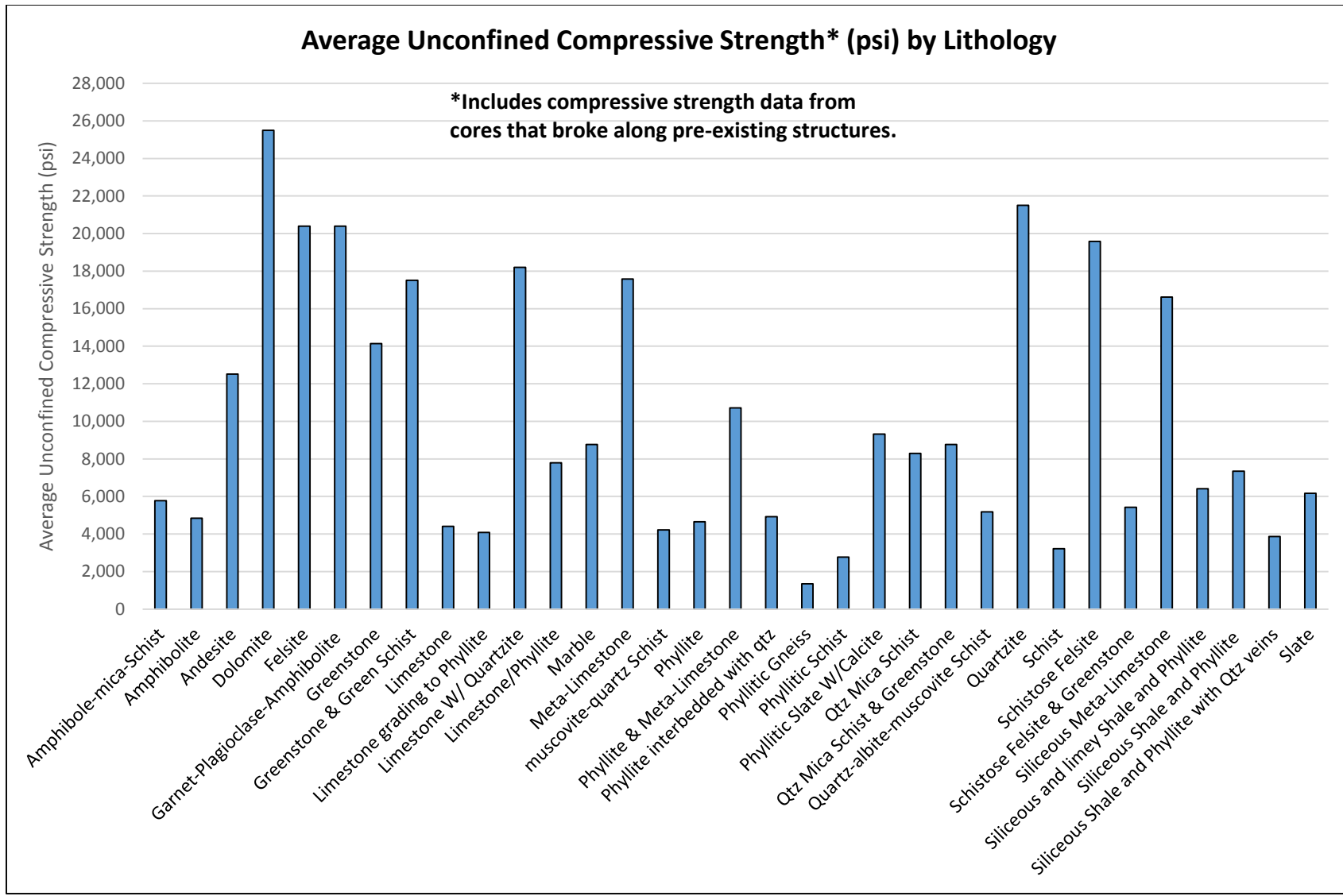


Figure 4: Graph of average compressive strength sorted by lithology.

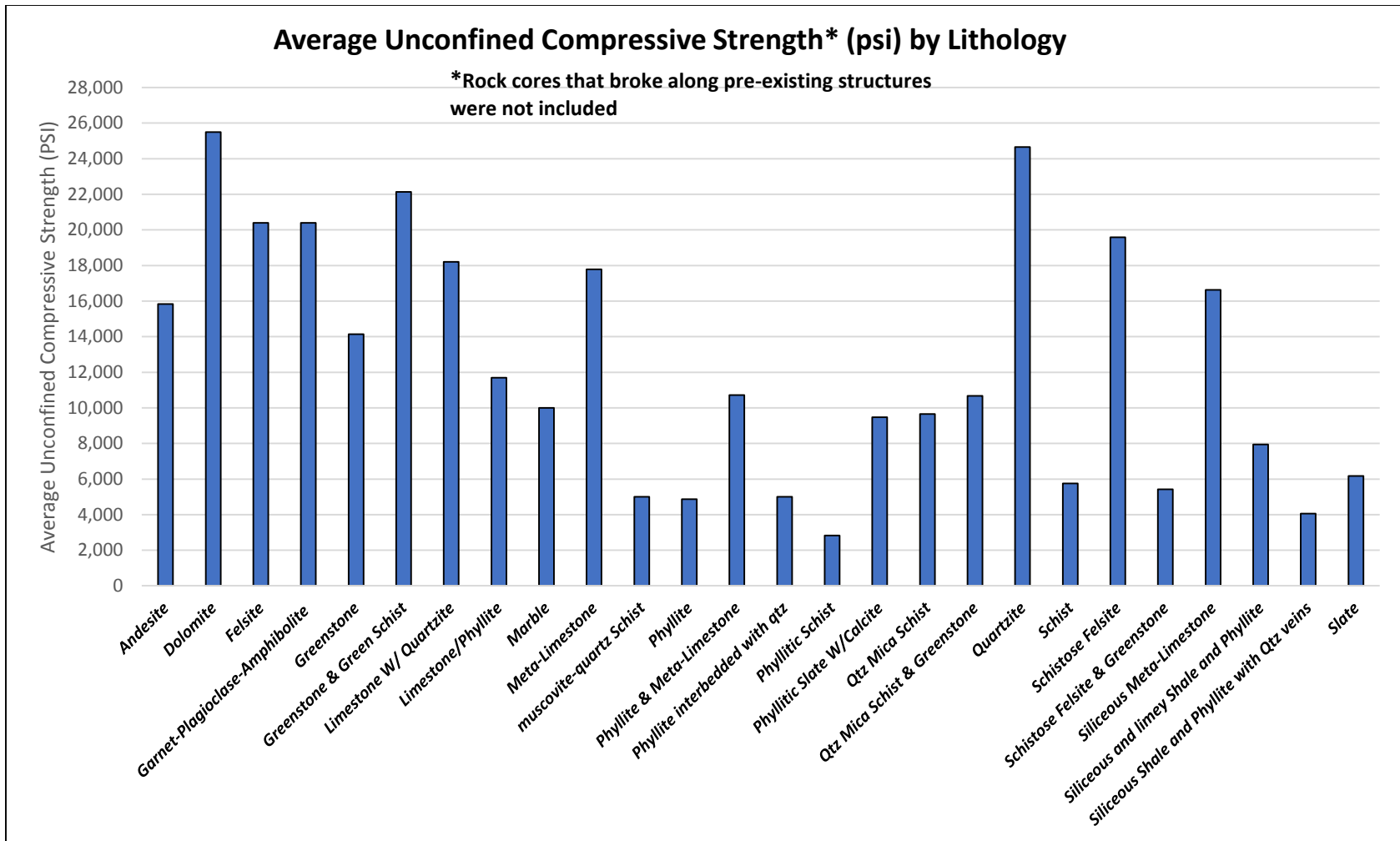


Figure 5: Graph of average compressive strength of rock cores that did not break along pre-existing discontinuities, sorted by lithology.

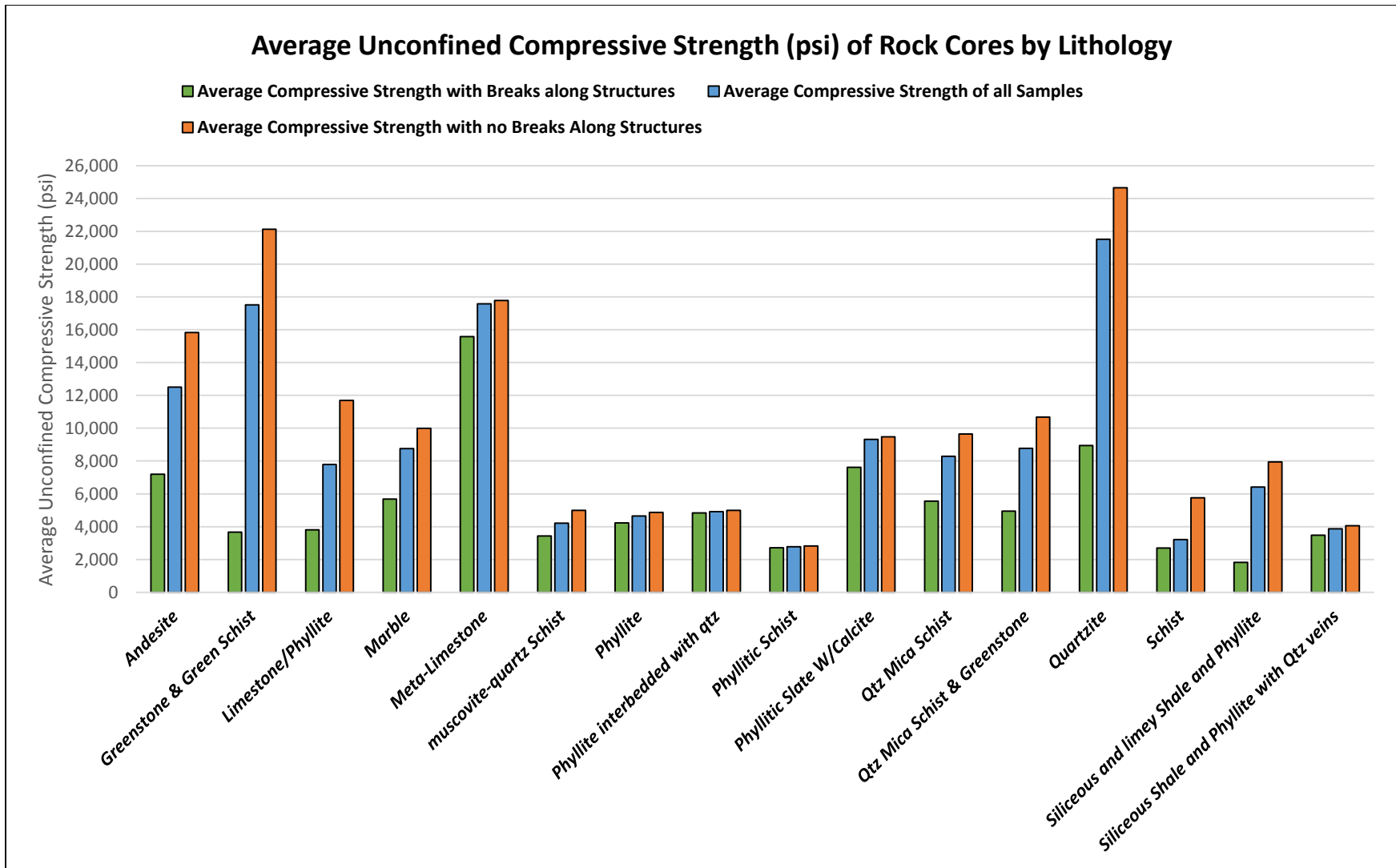


Figure 6: The average compressive strength of all rock cores tested in unconfined compression versus the average compressive strength of rock cores that failed along pre-existing discontinuities and those that did not fail along pre-existing discontinuities. Note that in all cases, the average compressive strength of rock cores that did not break along pre-existing discontinuities is higher than those that did.

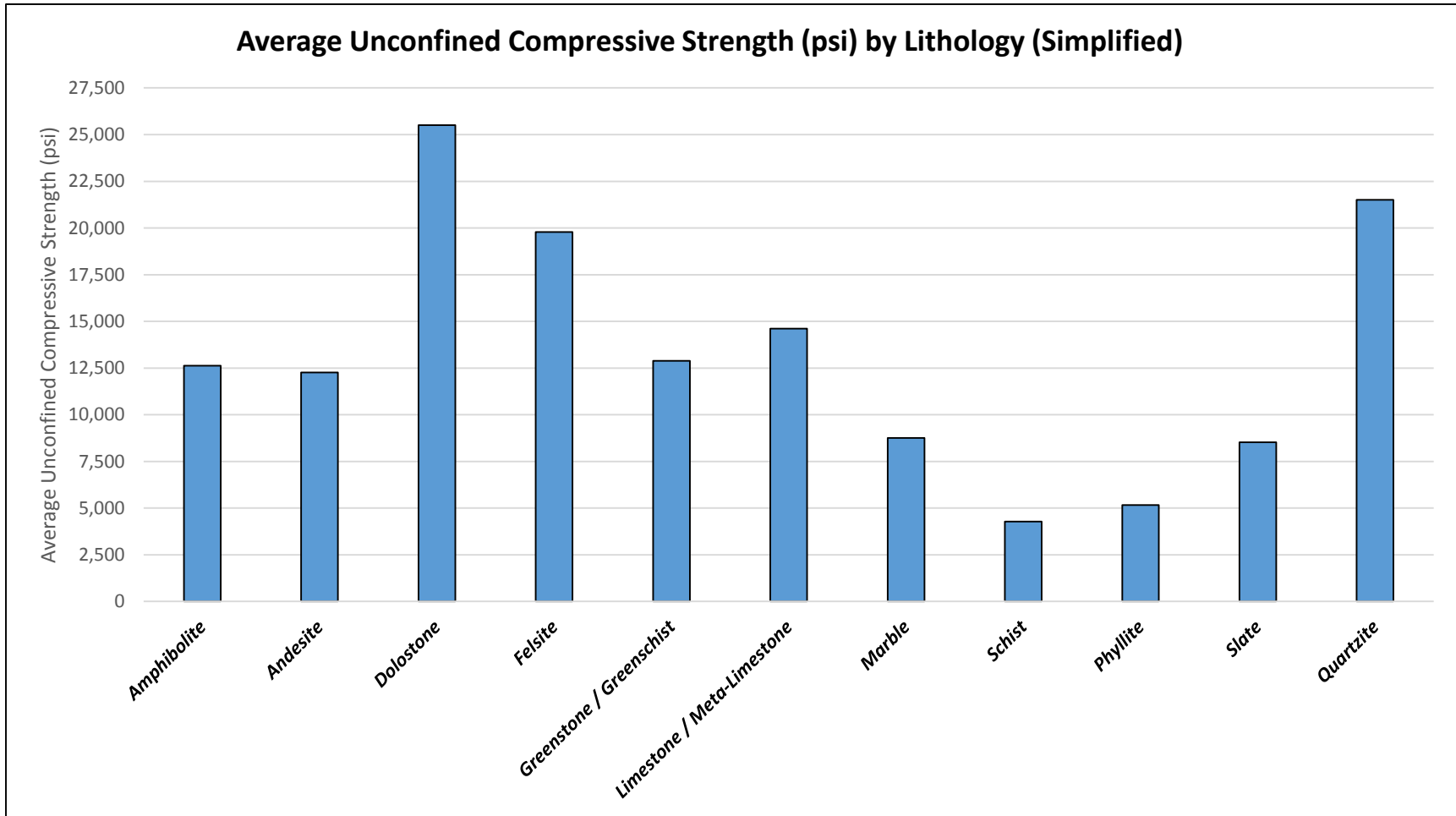


Figure 7: Average UCS by simplified lithology. All UCS values used to calculate the average UCS includes rock cores that contained discontinuities and rock cores that did not contain discontinuities.

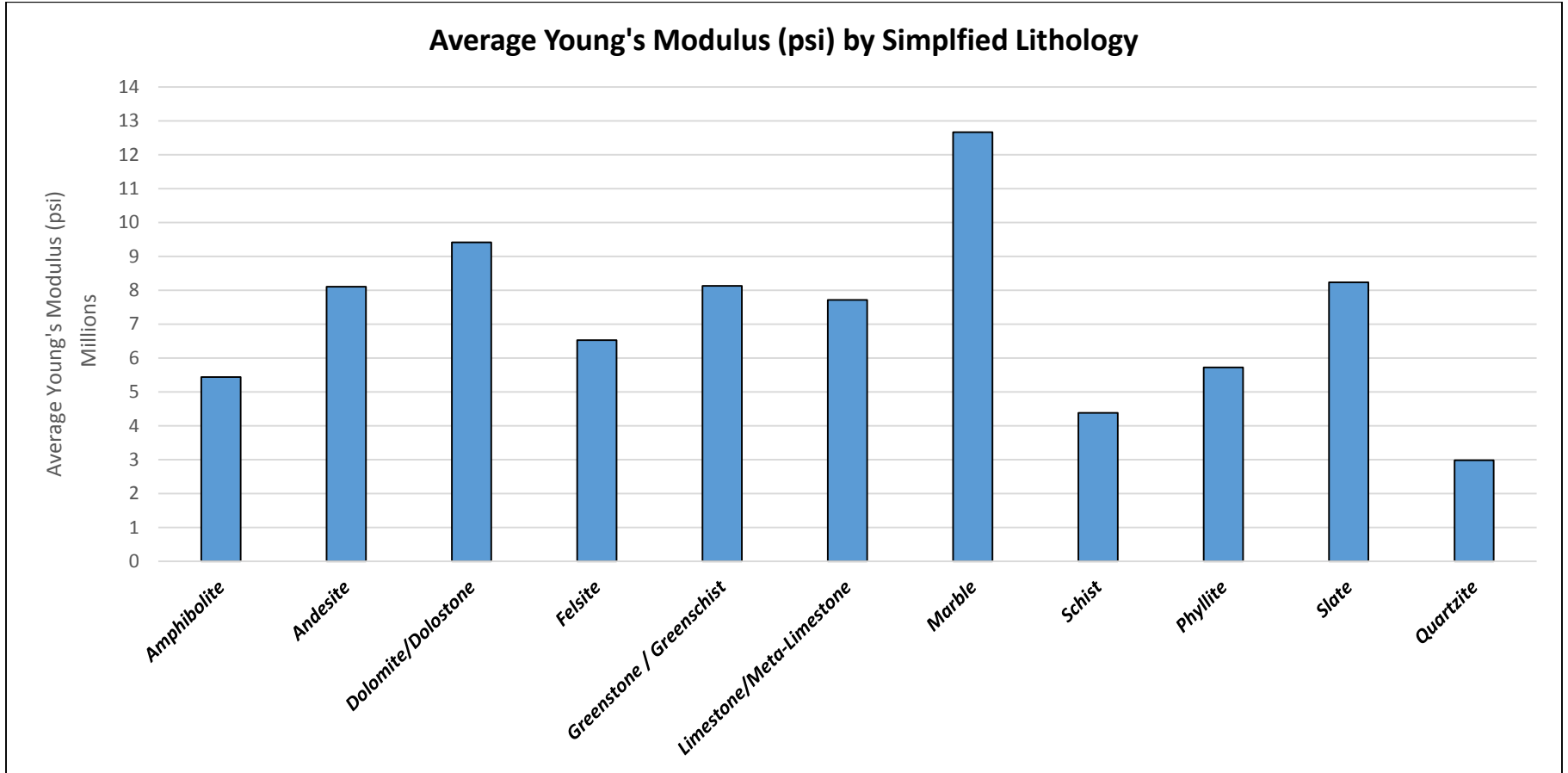


Figure 8: Average Young's Modulus sorted by simplified lithology.

SUMMARY

An excel file of rock cores that have been tested for UCS by VTrans was created and analyzed. These test results are intended to give design engineers and geologists a regionally specific indication of the range of UCS and modulus values for Vermont rock and are not intended to be a substitute for site specific data.

Rock cores were sorted by lithology. Then average UCS values and average Young's Modulus values were calculated.

A comparison of the average UCS of rock cores of the same lithology that broke along pre-existing discontinuities was made with average UCS of rock cores of the same lithology that did not break along pre-existing discontinuities. Average UCS of rock cores that failed along pre-existing discontinuities was lower than average UCS of rock cores which did not have pre-existing discontinuities in them.

As new rock core samples are tested, the test results will be added to the excel sheet and new charts will be produced.

A future research project may include the sampling of rock cores of lithologies that we lack UCS data on. This will further improve the accuracy of the average UCS charts and allow VTrans engineering staff to accurately estimate the average UCS of Vermont's rocks.

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH SECTION
VT-AOT-MRD 58-12

VERMONT STANDARD PROCEDURE FOR THE
DETERMINATION OF UNIAXIAL COMPRESSIVE STRENGTH OF
ROCK CORES

1. SCOPE

1.1. This method of test is intended for use in determining the uniaxial compressive strength of rock core samples collected from Agency projects.

2. REFERENCE DOCUMENTS

2.1. ASTM D7012 - 10 Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures.

2.2. ASTM D4543 - 08 Standard Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerances.

3. APPARATUS

3.1. Apparatus shall be as described for Methods C and D in ASTM D7012 - 10.

3.2. Concrete Saw.

3.3. Disc grinder with coarse and medium coarse disks.

3.4. Strain measuring device.

3.5. Camera.

4. SAFETY PRECAUTIONS

4.1. Protective cage around sample shall be in place during test.

4.2. Safety glasses and protective foot ware must be worn during testing.

5. PROCEDURE

5.1. Sample Collection, Selection And Preparation

5.1.1. Rock core samples are to be selected from NX sized (2.154-inch diameter) rock cores. The geologist will select representative samples for testing. Each test specimen shall be between 4.5 and 5 inches in length to ensure the final specimen after preparation maintains a length to diameter ratio of 2.0 to 2.5. The specimen shall be a solid competent specimen with no visible open fractures, voids or other potential weak features that might make preparation difficult.

5.1.2. Samples should be numbered and labeled using an indelible marker while in the rock core box. The convention is as follows: B102-R1-S3 where the first part of the number represents the boring the sample was selected from, the second number is the core run the sample was selected from and the last number is the sequential sample from that core run. In addition, the depth of the specimen should be marked on the sample. The depth corresponds to the mid-point of the specimen.

- 5.1.3. Each sample end is to be cut perpendicular to the axis of the specimen using the concrete saw. Care must be exercised to assure a smooth square cut end with no chipping on the ends. The ends of the samples are to be ground smooth and orthogonal with the central axis of the specimen. This is accomplished using the Eberbach disc grinder.
- 5.1.4. Using a caliper, measure the length and diameter of each test specimen and record on lab test data sheet (Attachment).
- 5.1.5. Wrap each sample in plastic wrap. Make sure excess plastic wrap does not extend over the ends of the specimen.

5.2. TESTING PROCEDURE

- 5.2.1. Start-Up for Tinius Olsen. Turn power on with breaker on wall. Turn pump on; run Tinius Olsen base up & down to warm up hydraulics. Turn the Jog button to off so when you are moving the base up or down you do not accidentally break core or equipment.
- 5.2.2. Start computer & Navigator software.
- 5.2.3. Connect extensometer to the Tinius testing machine.
- 5.2.4. Install the cube testing head and platens onto the Tinius Testing machine.
- 5.2.5. Open the Navigator software and click on the EDIT button. Change the testing procedure in the software to the NX Core Strain test.
- 5.2.6. Place test specimen in the machine and place safety cage around the sample.
- 5.2.7. Place extensometer on the center of the specimen. Try to get it as close to the center as possible. Remove the pins from the extensometer.
- 5.2.8. Zero out the Load, Position and Auxiliary buttons.
- 5.2.9. Enter test data into the software. (Lab #, diameter, depth of sample, etc.)
- 5.2.10. Run the test until the sample fails.
- 5.2.11. Click on the Accept button to save the test results.
- 5.2.12. When asked to return the crosshead, click **cancel**. Manually lower the head using the down arrow in the menu bar.
- 5.2.13. Save the test results. The test results will be saved in C:\Rock Core.
- 5.2.14. Navigate to G:\Soils and Foundations\Projects\((your target project))\Rock Core Testing\ and create a subdirectory for the sample tested. The attached Figure 1 shows an example of the folder structure. Copy all test data from C:\Rock Core to the newly created sample folder on the G:\ drive. After confirming that all data was successfully copied, delete all data files in the C:\Rock Core folder. This assures that the folder is clear before the next test is performed.
- 5.2.15. Remove extensometer and insert pins.
- 5.2.16. Remove tested sample and photograph it.
- 5.2.17. Clean off platens of any accumulated rock fragments.
- 5.2.18. Repeat steps 5.2.6. to 5.2.17. for any additional samples.
- 5.2.19. Shut-down Tinius Olsen. When testing is finished park Tinius Olsen in the down position and shut computer down. Turn power off with breaker on wall. NOTE: Between testing (if long period of time will pass) leave Tinius Olsen powered up but turn hydraulic pump off.
- 5.2.20. Place tested samples back into the rock core box being careful to preserve the post-test condition and position of the core.

6. CALCULATIONS AND REPORTING

Upon test completion, the engineer or geologist shall prepare a graph of stress (vertical axis) vs. strain (horizontal axis) from zero-strain to sample failure.

- 6.1. Open the file Points.csv.

- 6.2. Create a new column labeled “Strain” and calculate the strain for each reading by dividing values in the *Instrument 1 (in) column* by 2.0-inches (the distance between the extensometer gauges).
- 6.3. For ease of use, copy the Stress column and place it to the right of the Strain column. Figure 2 in attachment shows a portion of this newly modified file.
- 6.4. Construct a scatter plot representing stress/strain values from zero-stress to sample failure (ideally, you want to include a point or two past failure in order to make the ultimate failure point noticeable on the graph). Save graph as a new sheet within the file you are working with.
- 6.5. Label the graph with the project name, project number and laboratory sample number. Label each axis and copy the information from the Graph.htm file to a text box on the graph.
- 6.6. Calculate Young’s modulus from zero stress to ½ ultimate stress using the secant method (c) described in ASTM D7012-10 11.2.5.3. Report young’s modulus and method used on the plot.
- 6.7. Crop the photo taken of the sample after testing and place this photo onto the plot.
- 6.8. Save the file in Excel according to the boring, run and sample you are working with.
Example: B104R2S3_Stess_Strain.xlsx
- 6.9. Have another engineer or geologist check your chart and supporting data and have them initial the checked by line in the upper right hand corner of the graph. An example of a properly prepared report is provided as Figure 3 in attachment.
- 6.10. The completed stress/strain file should then be saved to the folder appropriate for the particular project, boring and sample location. Please note that each sample will have its own folder (see attachment Figure 1).

ATTACHMENTS

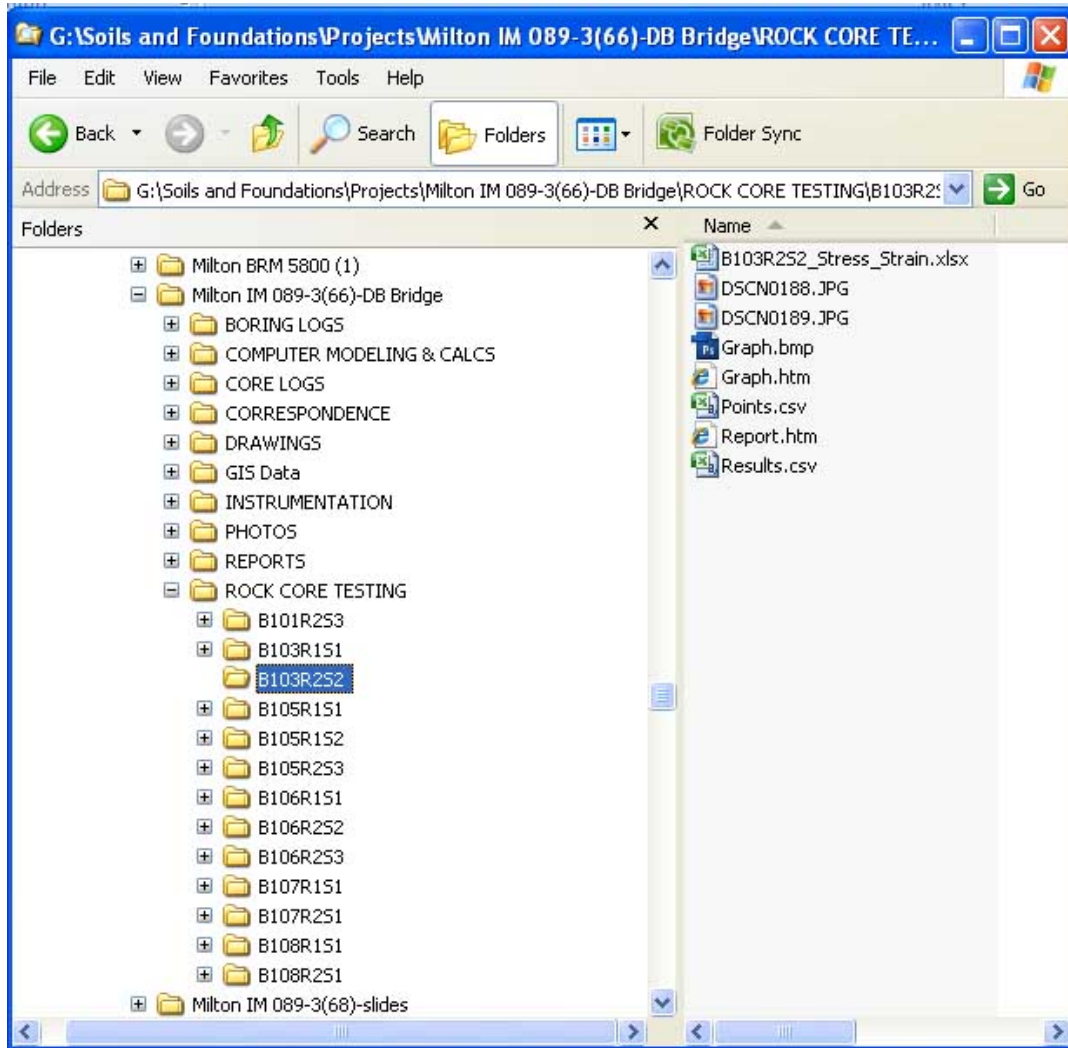


Figure 1 Example of file folder structure. The Graph.bmp, Graph.htm, Points.csv, Report.htm and Results.csv files were created by the Navigator software. The jpg files are the photo files of the test sample and the B103R252_Stress_Strain.xlsx file is the modified Points file with chart you prepared.

ATTACHMENTS

Force (lbf)	Stress (psi)	Instrument 1 (in)		Strain	Stress (psi)
241.5	75.58	0.00028		0.00014	75.58
410.8	128.57	0.00036		0.00018	128.57
592.6	185.48	0.00043		0.000215	185.48
750.2	234.8	0.00047		0.000235	234.8
870.8	272.5	0.00051		0.000255	272.5
963	301.4	0.00053		0.000265	301.4

Figure 2 Example of modified Points.csv file with Stress/Strain columns.

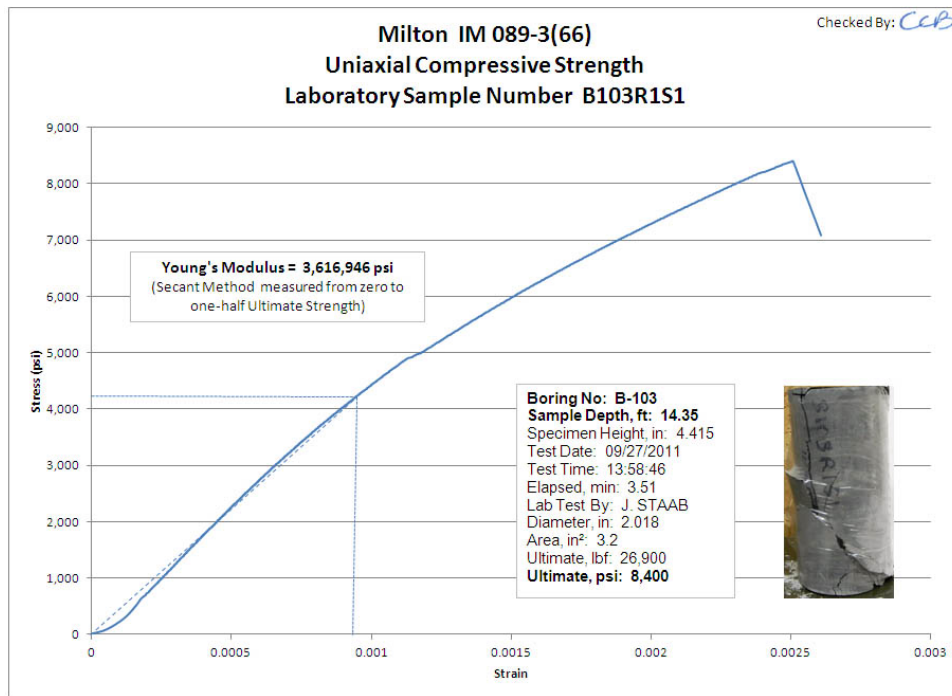


Figure 3 Example UCS Test report.

ATTACHMENTS

Uniaxial Compressive Strength of Rock
Test Data Sheet

Equipment Used

Tinius Olsen
Epsilon Extensometer (s/n-E82765)

Specimen Prepared by: _____
Test performed by: _____
Date tested _____

Project: _____ Boring: _____

Lab number: _____

Moisture condition of core is laboratory air-dry unless recorded differently.

Temperature when tested _____ Dip _____
Depth (feet) _____
Specimen Length (in.) _____
Specimen Diameter (in.) _____

Geological Description

Was Extensometer removed during test? Yes _____ No _____
Was core tested to failure? Yes _____ No _____

Maximum Load applied (Ultimate lbf.) _____
Maximum Stress applied (Ultimate psi.) _____
Young's modulus (*E*, psi.) _____

Comments: _____



Sketched Fracture

Examples of fractures

