PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING, IGNACE AREA

WP04b Data Report – Geomechanical Testing of Core for IG_BH02

APM-REP-01332-0251 **April 2021**

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REPORT

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WP04b Data Report - Geomechanical Testing of Core for IG_BH02

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1671632 (3400B)
NWMO Report: APM-REP-01332-0251

April 2021

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WP4B DATA REPORT
GEOMECHANICAL TESTING OF CORE FOR IG_BH02

CLIENT INFORMATION

Project Name:	Phase 2 Initial Borehole Drilling and Testing, Ignace Area
Project Number:	1671632
Client PO Number:	2000141 (Formerly 01559 A-TGS)
Document Name:	1671632 (3400B) IG_BH02_WP04B_Report_19April2021_r2a.docx

Client: Nuclear Waste Management Organization (NWMO)
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ISSUE/REVISION INDEX

Issue Code	Revision					Revision Details
	No.	By	Rev'd.	App.	Date	
RR	0	KF	DD	JLC	Jan 22, 2021	Final Draft released for review and comment
RI	1	KF	DD	JLC	Mar 04, 2021	Final released for information
RI	2	KF	DD	JLC	April 19,2021	Final released for information

Issue Codes: RR = Released for Review and Comments, RI = Released for Information

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1.0 INTRODUCTION

The Initial Borehole Drilling and Testing project in the Wabigoon and Ignace Area, Ontario is part of Phase 2 Geoscientific Preliminary Field Investigations of the NWMO's Adaptive Phased Management (APM) Site Selection Phase.

This project involves the drilling and testing of three deep boreholes within the northern portion of the Revell batholith. The third drilled borehole, IG_BH02, is located a direct distance of approximately 21 km southeast of the Wabigoon Lake Ojibway Nation and a direct distance of 43 km northwest of the Town of Ignace. Access to the IG_BH02 drill site is via Highway 17, primary logging roads, and purpose specific developed roads, as shown on Figure 1.

The project was carried out by a team led by Golder Associates Ltd. (Golder) on behalf of the NWMO. This report describes the testing methodology and results for Work Package 04B (WP04B): Geomechanical Testing of Core for IG_BH02, which includes: Uniaxial Compressive Strength tests (w/ elastic constants), Indirect Tensile (Brazilian) Strength tests, P-wave and S-wave ultrasonic pulse velocity and acoustic emissions (AE) measurements (on UCS tests). Wet and dry density, and water content were measured for all tested samples.

2.0 BACKGROUND INFORMATION

2.1 Geological Setting

The approximately 2.7 billion year old Revell batholith is located in the western part of the Wabigoon Subprovince of the Archean Superior Province. The batholith is roughly elliptical in shape trending northwest, is approximately 40 km in length, 15 km in width, and covers an area of approximately 455 km^2. Based on geophysical modelling, the batholith is approximately 2 km to 3 km thick through the center of the northern portion (SGL 2015). The batholith is surrounded by supracrustal rocks of the Raleigh Lake (to the north and east) and Bending Lake (to the southwest) greenstone belts (Figure 2).

Borehole IG_BH02 is located within an investigation area of approximately 19 km^2 in size, situated in the northern portion of the Revell batholith. Bedrock exposure in the area is generally very good due to minimal overburden, few water bodies, and relatively recent logging activities. Ground elevations generally range from 400 to 450 m above sea level. The ground surface broadly slopes towards the northwest as indicated by the flow direction of the main rivers in the area. Local water courses tend to flow to the southwest towards Mennin Lake (Figure 1).

Four main rock units are identified in the supracrustal rock group: mafic metavolcanic rocks, intermediate to felsic metavolcanic rocks, metasedimentary rocks, and mafic intrusive rocks (Figure 2). Sedimentation within the supracrustal rock assemblage was largely synvolcanic, although sediment deposition in the Bending Lake area may have continued past the volcanic period (Stone 2009; Stone 2010a; Stone 2010b). All supracrustal rocks are affected, to varying degrees, by penetrative brittle-ductile to ductile deformation under greenschist- to amphibolite-facies metamorphic conditions (Blackburn and Hinz 1996; Stone et al. 1998). In some locations, primary features, such as pillow basalt or bedding in sedimentary rocks are preserved, in other locations, primary relationships are completely masked by penetrative deformation. Uranium-lead (U-Pb) geochronological analysis of the supracrustal rocks produced ages that range between 2734.6 +/-1.1 Ma and 2725 +/-5 Ma (Stone et al. 2010).

Three main suites of plutonic rock are recognized in the Revell batholith, including, from oldest to youngest: a Biotite Tonalite to Granodiorite suite, a Hornblende Tonalite to Granodiorite suite, and a Biotite Granite to

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Granodiorite suite (Figure 2). Plutonic rocks of the Biotite Tonalite to Granodiorite suite occur along the southwestern and northeastern margins of the Revell batholith. The principal type of rock within this suite is a white to grey, medium-grained, variably massive to foliated or weakly gneissic, biotite tonalite to granodiorite. One sample of foliated and medium-grained biotite tonalite produced a U-Pb age of 2734.2+/-0.8 Ma (Stone et al. 2010). The Hornblende Tonalite to Granodiorite suite occurs in two irregularly-shaped zones surrounding the central core of the Revell batholith. Rocks of the Hornblende Tonalite to Granodiorite suite range compositionally from tonalite through granodiorite to granite and also include significant proportions of quartz diorite and quartz monzodiorite. One sample of coarse-grained grey mesocratic hornblende tonalite produced a U-Pb age of 2732.3+/-0.8 Ma (Stone et al. 2010). Rocks of the Biotite Granite to Granodiorite suite underlie most of the northern, central and southern portions of the Revell batholith. Rocks of this suite are typically coarse-grained, massive to weakly foliated, and white to pink in colour. The Biotite Granite to Granodiorite suite ranges compositionally from granite through granodiorite to tonalite. A distinct potassium (K)-Feldspar Megacrystic Granite phase of the Biotite Granite to Granodiorite suite occurs as an oval-shaped body in the central portion of the Revell batholith (Figure 2). One sample of coarse-grained, pink, massive K-feldspar megacrystic biotite granite produced a U-Pb age of 2694.0+/-0.9 Ma (Stone et al. 2010).

The bedrock surrounding IG_BH02 is composed mainly of massive to weakly foliated felsic intrusive rocks that vary in composition between granodiorite and tonalite, and together form a relatively homogeneous intrusive complex. Bedrock identified as tonalite transitions gradationally into granodiorite and no distinct contact relationships between these two rock types are typically observed (SRK and Golder 2015; Golder and PGW 2017). Massive to weakly foliated granite is identified at the ground surface to the northwest of the feldspar-megacrystic granite. The granite is observed to intrude into the granodiorite-tonalite bedrock, indicating it is distinct from, and younger than, the intrusive complex (Golder and PGW 2017).

West-northwest trending mafic dykes interpreted from aeromagnetic data extend across the northern portion of the Revell batholith and into the surrounding greenstone belts. One mafic dyke occurrence, located to the northwest of IG_BH01, is approximately 15-20 m wide (Figure 2). All of these mafic dykes have a similar character and are interpreted to be part of the Wabigoon dyke swarm. One sample from the same Wabigoon swarm produced a U-Pb age of 1887+/-13 Ma (Stone et al. 2010), indicating that these mafic dykes are Proterozoic in age. It is assumed based on surface measurements that these mafic dykes are sub-vertical (Golder and PGW 2017).

Long, narrow valleys are located along the western and southern limits of the investigation area (Figure 1). These local valleys host creeks and small lakes that drain to the southwest and may represent the surface expression of structural features that extend into the bedrock. A broad valley is located along the eastern limits of the investigation area and hosts a more continuous, un-named water body that flows to the south. The linear and segmented nature of this waterbody's shorelines may also represent the surface expression of structural features that extend into the bedrock.

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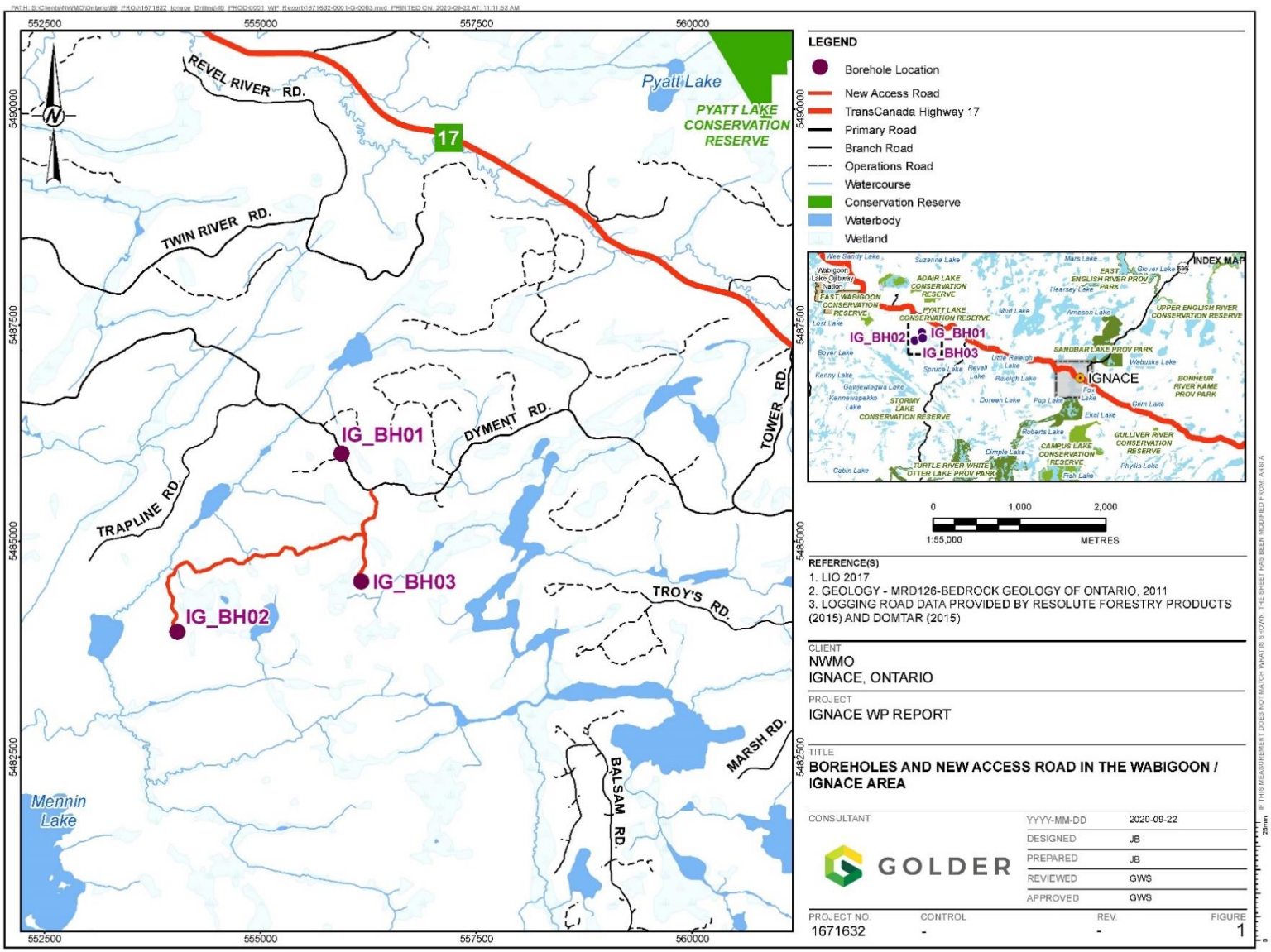


Figure 1: Location of IG_BH02 in Relation to the Wabigoon / Ignace Area

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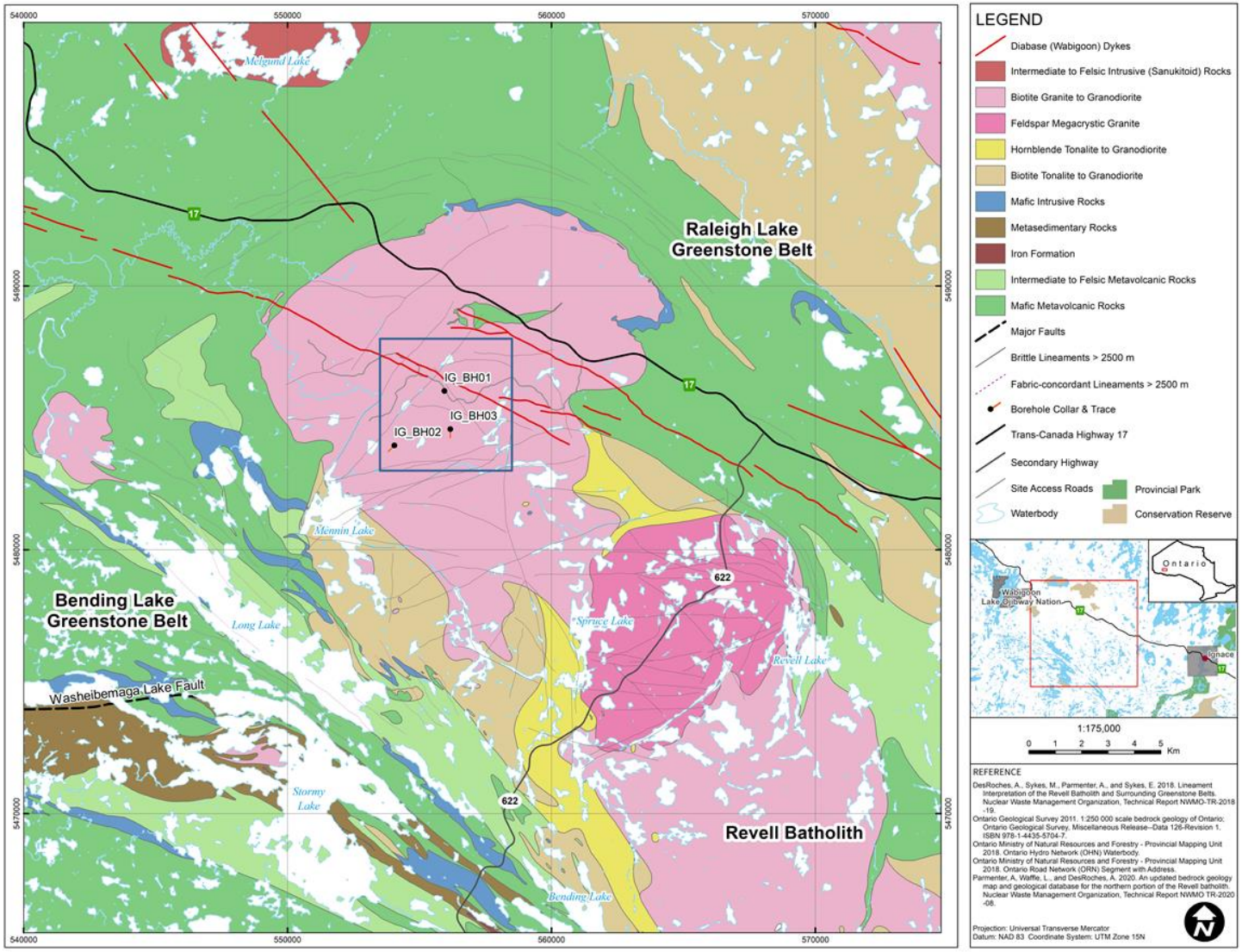


Figure 2: Geological setting and location of boreholes IG_BH01, IG_BH02 and IG_BH03 in the northern portion of the Revell batholith

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Regional observations from mapping have indicated that structural features are widely spaced (typical 30 to 500 cm spacing range) and dominantly comprised of sub-vertical joints with two dominant orientations, northeast and northwest trending (Golder and PGW 2017). Interpreted bedrock lineaments generally follow these same dominant orientations in the northern portion of the Revell batholith (Figure 2; DesRoches et al. 2018). Minor sub-horizontal joints have been observed with minimal alteration, suggesting they are younger and perhaps related to glacial unloading. One mapped regional-scale fault, the Washeibemaga Lake fault, trends east and is located to the west of the Revell batholith (Figure 2). Ductile lineaments, also shown on Figure 2, follow the trend of foliation mapped in the surrounding greenstone belts. Additional details of the lithological units and structures found at surface within the investigation area are reported in Golder and PGW (2017).

2.2 Technical Objectives

The technical objective of the geomechanical laboratory testing program is to assess the key geomechanical properties of the crystalline host rock within the repository horizon (presently assumed to be between depths of approximately 400 and 600 m).

Uniaxial Compressive Strength (UCS) testing of core samples was performed on 3 samples to determine the intact unconfined compressive strength and elastic properties (elastic moduli and Poisson's ratio) of the bedrock in the repository horizon. Additional non-destructive testing/measurements for each UCS core sample included:

- Determination of moisture content and rock density;
- Determination of P-wave and S-wave ultrasonic pulse velocities and determination of ultrasonic elastic constants; and
- Monitoring and recording of incremental and cumulative acoustic emissions throughout each test.

Crack Initiation and Crack Damage stress levels were interpreted from the stress strain curves for each test and compared to interpreted AE results for verification.

Indirect Tensile (Brazilian) Strength testing of core samples were performed on 3 samples (selected adjacent to the UCS samples) to determine the tensile strength of the rock.

2.3 Description of Testing Procedures

The geomechanical testing program was carried out at the CANMET-MMSL rock mechanics testing facility located in Bells Corners (Ottawa), Ontario. Laboratory tests were carried out according to CANMET-MMSL's Standard Operating Procedures (SOPs), which follow ASTM standard test methods:

Preparation and Non-destructive Testing

- ASTM D4543-19 Standard Practices for Preparing Rock Core as Cylindrical Test Specimens and Verifying Conformance to Dimensional and Shape Tolerances
- ASTM D2216-19 Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
- ASTM D7263-09 (2018) ε2, Laboratory Determination of Density (Unit Weight) of Soil Specimens

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UCS Testing and Elastic Parameters

- ASTM D7012-14ε1 Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures

Indirect Tensile Strength Testing

- ASTM D3967-16 Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens

2.4 Test Apparatus and Procedures

2.4.1 Sample Preparation

Preparation of cylindrical specimens for UCS tests, and verification of conformance to dimensional and shape tolerances were done according to the ASTM D4543-19 standard test method. Fresh water was used for cutting and end preparation. Specimen ends were ground flat to within 0.025 mm and parallel to each other as specified by the ASTM standard test method for a loading system with fixed platens.

Specimen dimensions, i.e. length and average diameter, were measured to the nearest 0.01 mm. Cross-sectional area and volume were determined. Specimens were weighted to the nearest 0.1 g, and density was computed to the nearest 0.01 g/cm^3 as well. Zero-pressure P- and S-wave velocities were also measured.

Specimens with a nominal thickness-to-diameter ratio of 0.66 were prepared to carry out splitting tensile (Brazilian) tests.

2.4.2 Uniaxial Compressive Strength (UCS) Tests

UCS tests were carried out using a computer-controlled, servo-hydraulic MTS Rock Mechanics Testing System, Model 815, consisting of a 2.6 MN rated capacity load cell, the load frame itself, the hydraulic power supply, and digital controllers and test software to control experiments. Displacements were converted into strains, taking into account the specific dimensions of each test specimen. UCS test specimens were covered by a thin Teflon heat shrink jacket prior the beginning of the test to protect the instrumentation and avoid the projection of fragments, especially when testing brittle materials. Test specimens were loaded up to failure at constant axial displacement rate, e.g. controlled strain rate, equal to 0.0009 mm/sec for 60 mm OD specimens, with failure expected between 5 and 10 minutes after the beginning of loading for UCS tests, in accordance with the requirements of the ASTM D7012-14ε1 standard test method for UCS tests. All data, e.g. time, axial load, axial stress, and axial and circumferential displacements, were sampled and recorded every 0.2 second over the whole test duration, and converted into engineering units afterwards, i.e. conversion of loads and displacements into stresses and strains, respectively.

2.4.2.1 Acoustic Emissions (AE) Data Acquisition

Acoustic emissions were recorded during UCS tests. The system used was a Pocket AE-2™ system manufactured by Physical Acoustics Corporation (PAC). This system is a dual channel 18-bit system connected to Pico™ sensors with a frequency range of 200-750 kHz and a sampling rate of 20Ms/sec.

Two sensors were fixed on opposite sides of UCS test specimens, at 180 degrees from each other, one sensor being fixed 3 cm above the specimen mid-section, and the second sensor 3 cm below the mid-section, so these

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were not interfering with the movement of the MTS chain extensometer. Acoustic emission data were recorded systematically. Main features recorded were the number of emissions (or hits) and the waveform signal.

2.4.3 Indirect Tensile Strength (Brazilian) Tests

Tests were performed on the same system used for the UCS testing, but with a smaller load cell for higher accuracy, e.g., a rated capacity of 500 kN. Test specimens were loaded diametrically at a constant load rate of 0.10 kN/sec, with breakage expected sometime between two and five minutes after the beginning of the test. Tests were carried out in conformity with the requirements of the ASTM D3967-16 standard test method for indirect tensile (Brazilian) strength tests. All test data, i.e., time, diametral load, tensile stress and vertical displacement (Ram LVDT), were recorded every 0.2 seconds over the whole test duration.

2.4.4 Water Content and Density Measurements

The samples were measured and weighed before testing. After testing they were weighed and placed in the oven after completion of the test to start the drying process. Because of the destructive nature of the UCS and Brazilian tests, there is a possibility that some of the sample material may be lost during testing, which will make it difficult to know the exact volume of the sample after the test. Due to the lower porosity of the tonalite, any loss, however small, can have a significant effect in the determination of the water content and dry density. Therefore, the more precise way to determine the dry density is using the bulk density and the measured water content.

The density of the bulk samples, as received, is calculated as follows:

Volume of the prepared sample = V

Mass of the prepared sample = M

$$\rho_{\text{bulk}} = \frac{M}{V}$$

The water content of the sample is calculated as follows:

Mass of the sample after testing (initial mass before drying) = M_{init}

Mass of the sample after drying = M_{dry}

$$w = \frac{M_{init} - M_{dry}}{M_{dry}}$$

Calculation of the sample dry density:

$$\rho_{\text{dry}} = \frac{\rho_{\text{bulk}}}{1 + w}$$

Note that when no material is lost, and the mass and volume after the test have not changed, the dry density reverts to

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$$\rho_{\text{dry}} = \frac{M_{dry}}{V}$$

2.5 Analysis of Data

2.5.1 Zero Pressure P-S Wave Velocity Tests

P (compressive) and S (shear) wave velocities are determined from the time taken by a sinusoidal wave to travel across the test specimen along its longitudinal axis. P- and S-wave velocities were determined prior to the UCS testing for all UCS specimens prepared for the test program. Dynamic elastic constants are calculated by the following expressions:

$$E_D = \frac{\rho V_S^2 (3V_P^2 - 4V_S^2)}{V_P^2 - V_S^2}$$

$$G_D = \rho V_S^2$$

$$\nu_D = \frac{V_P^2 - 2V_S^2}{2(V_P^2 - V_S^2)}$$

where:

E_D – dynamic Young's modulus
G_D – dynamic shear modulus
ν_D – dynamic Poisson's ratio
V_P – compressive (P) wave velocity
V_S – shear (S) wave velocity
ρ – density

2.5.2 Uniaxial Compressive Strength (UCS) Tests

Raw original data recorded during uniaxial compression tests consist of axial load, and axial and circumferential displacements. Axial displacements are corrected for the compression of steel platens, between which displacements are measured, and the circumferential displacement is corrected for the gap between the measuring chain-extensometer and the specimen side. Engineering stresses and strains are computed using the following formulas:

$$\sigma_1 = \frac{P}{A_0}$$

$$\varepsilon_A = \frac{\Delta L}{L_0}$$

$$\varepsilon_C = \frac{\Delta D}{D_0}$$

where:

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σ_1 – axial stress
P – axial load
A_0 – initial cross-sectional area of the specimen
ε_A – axial strain
ε_C – circumferential strain
ΔL – change in specimen length
L_0 – specimen length
ΔD – change in specimen circumference
D_0 – specimen circumference

The volumetric strain (ε_V) is defined by the following expression:

$$\varepsilon_V = \varepsilon_A + 2\varepsilon_C$$

The compressive strength (UCS) was determined for all UCS tests carried out during the test program. Tangent Young's modulus (E) and Poisson's ratio (ν) were determined at an average stress level of 40% of the UCS, averaged over 30-50% of the axial stress interval, expressed as a percentage of the compressive strength. Strength and elastic properties are given by the following expressions:

$$UCS = \frac{P_C}{A_0}$$

$$E_{40} = \frac{\sigma_{40}}{\varepsilon_{40_Axial}}$$

$$\nu_{40} = -\frac{\varepsilon_{40_Circ}}{\varepsilon_{40_Axial}}$$

where:

UCS – uniaxial compressive strength
P_C – ultimate axial load on the specimen at failure
A_0 – cross-sectional area of the specimen
E_{40} – average tangent Young's modulus, computed at 40% of the UCS, averaged over 30-50 % of the axial stress interval
ν_{40} – average tangent Poisson's ratio, also computed at 40% of the UCS, averaged over the same stress interval
σ_{40} – average stress at 40% of the UCS over the same stress interval
$\varepsilon_{40_Axial}, \varepsilon_{40_Circ}$ – average axial and circumferential strain at 40% of the UCS over the same stress interval

As mentioned, strain data are obtained from displacements measured with the mechanical sensors, e.g. axial LVDTs and MTS circumferential chain-extensometer.

The crack damage threshold, σ_{CD}, was taken as the stress level at which the volumetric strain, ε_V, reaches its maximum and starts reversing direction, i.e. the inflexion point on the $\sigma_1 - \varepsilon_V$ graph, hence indicating dilation due to the formation and growth of unstable cracks. Theoretically, it is assumed that the progressive fracturing process starts above the crack damage threshold, leading to the failure of the rock material (Ghazvinian et al., 2012).

The crack initiation threshold, σ_{CI}, was taken as the stress level at which the crack volumetric strain, ε_{VC}, reaches its maximum and starts reversing direction, i.e. the inflexion point on the $\sigma_1 - \varepsilon_{VC}$ graph, hence indicating a departure from elasticity, and the development and growth of stable cracks. The crack volumetric strain, ε_{VC}, is

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given by the difference between the volumetric strain, ε_V, and the elastic volumetric strain, ε_{VE}, recorded during UCS tests assuming a perfectly linear elastic material, following these expressions:

$$\varepsilon_{VC} = \varepsilon_V - \varepsilon_{VE}$$

$$\varepsilon_{VE} = \frac{1 - 2\nu_{40}}{E_{40}}\sigma_1$$

2.5.3 Acoustic Emissions Data

The counts per time period and cumulative counts per time period of AE hits, as well as energy per time period and cumulative energy per time period for each specimen are provided in Appendix B. Recording of the acoustic emissions did not start at exactly the same time as the recording of the strains; therefore, the two records (strains and AE) were time-matched at the peak stress in order to compare the time (and stress) of the crack initiation process. Crack initiation is defined at the time that systematic cracking develops (not the first crack) which can be identified as the change in the slope of the cumulative energy graph. Crack damage starts when individual cracks start to coalesce and create a localized feature; this threshold can be more difficult to identify in the AE data. Figure 3 shows the cumulative energy for both sensors for samples IG_BH02_UC001/002/003 and the crack initiation stress as interpreted from the stress strain data. The AE record seems to suggest a lower CI value, although the interpretation can be somewhat subjective. For this reason, the interpretation from the UCS crack volumetric strain is considered to provide more consistent results.

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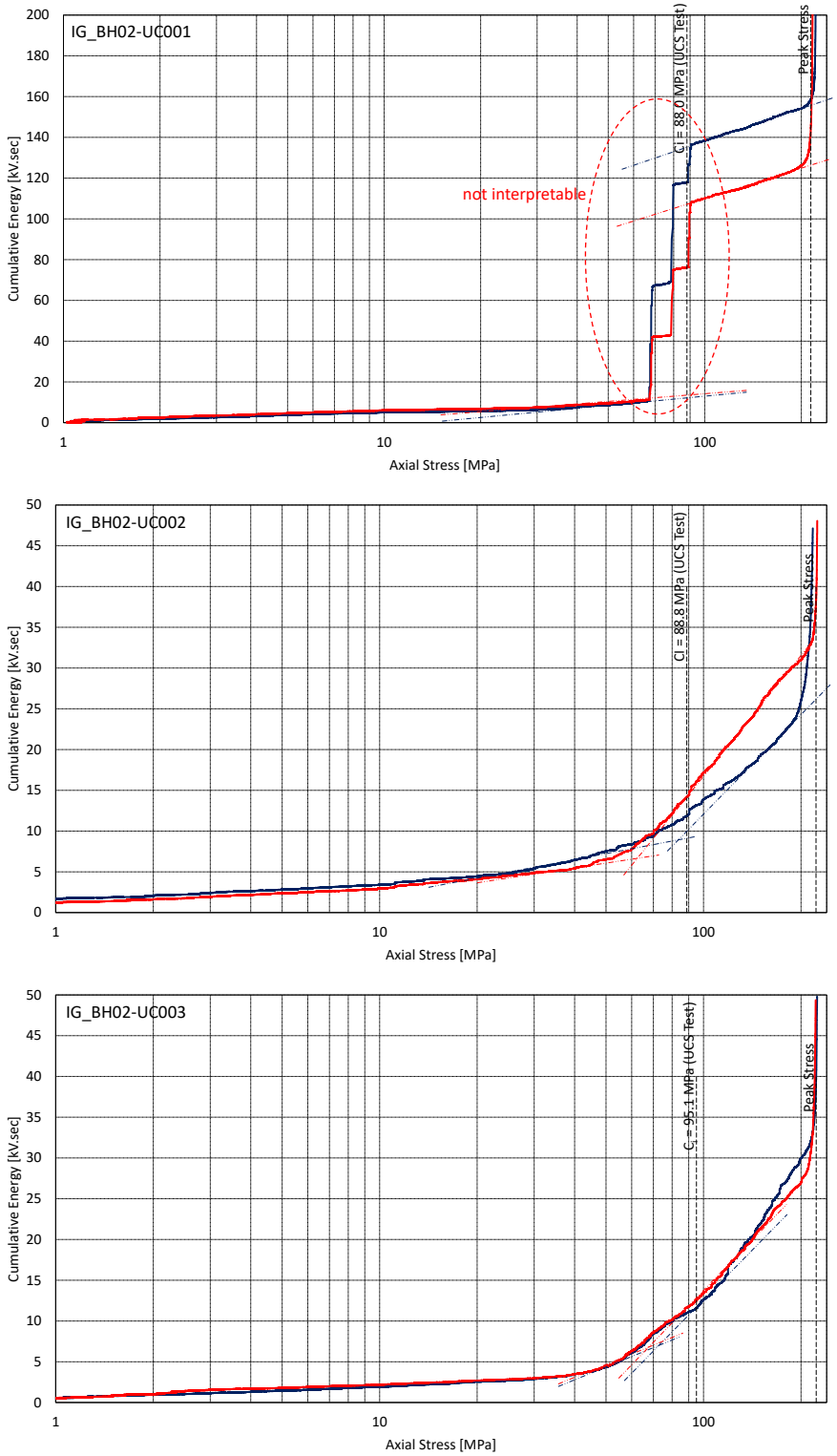


Figure 3: Cumulative energy (kilovolt·sec) vs axial stress (MPa) measured during UCS testing – 2 channels

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2.5.4 Indirect Tensile (Brazilian) Strength Tests

The indirect tensile (Brazilian) strength of a test specimen at failure, σ_T, is given by the following expression:

$$\sigma_T = \frac{2P}{\pi DT}$$

where:

σ_T – tensile strength
P – diametrical load on the specimen at failure
D – diameter of the specimen
T – thickness of the specimen

3.0 LABORATORY RESULTS

3.1 Dimensions and Physical Properties of Specimens

The specimen number, top of specimen depth, rock type (according to terminology adopted in WP03), specimen dimensions, mass, bulk density (as received), dry density, and moisture content for all UCS and Brazilian test specimens are shown in Table 1.

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Table 1: Dimensions and Physical Properties of Lab Specimens

Sample ID	Depth (m)[1]	Rock Type	Diameter (mm)	Length (mm)	L:D Ratio	Mass (g)	Bulk Density[2] (g/cm^3)	Dry Density (g/cm^3)	Moisture Content[2,3] (%)
IG_BH02_UC001	416.25	Biotite Tonalite	60.85	137.03	2.25	1060.83	2.66	2.66	0.11
IG_BH02_UC002	494.36	Biotite Tonalite	60.40	137.02	2.27	1047.13	2.67	2.66	0.13
IG_BH02_UC003	580.74	Biotite Tonalite	60.32	137.02	2.27	1044.89	2.67	2.67	0.13
IG_BH02_BR001	416.52	Biotite Tonalite	60.89	39.80	0.65	308.25	2.66	2.65	0.18
IG_BH02_BR002	494.59	Biotite Tonalite	60.37	39.75	0.66	304.04	2.67	2.67	0.20
IG_BH02_BR003	582.68	Biotite Tonalite	60.34	39.96	0.66	304.99	2.67	2.66	0.21

[1]Top depth of prepared sub-sample (depth along borehole)

[2]As-received

[3]Specimens were oven-dried accordance with ASTM D2216-19.

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3.2 Laboratory Testing Results

Table 2 shows a summary of the average strength properties determined from the current testing program. Table 3 and Table 4 present the results of the individual strength and dynamic UCS tests. Table 5 presents the results of the Brazilian testing.

Table 2: Average strength properties and elastic moduli for Biotite Tonalite in the repository horizon

Rock Type	UCS (MPa)	σ_{CI} (MPa)	σ_{CD} (MPa)	σ_T (MPa)	E_{40} (GPa)	ν_{40}
Biotite Tonalite	219.8	90.6	164.6	8.82	67.4	0.167

The results of the three UCS tests shown in Table 3 are very consistent and within the expected values for the biotite tonalite. The average value for the UCS is 220 MPa (min = 214 MPa; max = 223 MPa). The number of samples is too small to report additional statistics. All specimens reached peak strength at an axial strain of about 0.4%. Stress-strain graphs and photographs of broken test specimens are shown in Appendix A.

Crack Damage (CD) and Crack Initiation (CI) thresholds, or stress levels, determined for all UCS tests carried out during the test program are shown in Table 3. Both crack initiation and crack damage thresholds (σ_{CI} and σ_{CD}) are well correlated with the UCS. Volumetric strain graphs were plotted against the axial stress, σ_1. These are displayed in Appendix A, adjacent to stress-strain graphs and photographs of all intact and broken test specimens.

The following average relationships were obtained:

$$\sigma_{CI} = 0.41 \times UCS$$

$$\sigma_{CD} = 0.75 \times UCS$$

The results of the indirect tensile (Brazilian) strength tests provided in Table 5 are also quite consistent, with an average value for the tensile strength (σ_T) of 8.82 MPa. Load-time and stress-displacement graphs, and photographs of all intact and broken test specimens are shown in Appendix C. The relationship between the Brazilian tensile strength and the UCS is as follows:

$$\sigma_T = 0.040 \times UCS$$

The correlation observed between the Young's modulus (E_{40}) and the UCS, both expressed in MPa, is as follows:

$$E_{40} = 307 \times UCS$$

This relationship fits in well with the expected values for granitic rocks. P- and S-wave velocities are shown in Table 4. The estimates of elastic moduli from the bench top dynamic testing are about 38% to 45% lower than those obtained from the UCS testing. This can be explained by the fact that the sample is in a stress-free state and open micro cracks would yield slower velocities than under a compressed state.

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Table 3: Strength and Strain properties determined from UCS tests

Sample ID	Depth (m)[1]	Date Tested	UCS (MPa)	Young's Modulus (GPa)	Poisson's ratio	Axial Strain @ peak (%)	Max. Vol. Strain (%)	Crack Initiation Threshold (MPa)	Crack Damage Threshold (MPa)	Description of Failure Mode
IG_BH02_UC001	416.25	Jan-23-20	214.2	63.7	0.180	0.424	0.203	88.0	150.7	Massive[2], axial splitting over whole specimen length
IG_BH02_UC002	494.36	Jan-23-20	222.5	67.9	0.176	0.414	0.211	88.7	168.8	Massive[2], axial splitting over whole specimen length
IG_BH02_UC003	580.74	Jan-23-20	222.8	70.6	0.145	0.395	0.208	95.1	174.3	Massive[2], axial splitting over whole specimen length

[1]Top depth of prepared sub-sample (depth along borehole)
[2]Massive Failure indicates failure through intact rock

Table 4: Dynamic properties determined from UCS tests

Sample ID	Depth (m)[1]	Date Tested	P-wave Velocity (km/sec)	S-wave Velocity (km/sec)	Dynamic Young's Modulus (GPa)	Dynamic Shear Modulus (GPa)	Dynamic Poisson's ratio
IG_BH02_UC001	416.25	Jan-23-20	3.81	2.37	35.41	14.96	0.183
IG_BH02_UC002	494.36	Jan-23-20	3.98	2.49	39.03	16.55	0.179
IG_BH02_UC003	580.74	Jan-23-20	4.28	2.61	43.89	18.25	0.203

[1]Top depth of prepared sub-sample (depth along borehole)

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Table 5: **Tensile strength determined from Brazilian tests**

Sample ID	Depth (m)[1]	Date Tested	Failure Load (kN)	Tensile Strength (MPa)	Description of Failure Mode
IG_BH02_BR001	416.52	Jan-23-20	26.70	7.01	Perfectly diametral tensile splitting
IG_BH02_BR002	494.59	Jan-23-20	33.72	8.94	Perfectly diametral tensile splitting
IG_BH02_BR002	582.68	Jan-23-20	39.60	10.51	Perfectly diametral tensile splitting

[1]Top depth of prepared sub-sample (depth along borehole)

4.0 DATA QUALITY

All samples sent to the laboratory were accounted for and raw testing data were sent back in digital format. The results were checked against expected values and were deemed reasonable. In addition, ratios of moduli to UCS and tensile strength to UCS were within the expected ranges for this rock type. Photographs of the samples before and after testing were also delivered (Appendix A). The failure mode confirms that the UCS values are representative of the intact rock strength.

The moisture content for the Brazilian samples is noticeably higher than for the UCS samples. It is conceivable that for rocks with very low and poorly connected porosity, such as the Biotite Tonalite, the drying process will only eliminate surface or near-surface water and the results are affected by the surface area to volume ratios. The surface area to volume ratio for the Brazilian samples is higher than that for the UCS samples, thus resulting in higher moisture content measurements.

4.1 Uncertainties and Limitations

At this point in the program, the number of samples tested is very limited. Although the results of the three UCS tests and the three Brazilian tests were very consistent, the sample population is too small to establish statistical data and confidence limits. As the program evolves and more data become available, statistical analyses of the data will provide more information on the degree of confidence.

In the measurement of moisture content, the samples were weighed before testing and placed in the oven after completion of the test to start the drying process. It has been observed that because of the destructive nature of the UCS and Brazilian tests, some of the sample material may have been lost during testing. Due to the lower porosity of the tonalite, any loss, however small, can have a significant effect in the determination of the water content and dry density.

In this report, the interpretation of Crack Initiation (CI) and Crack Damage (CD) have been based on the maximum crack volumetric strain and the volumetric strain reversal, respectively. A better reported method of interpreting the crack initiation is to follow the Tangent Lateral Stiffness method (Ghazvinian et al., 2012), which

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considers the same raw data but amplifies the change in lateral strain making identification of systematic diversion more defined. It is recommended this method be used in future work.

Crack damage (CD) is defined as the onset of significant and sustained deviation from linear axial stress vs axial strain behaviour preceding sample failure (Diederichs et al 2004). Volumetric strain reversal may or may not correspond to CD in uniaxial conditions depending on the internal damage mechanisms; therefore, it is recommended that the deviation from the linear section of the stress strain curve be determined by plotting the tangent modulus (slope of the stress strain curve) to identify the onset of the deviation. Alternatively, similarly to the method to determine CI, the Tangent Axial Stiffness can be used to interpret CD. It is recommended that one of these two methods be used in future work.

5.0 REFERENCES

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APPENDIX A

UCS Tests: Stress-Strain Graphs and Photographs of Intact and Broken Test Specimens

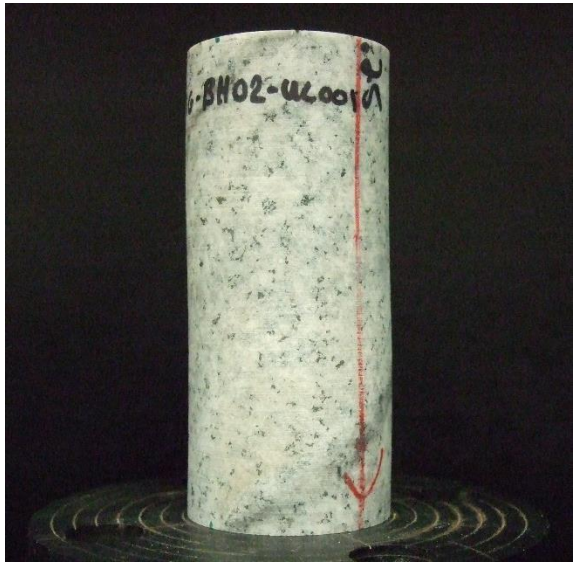
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Table A-1: List of uniaxial compression test specimens

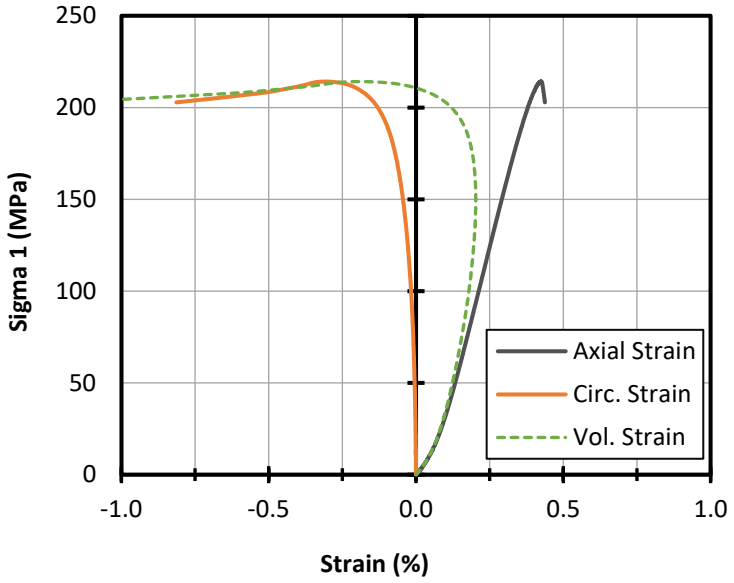
Specimen No.	Depth (m)[1]	Rock Type	Page
IG_BH01_UC001	416.25	Biotite Tonalite	A-2
IG_BH01_UC002	494.36	Biotite Tonalite	A-3
IG_BH01_UC003	580.74	Biotite Tonalite	A-4

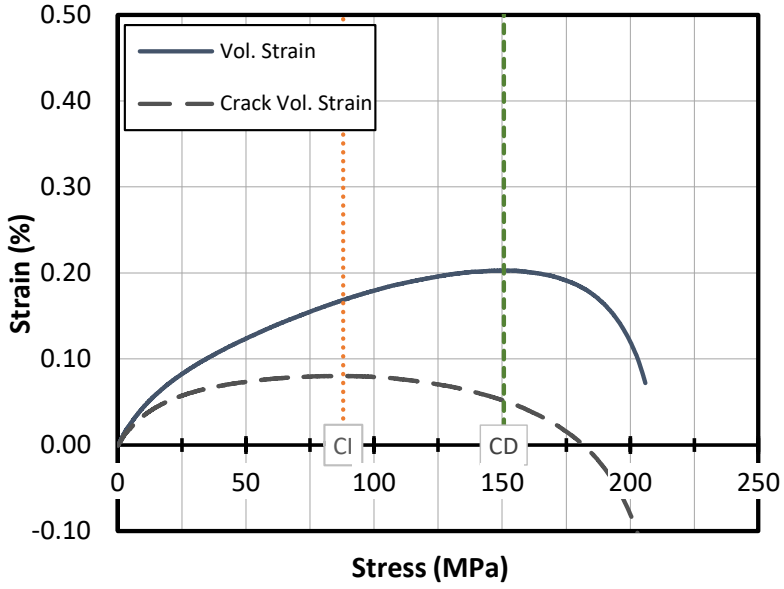
[1]Top depth of prepared sub-sample

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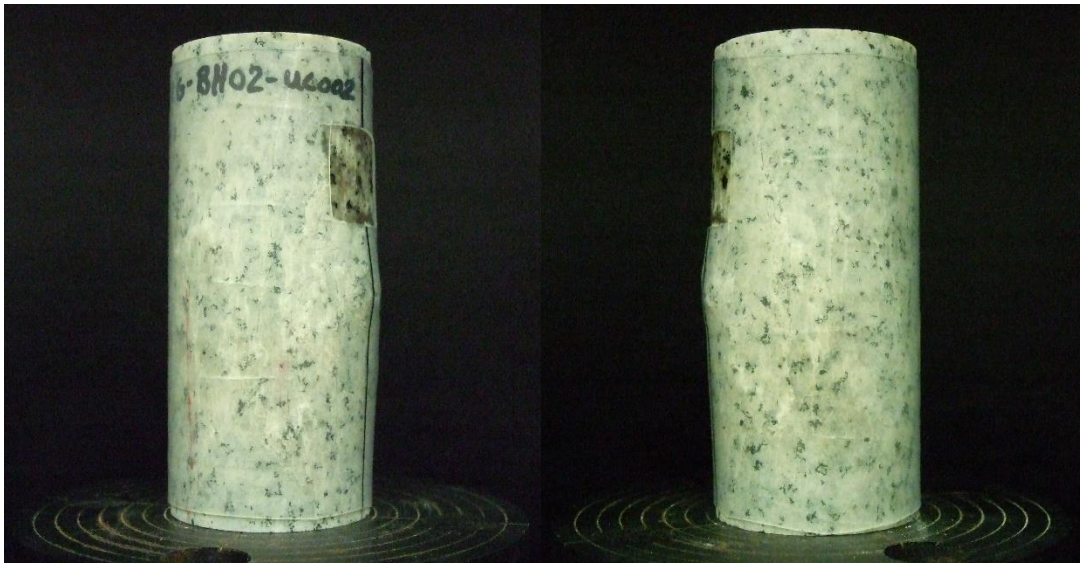


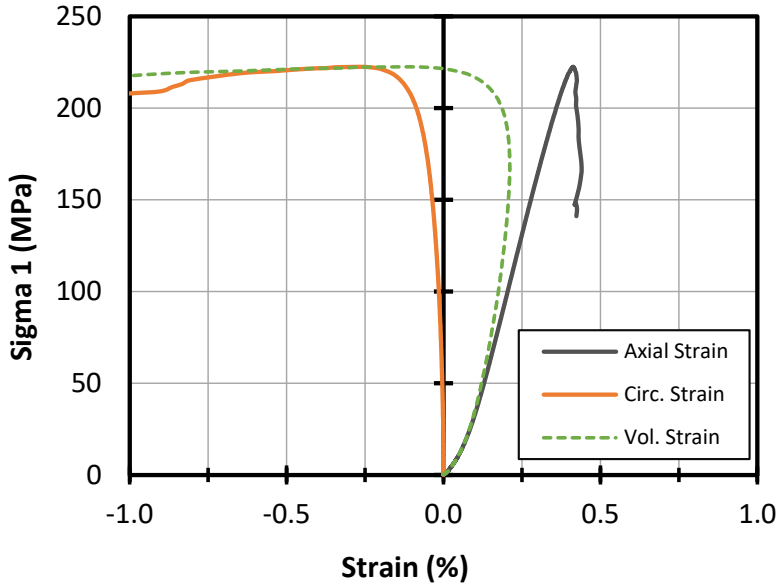


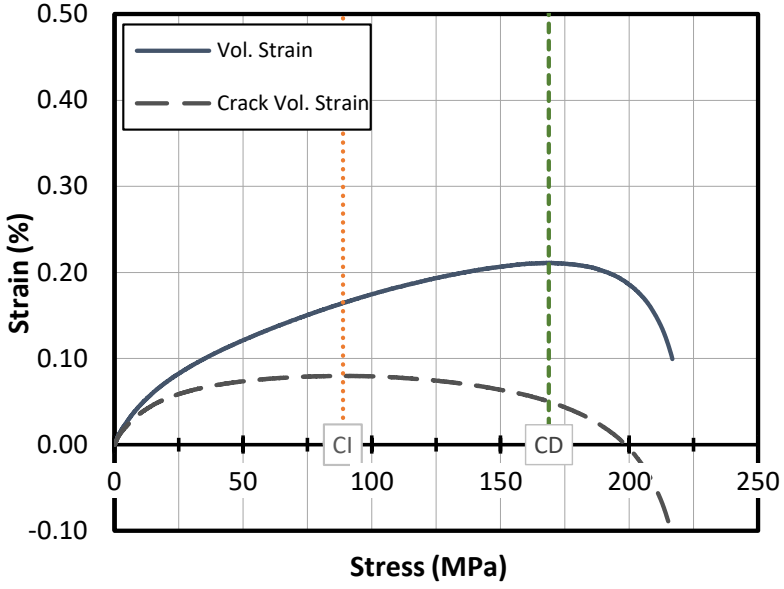
Test Specimen IG_BH02_UC001 – Depth = 416.25 m: Intact and broken specimen photographs and stress-strain curves

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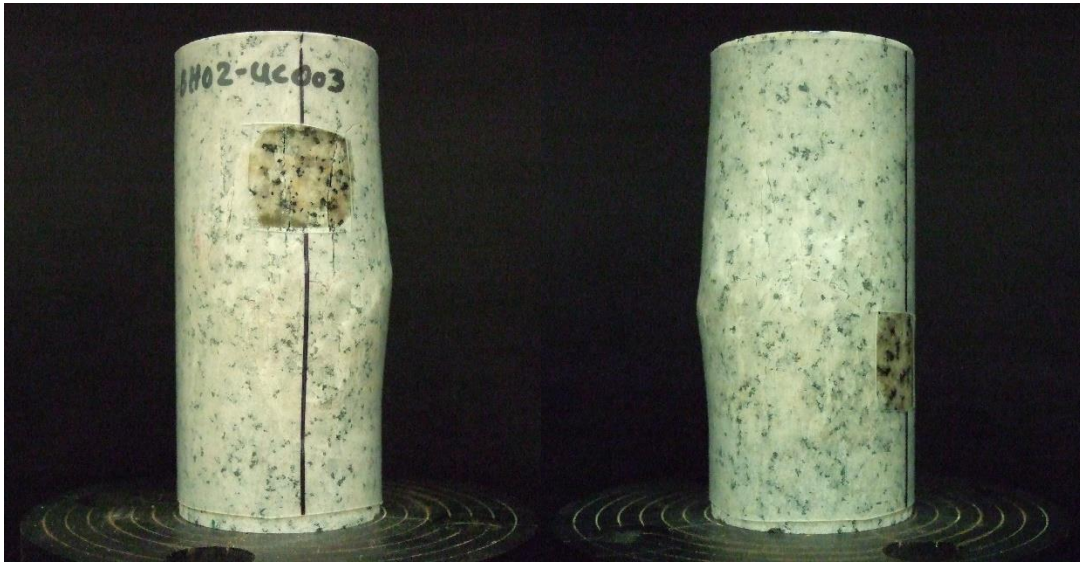


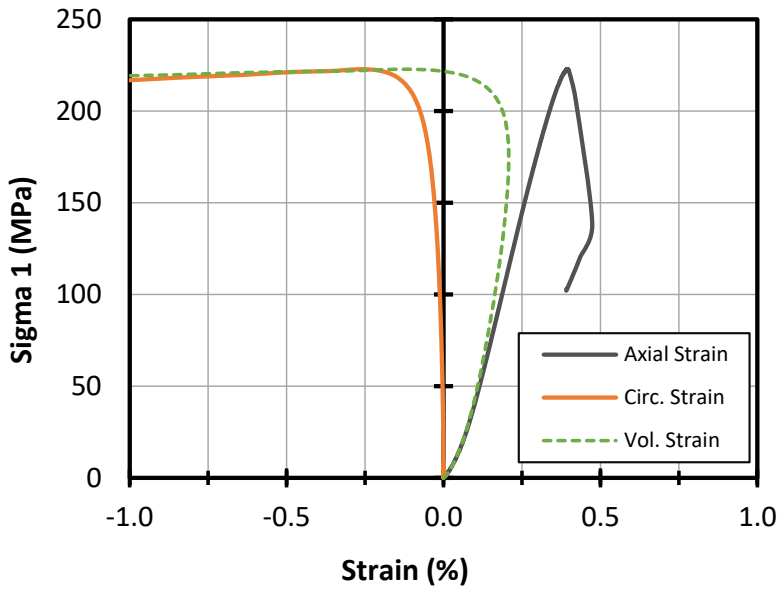


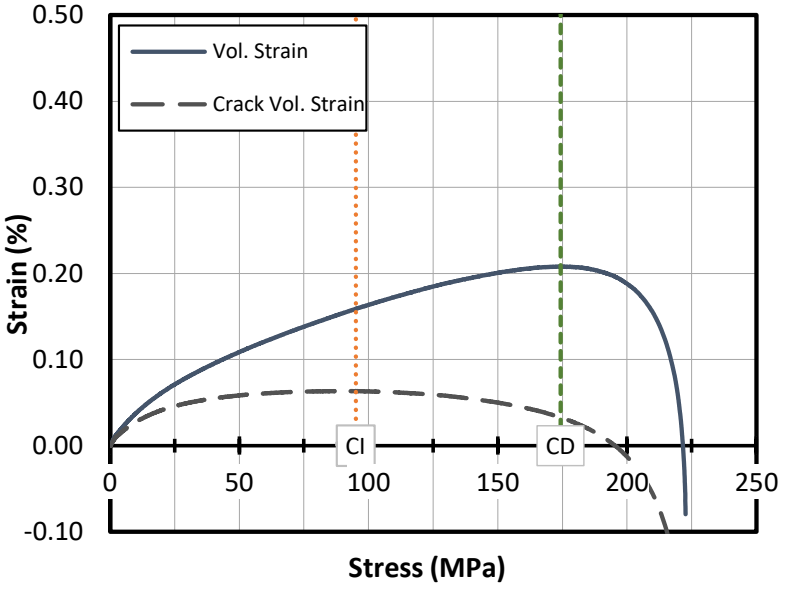
Test Specimen IG_BH02_UC002 – Depth = 494.36 m: Intact and broken specimen photographs and stress-strain curves

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Test Specimen IG_BH02_UC003 – Depth = 580.74 m: Intact and broken specimen photographs and stress-strain curves

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APPENDIX B

Acoustic Emission Data and Graph Report

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Test Summary

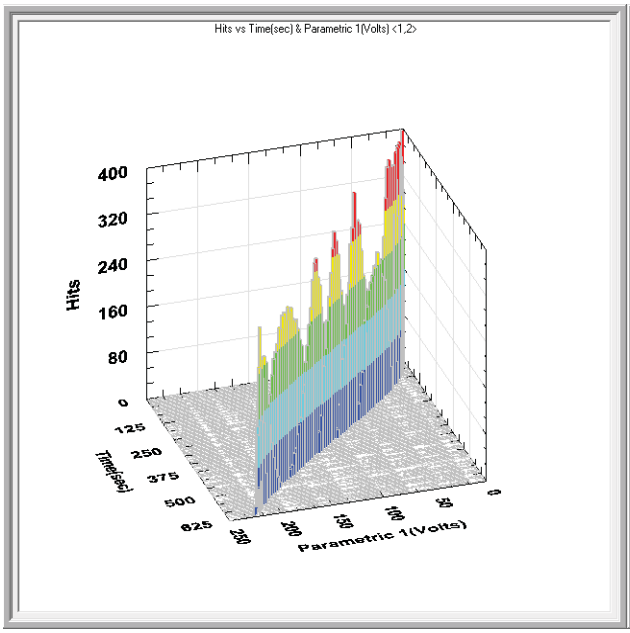
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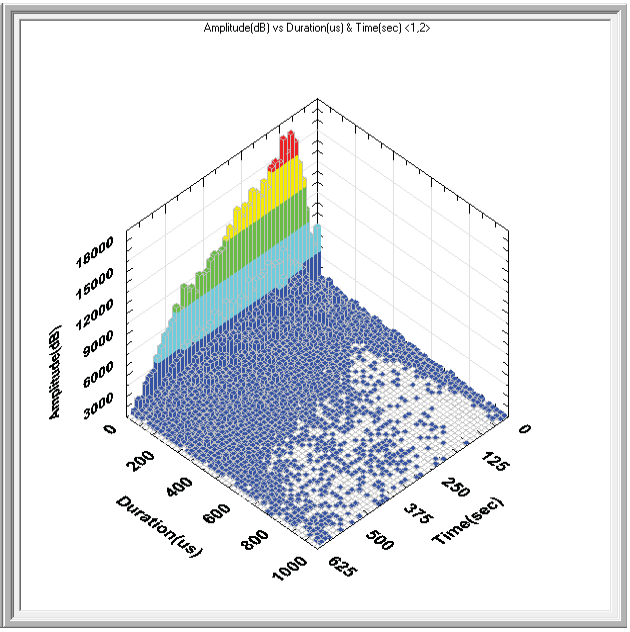
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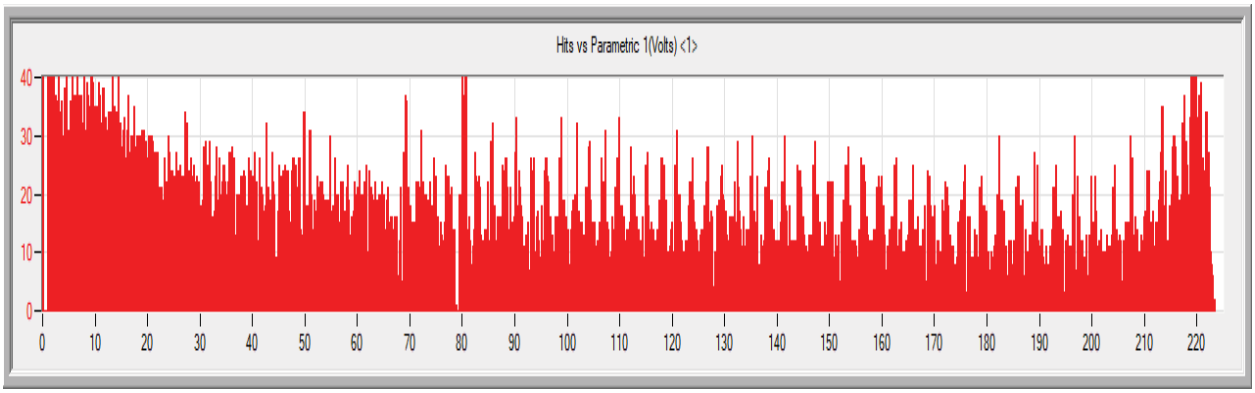
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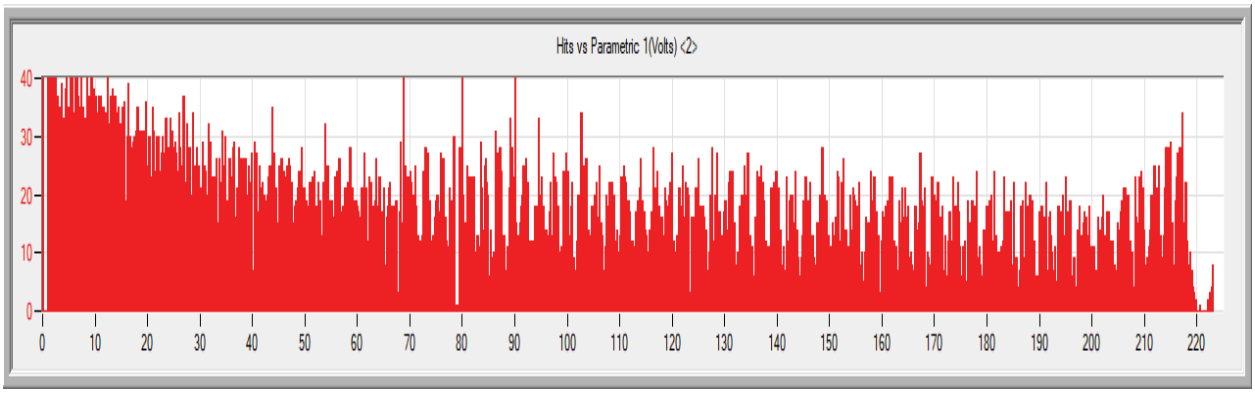


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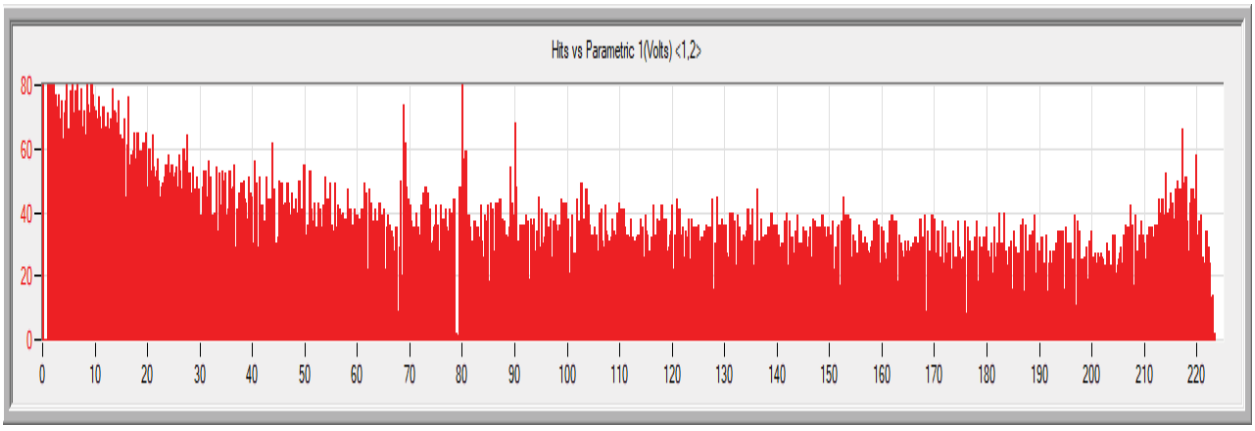
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Number of Hits vs. Axial Stress (MPa): Channel 2

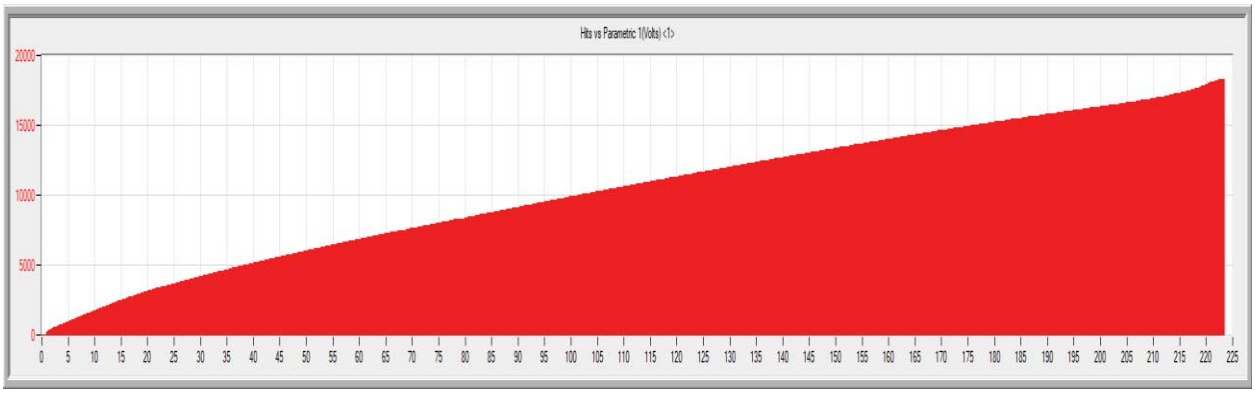


Number of Hits vs. Axial Stress (MPa): Channels 1+2

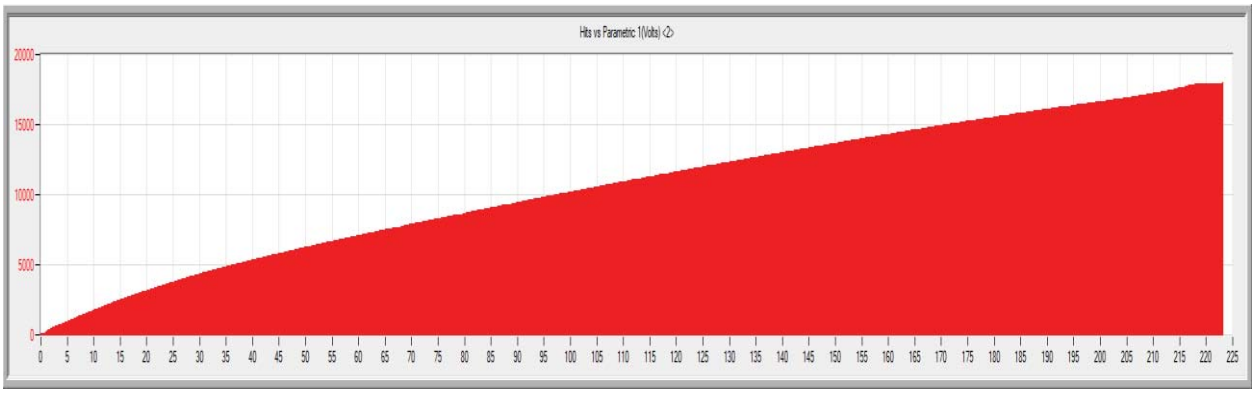


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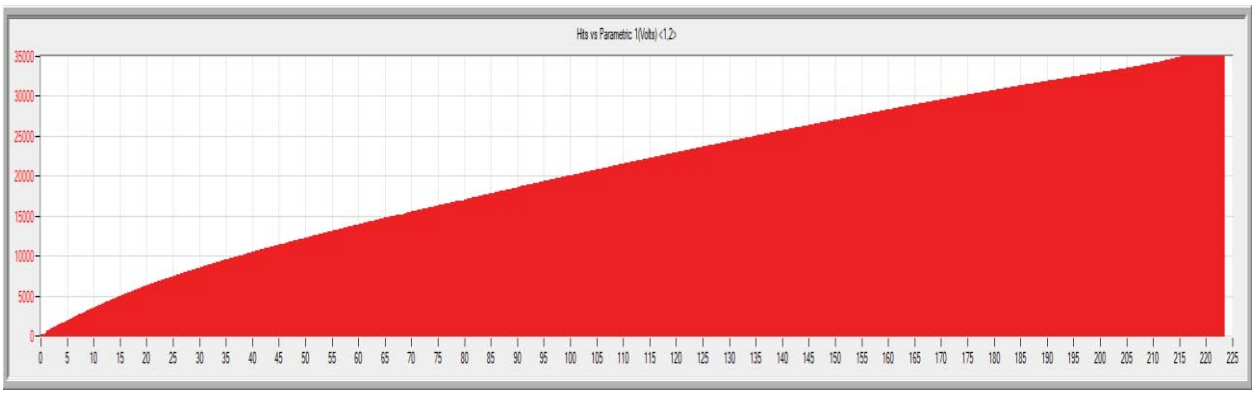
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Cumulative Number of Hits vs. Axial Stress (MPa): Channels 1+2



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Test Summary

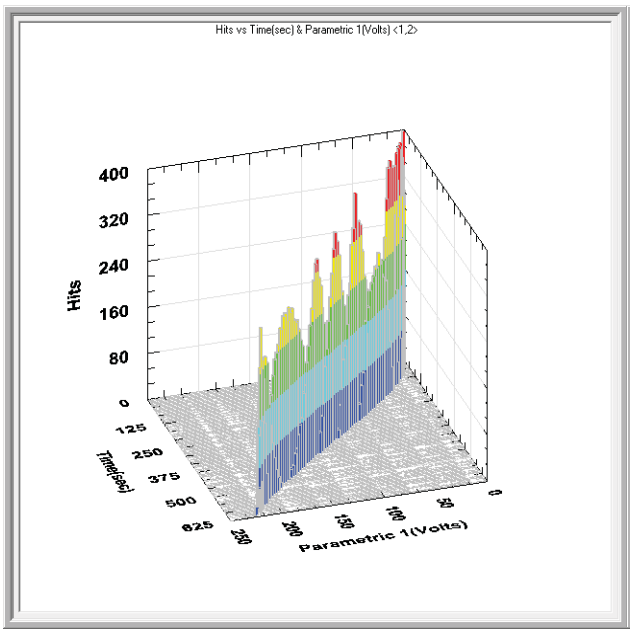
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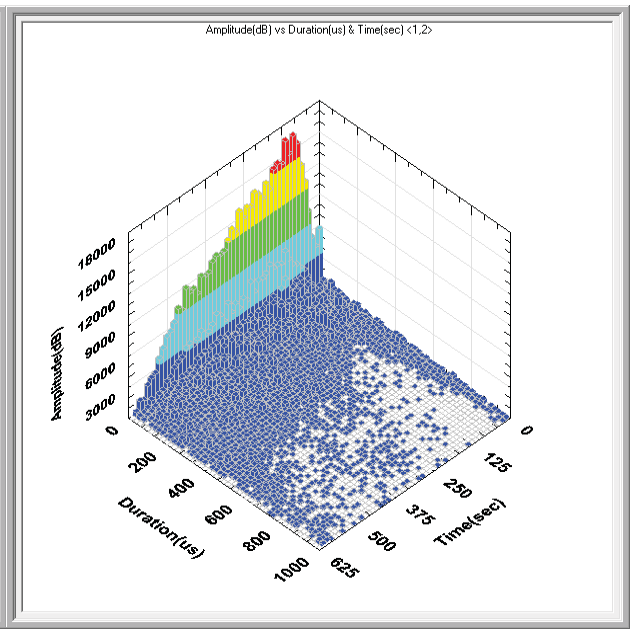
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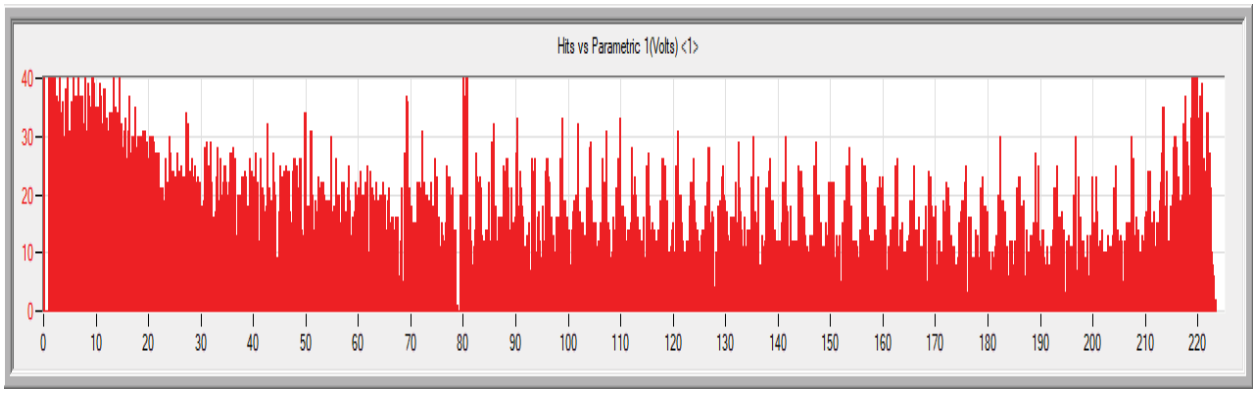
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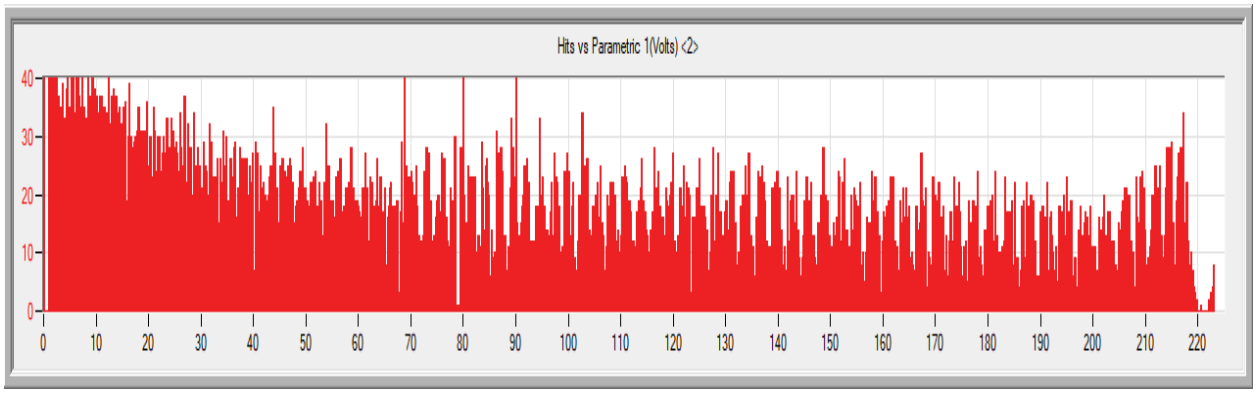


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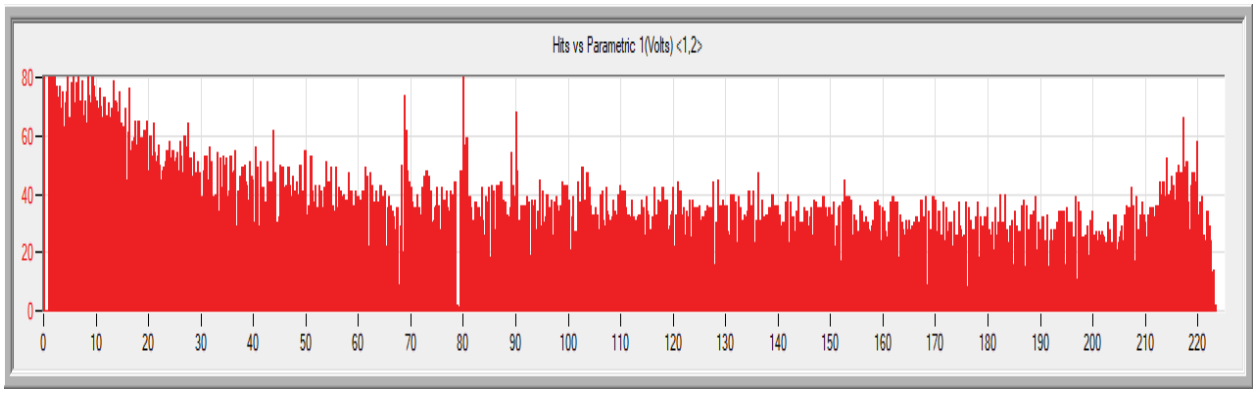
Number of Hits vs. Axial Stress (MPa): Channel 1



Number of Hits vs. Axial Stress (MPa): Channel 2

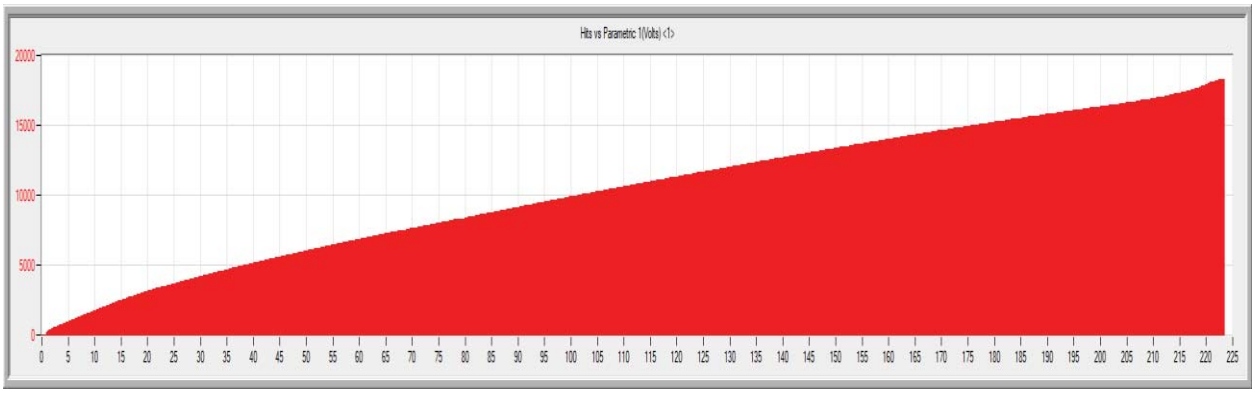


Number of Hits vs. Axial Stress (MPa): Channels 1+2

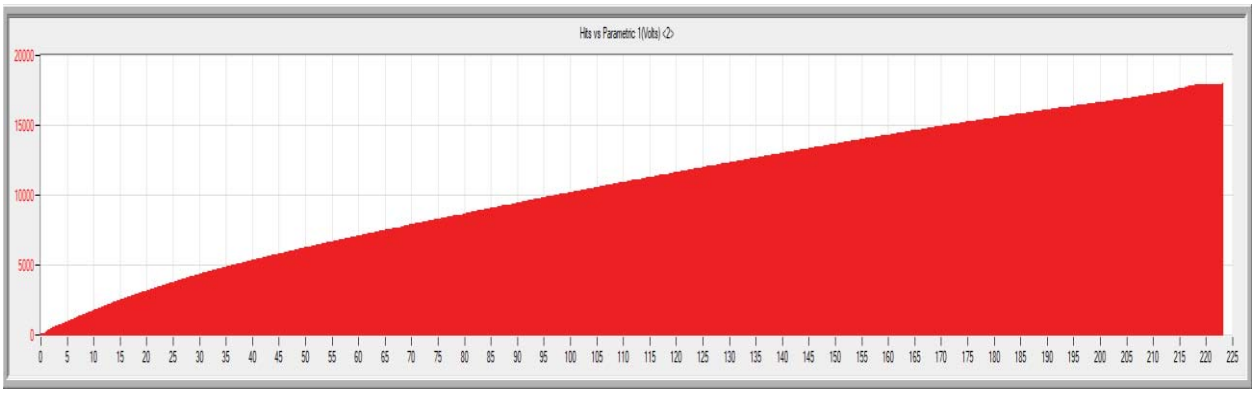


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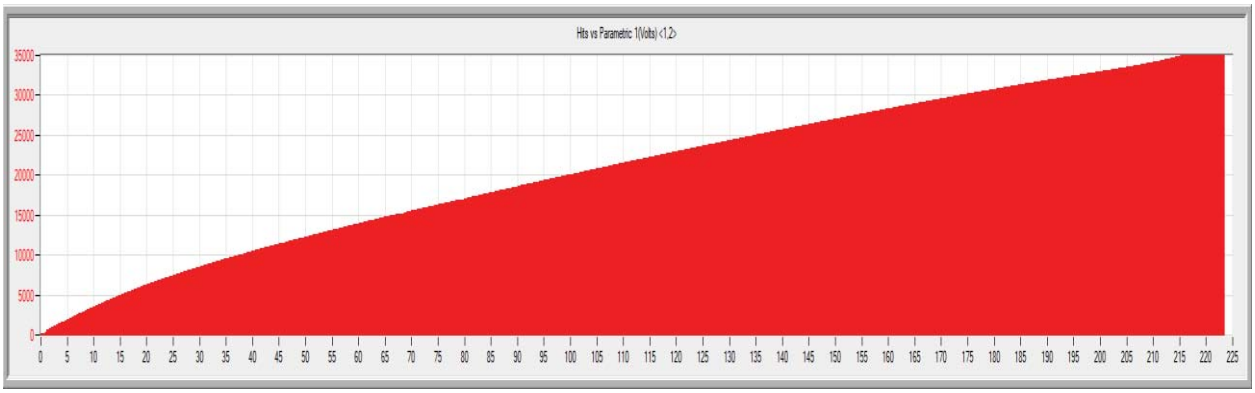
Cumulative Number of Hits vs. Axial Stress (MPa): Channel 1



Cumulative Number of Hits vs. Axial Stress (MPa): Channel 2



Cumulative Number of Hits vs. Axial Stress (MPa): Channels 1+2



Test Summary

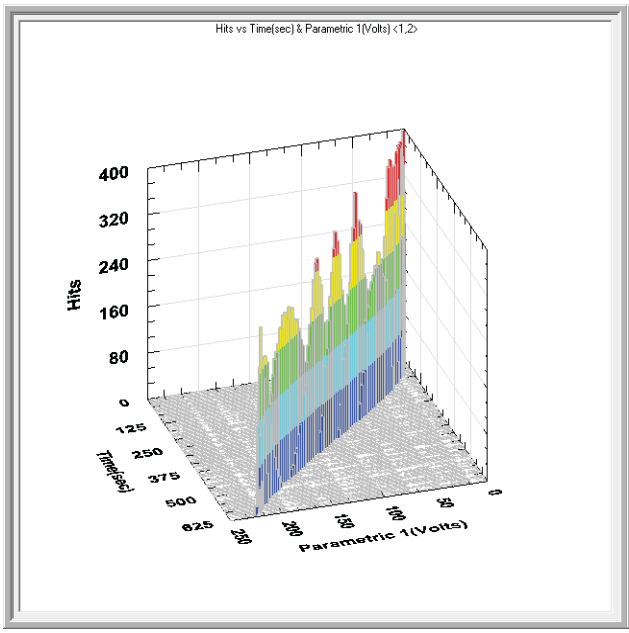
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P:\lab data\S Gaines\P-002797.002_Golder_NWMO\Data\Batch 3 (BH02)\AE\IG-BH02-UC03\IG-BH02-UC03.dta

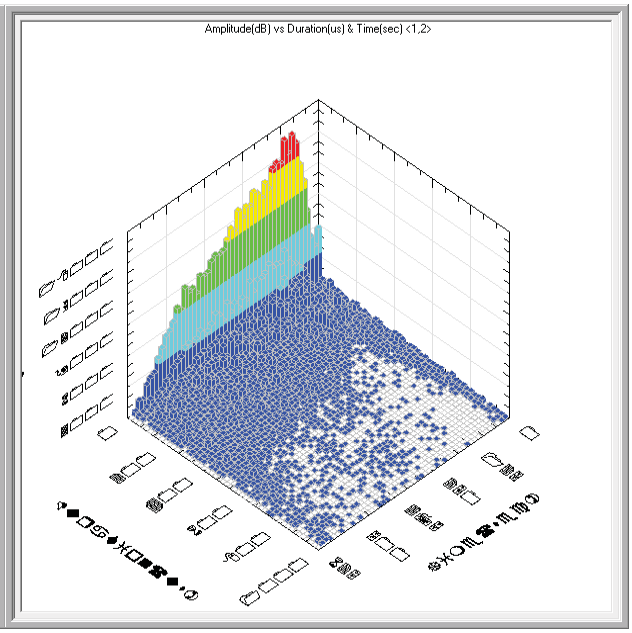
Total AEHits    :       34274
Total TDDs      :          60
Total Waveforms:       34274
Total Resumes   :           1
Total Pauses    :           1
Total TimeMarks:           0

Channel         AEHits
      1          17430
      2          16844


HIT DRIVEN DATA:
          Feature Chan         Minimum         Maximum         Average         Std Dev
         Risetime    1          0.0000      13016.0000       152.3746       894.5154
           Counts    1          1.0000      32745.0000        83.9391       949.3165
           Energy    1          0.0000      65535.0000        65.8655      1662.4489
         Duration    1          0.0000    1000000.0000      1952.9125     33749.9876
        Amplitude    1         40.0000        100.0000        46.6985         7.7039
        Threshold    1         40.0000         40.0000        40.0000        -1.#IND
      SigStrength    1          0.0000 10266957824.0000   1168122.2500  80449925.7255
        AbsEnergy    1          0.0000 54648406016.0000   3571857.5000 414683840.3587
      Parametric1    1          0.1707        228.5131       102.8139        69.9440
         Risetime    2          0.0000      13094.0000       200.4946      1036.0279
           Counts    2          1.0000      31124.0000        80.1958       876.0356
           Energy    2          0.0000      65535.0000        68.2062      1600.6584
         Duration    2          0.0000    1000000.0000      2331.2788     35877.5922
        Amplitude    2         40.0000        100.0000        46.7809         7.9231
        Threshold    2         40.0000         40.0000        40.0000         0.0019
      SigStrength    2          0.0000 1206624000.0000    549370.8750  16239120.0955
        AbsEnergy    2          0.0000  836908096.0000    265606.7813  12100993.3938
      Parametric1    2          0.1707        228.5131       103.2409        68.9580

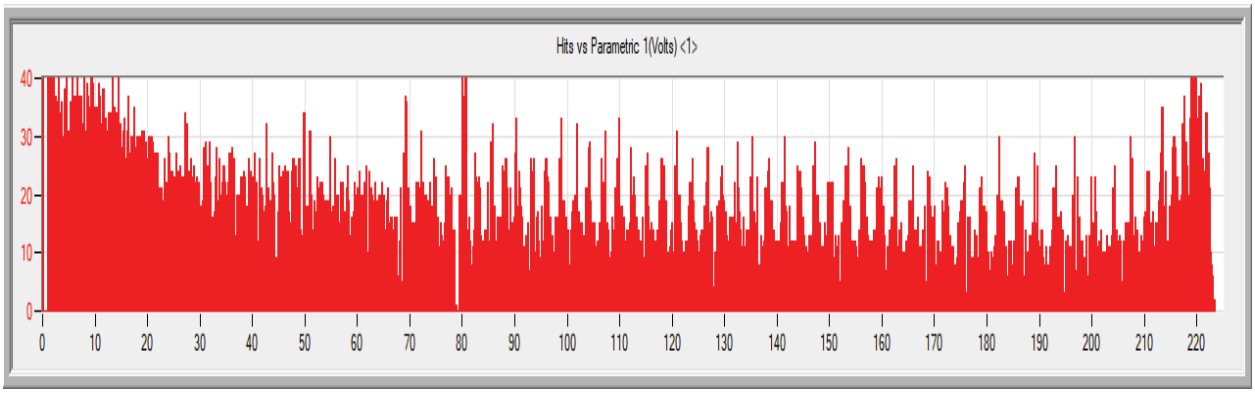
TIME DRIVEN DATA:
          Feature Chan         Minimum         Maximum         Average         Std Dev
              asl    1         27.0000         69.0000        35.5833         8.6627
              asl    2         26.0000         68.0000        35.7667         8.6552
      Parametric1               1.4506        228.4277       114.1925        74.1128
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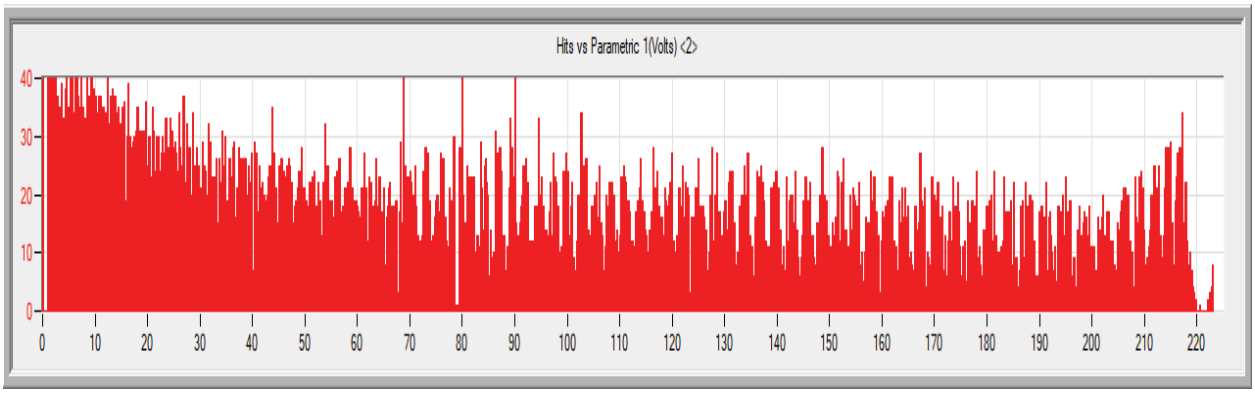


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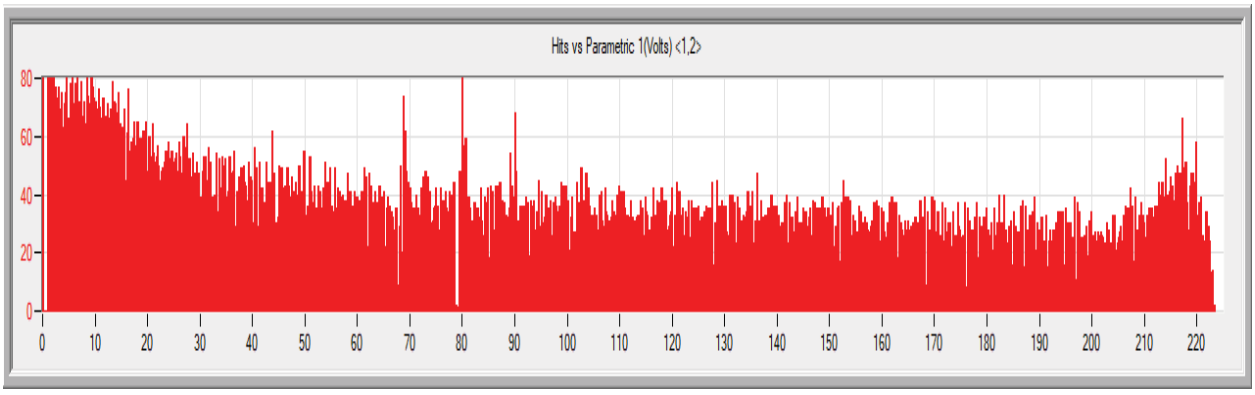
Number of Hits vs. Axial Stress (MPa): Channel 1



Number of Hits vs. Axial Stress (MPa): Channel 2

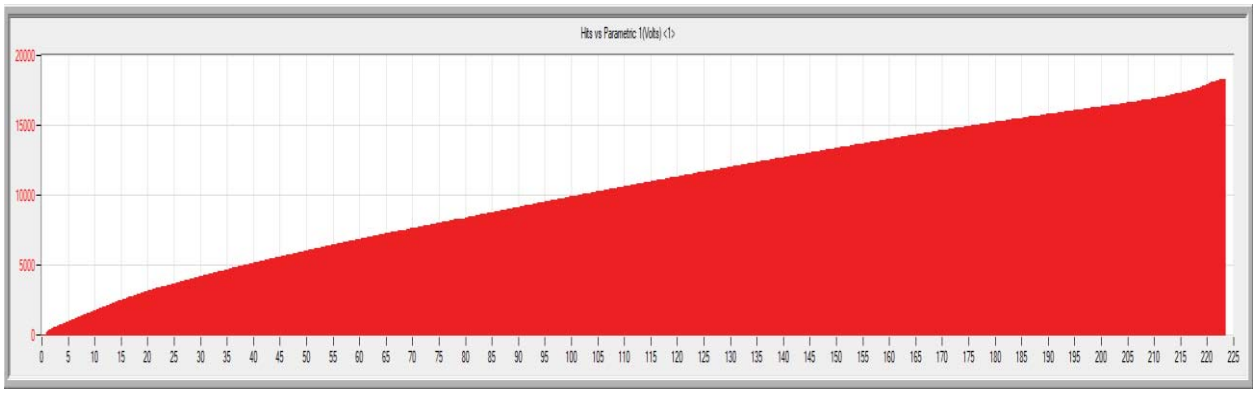


Number of Hits vs. Axial Stress (MPa): Channels 1+2

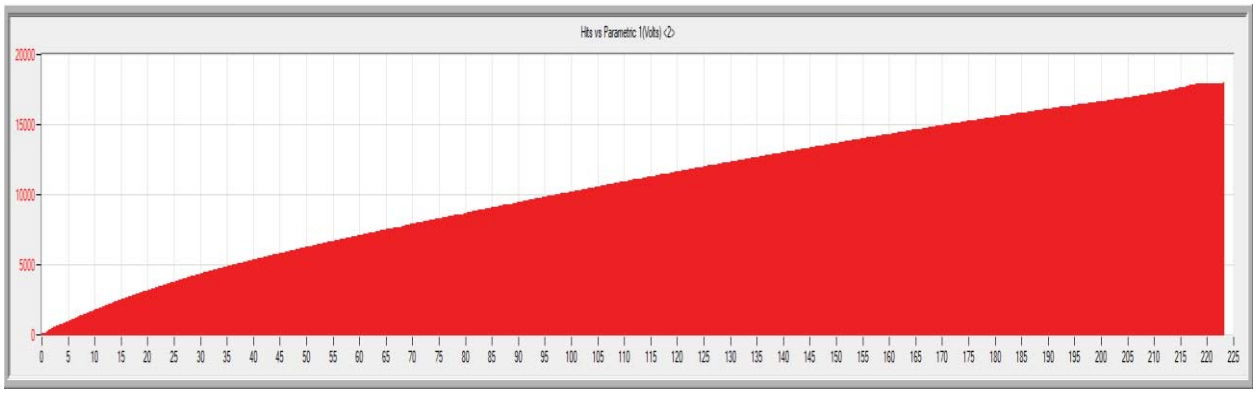


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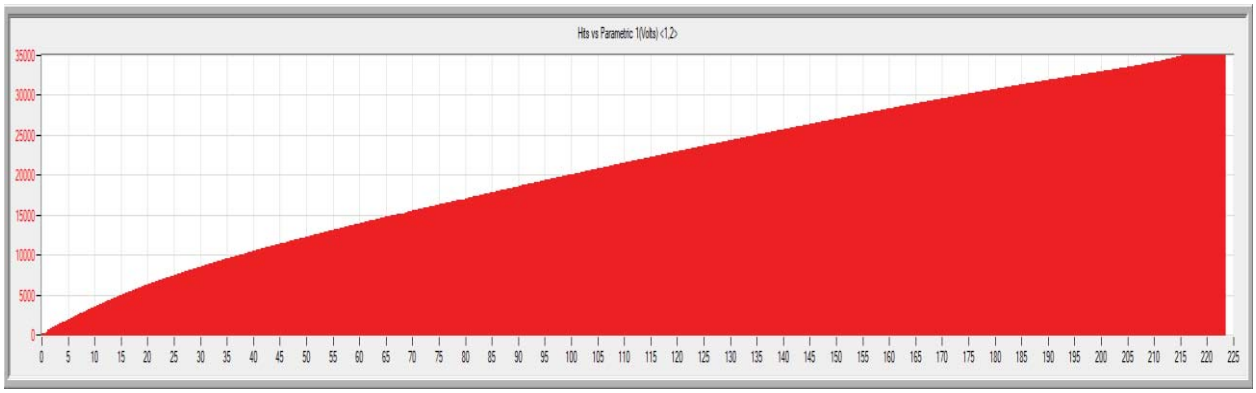
Cumulative Number of Hits vs. Axial Stress (MPa): Channel 1



Cumulative Number of Hits vs. Axial Stress (MPa): Channel 2



Cumulative Number of Hits vs. Axial Stress (MPa): Channels 1+2



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APPENDIX C

Indirect Tensile (Brazilian) Strength Tests: Load-Time and Stress-Displacement Graphs and Photographs of Intact and Broken Test Specimens

DocuSign Envelope ID: AD9AD38E-925E-4B7B-BE60-22C98DD766AE

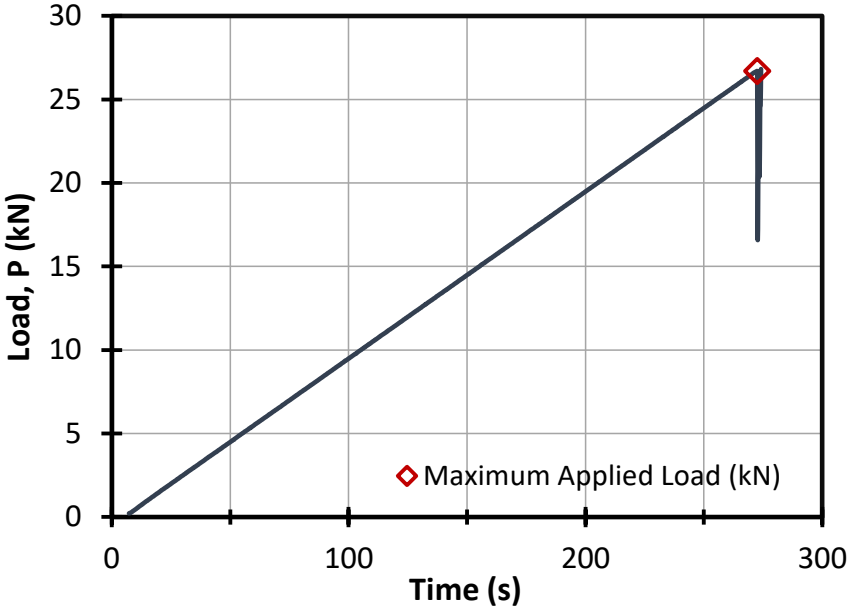
Table C-1: List of indirect tensile (Brazilian) test specimens

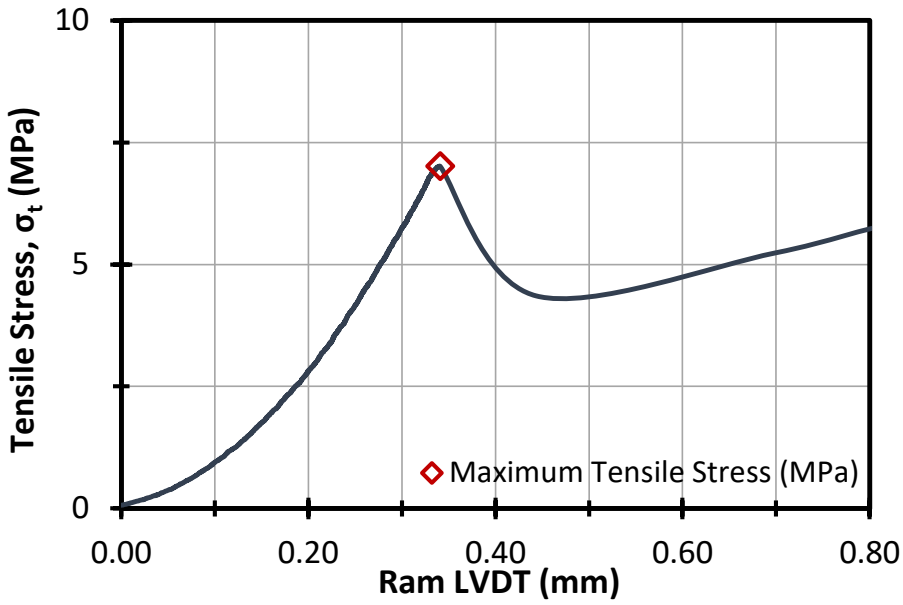
Specimen No.	Depth (m)[1]	Rock Type	Page
IG_BH02_BR001	416.52	Biotite Tonalite	C-2
IG_BH02_BR002	494.59	Biotite Tonalite	C-3
IG_BH02_BR003	582.68	Biotite Tonalite	C-4

[1]Top depth of prepared sub-sample

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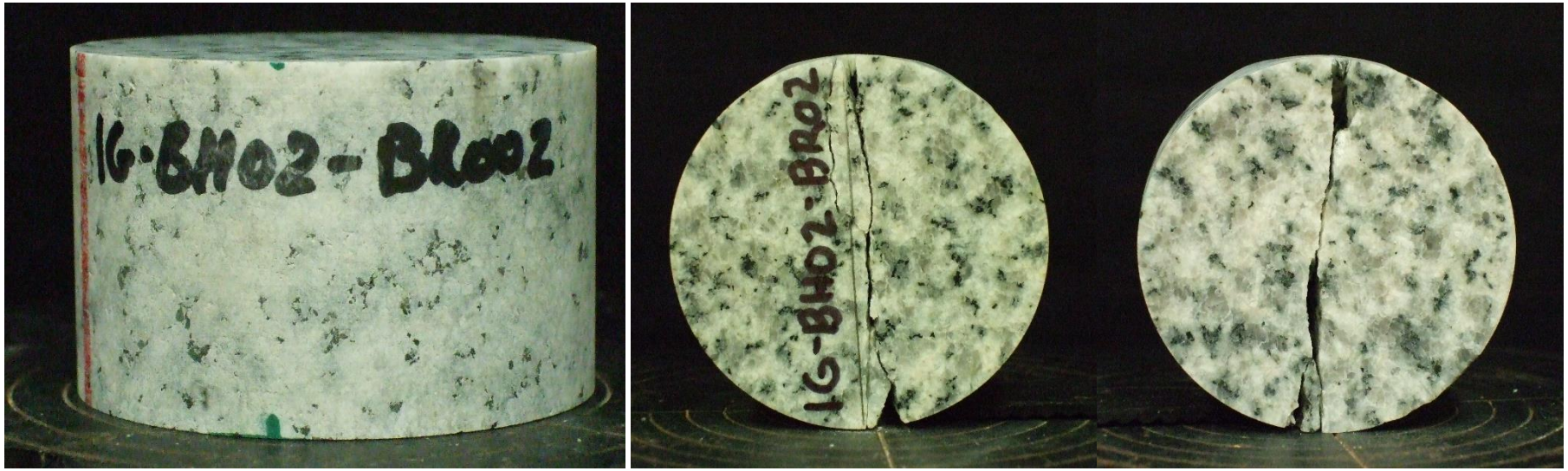


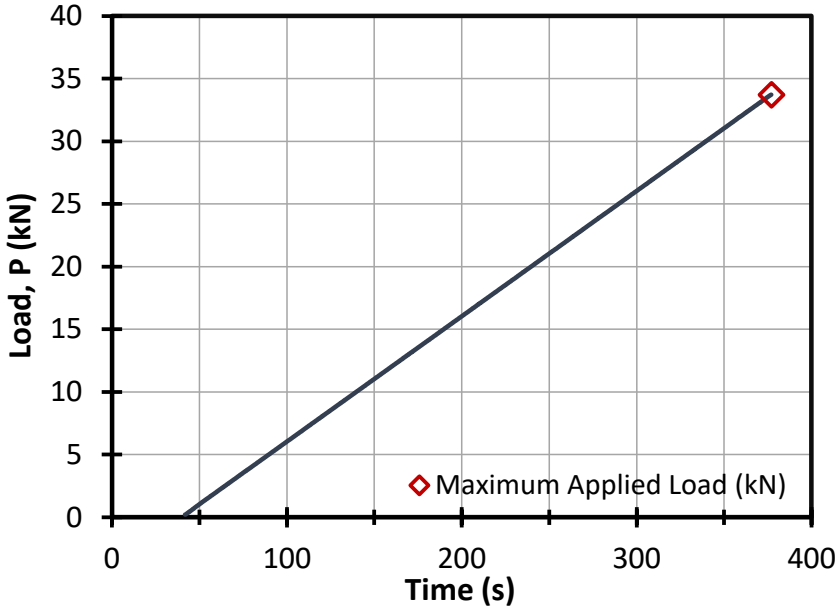


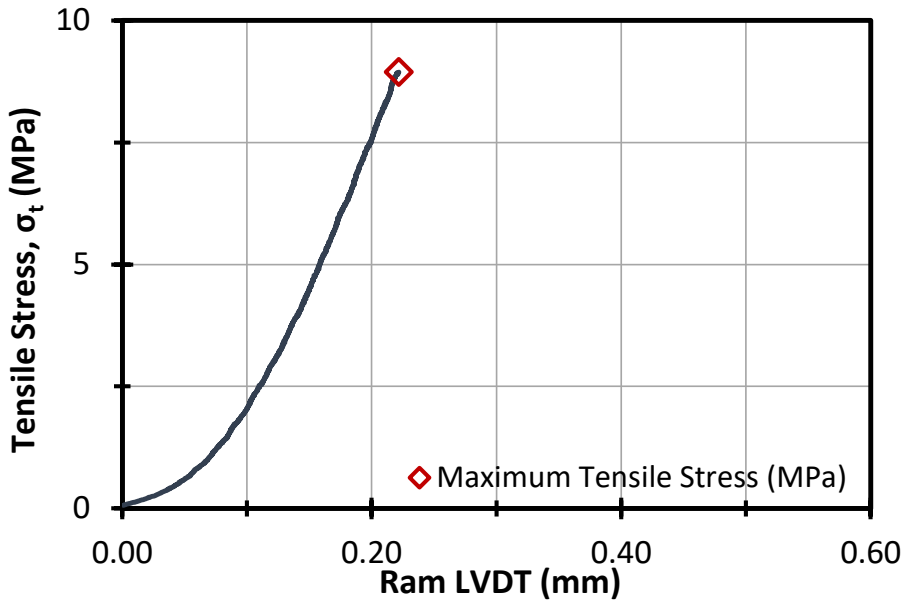


Test Specimen IG_BH02_BR001 – Depth = 416.52 m: Intact and broken specimen photographs; load-time and stress-displacement curves

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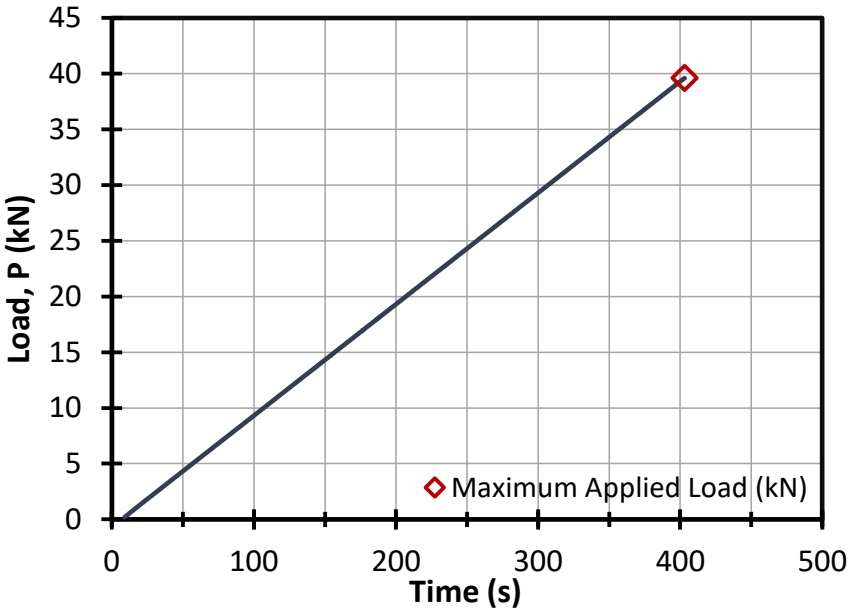


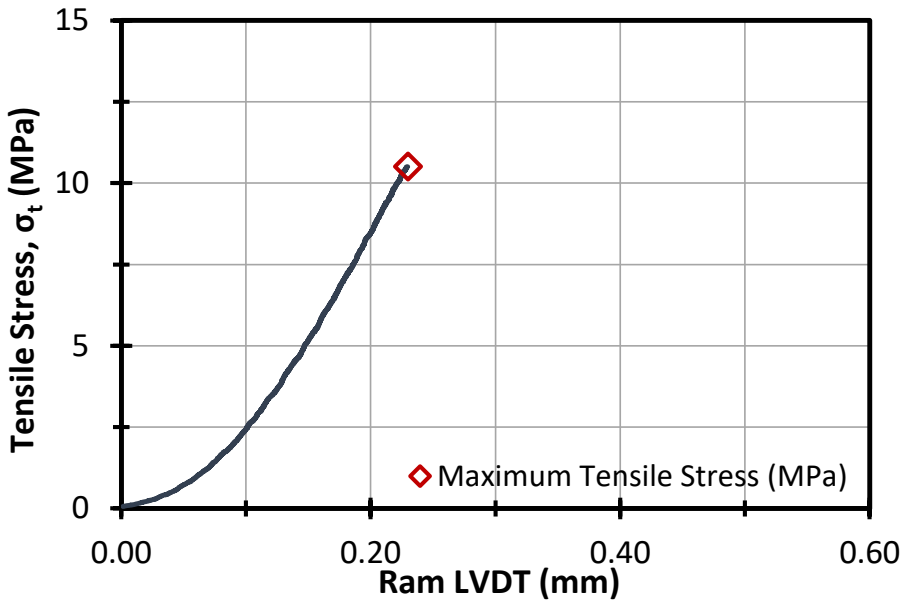


Test Specimen IG_BH02_UC002 – Depth = 494.59 m: Intact and broken specimen photographs; load-time and stress-displacement curves

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Test Specimen IG_BH02_UC003 – Depth = 582.68 m: Intact and broken specimen photographs; load-time and stress-displacement curves

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