Technical Report

Title: ***Laboratory Swell Testing of DGR-2 Core***

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2	June 18, 2010	Minor revisions to address NWMO editorial comments of June 15, 2010. Updating of references.

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1 Introduction

The results described in this Technical Report constitute one component of Intera Engineering Ltd. (2006, 2008a) Geoscientific Site Characterization Plan (GSCP) for the Bruce Deep Geologic Repository (DGR). A potential DGR site is being investigated for disposal of low and intermediate level radioactive waste at the Bruce nuclear site near Tiverton Ontario. The GSCP describes recommended methods and approaches to acquire the necessary geoscientific information to support (1) the development of descriptive geosphere models of the Bruce site and (2) the preparation of an environmental assessment and site preparation and construction license application for submission to the Canadian Nuclear Safety Commission.

Work described in this Technical Report was completed in accordance with Intera Test Plan TP-07-04 – Geomechanical Lab Testing of DGR-1 & DGR-2 Core (Intera Engineering Ltd., 2008b), prepared following the general requirements of the Intera DGR Project Quality Plan (Intera Engineering Ltd., 2007).

K. Y. Lo Inc. was contracted by Intera Engineering Ltd. to perform laboratory swell tests on cores of shale and argillaceous limestone from deep borehole DGR-2 as a part of the Bruce site DGR Project. The goal of conducting this program was to investigate the swelling behaviour of the rock samples to examine whether the swelling characteristics of the rock cores encountered in borehole DGR-2 are consistent with the results of previous tests that have been carried out on similar rocks. These include Queenston Formation shale, Georgian Bay Formation shale, Blue Mountain Formation shale, Cobourg Formation argillaceous limestone and Sherman Fall Formation argillaceous limestone in projects designed and constructed in the past. To allow direct comparison with the previous results, the same testing methodology developed at the University of Western Ontario by Lo et al., (1978) is utilized in this project. For this purpose, the following tests were proposed:

- 6 free swell tests, 3 in fresh water and 3 in synthetic formation water, on Queenston Formation rock samples (red shale & siltstone, 6 samples from approx. 450 m depth);
- 6 free swell tests, 3 in fresh water and 3 in synthetic formation water, on Georgian Bay Formation rock samples (grey shale & siltstone, 6 samples from approx. 550 m depth);
- 6 free swell tests, 3 in fresh water and 3 in synthetic formation water, on Blue Mountain Formation rock samples (grey shale, 6 samples from approx. 600 m depth);
- 6 free swell tests, 3 in fresh water and 3 in synthetic formation water, on Cobourg Formation and Sherman Fall Formation rock samples (argillaceous limestone; 6 samples from approx. 650 m depth).

This Technical Report (TR) summarizes the results obtained from laboratory swell testing conducted on rock core samples of shale and argillaceous limestone collected from borehole DGR-2.

2 Rock Conditions as Received

Borehole DGR-2 was drilled to about 862 m depth from April, 2007 to August, 2007 at the Bruce nuclear site. The core lengths of borehole DGR-2 recovered from depths from 458 m to 702 m were received for laboratory swell testing on June 4, 6, 26, and July 2, 2007.

The rock cores of approximately HX size (~ 76 mm in diameter) were successively received from Intera Engineering Ltd. The summary of received cores is presented in Table 1. All of the core lengths were received in double vacuum-sealed polyethylene and aluminum foil bags. Photos of rock cores received are shown in Appendix A.

The cores from the Queenston Formation were samples of red and grey shale. All Georgian Bay Formation samples were grey shale, but some of them were interbedded with limestone/silty layers. The Blue Mountain Formation cores were dark grey shale, while the cores from the Cobourg and Sherman Fall Formations were argillaceous grey limestone with shale stringers. All core lengths were superficially dried when received.

Table 1 Summary of DGR-2 Core Samples Received

Sample ID	Formation	Sample Description
DGR2-458.46	Queenston	red shale
DGR2-473.41	Queenston	red shale
DGR2-489.25	Queenston	red and grey shale
DGR2-489.32	Queenston	red and grey shale
DGR2-505.15	Queenston	grey shale and argillaceous limestone
DGR2-517.33	Queenston	red and green shale
DGR2-525.41	Georgian Bay	grey shale with siltstone interbeds
DGR2-541.63	Georgian Bay	grey shale with siltstone interbeds
DGR2-546.21	Georgian Bay	greenish grey shale with limestone/siltstone interbeds
DGR2-555.12	Georgian Bay	greenish grey shale with limestone/siltstone interbeds
DGR2-567.61	Georgian Bay	greenish grey shale
DGR2-567.68	Georgian Bay	greenish grey shale
DGR2-632.53	Blue Mountain	dark grey shale
DGR2-632.58	Blue Mountain	dark grey shale
DGR2-645.20	Blue Mountain	dark grey shale
DGR2-645.22	Blue Mountain	dark grey shale
DGR2-645.28	Blue Mountain	dark grey shale
DGR2-645.32	Blue Mountain	dark grey shale
DGR2-649.85	Blue Mountain	dark grey shale
DGR2-649.93	Blue Mountain	dark grey shale
DGR2-650.74	Blue Mountain	dark grey shale
DGR2-664.42	Cobourg	grey mottled argillaceous limestone with shale stringers
DGR2-664.47	Cobourg	grey mottled argillaceous limestone with shale stringers
DGR2-684.85	Cobourg	grey argillaceous limestone
DGR2-684.91	Cobourg	grey argillaceous limestone
DGR2-701.24	Sherman Fall	grey argillaceous limestone with shale stringers
DGR2-701.29	Sherman Fall	grey argillaceous limestone with shale stringers

It was understood that the core pieces as packaged were single, continuous core lengths. However, upon opening, some cores form the Georgian Bay and Blue Mountain formations were observed to have separated into a series of shorter cylindrical pieces or disks, as can be seen on the photos in Appendix A (Figures A3 (e) and (f) and Figures A4 (a) and (d)). The fracture surfaces were smooth planar separations perpendicular to the vertical core axis and parallel to the horizontal bedding planes. The disking process continued during preparation and testing of samples.

The mixture of salts for preparing synthetic formation water was supplied by Intera Engineering Ltd. The resultant chemistry of the prepared formation water is listed in Table 2 and is a Na-Ca-Cl brine.

Table 2 Summary of Synthetic Formation Water Chemistry

Parameter	Concentration (g/L)	Parameter	Concentration (g/L)
Sodium	48	Chloride	150
Calcium	32	Sulphate	0.5
Magnesium	6.0	Total Dissolved Solids	238.6
Potassium	2.1		

3 Testing Program

For the measurement of the swelling properties 6 free swell tests, 3 in fresh water and 3 in formation water, were intended to be performed for Queenston, Georgian Bay, Blue Maintain and Cobourg/Sherman Fall Formations. Difficulties were, however, encountered during sample preparation and testing because the disking described earlier. Ultimately, 11 free swell tests in fresh water and 12 free swell tests in formation water were successfully carried out.

One of the Georgian Bay Formation samples broke during the first measurement. In addition to free swell tests, four semi-confined swell tests were performed on short Blue Mountain Formation shale samples in lieu of free swell tests. The summary of the testing program is included in Tables 3 and 4 for the samples submerged in fresh and formation water, respectively. All swell tests were carried out on vertically-cored specimens and include calcite content testing on each sample. The calcite content was measured on the specimens after swelling tests.

Free swell tests were performed using the method developed by Lo et al., (1978). In this type of test, the rock cores were permitted to strain unrestricted in all directions. The “UWO deformation gauge” shown on Figure 1 was used to measure the dimensions of two horizontal (X and Y) and a vertical (axial) (Z) directions for 100 days. The dial gauge is graduated in 0.0025 mm divisions. During testing, the rock specimens were submerged in water. The diameter-length ratio of the cylindrical sample required is 1 to 1. However, for the Blue Mountain Formation the number of core pieces of sufficient length for free swell testing was unavailable because of disking. Only swelling properties in X and Y directions could be measured on those samples. Because of this limitation, four semi-confined tests were also set up to measure vertical swelling of the Blue Mountain shale samples.

The semi-confined swell test method used was also described in Lo et al., (1978). In this type of test, the rock specimen was submerged in water and the strain changes in only one direction were monitored by a dial gauge reading to 0.0025 mm. A small constant pressure of 3 kPa was applied to the rock sample in the direction of measurement while deformations in perpendicular directions remained unrestricted. A typical setup is shown in Figure 2.

Following the method used by Lo et al., (1978), test data were analysed by plotting strain vs. the logarithm (to the base of 10) of elapsed time. The average slope of such a plot gives an indication of tendency of the rock to expand upon stress relief and was taken as an index of the “swelling potential” of the rock being tested. For some tests, however, the graphs were essentially curvilinear but could be treated as approximately linear over limited ranges of time.

Table 3 Summary of Borehole DGR-2 Samples Tested in Fresh Water

Rock Formation	Depth (m)	Sample #	Sample Description	Type of Test	Swell Test Started	Swell Test Completed	Remarks (swelling potentials measured)
Queenston Formation	458.46	FST-1-W	Red Shale	Free Swell Test	06/06/2007	11/07/2007	horizontal and vertical directions for 35 days then sample broke
	489.25	FST-4-W	Grey Shale	Free Swell Test	07/06/2007	20/09/2007	horizontal and vertical directions for 20 days then sample broke, only in H-directions measured after
	505.15	FST-2-W	Grey Shale	Free Swell Test	06/06/2007	20/09/2007	horizontal and vertical directions
Georgian Bay Formation	525.41	FST-3-W	Grey Shale with Siltstone Interbeds	Free Swell Test	06/06/2007	20/09/2007	horizontal and vertical directions
	555.12	FST-5-W	Greenish Grey Shale with Limestone/Siltstone Interbeds	Free Swell Test	07/06/2007	20/09/2007	horizontal and vertical directions
	567.68	FST-7-W	Greenish Grey Shale	Free Swell Test	07/06/2007	08/06/2007	sample broke after first measurement
Blue Mountain Formation	632.53	FST-10-W	Dark Grey Shale	Free Swell Test	07/06/2007	03/09/2007	short sample; only horizontal directions for 87 days then sample broke
	645.2	FST-16-W	Dark Grey Shale	Free Swell Test	29/06/2007	28/09/2007	short sample; only horizontal directions
	649.85	FST-12-W	Dark Grey Shale	Free Swell Test	07/06/2007	28/09/2007	short sample; only horizontal directions
	645.22	SCST-1-W	Dark Grey Shale	Semi-Confined Swell Test	29/06/2007	08/10/2007	only vertical directions
	650.74	SCST-3-W	Dark Grey Shale	Semi-Confined Swell Test	29/06/2007	08/10/2007	only vertical directions
Cobourg Formation	664.42	FST-18-W	Mottled Argillaceous Grey Limestone with Shale Stringers	Free Swell Test	03/07/2007	12/10/2007	horizontal and vertical directions
	684.85	FST-20-W	Argillaceous Grey Limestone	Free Swell Test	03/07/2007	12/10/2007	horizontal and vertical directions
Sherman Fall Formation	701.24	FST-22-W	Argillaceous Grey Limestone with Shale Stringers	Free Swell Test	03/07/2007	12/10/2007	horizontal and vertical directions

Table 4 Summary of Borehole DGR-2 Samples Tested in Formation Water

Rock Formation	Depth (m)	Sample #	Sample Description	Type of Test	Swell Test Started	Swell Test Completed	Remarks (swelling potentials measured)
Queenston Formation	473.41	FST-1-FW	Red Shale	Free Swell Test	06/06/2007	20/09/2007	horizontal and vertical directions
	489.25	FST-4-FW	Grey Shale	Free Swell Test	07/06/2007	20/09/2007	horizontal and vertical directions
	517.33	FST-2-FW	Red and Grey Shale	Free Swell Test	06/06/2007	20/09/2007	horizontal and vertical directions
Georgian Bay Formation	541.63	FST-3-FW	Grey Shale with Siltstone Interbeds	Free Swell Test	06/06/2007	20/09/2007	horizontal and vertical directions
	546.21	FST-9-FW	Greenish Grey Shale with Limestone/Siltstone Interbeds	Free Swell Test	07/06/2007	20/09/2007	horizontal and vertical directions
	567.61	FST-6-FW	Greenish Grey Shale	Free Swell Test	07/06/2007	20/09/2007	horizontal and vertical directions for 55 days then sample broke, only in H-directions measured after
Blue Mountain Formation	632.58	FST-11-FW	Dark Grey Shale	Free Swell Test	07/06/2007	28/09/2007	short sample; only horizontal directions
	645.22	FST-15-FW	Dark Grey Shale	Free Swell Test	29/06/2007	28/09/2007	short sample; only horizontal directions
	649.93	FST-13-FW	Dark Grey Shale	Free Swell Test	07/06/2007	28/09/2007	horizontal and vertical directions for 16 days then sample broke, only in H-directions measured after
	645.28	SCST-2-FW	Dark Grey Shale	Semi-Confined Swell Test	29/06/2007	08/10/2007	only vertical directions
	645.32	SCST-4-FW	Dark Grey Shale	Semi-Confined Swell Test	29/06/2007	08/10/2007	only vertical directions
Cobourg Formation	664.47	FST-17-FW	Mottled Argillaceous Grey Limestone with Shale Stringers	Free Swell Test	03/07/2007	12/10/2007	horizontal and vertical directions
	684.91	FST-19-FW	Argillaceous Grey Limestone	Free Swell Test	03/07/2007	12/10/2007	horizontal and vertical directions
Sherman Fall Formation	701.29	FST-21-FW	Argillaceous Grey Limestone with Shale Stringers	Free Swell Test	03/07/2007	12/10/2007	horizontal and vertical directions

Figure 1 ”UWO Deformation Gauge” Used to Measure the Dimensions of Two Horizontal and a Vertical Directions in Free Swell Tests

Figure 2 Semi-Confined Swell Test Set Up

The data of the first 10 days of testing was discarded because it might be from the time required for the specimen to reach environmental equilibrium and may be related to humidity and temperature changes in the early stages of expansion. Therefore, in order that results might be compared, values were taken from the log-cycle of time between 10 and 100 days. This is the practice for all swelling tests performed since the introduction of the method. The slope of the best fit line to the data is rounded off to 0.01 % strain per log-cycle of time. The swelling potential, thus determined, serves as a simple parameter for preliminary evaluation of the degree of importance of the rock swelling problem.

4 Results of Laboratory Testing

4.1 Swell Tests in Fresh Water

The results of swell testing on the samples submerged in fresh water are presented in Table 5. Calcite content determined from each specimen after testing is also listed in the table. Calcite contents were determined using the gasometric method on a Chittick apparatus (Dreimanis, 1962). Figures in Appendix B show records for the swelling strain versus logarithm of elapsed time for the free swell and semi-confined tests in fresh water. During testing, two specimens (FST-1-W and FST-10-W) broke and measurements on these samples were terminated. Two specimens (FST-4-W and FST-5-W) disked near the ends causing the vertical gauges to be detached from the main body of specimens. Measurements in the two horizontal directions were continued in these samples.

As shown on the figures in Appendix B, two Queenston Formation shale samples (FST-1-W and FST 4-W) with calcite content of 7.1% and 9.4%, respectively, demonstrated some swelling behaviour, while the third sample FST-2-W did not swell probably due to high calcite content (30.3%). The horizontal swelling potential (HSP) and vertical swelling potential (VSP) of these samples, defined as the rate of swelling in percent strain per log cycle of time between 10 and 100 days, generally lie between 0 and 0.19 %/log cycle and between 0 and 0.18 %/log cycle, respectively.

The Georgian Bay Formation sample FST-5-W with the calcite content of 5.5% showed the significant vertical swelling potential of 0.7 %/log cycle and negligible horizontal swelling, while the other sample FST-3-W with the calcite content of 21.9 % did not swell in the vertical direction and swelled slightly in the horizontal direction (HSP=0.02 %/log cycle).

Two short shale samples from the Blue Mountain Formation (FST-10-W and FST-12-W) did not swell in the horizontal directions, while the sample FST-16-W swelled somewhat (HSP=0.06 %/Log cycle). The results of semi-confined tests on two Blue Mountain Formation shale samples (SCST-1-W and SCST-3-W) indicated the vertical swelling potential between 0.25 and 0.35 %/log cycle in these samples.

The samples from the Cobourg and Sherman Fall Formations did not swell. It can be observed from the results shown in Appendix B that the horizontal swelling potentials of the Queenston, Georgian Bay and Blue Mountain Formations are isotropic.

4.2 Swell Tests in Formation Water

The results of swell testing on the samples submerged in synthetic formation water are presented in Table 6. Calcite content determined from each specimen after testing is also listed in the table. Records for the swelling strain versus logarithm of elapsed time for the free swell and semi-confined tests in formation water are shown in Appendix C. During testing, two specimens (FST-6-FW and FST-13-FW) from this group disked near the ends causing the vertical gauges to be detached from the main body of specimens, so only swelling in the horizontal directions were monitored subsequently.

Table 5 Summary of Results of Swell Tests on Rock Samples From Borehole DGR-2 Submerged in Fresh Water

Rock Formation	Type of Test	Sample #	Depth (m)	Diameter (mm)	Height (mm)	Applied Pressure (MPa)	Calcite Content (%)	Swelling Potential Vertical (%/logcycle)	Swelling Potential Horizontal (%/logcycle)	Remarks (swelling potentials measured)
Queenston Formation	Free Swell Test	FST-1-W	458.46	75.69	75.37	0	7.1	0	0.12	horizontal and vertical directions for 35 days then sample broke
	Free Swell Test	FST-4-W	489.25	75.89	71.3	0	9.4	0.18	0.19	horizontal and vertical directions for 20 days then sample broke, only in H-directions measured after
	Free Swell Test	FST-2-W	505.15	75.85	67.42	0	30.3	0	0	horizontal and vertical directions
Georgian Bay Formation	Free Swell Test	FST-3-W	525.41	75.81	62.14	0	21.9	0	0.02	horizontal and vertical directions
	Free Swell Test	FST-5-W	555.12	74.69	73.77	0	5.5	0.7	0	horizontal and vertical directions for 75 days then sample broke, only in H-directions measured after
	Free Swell Test	FST-7-W	567.68	75.94	71.2	0	6.5	–	–	
Blue Mountain Formation	Free Swell Test	FST-10-W	632.53	75.97	N/A	0	7.7	–	0	short sample; only horizontal directions for 87 days then sample broke
	Free Swell Test	FST-16-W	645.2	76.09	N/A	0	5.8	–	0.06	short sample; only horizontal directions
	Free Swell Test	FST-12-W	649.85	75.98	N/A	0	8.3	–	0	short sample; only horizontal directions
	Semi-Confined Swell Test	SCST-1-W	645.22	76.07	26.6	0.003	7.1	0.35	–	only vertical directions
	Semi-Confined Swell Test	SCST-3-W	650.74	75.6	41.31	0.003	5.5	0.25	–	only vertical directions
Cobourg Formation	Free Swell Test	FST-18-W	664.42	75.79	71.03	0	84.2	0	0	horizontal and vertical directions
	Free Swell Test	FST-20-W	684.85	75.48	71.04	0	73.9	0	0	horizontal and vertical directions
Sherman Fall Formation	Free Swell Test	FST-22-W	701.24	75.56	68.25	0	76.9	0	0	horizontal and vertical directions

Table 6 Summary of Results of Swell Tests on Rock Samples From Borehole DGR-2 Submerged in Formation Water

Rock Formation	Type of Test	Sample #	Depth (m)	Diameter (mm)	Height (mm)	Applied Pressure (MPa)	Calcite Content (%)	Swelling Potential Vertical (%/logcycle)	Swelling Potential Horizontal (%/logcycle)	Remarks (swelling potentials measured)
Queenston Formation	Free Swell Test	FST-1-FW	473.41	75.83	71.18	0	29.9	0	0	horizontal and vertical directions
	Free Swell Test	FST-4-FW	489.25	75.84	73.59	0	23	0	0	horizontal and vertical directions
	Free Swell Test	FST-2-FW	517.33	75.91	50.49	0	23.1	0	0	horizontal and vertical directions
Georgian Bay Formation	Free Swell Test	FST-3-FW	541.63	75.51	73.09	0	3.3	0	0	horizontal and vertical directions
	Free Swell Test	FST-9-FW	546.21	75.85	77.63	0	57.7	0	0	horizontal and vertical directions
	Free Swell Test	FST-6-FW	567.61	75.92	70.92	0	16.2	0	0	horizontal and vertical directions for 55 days then sample broke, only in H-directions measured after
Blue Mountain Formation	Free Swell Test	FST-11-FW	632.58	75.93	N/A	0	6.2		0	short sample; only horizontal directions
	Free Swell Test	FST-15-FW	645.22	76.02	N/A	0	5.7	–	0	short sample; only horizontal directions
	Free Swell Test	FST-13-FW	649.93	75.38	56.99	0	11.7	–	0	horizontal and vertical directions for 16 days then sample broke, only in H-directions measured after
	Semi-Confined Swell Test	SCST-2-FW	645.28	76.12	37.62	0.003	7.5	0.3	–	only vertical directions
	Semi-Confined Swell Test	SCST-4-FW	645.32	76.05	36.39	0.003	5.3	0.3	–	only vertical directions
Cobourg Formation	Free Swell Test	FST-17-FW	664.47	75.73	72.3	0	90	0	0	horizontal and vertical directions
	Free Swell Test	FST-19-FW	684.91	75.52	70.66	0	77.8	0	0	horizontal and vertical directions
Sherman Fall Formation	Free Swell Test	FST-21-FW	701.29	75.4	70.94	0	87.7	0	0	horizontal and vertical directions

As shown on the figures in Appendix C, no samples submerged in formation water swelled, and some samples exhibited contraction. For these tests, it is also considered to be non-swelling. Only the two samples of Blue Mountain Formation shale demonstrated the vertical swelling potential of 0.3 %/log cycle in semi-confined tests.

5 Discussion of Test Results

Shaly formations in Ontario constitute the main engineering materials in which underground structures are often constructed. It is well recognized that long-term, time-dependent deformation of these shales cause major problem in the design and construction of these structures (Lo et al., 1978; Lo, 1986; Lo and Lee, 1990). In the past, Lo and his coworkers (Lo et al., 1978; Lo, 1986; Lee, 1988; Huang, 1993) performed comprehensive experimental studies on shaly rocks from Southern Ontario to characterize their swelling behaviour. The test apparatus and the methods of measurement were originally developed at the University of Western Ontario by Lo et al., (1978).

A summary of swell tests results of the Queenston, Georgian Bay and Blue Mountain shale formations, and the Cobourg and Sherman Fall argillaceous limestone formations from Ontario submerged in fresh water from different projects and rock formations studies is presented in Table 7. The testing methodology developed by Lo et al., (1978) was utilized in all of the projects listed in Table 7.

Table 7 shows that all three shale formations exhibit swelling behaviour in free swell testing. The Queenston Formation shale in previous studies on samples at shallower depth exhibited the swelling potential in horizontal directions in the range of 0 to 0.34 %/log cycle and the vertical swelling potential between 0.02 and 0.54 %/log cycle. The swelling potentials of the Queenston samples which are taken at greater depths are lower in the present investigation than previous studies.

The Georgian Bay Formation shale from previous studies showed that the horizontal swelling potential ranges from 0 to 0.34 %/log cycle, while vertical swelling potential ranges from 0.2 to 1.4 %/log cycle. In the present study, the swelling potentials of the Georgian Bay samples are generally lower than reported in previous studies.

The range of the horizontal swelling potential measured in the Blue Mountain Formation shale from previous studies was around 0.15 %/log cycle, while the vertical swelling potential was between 0.9 and 1.05 %/log cycle. The swelling potentials of Blue Mountain Formation shale in this study are generally lower than reported in previous studies.

In the tests of all specimens in synthetic formation water from the shale formations, the samples exhibited no swelling or some contractions. The results are consistent with the findings by Lo and Lee (1990) on the effects of ambient fluids on swelling of Queenston Formation shale.

Table 7 also includes free swell tests results of the Cobourg and Sherman Fall Formation argillaceous limestones from the present site and from other locations in Ontario. These rock formations in the previous studies on samples at shallower depth exhibited the swelling potential in horizontal directions in the range of 0 to 0.11 %/log cycle and the vertical swelling potential between 0.03 and 0.25 %/log cycle. The samples of Cobourg and Sherman Fall Formation argillaceous limestones in the present study did not swell.

Table 7 Summary of Swell Tests Results of Shale Formations Submerged in Fresh Water From Different Projects and Studies

Shale Formation	Project or Location	Year of Investigation	Depth (m)	Calcite Content (%)	Swelling Potential (% log cycle)		Source of Test Results
					Vertical	Horizontal	
Queenston	Bruce Site DGR	2007	458.5-505.2	7.1-30.3	0-0.18	0-0.19	Present Study
	SABNGS No.3	1984	79.4-121.6	2.1-7.8	-	0.27-0.33	Lee (1988)
	SABNGS No.3	1985 -1987	95.6-114.3	3.5-8.5	0.37-0.54	0.22-0.34	Lo and Lee (1990)
	Hamilton	1987	11.6-25.4	13.1-27.8	0.02-0.26	0-0.05	Lee (1988)
Georgian Bay	Bruce Site DGR	2007	525.4-567.7	5.5-21.9	0-0.7	0-0.02	Present Study
	Scotia Plaza	1984	11.5-27.9	1.8-20.5	-	0.02-0.24	Trow and Lo (1988)
	Sky Dome	1984	11.3-34.5	2.3-5.1	0.23-0.62	0.08-0.26	Lo et al. (1987)
	Lakeview Deep hole	1986	14-140	1.8-7.6	0.52-1.4	0.1-0.34	Lee (1988)
	John St. Tunnel	1987	13.5-17.9	1.5-2.9	0.2-0.32	0-0.07	Lee (1988)
Blue Mountain	Bruce Site DGR	2007	632.5-650.7	5.5-8.3	0.25-0.35	0-0.06	Present Study
	Lakeview Deep hole	1986	177	3.6-18.5	0.9-1.05	0.15-0.16	Lee (1988)
Cobourg & Sherman Fall (Lindsay)	Bruce Site DGR	2007	664.4-701.2	73.9-84.2	0	0	Present Study
	Darlington GS	1983	1.1-7.5	-	0.03-0.11	0-0.07	Report to Ontario Hydro
	Lakeview Deep hole	1986	189.2-230.4	-	0.08-0.25	0-0.11	Report to Ontario Hydro

6 Conclusions

A preliminary investigation on the swelling behaviour of rock samples from deep borehole DGR-2 has been performed as a part of the Bruce Site Deep Geologic Repository (DGR) Project. The main objective of the laboratory swell testing was to examine whether the swelling characteristics of the rock cores encountered in borehole DGR-2 are consistent with the results of previous tests that had been carried out on the Queenston Formation shale, Georgian Bay Formation shale, Blue Mountain Formation shale, Cobourg Formation argillaceous limestone and Sherman Fall Formation argillaceous limestone. Based on the results of this test program, the following conclusions are made:

(a) Queenston, Georgian Bay and Blue Mountain shales at the Bruce site possess lower swelling potentials in the horizontal and vertical directions when submerged in fresh water compared to samples of the same formation form shallower depths at other locations in Ontario. The horizontal swelling potentials of these formations are isotropic.

(b) Queenston, Georgian Bay and Blue Mountain shales at the Bruce site do not swell in reconstituted formation water.

(c) Cobourg and Sherman Fall argillaceous limestone at the Bruce site do not swell either in fresh or formation water.

7 Data Quality and Use

Data on swelling properties of DGR-2 shale and argillaceous limestone core described in this Technical Report are based on testing conducted in accordance with established and well-defined test procedures of Lo et al., (1978).

The results presented in this Technical Report are suitable for assessing the swelling properties of shale and argillaceous limestone bedrock formations intersected by DGR-2, and the development of descriptive geomechanical models of the Bruce DGR site.

8 References

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APPENDIX A

Photos of Cores Received

A1. CORES AS RECEIVED

Figure A1. Cores Received in Double Vacuum-sealed Polyethylene and Aluminum Foil Bags

A2. QUEENSTON FORMATION

Figure A2 (a). Queenston Formation – Sample DGR2-458.46 (Received on June 04, 2007)

Figure A2 (b). Queenston Formation – Sample DGR2-473.41 (Received on June 04, 2007)

Figure A2 (c). Queenston Formation – Sample DGR2-489.29 (Received on June 06, 2007)

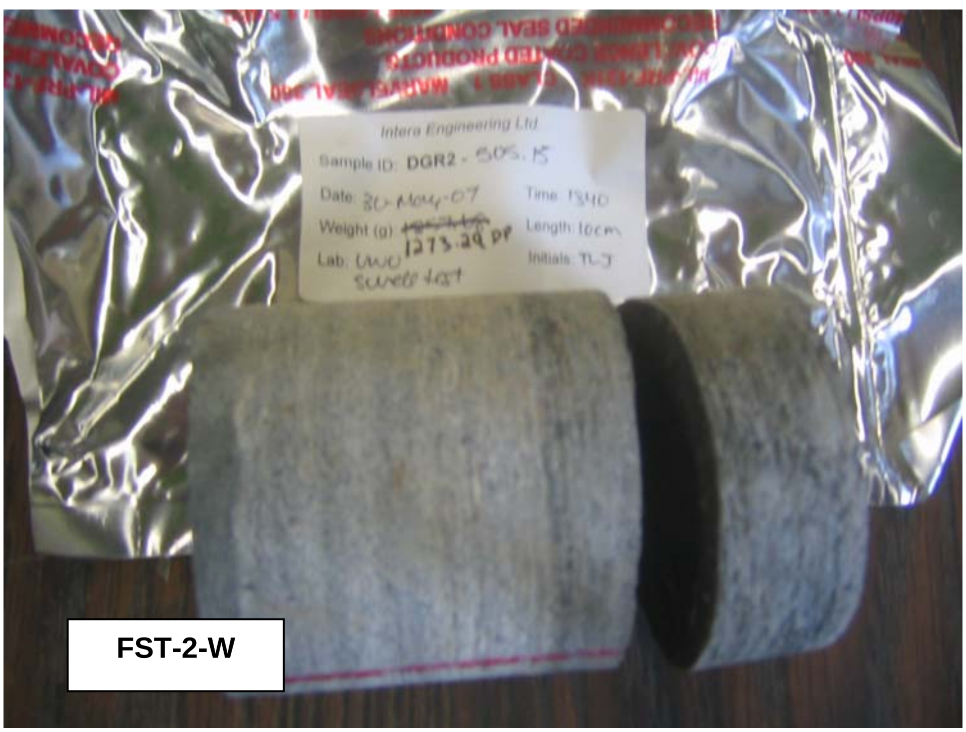


Figure A2 (d). Queenston Formation – Sample DGR2-505-15 (Received on June 04, 2007)

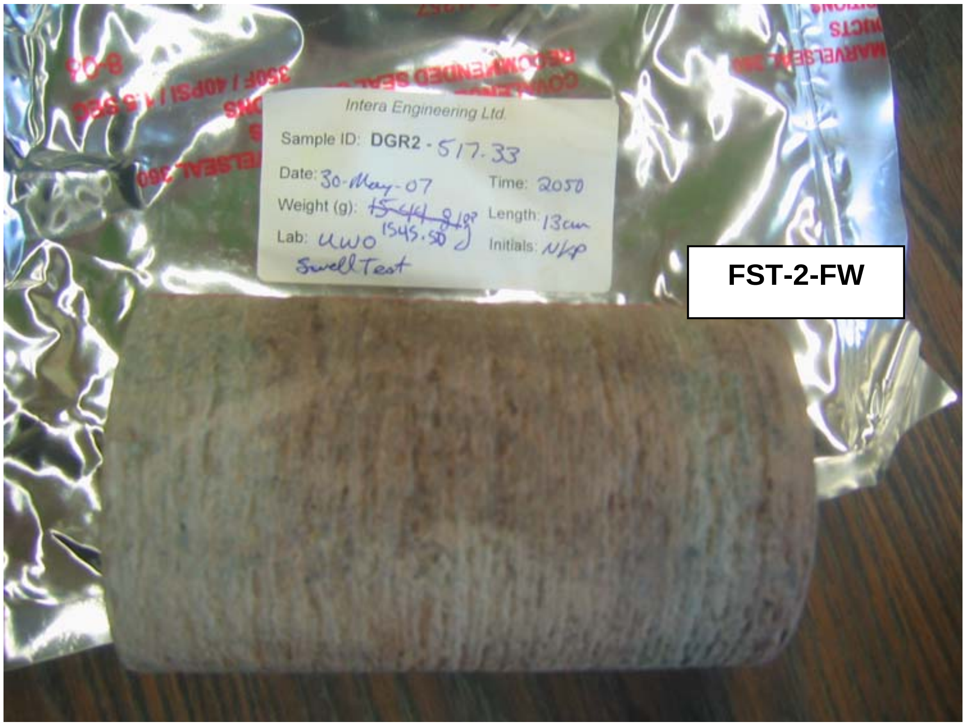


Figure A2 (e). Queenston Formation – Sample DGR2-517.33 (Received on June 04, 2007)

A3. GEORGIAN BAY FORMATION

Figure A3 (a). Georgian Bay Formation – Sample DGR2-525.41 (Received on June 04, 2007)

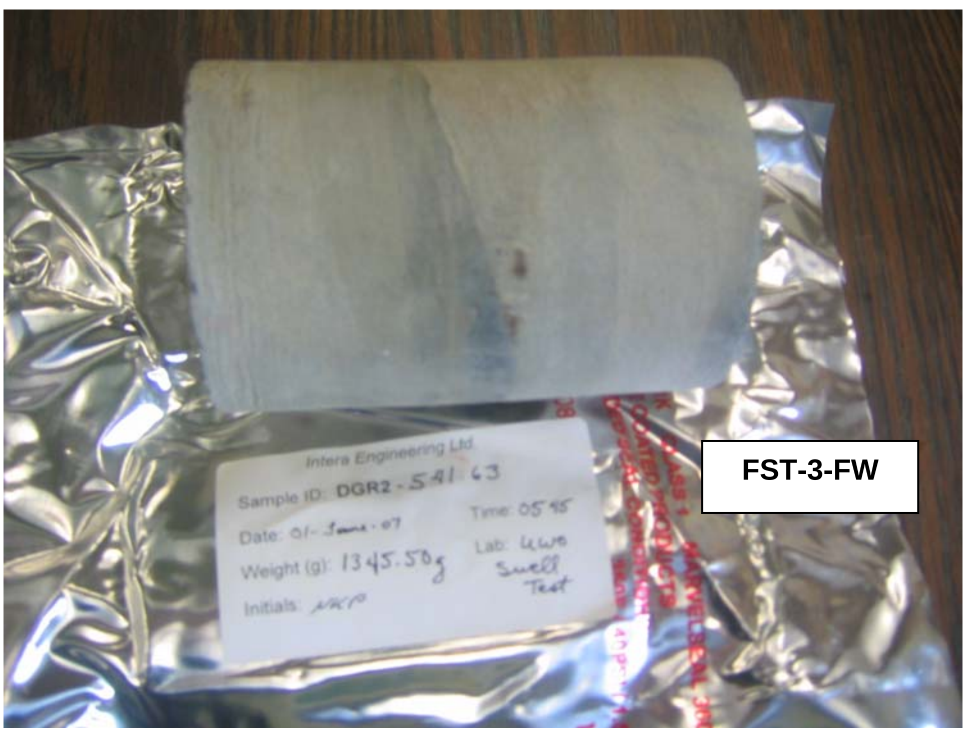


Figure A3 (b). Georgian Bay Formation – Sample DGR2-541.63 (Received June 04, 2007)

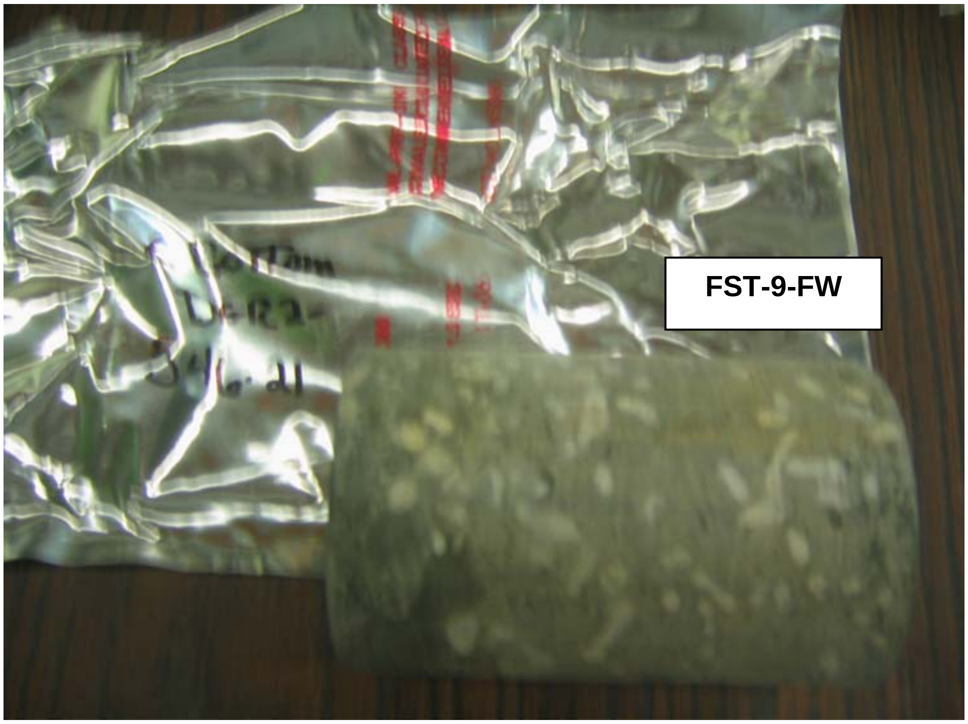


Figure A3 (c). Georgian Bay Formation – Sample DGR2-546.21 (Received on June 06, 2007)

Figure A3 (d). Georgian Bay Formation – Sample DGR2-555.12 (Received June 06, 2007)

Figure A3 (e). Georgian Bay Formation – Sample DGR2-567.65 (Received on June 06, 2007)

Figure A3 (f). Georgian Bay Formation – Sample DGR2-594.47 (Received on June 06, 2007)

A4. BLUE MOUNTAIN FORMATIONS

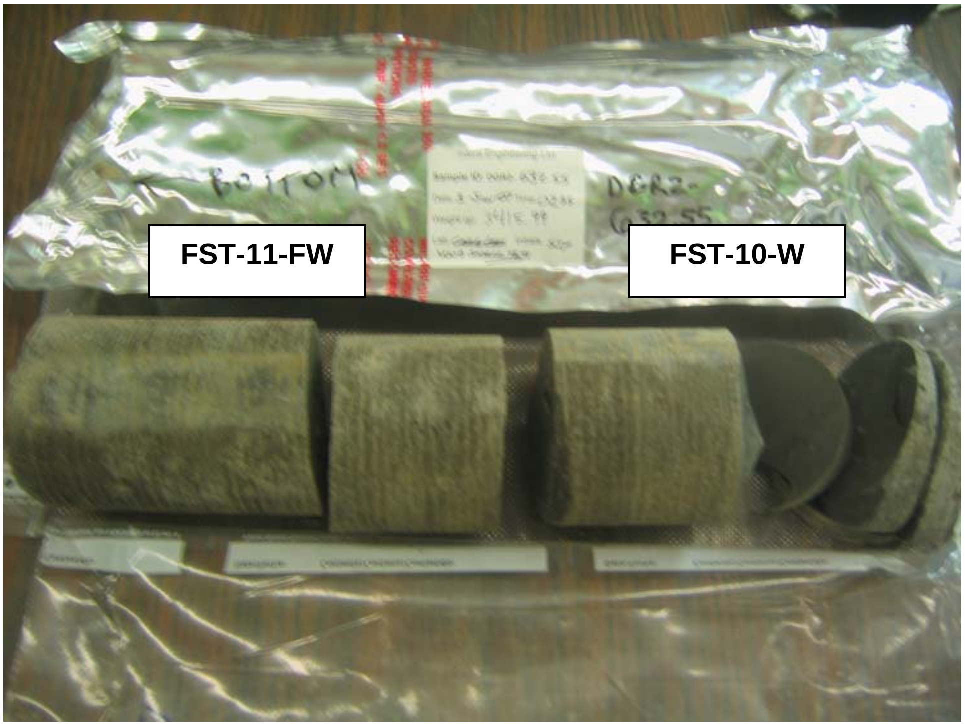


Figure A4 (a). Blue Mountain Formation – Sample DGR2-632-55 (Received June 06, 2007)

Figure A4 (b). Blue Mountain Formation – Sample DGR2-645.22 (Received on June 26, 2007); Sample broken designated for Semi-confined swell tests

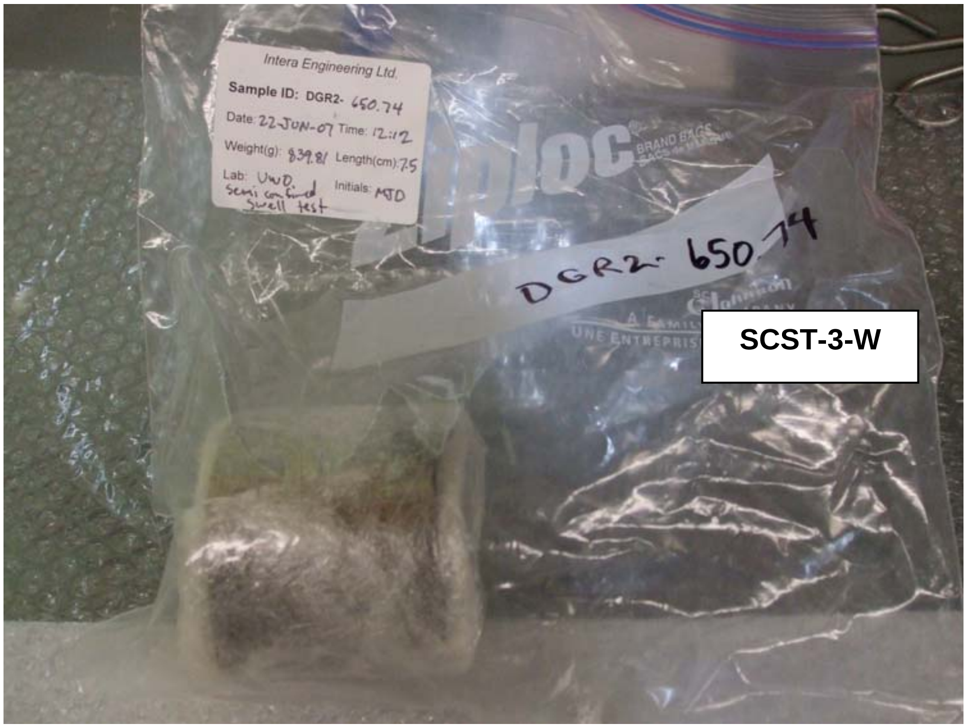


Figure A4 (c). Blue Mountain Formation – Sample DGR2-650.74 (Received on June 26, 2007); Sample broken designated for Semi-confined swell tests

Figure A4 (d). Blue Mountain Formation – Sample DGR2-649.90 (Received on June 06, 2007)

A5. COBOURG FORMATION

Figure A5 (a). Cobourg Formation – Sample DGR2-664.45 (Received on July 02, 2007)

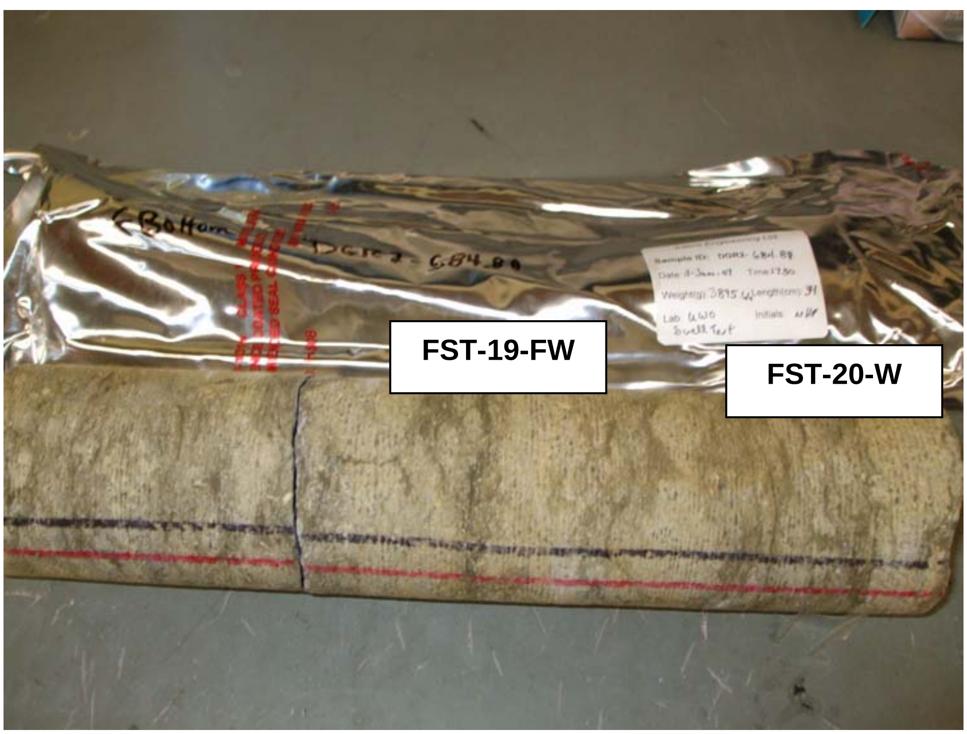


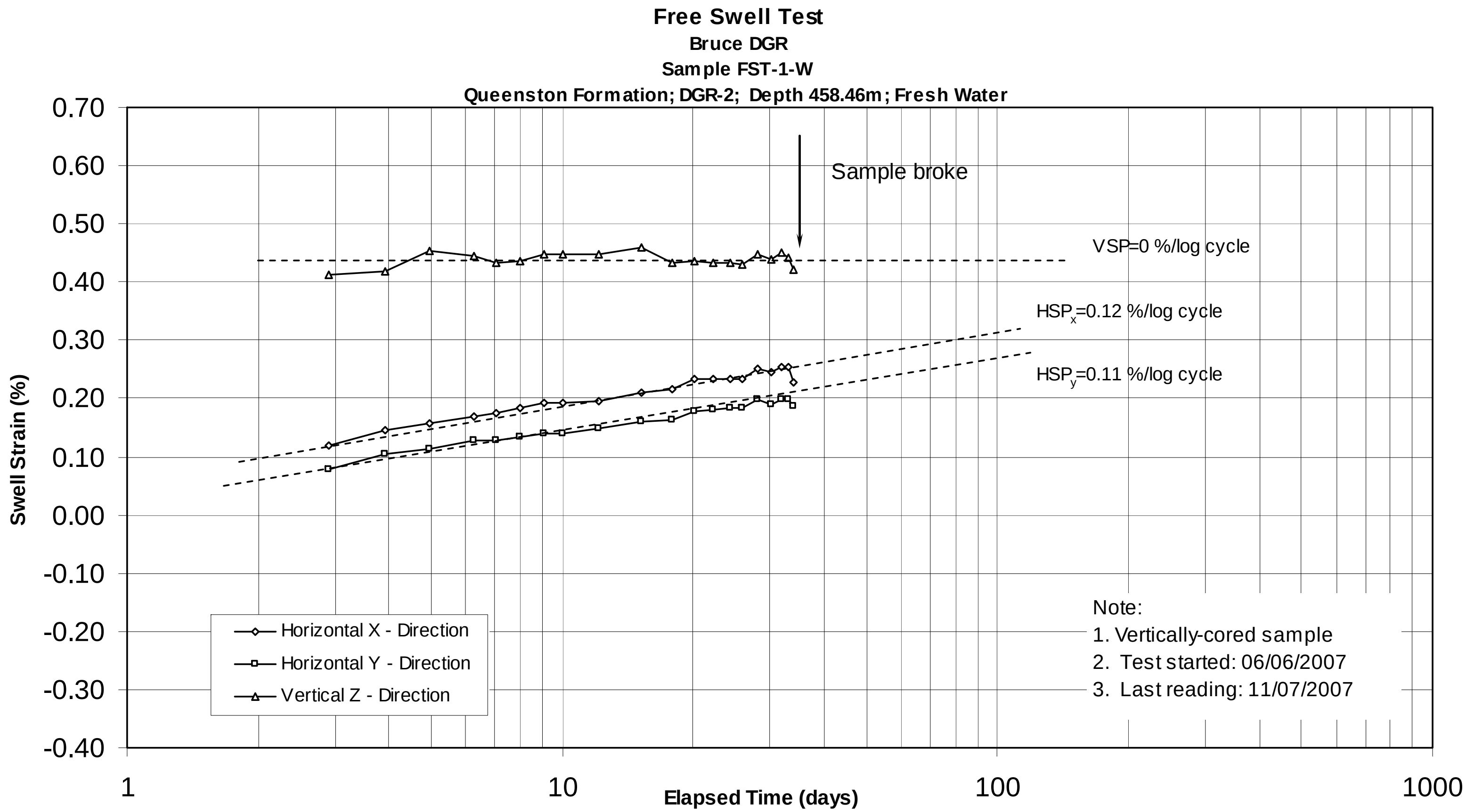
Figure A5 (b). Cobourg Formation – Sample DGR2-684.80 (Received on July 02, 2007)

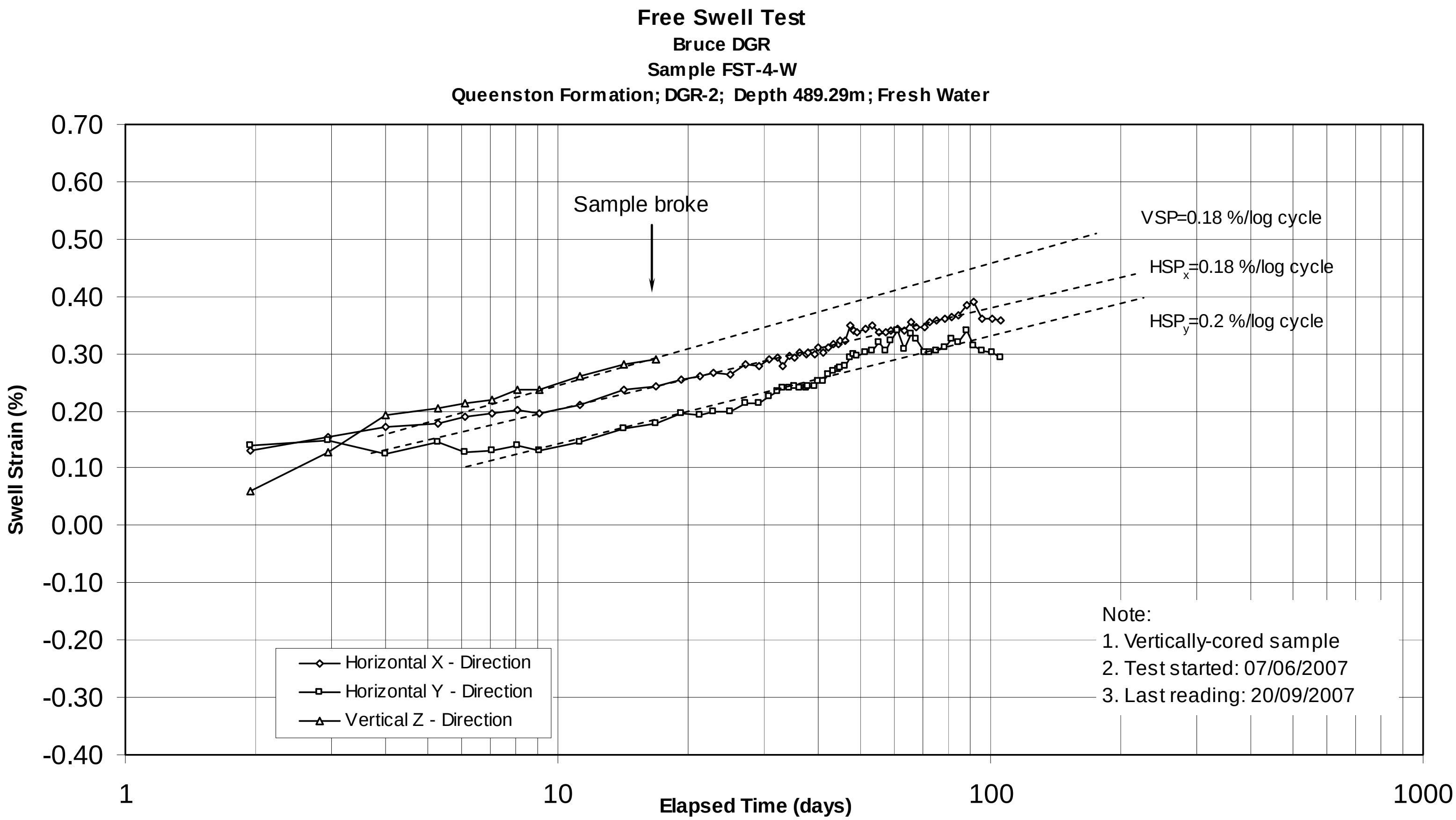
A6. SHERMAN FALL FORMATION

Figure A6 (a). Sherman Fall Formation – Sample DGR2 – 701.27 (Received on July 02, 2007)

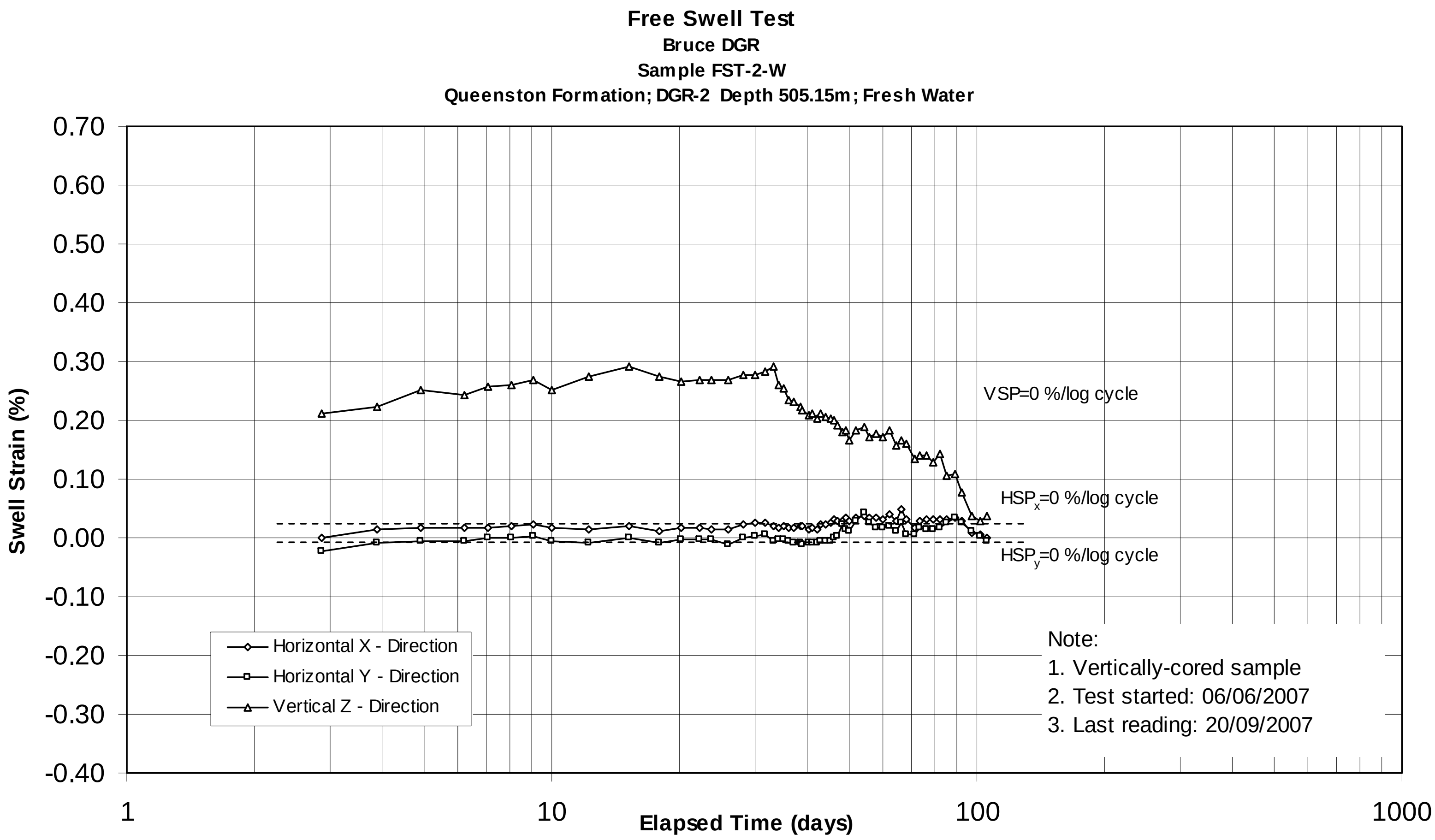
APPENDIX B

Swelling Strain vs Logarithm of Elapsed Time for Free Swell and Semi-confined Tests in Fresh Water

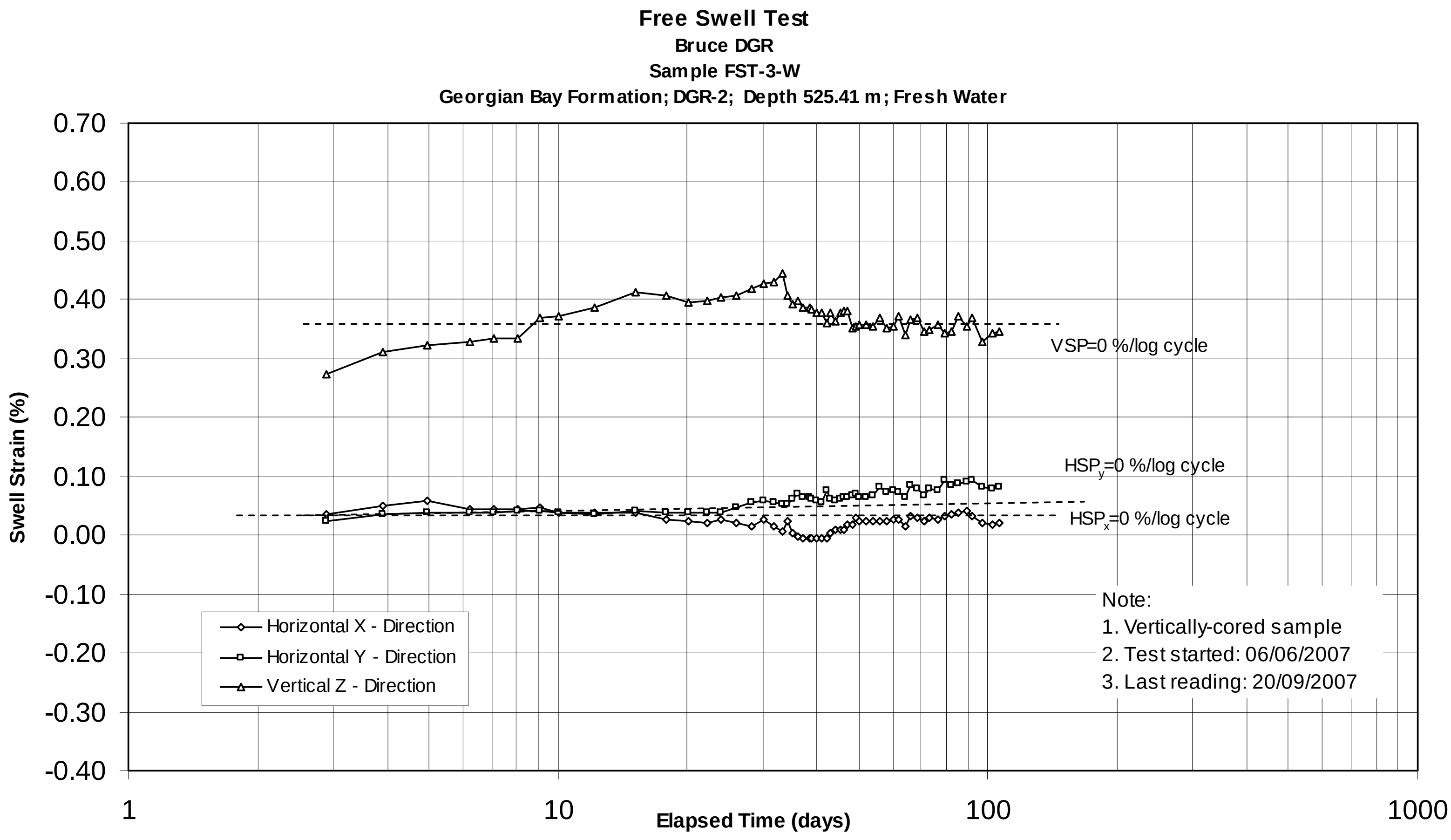

Free Swell Test
Bruce DGR
Sample FST-1-W
Queenston Formation; DGR-2; Depth 458.46m; Fresh Water
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
Swell Strain (%)
1
10
100
1000
Elapsed Time (days)
Sample broke
VSP=0 %/log cycle
HSPx=0.12 %/log cycle
HSPy=0.11 %/log cycle
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
Note:
1. Vertically-cored sample
2. Test started: 06/06/2007
3. Last reading: 11/07/2007



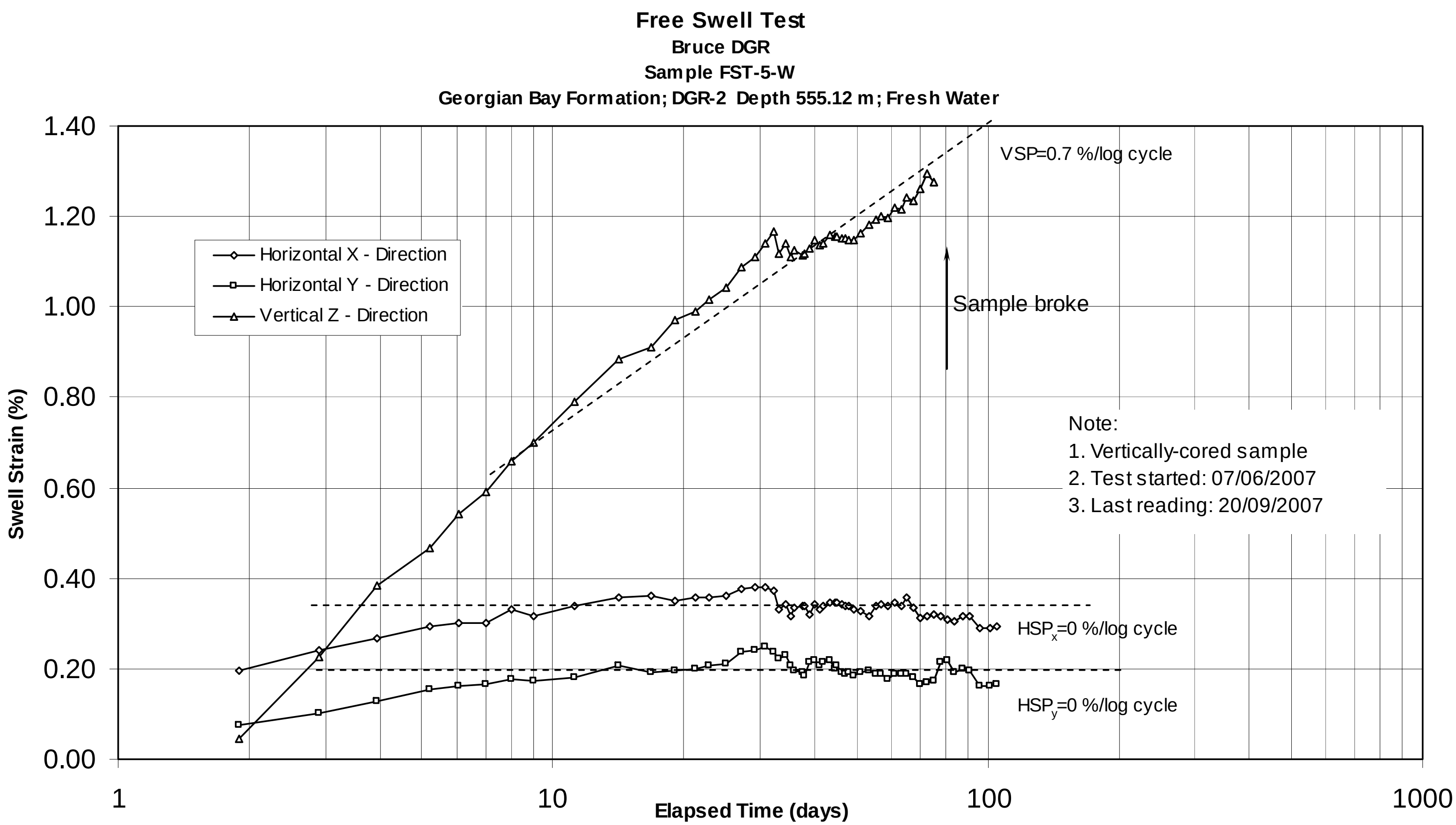
Free Swell Test
Bruce DGR
Sample FST-4-W
Queenston Formation; DGR-2; Depth 489.29m; Fresh Water
Sample broke
VSP=0.18 %/log cycle
HSPx=0.18 %/log cycle
HSPy=0.2 %/log cycle
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Elapsed Time (days)
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 20/09/2007



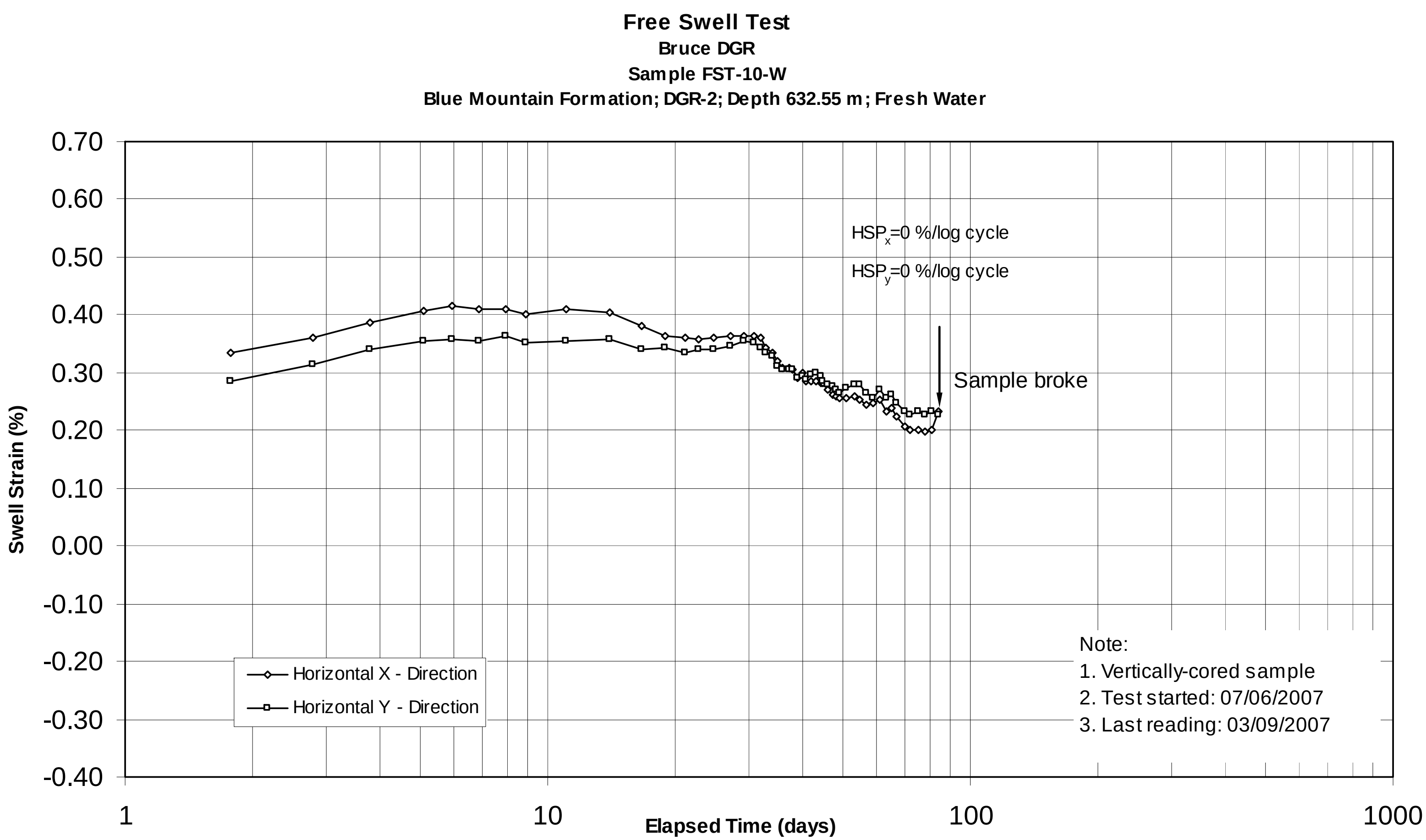
Free Swell Test
Bruce DGR
Sample FST-2-W
Queenston Formation; DGR-2 Depth 505.15m; Fresh Water
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Elapsed Time (days)
VSP=0 %/log cycle
HSPx=0 %/log cycle
HSPy=0 %/log cycle
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
Note:
1. Vertically-cored sample
2. Test started: 06/06/2007
3. Last reading: 20/09/2007



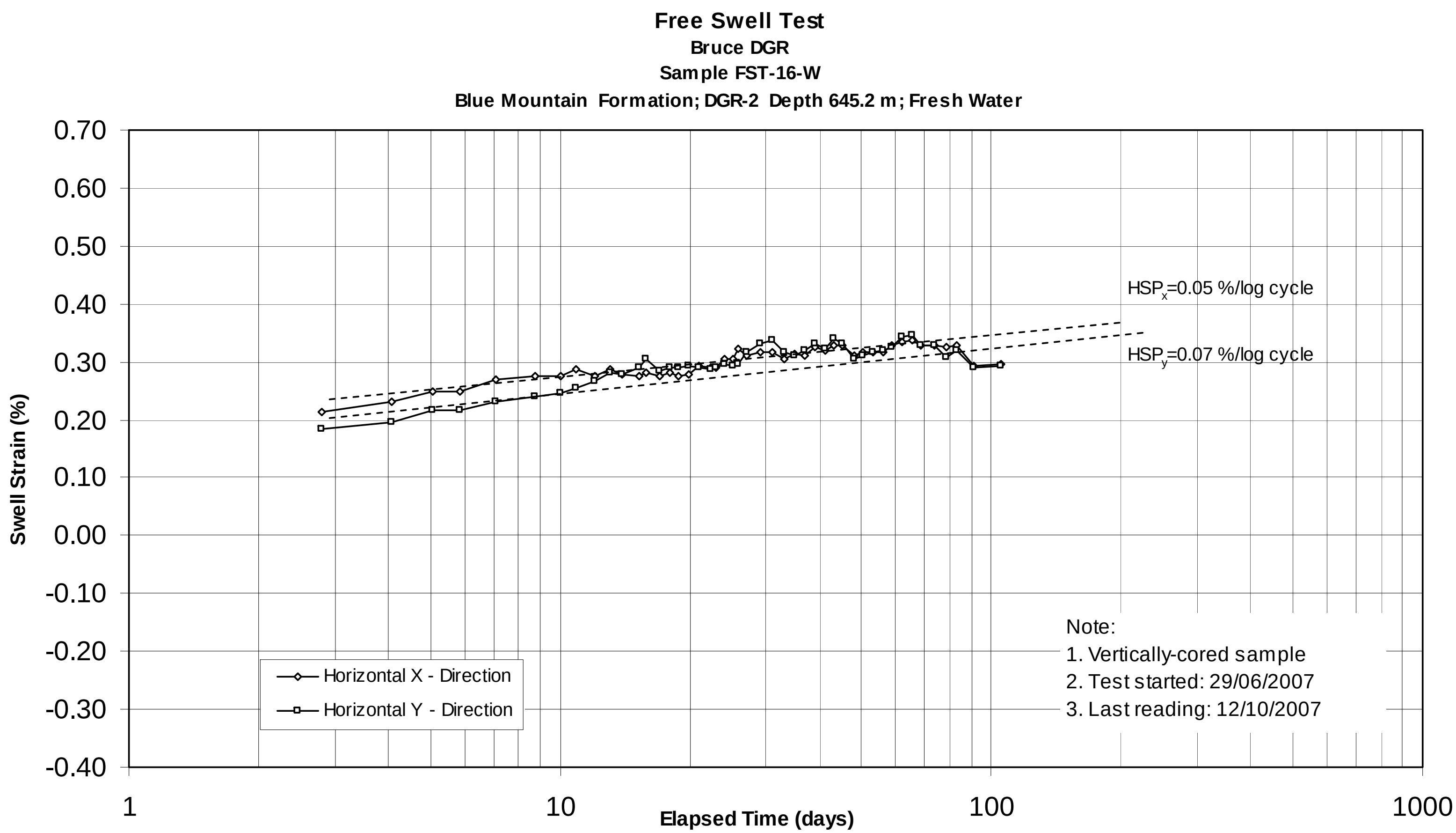
Free Swell Test
Bruce DGR
Sample FST-3-W
Georgian Bay Formation; DGR-2; Depth 525.41 m; Fresh Water
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Elapsed Time (days)
VSP=0 %/log cycle
HSPy=0 %/log cycle
HSPx=0 %/log cycle
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
Note:
1. Vertically-cored sample
2. Test started: 06/06/2007
3. Last reading: 20/09/2007



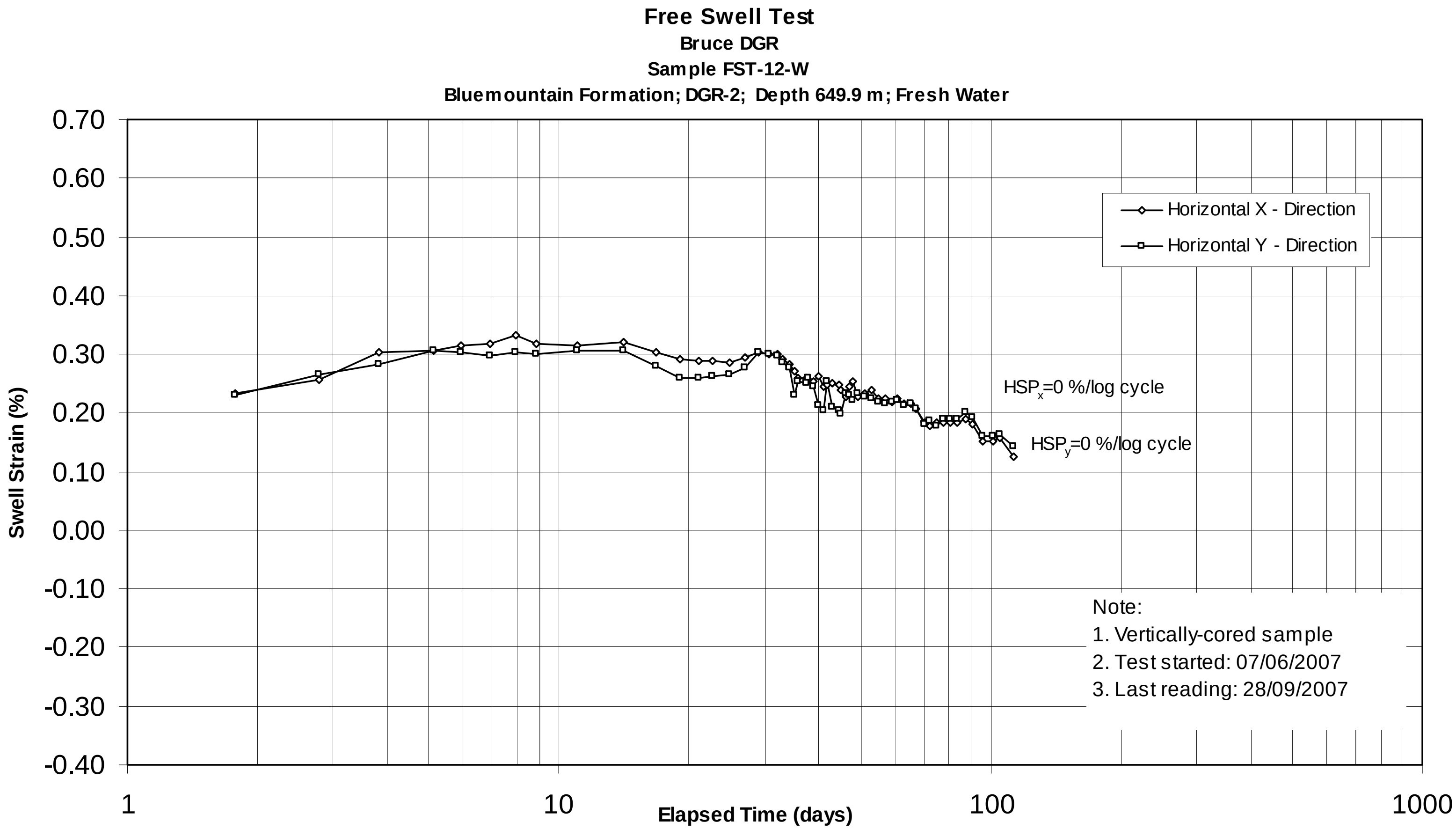
Free Swell Test
Bruce DGR
Sample FST-5-W
Georgian Bay Formation; DGR-2 Depth 555.12 m; Fresh Water
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
VSP=0.7 %/log cycle
Sample broke
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 20/09/2007
HSPx=0 %/log cycle
HSPy=0 %/log cycle
Swell Strain (%)
Elapsed Time (days)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
10
100
1000

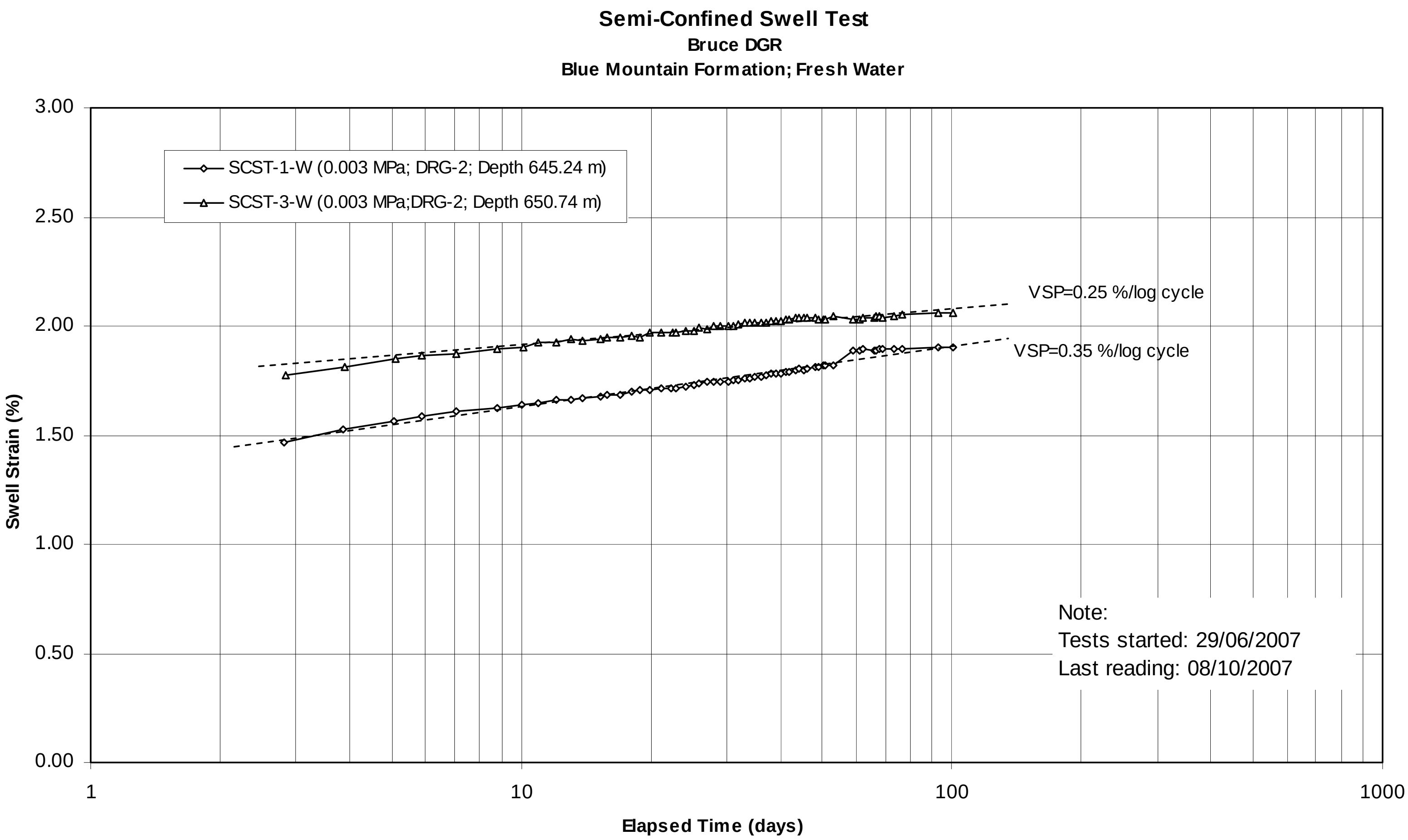


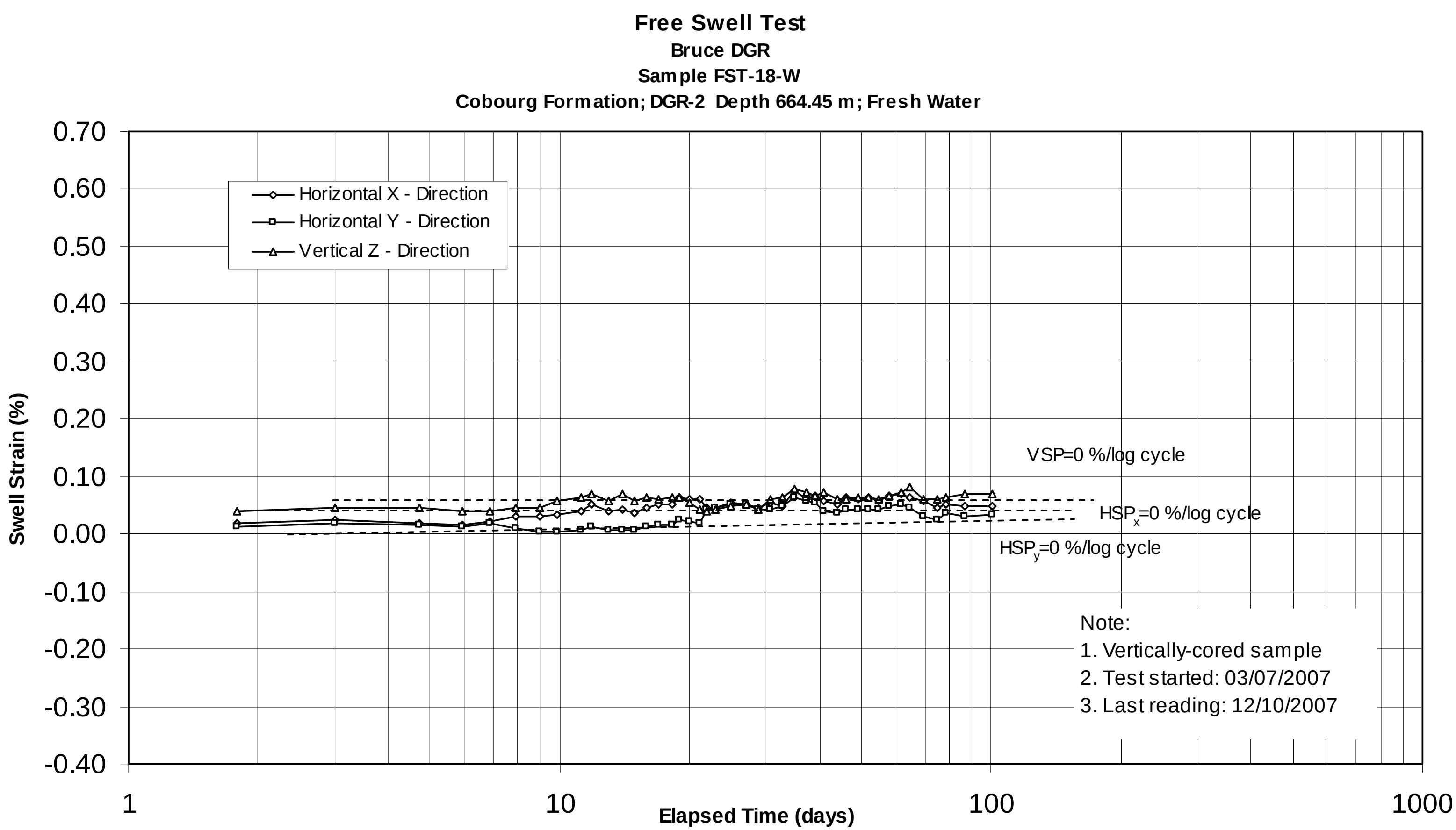
Free Swell Test
Bruce DGR
Sample FST-10-W
Blue Mountain Formation; DGR-2; Depth 632.55 m; Fresh Water
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
HSPx=0 %/log cycle
HSPy=0 %/log cycle
Sample broke
Horizontal X - Direction
Horizontal Y - Direction
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 03/09/2007
1
10
100
1000
Elapsed Time (days)

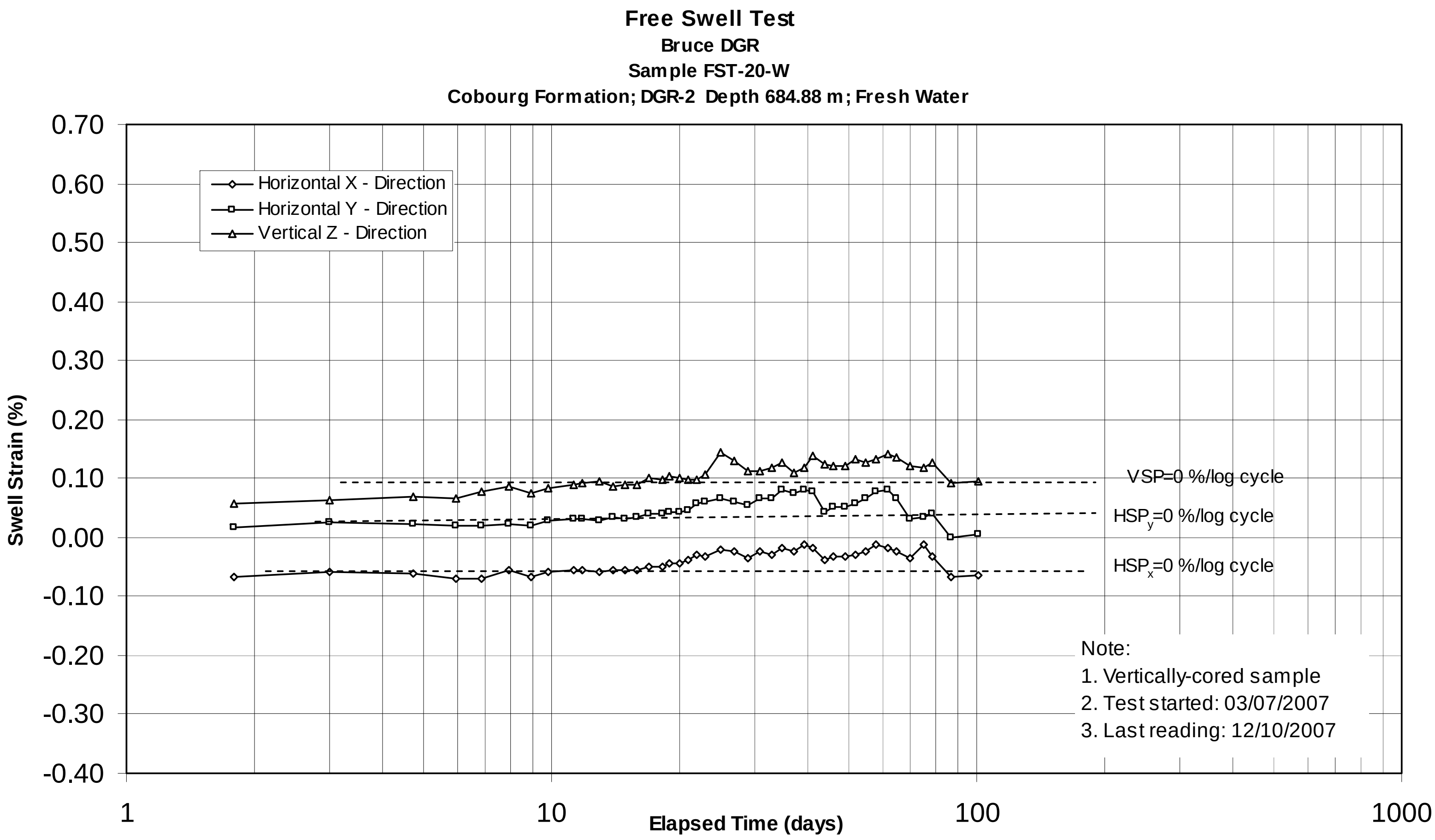


Free Swell Test
Bruce DGR
Sample FST-16-W
Blue Mountain Formation; DGR-2 Depth 645.2 m; Fresh Water
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Elapsed Time (days)
HSPx=0.05 %/log cycle
HSPy=0.07 %/log cycle
Horizontal X - Direction
Horizontal Y - Direction
Note:
1. Vertically-cored sample
2. Test started: 29/06/2007
3. Last reading: 12/10/2007

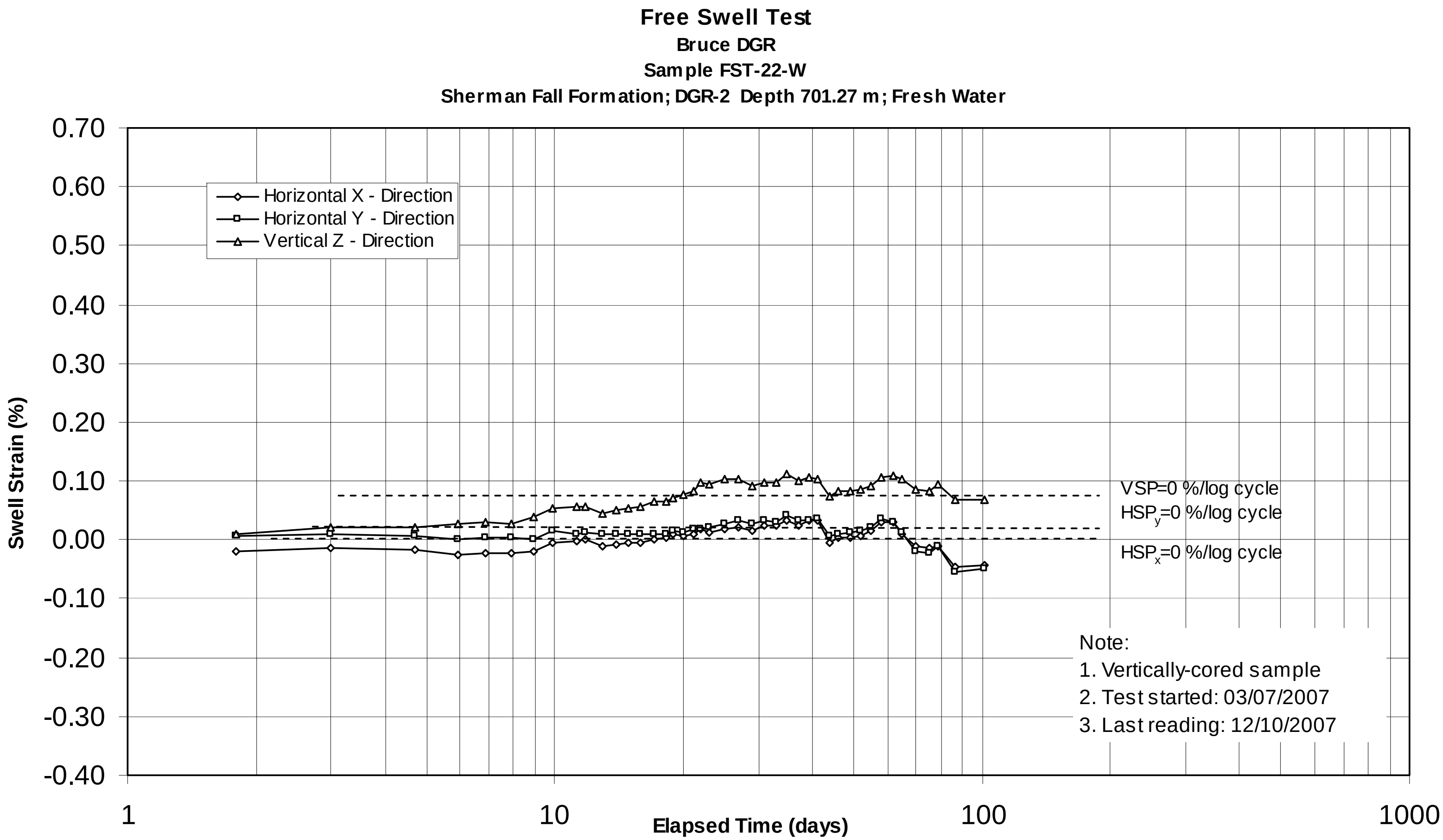

Free Swell Test
Bruce DGR
Sample FST-12-W
Bluemountain Formation; DGR-2; Depth 649.9 m; Fresh Water
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Elapsed Time (days)
Horizontal X - Direction
Horizontal Y - Direction
HSPx=0 %/log cycle
HSPy=0 %/log cycle
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 28/09/2007


Semi-Confined Swell Test
Bruce DGR
Blue Mountain Formation; Fresh Water
SCST-1-W (0.003 MPa; DRG-2; Depth 645.24 m)
SCST-3-W (0.003 MPa;DRG-2; Depth 650.74 m)
VSP=0.25 %/log cycle
VSP=0.35 %/log cycle
Note:
Tests started: 29/06/2007
Last reading: 08/10/2007
Swell Strain (%)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
10
100
1000
Elapsed Time (days)


Free Swell Test
Bruce DGR
Sample FST-18-W
Cobourg Formation; DGR-2 Depth 664.45 m; Fresh Water
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
VSP=0 %/log cycle
HSPx=0 %/log cycle
HSPy=0 %/log cycle
Note:
1. Vertically-cored sample
2. Test started: 03/07/2007
3. Last reading: 12/10/2007
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Elapsed Time (days)

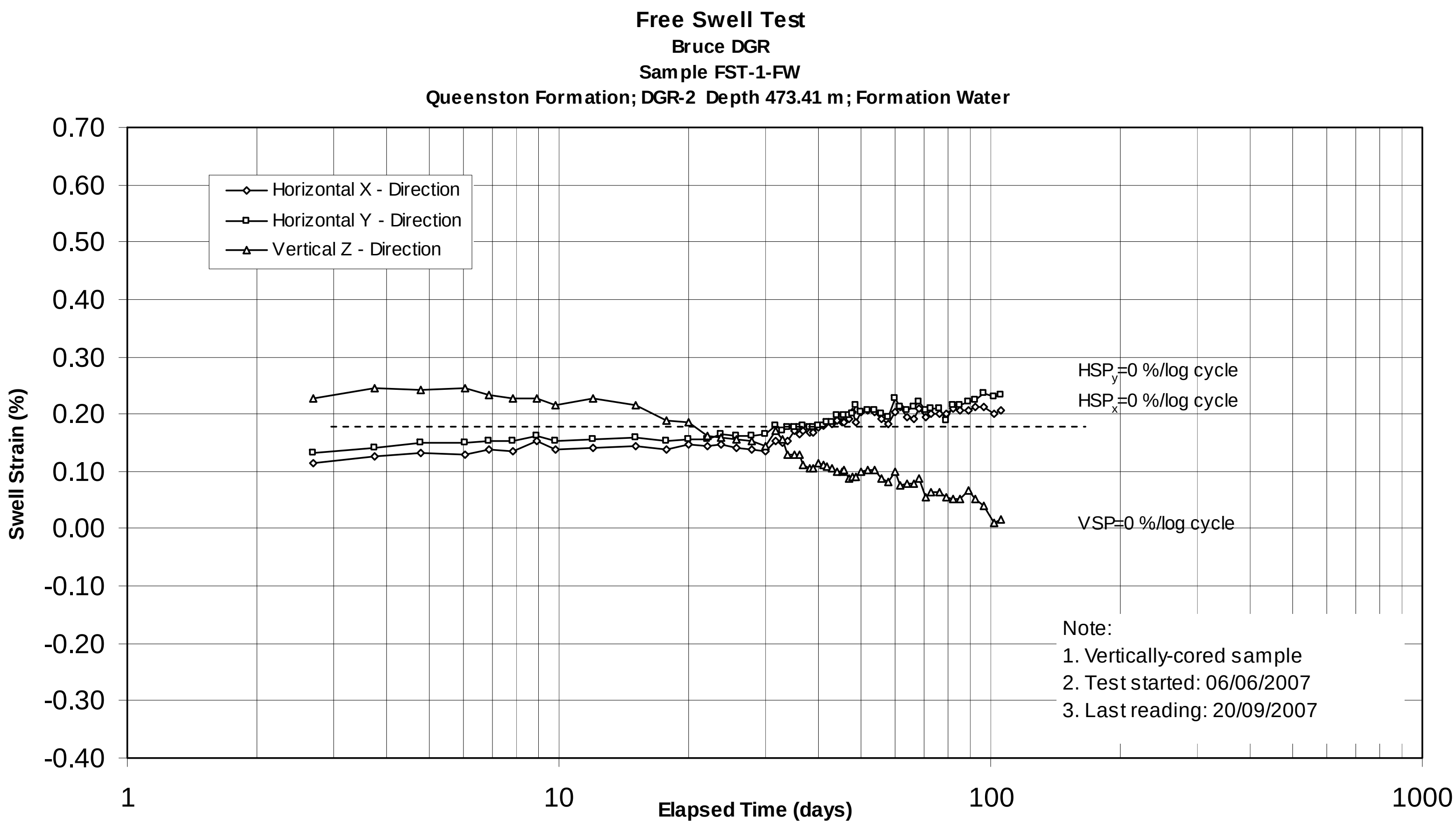


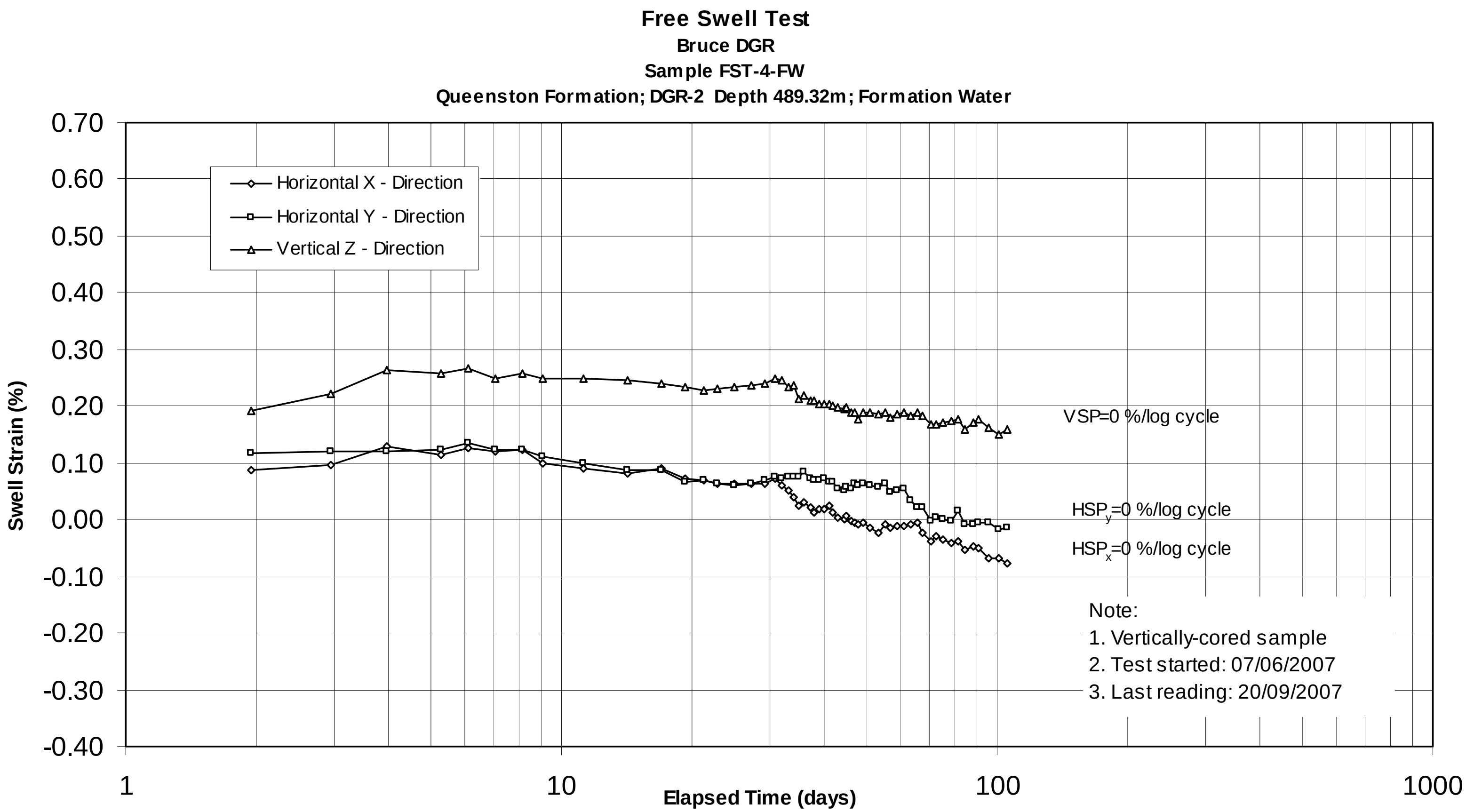
Free Swell Test
Bruce DGR
Sample FST-20-W
Cobourg Formation; DGR-2 Depth 684.88 m; Fresh Water
Swell Strain (%)
Elapsed Time (days)
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
VSP=0 %/log cycle
HSPy=0 %/log cycle
HSPx=0 %/log cycle
Note:
1. Vertically-cored sample
2. Test started: 03/07/2007
3. Last reading: 12/10/2007


Free Swell Test
Bruce DGR
Sample FST-22-W
Sherman Fall Formation; DGR-2 Depth 701.27 m; Fresh Water
Swell Strain (%)
Elapsed Time (days)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
VSP=0 %/log cycle
HSPy=0 %/log cycle
HSPx=0 %/log cycle
Note:
1. Vertically-cored sample
2. Test started: 03/07/2007
3. Last reading: 12/10/2007

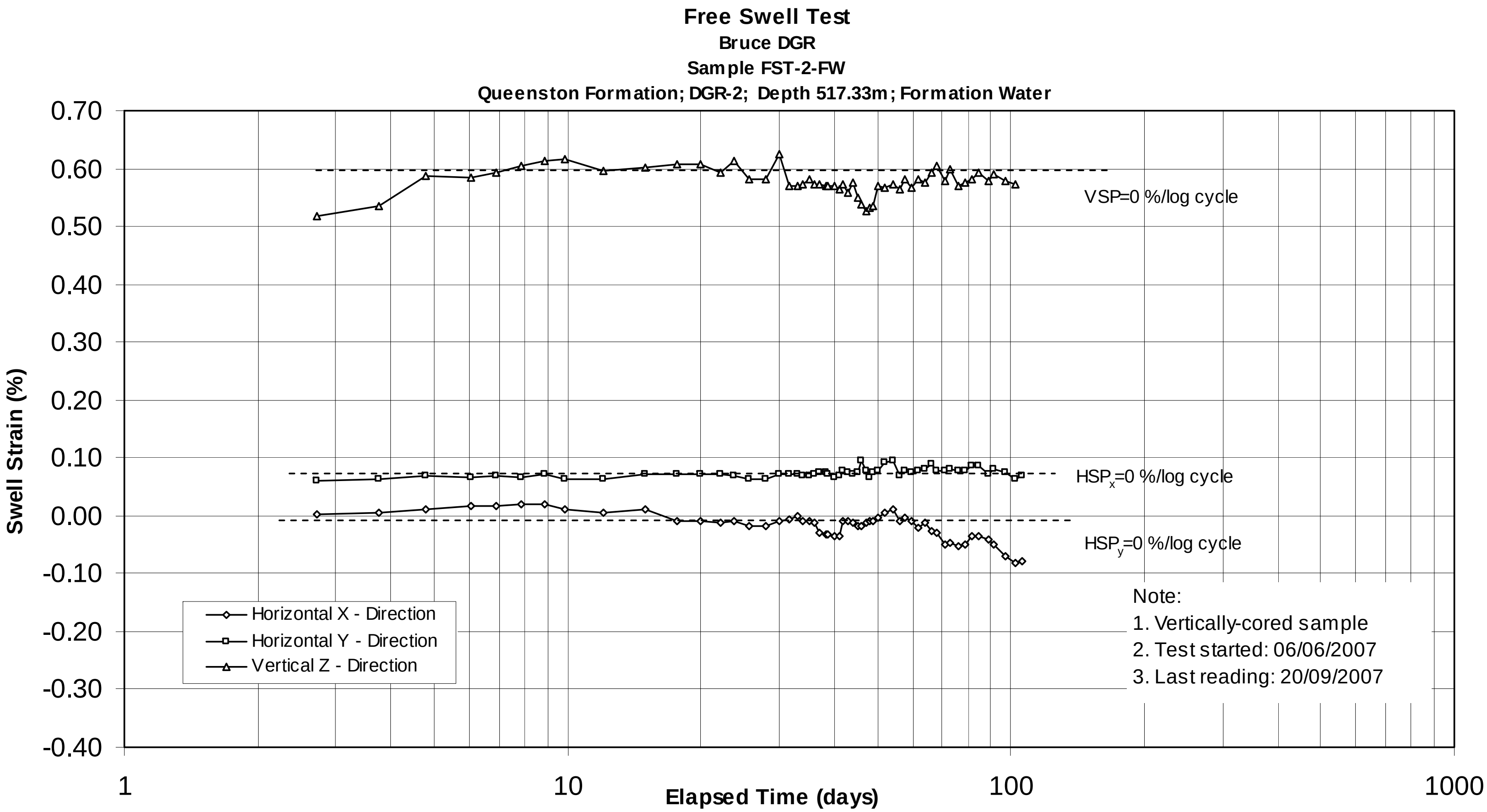
APPENDIX C

Swelling Strain vs Logarithm of Elapsed Time for Free Swell and Semi-confined Tests in Formation Water

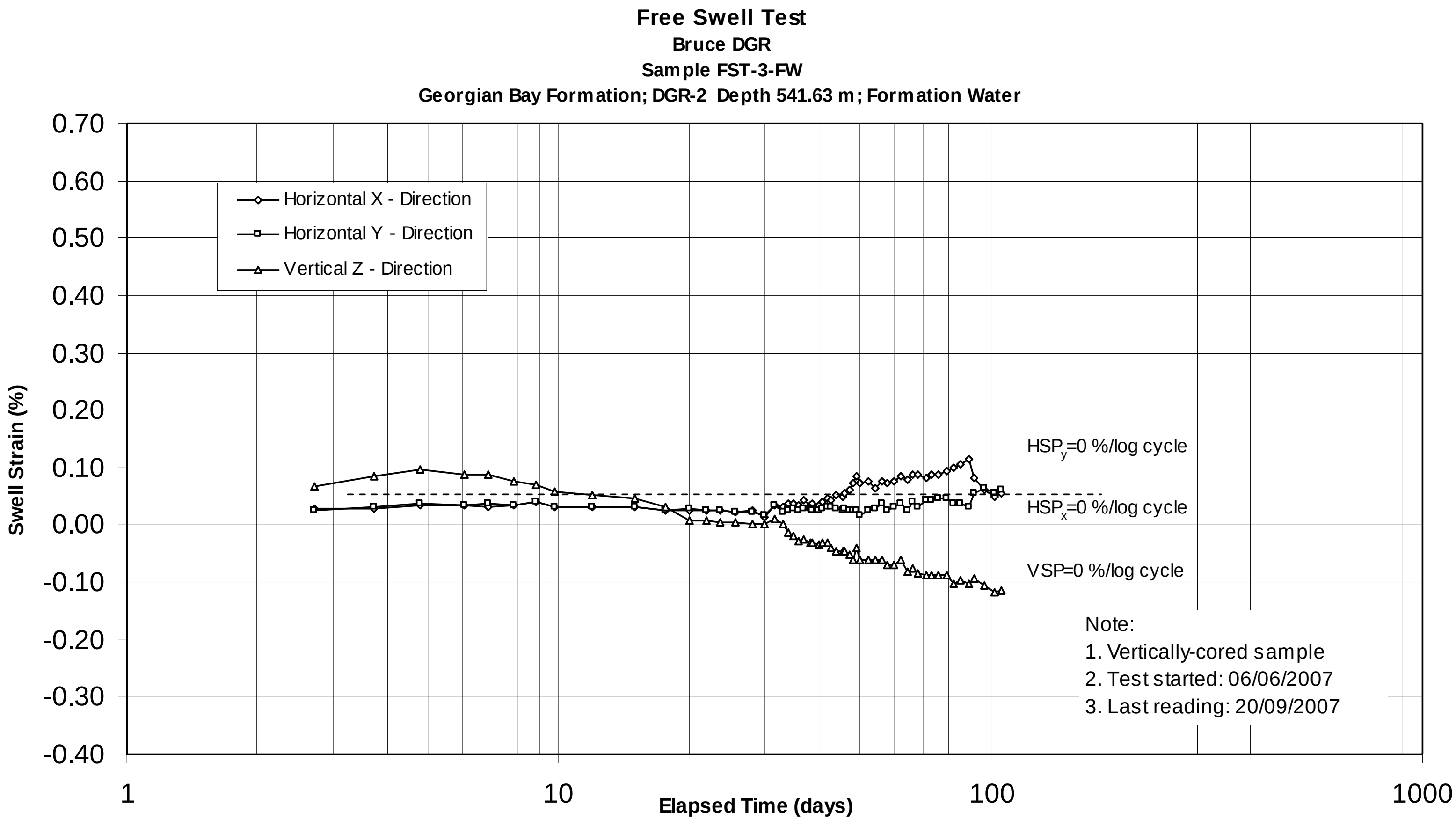

Free Swell Test
Bruce DGR
Sample FST-1-FW
Queenston Formation; DGR-2 Depth 473.41 m; Formation Water
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
HSPy=0 %/log cycle
HSPx=0 %/log cycle
VSP=0 %/log cycle
Note:
1. Vertically-cored sample
2. Test started: 06/06/2007
3. Last reading: 20/09/2007
Swell Strain (%)
Elapsed Time (days)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000



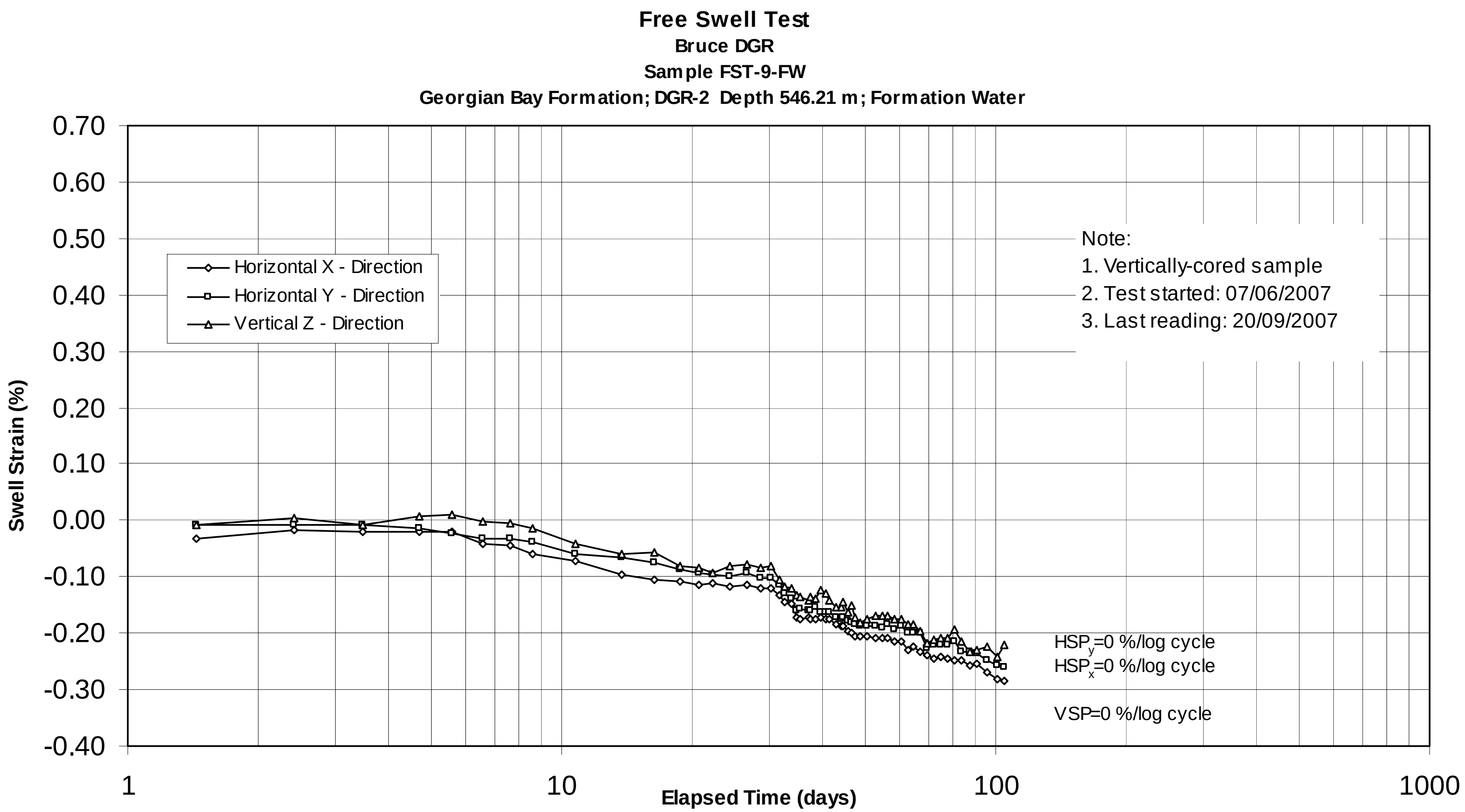
Free Swell Test
Bruce DGR
Sample FST-4-FW
Queenston Formation; DGR-2 Depth 489.32m; Formation Water
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
VSP=0 %/log cycle
HSP$_y$=0 %/log cycle
HSP$_x$=0 %/log cycle
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 20/09/2007
Swell Strain (%)
Elapsed Time (days)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000



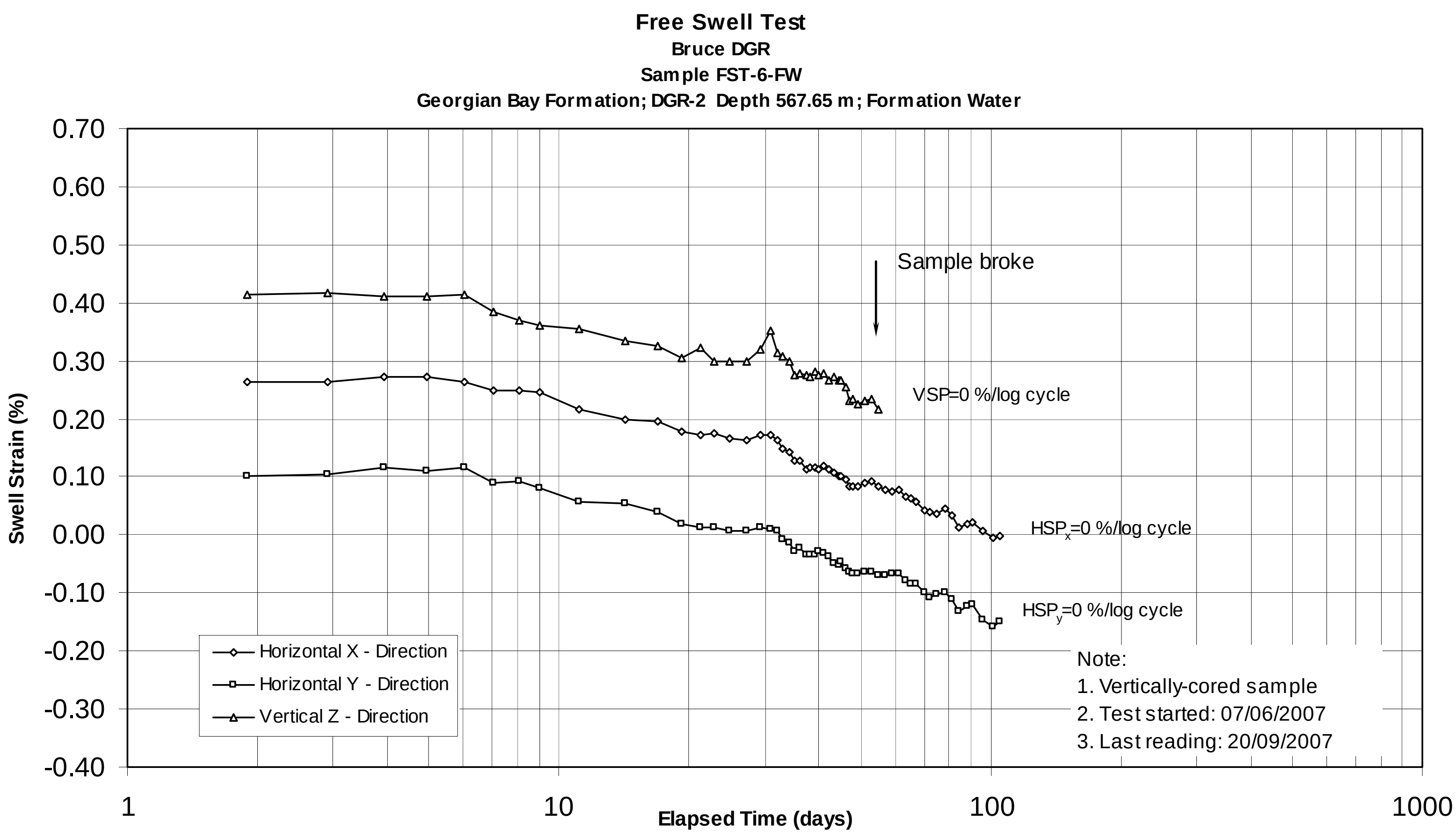
Free Swell Test
Bruce DGR
Sample FST-2-FW
Queenston Formation; DGR-2; Depth 517.33m; Formation Water
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Elapsed Time (days)
VSP=0 %/log cycle
HSPx=0 %/log cycle
HSPy=0 %/log cycle
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
Note:
1. Vertically-cored sample
2. Test started: 06/06/2007
3. Last reading: 20/09/2007



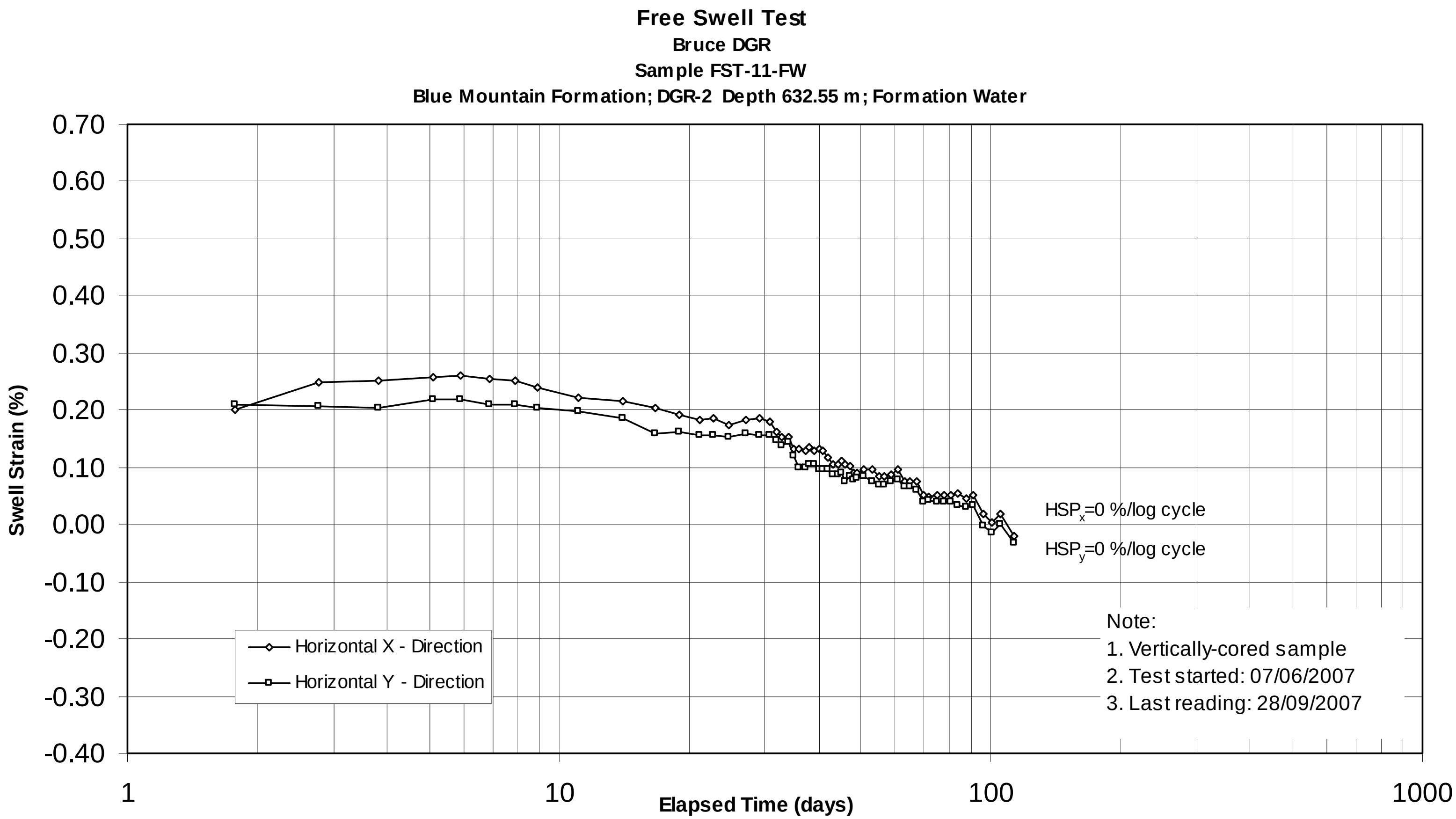
Free Swell Test
Bruce DGR
Sample FST-3-FW
Georgian Bay Formation; DGR-2 Depth 541.63 m; Formation Water
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
HSPy=0 %/log cycle
HSPx=0 %/log cycle
VSP=0 %/log cycle
Note:
1. Vertically-cored sample
2. Test started: 06/06/2007
3. Last reading: 20/09/2007
Swell Strain (%)
Elapsed Time (days)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000



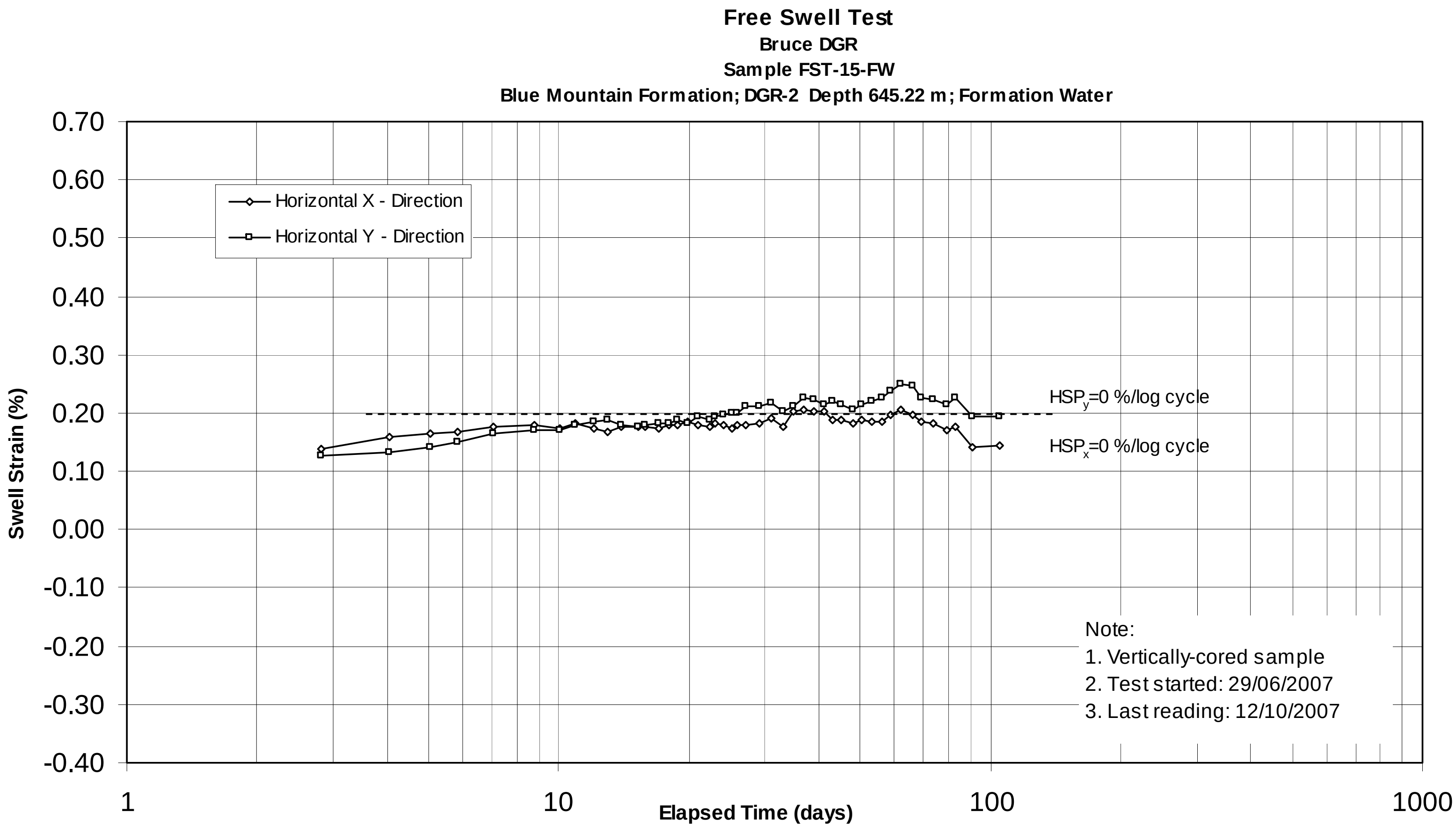
Free Swell Test
Bruce DGR
Sample FST-9-FW
Georgian Bay Formation; DGR-2 Depth 546.21 m; Formation Water
Swell Strain (%)
Elapsed Time (days)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 20/09/2007
HSPy=0 %/log cycle
HSPx=0 %/log cycle
VSP=0 %/log cycle

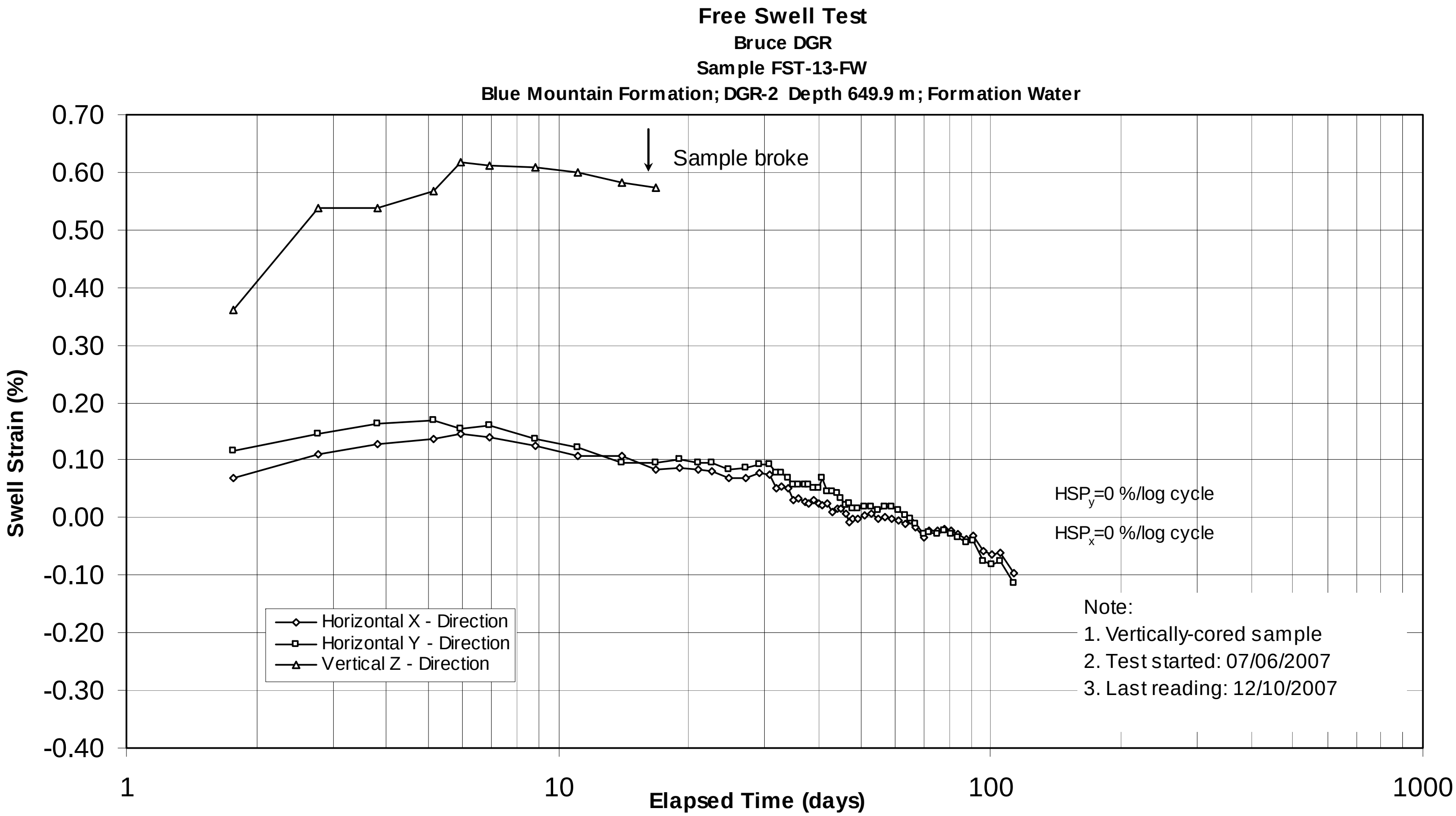


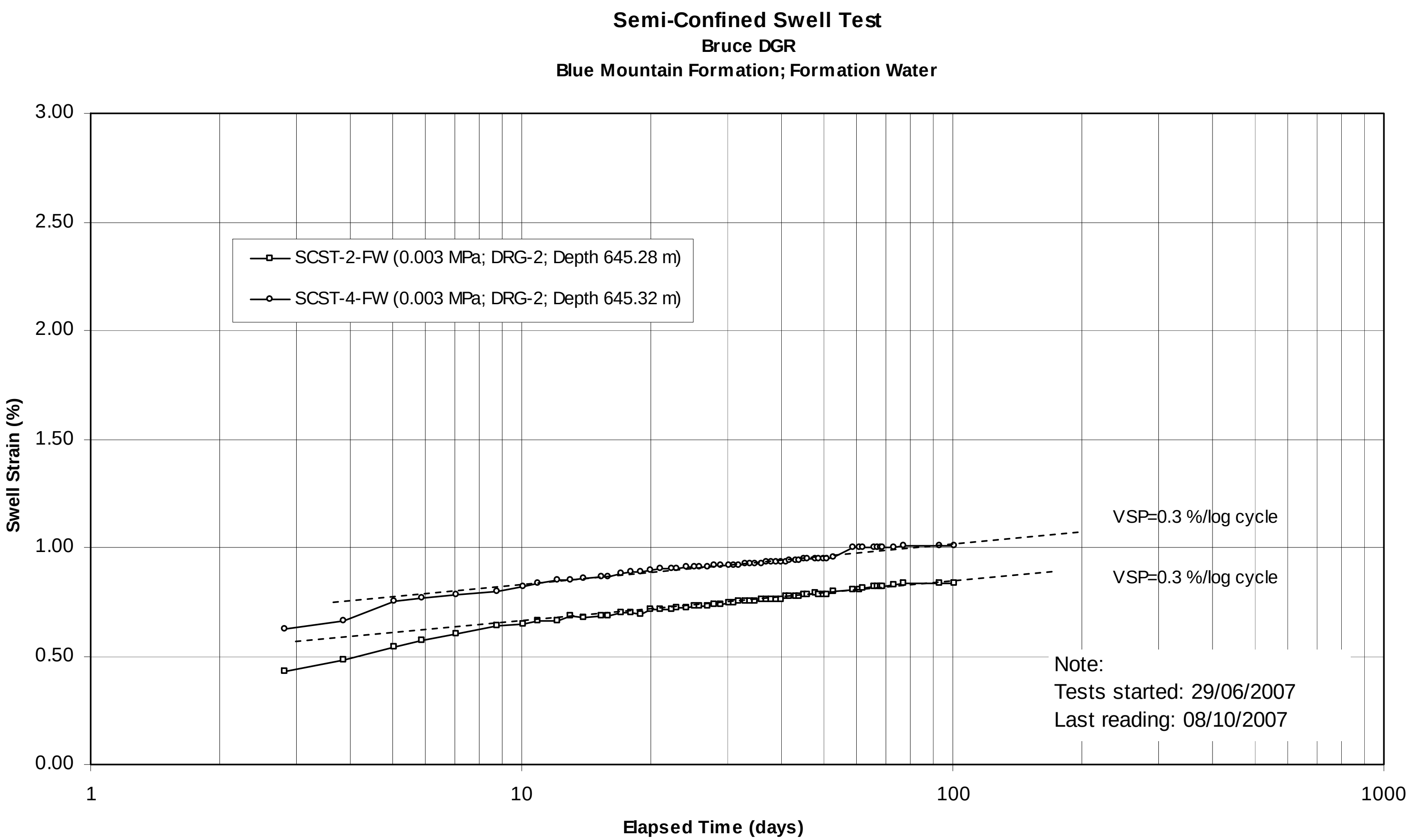
Free Swell Test
Bruce DGR
Sample FST-6-FW
Georgian Bay Formation; DGR-2 Depth 567.65 m; Formation Water
Swell Strain (%)
Elapsed Time (days)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Sample broke
VSP=0 %/log cycle
HSPx=0 %/log cycle
HSPy=0 %/log cycle
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 20/09/2007



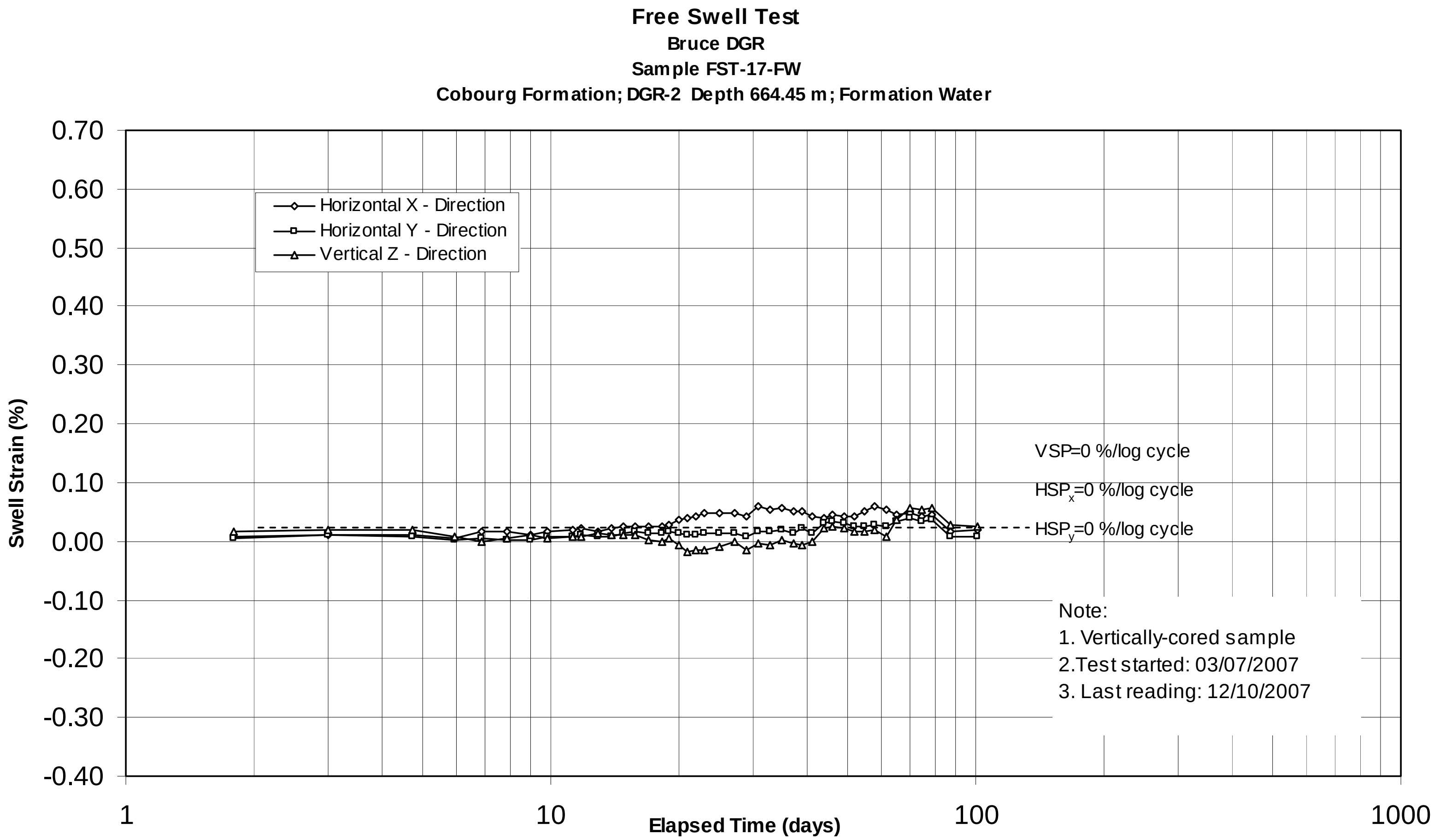
Free Swell Test
Bruce DGR
Sample FST-11-FW
Blue Mountain Formation; DGR-2 Depth 632.55 m; Formation Water
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
Swell Strain (%)
1
10
100
1000
Elapsed Time (days)
HSPx=0 %/log cycle
HSPy=0 %/log cycle
Horizontal X - Direction
Horizontal Y - Direction
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 28/09/2007


Free Swell Test
Bruce DGR
Sample FST-15-FW
Blue Mountain Formation; DGR-2 Depth 645.22 m; Formation Water
Horizontal X - Direction
Horizontal Y - Direction
HSP$_y$=0 %/log cycle
HSP$_x$=0 %/log cycle
Note:
1. Vertically-cored sample
2. Test started: 29/06/2007
3. Last reading: 12/10/2007
Swell Strain (%)
Elapsed Time (days)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000

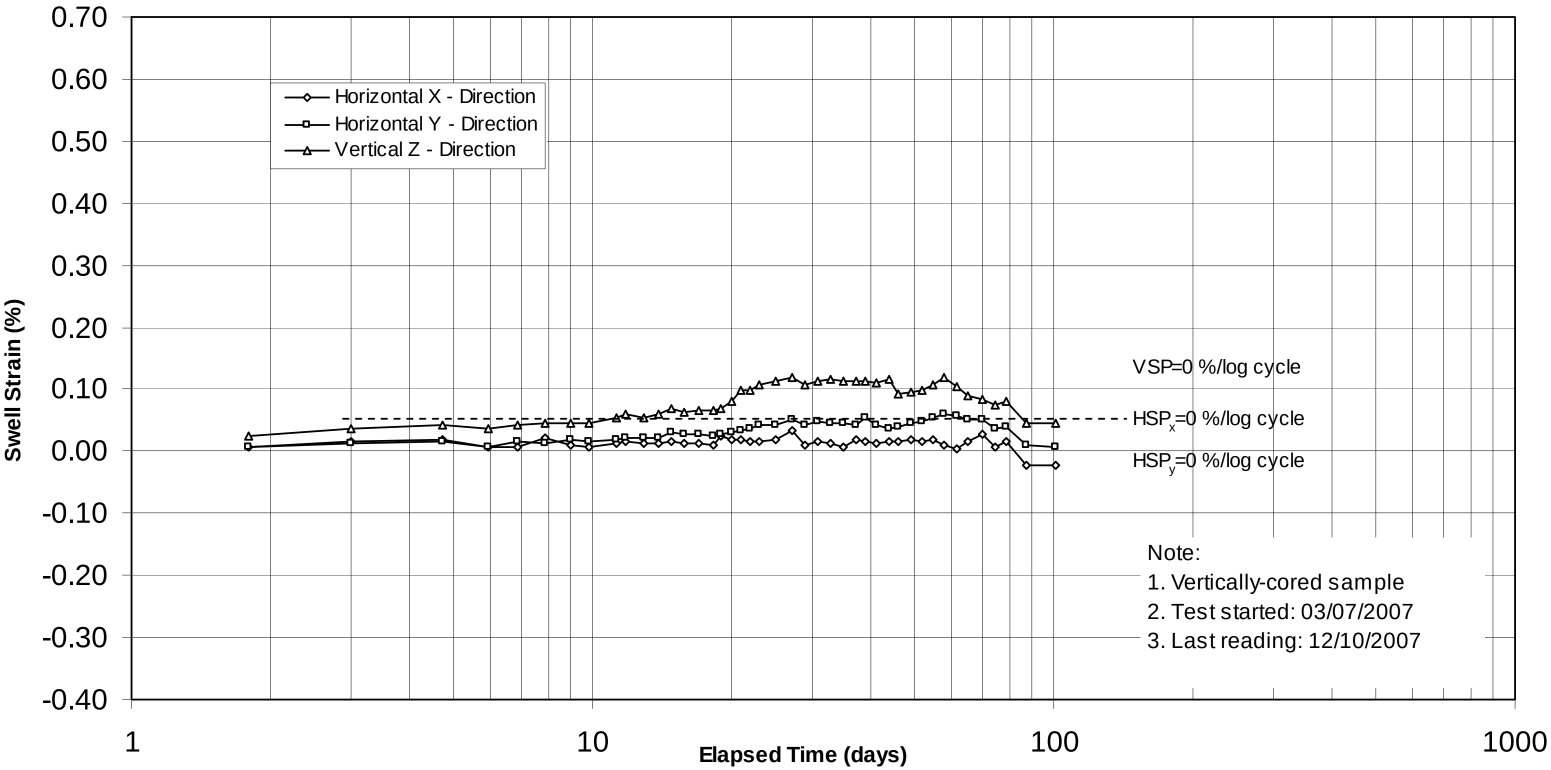

Free Swell Test
Bruce DGR
Sample FST-13-FW
Blue Mountain Formation; DGR-2 Depth 649.9 m; Formation Water
Swell Strain (%)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Elapsed Time (days)
Sample broke
HSPy=0 %/log cycle
HSPx=0 %/log cycle
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
Note:
1. Vertically-cored sample
2. Test started: 07/06/2007
3. Last reading: 12/10/2007



Semi-Confined Swell Test
Bruce DGR
Blue Mountain Formation; Formation Water
SCST-2-FW (0.003 MPa; DRG-2; Depth 645.28 m)
SCST-4-FW (0.003 MPa; DRG-2; Depth 645.32 m)
VSP=0.3 %/log cycle
VSP=0.3 %/log cycle
Note:
Tests started: 29/06/2007
Last reading: 08/10/2007
Swell Strain (%)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1
10
100
1000
Elapsed Time (days)


Free Swell Test
Bruce DGR
Sample FST-17-FW
Cobourg Formation; DGR-2 Depth 664.45 m; Formation Water
Swell Strain (%)
Elapsed Time (days)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1
10
100
1000
Horizontal X - Direction
Horizontal Y - Direction
Vertical Z - Direction
VSP=0 %/log cycle
HSP$_x$=0 %/log cycle
HSP$_y$=0 %/log cycle
Note:
1. Vertically-cored sample
2.Test started: 03/07/2007
3. Last reading: 12/10/2007

Free Swell Test
Bruce DGR
Sample FST-19-FW
Cobourg Formation; DGR-2 Depth 684.88 m; Formation Water



Free Swell Test
Bruce DGR
Sample FST-21-FW
Sherman Fall Formation; DGR-2 Depth 701.27 m; Formation Water