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Mechanical Properties of Heavy Oil-Sand and its Viscosity as a Function of Pressure and Temperature

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July 1987

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Final Report for Task D. Petrophysics Relating to Compaction of Annex IX, Subsidence due to Fluid Withdrawal. Part of the Implementing Agreement between the Department of Energy of the United States and the Ministry of Energy and Mines of the Republic of Venezuela.

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ABSTRACT

Laboratory tests were conducted to determine the mechanical properties of oil-sand and shale samples from the Faja region of Venezuela at elevated temperature and pressure. Results describe pressure-volume (PV) behavior at temperatures of 23 and 125°C; the effect of mechanical disturbance on PV behavior; EOS at temperatures of 23, 125, and 250°C and effective pressures to 150 MPa; and creep/compaction behavior at temperatures of 23 and 125°C.

Data from PV tests on oil-sand show that increasing temperature from 23 to 125°C had very little effect on this material. Mechanical disturbance of oil-sand prior to PV testing lowered values of K . The compressive strength of oil-sand increased as effective pressure (P_E) was raised and at both temperatures, samples tested at equivalent P_E had similar strengths. Compressive strength of oil-sand seems to be controlled by the drainage of pore fluid during axial deformation. Nearly all oil-sand samples exhibited strain-hardening.

PV tests conducted on shale show that increasing temperature from 23 to 125°C reduced values of K one third. Mechanical disturbance significantly affected the PV response of shale samples due to the friable nature of the material. Data for shale samples tested in triaxial compression show that ultimate stress increases with increasing pressure and increasing temperature.

Results of long-term creep compaction tests show a linear change in sample volume as a function of the log of time and that the rate of volume change with time was larger at 125°C than at 23°C for both oil-sand and shale.

1. INTRODUCTION

Heavy oil-sands often have an oil-plus-water content as high as 80%. They have very low structural strength and exhibit extensive compaction when pore fluid is withdrawn. In Venezuela, where there are large deposits of heavy oil-sand, production of the petroleum from the oil-sand reservoirs has caused subsidence in some of the oil-producing regions. To anticipate the extent of subsidence and other reservoir behavior that might be caused by present or future oil production, the Venezuelan national oil organization, INTEVEP, has commissioned an extensive research program. Studies are under way to develop models that will predict subsidence and its effect on surface water movement. In addition, laboratory investigations of the mechanical properties of reservoir materials are being done to provide improved data for input to the models. As part of the laboratory research effort, the Earth Sciences Department at Lawrence Livermore National Laboratory has performed a series of laboratory tests on samples of the heavy oil-sand reservoir and shale caprock found in the Faja oil reservoir in eastern Venezuela. These tests were performed under Task D of Article IX of Department of Energy/MEM Agreement. These tests will provide insight into the material behavior at conditions that simulate the in situ production environment.

The aim of laboratory tests performed at LLNL is to:

1. Provide guidance in the interpretation or use of laboratory data in reservoir modeling by determining the effect of mechanical disturbance on properties of core measured in the laboratory.
2. Provide equation-of-state (EOS) data for the mechanical properties of the oil-sand and shale caprock over a range of temperatures and pressures appropriate to in situ and production conditions in the Faja formation. The EOS data is required input for computer modeling of reservoir behavior and consists of stress-strain plots from triaxial tests.
3. Provide laboratory data on the long-term creep or secondary compaction properties of the oil-sand and shale materials at appropriate temperatures and pressures. These data are important for modeling the time-dependent behavior of the reservoir and caprock materials both during and subsequent to reservoir production.

To provide the desired data, a sequence of laboratory tests was performed that included over 30 triaxial tests, 12 pressure-volume tests, and 15 long-term creep/compaction tests. In all, more than 56 samples were tested. This report documents the apparatus and testing methods, presents results and preliminary analyses of the test data, and includes tables of the reduced data as appendices.

This report presents some of the first laboratory data on the mechanical behavior of shales and heavy oil-sands at temperatures to 250°C and pressures to 300 MPa. Results include pressure-volume (PV) relations for oil-sand and shale at two temperatures; quantitative results on the effect of mechanical disturbance on pressure-volume behavior; and Mohr-Coulomb failure envelopes, as a function of temperature, for oil-sand and shale. Other work on shales at elevated temperature is discussed by Johnston.¹

It is important to note that this report is preliminary and results should be used carefully in any modeling effort. Tests at these conditions on unconsolidated or friable materials such as the oil-sand and shale are inherently difficult. We spent a great deal of time developing test techniques, and several test attempts were unsuccessful.

However, much new information is presented here. The experimental results provide insight into mechanisms important to the performance and stability of reservoir and caprock materials encountered by INTEVEP.

To perform measurements at the desired conditions (confining pressures to 300 MPa and temperatures to 250°C), several new pieces of apparatus were designed and constructed. These include a high-temperature triaxial vessel with capability for pore pressure control, an automated pore-fluid volumeter system, and two manual pore-fluid volumeter systems.

2. METHODOLOGY

2.1 CORE PREPARATION

Core samples of oil-sand and shale were received in a partially frozen condition and were immediately placed in a freezer and kept at -20°C. The lengths of core received were 0.5 to 1 m long. These pieces were cut into 10-cm (4-inch) sections and returned to the freezer. Test specimens were prepared from the 10-cm sections as follows. We constructed a watertight wooden

"sandbox" large enough to hold several 10-cm sections (see Fig. 1). This box was placed in the freezer and allowed to come to equilibrium temperature. A quantity of clean Ottawa sand sufficient to fill the box was also placed in the freezer. Core sections were then positioned in the box and sand was added to fill the box, so that only the ends of the core sections were exposed. Then very cold water was added slowly to the sand and allowed to freeze. Thus, the core sections were held firmly by the sand-ice mixture, which also kept the sections frozen during the coring operation. When the saturated sand was frozen, the bottom of the box was removed and test specimens were cored with a diamond-tipped core barrel at slow speeds. A silicone lubricant was used to enhance cutting. We cored each specimen individually and returned the sand box assembly to the freezer to refreeze the assembly before coring the next sample.

The test specimens were each wrapped with two layers of Teflon tape and one layer of plastic tape. Then they were cut to length with a diamond saw and lapped on a dry diamond lap wheel to obtain right-circular cylinders. Both 2.54-cm-diameter and 4.45-cm-diameter specimens were produced from the original oil-sand and shale cores. The plastic tape and one layer of Teflon tape were then removed, and specimens were weighed and measured. While the specimens were still frozen, they were converted into sample test assemblies as shown in Figs. 2 (a and b). Porous spacers (hastaloy disks) and endcaps were placed at the end of the specimens, and the entire assembly was jacketed with either viton shrink tubing (for tests at 23°C) or fluorosilicone sealant (Dow Corning Q4-2817 for tests at higher temperatures). The pore fluid ports in the endcaps were sealed, and the jacketed specimens were allowed to warm to room temperature before testing.

2.2 TESTING METHODS

2.2.1 Triaxial Tests

Triaxial tests were performed on 2.54-cm-diameter samples. The apparatus used for triaxial testing is shown in Fig. 3. The following procedure was used to perform the triaxial tests:

1. A jacketed sample was assembled into the test vessel, and the vessel was inserted into the press.

Figure 1. Sandbox assembly for coring samples while keeping them frozen.

Figure 2. (a) Sample assembly for triaxial and PV tests; (b) sample assembly for long-term creep compaction tests.

Figure 4. Data processing methodology for triaxial tests.

2. The pore fluid line to the sample was evacuated and then filled with distilled water.

3. The vessel assembly was heated to test temperature. Confining and pore pressures were maintained at minimal levels during heating.

4. Confining and pore pressures were raised to desired levels, with pore pressure carefully maintained at one-half the confining pressure. The confining pressure was attained by a manually operated air-over-oil pump. Pore pressure was controlled manually using a calibrated volumometer.

5. Axial force was applied to deform the specimen with the desired amount of axial strain. Confining and pore pressures were maintained constant during the axial deformation.

Several parameters were recorded during these tests, including axial displacement, axial force on the sample, confining pressure, pore pressure, temperature of the sample, and volume of expelled pore fluid. Expelled pore volume during the period 2 to 5 min after the test was also noted. Data were recorded by both analog and digital recording devices. Volumometer displacement (change in pore volume) was recorded manually.

Data from the triaxial tests were reduced as follows. First, analog force/displacement charts were digitized with a digitizing tablet and the SIGMASCAN² program on an IBM PC. SIGMASCAN produced files of force and displacement values in an ASCII format. These ASCII files were read into LOTUS 1-2-3³ on an IBM PC, and data were reduced to stress and strain (the processing methodology is outlined in Fig. 4.) The reduced data were written to x,y files from LOTUS 1-2-3 and plotted using the SAC⁴ program at LLNL.

Two corrections were applied to the cross-sectional area to allow computation of axial stress. First, the cross section of the sample was corrected for deformation due to confining pressure. This correction was of the form:

$$A_p = C_p A_o \text{ where } 0 < C_p < 1.0,$$

where A_p = area at effective pressure
 A_o = initial area
 C_p = pressure correction

We derived data for this correction from results of the PV tests conducted for Task D.2. Cross-sectional area of the sample was also corrected for the barrelling effect associated with axial deformation, using the relation

$$A_{p,e} = A_p(1+e),$$

where e = axial strain.

2.2.2 Pressure-Volume Tests and Long-Term Creep Compaction Tests

Pressure-Volume (PV) tests monitored change in volume due to increasing hydrostatic pressure. These tests were performed on 1-in.-diameter cores with the apparatus shown in Fig. 5. The following procedure represents the test sequence:

1. A jacketed sample was assembled into the test vessel.
2. The pore fluid line to the sample was evacuated and then filled with deionized water.
3. The vessel assembly was heated to test temperature. Confining and pore pressures were maintained at minimal levels during heating.
4. Confining and pore pressures were raised in incremental steps to a maximum confining pressure of 50 MPa, with pore pressure carefully maintained at 5 MPa. (While confining pressure was raised to 10 MPa, pore pressure was maintained at 2.5 MPa.) Data were recorded at each pressure step.
5. Confining pressure was decreased in incremental steps, with pore pressure maintained at 5 MPa. Data were recorded at each step.

Apparatus for the long-term creep experiments is shown in Fig. 6. The long term, creep/compaction procedures for these tests were the same as steps 1 through 3 of the PV tests; then the confining and pore pressures were raised to the desired levels and maintained for long periods of time (weeks), with pore pressure maintained at one-half the confining pressure. Data were recorded several times a day during these tests.

Data for PV and long-term creep tests included initial sample volume, confining pressure, pore pressure, temperature, and volumometer displacement.

Data were recorded manually and with the A/D digital recording devices. We obtained manual measurements on the volumometer by measuring volumometer piston position at each confining pressure, using a dial caliper gauge for the PV tests and using a vernier scale for the long-term creep tests. The displacements were used to compute volume of expelled fluid.

Volumometer displacement, confining pressure, and pore pressure data were entered into the Lotus 1-2-3 program on an IBM PC. The volume of expelled fluid was calculated from the volumometer displacement. The change in volume of the sample was assumed to be equal to the volume of fluid expelled.

Figure 5. Apparatus for INTEVEP parameter evaluation.

Figure 6. INTEVEP long-term creep/compaction test apparatus.

2.3 SAMPLE DESCRIPTION

Core from the Faja region consisted of shale samples from depths between 3202 and 3211 ft and oil-sand samples from depths between 3278 and 3280 ft and between 3307 and 3309 ft. Core sections and general core description are listed in Table 1; Table 2 presents a complete list of samples, depths, densities, and other specimen information.

The oil-sand samples had an average wet density of 1.89 g/cc (standard deviation = 0.05), and the average wet density of the shale samples was 2.0 g/cc (standard deviation = 0.1). We did not determine dry density, porosity, or void ratio for the samples because specialized equipment, not available at LLNL, is required to accurately measure these parameters on materials saturated with organic fluids and water. We recommend that core samples be analyzed for porosity and oil/water content by one of the many commercial laboratories that specialize in this type of testing.

3. RESULTS

3.1 TASK D.1 PRESSURE-VOLUME BEHAVIOR AND THE EFFECT OF MECHANICAL DISTURBANCE

We conducted PV tests on oil-sand and shale samples at 23 and 125°C. To determine the effect of disturbance on the PV behavior at each temperature, we tested undisturbed specimens and specimens that had been strained to 5 and 10% of their axial length in unconfined triaxial tests (see Task D.2).

The tests were conducted as described in Section 2.2.2. In reducing the data, we assumed that the total change in volume of the sample could be approximated by the amount of fluid expelled from the sample measured by the volumometer. During these tests, confining pressure was raised in increments of 10 MPa (except at very low pressures), and pore pressure was held constant at 5 MPa by using a servo-controlled pore fluid volumometer. At each effective pressure, the displacement of the volumometer was digitally and manually recorded after the volumometer had reached an equilibrium position. The change in pore volume was directly computed from the displacement of the volumometer. Values were normalized to the initial volume of the sample before any disturbance was introduced.

Table 1. Core depth and descriptions Intevap well, MFB-264.

DEPTH	DESCRIPTION
3202'	Grey, fine grained rock
3204'	with black, oil-rich stringers
3206'	(Shale caprock for the reservoir)
3207'	
3210'	
3211'	
3278'-10"	Black, oil-rich material
3279'-10"	~80% Hydrocarbon
3280'-10"	(Re: Luis Roca)
3307'-10"	Black, oil-rich material
3308'-10"	Similar to above core
3309'-6"	

Table 2. Specimen description.

Sample No.	Depth	Type	Test Conditions			Length (cm)	Diameter (cm)	Volume (cc)	Wet	Density (gm/cc)
			Strain (%)	Temperature (°C)	Pressure (MPa)				Weight (gm)	
1	3204'	SH	10	23	50.0	5.718	2.489	27.824	54.00	1.94
2	3204'	SH	10	23	20.0	4.496	2.560	23.146	47.00	2.03
3	3204'	SH	10	23	0.1	5.060	2.545	25.740	54.00	2.10
4	3206'	SH	10	23	0.1	3.708	2.576	19.321	41.10	2.13
5	3206'	SH	5	23	0.1	3.744	2.530	18.819	41.25	2.19
6	3206'	SH	10	(134)/125	0.1	3.860	2.550	19.655	39.38	2.00
7	3202'	SH	5	(134)/125	0.1	5.190	2.660	28.797	52.86	1.84
8	3202'	SH	10	250	0.1	5.100	2.620	27.510	53.14	1.93
9	3204'	SH	10	23	270.0	5.131	2.500	25.17	52.02	2.07
10	3279'10"	OS	10	23	0.1	4.864	2.540	24.647	45.94	1.86
11	3308'10"	OS	5	23	0.1	4.869	2.530	24.426	45.10	1.85
12	3206'	SH	10	23	10.0	5.070	2.535	25.574	52.20	2.04
13	3206'	SH	10	23	5.0	3.600	2.510	17.826	30.38	1.70
14	3210'	SH	10	23	2.0	3.551	2.630	19.274	37.92	1.97
15	3307'10"	OS	10	23	50.0	4.844	2.510	23.958	46.70	1.95
16	3308'10"	OS	10	23	20.0	4.674	2.490	22.837	43.64	1.91
17	3307'10"	OS	10	23	10.0	4.989	2.517	24.824	46.30	1.87
18	3308'10"	OS	10	23	5.0	4.834	2.565	25.011	46.46	1.86
19	3307'10"	OS	10	125	50.0	4.737	2.527	23.764	42.54	1.79
20	3308'10"	OS	10	125	20.0	4.765	2.504	23.473	44.06	1.88
20A	3307'10"	OS	10	125	20.0	4.575	2.527	22.95	43.84	1.91
21	3308'10"	OS	10	125	10.0	4.745	2.517	23.611	46.34	1.96
22	3210'	SH	10	125	10.0	4.877	2.578	25.458	50.32	1.98
23	3202'	SH	5/10	125	0.1	3.937	2.578	20.552	41.82	2.03
24	3308'10"	OS	10	125	0.1	5.141	2.375	22.773	43.84	1.93
25	3308'10"	OS	5	125	0.1	4.272	2.502	21.003	40.00	1.90

Sample No.	Depth	Type	Test Conditions		Pressure (MPa)	Length (cm)	Diameter (cm)	Volume (cc)	Wet Weight (gm)	Density (gm/cc)
			Strain (%)	Temperature (°C)						
26	3202'	SH	10	125	20.0	4.890	2.502	24.038	48.58	2.02
26A	3211'	SH	10	125	20.0	3.602	2.609	19.25	40.24	2.09
27	3211'	SH	10	125	25.0	4.529	2.515	22.49	45.92	2.04
27A	3211'	SH	10	125	50.0	4.803	2.578	25.073	48.92	1.95
27B	3202'	SH	10	125	50.0	3.635	2.565	18.79	36.16	1.92
28	3202'	SH	10	250	0.1	3.884	2.525	19.718	40.32	2.04
29	3202'	SH	5	250	0.1	3.762	2.591	19.831	40.00	2.02
30	3308' 10"	OS	5	250	0.1	4.844	2.499	23.765	46.46	1.95
31	3308' 10"	OS	10	250	0.1	4.801	2.629	26.057	48.46	1.86
32	3280' 10"	OS	10	125	300.0	5.139	2.520	25.61	46.60	1.82
33	3210'	SH	10	125	300.0	4.092	2.578	21.36	43.48	2.04
34	3211'	SH	10	250	300	3.620	2.642	19.84	40.70	2.05

3.1.1 Oil-Sand: Pressure-Volume Behavior

The PV data for undisturbed oil-sand at 23 and 125°C are plotted in Fig. 7; tabulated values are in Appendix A. These data indicate that at 23°C the undisturbed oil-sand sample behaved like a saturated sand. Bulk modulus for this sample increased from 430 MPa for effective pressures below 25 MPa to 670 MPa for effective pressures in the range 25 to 45 MPa. As effective pressure was decreased, the sample recovered only a very small portion of the volume, indicating that permanent compaction of pore space occurred as pore fluid drained from the saturated sand. Results for the undisturbed sample tested at 125°C indicate that raising effective pressure to 5 MPa caused a volumetric strain of ~5%. As effective pressure was increased above 5 MPa, this sample responded in a nearly identical way to that of the one tested at 23°C. This can be verified by comparing the bulk moduli over equivalent pressure ranges (Table 3).

These data indicate that the bulk modulus of the "undisturbed" heavy oil-sand samples was 430-670 MPa. Increasing the temperature on an unconfined sample to 125°C caused thermal cracking or some other type of sample expansion and created about 5% void space. However, when effective pressure was increased to 5 MPa or more, the void space closed and the rock behaved as it would at room temperature. This implies that at in situ reservoir pressures, heating the oil-sand to 125°C will have little effect on the bulk modulus. These data also indicate that, at both temperatures, the decrease in volume with increasing effective pressure was caused by permanent pore compaction that occurred as pore fluid was expelled from the sample.

A PV test attempted on oil-sand samples at 250°C was unsuccessful because the sample jacket ruptured.

3.1.2 Oil-Sand: Effect of Disturbance

Data for PV tests conducted on undisturbed and disturbed oil-sand samples at 23°C are shown in Fig. 8. Disturbed samples were strained to 5 or 10% axial strain at unconfined conditions (see Section 3.2.1) prior to the PV tests. These data show that, as effective pressure was raised to 2.5 MPa, the two disturbed samples lost approximately 6% of their volume, which is consistent if

Figure 7. The PV data for oil-sand at 23 and 125°C.

Table 3. Bulk modulus of oil-sand and shale at 23 and 125°C.

Temperature	Oil-Sand			Shale		
	Undisturbed	5%	10%	Undisturbed	5%	10%
		Disturbed	Disturbed		Disturbed	Disturbed
23°C	670	555	4000	2100	800	1000
125°C	670	--*	1176	1660	1000	1176

*Unsuccessful test.

Figure 8. The PV data for undisturbed and disturbed oil-sand at 23°C.

one assumes that cracks closed and other void spaces were introduced during unconfined axial compression. As effective pressure was increased from 2.5 to 25 MPa, both disturbed samples showed similar behavior and compacted at nearly the same rate as the undisturbed sample in this pressure range. As effective pressure was raised above 25 MPa, the 5% sample continued to compact at a rate similar to the undisturbed sample while the sample with 10% disturbance compacted very little and behaved as a highly consolidated sand with no apparent change in pore volume.

The results of these tests indicate that void space introduced by disturbance of 5-to-10% axial strain closes at effective pressures greater than 7.5 MPa. However, a disturbance of 10% strain appears to have introduced some permanent compaction into the sample.

Data for undisturbed and disturbed oil-sand tested at 125°C are plotted in Fig. 9. The disturbed samples were tested at 125°C in the triaxial apparatus (see Section 2.2.1). The samples were removed from the triaxial vessel after it had cooled to room temperature. The pore fluid ports were sealed, and the samples were stored at room temperature until they were tested in the PV apparatus. The jacket on the 5% disturbed sample ruptured when effective pressure was raised to 5 MPa; thus, only one data point was available for this sample. The results show that at 125°C, the initial compaction for disturbed samples was greater than that for the undisturbed sample. However, the behavior was similar to that of disturbed samples at 23°C. In the pressure range 5 to 25 MPa, we again see that the disturbed sample behaved similarly to the undisturbed sample. As pressure was raised above 35 MPa, the 10% sample showed no observable compaction, indicating that (as before) a 10% disturbance caused some permanent compaction of pore space in the sample.

The oil-sand data indicate that the disturbances of 5 and 10% introduced void space equal to 5-7% of the initial volume into the samples. This void space closed as effective pressure was raised to 7.5 MPa. A disturbance of 10% appears to have introduced some permanent compaction into the oil-sand. At effective pressures below 25 MPa, the 10% disturbed material behaved similarly to that disturbed only 5%; but as effective stress was raised above 25 MPa, the 10% material became very stiff. Temperature had very little effect because the disturbed material behavior at 125°C was similar to its behavior at 23°C.

Figure 9. The PV data for undisturbed and disturbed oil-sand at 125°C.

3.1.3 Undisturbed Shale: Pressure-Volume Behavior

Pressure-volume (PV) behavior for undisturbed shale samples tested at effective stress to 45 MPa and at temperatures of 23 and 125°C is shown in Fig. 10 and tabulated values are in Appendix A. Data for the sample tested at 23°C show that for P_E lower than 2.5 MPa, the compressibility of the shale was below the resolution of the testing apparatus. As effective pressure was raised to 45 MPa, the sample compacted linearly with increasing effective pressure; we calculated the bulk modulus to be 2100 MPa for this pressure range (see Table 3). As effective pressure was lowered, the sample regained only about one-fourth of the volume lost, indicating that the increased effective pressure caused permanent compaction of pore space. The sample tested at 125°C experienced a volume strain of 0.05 as effective pressure was raised to 5 MPa. As effective pressure P_E was increased from 5 to 45 MPa, this sample showed a slight increase in slope of the PV curve with increasing pressure. Calculation of bulk modulus (K) over the pressure range 25 to 45 MPa indicates a value of approximately 1660 MPa, which is somewhat lower than the value of K calculated for the 23°C sample.

Comparison of results from the tests at 23 and 125°C indicates that the sample tested at 23°C compressed linearly with increasing effective pressure. The data also indicate that heating to 125°C caused mechanical disturbance and opened pore space and/or cracks in the friable shale sample. These cracks closed as effective pressure was raised above 5 MPa. More importantly, at effective pressures to 45 MPa, the bulk modulus of the heated sample was significantly less than that of the unheated sample, showing that the high temperature shale was more compressible. This might be due to changes in the viscosity and compressibility of the oil phase present in the shale or to other mechanisms such as changes in surface tension of liquid phases with temperature. Explanation of this behavior requires study beyond the scope of this report.

3.1.4 Shale: Effect of Disturbance

Results of PV tests on disturbed and undisturbed shale samples tested at 23°C are shown in Fig. 11. Here we define disturbed samples as those strained to 5 and 10% axial strain in unconfined triaxial tests (see Section 3.2.2 and Appendix C). In these triaxial tests, both of the shale samples exhibited brittle or

Figure 10. The PV behavior of undisturbed shale at 23 and 125°C.

Figure 11. The PV data for undisturbed and disturbed shale at 23°C.

transitional behavior with strain-softening occurring at strains greater than 0.03. The PV data for both disturbed samples show that, as effective pressure was raised to 2.5 MPa, significant volume changes occurred. As effective pressure was increased from 2.5 to 45 MPa, both of the disturbed samples showed similar behavior and the 5% sample was slightly more compressible than the 10% sample. This indicates that, as with the oil-sand samples, axial strain of 10% may introduce some permanent compaction into the samples. Summary data given in Table 3 indicate that, at 23°C, computed values of bulk modulus of the disturbed samples are approximately one-half of that for the undisturbed sample.

The PV data for undisturbed and disturbed shale samples tested at 125°C are plotted in Fig. 12; tabulated data are in Appendix A. These data show that, as effective pressure was raised to 5 MPa, there was little difference between the behavior of the disturbed and undisturbed samples because they all compacted about 5%. As effective pressure was raised from 5 to 45 MPa, the 5% disturbed sample was somewhat more compressible than the undisturbed sample. However, the 10% sample continued to compact at a high rate as effective pressure was raised from 5 to 15 MPa. At effective pressures above 15 MPa, the behavior of all three samples was similar, which indicates that mechanical disturbance had less effect on shale samples at 125°C than at 23°C. All of the shale samples tested at 125°C showed about 5% volume strain as effective pressure was raised to 5 MPa.

This is the only test of the series in which the 5% disturbed sample compacted less than the 10% disturbed sample and can be explained by considering the density of the samples (see Table 1). Sample 7 (5%) had an anomalously low density of 1.84 g/cm³ and was quite weak in unconfined axial compression (ultimate stress = 0.8 MPa). Sample 23 (10%) had a higher density (2.03 g/cm³) and was stronger in unconfined axial compression (ultimate stress = 8 MPa) and failed by brittle fracture. Our interpretation is that disturbance of sample 7 caused permanent compaction, but disturbance of sample 23 caused extensive cracking.

In summary, at 23°C, mechanical disturbance of the samples significantly affected the PV behavior of shale at both low and high pressures. At the lower pressures, significant closure of cracks or fissures was evident, and at higher pressures, the bulk modulus was reduced by as much as a factor of 2. Mechanical disturbance had less effect on the samples tested at 125°C. At this

Figure 12. The PV data for undisturbed and disturbed shale at 125°C.

temperature, undisturbed and disturbed samples behaved alike as effective pressure was increased from 0 to 5 MPa. However, above 25 MPa, the bulk modulus of disturbed samples was lower than for the undisturbed sample. Moreover, these results indicate that, as pressure was raised from 25 to 45 MPa, the bulk modulus of the disturbed samples at both temperatures was 800-1200 MPa. Thus, for a disturbed sample, temperature had little effect on compressibility in this pressure range. These results also show that samples of both oil-sand and shale were not significantly disturbed by the coring, handling, and shipping activities that occurred prior to testing.

3.2 TASK D.2: LABORATORY DETERMINATION OF PARAMETERS FOR MODEL SIMULATIONS: TRIAXIAL TESTS

The objective of this task is to provide parameters for input to reservoir behavior models. Work conducted on this task included triaxial tests on both oil-sand and shale at a series of temperatures and pressures. The stress-strain data determined from these tests was used to determine Mohr-Coulomb failure envelopes for these materials at temperatures of 23, 125, and 250°C.

In all, we conducted more than 34 triaxial tests for this task. During all tests, pore fluid pressure was maintained at one-half the confining fluid pressure.

3.2.1 Oil-Sand Triaxial Tests

Oil-sand samples were tested at 23, 125, and 250°C and at confining pressures ranging from 0.1 to 300 MPa. Stress-strain plots for tests at 23°C are shown in Figs. B-1 to B-5 in Appendix B. Tabulated data for each test are also contained in Appendix B. Results are shown as axial stress ($\sigma_1 - \sigma_3$) vs. axial strain. A typical stress-strain plot is shown in Fig. 13. This plot shows the various regions of the stress-strain curve, including an initial elastic compression, peak or ultimate stress, and residual stress after failure. The data for two unconfined tests are shown in Fig. 14. These samples behaved in a strain-hardening manner, and axial compressive strength increased from approximately 0.5 MPa at 0.007 strain to approximately 1.75 MPa at 0.08 strain. The effect of raising effective

Figure 13. Stress-strain data for oil-sand at 23°C and pressure of 5 MPa.

Figure 14. Stress-strain data for unconfined oil-sand at 23°C.

pressure to values in the range 2.5 to 25 MPa is shown in Fig. 15. As expected, samples tested at the highest effective pressures were strongest. However, these data show that, as effective pressure was increased in the range 2.5 to 10 MPa, compressive strength of the oil-sand remained relatively constant. The results indicate that the material undergoes a brittle-to-ductile transition in this pressure range because the behavior at $P_E = 2.5$ MPa is brittle, but clearly ductile behavior is shown at $P_E = 10$ MPa. Note that, at strains greater than about 0.04, all samples show strain-hardening behavior.

These results show that, although the oil-sand was unconsolidated at unconfined conditions when confining pressure was applied, some failure occurred via a faulting mechanism. This is illustrated by the test of sample 18 (Figure B-2), which shows significant loss of strength after failure and by the test of sample 17 (Figure B-3). The overall behavior of sample 17 suggests failure by ductile flow and strain-hardening. However, at least three failure events occurred during the test in which the strength dropped by a few MPa. This suggests that faulting occurred within the confined samples of oil-sand at 23°C.

Results of triaxial tests on oil-sand at 125°C and at various confining pressures are presented in Figures B-6 to B-11. Tabulated data for these tests are included in Appendix B. Again, data are plotted as $\sigma_1 - \sigma_3$ vs. axial strain. Unconfined samples (Fig. 16) have an ultimate strength of approximately 0.25 MPa and show strain-softening behavior. Stress-strain curves for samples tested at effective pressures from 5 to 150 MPa are shown in Fig. 17. As effective pressure was raised to 150 MPa ($T = 125^\circ\text{C}$), compressive strength generally increased with confining pressure and values of $(\sigma_1 - \sigma_3)$ were 7 to 35 MPa. Samples tested at effective pressures of 5-25 MPa deformed by ductile flow and showed strain-hardening behavior. This indicated that, at these pressure and temperature conditions, pore fluid drained from the samples during deformation and strength was increased due to increased grain-to-grain contact. The oil-sand sample tested at an effective pressure of 150 MPa exhibited elastic behavior at strains less than or equal to 0.01 and yielded by ductile flow at strains greater than 0.02. The ultimate stress for this sample was 32 MPa.

Oil-sand samples were also tested at 250°C under unconfined conditions. Data for these tests are plotted in Figures B-12 and tabulated data are presented in Appendix B. The samples in these tests failed at an axial

Figure 15. Stress-strain curves for oil-sand samples tested at 23°C and effective pressure to 25 MPa.

Figure 16. Stress-strain plots for unconfined oil-sand samples at 125°C.

Figure 17. Stress-strain plots for oil-sand samples tested at 125°C .

stress of approximately 1 MPa, which is similar to the value measured for unconfined oil-sand at 23°C. Attempts to test oil-sand at 250°C and at elevated effective pressures were unsuccessful due to jacket failures.

Mohr-Coulomb failure envelopes for the oil-sand samples at 23 and 125°C were constructed as follows (Fig. 18). First, a line was fitted (graphically) to the ductile (plastic) portion of the stress-strain curves for each oil-sand sample, and the value of $\sigma_1 - \sigma_3$ at 4% strain along this line was read from the graph. For these tests,

$$\sigma_2 = \sigma_3 = P_E;$$

so σ_1 (4%) was computed as

$$\sigma_1(4\%) = (\sigma_1 - \sigma_3)_{4\%} + P_E.$$

The strength at 4% was chosen because all samples displayed ductile behavior at this strain. Values of $\sigma_1 - \sigma_3$ at 4% strain are tabulated in Table 4.

The Mohr circles show that raising the temperature from 23 to 125°C had very little effect on the compressive or shear strength of oil-sand. At effective stress below 35 MPa, the angle of internal friction is approximately 15 degrees. (Note that data for sample 21 do not fit this trend and were omitted from the plot. This sample was unusually strong.)

The above results show that, by increasing temperature from 23 to 125°C, the compressive behavior of oil-sand was affected in the following ways. First, the unconfined compressive strength decreased with increasing temperature, from between 1 to 2 MPa at 23°C to 0.25 MPa at 125°C. The samples are stronger at 23°C, possibly because at this temperature the oil in the pore was quite viscous and helped to bond the sample together. At 125°C, the oil viscosity was lower and provided less bonding, which allowed the sample to split more easily. Results of confined tests show that at both temperatures compressive strength increased as effective pressure was raised. Samples tested at equivalent pressures had similar strengths, and most of the samples strain-hardened throughout the test. However, for samples tested at equivalent pressures, those tested at 23°C were slightly stronger at strains less than 0.03, but the plastic modulus (rate of increasing strength with increasing strain) was higher for samples tested at 125°C.

Figure 18. Mohr circles for oil-sand showing results from tests at 23 and 125°C.

Table 4. Summary data for oil-sand.

Sample No.	Depth (ft)	Confining Pressure (MPa)	Effective Pressure ($P_E = \sigma_3$)	Test Temperature ($^{\circ}\text{C}$)	Elastic Modulus (MPa)	Plastic Modulus (MPa)	$\Delta V/V_0$	$\sigma_1 - \sigma_3$ (@ $\epsilon=4\%$) (MPa)
10	3279	0.1	--	23	67	16	--	1.3
11	3279	0.1	--	23	35	11	--	0.94
18	3308	5	2.5	23	410	39	0.032	7.9*
17	3307	10	5	23	--	62	0.068	3
16	3308	20	10	23	741	36	0.071	7.4
15	3307	50	25	23	810	31	0.062	15
24	3308	0.1	--	125	57	0.23	--	0.3
25	3308	0.1	--	125	133	--	--	--
21	3308	10	5	125	--	71	0.042	8.5
20	3308	20	10	125	3750	66	0.060	7
20A	3307	20	10	125	--	52	0.132	7
19	3307	50	25	125	--	156	0.114	15.5
32	3280	300	150	125	4000	15	0.081	32
30	3308	0.1	--	250	--	15	--	1.2
31	3308	0.1	--	250	--	--	--	1.6

*At 3% strain

The strain-hardening behavior of the samples can be explained by increased grain-to-grain contact as strain increased, which is caused by draining of pore fluid during the test. The volume of fluid expelled during each test, normalized to the volume of the sample, is listed in Table 4. Fluid was expelled during all tests on oil-sand, and, generally, more fluid was expelled during tests at 125°C. As the pore fluid was expelled, porosity and void ratio decreased and grain-to-grain contact increased. It is interesting to note that the stress-strain curves for the 125°C tests are smoother in character and do not contain as many "faulting" events.

In summary, raising the temperature from 23 to 125°C did not have a major effect on the compressive strength of oil-sand. The compressive strength seems to be controlled by pore fluid drainage from the material as axial compression was applied. The oil-sand had very little matrix strength; as pore fluid was expelled, porosity and void ratio decreased, density increased, and grain-to-grain contact increased. Pore fluid drainage was somewhat enhanced at 125°C by both the decreasing viscosity of the petroleum and the mechanical disturbance caused by heating (see PV results in Section 3.1.1). Oil-sand samples tested at 125°C strain-hardened at a slightly faster rate than samples tested at 23°C.

3.2.2 Shale

Samples of the shale formation that overlies the oil-sand were also tested at triaxial conditions at temperatures of 23, 125, and 250°C and at confining pressures to 300 MPa. Tabulated data for these tests are presented in Appendix C, along with a stress-strain plot for each sample. Data for two unconfined samples tested at 23°C are shown in Fig. 19. Each sample failed by brittle fracture at a strain of 0.025 or less. Values of ultimate stress were 5.7 and 5.4 MPa. Both samples had significant residual strength at strains greater than 0.04. Data for samples tested at effective pressures 1-5 MPa are shown in Fig. 20. These samples failed in a transitional mode with ultimate stress of 7 to 12 MPa. Samples tested at effective pressures 10-150 MPa are shown in Fig. 21. These samples all failed in a ductile mode, and all showed strain-hardening at strains greater than 0.03. Figure 21 shows that at 23°C raising effective pressure above 25 MPa had little effect on the compressive strength of the shale.

Figure 19. Stress-strain behavior for unconfined shale samples tested at 23°C.

Figure 20. Stress-strain behavior for shale samples at effective pressures of 1, 2.5, and 5 MPa.

Figure 21. Stress-strain behavior for shale samples tested at $P_E = 10$ to 150 MPa.

The Mohr circles for shale tested at 23°C are shown in Fig. 22. Using the classical failure analysis, we found that the shale had a friction angle of 35 degrees at stress levels less than 20 MPa. At pressures above 25 MPa, compressive stress had little effect on the shear stress; that is, maximum shear stress remained constant at approximately 12 MPa as compressive stress was increased.

The effect of increased effective pressure on shale at a temperature of 125°C is shown in Figs. C-8 to C-14 in Appendix C. Unconfined samples (Figs. C-8,9) showed failure by brittle fracture with an ultimate strength of 0.9 MPa at a strain of 0.04. Samples tested at effective pressures 5-150 MPa are shown in Fig. 23. Failure strength increased with increasing pressure, and all samples yielded at strains in the range of 1 to 4%.

Mohr circles for samples tested at 125°C are plotted in Fig. 24. This plot indicates that, at pressures less than 35 MPa, the shale had a friction angle in the range of 12 to 18 degrees.

Shale samples were also tested at 250°C and at pressures of 0.1 and 300 MPa. Results are presented in Appendix C as stress-strain plots and as tabulated data. Data for these tests show that the unconfined samples failed by brittle fracture and had ultimate stress values similar to the unconfined samples tested at 23 and 125°C. One sample tested at $P_E = 150$ MPa failed by ductile flow, and its ultimate strength of 74 MPa was the highest of all the shale samples. Values of elastic modulus for these samples are listed in Table 5. The moduli for these shale samples are quite variable, but they generally increase with increased effective pressure.

The Mohr circles for shale tested at 23, 125, and 250°C are plotted in Fig. 25. This plot clearly shows that, at an effective pressure of 150 MPa, the shear strength of the shale at 250°C was approximately twice that at 23°C. This plot also shows that, at effective stresses greater than 25 MPa, the angle of friction for the shale increased with increasing temperature from approximately 0 degrees for samples at 23°C, to between 9 and 11 degrees. for samples at 250°C. However, at pressures less than 25 MPa, the shale was strongest at 23°C.

One possible interpretation of these data is that, as shown in Section 3.1.3, the shale was more compressible at the higher temperatures. Consequently at the higher temperatures, the sample was compacted by the

Figure 22. Mohr circles for shale tested at 23°C.

Figure 23. Stress-strain for shale at 125°C , $P_E = 5 - 150\text{ MPa}$.

Figure 24. Mohr circles for shale at 125°C.

Table 5. Summary data of shale.

Sample No.	Depth (ft)	Confining pressure (MPa)	Effective pressure (MPa)	Temperature (°C)	Elastic modulus ($\sigma_1 - \sigma_3$)@4%E (MPa)	Ultimate stress (MPa)
5	3206	0.1	--	23	314	5.4
4	3206	0.1	--	23	381	5.7
14	3210	2	1	23	268	8.2
13	3206	5	2.5	23	857	12
12	3206	10	5	23	--	7
2	3204	20	10	23	1622	23
1	3204	50	25	23	2500	18
9	3204	300	150	23	391	24
7	3202	0.1	--	125	--	0.86
23	3202	0.1	--	125	750	9
22	3210	10	5	125	--	7.6
26	3202	20	10	125	--	--
27	3211	50	25	125	3958	27
17A	3211	50	25	125	1850	14
27B	3202	50	25	125	694	16
33	3210	300	150	125	1695	45
28	3202	0.1	--	250	230	6.3
29	3202	0.1	--	250	490	12.3
34	3211	300	150	250	3550	74

Figure 25. Mohr circles for shale at 23, 125, and 250°C.

initial hydrostatic loading imposed before the axial stress was applied. Thus, material tested at higher temperatures had higher density, lower porosity, and a smaller void ratio. The viscosity of the pore fluid at this temperature was also lower. These factors provided for better pore fluid drainage, and greater grain-to-grain contact. Thus, the material was stronger in compression. In summary, these results indicate that the compressive strength of the shale caprock was dependent on pressure, temperature, and loading path.

3.3 TASK D.3: LONG-TERM CREEP/COMPACTION BEHAVIOR

We conducted long-term creep compaction tests to study the impact of effective stress (the difference between the confining stress and the pore pressure) and temperature on the long-term deformational behavior of reservoir shale and heavy oil-sand. We used cores of the Faja Formation provided by INTEVEP and referred to as core numbers 49 (3202 to 3204 ft--shale), 51 (3206 to 3208 ft - shale), and 70 (3278.83 to 3280.83 ft--heavy oil-sand), with an additional shale sample from a 3309.5-ft depth. In the first two tests, Creep 1 and Creep 2, we kept the samples at room temperature and measured the volume change with time at confining pressures of approximately 600, 800, 1200, and 1600 psi (4.14, 5.52, 8.28, and 11.03 MPa). In all cases, we maintained the pore pressure at one-half the value of the confining pressure; thus, the effective stress was equal to the pore pressure. For the later tests, Creep 3, Creep 4, and Creep 5, we elevated the temperature to 125°C and kept the confining pressure equal to 800 psi (5.52 MPa), except for Creep 3, in which we raised the confining pressure to 1200 psi (8.28 MPa) later in the test.

We prepared the samples for the long-term creep tests in the same manner as we did for the uniaxial stress and PV tests. The preparation procedure is given in the previous section. In Creep 1, we used only one shale sample in the pressure vessel; for all the rest of the creep tests, three samples were in the vessel at one time. Temperature was controlled by a Microstar Heater Controller located outside of the pressure vessel. Two thermocouples placed inside the pressure vessel monitored the temperature, and the data were stored at one-hour intervals on the system computer. We used the heater only for the tests when temperature was to be held at 125°C; for the 25°C tests, the vessel temperature was at ambient. In Creeps 1-4, the sample pore pressure was

accessed through a porous spacer at only one end of the sample. In Creep 5, we put spacers on each end of the sample so that fluid could enter or exit the sample through both ends (doubly drained test). We maintained pore pressure at a value approximately one-half the confining pressure by manually adjusting the volumeters (see Fig. 6). During the first few hours of a test, we adjusted the pore pressure every 10 minutes. After the confining pressure and pore pressure stabilized, we adjusted the pore pressure less frequently and, eventually, only once or twice daily. The confining pressure was controlled by the computer once the system reached the desired temperature and pressure equilibrium. Confining pressure was raised at selected times during tests 1, 2, 3, 4; and for a few hours after each increase in confining pressure, pore pressure was adjusted every 10 minutes.

The volumeter measured an increase or decrease in the sample pore volume by measuring the volume of fluid added to or removed from the sample each time the pore pressure was adjusted. The computer recorded values of the pore pressure, confining pressure, and temperature every hour, or more frequently when changes were made in the confining pressure. On some occasions, when the operator arrived to make the manual adjustment in the pore pressure, he noted that the pore pressure had changed considerably. In some cases, the pore pressure change affected the experimental results. These cases are discussed in the following sections.

3.3.1 Results of the Long-Term Creep Tests

The tests performed on the Faja reservoir rocks are summarized in Table D-1 in the order in which they were finished. The pressure and temperature conditions for each test and each sample are also listed. In each case, we tried to keep pore pressure equal to one-half the confining pressure. A time delay occurs between the time a change in the pressure setting is made and the time the pressure actually changes in the vessel; when large changes are made in the pressure, the system can become unstable. For this reason, we kept the pressure changes to a minimum. In some cases, the effective pressure was not exactly equal to one-half the confining pressure. In this section, we discuss details of the results of each test and illustrate the results with a semilogarithmic plot of the fractional volume change vs. elapsed time in hours. Tabulated listings of data for long-term creep tests are in Appendix D.

Creep 1 (Table D-1a and Fig. 26) illustrates typical behavior of a Faja shale sample. Initially the confining pressure was approximately 900 psi (6.21 MPa). It was raised to approximately 1300 psi (8.97 MPa) after 210 hr and to approximately 1700 psi (11.7 MPa) after 375 hr. After an initial period of rapid change in volume when the pore pressure and confining pressure were first applied, the deformation became a linear function of the log of time. The initial rapid change in volume is generally referred to as primary compaction; the later stable linear change is referred to as secondary compaction. When the confining pressure was increased and the pore pressure was readjusted, another rapid decrease in volume (primary compaction) was followed by a period of stable secondary compaction. In Creep 1, this happened in both successive changes in confining and pore pressure. At 300 hr, there is a short step in the linear part of the curve, which is the result of a change in the pore pressure (and, hence, the effective pressure) that caused a temporarily rapid decrease in the volume. We performed a linear regression on the linear parts of the curves at each confining pressure range to determine the slope of the curve, or $d(V/V_0)/d(\log t)$. In the initial linear part of the curve, for a P_E (effective pressure) of 420 psi (2.90 MPa), the slope was $-1.72 \times 10^{-3} \text{ s}^{-1}$ (with volume change as a fraction, not a percent). For P_E of 625 psi (4.31 MPa for the second portion of the test), the slope is $-6.0 \times 10^{-3} \text{ s}^{-1}$ for the first linear portion and $-3.7 \times 10^{-3} \text{ s}^{-1}$ for the second linear portion. For the last part of the test, when P_E was 825 psi (5.69 MPa), the slope (determined by only two points) was $-1.2 \times 10^{-3} \text{ s}^{-1}$. The success of this initial test led us to use a similar procedure for the subsequent tests on the Faja reservoir rocks.

In Creep 2, we used three different rocks--two shale and one oil-sand. The results are listed in Tables D-2(a-d) and illustrated in Figs. 27 (a-c). Three confining pressures were used, approximately 540, 1200, and 1600 psi (3.72, 8.28, and 11.03 MPa). Pore pressures were different for each sample because we used separate volumeters. This test was run with temperature at ambient, approximately 25°C. The 3206-ft shale sample and 3280-ft oil sand, sample showed similar behavior. For these two samples, we observed a small net increase in volume during the first 120 hr of the test, when confining pressure (P_c) was 540 psi (3.72 MPa). When we increased P_c and the pore pressure (P_p) after 120 hr, the volume change behaved as we observed in the first creep test. The 3280-ft oil-sand sample volume increased a small

Figure 26. Creep results for a Faj shale sample, unknown depth. V/V_0 is expressed as a percent.

Figure 27. (a) Creep results for shale, 3309-ft sample at 25°C. V/V_0 is expressed as a percent. (b) Creep results for shale, 3206-ft sample at 25°C. V/V_0 is expressed as a percent. (c) Creep results for the oil-sand, 3280-ft sample at 25°C.

amount approximately 140 hr into the test, after P_c was increased. This aberration in the volume change behavior was probably not due to a change in pressure conditions because the effective pressure (P_E) was kept relatively constant (approximately 635 ± 30 psi). After approximately 180 hr, the volume change behavior became log-linear with time. Slopes of $d(V/V_0)/d(\log t)$ for the samples are summarized in Table 5.

In Creep 3, (two shale samples and one oil-sand sample), we used confining pressures of 800 and 1200 psi (5.5 and 8.27 MPa). Results of the test are listed in Tables D-3(a-c). The temperature of the heater controller was maintained at approximately 125°C for this test; temperatures measured by thermocouples in the pressure vessel were approximately 4-5°C higher. From the beginning to the end of this test, the two shale samples showed an increase of pore volume with time. This led us to suspect a failure of the sample jacket. Upon completion of the test, we observed a rupture in the jacket of the 3202-ft shale sample. We did not observe any jacket leaks in the 3204-ft shale sample, but the data indicates that the jacket probably failed early in the test. The only good data for this test, then, is for the oil-sand sample; it is plotted in Fig. 28. The creep data shows erratic changes in volume up until approximately 290 hr into the test, when a log-linear volume change with time becomes evident. The deviations from linear behavior [Fig. 28] were related to changes of 145 psi (1.0 MPa) or more in P_E during periods between times when the pore volume was readjusted. We used only points that fell on the linear trend of the curve when we determined the slopes of the volume-time behavior for this sample. The slope for the first segment of the curve, $P_E = 450$ psi (2.99 MPa), was $-66.1 \times 10^{-3} \text{ s}^{-1}$. The slope for the second part of the curve, when the average P_E was 645 psi (4.28 MPa) is $-103.8 \times 10^{-3} \text{ s}^{-1}$.

Two shale samples and one oil-sand sample were again used in Creep 4. In this case, we used only one value of confining pressure, which averaged 755 psi (5.21 MPa). Temperature was maintained at 125°C, as it was in Creep 3. The jacket of the 3207-ft shale sample failed early in the test as noted in Table D-4c. The oil-sand sample (Table D-4a, Fig. 29) hardly changed in volume between 10 and 100 hr, and then the volume decreased rapidly after approximately 145 hr, even though the pressure and temperature conditions were relatively constant, with an average P_E of 520 psi (3.59 MPa). The slope of the curve, when the volume decreased rapidly, was approximately $-146.0 \times 10^{-3} \text{ s}^{-1}$.

Figure 28. Creep results for the oil sand, 3280-ft sample at 125°C .

Figure 29. Creep results for the oil-sand, 3280-ft sample at 125°C .

The 3202-ft shale sample also showed two log-linear segments of creep behavior, as seen in Fig. 30. The initial slope was $-6.52 \times 10^{-3} \text{ s}^{-1}$; after 145 hr the slope increased to $-44.5 \times 10^{-3} \text{ s}^{-1}$. This change in slope occurred while P_E was maintained at an average value of 463 psi (3.19 MPa). The change in slope occurred at about the same time for both the shale and oil-sand samples, suggesting that some systematic change in the experimental conditions probably occurred at approximately 145 hr into the test. However, we found nothing in the test records to indicate any large or unusual changes in the temperature or pressure conditions.

After obtaining the questionable results of Creep 4, we decided to repeat the test conditions for Creep 5. In Creep 5 we kept P_C at approximately 800 psi (5.31 MPa) for the entire test run, which lasted almost 1000 hr. The temperature was maintained at 125°C as in Creep 3 and 4. In Creep 5, the samples were allowed to drain from both ends of the sample, resulting in much better data. The data for Creep 5 (Tables D-5(a-c) and Figs. 31 (a-c) are the best of the series. The two shale samples (3202- and 3206-ft) had a remarkably linear change in volume vs. the log of time throughout the entire test. The $d(V/V_0)/d(\log t)$ slope for 3202-ft shale was $-42.49 \times 10^{-3} \text{ s}^{-1}$ for an average P_E of 445 psi (3.071 MPa). The slope for 3206-ft shale was $-36.31 \times 10^{-3} \text{ s}^{-1}$ for time less than 300 hr, and $-40.26 \times 10^{-3} \text{ s}^{-1}$ for time greater than 300 hr, for an average P_E of 428 psi (2.96 MPa). The oil-sand sample [Fig. 31(c)] showed an increase in the rate of volume change after 600 hr, from a slope of $-77.2 \times 10^{-3} \text{ s}^{-1}$ (less than 200 hr) and $-68.2 \times 10^{-3} \text{ s}^{-1}$ (200 to 600 hr.) to $-112.7 \times 10^{-3} \text{ s}^{-1}$ after 600 hours. The average P_E for the oil-sand sample was 380 psi (2.52 MPa) in this test.

3.3.2 Long-Term Creep: Summary and Conclusions

Our creep tests were inherently different than the standard type of creep test discussed by other workers. Most drained creep tests of which we are aware are standard compaction or loading tests in which a uniform, time-invariant uniaxial load is applied to a sample under confining pressure and the length change of the sample is monitored over time. In our tests, the internal pore volume change was monitored over time for conditions in which

Figure 30. Creep results for shale, 3202-ft sample at 125°C.

Figure 31. (a) Creep results for the shale, 3202-ft sample at 125°C; (b) creep results for the shale, 3206-ft sample at 125°C; and (c) creep results for the oil-sand, 3278-ft sample at 125°C.

the temperature, pore pressure, and confining pressure were held as constant as possible under the experimental procedures. Because of the experimental procedures and very few volumometer adjustments, we were unable to completely assure that the pore pressure was constant at all times. Nevertheless, the experimental results indicate that in most cases the relatively small changes in P_E that occurred between times when the pore volume was adjusted did not significantly affect the overall results. Creep 5 shows that the data was improved by draining the sample from both ends. We recommend that porous spacers and pore pressure connections be made at both ends of the sample in future creep tests.

Even though these experiments were somewhat different than the standard type of creep test, we did observe a linear change in volume as a function of the log of time, as has been observed in standard types of creep tests on solid rock. In Table 6, we list the slopes of the curves of volume change vs. log time for the shale and oil-sand rock types, the two temperatures, and the various effective pressures used. The only systematic effects that we can note from Table 6 are that the rate of volume change with time was larger at 125 than 25°C for both the shale and oil-sand samples. Results also indicate that the rate of volume change with time is a very sensitive function of the effective pressure, although our data are not sufficiently complete to determine any systematic behavior.

Creep tests are inherently difficult to complete successfully because many opportunities arise for things to go wrong during a test that lasts 1000 hr or more. The tests that we report here should be considered only preliminary determinations of certain aspects of the creep behavior of the reservoir rocks studied. We suggest that these data be used only to gain insight into long-term deformational behavior of reservoir rocks and that the data probably are not suitable for making detailed calculations of reservoir behavior.

4. SUMMARY AND CONCLUSIONS

The PV tests indicate that the bulk modulus of the "undisturbed" heavy oil-sand samples was 430-670 MPa. Increasing the temperature on unconfined oil-sand to 125°C causes thermal cracking or some other mechanism that expands the sample, creating about 5% void. However, the void closed at effective

Table 6. Summary of long term creep test results.

<u>Temperature 25°C</u>			<u>Temperature 125°C</u>		
<u>Sample</u>	<u>P_E (psi)</u>	<u>Slope (s⁻¹ x10⁻³)</u>	<u>Sample</u>	<u>P_E (psi)</u>	<u>Slope (s⁻¹ x10⁻³)</u>
Shale 3309	200	-20.0	Shale 3202	463	-44.5
Shale	420	-1.72	Shale 3202	445	-42.5
Shale 3309	600	-19.9	Shale 3206	430	-36.3, -40.3
Shale 3206	615	-4.24			
Shale	625	-3.7			
Shale	825	-1.2			
Shale 3309	800	-11.7			
Shale 3206	820	-8.65			
Oil-sand 3280	635	-3.63	Oil-sand 3278	380	-77.2, -68.2, -112.7
Oil-sand 3280	836	-8.06	Oil-sand 3280	450	-66.1
			Oil-sand 3280	520	-146.0

pressures above 7.5 MPa, and the rock behaved as it would at room temperature. This implies that, at in situ reservoir pressures, heating the oil-sand to 125°C will have very little effect on the bulk modulus. Another result is that, at both 25 and 125°C, the decrease in volume with increasing effective pressure results from permanent pore compaction that occurs as pore fluid is expelled from the sample.

Tests on disturbed oil-sand samples indicate that the void introduced by mechanical disturbance was closed as effective pressure was raised above 7.5 MPa and that a disturbance of 10% axial strain may cause some permanent compaction of oil-sand. Increasing temperature from 23 to 125°C had very little effect on the disturbed oil-sand samples.

Results of PV tests for shale indicate that at 23°C the shale compresses linearly with a bulk modulus of ~2100 MPa. However, heating to 125°C caused mechanical disturbance and opened pore space and/or cracks in the friable shale sample. These cracks closed as effective pressure was raised above 45 MPa. More importantly, at effective pressures to 45 MPa, the bulk modulus of the 125°C sample was significantly less than that of the 23°C sample, showing that the high temperature shale was more compressible. This might be due to changes in the viscosity and compressibility of the oil phase present in the shale or to other mechanisms such as changes in surface tension of liquid phases with temperature. The tests also show that at 23°C mechanical disturbance significantly affected the PV behavior of shale; at pressures equivalent to those in the reservoir, the bulk modulus was reduced by as much as a factor of 2. Mechanical disturbance had less effect at 125°C. Moreover, these results indicate that, at pressures equivalent to reservoir conditions, all disturbed shale samples had bulk modulus in the range of 800 to 1200 MPa.

Triaxial tests on oil-sand indicate that temperature had very little effect on the unconfined compressive strength. Compressive strength of oil-sand increased with increasing effective stress, and samples tested at 23 and 125°C and at equivalent pressures had similar strengths. Ultimate stress for these samples ranged from 0.25 MPa for unconfined samples to more than 30 MPa for samples tested at an effective pressure of 150 MPa. Most of the oil-sand samples showed strain-hardening behavior, and some of the samples tested at 23°C showed evidence of failure by faulting events. Failure by faulting was not observed in samples tested at higher temperatures. Raising the temperature from 23 to 125°C did not have a major effect on the compressive

strength of oil-sand. Mohr-Coulomb failure analysis obtains an angle of internal friction of approximately 8 degrees at effective pressures below 25 MPa and essentially no internal friction at higher effective pressures.

Tests on shale indicate that, as expected, compressive strength increased with increasing effective pressure and that ultimate strength for this formation ranges from approximately 1 MPa for unconfined samples to more than 70 MPa for a sample tested at 250°C and effective pressure of 150 MPa. The results for the shale samples are quite variable. However, Mohr-Coulomb failure envelopes for the shales clearly show that, at pressures above 25 MPa, the shear strength of shale increases with increasing temperature. These results may be dependent on load path.

Results of long-term creep compaction tests show that there is a linear change in sample volume as a function of the log of time and that the rate of volume change with time was larger at 125°C than at 25°C for both shale and oil-sand. Results also indicate that the rate of volume change with time is dependent on effective pressure.

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APPENDIX A

TABULATED DATA FOR PV TESTS ON UNDISTURBED AND DISTURBED SAMPLES OF
OIL-SAND AND SHALE

FILE INDEX VZPV.WKS - PRESSURE/VOLUME TESTS

TEST #	WKS-LOC	P-C (MPa)	TEMP (C)	SAMPLE TYPE	SAMPLE #	DISTURBANCE
--------	---------	--------------	--------------	----------------	-------------	-------------

2	W1	50	23	OS	PV32	0%
				OS	PV11	5%
				OS	PV10	10%
5	AY1	50	125	OS	PV1/3a	0%
				OS	PV25	5%
				OS	PV24	10%
3	AE1	50	23	SH	PV9	0%
				SH	PV5	5%
				SH	PV4	10%
4	AO1	50	125	SH	PV33	0%
				SH	PV7	5%
				SH	PV23	10%

PV TEST #2 OIL-SAND T = 23 C
DEL V / Vo

P-eff (MPa)	OS-PV10 10%	OS-PV11 5%	OS-PV32 0%
0	0.000	0.000	0.000
2.5	0.059	0.067	0.000
7.5	0.080	0.083	0.014
5	0.076	0.078	0.009
15	0.100	0.104	0.030
25	0.122	0.129	0.054
35	0.127	0.150	0.071
45	0.127	0.165	0.084
35	0.127	0.163	0.084
25	0.127	0.161	0.082
15	0.126	0.156	0.077
5	0.118	0.148	0.071
7.5	0.121	0.152	0.074

PV TEST #5 OIL-SAND T = 125 C
DEL V / Vo

P-E (MPa)	OS	PV-24 10%	OS	PV-25 5%	OS	PV-1/1-3a 0%
0		0.000		0.000		0.000
5		0.073		0.063		0.049
15		0.098				0.073
25		0.123				0.093
35		0.138				0.111
45		0.140				0.123
35		0.148				0.123
25		0.148				0.120
15		0.149				0.117
5		0.149				0.110

PV TEST #3 SHALE T = 23 C
DEL V / Vo

P-eff (MPa)	SH-PV4 5%	SH-PV5 10%	SH-PV9 0%
0	0.000	0.000	0.000
2.5	0.096	0.079	0.000
5	-----	0.098	0.002
15	0.135	0.121	0.007
25	0.150	0.136	0.012
35	0.160	0.147	0.016
45		0.156	0.021
35		0.156	0.021
25		0.154	0.020
15		0.151	0.019
5		0.144	0.017
2.5		0.128	0.016
0		0.117	0.014

PV TEST #4 SHALE T = 125 C
DEL V / Vo

P-eff (MPa)	SH-PV7 5%	SH PV-33 0%	SH-PV23 10%
0	0.000	0.000	0.000
5	0.051	0.047	0.056
15	0.067	0.057	0.094
25	0.080	0.065	0.104
35	0.091	0.070	0.112
45	0.100	0.077	0.121
35	0.100	0.076	0.119
25	0.100	0.073	0.129
15	0.097	0.069	0.128
5	0.092	0.063	0.127

APPENDIX B

STRESS-STRAIN PLOTS AND TABULATED DATA FOR TRIAXIAL TESTS CONDUCTED ON
OIL-SAND SAMPLES

FILE INDEX VZOSAND.WKS - TRIAXIAL TESTS FOR OIL SAND

SAMPLE	PC	TYPE	TEMP C	LOCATION WKS
PV11	0.1	OIL-SAND	23	L1
PV10	0.1	OIL-SAND	23	V1
PV18	5	OIL-SAND	23	AE1
PV17	10	OIL-SAND	23	AN1
PV16	20	OIL-SAND	23	AW1
PV15	50	OIL-SAND	23	BF1
PV25	0.1	OIL-SAND	125	A200
PV24	0.1	OIL-SAND	125	J200
PV21	10	OIL-SAND	125	S200
PV20	20	OIL-SAND	125	AB200
PV20A	20	OIL-SAND	125	AK200
PV19	50	OIL-SAND	125	AT200
PV32	300	OIL-SAND	125	BC200
PV30	0.1	OIL-SAND	250	A300
PV31	0.1	OIL-SAND	250	J300

Figure B-1

TEST PV10 OIL-SAND T = 23 C
 CONFINING PRESSURE = 0.1 MPa L = 48.64 cm

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.000	0.000
0.055	0.100	0.001	0.161
0.100	0.181	0.002	0.291
0.120	0.200	0.002	0.321
0.315	0.300	0.006	0.480
0.400	0.367	0.008	0.586
0.437	0.400	0.009	0.639
0.541	0.500	0.011	0.797
0.600	0.550	0.012	0.875
0.700	0.592	0.014	0.940
0.770	0.600	0.016	0.952
0.900	0.602	0.019	0.952
1.000	0.614	0.021	0.969
1.100	0.641	0.023	1.010
1.200	0.662	0.025	1.040
1.300	0.682	0.027	1.069
1.363	0.700	0.028	1.097
1.500	0.739	0.031	1.155
1.700	0.757	0.035	1.179
1.877	0.800	0.039	1.241
2.000	0.828	0.041	1.282
2.200	0.882	0.045	1.360
2.269	0.900	0.047	1.385
2.400	0.925	0.049	1.421
2.500	0.943	0.051	1.445
2.600	0.966	0.053	1.477
2.729	1.000	0.056	1.526
2.900	1.040	0.060	1.581
3.000	1.062	0.062	1.612
3.170	1.100	0.065	1.664
3.300	1.137	0.068	1.715
3.400	1.160	0.070	1.747
3.500	1.180	0.072	1.773
3.600	1.189	0.074	1.784
3.700	1.195	0.076	1.790
3.773	1.200	0.078	1.794
3.900	1.207	0.080	1.800
4.000	1.217	0.082	1.811

TEST PV11 OIL-SAND T = 23 C
 CONFINING PRESSURE = 0.1 MPa

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.000	0.000
0.012	0.000	.000	0.000
0.032	0.100	0.001	0.163
0.100	0.150	0.002	0.244
0.182	0.200	0.004	0.324
0.300	0.268	0.006	0.433
0.365	0.300	0.007	0.485
0.500	0.349	0.010	0.562
0.637	0.400	0.013	0.643
0.700	0.408	0.014	0.655
0.800	0.412	0.016	0.660
1.000	0.434	0.021	0.692
1.100	0.450	0.023	0.715
1.300	0.468	0.027	0.742
1.400	0.484	0.029	0.765
1.473	0.500	0.030	0.790
1.700	0.545	0.035	0.857
1.900	0.569	0.039	0.891
2.104	0.600	0.043	0.936
2.200	0.623	0.045	0.970
2.300	0.650	0.047	1.011
2.400	0.675	0.049	1.047

Figure B-2

Oil-Sand sample #18 $T = 23\text{ C}$ $P_e = 2.5\text{ MPa}$

crtpv18.sac

TEST PV18 OIL-SAND T = 23 C
CONFINING PRESSURE = 5 MPa

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0	0	0.000	0.000
0.084	0.100	0.002	0.158
0.100	0.126	0.002	0.199
0.143	0.200	0.003	0.315
0.242	0.400	0.005	0.629
0.283	0.500	0.006	0.785
0.317	0.600	0.007	0.942
0.372	0.800	0.008	1.254
0.428	1.000	0.009	1.566
0.476	1.200	0.010	1.877
0.488	1.300	0.010	2.033
0.500	1.500	0.011	2.345
0.507	1.600	0.011	2.501
0.544	1.800	0.012	2.811
0.575	1.900	0.012	2.966
0.613	2.100	0.013	3.275
0.637	2.300	0.014	3.585
0.664	2.500	0.014	3.895
0.689	2.700	0.015	4.204
0.706	2.800	0.015	4.358
0.755	3.000	0.016	4.665
0.814	3.200	0.017	4.970
0.840	3.300	0.018	5.122
0.865	3.500	0.018	5.430
0.880	3.600	0.019	5.583
0.951	3.800	0.020	5.885
0.989	3.900	0.021	6.035
1.024	4.000	0.022	6.185
1.074	4.100	0.023	6.333
1.100	4.154	0.023	6.413
1.118	4.200	0.024	6.482
1.145	4.300	0.024	6.632
1.198	4.500	0.025	6.933
1.225	4.600	0.026	7.083
1.245	4.700	0.026	7.234
1.263	4.800	0.027	7.385
1.280	4.900	0.027	7.536
1.320	5.100	0.028	7.838
1.400	5.148	0.030	7.898
1.500	5.110	0.032	7.824
1.516	5.100	0.032	7.806
1.599	5.000	0.034	7.640
1.629	4.900	0.035	7.482
1.666	4.800	0.035	7.324
1.705	4.700	0.036	7.166
1.731	4.600	0.037	7.010
1.747	4.500	0.037	6.855
1.754	4.400	0.037	6.702
1.754	4.300	0.037	6.549
1.775	4.100	0.038	6.242
1.805	4.000	0.038	6.086
1.844	3.900	0.039	5.929
1.875	3.800	0.040	5.774

1.900	3.700	0.040	5.619
1.926	3.600	0.041	5.464
1.994	3.400	0.042	5.153
2.068	3.200	0.044	4.843
2.123	3.100	0.045	4.686
2.175	3.000	0.046	4.530
2.200	2.944	0.047	4.443
2.220	2.900	0.047	4.375
2.300	2.812	0.049	4.236
2.354	2.800	0.050	4.213
2.570	2.800	0.055	4.195
2.600	2.808	0.055	4.204
2.700	2.839	0.057	4.242
2.855	2.900	0.061	4.320
3.070	3.000	0.065	4.449
3.249	3.100	0.069	4.581
3.387	3.200	0.072	4.716
3.523	3.300	0.075	4.851
3.663	3.400	0.078	4.984
3.798	3.500	0.081	5.117
3.930	3.600	0.083	5.249
4.000	3.655	0.085	5.322
4.058	3.700	0.086	5.382
4.197	3.800	0.089	5.512
4.300	3.851	0.091	5.574
4.443	3.900	0.094	5.630
4.600	3.964	0.098	5.705

Figure B-3

TEST PV17 OIL-SAND T = 23 C
CONFINING PRESSURE = 10 MPa

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.000	0.000
0.000	0.160	0.000	0.264
0.015	0.200	.000	0.330
0.100	0.258	0.002	0.425
0.155	0.300	0.003	0.494
0.284	0.400	0.006	0.656
0.411	0.500	0.009	0.818
0.500	0.574	0.011	0.937
0.533	0.600	0.011	0.979
0.600	0.651	0.013	1.062
0.644	0.600	0.014	0.977
0.655	0.500	0.014	0.814
0.700	0.437	0.015	0.710
0.768	0.500	0.016	0.812
0.897	0.700	0.019	1.134
1.011	0.900	0.022	1.455
1.148	1.200	0.024	1.934
1.236	1.300	0.026	2.091
1.454	1.500	0.031	2.402
1.652	1.700	0.035	2.711
1.700	1.749	0.036	2.787
1.751	1.800	0.037	2.865
1.800	1.849	0.038	2.941
1.850	1.900	0.039	3.018
1.876	1.900	0.040	3.016
1.998	1.800	0.043	2.851
2.088	1.700	0.044	2.687
2.167	1.700	0.046	2.683
2.255	1.900	0.048	2.993
2.311	2.200	0.049	3.462
2.387	2.400	0.051	3.771
2.561	2.700	0.055	4.227
2.600	2.734	0.055	4.277
2.700	2.773	0.057	4.329
2.779	2.800	0.059	4.365
2.913	3.000	0.062	4.664
2.984	3.200	0.063	4.968
3.123	3.600	0.066	5.573
3.233	3.800	0.069	5.870
3.400	3.937	0.072	6.061
3.568	3.800	0.076	5.831
3.600	3.786	0.077	5.805
3.671	3.800	0.078	5.819
3.875	4.100	0.082	6.253
4.028	4.300	0.086	6.539
4.108	4.400	0.087	6.680
4.272	4.600	0.091	6.961
4.480	4.800	0.095	7.235
4.554	4.900	0.097	7.375
4.700	5.100	0.100	7.654
4.800	5.167	0.102	7.739

Figure B-4

Oil-Sand sample #16 $T = 23\text{ C}$ $P_e = 10\text{ MPa}$

crtpv16.sac

TEST PV16	OIL-SAND	T = 23 C		
CONFINING	PRESSURE = 20 MPa			
LENGTH=	1.748	DIA=	0.982	
AXIAL	AXIAL	AXIAL	AXIAL	
DISPL	FORCE	STRAIN	STRESS	
(mm)	(mv)		(MPa)	
0.000	0.000	0.000	0.000	
0.026	0.000	0.001	0.000	
0.051	0.100	0.001	0.170	
0.082	0.400	0.002	0.681	
0.122	0.800	0.003	1.360	
0.168	1.300	0.004	2.208	
0.217	1.700	0.005	2.884	
0.256	2.000	0.006	3.390	
0.295	2.200	0.007	3.726	
0.362	2.400	0.008	4.058	
0.382	2.500	0.009	4.226	
0.413	2.600	0.009	4.392	
0.558	3.000	0.013	5.051	
0.687	3.300	0.015	5.540	
0.826	3.600	0.019	6.025	
0.948	3.800	0.021	6.343	
1.015	3.900	0.023	6.500	
1.180	4.100	0.027	6.809	
1.274	4.200	0.029	6.960	
1.500	4.364	0.034	7.197	
1.567	4.400	0.035	7.245	
1.759	4.500	0.040	7.379	
1.889	4.600	0.043	7.522	
2.179	4.800	0.049	7.800	
2.313	4.900	0.052	7.940	
2.431	5.000	0.055	8.081	
2.682	5.200	0.060	8.360	
2.824	5.300	0.064	8.495	
2.900	5.336	0.065	8.540	
3.127	5.400	0.070	8.600	
3.366	5.500	0.076	8.716	
3.580	5.600	0.081	8.834	
3.724	5.700	0.084	8.965	
3.860	5.800	0.087	9.097	
3.993	5.900	0.090	9.228	
4.399	6.100	0.099	9.462	
4.500	6.142	0.101	9.507	
4.620	6.200	0.104	9.573	
4.623	6.200	0.104	9.573	

Figure B-5

TEST PV15	OIL-SAND	T = 23 C		
CONFINING	PRESSURE = 50 MPa			
LENGTH=	1.796	DIA=	0.988	
AXIAL	AXIAL	AXIAL	AXIAL	
DISPL	FORCE	STRAIN	STRESS	
(mm)	(mv)		(MPa)	
0.000	0.000	0.000	0.000	
0.003	0.000	.000	0.000	
0.124	0.200	0.003	3.416	
0.216	0.300	0.005	5.114	
0.300	0.362	0.007	6.158	
0.374	0.400	0.008	6.795	
0.400	0.415	0.009	7.047	
0.493	0.500	0.011	8.472	
0.594	0.600	0.013	10.144	
0.600	0.605	0.013	10.235	
0.710	0.700	0.016	11.805	
0.800	0.763	0.018	12.839	
0.900	0.765	0.020	12.841	
1.000	0.738	0.022	12.370	
1.100	0.723	0.024	12.095	
1.200	0.728	0.026	12.145	
1.300	0.767	0.028	12.779	
1.383	0.800	0.030	13.298	
1.500	0.837	0.033	13.885	
1.600	0.856	0.035	14.165	
1.700	0.867	0.037	14.316	
1.800	0.872	0.039	14.371	
1.900	0.885	0.042	14.553	
2.058	0.900	0.045	14.748	
2.114	0.900	0.046	14.731	
2.259	0.900	0.050	14.686	
2.400	0.909	0.053	14.793	
2.500	0.915	0.055	14.859	
2.600	0.921	0.057	14.926	
2.700	0.929	0.059	15.028	
2.800	0.939	0.061	15.144	
2.900	0.947	0.064	15.257	
3.100	0.959	0.068	15.381	
3.200	0.960	0.070	15.360	
3.400	0.964	0.075	15.368	
3.600	0.969	0.079	15.383	
3.700	0.976	0.081	15.464	

Figure B-6

Oil-Sand samples

$T = 125\text{ C}$

$P_e = 0.1\text{ MPa}$

crtpv25.sac
crtpv24.sac

TEST PV24 OIL-SAND T = 125 C
CONFINING PRESSURE = 0.1 MPa

LENGTH 1.993 DIAMETER 0.935

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
------------------------	------------------------	-----------------	--------------------------

0.000	0.000	0.000	0.000
0.002	0.100	.000	0.184
0.100	0.124	0.002	0.228
0.200	0.125	0.004	0.229
0.300	0.117	0.006	0.214
0.400	0.117	0.008	0.214
0.500	0.129	0.010	0.236
0.600	0.137	0.012	0.249
0.700	0.139	0.014	0.252
0.800	0.137	0.016	0.249
0.900	0.136	0.018	0.247
1.000	0.136	0.020	0.246
1.100	0.138	0.022	0.248
1.200	0.139	0.024	0.251
1.300	0.140	0.026	0.252
1.400	0.139	0.028	0.249
1.600	0.138	0.032	0.247
1.700	0.141	0.034	0.251
1.900	0.144	0.038	0.256
2.000	0.144	0.040	0.256
2.200	0.144	0.043	0.255
2.400	0.145	0.047	0.256
2.500	0.147	0.049	0.258
2.700	0.149	0.053	0.261
2.900	0.150	0.057	0.261
3.000	0.149	0.059	0.260
3.200	0.138	0.063	0.240
3.300	0.136	0.065	0.235
3.337	0.100	0.066	0.173

TEST PV25	OIL-SAND	T = 125 C		
CONFINING	PRESSURE = 0.1 MPa			
LENGTH	1.583	DIAMETER	0.985	
AXIAL	AXIAL	AXIAL	AXIAL	
DISPL	FORCE	STRAIN	STRESS	
(mm)	(mv)		(MPa)	
0.000	0.000	0.000	0.000	
0.100	0.161	0.002	0.266	
0.200	0.157	0.005	0.259	
0.300	0.158	0.007	0.260	
0.400	0.162	0.010	0.266	
0.500	0.164	0.012	0.269	
0.600	0.163	0.015	0.266	
0.700	0.152	0.017	0.249	
0.800	0.152	0.020	0.248	
0.900	0.140	0.022	0.228	
0.929	0.100	0.023	0.162	
1.000	0.096	0.025	0.155	
1.100	0.096	0.027	0.155	
1.200	0.096	0.030	0.155	
1.300	0.079	0.032	0.127	
1.400	0.011	0.035	0.017	
1.500	0.013	0.037	0.021	

Figure B-7

Oil-Sand sample #21 $T = 125\text{ C}$ $P_e = 5\text{ MPa}$

crtpv21.sac

TEST PV21 OIL-SAND T = 125 C

CONFINING PRESSURE = 10 MPa

LENGTH	1.793	DIAMETER	0.991	
AXIAL DISPL (mm)	AXIAL FORCE (mv)		AXIAL STRAIN	AXIAL STRESS (MPa)
0.008	0.000		.000	0.000
0.022	0.100		.000	0.170
0.018	0.200		.000	0.339
0.046	0.300		0.001	0.508
0.074	0.400		0.002	0.678
0.091	0.500		0.002	0.847
0.111	0.600		0.002	1.015
0.131	0.700		0.003	1.184
0.165	0.900		0.004	1.521
0.175	1.000		0.004	1.690
0.193	1.200		0.004	2.027
0.209	1.300		0.005	2.195
0.230	1.400		0.005	2.363
0.261	1.600		0.006	2.699
0.278	1.700		0.006	2.867
0.323	1.900		0.007	3.201
0.373	2.100		0.008	3.534
0.409	2.200		0.009	3.699
0.442	2.300		0.010	3.865
0.514	2.500		0.011	4.194
0.540	2.600		0.012	4.359
0.562	2.700		0.012	4.525
0.612	2.800		0.013	4.687
0.673	2.900		0.015	4.848
0.712	3.000		0.016	5.011
0.737	3.100		0.016	5.176
0.770	3.200		0.017	5.339
0.824	3.400		0.018	5.666
0.860	3.500		0.019	5.828
0.966	3.700		0.021	6.147
1.024	3.800		0.022	6.305
1.092	3.900		0.024	6.462
1.163	4.000		0.026	6.617
1.221	4.100		0.027	6.774
1.279	4.200		0.028	6.931
1.349	4.300		0.030	7.085
1.408	4.400		0.031	7.241
1.451	4.500		0.032	7.399
1.580	4.700		0.035	7.707
1.600	4.755		0.035	7.794
1.616	4.800		0.035	7.864
1.667	5.000		0.037	8.183
1.700	5.061		0.037	8.278
1.728	5.100		0.038	8.336
1.793	5.200		0.039	8.488
1.852	5.300		0.041	8.640
1.900	5.400		0.042	8.795
1.959	5.500		0.043	8.946
2.084	5.700		0.046	9.247
2.153	5.800		0.047	9.396
2.293	6.000		0.050	9.691
2.449	6.200		0.054	9.982
2.613	6.400		0.057	10.269

2.683	6.500	0.059	10.414
2.830	6.700	0.062	10.702
2.931	6.800	0.064	10.839
3.103	7.000	0.068	11.118
3.190	7.100	0.070	11.257
3.381	7.300	0.074	11.529
3.473	7.400	0.076	11.665
3.639	7.600	0.080	11.940
3.742	7.700	0.082	12.072
3.843	7.800	0.084	12.203
3.938	7.900	0.086	12.336
4.038	8.000	0.089	12.467
4.150	8.100	0.091	12.594
4.267	8.200	0.094	12.720
4.380	8.300	0.096	12.846
4.482	8.400	0.098	12.974
4.583	8.500	0.101	13.102
4.685	8.600	0.103	13.229
4.700	8.611	0.103	13.242
4.800	8.650	0.105	13.277

Figure B-8

TEST PV20	OIL-SAND	T = 125 C		
CONFINING	PRESSURE = 20 MPa			
LENGTH	1.739	DIAMETER	0.986	
AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)	
0.012	0.000	.000	0.000	
0.006	0.300	.000	0.518	
0.024	1.000	0.001	1.728	
0.029	1.600	0.001	2.764	
0.056	1.900	0.001	3.280	
0.099	2.200	0.002	3.794	
0.136	2.400	0.003	4.136	
0.160	2.500	0.004	4.306	
0.202	2.700	0.005	4.646	
0.228	2.800	0.005	4.815	
0.231	2.800	0.005	4.815	
0.244	2.700	0.006	4.641	
0.279	2.200	0.006	3.779	
0.306	2.200	0.007	3.777	
0.326	2.300	0.007	3.947	
0.431	2.800	0.010	4.793	
0.573	3.100	0.013	5.290	
0.664	3.200	0.015	5.449	
0.800	3.265	0.018	5.543	
0.872	3.300	0.020	5.594	
1.011	3.500	0.023	5.915	
1.065	3.600	0.024	6.076	
1.240	3.800	0.028	6.389	
1.366	3.900	0.031	6.539	
1.400	3.929	0.032	6.582	
1.484	4.000	0.034	6.689	
1.588	4.100	0.036	6.841	
1.664	4.200	0.038	6.996	
1.724	4.300	0.039	7.153	
1.797	4.400	0.041	7.308	
1.900	4.500	0.043	7.458	
2.000	4.569	0.045	7.555	
2.040	4.600	0.046	7.600	
2.139	4.700	0.048	7.749	
2.200	4.816	0.050	7.929	
2.300	4.812	0.052	7.906	
2.400	4.853	0.054	7.956	
2.416	4.900	0.055	8.031	
2.496	5.100	0.057	8.344	
2.596	5.200	0.059	8.489	
2.678	5.300	0.061	8.638	
2.838	5.500	0.064	8.933	
2.951	5.600	0.067	9.074	
3.119	5.700	0.071	9.203	
3.251	5.800	0.074	9.338	
3.351	5.900	0.076	9.479	
3.449	6.000	0.078	9.620	
3.536	6.100	0.080	9.763	
3.610	6.200	0.082	9.907	
3.813	6.400	0.086	10.183	
3.900	6.470	0.088	10.276	
3.937	6.500	0.089	10.316	
4.057	6.600	0.092	10.449	

4.230	6.800	0.096	10.727
4.322	6.900	0.098	10.864
4.409	7.000	0.100	11.002
4.498	7.100	0.102	11.138
4.500	7.103	0.102	11.143
4.567	7.200	0.103	11.279
4.600	7.262	0.104	11.369

Figure B-9

TEST PV20A OIL-SAND T = 125 C

CONFINING PRESSURE = 20 MPa

LENGTH 1.553 DIAMETER 0.995

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
------------------------	------------------------	-----------------	--------------------------

0.000	0.000	0.000	0.000
0.011	0.100	.000	0.170
0.030	0.200	0.001	0.339
0.051	0.300	0.001	0.509
0.086	0.500	0.002	0.847
0.142	0.800	0.004	1.353
0.205	1.100	0.005	1.858
0.245	1.300	0.006	2.193
0.321	1.600	0.008	2.694
0.389	1.800	0.010	3.026
0.476	2.000	0.012	3.354
0.576	2.200	0.015	3.681
0.634	2.300	0.016	3.842
0.749	2.500	0.019	4.165
0.810	2.600	0.021	4.325
0.845	2.700	0.021	4.487
0.947	3.000	0.024	4.973
1.082	3.300	0.027	5.452
1.193	3.600	0.030	5.931
1.275	3.800	0.032	6.248
1.361	4.000	0.035	6.563
1.457	4.200	0.037	6.875
1.538	4.300	0.039	7.025
1.600	4.337	0.041	7.076
1.727	4.400	0.044	7.156
1.828	4.500	0.046	7.300
1.900	4.512	0.048	7.308
1.970	4.600	0.050	7.437
2.029	4.800	0.051	7.749
2.214	5.100	0.056	8.197
2.262	5.100	0.057	8.188
2.366	5.200	0.060	8.327
2.425	5.300	0.061	8.476
2.505	5.400	0.064	8.619
2.600	5.478	0.066	8.724
2.623	5.500	0.066	8.754
2.715	5.600	0.069	8.894
2.779	5.700	0.070	9.039
2.835	5.800	0.072	9.185
2.892	5.900	0.073	9.331
2.981	6.100	0.076	9.627

Figure B-10

Oil-Sand sample #19

T = 125 C

Pe = 25 MPa

crtpv19.sac

TEST PV19 OIL-SAND T = 125 C				
CONFINING PRESSURE = 50 MPa				
LENGTH	1.769	DIAMETER	0.995	
AXIAL DISPL (mm)	AXIAL FORCE (mv)		AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000		.000	0.000
.000	0.200		.000	0.347
0.008	0.400		.000	0.695
0.020	0.600		.000	1.042
0.032	0.900		0.001	1.562
0.037	1.000		0.001	1.735
0.046	1.200		0.001	2.082
0.053	1.300		0.001	2.255
0.068	1.500		0.002	2.601
0.083	1.700		0.002	2.947
0.103	2.000		0.002	3.466
0.116	2.200		0.003	3.811
0.123	2.300		0.003	3.984
0.140	2.500		0.003	4.329
0.152	2.600		0.003	4.501
0.164	2.700		0.004	4.672
0.197	2.900		0.004	5.015
0.224	3.100		0.005	5.357
0.235	3.200		0.005	5.529
0.253	3.400		0.006	5.872
0.272	3.600		0.006	6.215
0.286	3.600		0.006	6.213
0.296	3.600		0.007	6.212
0.310	3.700		0.007	6.382
0.332	3.900		0.007	6.724
0.349	4.100		0.008	7.066
0.368	4.300		0.008	7.408
0.378	4.400		0.008	7.578
0.400	4.600		0.009	7.919
0.426	4.700		0.009	8.086
0.444	4.800		0.010	8.255
0.474	5.000		0.011	8.594
0.496	5.200		0.011	8.933
0.521	5.400		0.012	9.272
0.541	5.500		0.012	9.439
0.561	5.600		0.012	9.606
0.597	5.800		0.013	9.941
0.628	6.000		0.014	10.277
0.659	6.200		0.015	10.613
0.680	6.300		0.015	10.779
0.711	6.400		0.016	10.943
0.738	6.500		0.016	11.107
0.797	6.700		0.018	11.434
0.831	6.800		0.018	11.596
0.858	6.900		0.019	11.760
0.910	7.100		0.020	12.087
0.944	7.200		0.021	12.248
0.989	7.300		0.022	12.406
1.037	7.400		0.023	12.563
1.100	7.412		0.024	12.566
1.129	7.500		0.025	12.707
1.152	7.600		0.026	12.870
1.170	7.700		0.026	13.034

1.200	7.756	0.027	13.120
1.222	7.800	0.027	13.189
1.269	7.900	0.028	13.344
1.341	8.100	0.030	13.661
1.378	8.200	0.031	13.818
1.417	8.300	0.032	13.975
1.495	8.500	0.033	14.288
1.583	8.700	0.035	14.596
1.623	8.800	0.036	14.751
1.662	8.900	0.037	14.907
1.739	9.100	0.039	15.216
1.817	9.300	0.040	15.525
1.863	9.400	0.041	15.676
1.981	9.600	0.044	15.969
2.039	9.700	0.045	16.116
2.116	9.800	0.047	16.255
2.175	9.900	0.048	16.401
2.231	10.000	0.050	16.547
2.284	10.100	0.051	16.694
2.371	10.300	0.053	16.993
2.439	10.500	0.054	17.298
2.514	10.700	0.056	17.599
2.624	11.000	0.058	18.051
2.670	11.100	0.059	18.198
2.706	11.200	0.060	18.348
2.810	11.500	0.063	18.798
2.916	11.800	0.065	19.246
3.035	12.100	0.068	19.686
3.127	12.300	0.070	19.973
3.224	12.500	0.072	20.257
3.294	12.600	0.073	20.389
3.400	12.660	0.076	20.442
3.493	12.700	0.078	20.467
3.571	12.800	0.079	20.595
3.682	13.000	0.082	20.869
3.889	13.200	0.087	21.100

Figure B-11

TEST PV32 OIL-SAND T = 125 C			
CONFINING PRESSURE = 300 MPa			
LENGTH	1.91	DIAMETER	0.992
AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.044	0.000	0.001	0.000
0.062	0.000	0.001	0.000
0.067	0.100	0.001	0.174
0.081	0.500	0.002	0.872
0.087	1.000	0.002	1.744
0.103	1.800	0.002	3.139
0.108	2.300	0.002	4.010
0.118	3.000	0.002	5.229
0.125	3.700	0.003	6.449
0.130	4.100	0.003	7.145
0.145	4.800	0.003	8.362
0.162	5.500	0.003	9.579
0.170	6.300	0.003	10.970
0.176	6.900	0.004	12.013
0.189	7.500	0.004	13.055
0.196	8.100	0.004	14.097
0.207	8.800	0.004	15.312
0.225	9.600	0.005	16.697
0.240	10.200	0.005	17.736
0.262	11.100	0.005	19.292
0.279	11.700	0.006	20.327
0.292	12.300	0.006	21.364
0.309	13.000	0.006	22.572
0.328	13.600	0.007	23.605
0.344	14.100	0.007	24.465
0.364	14.500	0.008	25.148
0.396	15.100	0.008	26.172
0.424	15.700	0.009	27.196
0.450	16.400	0.009	28.394
0.464	16.800	0.010	29.078
0.480	17.200	0.010	29.761
0.520	17.700	0.011	30.601
0.560	18.100	0.012	31.267
0.582	18.300	0.012	31.598
0.622	18.600	0.013	32.090
0.663	18.900	0.014	32.580
0.718	19.200	0.015	33.060
0.855	19.600	0.018	33.656
0.998	19.600	0.021	33.558
1.000	19.598	0.021	33.554
1.101	19.500	0.023	33.318
1.200	19.422	0.025	33.119
1.255	19.300	0.026	32.874
1.329	19.100	0.027	32.485
1.400	19.030	0.029	32.320
1.500	19.028	0.031	32.251
1.600	19.067	0.033	32.254
1.649	19.100	0.034	32.278
1.785	19.200	0.037	32.359
1.900	19.260	0.039	32.387
2.000	19.272	0.041	32.343
2.100	19.272	0.043	32.279
2.169	19.300	0.045	32.281

2.200	19.319	0.045	32.293
2.300	19.384	0.047	32.338
2.323	19.400	0.048	32.350
2.400	19.448	0.049	32.381
2.448	19.500	0.050	32.437
2.530	19.600	0.052	32.551
2.621	19.700	0.054	32.659
2.720	19.800	0.056	32.761
2.822	19.900	0.058	32.862
2.900	19.980	0.060	32.943
2.914	20.000	0.060	32.967
3.014	20.200	0.062	33.233
3.114	20.400	0.064	33.497
3.157	20.500	0.065	33.632

Figure B-12

Oil-Sand samples

$T = 250\text{ C}$

$P_e = 0.1\text{ MPa}$

crtpv30.sac
crtpv31.sac

TEST PV30 OIL-SAND T = 250 C
 CONFINING PRESSURE = 0.1 MPa
 LENGTH 4.844 DIAMETER 2.499 (CM)

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.000	0.000
0.046	0.100	0.001	0.166
0.059	0.200	0.001	0.333
0.100	0.243	0.002	0.404
0.200	0.279	0.004	0.463
0.302	0.300	0.006	0.496
0.400	0.315	0.008	0.520
0.500	0.322	0.010	0.530
0.600	0.322	0.012	0.529
0.700	0.324	0.014	0.531
0.800	0.331	0.017	0.542
0.884	0.400	0.018	0.654
0.900	0.437	0.019	0.715
1.000	0.449	0.021	0.733
1.000	0.449	0.021	0.733
1.100	0.454	0.023	0.738
1.200	0.449	0.025	0.730
1.300	0.448	0.027	0.726
1.400	0.444	0.029	0.719
1.500	0.442	0.031	0.713
1.600	0.444	0.033	0.716
1.700	0.441	0.035	0.709
1.800	0.462	0.037	0.742
1.819	0.500	0.038	0.802
1.861	0.600	0.038	0.962
1.893	0.700	0.039	1.121
1.900	0.722	0.039	1.157
2.000	0.739	0.041	1.181
2.100	0.742	0.043	1.184
2.200	0.737	0.045	1.174
2.300	0.737	0.047	1.171
2.400	0.739	0.050	1.172
2.500	0.743	0.052	1.176

TEST PV31 OIL-SAND T = 250 C
 CONFINING PRESSURE = 0.1 MPa
 LENGTH 1.89 DIAMETER 1.035

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
.000	0.000	.0000	0.0000
0.006	0.100	0.0001	0.1504
0.012	0.200	0.0002	0.3008
0.015	0.300	0.0003	0.4511
0.018	0.400	0.0004	0.6014
0.021	0.500	0.0004	0.7518
0.026	0.600	0.0005	0.9020
0.032	0.700	0.0007	1.0522
0.038	0.800	0.0008	1.2024
0.046	0.900	0.0010	1.3525
0.057	1.000	0.0012	1.5024
0.141	1.100	0.0029	1.6497
0.241	1.138	0.0050	1.7039
0.341	1.131	0.0071	1.6886
0.441	1.114	0.0092	1.6599
0.541	1.107	0.0113	1.6466
0.641	1.110	0.0134	1.6476
0.841	1.120	0.0175	1.6564
0.941	1.125	0.0196	1.6590
1.141	1.119	0.0238	1.6443
1.380	1.112	0.0287	1.6265
1.559	1.100	0.0325	1.6026
1.754	1.100	0.0365	1.5963
1.941	1.100	0.0404	1.5903
2.041	1.095	0.0425	1.5802
2.241	1.093	0.0467	1.5706
2.519	1.096	0.0525	1.5662
2.641	1.100	0.0550	1.5683
2.941	1.106	0.0613	1.5670
3.041	1.102	0.0633	1.5587
3.241	1.101	0.0675	1.5519
3.441	1.103	0.0717	1.5480
3.650	1.107	0.0760	1.5473
3.741	1.100	0.0779	1.5350
3.794	1.092	0.0790	1.5227
3.841	1.100	0.0800	1.5320
3.901	1.142	0.0812	1.5889
3.941	1.200	0.0821	1.6681
4.041	1.204	0.0842	1.6704
4.096	1.207	0.0853	1.6734
4.241	1.200	0.0883	1.6585
4.268	1.189	0.0889	1.6431

APPENDIX C

STRESS-STRAIN PLOTS AND TABULATED DATA FOR TRIAXIAL TESTS CONDUCTED ON
SHALE SAMPLES

FILE INDEX VZSHALE.WKS - TRIAXIAL TESTS ON SHALE

SAMPLE	PC	DEPTH	TEMP C	LOCATION WKS
PV5	0.1	3206	23	J1
PV4	0.1	3206	23	S1
PV14	2	3210	23	AB1
PV13	5	3206	23	AK1
PV12	10	3206	23	AT1
PV2	20	3204	23	BB1
PV1	50	3204	23	BK1
PV9	300	3204	23	BT1
PV7	0.1	3202	125	A200
PV23	0.1	3202	125	BD200
PV22	10	3210	125	J200
PV26	20	3202	125	BO200
PV27	50	3211	125	S200
PV27A	50	3211	125	AB200
PV27B	50	3202	125	AK200
PV33	300	3210	125	AT200
PV28	0.1	3202	250	A400
PV29	0.1	3202	250	K400
PV34	300	***	250	V400

Figure C-1

TEST PV4 SHALE T-23 C				
CONFINING PRESSURE = 0.1 MPa				
LENGTH=	1.46	DIA=	1.014	
AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)	
0.044	0.100	0.001	0.157	
0.060	0.200	0.002	0.313	
0.178	1.100	0.005	1.716	
0.283	1.800	0.008	2.800	
0.355	2.400	0.010	3.725	
0.442	3.000	0.012	4.646	
0.540	3.700	0.015	5.715	
0.612	3.700	0.016	5.704	
0.700	3.676	0.019	5.654	
0.747	3.600	0.020	5.530	
0.791	3.500	0.021	5.370	
0.837	3.300	0.023	5.057	
0.850	3.100	0.023	4.749	
0.880	3.000	0.024	4.592	
0.921	2.900	0.025	4.435	
1.091	2.800	0.029	4.263	
1.151	2.800	0.031	4.256	
1.358	2.800	0.037	4.233	
1.400	2.788	0.038	4.210	
1.606	2.800	0.043	4.206	
1.800	2.866	0.049	4.284	
1.965	2.900	0.053	4.316	
2.100	2.918	0.057	4.328	
2.129	2.900	0.057	4.298	
2.157	2.800	0.058	4.147	

TEST PV5	Shale	T=23 C		
CONFINING	PRESSURE	= 0.1 MPa		
LENGTH=	1.474	DIA=	0.996	
AXIAL	AXIAL		AXIAL	AXIAL
DISPL	FORCE		STRAIN	STRESS
(mm)	(mv)			(MPa)
0.028	0.000		0.001	0.000
0.085	0.100		0.002	0.162
0.131	0.200		0.003	0.324
0.199	0.400		0.005	0.646
0.252	0.600		0.007	0.968
0.305	0.800		0.008	1.289
0.350	1.000		0.009	1.609
0.435	1.500		0.012	2.408
0.487	1.800		0.013	2.886
0.563	2.200		0.015	3.520
0.624	2.500		0.017	3.994
0.688	2.800		0.018	4.466
0.765	3.100		0.020	4.934
0.833	3.300		0.022	5.243
1.000	3.423		0.027	5.415
1.018	3.400		0.027	5.376
1.081	3.200		0.029	5.052
1.106	2.900		0.030	4.575
1.142	2.700		0.031	4.256
1.190	2.500		0.032	3.936
1.239	2.300		0.033	3.616
1.309	2.100		0.035	3.296
1.408	1.900		0.038	2.974
1.561	1.700		0.042	2.651
1.757	1.500		0.047	2.327
1.897	1.400		0.051	2.164
2.041	1.300		0.055	2.002
2.100	1.261		0.056	1.940
2.239	1.200		0.060	1.839
2.400	1.160		0.064	1.770
2.600	1.148		0.069	1.743
2.900	1.139		0.077	1.716
3.100	1.121		0.083	1.682
3.300	1.113		0.088	1.662
3.600	1.119		0.096	1.658
3.800	1.120		0.102	1.651

Figure C-2

Shale sample #14 T = 23 C Pe = 1 MPa

crtpv14.sac

TEST PV14 SHALE T-23 C
CONFINING PRESSURE = 2.0 MPa

LENGTH=	1.35	DIA=	1.035	
AXIAL DISPL (mm)	AXIAL FORCE (mv)		AXIAL STRAIN	AXIAL STRESS (MPa)
0.032	0.100		0.001	0.150
0.059	0.200		0.002	0.300
0.092	0.300		0.003	0.450
0.130	0.400		0.004	0.599
0.205	0.600		0.006	0.897
0.229	0.700		0.007	1.046
0.248	0.800		0.007	1.195
0.265	0.900		0.008	1.343
0.282	1.000		0.008	1.492
0.295	1.100		0.009	1.640
0.309	1.200		0.009	1.789
0.324	1.300		0.009	1.937
0.354	1.500		0.010	2.233
0.374	1.600		0.011	2.381
0.394	1.700		0.012	2.528
0.440	1.900		0.013	2.822
0.474	2.000		0.014	2.967
0.505	2.100		0.015	3.113
0.550	2.300		0.016	3.405
0.574	2.400		0.017	3.551
0.599	2.500		0.017	3.696
0.631	2.700		0.018	3.988
0.662	2.900		0.019	4.280
0.675	3.000		0.020	4.425
0.692	3.200		0.020	4.718
0.708	3.400		0.021	5.011
0.730	3.600		0.021	5.302
0.788	3.900		0.023	5.735
0.840	4.100		0.025	6.020
0.867	4.200		0.025	6.162
0.912	4.400		0.027	6.447
0.980	4.700		0.029	6.873
1.024	4.900		0.030	7.157
1.048	5.000		0.031	7.298
1.084	5.100		0.032	7.436
1.120	5.200		0.033	7.574
1.158	5.300		0.034	7.712
1.258	5.500		0.037	7.980
1.337	5.600		0.039	8.107
1.445	5.700		0.042	8.227
1.622	5.800		0.047	8.330
1.700	5.832		0.050	8.357
1.865	5.900		0.054	8.417
2.000	5.944		0.058	8.448
2.230	6.000		0.065	8.474
2.300	6.016		0.067	8.480
2.500	6.044		0.073	8.473
2.600	6.049		0.076	8.458

Figure C-3

Shale sample #13 $T = 23\text{ C}$ $P_e = 2.5\text{ MPa}$

crtpv13.sac

TEST PV13 SHALE T = 23 C
 CONFINING PRESSURE = 5.0 MPa
 LENGTH= 1.416 DIA= 0.989

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.021	0.000	0.0006	0.000
0.052	0.200	0.0015	0.329
0.118	0.400	0.0033	0.657
0.180	0.600	0.0050	0.983
0.251	0.500	0.0070	0.818
0.272	0.400	0.0076	0.654
0.305	0.400	0.0085	0.653
0.349	0.700	0.0097	1.142
0.359	1.100	0.0100	1.794
0.414	1.400	0.0115	2.280
0.453	1.600	0.0126	2.603
0.471	1.700	0.0131	2.764
0.484	1.200	0.0135	1.950
0.485	1.600	0.0135	2.601
0.522	2.000	0.0145	3.247
0.553	2.400	0.0154	3.894
0.566	2.800	0.0157	4.541
0.580	3.100	0.0161	5.026
0.636	3.500	0.0177	5.665
0.651	3.900	0.0181	6.310
0.660	4.200	0.0184	6.794
0.682	4.500	0.0190	7.275
0.712	4.800	0.0198	7.754
0.737	5.200	0.0205	8.394
0.751	5.500	0.0209	8.875
0.768	5.800	0.0214	9.354
0.796	6.100	0.0221	9.831
0.817	6.400	0.0227	10.308
0.847	6.800	0.0236	10.944
0.870	7.000	0.0242	11.259
0.913	7.300	0.0254	11.728
0.927	7.400	0.0258	11.884
0.947	7.500	0.0263	12.038
0.971	7.700	0.0270	12.351
0.988	7.800	0.0275	12.505
0.986	7.700	0.0274	12.346
0.998	7.500	0.0278	12.021
1.015	7.200	0.0282	11.535
1.011	6.900	0.0281	11.056
0.999	6.700	0.0278	10.739
0.989	6.400	0.0275	10.261

Figure C-4

TEST PV12 SHALE T-23 C				
CONFINING PRESSURE = 10.0 MPa				
LENGTH=	1.995	DIA=	0.998	
AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)	
0.013	0.000	.000	0.000	
0.020	0.100	.000	0.162	
0.053	0.300	0.001	0.485	
0.117	0.600	0.002	0.970	
0.151	0.800	0.003	1.292	
0.164	0.900	0.003	1.453	
0.187	1.100	0.004	1.775	
0.222	1.300	0.004	2.097	
0.271	1.500	0.005	2.417	
0.344	1.700	0.007	2.735	
0.382	1.800	0.008	2.894	
0.455	2.000	0.009	3.211	
0.501	2.100	0.010	3.368	
0.550	2.200	0.011	3.525	
0.689	2.500	0.014	3.995	
0.780	2.700	0.015	4.307	
0.907	3.000	0.018	4.774	
1.057	3.300	0.021	5.236	
1.175	3.500	0.023	5.541	
1.397	3.800	0.028	5.990	
1.539	4.000	0.030	6.289	
1.694	4.200	0.033	6.584	
1.932	4.400	0.038	6.866	
2.130	4.500	0.042	6.995	
2.300	4.554	0.045	7.056	
2.481	4.600	0.049	7.104	
2.600	4.621	0.051	7.121	
2.800	4.650	0.055	7.137	
3.100	4.684	0.061	7.150	
3.400	4.687	0.067	7.115	
3.600	4.683	0.071	7.083	
3.800	4.689	0.075	7.065	
4.100	4.699	0.081	7.043	
4.216	4.700	0.083	7.029	
4.500	4.727	0.089	7.033	

Figure C-5

TEST PV2 SHALE T 23 C
 CONFINING PRESSURE = 20.0 MPa
 LENGTH= 1.77 DIA= 1.008

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.010	0.000	.000	0.000
0.024	0.200	0.001	0.320
0.067	0.600	0.001	0.960
0.121	1.200	0.003	1.917
0.162	1.700	0.004	2.713
0.206	2.000	0.005	3.189
0.285	2.500	0.006	3.979
0.360	3.000	0.008	4.767
0.466	3.900	0.010	6.182
0.567	5.000	0.013	7.908
0.657	6.300	0.015	9.945
0.719	7.700	0.016	12.139
0.767	9.300	0.017	14.645
0.841	10.700	0.019	16.823
0.902	12.200	0.020	19.156
0.970	13.300	0.022	20.852
1.046	14.100	0.023	22.070
1.086	14.500	0.024	22.676
1.205	15.100	0.027	23.553
1.328	15.100	0.030	23.491
1.535	15.100	0.034	23.386
1.892	15.200	0.042	23.362
1.947	15.300	0.043	23.488
2.086	15.600	0.046	23.878
2.270	16.000	0.050	24.395
2.455	16.200	0.055	24.603
2.617	16.200	0.058	24.519
2.814	16.100	0.063	24.268
2.902	16.000	0.065	24.073
2.986	15.900	0.066	23.880
3.177	15.800	0.071	23.636
3.499	15.700	0.078	23.330
3.646	15.700	0.081	23.259
3.674	15.800	0.082	23.394

Figure C-6

Shale sample #1

T = 23 c

Pe = 25 MPa

crtpv1.sac

TEST PV1 SHALE T-23 C				
CONFINING PRESSURE = 50.0 MPa				
LENGTH=	2.251	DIA=	0.98	
AXIAL DISPL (mm)	AXIAL FORCE (mv)		AXIAL STRAIN	AXIAL STRESS (MPa)
.000	0.000		.000	0.000
0.003	0.200		.000	0.338
0.032	1.200		0.001	2.028
0.049	2.000		0.001	3.380
0.064	2.800		0.001	4.730
0.084	3.100		0.001	5.235
0.116	3.500		0.002	5.908
0.144	4.000		0.003	6.748
0.187	4.900		0.003	8.261
0.227	5.800		0.004	9.771
0.250	6.400		0.004	10.777
0.289	7.000		0.005	11.780
0.335	7.800		0.006	13.116
0.386	8.400		0.007	14.112
0.411	8.600		0.007	14.442
0.460	8.300		0.008	13.926
0.528	8.100		0.009	13.574
0.627	7.900		0.011	13.217
0.710	7.600		0.012	12.696
0.736	7.600		0.013	12.691
0.769	7.700		0.013	12.851
0.812	8.500		0.014	14.175
0.849	9.000		0.015	14.999
0.898	9.500		0.016	15.819
0.957	9.800		0.017	16.302
1.083	9.900		0.019	16.433
1.099	10.000		0.019	16.595
1.208	11.100		0.021	18.385
1.365	10.900		0.024	18.006
1.458	10.900		0.025	17.977
1.690	10.800		0.030	17.742
1.839	10.700		0.032	17.533
2.000	10.636		0.035	17.382
2.164	10.700		0.038	17.438
2.286	11.000		0.040	17.889
2.477	11.500		0.043	18.643
2.581	11.700		0.045	18.934
2.759	12.000		0.048	19.362
2.918	12.300		0.051	19.793
3.086	12.600		0.054	20.220
3.333	13.000		0.058	20.776
3.498	13.300		0.061	21.198
3.676	13.800		0.064	21.931
3.866	14.400		0.068	22.813
3.986	14.700		0.070	23.243
4.166	15.200		0.073	23.962
4.333	15.600		0.076	24.526
4.548	16.000		0.080	25.068
4.728	16.300		0.083	25.464
4.916	16.600		0.086	25.853
5.142	16.900		0.090	26.225
5.239	17.000		0.092	26.339
5.317	17.100		0.093	26.461

Figure C-7

Shale sample #9

T = 23 C

Pe = 150 MPa

crtpv9.sac

TEST PV9 SHALE T-23 C			
CONFINING PRESSURE = 300 MPa			
LENGTH=	1.965	DIA=	0.984
AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.000	0.000
0.019	0.000	.000	0.000
0.024	0.100	.000	0.174
0.038	0.600	0.001	1.043
0.064	1.300	0.001	2.260
0.083	1.800	0.002	3.128
0.103	2.200	0.002	3.821
0.141	2.800	0.003	4.859
0.191	3.300	0.004	5.722
0.278	4.000	0.006	6.923
0.400	4.220	0.008	7.287
0.439	4.000	0.009	6.901
0.485	3.600	0.010	6.205
0.537	3.100	0.011	5.338
0.579	2.800	0.012	4.817
0.611	2.800	0.012	4.814
0.655	3.000	0.013	5.154
0.781	3.700	0.016	6.340
0.935	4.500	0.019	7.688
1.064	5.200	0.021	8.861
1.227	6.000	0.025	10.192
1.400	6.700	0.028	11.343
1.565	7.300	0.031	12.319
1.735	8.100	0.035	13.624
1.921	9.000	0.038	15.083
2.084	9.800	0.042	16.372
2.284	10.900	0.046	18.140
2.497	11.700	0.050	19.393
2.658	12.300	0.053	20.325
2.877	13.200	0.058	21.721
3.055	13.800	0.061	22.632
3.236	14.200	0.065	23.209
3.490	14.500	0.070	23.587
3.600	14.563	0.072	23.641
3.800	14.560	0.076	23.548
4.000	14.548	0.080	23.440
4.180	14.600	0.084	23.447
4.399	14.900	0.088	23.832
4.542	15.200	0.091	24.248
4.698	15.400	0.094	24.497
4.892	15.400	0.098	24.410
5.000	15.340	0.100	24.266
5.241	15.400	0.105	24.255
5.300	15.439	0.106	24.291

Figure C-8

Shale sample #7

T = 125 C

P_e = 0.1 MPa

crtpv7.sac

TEST PV7	SHALE	T = 125 C		
CONFINING	PRESSURE = 0.1 MPa			
LENGTH	2.045	DIAMETER	1.046	
AXIAL	AXIAL	AXIAL	AXIAL	
DISPL	FORCE	STRAIN	STRESS	
(mm)	(mv)		(MPa)	
0.000	0.000	0.000	0.000	
0.400	0.042	0.008	0.061	
0.677	0.100	0.013	0.145	
0.880	0.200	0.017	0.290	
1.210	0.400	0.023	0.576	
1.412	0.500	0.027	0.717	
1.600	0.552	0.031	0.789	
1.949	0.600	0.038	0.852	
2.100	0.614	0.040	0.869	
2.563	0.600	0.049	0.842	
2.800	0.567	0.054	0.793	
3.000	0.533	0.058	0.742	
3.100	0.524	0.060	0.729	

Figure C-9

Shale sample #23 T = 125 C P-E = 0.1 MPa

TEST PV23 SHALE T = 125 C
 CONFINING PRESSURE = 0.1 MPa

LENGTH	39.37	DIAMETER	25.78	
AXIAL DISPL (mm)	AXIAL FORCE (mv)		AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000		0.0000	0.00
0.043	0.100		0.0011	0.16
0.078	0.200		0.0020	0.31
0.086	0.300		0.0022	0.47
0.100	0.333		0.0025	0.52
0.131	0.400		0.0033	0.62
0.163	0.500		0.0041	0.78
0.178	0.600		0.0045	0.93
0.200	0.680		0.0051	1.06
0.211	0.700		0.0054	1.09
0.238	0.800		0.0060	1.24
0.263	0.900		0.0067	1.40
0.286	1.000		0.0073	1.55
0.300	1.081		0.0076	1.68
0.304	1.100		0.0077	1.71
0.324	1.200		0.0082	1.86
0.338	1.300		0.0086	2.02
0.349	1.400		0.0089	2.17
0.371	1.500		0.0094	2.32
0.379	1.600		0.0096	2.48
0.398	1.700		0.0101	2.63
0.400	1.711		0.0102	2.65
0.418	1.800		0.0106	2.79
0.435	1.900		0.0110	2.94
0.448	2.000		0.0114	3.09
0.456	2.100		0.0116	3.25
0.466	2.200		0.0118	3.40
0.478	2.300		0.0121	3.55
0.485	2.400		0.0123	3.71
0.490	2.500		0.0125	3.86
0.500	2.537		0.0127	3.92
0.519	2.600		0.0132	4.01
0.538	2.700		0.0137	4.17
0.537	2.800		0.0136	4.32
0.549	2.900		0.0139	4.47
0.558	3.000		0.0142	4.63
0.563	3.100		0.0143	4.78
0.569	3.200		0.0145	4.93
0.591	3.300		0.0150	5.08
0.600	3.338		0.0152	5.14
0.614	3.400		0.0156	5.24
0.623	3.500		0.0158	5.39
0.636	3.600		0.0162	5.54
0.664	3.700		0.0169	5.69
0.676	3.800		0.0172	5.84
0.684	3.900		0.0174	6.00
0.692	4.000		0.0176	6.15
0.700	4.098		0.0178	6.30
0.701	4.100		0.0178	6.30
0.703	4.200		0.0178	6.45
0.717	4.300		0.0182	6.61
0.727	4.400		0.0185	6.76
0.749	4.500		0.0190	6.91

0.751	4.600	0.0191	7.06
0.754	4.700	0.0192	7.21
0.785	4.800	0.0199	7.36
0.800	4.859	0.0203	7.45
0.805	4.900	0.0205	7.51
0.807	5.000	0.0205	7.66
0.817	5.100	0.0207	7.81
0.826	5.200	0.0210	7.97
0.836	5.300	0.0212	8.12
0.873	5.400	0.0222	8.26
0.900	5.475	0.0229	8.37
0.915	5.500	0.0232	8.41
0.942	5.600	0.0239	8.55
0.954	5.700	0.0242	8.70
0.960	5.800	0.0244	8.86
0.999	5.900	0.0254	9.00
1.024	5.900	0.0260	8.99
1.029	5.800	0.0261	8.84
1.038	5.700	0.0264	8.69
1.050	5.600	0.0267	8.53
1.067	5.500	0.0271	8.38
1.108	5.400	0.0281	8.21
1.156	5.300	0.0294	8.05
1.160	5.200	0.0295	7.90
1.164	5.100	0.0296	7.75
1.200	5.076	0.0305	7.70
1.297	5.000	0.0329	7.57
1.300	4.981	0.0330	7.54
1.384	4.900	0.0351	7.40
1.390	4.700	0.0353	7.10
1.393	4.600	0.0354	6.95
1.394	4.500	0.0354	6.80
1.390	4.400	0.0353	6.65
1.388	4.300	0.0353	6.50
1.395	4.200	0.0354	6.34
1.394	4.100	0.0354	6.19
1.400	4.006	0.0356	6.05
1.414	4.000	0.0359	6.04
1.500	3.853	0.0381	5.80
1.600	3.824	0.0406	5.75
1.611	3.800	0.0409	5.71
1.619	3.700	0.0411	5.56
1.667	3.600	0.0423	5.40
1.700	3.582	0.0432	5.37
1.733	3.500	0.0440	5.24
1.741	3.400	0.0442	5.09
1.800	3.359	0.0457	5.02
1.849	3.300	0.0470	4.93
1.858	3.200	0.0472	4.78
1.900	3.101	0.0483	4.63
1.907	3.100	0.0484	4.62
1.965	3.000	0.0499	4.47
2.000	2.913	0.0508	4.34
2.025	2.900	0.0514	4.31
2.098	2.800	0.0533	4.16
2.100	2.790	0.0533	4.14
2.200	2.739	0.0559	4.06

Figure C-10

Shale sample #22

T = 125 C

Pe = 5 MPa

crtpv22.sac

TEST PV22 SHALE T = 125 C

CONFINING PRESSURE = 10 MPa

LENGTH 1.873 DIAMETER 1.015

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
------------------------	------------------------	-----------------	--------------------------

0.000	0.000	.000	0.000
0.000	0.024	0.000	0.038
0.007	0.100	.000	0.161
0.017	0.300	.000	0.484
0.029	0.400	0.001	0.646
0.041	0.600	0.001	0.968
0.044	0.700	0.001	1.129
0.052	0.800	0.001	1.291
0.066	0.900	0.001	1.451
0.072	1.000	0.002	1.612
0.076	1.100	0.002	1.774
0.078	1.200	0.002	1.935
0.085	1.300	0.002	2.096
0.100	1.400	0.002	2.256
0.112	1.500	0.002	2.417
0.120	1.600	0.003	2.577
0.131	1.700	0.003	2.738
0.143	1.800	0.003	2.898
0.157	1.900	0.003	3.058
0.175	2.000	0.004	3.218
0.186	2.100	0.004	3.378
0.194	2.200	0.004	3.538
0.200	2.261	0.004	3.636
0.204	2.300	0.004	3.698
0.220	2.400	0.005	3.858
0.236	2.500	0.005	4.017
0.248	2.600	0.005	4.177
0.265	2.700	0.006	4.336
0.297	2.800	0.006	4.494
0.325	2.900	0.007	4.652
0.336	3.000	0.007	4.811
0.350	3.100	0.007	4.970
0.366	3.200	0.008	5.128
0.384	3.300	0.008	5.287
0.393	3.400	0.008	5.446
0.400	3.409	0.008	5.460
0.484	3.500	0.010	5.595
0.496	3.600	0.010	5.754
0.500	3.623	0.011	5.791
0.520	3.700	0.011	5.911
0.600	3.783	0.013	6.034
0.622	3.800	0.013	6.058
0.700	3.839	0.015	6.111
0.760	3.900	0.016	6.199
0.800	3.986	0.017	6.331
0.816	4.100	0.017	6.510
0.835	4.200	0.018	6.666
0.862	4.300	0.018	6.821
0.863	4.400	0.018	6.979
0.900	4.482	0.019	7.103
0.930	4.500	0.020	7.128
0.962	4.600	0.020	7.281
1.000	4.723	0.021	7.470

1.023	4.800	0.022	7.589
1.100	4.868	0.023	7.683
1.123	4.800	0.024	7.573
1.153	4.700	0.024	7.411
1.182	4.600	0.025	7.249
1.199	4.500	0.025	7.089
1.214	4.400	0.026	6.929
1.266	4.300	0.027	6.764
1.300	4.229	0.027	6.647
1.364	4.200	0.029	6.594
1.390	4.100	0.029	6.433
1.400	4.039	0.029	6.336
1.439	4.000	0.030	6.270
1.500	3.991	0.032	6.248
1.600	3.966	0.034	6.196
1.700	3.964	0.036	6.181
1.800	3.962	0.038	6.166
1.900	3.963	0.040	6.154
2.000	3.967	0.042	6.148
2.100	3.973	0.044	6.145
2.200	3.974	0.046	6.134
2.300	3.972	0.048	6.118
2.400	3.968	0.050	6.100
2.600	3.962	0.055	6.066
2.700	3.961	0.057	6.053
2.800	3.958	0.059	6.037
2.900	3.955	0.061	6.020
3.100	3.949	0.065	5.988
3.279	3.900	0.069	5.892
3.300	3.862	0.069	5.832
3.400	3.837	0.071	5.784
3.500	3.843	0.074	5.781
3.600	3.850	0.076	5.780
3.700	3.853	0.078	5.773
3.800	3.846	0.080	5.752
3.901	3.800	0.082	5.672
4.000	3.788	0.084	5.643
4.100	3.783	0.086	5.625
4.200	3.741	0.088	5.551
4.246	3.700	0.089	5.486
4.300	3.676	0.090	5.444
4.400	3.656	0.092	5.405
4.500	3.658	0.095	5.397
4.600	3.652	0.097	5.378
4.700	3.644	0.099	5.356
4.800	3.635	0.101	5.332
4.900	3.629	0.103	5.313
5.000	3.623	0.105	5.295

Figure C-11

Shale sample #27

T = 125 C

Pe = 25 MPa

crtpv27.sac

TEST PV27 SHALE T = 125 C

CONFINING PRESSURE = 50 MPa

LENGTH	1.741	DIAMETER	0.99	
AXIAL DISPL (mm)	AXIAL FORCE (mv)		AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000		0.000	0.000
0.011	0.300		.000	0.516
0.015	0.700		.000	1.203
0.011	1.200		.000	2.063
0.018	1.600		.000	2.750
0.025	2.100		0.001	3.609
0.029	2.300		0.001	3.952
0.036	2.700		0.001	4.639
0.041	3.100		0.001	5.325
0.048	3.500		0.001	6.011
0.057	4.000		0.001	6.869
0.062	4.400		0.001	7.555
0.068	4.800		0.002	8.240
0.074	5.100		0.002	8.754
0.084	5.400		0.002	9.267
0.091	5.700		0.002	9.780
0.100	6.300		0.002	10.808
0.109	6.900		0.002	11.834
0.112	7.200		0.003	12.348
0.118	7.600		0.003	13.033
0.120	7.900		0.003	13.546
0.127	8.300		0.003	14.230
0.138	8.800		0.003	15.083
0.149	9.300		0.003	15.937
0.168	9.600		0.004	16.444
0.168	9.600		0.004	16.444
0.165	9.700		0.004	16.616
0.160	10.200		0.004	17.474
0.173	10.500		0.004	17.983
0.182	10.800		0.004	18.493
0.191	11.000		0.004	18.832
0.200	11.075		0.005	18.956
0.209	11.100		0.005	18.995
0.207	11.200		0.005	19.167
0.206	11.700		0.005	20.023
0.219	12.000		0.005	20.531
0.236	12.100		0.005	20.694
0.243	12.300		0.006	21.033
0.258	12.900		0.006	22.051
0.263	13.400		0.006	22.903
0.279	13.900		0.006	23.750
0.301	14.400		0.007	24.592
0.313	14.600		0.007	24.927
0.327	14.700		0.007	25.089
0.358	14.900		0.008	25.413
0.383	15.200		0.009	25.910
0.420	15.600		0.009	26.570
0.440	15.700		0.010	26.728
0.504	15.900		0.011	27.030
0.600	15.986		0.014	27.118
0.663	15.900		0.015	26.934
0.688	15.600		0.016	26.411
0.695	15.200		0.016	25.730

0.694	14.900	0.016	25.223
0.697	14.600	0.016	24.714
0.710	14.400	0.016	24.368
0.729	14.300	0.016	24.189
0.757	14.200	0.017	24.004
0.798	13.900	0.018	23.476
0.839	13.700	0.019	23.117
0.900	13.638	0.020	22.981
1.000	13.640	0.023	22.933
1.096	13.300	0.025	22.315
1.114	13.100	0.025	21.970
1.156	13.000	0.026	21.782
1.193	13.000	0.027	21.765
1.273	13.200	0.029	22.060
1.353	13.500	0.031	22.522
1.415	13.700	0.032	22.825
1.514	13.900	0.034	23.108
1.558	14.000	0.035	23.252
1.662	14.300	0.038	23.696
1.733	14.500	0.039	23.991
1.860	14.900	0.042	24.584
1.958	15.200	0.044	25.026
2.048	15.500	0.046	25.471
2.142	15.900	0.048	26.075
2.254	16.300	0.051	26.666
2.315	16.500	0.052	26.958
2.427	16.900	0.055	27.546
2.546	17.400	0.058	28.289
2.643	17.800	0.060	28.879
2.763	18.400	0.062	29.776
2.877	18.900	0.065	30.511
2.985	19.300	0.068	31.085
3.103	19.800	0.070	31.811
3.200	20.300	0.072	32.548
3.280	20.800	0.074	33.293
3.342	21.200	0.076	33.889
3.438	21.600	0.078	34.459
3.500	21.656	0.079	34.504
3.582	21.700	0.081	34.515
3.700	21.774	0.084	34.546
3.800	21.792	0.086	34.503
3.876	21.800	0.088	34.462
4.000	21.812	0.090	34.392
4.020	21.800	0.091	34.359
4.100	21.760	0.093	34.239
4.207	21.800	0.095	34.226
4.291	22.000	0.097	34.481
4.357	22.200	0.099	34.746
4.500	22.324	0.102	34.838
4.600	22.330	0.104	34.776
4.700	22.324	0.106	34.695
4.763	22.300	0.108	34.614
4.872	22.200	0.110	34.382
4.914	22.200	0.111	34.353
5.000	22.231	0.113	34.340
5.100	22.221	0.115	34.256
5.200	22.259	0.118	34.245
5.255	22.300	0.119	34.270
5.376	22.400	0.122	34.339
5.400	22.416	0.122	34.348

5.500	22.464	0.124	34.351
5.600	22.482	0.127	34.309
5.700	22.458	0.129	34.205
5.800	22.425	0.131	34.086
5.852	22.400	0.132	34.013
6.040	22.300	0.137	33.734
6.100	22.289	0.138	33.677
6.200	22.300	0.140	33.627

Figure C-12

Shale sample #27a T = 125 C Pe = 25 MPa

crtpv27a.sac

TEST PV27A SHALE T = 125 C

CONFINING PRESSURE = 50 MPa

LENGTH	1.865	DIAMETER	1.015	
AXIAL DISPL (mm)	AXIAL FORCE (mv)		AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000		.000	0.000
0.007	0.000		.000	0.000
0.020	0.100		.000	0.164
0.033	0.500		0.001	0.817
0.047	0.800		0.001	1.307
0.066	1.200		0.001	1.960
0.068	1.300		0.001	2.123
0.090	1.800		0.002	2.939
0.116	2.500		0.002	4.080
0.141	3.000		0.003	4.893
0.163	3.300		0.003	5.380
0.211	3.800		0.004	6.189
0.254	4.200		0.005	6.834
0.304	4.600		0.006	7.477
0.359	5.000		0.008	8.118
0.499	5.200		0.011	8.418
0.512	5.100		0.011	8.253
0.529	4.800		0.011	7.765
0.531	4.700		0.011	7.603
0.543	4.200		0.011	6.793
0.556	3.600		0.012	5.821
0.576	3.600		0.012	5.818
0.596	3.700		0.013	5.977
0.632	4.400		0.013	7.103
0.652	5.200		0.014	8.391
0.669	5.800		0.014	9.356
0.695	6.400		0.015	10.318
0.727	7.000		0.015	11.278
0.776	7.600		0.016	12.232
0.811	7.900		0.017	12.705
0.841	8.000		0.018	12.858
0.900	8.069		0.019	12.953
1.000	8.062		0.021	12.915
1.057	8.100		0.022	12.961
1.145	8.300		0.024	13.257
1.232	8.700		0.026	13.871
1.300	8.929		0.027	14.217
1.420	8.800		0.030	13.976
1.529	8.500		0.032	13.470
1.594	8.300		0.034	13.135
1.701	8.000		0.036	12.633
1.779	7.900		0.038	12.455
1.890	7.800		0.040	12.270
2.019	7.700		0.043	12.081
2.100	7.668		0.044	12.010
2.200	7.637		0.046	11.938
2.341	7.500		0.049	11.691
2.456	7.300		0.052	11.353
2.533	7.200		0.053	11.180
2.641	7.200		0.056	11.156
2.799	7.500		0.059	11.584
2.927	7.400		0.062	11.401
3.011	7.200		0.064	11.074

3.166	7.200	0.067	11.040
3.273	7.300	0.069	11.170
3.387	7.300	0.071	11.145
3.557	7.100	0.075	10.803
3.600	7.085	0.076	10.771
3.694	7.100	0.078	10.774
3.868	7.200	0.082	10.889
4.020	7.100	0.085	10.706
4.100	7.073	0.087	10.649
4.156	7.100	0.088	10.677
4.200	7.120	0.089	10.698
4.372	7.200	0.092	10.783
4.413	7.200	0.093	10.774
4.569	7.200	0.096	10.742
4.700	7.231	0.099	10.761
4.800	7.249	0.101	10.767
4.900	7.254	0.103	10.754

Figure C-13

TEST PV27B SHALE T = 125 C

CONFINING PRESSURE =50 MPA

LENGTH 1.362 DIAMETER 1.01

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.000	0.000
0.100	0.063	0.003	0.104
0.102	0.100	0.003	0.165
0.105	0.500	0.003	0.824
0.104	0.800	0.003	1.318
0.117	1.100	0.003	1.811
0.154	1.600	0.004	2.632
0.180	1.900	0.005	3.123
0.209	2.300	0.006	3.777
0.241	2.700	0.007	4.430
0.262	3.000	0.008	4.919
0.281	3.300	0.008	5.408
0.296	3.600	0.009	5.897
0.308	3.800	0.009	6.222
0.313	3.900	0.009	6.385
0.348	4.400	0.010	7.196
0.375	4.800	0.011	7.845
0.402	5.200	0.012	8.492
0.438	5.600	0.013	9.136
0.464	5.900	0.013	9.618
0.491	6.200	0.014	10.099
0.511	6.400	0.015	10.419
0.548	6.900	0.016	11.221
0.590	7.400	0.017	12.020
0.617	7.700	0.018	12.498
0.645	8.000	0.019	12.974
0.682	8.400	0.020	13.609
0.714	8.700	0.021	14.082
0.728	8.800	0.021	14.238
0.782	9.200	0.023	14.863
0.815	9.400	0.024	15.172
0.854	9.600	0.025	15.477
0.926	9.900	0.027	15.929
0.961	10.000	0.028	16.074
1.038	10.100	0.030	16.199
1.100	10.124	0.032	16.209
1.126	10.100	0.033	16.160
1.200	10.021	0.035	16.000
1.300	10.022	0.038	15.958
1.400	10.019	0.040	15.908
1.500	10.016	0.043	15.859
1.582	10.000	0.046	15.798
1.600	9.995	0.046	15.782
1.700	9.971	0.049	15.701
1.800	9.981	0.052	15.674
1.900	9.976	0.055	15.623
1.976	10.000	0.057	15.628
2.000	10.010	0.058	15.633
2.108	10.100	0.061	15.727
2.146	10.200	0.062	15.866

Figure C-14

TEST PV33 SHALE T-125 C
CONFINING PRESSURE = 300 MPa

LENGTH AXIAL DISPL (mm)	40.92 AXIAL FORCE (mv)	DIAMETER 25.78 AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.0000	0.00
0.000	0.005	0.0000	0.01
0.000	0.054	0.0000	0.08
0.006	0.200	0.0001	0.31
0.017	0.600	0.0004	0.94
0.022	1.000	0.0005	1.56
0.030	1.400	0.0007	2.19
0.042	1.600	0.0010	2.50
0.052	1.800	0.0013	2.81
0.075	2.400	0.0018	3.75
0.092	2.800	0.0022	4.37
0.109	3.200	0.0027	4.99
0.147	4.000	0.0036	6.23
0.171	4.600	0.0042	7.16
0.194	5.200	0.0047	8.09
0.220	5.800	0.0054	9.02
0.259	6.600	0.0063	10.26
0.303	7.400	0.0074	11.49
0.324	7.800	0.0079	12.10
0.360	8.600	0.0088	13.33
0.407	9.600	0.0100	14.87
0.438	10.200	0.0107	15.78
0.480	11.200	0.0117	17.31
0.525	12.000	0.0128	18.53
0.575	12.800	0.0141	19.74
0.629	13.800	0.0154	21.26
0.679	14.600	0.0166	22.46
0.695	14.800	0.0170	22.76
0.737	15.400	0.0180	23.66
0.766	16.200	0.0187	24.87
0.772	16.800	0.0189	25.79
0.770	17.400	0.0188	26.71
0.770	18.200	0.0188	27.94
0.777	19.200	0.0190	29.47
0.778	19.600	0.0190	30.08
0.781	20.000	0.0191	30.70
0.802	21.000	0.0196	32.21
0.828	21.800	0.0202	33.42
0.852	22.600	0.0208	34.63
0.870	23.200	0.0213	35.53
0.892	24.000	0.0218	36.74
0.913	24.600	0.0223	37.64
0.935	25.200	0.0229	38.53
0.955	25.800	0.0233	39.43
0.968	26.200	0.0236	40.03
1.008	27.200	0.0246	41.52
1.047	28.000	0.0256	42.70
1.071	28.400	0.0262	43.29
1.100	28.800	0.0269	43.87
1.146	29.200	0.0280	44.43
1.237	29.600	0.0302	44.94
1.353	29.600	0.0331	44.81
1.407	29.000	0.0344	43.85

1.420	28.400	0.0347	42.93
1.451	27.600	0.0355	41.69
1.493	27.000	0.0365	40.74
1.542	26.800	0.0377	40.39
1.684	26.800	0.0412	40.26
1.747	27.000	0.0427	40.50
1.844	27.400	0.0451	41.01
1.987	28.000	0.0486	41.76
2.114	28.400	0.0517	42.24
2.374	28.800	0.0580	42.57
2.400	28.831	0.0587	42.59
2.552	29.000	0.0624	42.69
2.627	29.200	0.0642	42.91

Figure C-15

Sample #28

TEST PV28 SHALE T = 250 C
 CONFINING PRESSURE = 0.1 MPa
 LENGTH 38.84 DIAMETER 25.25

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.0000	0.000
0.005	0.016	0.0001	0.026
0.010	0.100	0.0003	0.163
0.050	0.200	0.0013	0.326
0.100	0.245	0.0026	0.398
0.200	0.261	0.0051	0.423
0.294	0.300	0.0076	0.485
0.294	0.300	0.0076	0.485
0.274	0.300	0.0071	0.486
0.300	0.313	0.0077	0.506
0.400	0.354	0.0103	0.572
0.485	0.400	0.0125	0.644
0.626	0.500	0.0161	0.802
0.700	0.572	0.0180	0.916
0.729	0.600	0.0188	0.960
0.844	0.700	0.0217	1.117
0.900	0.715	0.0232	1.139
1.000	0.739	0.0257	1.175
1.076	0.800	0.0277	1.269
1.131	0.900	0.0291	1.426
1.200	0.943	0.0309	1.492
1.300	0.948	0.0335	1.496
1.400	0.940	0.0360	1.480
1.500	0.954	0.0386	1.497
1.600	0.956	0.0412	1.497
1.700	0.986	0.0438	1.540
1.741	1.000	0.0448	1.561
1.800	1.042	0.0463	1.624
1.900	1.080	0.0489	1.680
1.982	1.100	0.0510	1.707
2.100	1.119	0.0541	1.731
2.181	1.200	0.0561	1.853
2.247	1.300	0.0579	2.004
2.321	1.400	0.0598	2.154
2.386	1.500	0.0614	2.304
2.439	1.600	0.0628	2.455
2.518	1.800	0.0648	2.756
2.549	1.900	0.0656	2.907
2.597	2.100	0.0669	3.210
2.643	2.300	0.0681	3.511
2.685	2.500	0.0691	3.813
2.706	2.600	0.0697	3.963
2.736	2.700	0.0704	4.113
2.766	2.800	0.0712	4.262
2.804	2.900	0.0722	4.410
2.848	3.100	0.0733	4.709
2.875	3.200	0.0740	4.858
2.900	3.300	0.0747	5.007
2.928	3.400	0.0754	5.155
2.953	3.500	0.0760	5.304
2.974	3.600	0.0766	5.452
3.002	3.700	0.0773	5.600
3.033	3.800	0.0781	5.747

3.067	3.900	0.0790	5.894
3.089	4.000	0.0795	6.042
3.106	4.100	0.0800	6.190
3.126	4.200	0.0805	6.338
3.145	4.200	0.0810	6.335
3.153	4.100	0.0812	6.183
3.155	4.000	0.0812	6.032
3.164	3.900	0.0815	5.880
3.167	3.800	0.0815	5.729
3.167	3.700	0.0815	5.578
3.174	3.600	0.0817	5.427
3.181	3.500	0.0819	5.275
3.185	3.400	0.0820	5.124
3.195	3.300	0.0823	4.972
3.212	3.200	0.0827	4.819
3.225	3.100	0.0830	4.667
3.249	3.000	0.0837	4.514
3.300	2.940	0.0850	4.418
3.308	2.900	0.0852	4.357
3.400	2.816	0.0875	4.221
3.472	2.800	0.0894	4.191
3.485	2.800	0.0897	4.190
3.500	2.801	0.0901	4.190
3.600	2.810	0.0927	4.193
3.686	2.800	0.0949	4.170
3.700	2.795	0.0953	4.161
3.800	2.758	0.0978	4.097

Figure C-16

Shale sample #29 $T = 250^\circ \text{C}$ $P_e = 0.1 \text{ MPa}$

TEST PV29 SHALE T = 250 C

CONFINING PRESSURE = 0.1 MPa

LENGTH 37.62 DIAMETER 25.91

AXIAL DISPL (mm)	AXIAL FORCE (mv)	AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000	0.0000	0.000
0.050	0.014	0.0013	0.021
0.090	0.100	0.0024	0.154
0.100	0.134	0.0027	0.206
0.183	0.200	0.0049	0.308
0.200	0.201	0.0053	0.310
0.300	0.203	0.0080	0.312
0.400	0.208	0.0106	0.318
0.493	0.300	0.0131	0.458
0.500	0.304	0.0133	0.464
0.615	0.400	0.0164	0.609
0.676	0.500	0.0180	0.761
0.700	0.529	0.0186	0.804
0.743	0.600	0.0198	0.911
0.800	0.677	0.0213	1.027
0.819	0.700	0.0218	1.061
0.866	0.800	0.0230	1.211
0.898	0.900	0.0239	1.361
0.900	0.908	0.0239	1.373
0.930	1.000	0.0247	1.511
0.965	1.100	0.0257	1.661
0.997	1.200	0.0265	1.810
1.032	1.300	0.0274	1.959
1.064	1.400	0.0283	2.108
1.084	1.500	0.0288	2.257
1.100	1.583	0.0292	2.381
1.111	1.600	0.0295	2.406
1.141	1.700	0.0303	2.555
1.170	1.800	0.0311	2.703
1.197	1.900	0.0318	2.851
1.219	2.000	0.0324	2.999
1.240	2.100	0.0330	3.148
1.271	2.200	0.0338	3.295
1.298	2.300	0.0345	3.442
1.317	2.400	0.0350	3.590
1.339	2.500	0.0356	3.738
1.357	2.600	0.0361	3.886
1.374	2.700	0.0365	4.033
1.399	2.800	0.0372	4.180
1.419	2.900	0.0377	4.327
1.432	3.000	0.0381	4.475
1.445	3.100	0.0384	4.622
1.460	3.200	0.0388	4.770
1.486	3.400	0.0395	5.064
1.500	3.459	0.0399	5.150
1.506	3.500	0.0400	5.211
1.523	3.600	0.0405	5.357
1.542	3.700	0.0410	5.503
1.556	3.800	0.0414	5.650
1.568	3.900	0.0417	5.797
1.582	4.100	0.0420	6.092
1.593	4.200	0.0423	6.239
1.599	4.300	0.0425	6.387

1.622	4.400	0.0431	6.531
1.661	4.500	0.0442	6.673
1.673	4.600	0.0445	6.819
1.689	4.700	0.0449	6.965
1.703	4.800	0.0453	7.110
1.716	4.900	0.0456	7.256
1.727	5.100	0.0459	7.550
1.738	5.200	0.0462	7.696
1.753	5.300	0.0466	7.841
1.775	5.400	0.0472	7.984
1.798	5.500	0.0478	8.127
1.800	5.514	0.0478	8.148
1.808	5.600	0.0481	8.273
1.818	5.700	0.0483	8.419
1.829	5.800	0.0486	8.564
1.842	5.900	0.0490	8.709
1.853	6.100	0.0492	9.002
1.862	6.200	0.0495	9.147
1.868	6.300	0.0496	9.293
1.883	6.400	0.0500	9.437
1.906	6.500	0.0507	9.579
1.928	6.600	0.0513	9.721
1.946	6.700	0.0517	9.864
1.965	6.900	0.0522	10.153
1.986	7.000	0.0528	10.295
2.000	7.091	0.0532	10.425
2.000	7.098	0.0532	10.436
2.000	7.100	0.0532	10.438
2.026	7.200	0.0538	10.578
2.043	7.300	0.0543	10.721
2.063	7.400	0.0548	10.862
2.078	7.500	0.0552	11.005
2.092	7.600	0.0556	11.148
2.103	7.700	0.0559	11.291
2.117	7.800	0.0563	11.434
2.126	7.900	0.0565	11.578
2.132	8.000	0.0567	11.722
2.141	8.100	0.0569	11.866
2.150	8.200	0.0572	12.010
2.155	8.300	0.0573	12.155
2.167	8.400	0.0576	12.298
2.181	8.400	0.0580	12.294
2.182	8.300	0.0580	12.147
2.189	8.100	0.0582	11.852
2.200	7.900	0.0585	11.556
2.200	7.879	0.0585	11.526
2.201	7.800	0.0585	11.410
2.204	7.700	0.0586	11.262
2.200	7.600	0.0585	11.117
2.200	7.509	0.0585	10.984
2.200	7.463	0.0585	10.916

Figure C-17

Shale sample #34 $T = 250^\circ \text{C}$ $P_e = 150 \text{ MPa}$

crtpv34.sac

-147-

TEST PV34 SHALE T = 250 C

CONFINING PRESSURE = 300 MPa

LENGTH	36.2	DIAMETER	26.42	
AXIAL DISPL (mm)	AXIAL FORCE (mv)		AXIAL STRAIN	AXIAL STRESS (MPa)
0.000	0.000		0.0000	0.0
0.139	0.600		0.0039	0.9
0.148	1.200		0.0041	1.8
0.159	1.800		0.0044	2.7
0.170	2.400		0.0047	3.6
0.186	3.600		0.0051	5.3
0.204	4.800		0.0056	7.1
0.228	6.000		0.0063	8.9
0.268	7.800		0.0074	11.5
0.291	9.600		0.0080	14.2
0.310	10.800		0.0086	16.0
0.331	12.000		0.0091	17.7
0.346	13.200		0.0096	19.5
0.372	15.000		0.0103	22.1
0.386	16.200		0.0107	23.9
0.402	17.400		0.0111	25.6
0.414	18.600		0.0114	27.4
0.431	19.800		0.0119	29.1
0.447	21.000		0.0123	30.9
0.463	22.200		0.0128	32.7
0.479	24.000		0.0132	35.3
0.486	24.600		0.0134	36.2
0.505	25.800		0.0140	37.9
0.525	27.000		0.0145	39.6
0.559	28.800		0.0154	42.2
0.574	30.000		0.0159	44.0
0.592	31.200		0.0163	45.7
0.594	31.800		0.0164	46.6
0.591	33.000		0.0163	48.4
0.661	35.400		0.0183	51.8
0.683	36.600		0.0189	53.5
0.707	38.400		0.0195	56.1
0.721	39.600		0.0199	57.8
0.747	41.400		0.0206	60.4
0.772	42.600		0.0213	62.1
0.820	43.800		0.0226	63.8
0.843	44.400		0.0233	64.6
0.855	45.000		0.0236	65.5
0.871	46.200		0.0240	67.2
0.903	47.400		0.0249	68.9
0.940	48.600		0.0260	70.6
0.992	49.800		0.0274	72.2
1.039	50.400		0.0287	73.0
1.200	50.900		0.0331	73.4
1.311	50.400		0.0362	72.5
1.359	49.800		0.0375	71.5
1.416	49.200		0.0391	70.5
1.576	49.200		0.0435	70.2
1.638	49.800		0.0453	71.0
1.800	49.943		0.0497	70.9
1.861	49.200		0.0514	69.7
1.911	48.600		0.0528	68.8
2.040	48.600		0.0563	68.5

2.087	49.200	0.0577	69.3
2.199	50.400	0.0607	70.8
2.296	51.000	0.0634	71.4
2.344	51.000	0.0647	71.4
2.423	49.800	0.0669	69.5
2.512	48.600	0.0694	67.7
2.645	47.400	0.0731	65.8
2.769	47.400	0.0765	65.6
2.891	48.000	0.0799	66.2
2.911	48.000	0.0804	66.2
3.000	47.880	0.0829	65.9
3.013	48.000	0.0832	66.0
3.131	48.600	0.0865	66.6
3.166	47.400	0.0875	64.9
3.505	47.400	0.0968	64.4
3.600	47.654	0.0994	64.6
3.674	48.000	0.1015	64.9
3.764	48.600	0.1040	65.6
3.878	49.200	0.1071	66.2
4.012	49.800	0.1108	66.8
4.035	49.800	0.1115	66.7
4.103	49.200	0.1133	65.8
4.130	48.000	0.1141	64.2
4.200	47.702	0.1160	63.7
4.256	48.000	0.1176	64.0
4.314	48.000	0.1192	63.9
4.309	47.400	0.1190	63.1
4.305	45.600	0.1189	60.7
4.317	43.800	0.1193	58.3
4.326	43.200	0.1195	57.5

APPENDIX D

TABULATED DATA FOR LONG-TERM CREEP/COMPACTION TESTS ON OIL-SAND AND SHALE SAMPLES

Table D-1. Summary of conditions of the long-term creep tests.

Test No. (date)	Sample	Core	Depth (ft)	Temperature (°C)	Pressure				Initial Volume	Density
					Confining (psi)	(MPa)	Effective (psi)	(MPa)		
1. (4/30/86-5/27/86)	Shale	ND*	ND	25	900	6.21	420	2.90	101.69	ND
					1300	8.97	625	4.31	101.69	ND
					1700	11.72	825	5.69	101.69	ND
2. (7/14/86-8/15/86)	2a Shale	ND	3309.6-ft	25	540	3.72	200	1.38	73.47	1.701
					1200	8.28	600	4.14		
					1600	11.03	800	5.52		
	2b Shale	ND	3206-ft	25	540	3.72	175	1.21	102.73	1.97
					1200	8.28	615	4.24		
					1600	11.03	820	5.44		
	2c Shale	ND	3280-ft	25	540	3.72	165	1.10	72.26	1.85
					1200	8.28	635	4.21		
					1600	11.03	836	5.55		
3. (9/3/86-10/13/86)	3a Shale	49	3202-ft	125	800	5.52	400	2.76	78.1	2.074
					1200	8.28	540	3.72		
	3b Shale	70	3280-ft	125	800	5.52	450	3.10	59.39	1.818
					1200	8.28	645	4.45		
	3c Shale	49	3204-ft	125	800	5.52	400	2.76	74.46	1.947
					1200	8.28	600	4.14		
4. (10/21/86-10/31/86)	4a Oil Sand	70	3280-ft	125	750	5.17	520	3.59	55.26	ND
	4b Shale	49	3202-ft	125	750	5.17	460	3.17	69.37	ND
	4c Shale	51	3207-ft	125	Sample jacket failed, test not completed				71.78	ND
5. (3/ 3/87-4/16/87)	5a Shale	49	3202-ft	125	800	5.52	445	3.07	85.16	1.926
	5b Shale	51	3206-ft	125	800	5.52	430	2.97	78.65	1.920
	5c Oil Sand	70	3278-ft	125	800	5.52	380	2.62	40.68	1.893

Table D.1.a - Data for test #1
 Faja shale, depth unknown
 Volume = 101.69 CC, 25 °C
 Run started on 4/30/86; ended on 5/27/86

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	Ref. V	VV	V/V ₀
1.0	0	443.20	878.96	435.76	8.246	0	100
47	1.67	412.72	917.96	505.24	3.368	4.879	95.20
121	2.08	413.74	915.56	501.82	3.303	4.944	95.14
137	2.14	412.72	911.96	499.24	3.290	4.957	95.13
161	2.21	413.80	917.96	504.16	3.274	4.972	95.11
208	2.32	553.84	1015.16	461.32	3.274	4.972	95.11
216	2.33	613.18	1308.86	695.69	2.877	5.370	94.72
235	2.37	613.48	1320.98	707.50	2.828	5.418	94.67
283	2.45	617.26	1309.76	692.50	2.800	5.447	94.64
291	2.46	680.68	1367.96	687.28	2.774	5.473	94.62
307	2.49	615.16	1315.46	700.30	2.736	5.510	94.58
330	2.52	613.06	1316.96	703.90	2.716	5.531	94.56
363	2.56	669.10	1336.16	667.06	2.709	5.537	94.55
383	2.58	828.88	1716.56	887.68	2.596	5.650	94.44
430	2.63	832.36	1710.56	878.20	2.498	5.749	94.35
454	2.66	831.46	1764.86	933.40	2.464	5.783	94.31
640	2.81	810.28	1709.06	898.78	2.445	5.801	94.30

Table D.2.a - Data for Test #2a - FAJA Shale, 3309.6-ft depth
Volume = 73.47 cm³, density 1.70 gm/cm³, 25°C
Run started on 7/14/86; ended on 8/15/86

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	R. V	V V	V/V ₀
1.6	0.20	319.9	542.4	222.5	4.435	0.268	99.635
16.9	1.23	349.7	543.6	193.9	4.235	0.468	99.363
21.6	1.33	329.5	553.6	224.1	4.071	0.632	99.140
25.3	1.40	320.6	547.4	226.8	3.901	0.802	98.908
41.0	1.61	324.7	541.7	217.0	3.587	1.116	98.481
45.5	1.66	345.1	544.7	199.6	2.498	2.205	96.999
49.0	1.69	327.6	548.6	221.0	3.417	1.286	98.250
65.0	1.81	343.2	545.2	202.0	2.920	1.783	97.573
73.0	1.86	321.3	546.4	225.1	2.798	1.905	97.407
89.0	1.95	326.7	553.0	226.3	2.695	2.008	97.267
98.0	1.99	381.7	545.2	163.5	2.647	2.056	97.202
114.0	2.06	318.3	551.2	232.9	2.762	1.941	97.358
122.0	2.09	319.7	549.1	229.4	2.716	1.987	97.295
139.0	2.14	317.9	547.6	229.7	2.668	2.035	97.230
147.0	2.17	306.1	544.7	238.6	2.653	2.050	97.210
162.5	2.21	307.5	543.6	236.1	2.648	2.055	97.203
186.5	2.27	636.8	1217.3	580.5	2.097	2.606	96.453
195.0	2.29	627.0	1216.9	589.9	2.033	2.670	96.366
211.0	2.32	617.9	1217.2	599.3	1.984	2.719	96.299
219.0	2.34	622.3	1218.7	596.4	1.934	2.769	96.231
239.0	2.38	678.6	1204.1	525.5	1.914	2.789	96.204
243.0	2.39	613.7	1218.8	605.1	1.883	2.820	96.162
259.0	2.41	615.6	1218.6	603.0	1.858	2.845	96.128
267.0	2.43	582.9	1217.7	634.8	1.821	2.882	96.077
283.0	2.45	605.7	1219.8	614.1	1.790	2.913	96.035
291.0	2.46	622.3	1229.0	606.7	1.768	2.935	96.005
307.5	2.49	604.7	1221.2	616.5	1.746	2.957	95.975
314.0	2.50	579.7	1224.1	644.4	1.717	2.986	95.936
329.5	2.52	605.8	1218.5	612.7	1.705	2.998	95.919
337.5	2.53	606.3	1218.2	611.9	1.698	3.005	95.910
401.5	2.60	605.2	1216.5	611.3	1.69	3.013	95.899
409.5	2.61	605.4	1216.6	611.2	1.678	3.025	95.883
433.5	2.64	604.5	1218.8	614.3	1.667	3.036	95.868
449.5	2.65	602.7	1194.7	592.0	1.672	3.031	95.875
473.5	2.68	603.3	1217.4	614.1	1.673	3.030	95.876
474.5	2.68	805.4	1617.2	811.8	1.662	3.041	95.861
477.5	2.68	807.7	1619.8	812.1	1.643	3.060	95.835
481.5	2.68	809.8	1626.1	816.3	1.614	3.089	95.796
497.5	2.70	800.3	1618.4	818.1	1.593	3.110	95.767
506	2.70	807.4	1622.1	814.7	1.572	3.131	95.738
569.5	2.76	802.8	1618.6	815.8	1.555	3.148	95.715
578	2.76	806.8	1619.6	812.8	1.538	3.165	95.692
593.5	2.77	804.5	1622.3	817.8	1.527	3.176	95.677
602	2.78	809	1619.8	810.8	1.512	3.191	95.657
617.5	2.79	805.2	1622.3	817.1	1.494	3.209	95.632
626	2.80	803	1620.4	817.4	1.482	3.221	95.616
650	2.81	805.6	1619.6	814.0	1.483	3.220	95.617
666	2.82	797.8	1617.9	820.1	1.491	3.212	95.628

Table D.2.b - Data for Test #2b - FAJA Shale, 3206-ft depth
Volume = 102.73 cm³, Density 1.97 gm/cm³, 25°C
Run started on 7/14/86; ended on 8/15/86

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	R. V	∇ V	V/V ₀
1.6	0.20	370.8	542.4	171.6	2.822	-0.015	100.015
16.9	1.23	371.1	543.6	172.5	2.853	-0.046	100.045
21.6	1.33	371.2	553.6	182.4	2.850	-0.043	100.042
25.3	1.40	372.2	547.4	175.2	2.856	-0.049	100.048
41.0	1.61	370.8	541.7	170.9	2.895	-0.088	100.086
45.5	1.66	373.6	544.7	171.1	2.905	-0.098	100.095
49.0	1.69	372.8	548.6	175.8	2.897	-0.090	100.088
65.0	1.81	373.6	545.2	171.6	2.925	-0.118	100.115
73.0	1.86	372.1	546.4	174.3	2.920	-0.113	100.110
89.0	1.95	371.8	553.0	181.2	2.928	-0.121	100.118
98.0	1.99	372.1	545.2	173.1	2.936	-0.129	100.126
114.0	2.06	374.5	551.2	176.7	2.949	-0.142	100.138
122.0	2.09	373.7	549.1	175.4	2.943	-0.136	100.132
139.0	2.14	369.9	547.6	177.7	2.943	-0.136	100.132
147.0	2.17	371.9	544.7	172.8	2.953	-0.146	100.142
162.5	2.21	371.6	543.6	172.0	2.969	-0.162	100.158
186.5	2.27	602.1	1217.3	615.2	2.247	0.560	99.455
195.0	2.29	603.4	1216.9	613.5	2.215	0.592	99.424
211.0	2.32	601.0	1217.2	616.2	2.203	0.604	99.412
219.0	2.34	600.8	1218.7	617.9	2.186	0.621	99.396
239.0	2.38	594.8	1204.1	609.3	2.180	0.627	99.390
243.0	2.39	601.8	1218.8	617.0	2.170	0.637	99.380
259.0	2.41	601.7	1218.6	616.9	2.165	0.642	99.375
267.0	2.43	602.3	1217.7	615.4	2.149	0.658	99.359
283.0	2.45	602.3	1219.8	617.5	2.135	0.672	99.346
291.0	2.46	604.0	1229.0	625.0	2.120	0.687	99.331
307.5	2.49	601.8	1221.2	619.4	2.113	0.694	99.324
314.0	2.50	602.3	1224.1	621.8	2.099	0.708	99.311
329.5	2.52	600.7	1218.5	617.8	2.095	0.712	99.307
337.5	2.53	601.5	1218.2	616.7	2.089	0.718	99.301
401.5	2.60	601.4	1216.5	615.1	2.086	0.721	99.298
409.5	2.61	601.5	1216.6	615.1	2.074	0.733	99.286
433.5	2.64	601.7	1218.8	617.1	2.072	0.735	99.285
449.5	2.65	601.0	1194.7	593.7	2.086	0.721	99.298
473.5	2.68	600.9	1217.4	616.5	2.086	0.721	99.298
474.5	2.68	803.9	1617.2	813.3	1.962	0.845	99.177
477.5	2.68	803.8	1619.8	816.0	1.933	0.874	99.149
481.5	2.68	803.7	1626.1	822.4	1.898	0.909	99.115
497.5	2.70	801.4	1618.4	817.0	1.874	0.933	99.092
506.0	2.70	799.0	1622.1	823.1	1.841	0.966	99.060
569.5	2.76	801.2	1618.6	817.4	1.814	0.993	99.033
578.0	2.76	801.5	1619.6	818.1	1.793	1.014	99.013
593.5	2.77	799.9	1622.3	822.4	1.786	1.021	99.006
602.0	2.78	801.2	1619.8	818.6	1.769	1.038	98.990
617.5	2.79	798.7	1622.3	823.6	1.754	1.053	98.975
626.0	2.80	799.9	1620.4	820.5	1.744	1.063	98.965
650.0	2.81	801.2	1619.6	818.4	1.743	1.064	98.964
666.0	2.82	798.9	1617.9	819.0	1.756	1.051	98.977

Table D.2.c - Data for Test #2c - FAJA Oil Sand, 3280-ft depth
Volume = 72.26 cm³, Density 1.85 gm/cm³, 25°C
Run started on 7/14/86; ended on 8/15/86

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	R. V	∇ V	V/V ₀
1.6	0.20	371.9	542.4	170.5	5.261	-0.027	100.037
16.9	1.23	379.8	543.6	163.8	5.311	-0.077	100.107
21.6	1.33	382.1	553.6	171.5	5.312	-0.078	100.108
25.3	1.40	383.7	547.4	163.7	5.318	-0.084	100.116
41.0	1.61	378.9	541.7	162.8	5.352	-0.118	100.163
45.5	1.66	382.5	544.7	162.2	5.362	-0.128	100.177
49.0	1.69	385.0	548.6	163.6	5.357	-0.123	100.170
65.0	1.81	385.2	545.2	160.0	5.385	-0.151	100.209
73.0	1.86	385.2	546.4	161.2	5.381	-0.147	100.203
89.0	1.95	384.1	553.0	168.9	5.386	-0.152	100.210
98.0	1.99	381.7	545.2	163.5	5.393	-0.159	100.220
114.0	2.06	386.6	551.2	164.6	5.392	-0.158	100.219
122.0	2.09	386.5	549.1	162.6	5.385	-0.151	100.209
139.0	2.14	374.8	547.6	172.8	4.955	0.279	99.614
147.0	2.17	383.9	544.7	160.8	4.968	0.266	99.632
162.5	2.21	381.1	543.6	162.5	4.988	0.246	99.660
186.5	2.27	586.3	1217.3	631.0	4.973	0.261	99.639
195.0	2.29	587.3	1216.9	629.6	4.767	0.467	99.354
211.0	2.32	578.4	1217.2	638.8	4.760	0.474	99.344
219.0	2.34	582.5	1218.7	636.2	4.747	0.487	99.326
239.0	2.38	570.6	1204.1	633.5	4.757	0.477	99.340
243.0	2.39	582.9	1218.8	635.9	4.752	0.482	99.333
259.0	2.41	582.8	1218.6	635.8	4.752	0.482	99.333
267.0	2.43	581.8	1217.7	635.9	4.735	0.499	99.309
283.0	2.45	584.5	1219.8	635.3	4.729	0.505	99.301
291.0	2.46	582.4	1229.0	646.6	4.709	0.525	99.273
307.5	2.49	582.9	1221.2	638.3	4.710	0.524	99.275
314.0	2.50	582.5	1224.1	641.6	4.694	0.540	99.253
329.5	2.52	583.7	1218.5	634.8	4.698	0.536	99.258
337.5	2.53	583.4	1218.2	634.8	4.694	0.540	99.253
401.5	2.60	583.2	1216.5	633.3	4.704	0.530	99.267
409.5	2.61	583.6	1216.6	633.0	4.692	0.542	99.250
433.5	2.64	583.6	1218.8	635.2	4.697	0.537	99.257
449.5	2.65	582.0	1219.0	637.0	4.717	0.517	99.285
473.5	2.68	582.2	1217.4	635.2	4.722	0.512	99.291
474.5	2.68	785.3	1617.2	831.9	4.622	0.612	99.153
477.5	2.68	788.9	1619.8	830.9	4.603	0.631	99.127
481.5	2.68	784.4	1626.1	841.7	4.573	0.661	99.085
497.5	2.70	786.2	1618.4	832.2	4.567	0.667	99.077
506.0	2.70	784.7	1622.1	837.4	4.542	0.692	99.042
569.5	2.76	783.5	1618.6	835.1	4.534	0.700	99.031
578.0	2.76	785.0	1619.6	834.6	4.517	0.717	99.008
593.5	2.77	780.0	1622.3	842.3	4.516	0.718	99.006
602.0	2.78	784.7	1619.8	835.1	4.501	0.733	98.986
617.5	2.79	783.3	1622.3	839.0	4.492	0.742	98.973
626.0	2.80	783.2	1620.4	837.2	4.484	0.750	98.962
650.0	2.81	784.7	1619.6	834.9	4.490	0.744	98.970
666.0	2.82	777.8	1617.9	840.1	4.509	0.725	98.997

Table D.2.d. Summary Data for Creep Test #2

Sample	P_E	Slope, $\times 10^{-3} \text{ s}^{-1}$
Shale, 3309 ft	200 psi (1.38 MPa)	-20.0
	600 psi (4.14 MPa)	-19.91
	800 psi (5.52 MPa)	-11.69
Shale, 3206 ft	175 psi (1.21 MPa)	+1.15
	615 psi (4.24 MPa)	-4.24
	820 psi (5.44 MPa)	-8.65
Oil-sand, 3280 ft	165 psi (1.10 MPa)	Positive slope
	635 psi (4.21 MPa)	-3.63
	836 psi (5.55 MPa)	-8.06

Note that the slope values for the 3309-ft shale sample are much higher than the other samples; this can also be seen in the plotted data (Figure 2a).

Table D.3.a - Data for Test #3a - FAJA SHALE, 3202-FT DEPTH, Core #49
VOLUME = 78.1 cm³, DENSITY 2.07 gm/cm³, 125°C
Run started on 9/3/87; ended on 10/13/87

Time/Hr	LOG t	<u>Pressure in MPa</u>			<u>Volume in cm³</u>		
		Pp	Pc	Pe	R. V.	V V	V/V ₀
119.5	2.08	1.407	5.547	4.140	4.918	-1.060	101.476
127.5	2.11	2.230	5.541	3.311	5.172	-1.314	101.830
143.5	2.16	2.439	5.597	3.158	5.315	-1.457	102.029
151.5	2.18	1.867	5.448	3.581	5.580	-1.722	102.398
167.5	2.22	1.804	5.546	3.742	5.733	-1.875	102.611
175.5	2.24	2.451	5.491	3.040	6.018	-2.160	103.008
191.5	2.28	1.806	5.477	3.671	6.145	-2.287	103.185
199.5	2.30	3.718	5.372	1.654	6.322	-2.464	103.432
215.5	2.33	2.004	5.428	3.424	6.528	-2.670	103.719
223.5	2.35	2.203	5.374	3.171	6.666	-2.808	103.911
288.5	2.46	1.697	5.494	3.797	6.925	-3.067	104.272
296.5	2.47	3.026	5.565	2.539	7.102	-3.244	104.518
311.5	2.49	2.242	5.505	3.263	7.283	-3.425	104.770
320.5	2.51	3.267	5.461	2.194	7.487	-3.629	105.054
336.5	2.53	2.222	5.498	3.276	7.676	-3.818	105.318
344.5	2.54	4.664	5.565	0.901	7.933	-4.075	105.675
359.5	2.56	2.339	5.498	3.159	8.172	-4.314	106.008
368.5	2.57	4.396	5.509	1.113	8.347	-4.489	106.252
384.5	2.58	3.869	5.517	1.648	8.586	-4.728	106.585
392.5	2.59	3.488	5.520	2.032	8.843	-4.985	106.943
460.0	2.66	4.184	5.351	1.167	10.105	-6.247	108.701
479.0	2.68	2.744	5.662	2.918	10.105	-6.247	108.701
503.0	2.70	4.375	5.494	1.119	11.010	-7.152	109.961
527.0	2.72	2.448	5.550	3.102	11.449	-7.591	110.572
551.0	2.74	2.515	5.511	2.996	11.659	-7.801	110.865
552.5	2.74	4.154	8.232	4.078	11.727	-7.869	110.960
554.5	2.74	4.029	8.254	4.225	11.765	-7.907	111.013
555.5	2.74	4.040	8.287	4.247	11.796	-7.938	111.056
558.5	2.75	4.111	8.383	4.272	11.863	-8.005	111.149
624.5	2.80	2.865	8.213	5.348	12.001	-8.143	111.341
648	2.81	3.512	8.274	4.762	12.142	-8.284	111.538
671	2.83	3.722	8.341	4.619	12.277	-8.419	111.726
697	2.84	3.171	8.320	5.149	12.404	-8.546	111.903
744	2.87	3.578	8.299	4.721	12.529	-8.671	112.077
791	2.90	3.686	8.250	4.564	12.651	-8.793	112.247
814	2.91	3.126	8.032	4.906	12.886	-9.028	112.574
838	2.92	3.51	8.290	4.780	13.25	-9.392	113.081
861.5	2.94	4.185	8.285	4.100	13.46	-9.605	113.377
885.5	2.95	3.908	8.262	4.354	13.626	-9.768	113.604
951	2.98	4.357	8.279	3.922	14.279	-10.421	114.514

Table D.3.b - Data for Test #3b - FAJA Oil Sand, 3280-FT DEPTH, Core #70
 VOLUME = 59.39 cm³, DENSITY 1.82 gm/cm³, 125°C
 Run started on 9/3/87; ended on 10/13/87

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	R. V	V V	V/V ₀
119.5	2.08	3.607	5.547	1.940	0.065	0.053	99.911
127.5	2.11	3.307	5.541	2.234	-0.005	0.123	99.793
143.5	2.16	2.863	5.597	2.734	-0.047	0.165	99.722
151.5	2.18	3.073	5.448	2.375	-0.360	0.478	99.195
167.5	2.22	3.208	5.546	2.338	-0.401	0.519	99.126
175.5	2.24	3.036	5.491	2.455	-0.239	0.357	99.399
191.5	2.28	3.110	5.477	2.367	-0.276	0.394	99.337
199.5	2.30	2.992	5.372	2.380	-0.340	0.458	99.229
215.5	2.33	2.924	5.428	2.504	-0.379	0.497	99.163
223.5	2.35	2.871	5.374	2.503	-0.433	0.551	99.072
288.5	2.46	3.347	5.494	2.147	-0.489	0.607	98.978
296.5	2.47	3.296	5.565	2.269	-0.555	0.673	98.867
311.5	2.49	3.051	5.505	2.454	-0.600	0.718	98.791
320.5	2.51	3.239	5.461	2.222	-0.666	0.784	98.680
336.5	2.53	3.053	5.498	2.445	-0.708	0.826	98.609
344.5	2.54	3.082	5.565	2.483	-0.763	0.881	98.517
359.5	2.56	2.781	5.498	2.717	-0.806	0.924	98.444
368.5	2.57	3.044	5.509	2.465	-0.865	0.983	98.345
384.5	2.58	3.285	5.517	2.232	-0.911	1.029	98.267
392.5	2.59	3.232	5.520	2.288	-0.962	1.080	98.182
460.0	2.66	3.480	5.351	1.871	-1.007	1.125	98.106
479.0	2.68	3.130	5.662	2.532	-1.325	1.443	97.570
503.0	2.70	2.901	5.494	2.593	-1.427	1.545	97.399
527.0	2.72	2.894	5.550	2.656	-1.509	1.627	97.260
551.0	2.74	2.841	5.511	2.670	-1.591	1.709	97.122
552.5	2.74	4.280	8.232	3.952	-1.582	1.700	97.138
554.5	2.74	4.234	8.254	4.020	-1.601	1.719	97.106
555.5	2.74	4.252	8.287	4.035	-1.644	1.762	97.033
558.5	2.75	4.063	8.383	4.320	-1.655	1.773	97.015
624.5	2.80	4.808	8.213	3.405	-1.729	1.847	96.890
648	2.81	4.667	8.274	3.607	-1.798	1.916	96.774
671	2.83	4.343	8.341	3.998	-1.631	1.749	97.055
697	2.84	5.025	8.320	3.295	-1.927	2.045	96.557
744	2.87	4.501	8.299	3.798	-1.994	2.112	96.444
791	2.90	4.806	8.250	3.444	-1.847	1.965	96.691
814	2.91	4.8	8.032	3.208	-2.001	2.119	96.432
838	2.92	4.4	8.290	3.896	-2.375	2.493	95.802
861.5	2.94	4.3	8.285	4.000	-2.471	2.589	95.641
885.5	2.95	4.112	8.262	4.150	-2.308	2.426	95.915
951	2.98	4.189	8.279	4.090	-2.401	2.519	95.759

Table D.3.c - Data for Test #3c - FAJA Shale, 3204-FT DEPTH, Core #49
VOLUME = 74.46 cm³, DENSITY 1.95 gm/cm³, 125°C
Run started on 9/3/87; ended on 10/13/87

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	R. V	V V	V/V ₀
119.5	2.08	2.679	5.547	2.868	3.272	-2.116	102.842
127.5	2.11	2.602	5.541	2.939	3.315	-2.159	102.900
143.5	2.16	2.736	5.597	2.861	3.177	-2.021	102.714
151.5	2.18	2.706	5.448	2.742	3.233	-2.077	102.789
167.5	2.22	2.662	5.546	2.884	3.277	-2.121	102.849
175.5	2.24	2.719	5.491	2.772	3.307	-2.151	102.889
191.5	2.28	2.721	5.477	2.756	3.350	-2.194	102.947
199.5	2.30	2.720	5.372	2.652	3.369	-2.213	102.972
215.5	2.33	2.737	5.428	2.691	3.400	-2.244	103.014
223.5	2.35	2.755	5.374	2.619	3.418	-2.262	103.038
288.5	2.46	2.868	5.494	2.626	3.477	-2.321	103.117
296.5	2.47	2.806	5.565	2.759	3.466	-2.310	103.102
311.5	2.49	2.785	5.505	2.720	3.477	-2.321	103.117
320.5	2.51	2.767	5.461	2.694	3.475	-2.319	103.114
336.5	2.53	2.782	5.498	2.716	3.481	-2.325	103.122
344.5	2.54	2.792	5.565	2.773	3.476	-2.320	103.116
359.5	2.56	2.740	5.498	2.758	3.475	-2.319	103.114
368.5	2.57	2.744	5.509	2.765	3.476	-2.320	103.116
384.5	2.58	2.784	5.517	2.733	3.476	-2.320	103.116
392.5	2.59	2.748	5.520	2.772	3.476	-2.320	103.116
460.0	2.66	2.695	5.351	2.656	3.477	-2.321	103.117
479.0	2.68	3.057	5.662	2.605	3.487	-2.331	103.131
503.0	2.70	2.780	5.494	2.714	3.463	-2.307	103.098
527.0	2.72	2.763	5.550	2.787	3.460	-2.304	103.094
551.0	2.74	2.777	5.511	2.734	3.466	-2.310	103.102
552.5	2.74	4.200	8.232	4.032	3.427	-2.271	103.050
554.5	2.74	4.134	8.254	4.120	3.419	-2.263	103.039
555.5	2.74	4.164	8.287	4.123	3.417	-2.261	103.037
558.5	2.75	4.217	8.383	4.166	3.413	-2.257	103.031
624.5	2.80	4.138	8.213	4.075	3.405	-2.249	103.020
648	2.81	4.147	8.274	4.127	3.404	-2.248	103.019
671	2.83	4.155	8.341	4.186	3.403	-2.247	103.018
697	2.84	4.114	8.320	4.206	3.396	-2.240	103.008
744	2.87	4.146	8.299	4.153	3.400	-2.244	103.014
791	2.90	4.165	8.250	4.085	3.400	-2.244	103.014
814	2.91	3.982	8.032	4.050	3.396	-2.240	103.008
838	2.92	4.095	8.290	4.195	3.711	-2.555	103.431
861.5	2.94	4.139	8.285	4.146	3.762	-2.606	103.500
885.5	2.95	4.174	8.262	4.088	3.782	-2.626	103.527
951	2.98	4.145	8.279	4.134	3.803	-2.647	103.555

Table D.4.a - Data for Test #4a - FAJA Sandstone, 3280-FT DEPTH, Core #70
VOLUME = 55.26 cm³, 125°C
Run started on 10/21/87; ended on 10/31/87

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	R. V	V V	V/V ₀
2.0	0.30	3.000	5.583	2.583	-0.359	0.255	99.539
3.0	0.48	4.174	5.915	1.741	-0.841	0.737	98.666
4.0	0.60	4.995	5.305	0.310	-0.733	0.629	98.862
5.0	0.70	4.982	5.075	0.093	-0.919	0.815	98.525
6.5	0.81	4.486	5.813	1.327	-1.170	1.066	98.071
9.5	0.98	3.118	5.582	2.464	-1.371	1.267	97.707
21.5	1.33	2.842	5.384	2.542	-1.375	1.271	97.700
29.5	1.47	2.763	5.558	2.795	-1.390	1.286	97.673
45.5	1.66	2.666	5.470	12.804	-1.393	1.289	97.667
59.5	1.77	2.661	4.867	2.206	-1.397	1.293	97.660
75.5	1.88	2.725	4.967	2.242	-1.391	1.287	97.671
82.5	1.92	2.888	5.025	2.137	-1.399	1.295	97.657
147.5	2.17	4.586	4.957	0.371	-1.426	1.322	97.608
153.5	2.19	3.307	5.032	1.725	-1.556	1.452	97.372
169.5	2.23	2.573	4.904	2.331	-1.878	1.774	96.790
177.5	2.25	4.317	5.053	0.736	-1.990	1.886	96.587
194.5	2.29	4.109	4.882	0.773	-2.036	1.932	96.504
217.5	2.34	4.622	4.933	0.311	-2.536	2.432	95.599
222.5	2.35	3.137	4.867	1.730	-3.304	3.200	94.209
241.5	2.38	3.841	4.959	1.118	-3.291	3.187	94.233

Tabel D.4.b - Data for Test #4b - FAJA SHALE, 3202-FT DEPTH, Core #49
 VOLUME = 69.37 cm³, 125 °C
 Run started on 10/21/87; ended on 10/31/87

Time/Hr	LOG t	<u>Pressure in MPa</u>			<u>Volume in cm³</u>		
		Pp	Pc	Pe	R. V	∇V	V/V ₀
2.0	0.30	3.202	5.583	2.381	-0.623	0.481	99.307
3.0	0.48	3.426	5.915	2.489	-0.996	0.854	98.769
4.0	0.60	2.825	5.305	2.480	-1.057	0.915	98.681
5.0	0.70	2.341	5.075	2.734	-1.097	0.955	98.623
6.5	0.81	2.667	5.813	3.146	-1.105	0.963	98.612
9.5	0.98	3.242	5.582	2.340	-1.090	0.948	98.633
21.5	1.33	3.228	5.384	2.156	-1.133	0.991	98.571
29.5	1.47	3.401	5.558	2.157	-1.294	1.152	98.339
45.5	1.66	3.277	5.470	32.193	-1.356	1.214	98.250
59.5	1.77	3.514	4.867	1.353	-1.490	1.348	98.057
75.5	1.88	3.772	4.967	1.195	-1.549	1.407	97.972
82.5	1.92	3.527	5.025	1.498	-1.654	1.512	97.820
147.5	2.17	3.350	4.957	1.607	-1.719	1.577	97.727
153.5	2.19	3.024	5.032	2.008	-1.832	1.690	97.564
169.5	2.23	3.220	4.904	1.684	-1.896	1.754	97.472
177.5	2.25	3.152	5.053	1.901	-1.992	1.850	97.333
194.5	2.29	3.096	4.882	1.786	-2.048	1.906	97.252
217.5	2.34	3.541	4.933	1.392	-2.252	2.110	96.958
222.5	2.35	2.864	4.867	2.003	-2.327	2.185	96.850
241.5	2.38	3.198	4.959	1.761	-2.391	2.249	96.758

Table D.4.c - Data for Test #4c - FAJA Shale, 3207-FT DEPTH, Core #51
VOLUME = 71.78 cm³, 125°C
Run started on 10/21/87; ended on 10/31/87

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	R. V	V V	V/V ₀
2.0	0.30	3.213	5.583	2.370	-1.632	0.571	99.205
3.0	0.48	4.215	5.915	1.700	-2.577	1.516	97.888
4.0	0.60	3.917	5.305	1.388	-2.794	1.733	97.586
5.0	0.70	4.356	5.075	0.719	-3.014	1.953	97.279
6.5	0.81	4.369	5.813	1.444	-3.383	2.322	96.765
9.5	0.98	4.892	5.582	0.690	-3.852	2.791	96.112
21.5	1.33	4.820	5.384	0.564	-4.170	3.109	95.669
29.5	1.47	5.294	5.558	0.264	-5.592	4.531	93.688
59.5	1.77	4.724	4.867	0.1435	leak	-1.061	101.478
223.5	2.35	2.755	5.374	2.619	3.418	-4.479	106.240
288.5	2.46	2.868	5.494	2.626	3.477	-4.538	106.322
296.5	2.47	2.806	5.565	2.759	3.466	-4.527	106.307
311.5	2.49	2.785	5.505	2.720	3.477	-4.538	106.322
320.5	2.51	2.767	5.461	2.694	3.475	-4.536	106.319
336.5	2.53	2.782	5.498	2.716	3.481	-4.542	106.328
344.5	2.54	2.792	5.565	2.773	3.476	-4.537	106.321
359.5	2.56	2.740	5.498	2.758	3.475	-4.536	106.319
368.5	2.57	2.744	5.509	2.765	3.476	-4.537	106.321
384.5	2.58	2.784	5.517	2.733	3.476	-4.537	106.321
392.5	2.59	2.748	5.520	2.772	3.476	-4.537	106.321

Table D.5.a - Data for Test #5a - FAJA Shale, 3202-ft depth, Core #49
Volume = 85.16 cm³, Density 1.93 gm/cm³, 125°C
Run started on 3/3/87; ended on 4/16/87

Time/Hr	LOG t	<u>Pressure in MPa</u>			<u>Volume in cm³</u>		
		Pp	Pc	Pe	R. V	V V	V/V ₀
15.0	1.18	1.091	5.652	4.561	2.183	0.330	99.612
24.0	1.38	2.460	5.799	3.339	1.594	0.919	98.921
47.5	1.68	2.480	5.624	3.144	0.965	1.548	98.182
111.5	2.05	1.252	5.321	4.069	-0.101	2.614	96.930
120.5	2.08	2.242	5.314	3.072	-0.951	3.464	95.932
140.5	2.15	1.943	5.264	3.321	-1.213	3.726	95.625
144.5	2.16	2.375	5.466	3.091	-1.325	3.838	95.493
159.5	2.20	1.872	5.226	3.354	-1.480	3.993	95.311
167.5	2.22	2.475	5.750	3.296	-1.590	4.103	95.182
183.5	2.26	2.246	5.383	3.137	-1.709	4.222	95.042
360.5	2.56	2.564	5.473	2.909	-2.640	5.153	93.949
376.0	2.58	2.252	5.476	3.224	-2.704	5.217	93.874
384.0	2.58	2.714	5.731	3.017	-2.750	5.263	93.820
399.0	2.60	2.698	5.426	2.728	-2.799	5.312	93.762
407.0	2.61	2.775	5.312	2.537	-2.836	5.349	93.719
461.0	2.66	2.391	5.493	3.102	-2.959	5.472	93.574
470.0	2.67	2.660	5.549	2.889	-3.026	5.539	93.496
486.0	2.69	2.307	5.232	2.925	-3.083	5.596	93.429
494.0	2.69	2.631	5.330	2.699	-3.125	5.638	93.380
510.0	2.71	2.443	5.442	2.999	-3.152	5.665	93.348
518.0	2.71	2.567	5.517	2.950	-3.184	5.697	93.310
542.0	2.73	2.710	5.586	2.876	-3.244	5.757	93.240
557.0	2.75	2.536	5.560	3.024	-3.288	5.796	93.194
566.0	2.75	2.551	5.511	2.960	-3.314	5.827	93.158
639.0	2.81	2.455	5.317	2.862	-3.474	5.987	92.970
662.0	2.82	2.569	5.449	2.880	-3.532	6.045	92.902
686.0	2.84	2.669	5.455	2.786	-3.595	6.108	92.828
710.0	2.85	2.478	5.482	3.004	-3.636	6.149	92.779
733.5	2.87	2.491	5.564	3.073	-3.697	6.210	92.708
805.5	2.91	2.333	5.616	3.283	-3.829	6.342	92.553
829.5	2.92	2.531	5.299	2.768	-3.917	6.430	92.450
852.5	2.93	2.751	5.452	2.701	-3.977	6.490	92.379
877.5	2.94	2.601	5.554	2.953	-4.011	6.524	92.339
901.5	2.95	2.667	5.522	2.855	-4.071	6.584	92.269
997.5	3.00	2.458	5.572	3.114	-4.214	6.727	92.101

Table D.5.b - Data for Test #5b - FAJA Shale, 3206-ft depth, Core #51
Volume = 78.65 cm³, Density 1.92 gm/cm³, 125°C
Run started on 3/3/87; ended on 4/16/87

Time/Hr	LOG t	Pressure in MPa			Volume in cm ³		
		Pp	Pc	Pe	R. V	V V	V/V ₀
15.0	1.18	1.598	5.652	4.054	1.464	1.049	98.666
24.0	1.38	2.742	5.799	3.057	1.140	1.373	98.254
47.5	1.68	2.520	5.624	3.104	0.965	1.548	98.032
111.5	2.05	2.181	5.321	3.140	-0.358	2.871	96.350
120.5	2.08	2.550	5.314	2.764	-0.600	3.113	96.042
140.5	2.15	2.002	5.264	3.262	-0.781	3.294	95.812
144.5	2.16	2.504	5.466	2.962	-0.860	3.373	95.711
159.5	2.20	2.101	5.226	3.125	-0.993	3.506	95.542
167.5	2.22	2.520	5.750	3.230	-1.064	3.577	95.452
183.5	2.26	2.476	5.383	2.907	-1.149	3.662	95.344
360.5	2.56	2.624	5.473	2.849	-1.967	4.480	94.304
376.0	2.58	2.266	5.476	3.210	-2.018	4.531	94.239
384.0	2.58	2.661	5.731	3.070	-2.057	4.570	94.189
399.0	2.60	2.712	5.426	2.714	-2.104	4.617	94.130
407.0	2.61	2.681	5.312	2.631	-2.134	4.647	94.092
461.0	2.66	2.529	5.493	2.964	-2.242	4.755	93.954
470.0	2.67	2.660	5.549	2.889	-2.304	4.817	93.875
486.0	2.69	2.293	5.232	2.939	-2.355	4.868	93.811
494.0	2.69	2.665	5.330	2.665	-2.399	4.912	93.755
510.0	2.71	2.592	5.442	2.850	-2.428	4.941	93.718
518.0	2.71	2.512	5.517	3.005	-2.440	4.953	93.702
542.0	2.73	2.684	5.586	2.902	-2.481	4.994	93.650
557.0	2.75	2.591	5.560	2.969	-2.527	5.040	93.592
566.0	2.75	2.682	5.511	2.829	-2.564	5.077	93.545
639.0	2.81	2.469	5.317	2.848	-2.706	5.219	93.364
662.0	2.82	2.589	5.449	2.860	-2.755	5.268	93.302
686.0	2.84	2.696	5.455	2.759	-2.810	5.323	93.232
710.0	2.85	2.989	5.482	2.493	-2.849	5.362	93.182
733.5	2.87	2.641	5.564	2.923	-2.910	5.423	93.105
805.5	2.91	2.407	5.616	3.209	-3.024	5.537	92.960
829.5	2.92	2.539	5.299	2.760	-3.103	5.616	92.860
852.5	2.93	2.683	5.452	2.769	-3.156	5.669	92.792
877.5	2.94	2.663	5.554	2.891	-3.189	5.702	92.750
901.5	2.95	2.659	5.522	2.863	-3.239	5.752	92.687
997.5	3.00	2.617	5.572	2.955	-3.384	5.897	92.502

Tabel D.5.c - Data for Test #5c - FAJA Heavy Oil Sandstone, 3278-ft depth, Core #70
 Volume = 40.68 cm³, Density 1.89 gm/cm³, 125°C
 Run started on 3/3/87; ended on 4/16/87

Time/Hr	LOG t	<u>Pressure in MPa</u>			<u>Volume in cm³</u>		
		Pp	Pc	Pe	R. V	V V	V/V ₀
15.0	1.18	2.925	5.652	2.727	2.429	0.343	99.157
24.0	1.38	2.835	5.799	2.964	2.206	0.566	98.609
47.5	1.68	2.869	5.624	2.755	1.991	0.781	98.080
111.5	2.05	2.568	5.321	2.753	0.974	1.798	95.580
120.5	2.08	2.753	5.314	2.561	0.836	1.936	95.241
140.5	2.15	2.852	5.264	2.412	0.623	2.149	94.717
144.5	2.16	2.750	5.466	2.716	0.607	2.165	94.678
159.5	2.20	2.829	5.226	2.397	0.450	2.322	94.292
167.5	2.22	3.144	5.750	2.606	0.400	2.372	94.169
183.5	2.26	2.901	5.383	2.482	0.291	2.481	93.901
360.5	2.56	2.870	5.473	2.603	-0.308	3.080	92.429
376.0	2.58	2.847	5.476	2.629	-0.372	3.144	92.271
384.0	2.58	2.802	5.731	2.929	-0.373	3.145	92.269
399.0	2.60	2.865	5.426	2.561	-0.436	3.208	92.114
407.0	2.61	2.711	5.312	2.601	-0.436	3.208	92.114
461.0	2.66	2.966	5.493	2.527	-0.577	3.349	91.767
470.0	2.67	2.817	5.549	2.732	-0.596	3.368	91.721
486.0	2.69	2.807	5.232	2.425	-0.671	3.443	91.536
494.0	2.69	2.982	5.330	2.348	-0.696	3.468	91.475
510.0	2.71	2.754	5.442	2.688	-0.715	3.487	91.428
518.0	2.71	2.916	5.517	2.601	-0.742	3.514	91.362
542.0	2.73	2.758	5.586	2.828	-0.789	3.561	91.246
557.0	2.75	2.950	5.560	2.610	-0.836	3.608	91.131
566.0	2.75	2.909	5.511	2.602	-0.859	3.631	91.074
639.0	2.81	2.801	5.317	2.516	-1.018	3.790	90.683
662.0	2.82	2.970	5.449	2.479	-1.083	3.855	90.524
686.0	2.84	2.805	5.455	2.650	-1.130	3.902	90.408
710.0	2.85	2.994	5.482	2.488	-1.206	3.978	90.221
733.5	2.87	3.118	5.564	2.446	-1.283	4.055	90.032
805.5	2.91	2.849	5.616	2.767	-1.434	4.206	89.661
829.5	2.92	2.894	5.299	2.405	-1.520	4.292	89.449
852.5	2.93	2.876	5.452	2.576	-1.583	4.355	89.294
877.5	2.94	2.844	5.554	2.710	-1.630	4.402	89.179
901.5	2.95	2.750	5.522	2.772	-1.689	4.461	89.034
997.5	3.00	3.011	5.572	2.561	-1.904	4.676	88.505