Rock Mechanical Testing

Triaxial tests on sandstone
Well 15/9-19A

981002-1 20 March 1998

Client: **Statoil**

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Contract reference: No.: ANS 027467/V0003

For the Norwegian Geotechnical Institute

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Summary

Eight CID-triaxial tests have been performed on sandstone from well 15/9-19A in the North Sea. The consolidation stresses varied from 2 to 28.7 MPa. The following results were obtained for the two depth intervals included in the investigation:

- **Depth interval (MD RKB) 3870.50 - 3870.70 meters**
  - Porosity ..... 25.0 - 26.4 %
  - Unit weight ..... 20.3 - 20.9 kN/m^3
  - Poisson's ratio (half-way to failure) ..... 0.20 - 0.46
  - Deformation modulus (half-way to failure), E ..... 12.5 - 18.0 GPa
  - Friction angle ..... 32.4°
  - Attraction intercept ..... 16.0 MPa
  - Cohesion intercept ..... 10.1 MPa
  - P-wave velocity for tests with consolidation stress higher than 2 MPa ..... 3460 -3760 m/s
  - S-wave velocity for tests with consolidation stress higher than 2 MPa ..... 2060 -2200 m/s

- **Depth interval (MD RKB) 3887.30 - 3887.50 meters**
  - Porosity ..... 20.1 - 21.0 %
  - Unit weight ..... 21.6 - 21.8 kN/m^3
  - Poisson's ratio (half-way to failure) ..... 0.25 - 0.42
  - Deformation modulus (half-way to failure), E ..... 11.4 - 15.9 GPa
  - Friction angle ..... 37.0°
  - Attraction intercept ..... 14.2 MPa
  - Cohesion intercept ..... 10.7 MPa
  - P-wave velocity for tests with consolidation stress higher than 2 MPa ..... 3040 -3930 m/s
  - S-wave velocity for tests with consolidation stress higher than 2 MPa ..... 1800 -2280 m/s

The Poisson's ratios were lower and the E-moduli higher the higher the consolidation stresses.

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Review and reference document

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1 INTRODUCTION

Eight drained triaxial compressions tests, all on sandstone, have been performed at NGI at the request of Statoil through Liv Myhre. The tests were performed on material from Well 15/9-19A in the North Sea at the depth interval (MD RKB) from 3870 to 3888 meters.

The testing specifications given by Statoil in their contract No. ANS 027467 variation order V0003, and later instructions given by Tor Harald Hansen at Statoil to saturate the specimens with lamp oil and measure acoustic velocity, have been followed.

2 KEY INFORMATION ABOUT THE TRIAXIAL EQUIPMENT

The piston force is measured inside the triaxial cell to avoid the uncertainty represented by piston friction. Between the lower end of the piston and the top cap there is a spherical seat.

For drained tests on materials where it is necessary to check that significant excess pore pressures do not build up in the specimen during shearing, the pore pressure, for certain intervals, is measured at one end of the specimen while there is free drainage at the other end.

The horizontal displacement sensors are mounted on metal pins that go through the confining rubber membrane. One sensor is measuring the change in diameter approximately 13 mm below the midheight of the specimen (parallel with the strike of the layering, if any), and one is measuring the change in diameter approximately 13 mm above the midheight of the specimen, the two diameters being rotated 90 degrees w.r.t. each other.

The vertical displacement of the specimen is measured externally over the whole specimen height by measuring the travel of the piston through the top of the triaxial cell. This measurement is corrected for false displacements due to effects of cell pressure and piston load. The vertical compression is also measured internally over the middle 26 mm of the specimen height.

The triaxial cell used for this project was equipped with P- and S-wave transducers to measure acoustic velocity along the axis of the specimen

3 PROCEDURES USED FOR THE TRIAXIAL TESTS

Eight 38 mm plugs were sent to NGI sealed in wax.

The ends of the specimens were considered to be too loose to be ground. They were therefore trimmed in a cylindrical cradle with a steel straightedge and cast in gypsum. After weighing and measurement of height and diameter, the

triaxial test specimen was mounted into the triaxial cell and subjected to full vacuum (i.e. close to 100 kPa). The deformations of the specimen due to application of the vacuum were found to be insignificant and were therefore neglected.

The following operations were then performed:

1) Application of a total all-around stress equal to 0.5 MPa. (The effective stress was then close to 0.6 MPa due to the vacuum inside the specimen). The piston through the top of the triaxial cell was now lowered to be in contact with the top cap (which is sitting on the top of the specimen), and the external deformation sensor was set to show a value which was compatible with the reading of the internal vertical deformation sensors.

2) Release of the suction by allowing lamp oil to go into the specimen. A back pressure of 1 MPa was then applied.

3) Then the cell pressure was increased until the effective all-around stress was equal to the specified consolidation stress (2, 7.5, 15 or 28.7 MPa), and shearing was done drained by increasing the total vertical stress and keeping the total horizontal stress constant. The consolidation stresses were kept constant for about 100 minutes before start of shearing. Rate of vertical strain at failure was about 12 mS per hour.

4) P- and S-wave velocities were measured at end of consolidation and twice during shearing prior to failure.

The initial liquid content was determined from the initial "wet" weight and the final dry weight (after drying at +105°C) of the triaxial test specimens. The initial unit weight was determined from the initial wet weight of the specimen and the initial dimensions.

Colour photographs of the test specimens are generally taken prior to and after testing. The photographs prior to testing for the first test to be performed, i.e. test 1G, was taken after removal of the gladpack enclosing the specimen under the wax layer. However, later it was found better for the further handling of the specimen not to remove the gladpack. All other specimens are therefore photographed with the gladpack layer on, although this gives somewhat less good photographs. The two last specimens to be tested, i.e. 7G and 8G, were, due to a mistake, not photographed prior to testing.

4 TEST RESULTS

4.1 General

The test results are given in Tables 1 to 5 and in Figures 1 to 50. The symbols used in tables and figures are defined in the list of symbols in Chapter 5.

The test numbers 1G, 2G and so on have been repeated in all the tables because they are the shortest identification numbers used. They are in the further description below and in all figures simply referred to as "test numbers".

The vertical strain at failure calculated from the external measurement of vertical compression is higher than calculated from the internal (local) vertical strain sensors. The main reason for this is believed to be that it was difficult to trim the specimen ends properly. The calculation of vertical strain during consolidation and shearing, until failure took place, is therefore, for all tests, based on internal (i.e. local) measurement of vertical strain over 25 mm of the specimen height at midheight of the specimen. When failure takes place, the internal sensors are, in some cases, disturbed by the development of shear planes. The calculation of vertical strain after failure has therefore been based on external measurements.

When computing the deviatoric vertical stress, the deviator load (as measured by the internal load cell) is distributed over the actual specimen area (not the initial area) as computed from the horizontal strain sensors.

4.2 Results presented in tables

In Table 1, material description is given together with the initial dimensions of the specimens.

Table 2 contains some routine data and values at end of consolidation. Computation of unit weight, in kN/m^3, is found by multiplying the density in g/cm^3 with 9.81 m/s^2. Porosity has been computed from the measured diameter and height of the specimen and its dry mass, assuming the density of dry mass to be equal to 2.67 g/cm^3.

All strains in Table 2 are given in thousands of the initial specimen dimensions. It should be noted that "volumetric strain" is equal to "vertical strain" plus two times the "horizontal strain", the latter being measured by the horizontal displacement sensors. (In some previous reports this parameter has been called octahedral strain.)

Table 3 gives stress-strain parameters and data at failure. Failure has been defined to occur when the vertical stress reaches a maximum value.

The values of Poisson's ratio, μ, and deformation modulus, E, given in Table 3 have been computed for the change in *vertical* effective stress σ'_v from 40 to 60% of the difference between the peak value of σ'_v and the value of σ'_v at start of shearing.

In each individual test, when calculating μ-, and E- values, the following equations have been used both for the values in the tables and in the figures:

$$\Delta\varepsilon_V = \frac{1}{E}\left(\Delta\sigma'_V - 2\mu\Delta\sigma'_H\right)$$

$$\Delta\varepsilon_H = \frac{1}{E}\left(\Delta\sigma'_H - \mu\Delta\sigma'_V - \mu\Delta\sigma'_H\right)$$

These equations, where $\Delta\sigma'_V$ and $\Delta\sigma'_H$ are effective stress increments, and $\Delta\varepsilon_V$ and $\Delta\varepsilon_H$ the corresponding strain increments, give E and μ which again have been used to compute G as follows:

$$G = \frac{E}{2(1+\mu)}$$

It should be noted that the strains in Table 3 are zeroed at start of shearing, the strains being given in thousands of the specimen dimensions at start of shearing.

In Table 4 the effective shear strength parameters are given. Those have been determined for each of the two seal peels.

Table 5 gives the measured P- and S-wave velocities together with the vertical effective stresses at which they were measured. The S-wave velocity determinations for the two tests with the lowest consolidation stress (i.e. 2 MPa) are seen to be poor.

4.3 Results presented in figures

The figure numbers for the various tests can be found in Table 3 and in the list of figures. The symbols used are defined in the list of symbols.

The equations used to compute E, G and μ are given in Section 4.2.

The above equations are based on theory of isotropic elasticity. Thus, they are not valid for values of Poisson's ratio larger than 0.5. For vertical strains well below failure, the recorded values of horizontal strains give back-calculated Poisson's ratios lower than 0.5, but as failure is approached, much higher values are computed. This is especially true for specimens with low confining stress, and Figs. 3 and 28 show very high values of "Poisson's ratio" as failure

is approached and failure planes have formed. The term Poisson's ratio and the isotropic elasticity equations are not really appropriate as failure is approached. However, they are still used as a means of presenting the data in the figures.

Only plots for the shear stage are given, all strains being zeroed at start of shearing. The strains are given in thousands of the specimen dimensions at start of shearing. The tangent values of Poisson's ratio, μ, and deformation modulus E, have been computed for about 15 steps of vertical effective stress, starting at the beginning of shearing and ending at the maximum value of the vertical effective stress. The effective shear strength parameters (ϕ', c' and a') for the two depth intervals considered have been determined as shown in Figures 25 and 50. The attraction values determined have been used to compute mobilised friction, tan ρ.

5 LIST OF SYMBOLS

a'	Attraction inercept w.r.t. effective stresses (a' = c'/tan ϕ', c' being the cohesion intercept).
CID (= CD)	Triaxial test with isotropic consolidation followed by drained shearing.
E	*Deformation modulus*, being computed from the following equations: $\Delta\varepsilon_V = \frac{1}{E}\left(\Delta\sigma'_V - 2\mu\Delta\sigma'_H\right)$ $\Delta\varepsilon_H = \frac{1}{E}\left(\Delta\sigma'_H - \mu\Delta\sigma'_V - \mu\Delta\sigma'_H\right)$
$\varepsilon_V \equiv Ev$	*Vertical strain*, that is vertical displacement in per thousand of specimen height. Decrease in specimen height gives positive vertical strain.
$\varepsilon_H \equiv Eh$	*Horizontal strain.* Defined analogous with ε_V. Decrease in specimen diameter gives positive horizontal strain.
$\varepsilon_V + 2\varepsilon_H$	*Octahedral strain* = Volumetric strain.
ϕ'	Friction angle w.r.t. effective stresses.
G	*Shear modulus*, being computed from: $G = \frac{E}{2(1+\mu)}$
μ	Poisson's ratio, being computed from the same equations as E.
σ'_V	*Vertical effective stress.*
σ'_{VC}	*Vertical effective stress at end of consolidation*
σ'_H	*Horizontal effective stress.*
σ'_{HC}	*Horizontal effective stress at end of consolidation.*
$(\sigma'_V - \sigma'_H)/2$	*Shear stress.*
$(\sigma'_V + 2\sigma'_H)/3$	*Effective octahedral stress*

tan ρ	Mobilized friction. The value of ρ for a certain stress condition is the mobilized friction angle for the considered stress condition when the attraction intercept is assumed to be the same as the attraction intercept at failure.

Table 1 Material description and initial dimensions of test specimens

Well No.	Depth of seal peel MD RKB (m)	Test No.	NGI's file No.	Depth of test MD RKB (m)	Initial specimen height (mm)	Initial specimen diameter (mm)	Material description
15/9-19A	3870.50-3870.70	1G	TRI 438	3870.52	88.84	37.81	Sandstone
"	"	2G	TRI 440	3870.57	80.54	37.67	"
"	"	3G	TRI 441	3870.61	81.58	37.80	"
"	"	4G	TRI 444	3870.66	81.01	37.81	"
"	3887.30-3887.50	5G	TRI 445	3887.32	83.55	37.87	"
"	"	6G	TRI 446	3887.37	81.90	37.87	"
"	"	7G	TRI 448	3887.41	83.14	37.87	"
"	"	8G	TRI 451	3887.46	82.11	37.85	"

Table 2 Some routine data and values at end of consolidation for the triaxial tests

	Initial values			Values at end of consolidation				
Test No.	Liquid content (%)	Unit weight (kN/m^3)	Porosity (%)	Vertical effective stress (MPa)	Horizontal effective stress (MPa)	Vertical strain (mS)	Horizontal strain (mS)	Volumetric strain (mS)
1G	5.52	20.34	26.40	2.10	1.99	0.79	2.32	5.43
2G	6.19	20.87	24.96	7.54	7.46	3.73	4.89	13.51
3G	5.99	20.66	25.57	15.02	14.98	2.88	4.73	12.33
4G	5.71	20.5	25.96	28.70	28.63	0.09	7.61	15.32
5G	4.55	21.62	21.04	2.05	1.97	0.98	2.33	5.63
6G	4.29	21.71	20.52	7.50	7.46	1.88	3.83	9.54
7G	4.32	21.83	20.10	15.04	14.98	3.14	4.47	12.07
8G	4.47	21.80	20.32	28.70	28.65	3.67	5.60	14.86

Table 3 Stress-strain parameters and data at failure for CID triaxial tests

Test No.	Consol. stress (MPa)	Poisson's ratio	Deformation modulus, E (GPa)	Values at failure						Figures where results are presented
				Vertical effective stress (MPa)	Horizontal effective stress (MPa)	Shear stress (MPa)	Vertical strain (mS)	Horizontal strain (mS)	Volumetric strain (ms)	
1G	2.0	0.46	12.46	32.07	2.01	15.03	3.59	-3.66	-3.73	1-6, 25
2G	7.5	0.31	15.43	69.63	7.51	31.06	5.39	-4.26	-3-12	7-12, 25
3G	15.0	0.26	16.44	96.28	14.98	40.65	7.04	-3.07	0.90	13-18, 25
4G	28.7	0.20	18.01	125.02	28.63	48.19	6.06	-1.69	2.69	19-24, 25
5G	2.0	0.42	11.38	44.02	2.02	20.99	5.04	-4.99	-4.93	26-31, 50
6G	7.5	0.37	14.53	75.86	7.50	34.18	6.55	-4.87	-3.20	32-37, 50
7G	15.0	0.32	15.18	112.32	15.00	48.66	8.95	-6.10	-3.25	38-43, 50
8G	28.7	0.25	15.87	153.16	28.71	62.23	11.06	-4.46	2.14	44-49, 50

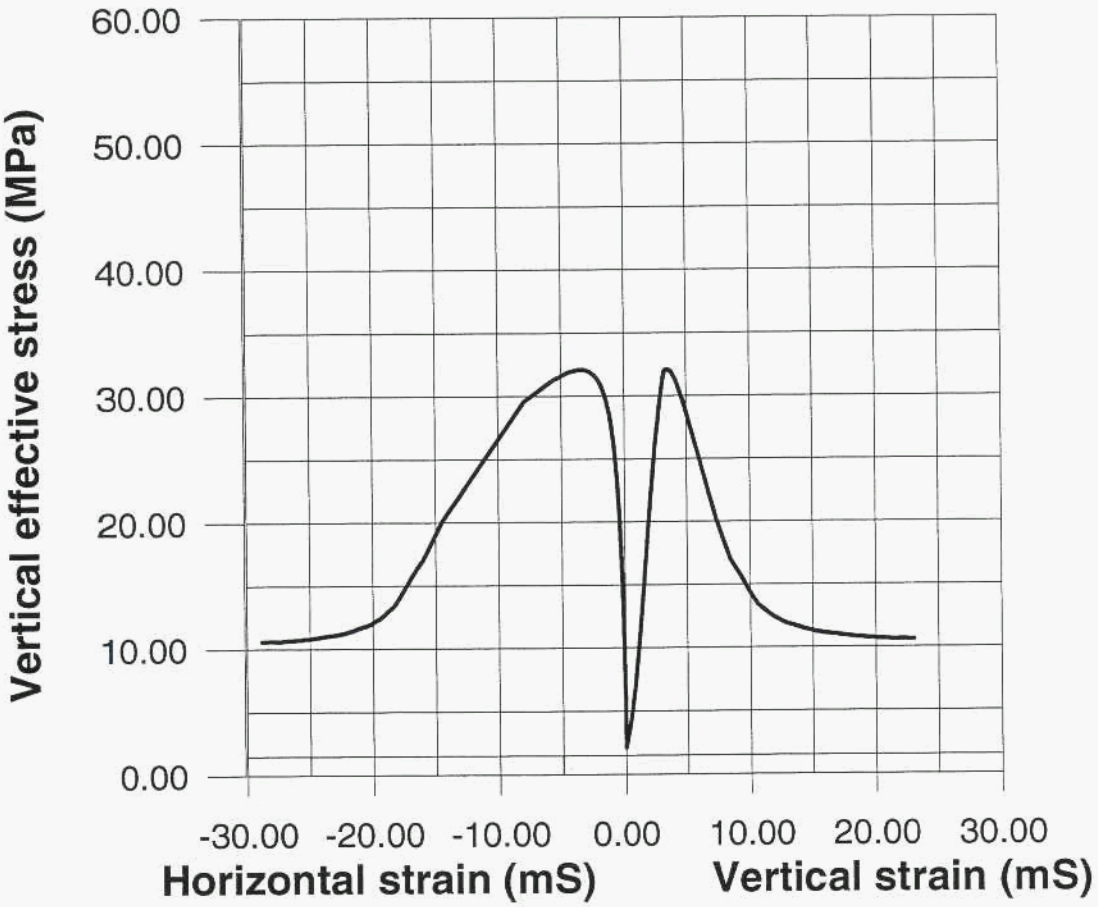
Table 4 Effective shear strength parameters from CID triaxial tests. The stress range where these parameters have been determined and can be used is shown in the figures referred to in the table. (Information about well No. and depth is given in Table 1.) *)

Test No.	See Figure No.	Friction angle ϕ' (degrees)	Attraction intercept (MPa)	Cohesion intercept (MPa)
1G - 4G	25	32.4	16.0	10.1
5G - 8G	50	37.0	14.2	10.7

*) The points from which the failure lines have been derived (by linear regression) are those where the vertical effective stress reaches a maximum value.

Table 5 P- and S-wave velocities from CID triaxial tests.
Poor S-wave velocity determinations are set in parenthesis

Test No.	Depth of Plug MD RKB (m)	Consolidation stress (MPa)	Phase of test	Vertical effective stress (MPa)	P-wave velocity (m/s)	S-wave velocity (m/s)	S-velocity / P-velocity
1G	3870.52	2.0	Consolidation	2.1	3012	-	
				2.1	-	(1352)	(0.45)
			Shearing	9.4	3343	-	
				11.5	-	(1670)	(0.50)
				25.4	3479	-	
				29.7	-	(1670)	(0.48)
2G	3870.57	7.5	Consolidation	7.5	3458	-	
				7.5	-	2059	0.60
			Shearing	20.7	3648	-	
				23.5	-	2130	0.58
				40.7	3703	-	
				43.7	-	2133	0.58
3G	3870.61	15.0	Consolidation	15.1	3660	-	
				15.0	-	2125	0.58
			Shearing	28.2	3722	-	
				30.3	-	2156	0.58
				52.9	3750	-	
				55.7	-	2152	0.57
4G	3870.66	28.7	Consolidation	28.7	3736	-	
				28.7	-	2989	0.59
				28.7	3729	-	
				28.7	-	2188	0.59
			Shearing	48.1	3765	-	
				49.9	-	2197	0.58
				72.6	3746	-	
				75.5	-	2188	0.58
				123.3	3682	-	
5G	3887.32	2. 0	Consolidation	2.1	3038	-	
				2.1	-	(1522)	(0.50)
			Shearing	8.4	3361	-	
				10.6	-	(1610)	(0.48)
				20.1	3551	-	
				22.1	-	(1681)	(0.47)
6G	3887.37	7.5	Consolidation	7.5	3429	-	
				7.5	-	1797	0.52
			Shearing	18.4	3651	-	
				20.7	-	1940	0.53
				44.5	3771	-	
				47.6	-	1987	0.53
7G	3887.41	15.0	Consolidation	15.1	3683	-	
				15.1	-	2022	0.55
			Shearing	36.5	3833	-	
				39.2	-	2108	0.55
				64.3	3869	-	
				67.0	-	2108	0.54
8G	3887.46	28.7	Consolidation	28.8	3860	-	
				28.7	-	2249	0.58
			Shearing	45.3	3891	-	
				48.0	-	2272	0.58
				83.7	3933	-	
				88.1	-	2279	0.58



Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.52 m	
Stage: Shearing		σ'_{Vc} = 2.10 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.99 MPa	
Part: 0	Test: 1G	TRI No.: 438	

Report No.	981002-1
Figure No.	1
Drawn by	Jon
Date	98-3-11
Checked	
Approved	TB

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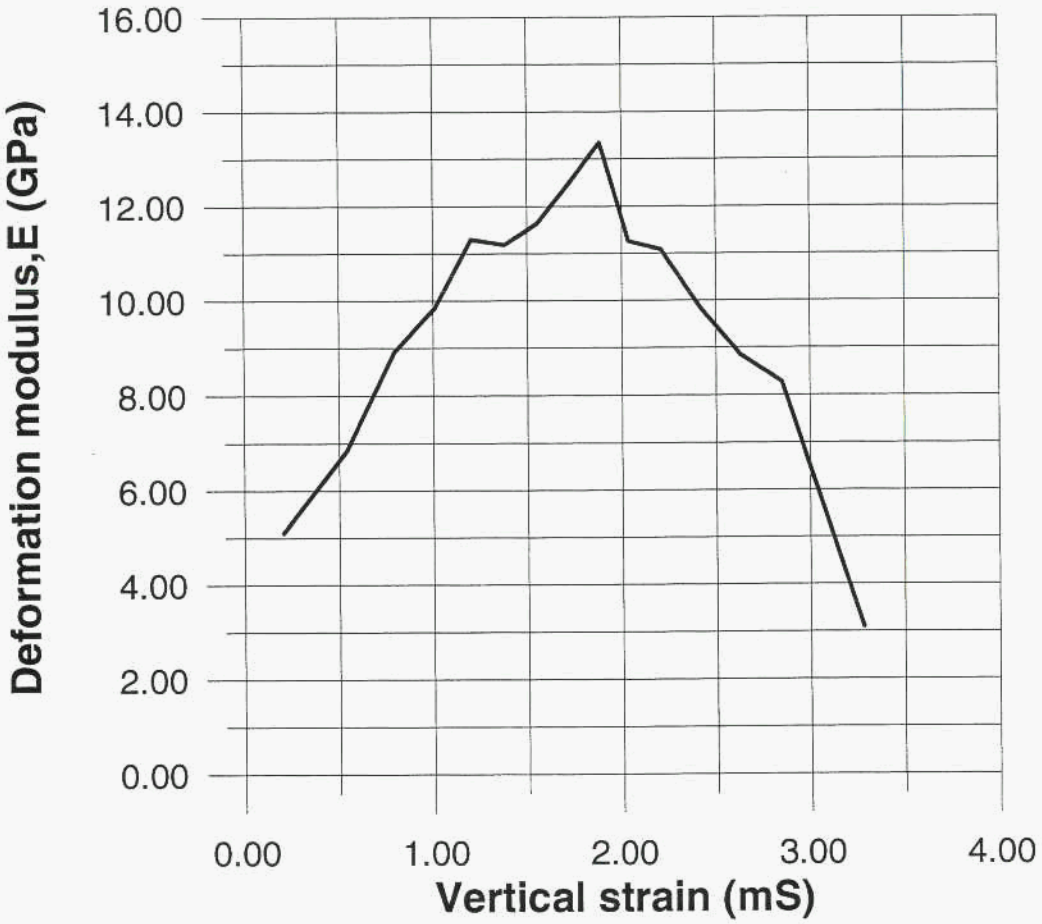

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.52 m	Drawn by: Jon	Date: 98-3-11
Stage: Shearing		σ'_{Vc} = 2.10 MPa	Checked:	NGI
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.99 MPa	Approved: TB	
Part: 0	Test: 1G	TRI No.: 438		

Report No. 981002-1 | Figure No. 2

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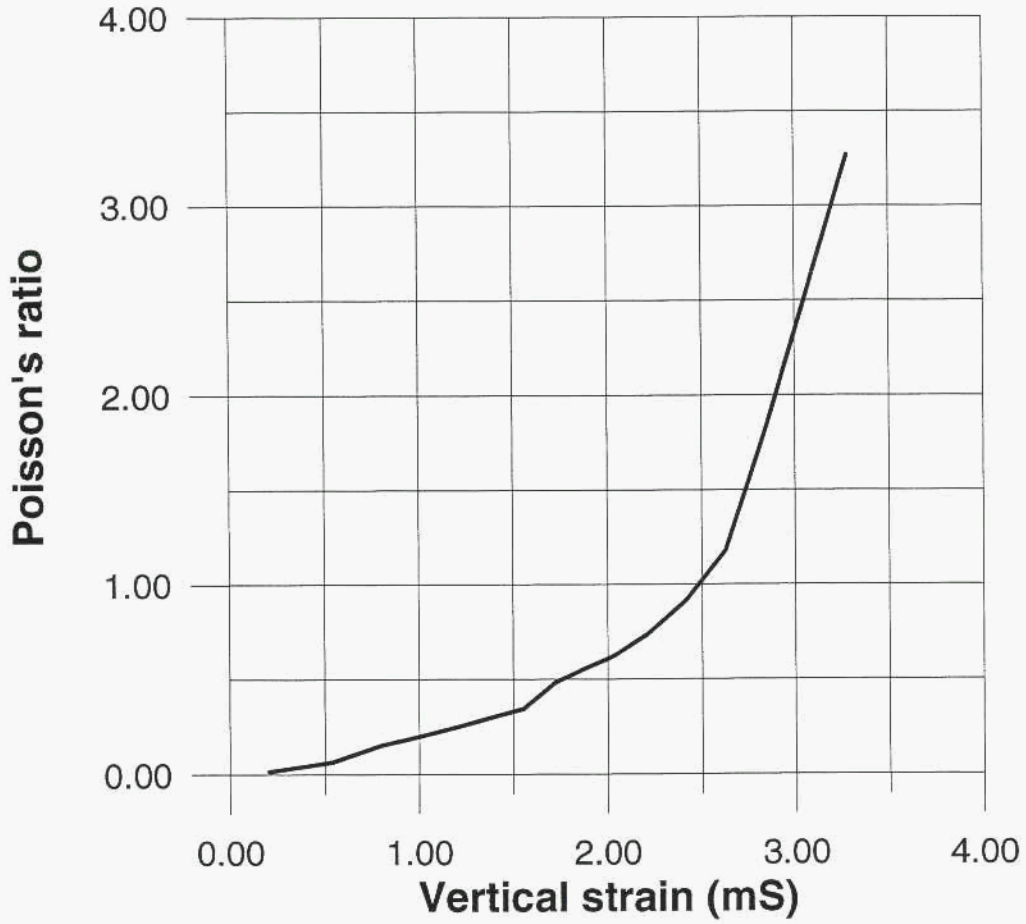

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.52 m	Drawn by: Jon	Date: 98-3-11
Stage: Shearing		σ'_{Vc} = 2.10 MPa	Checked:	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.99 MPa	Approved: TB	
Part: 0	Test: 1G	TRI No.: 438		

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Figure No. 3

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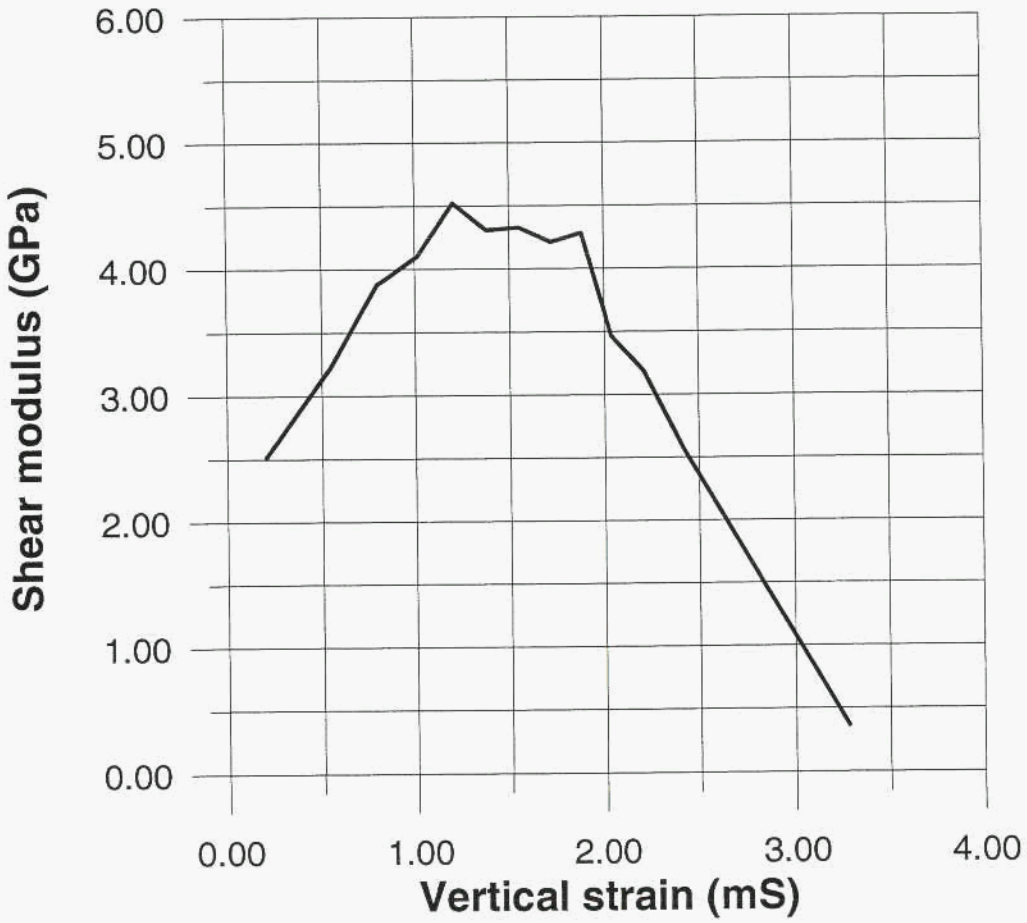

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.52 m	
Stage: Shearing		σ'_{Vc} = 2.10 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.99 MPa	
Part: 0	Test: 1G	TRI No.: 438	

Report No. 981002-1	Figure No. 4
Drawn by Jon	Date 98-3-11
Checked	
Approved TB	

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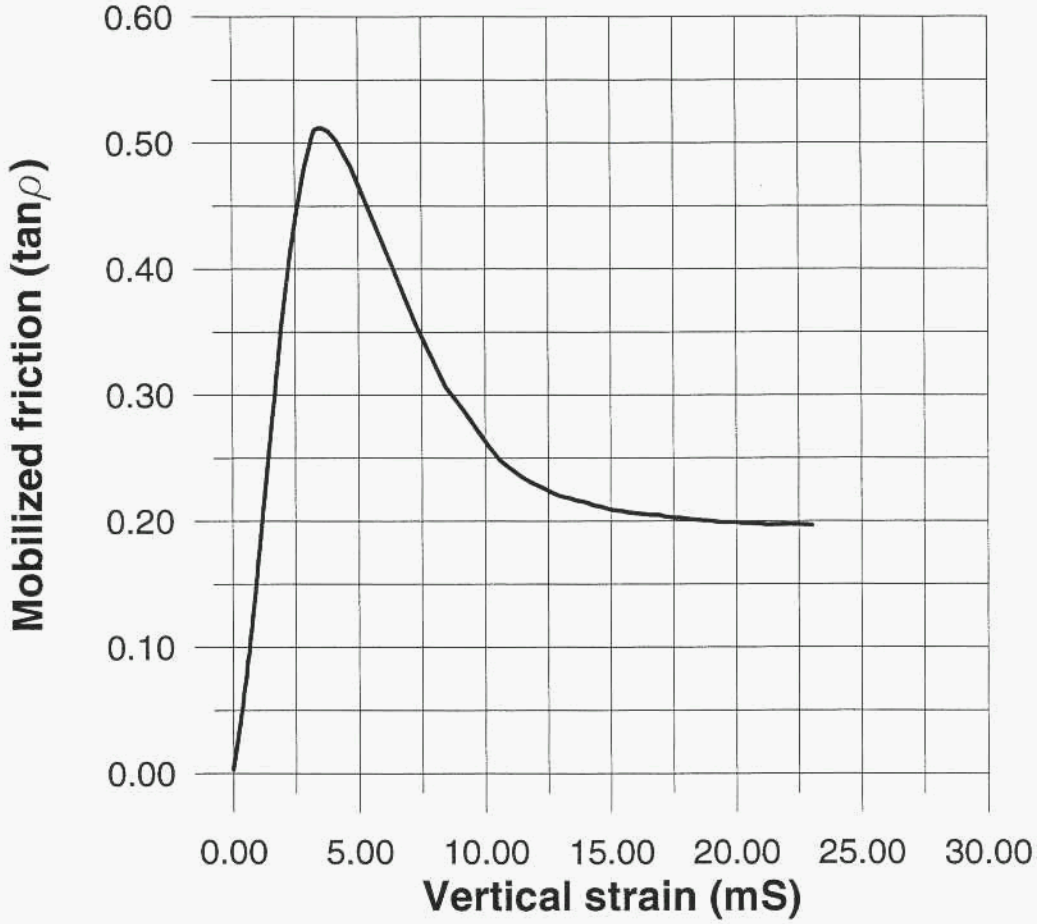

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.52 m	Report No. 981002 – 1	Figure No. 5
Stage: Shearing		σ'_{Vc} = 2.10 MPa	Drawn by Jon	Date 98-3-11
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.99 MPa	Checked	
Part: 0	Test: 1G	TRI No.: 438	Approved TB	NGI

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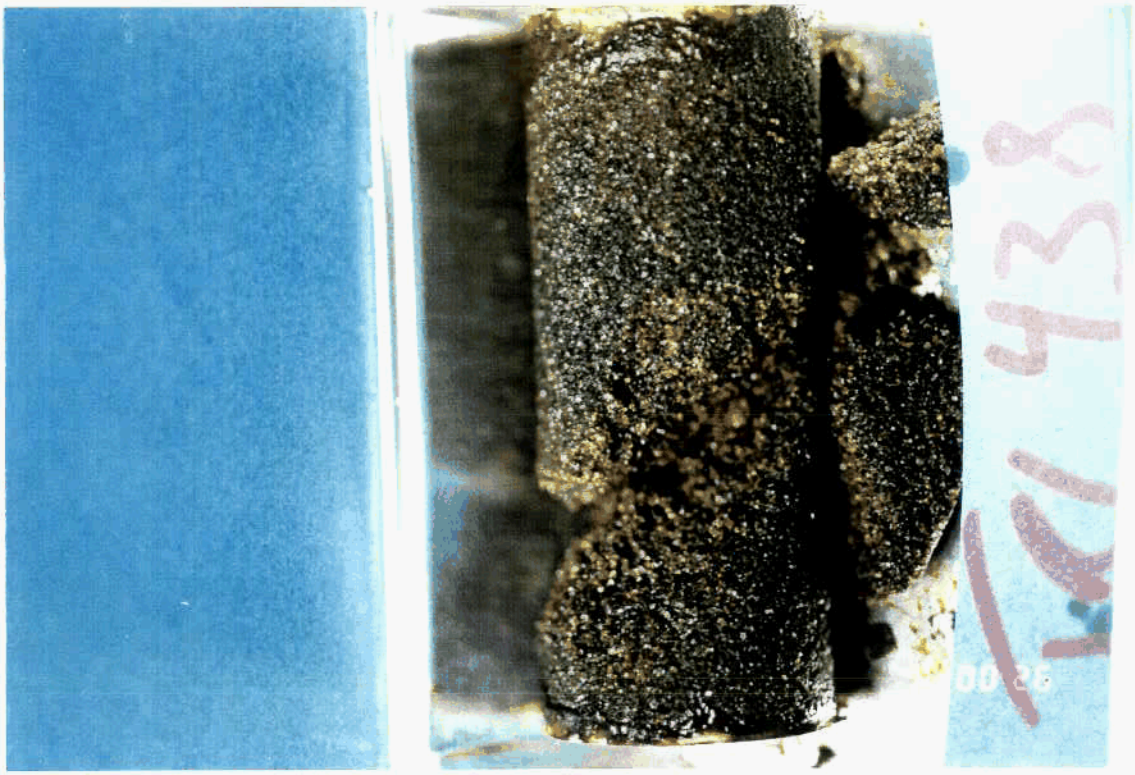

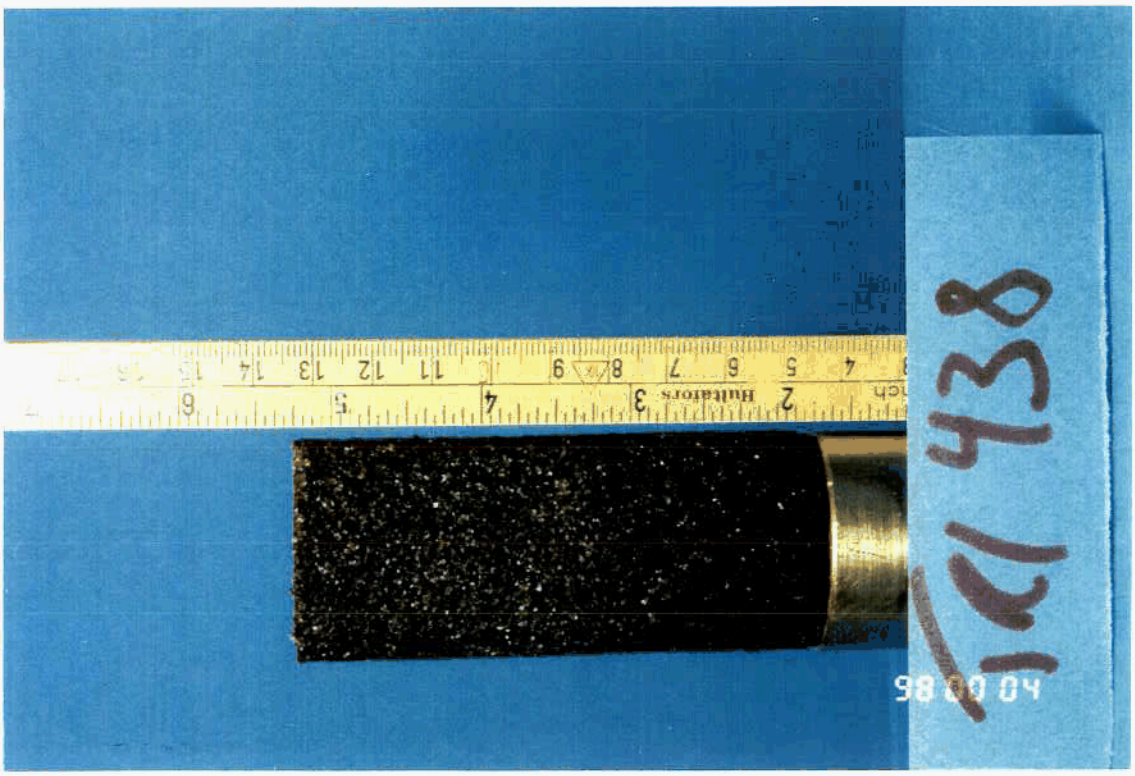

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.52 m	
Stage: Shearing		σ'_{Vc} = 2.10 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.99 MPa	
Part: 0	Test: 1G	TRI No.: 438	

Report No. 981002-1	Figure No. 6
Drawn by Jon	Date 98-3-11
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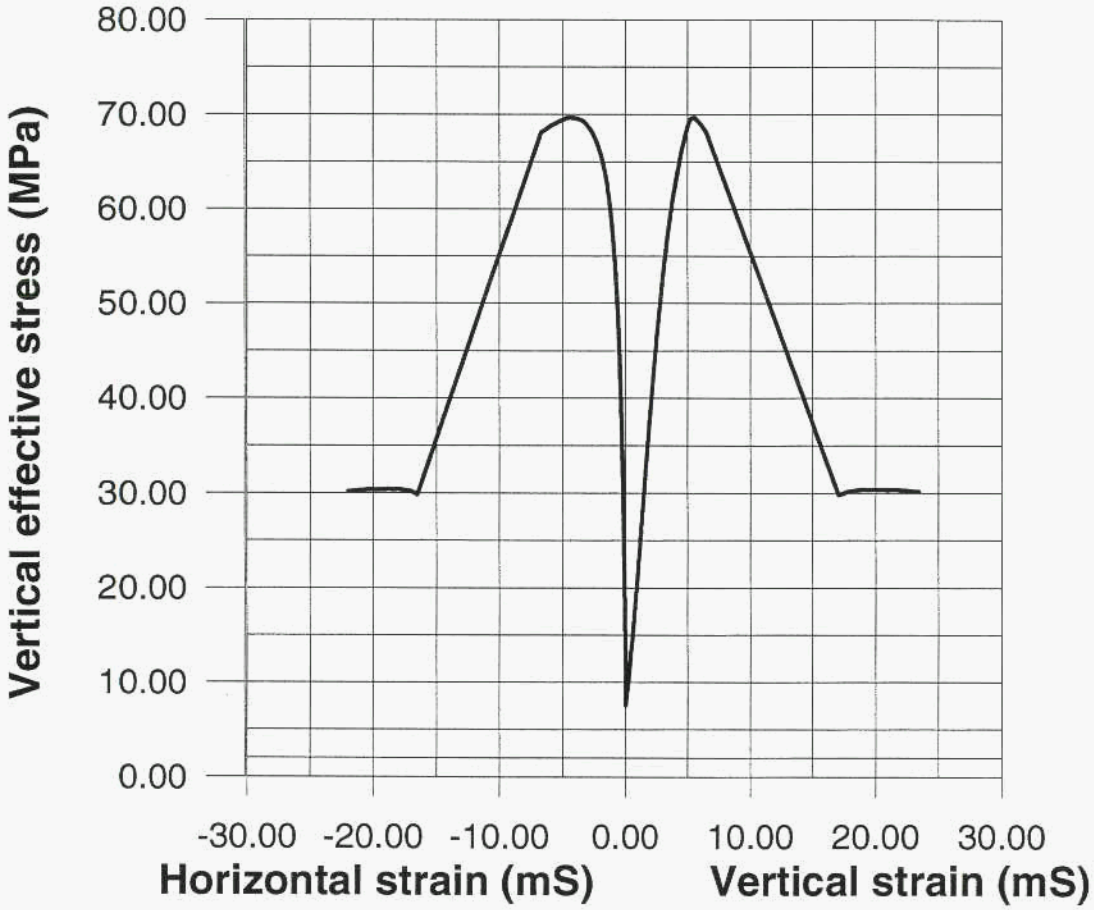

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.57 m	
Stage: Shearing		σ'_{Vc} = 7.54 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 2G	TRI No.: 440	

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Figure No.	7
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Date	98-3-11
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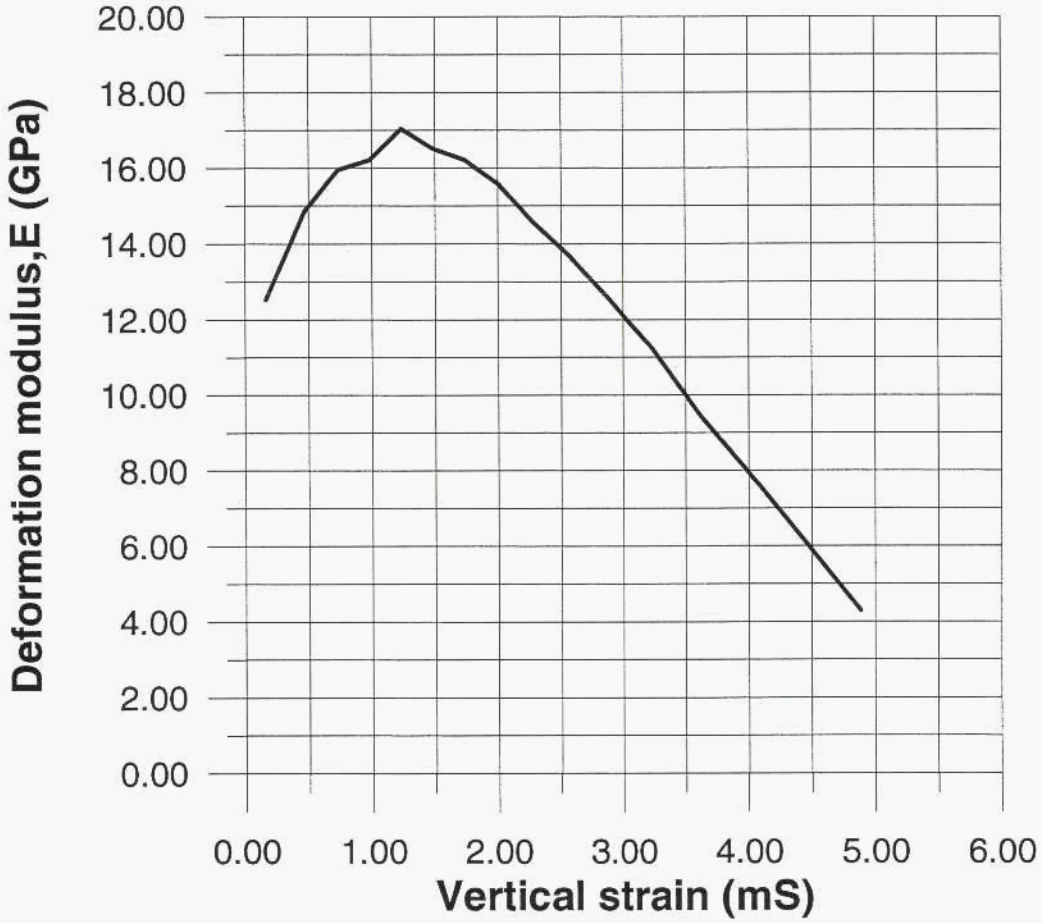

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.57 m	
Stage: Shearing		σ'_{Vc} = 7.54 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 2G	TRI No.: 440	

Report No.	981002-1
Figure No.	8
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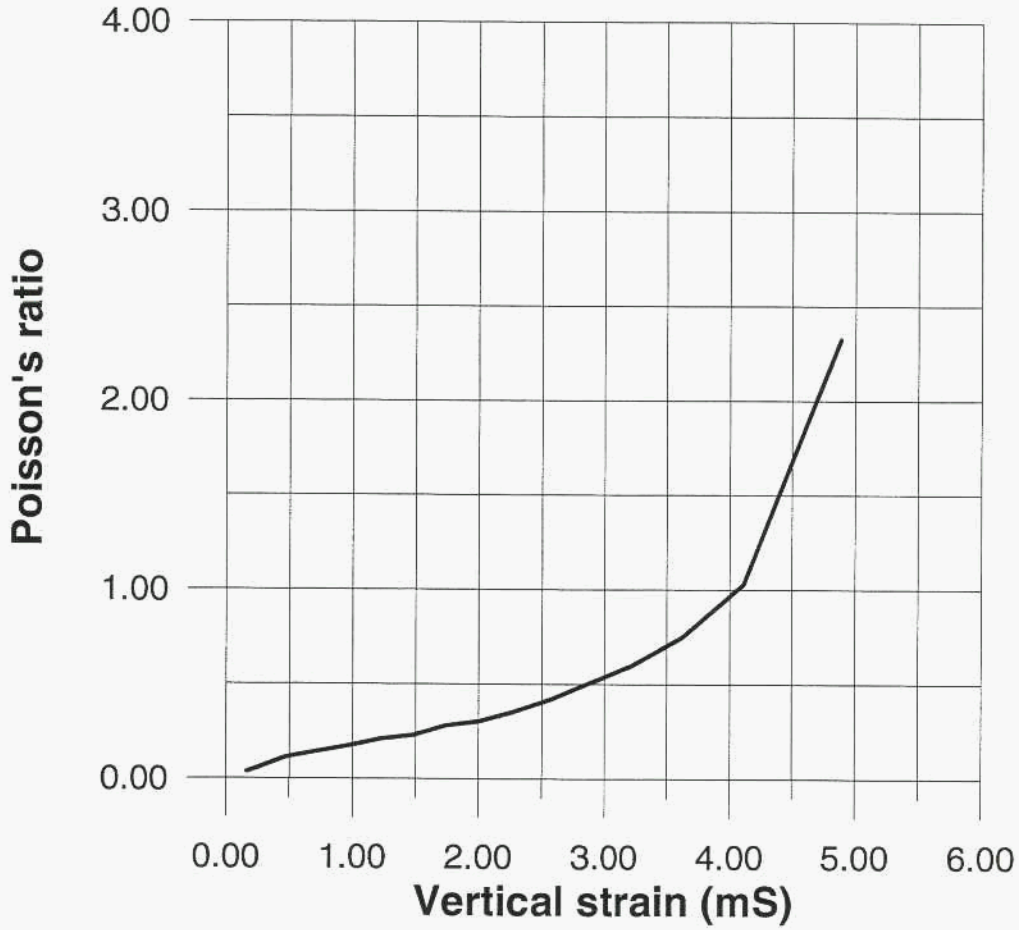

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.57 m	
Stage: Shearing		σ'_{Vc} = 7.54 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 2G	TRI No.: 440	

Report No. 981002-1	Figure No. 9
Drawn by Jon	Date 98-3-11
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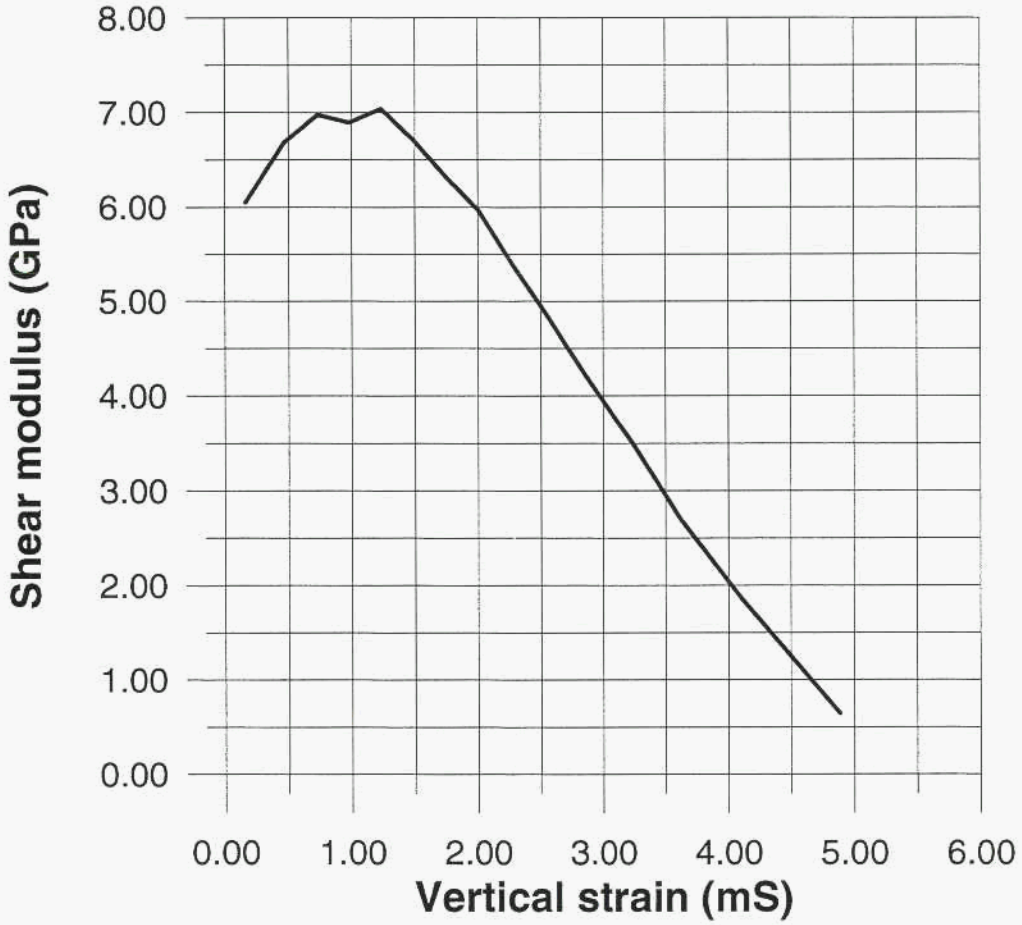

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.57 m	
Stage: Shearing		σ'_{Vc} = 7.54 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 2G	TRI No.: 440	

Report No.	981002-1
Figure No.	10
Drawn by	Jon
Date	98-3-11
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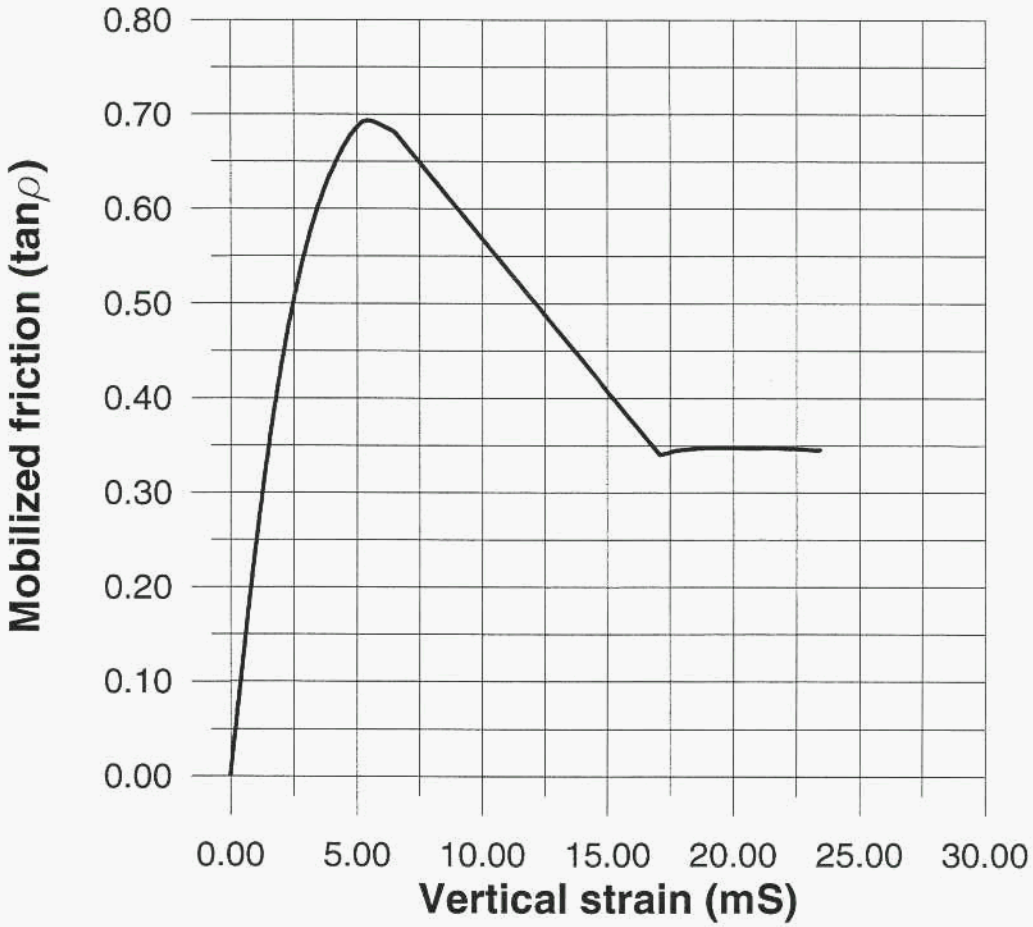

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.57 m	Drawn by: Jon	Date: 98-3-11
Stage: Shearing		σ'_{Vc} = 7.54 MPa	Checked:	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	Approved: TB	
Part: 0	Test: 2G	TRI No.: 440		

Report No. 981002-1 | Figure No. 11

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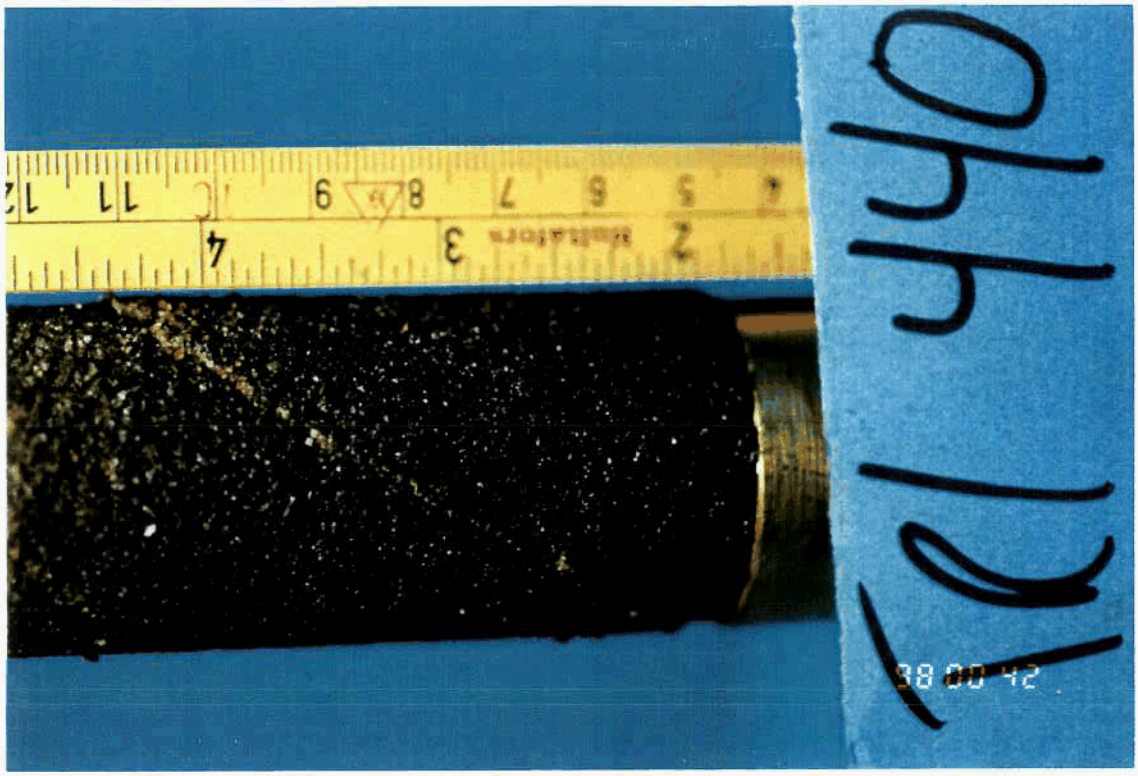

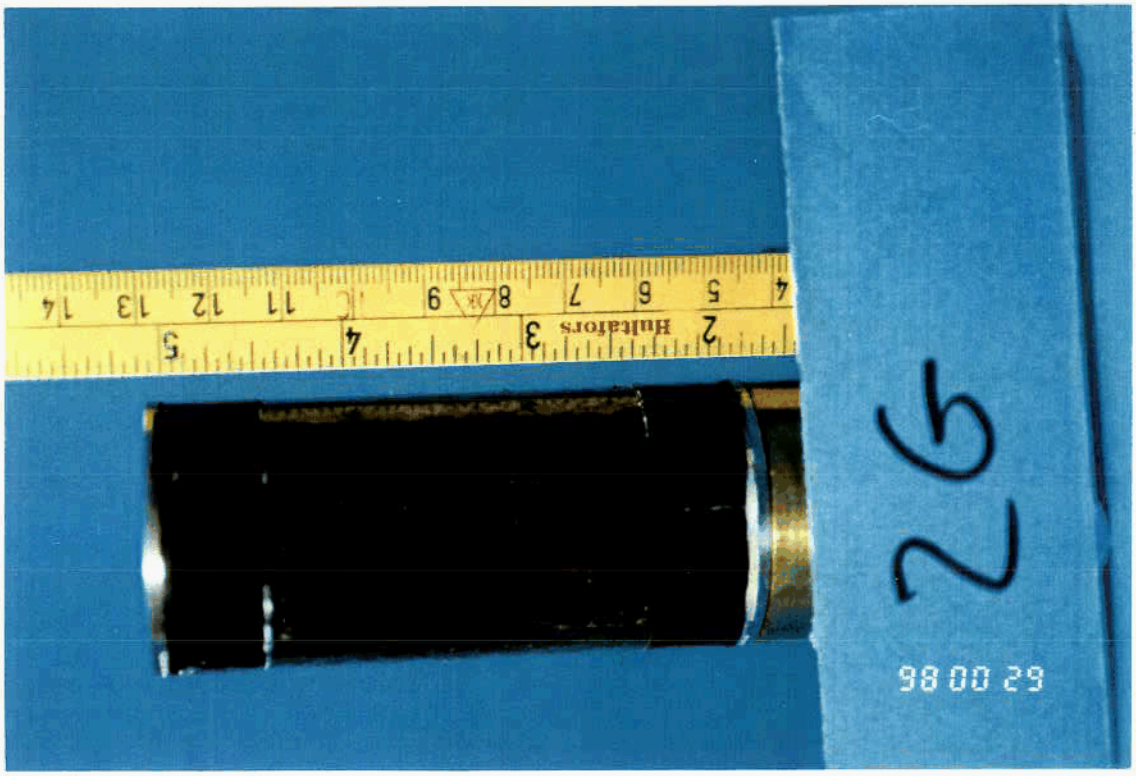

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.57 m	
Stage: Shearing		σ'_{Vc} = 7.54 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 2G	TRI No.: 440	

Report No. 981002-1	Figure No. 12
Drawn by Jon	Date 98-3-11
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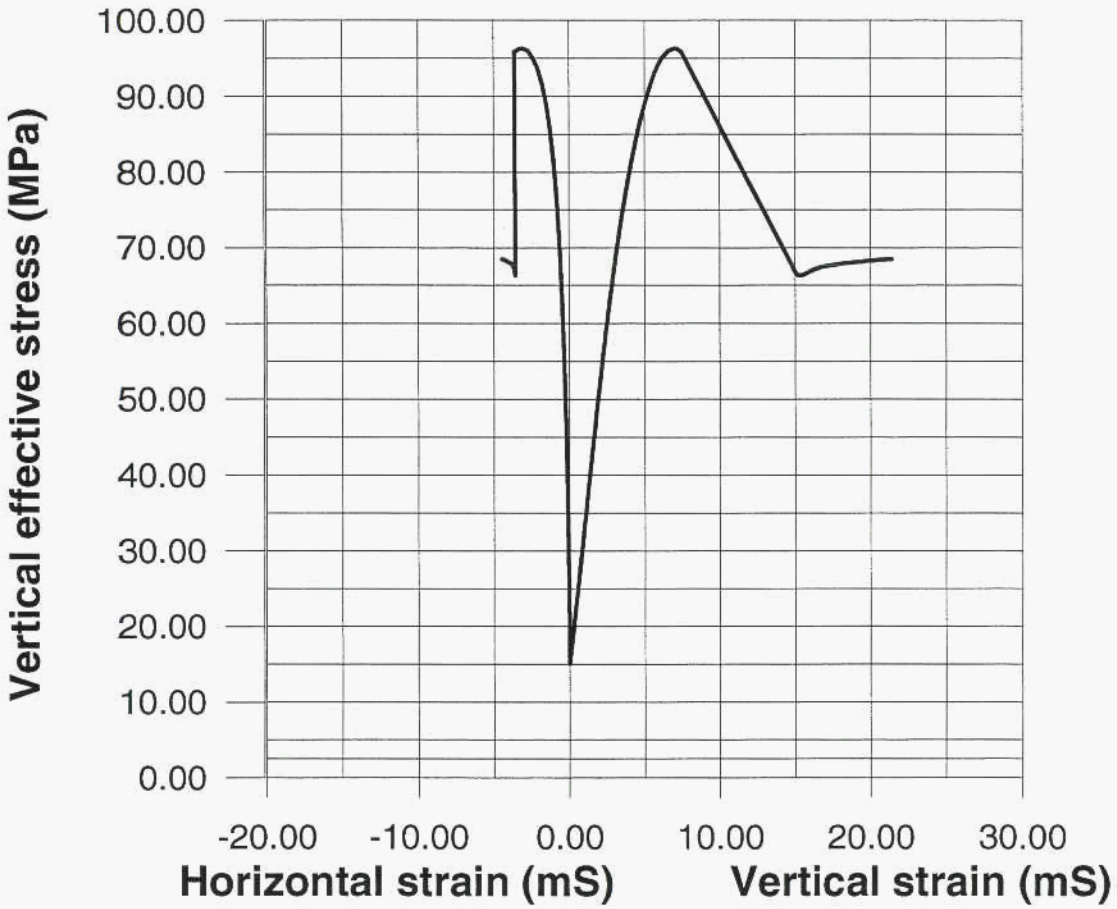

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.61 m	
Stage: Shearing		σ'_{Vc} = 15.02 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	
Part: 0	Test: 3G	TRI No.: 441	

Report No. 981002-1	Figure No. 13
Drawn by Jon	Date 98-3-11
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Approved TB	NGI

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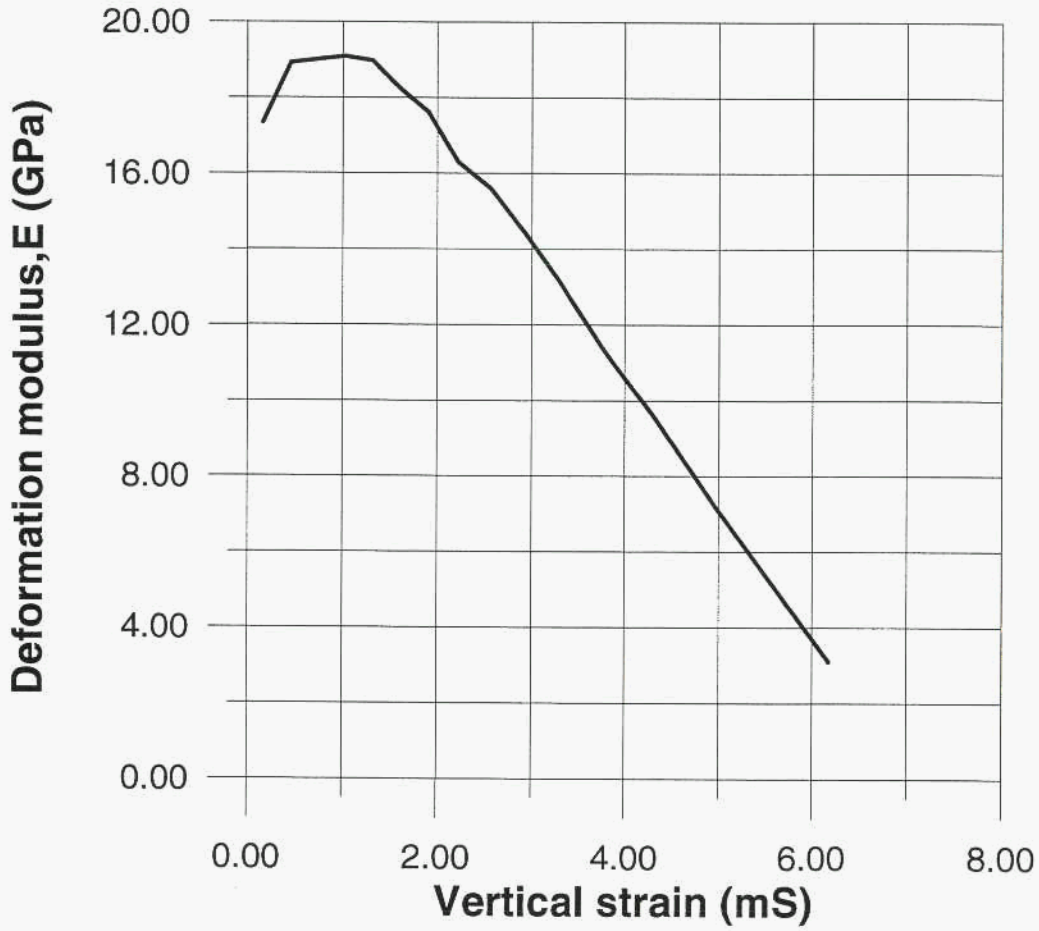

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.61 m	
Stage: Shearing		σ'_{Vc} = 15.02 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	
Part: 0	Test: 3G	TRI No.: 441	

Report No. 981002-1	Figure No. 14
Drawn by Jon	Date 98-3-11
Checked	NGI
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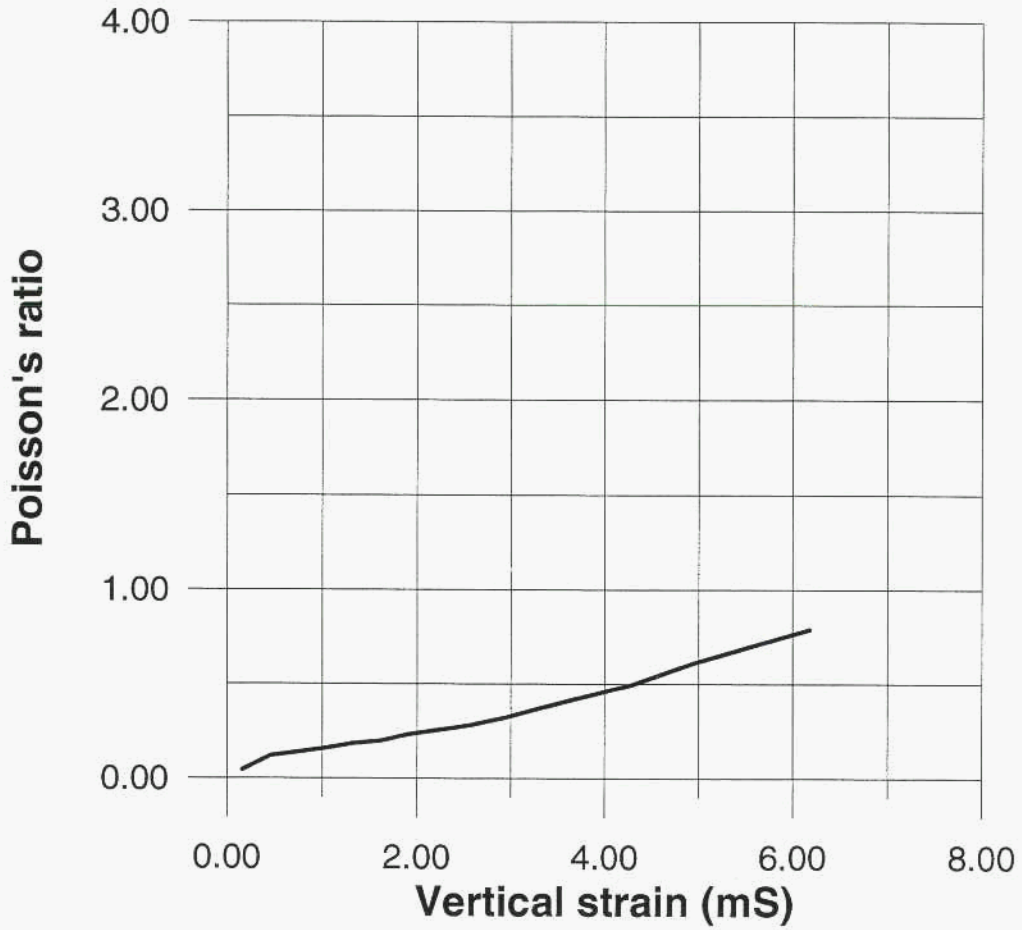

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.61 m	
Stage: Shearing		σ'_{Vc} = 15.02 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	
Part: 0	Test: 3G	TRI No.: 441	

Report No. 981002-1	Figure No. 15
Drawn by Jon	Date 98-3-11
Checked	
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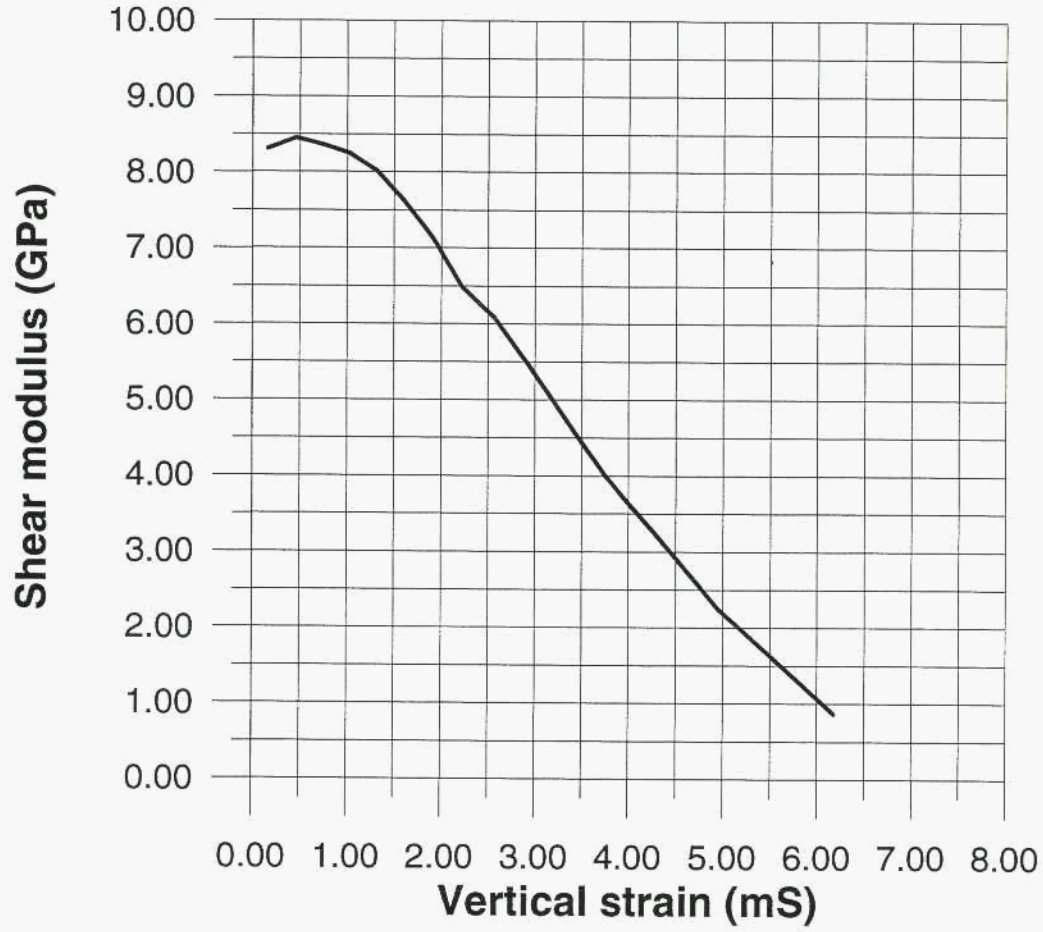

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.61 m	
Stage: Shearing		σ'_{Vc} = 15.02 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	
Part: 0	Test: 3G	TRI No.: 441	

Report No. 981002-1	Figure No. 16
Drawn by Jon	Date 98-3-11
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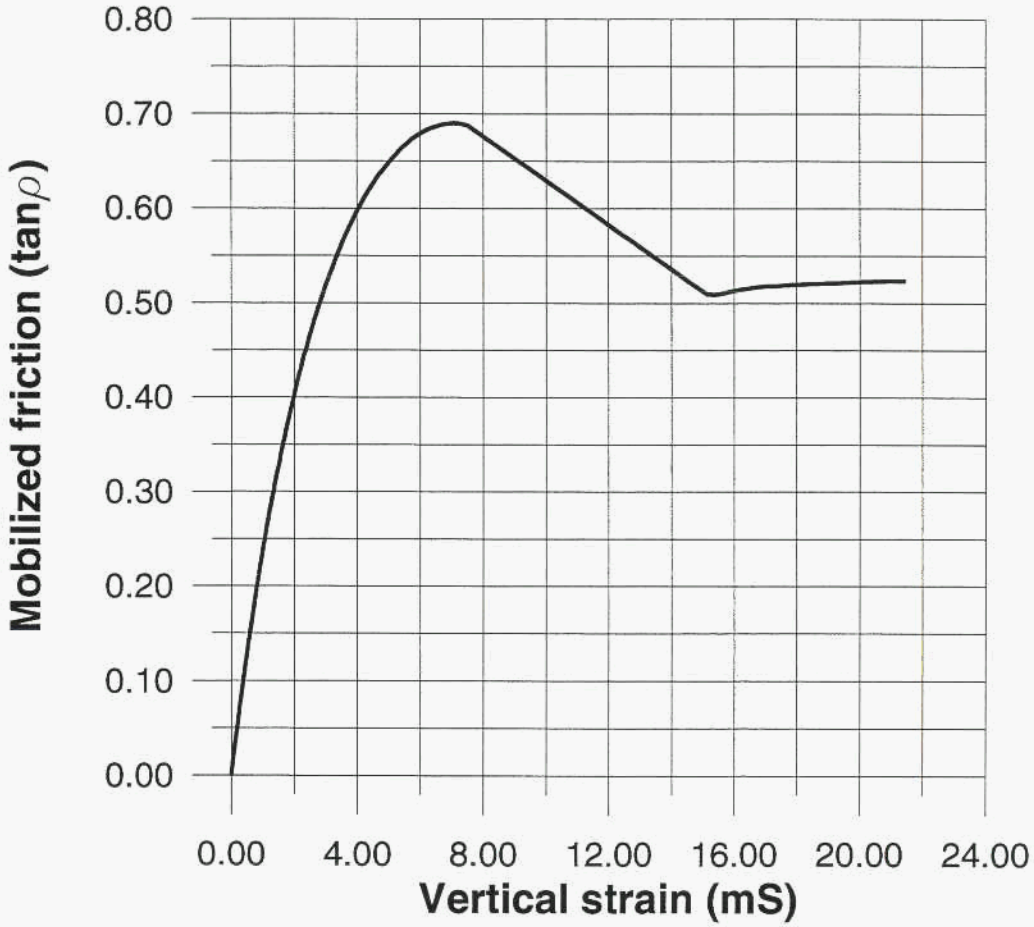

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.61 m	Drawn by: Jon	Date: 98-3-11
Stage: Shearing		σ'_{Vc} = 15.02 MPa	Checked:	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	Approved: TB	
Part: 0	Test: 3G	TRI No.: 441		

Report No. 981002-1 | Figure No. 17

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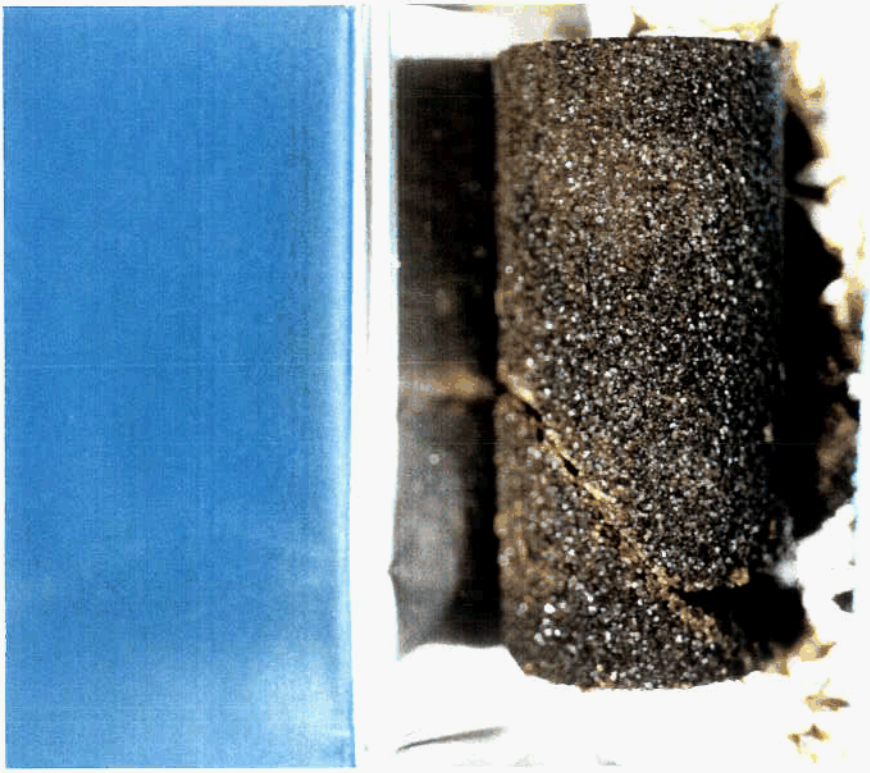

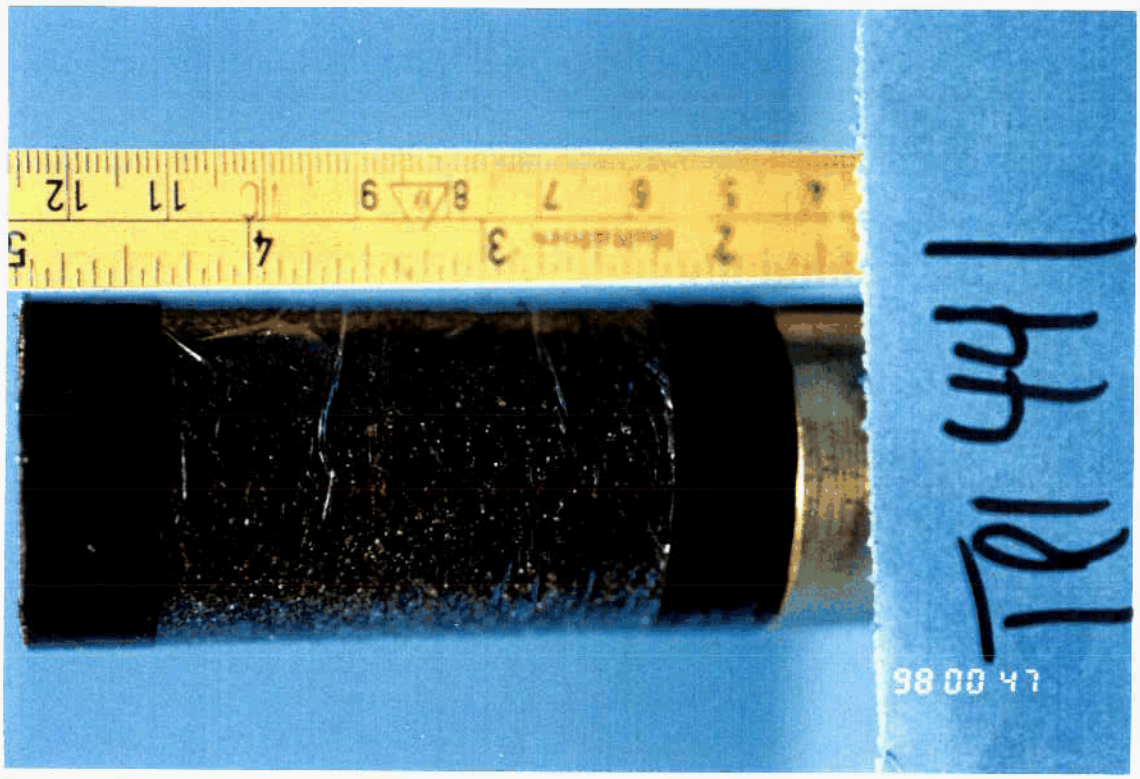

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.61 m	
Stage: Shearing		σ'_{Vc} = 15.02 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	
Part: 0	Test: 3G	TRI No.: 441	

Report No.	981002 - 1
Figure No.	18
Drawn by	Jon
Date	98-3-11
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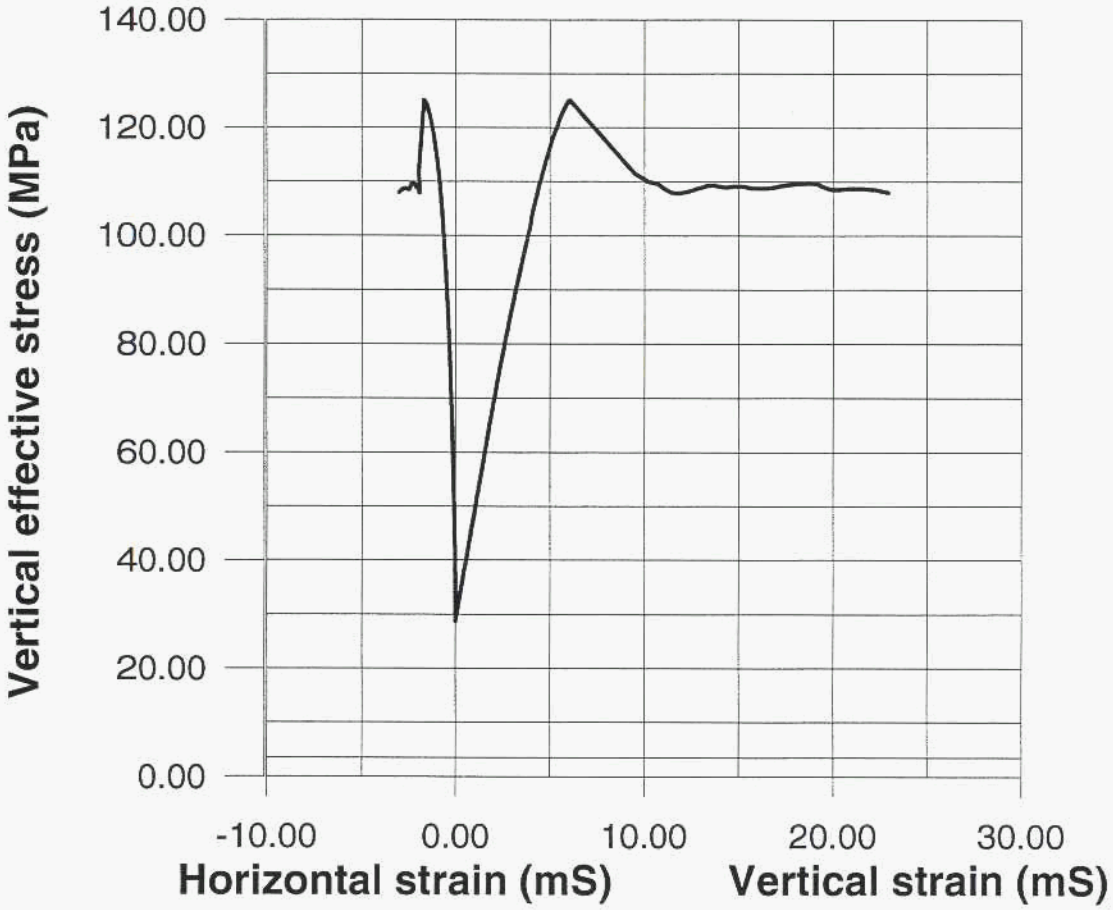

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.66 m	
Stage: Shearing		σ'_{Vc} = 28.70 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.63 MPa	
Part: 0	Test: 4G	TRI No.: 444	

Report No. 981002-1	Figure No. 19
Drawn by Jon	Date 98-3-11
Checked	
Approved TB	

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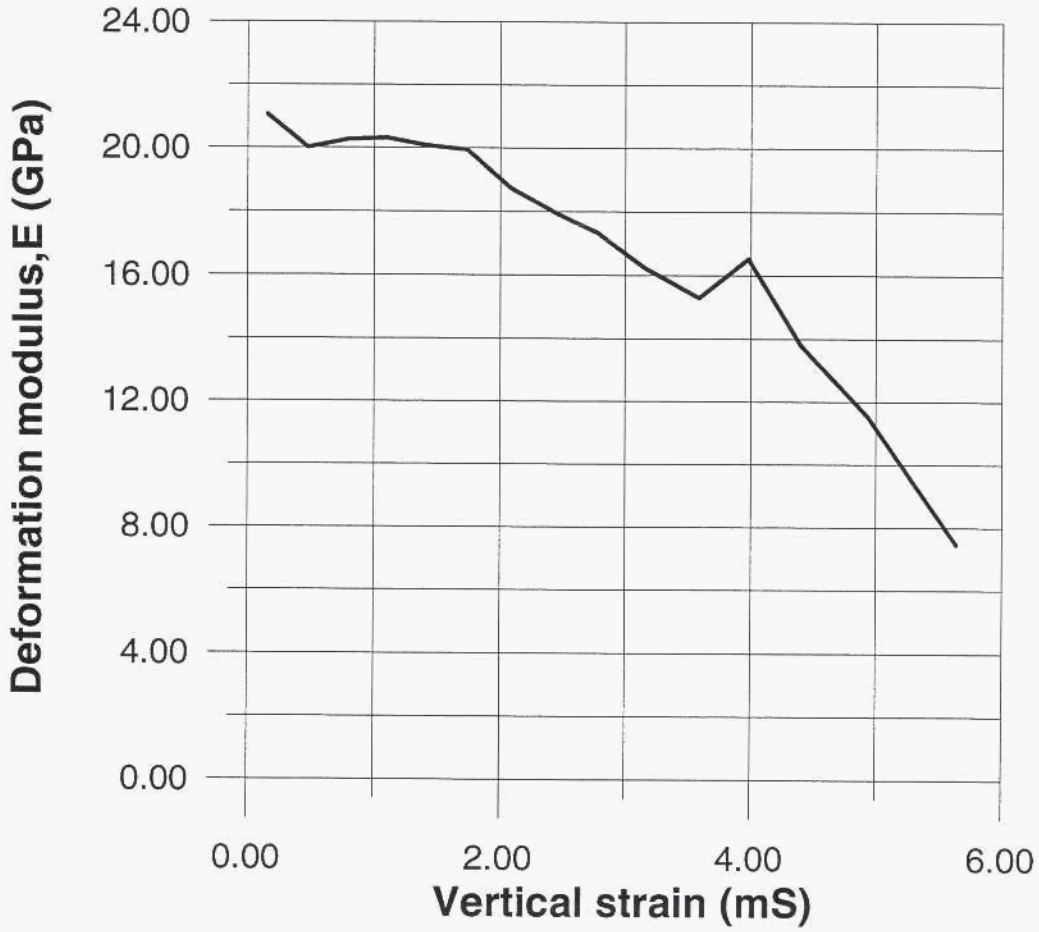

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.66 m	Report No. 981002-1	Figure No. 20
Stage: Shearing		σ'_{Vc} = 28.70 MPa	Drawn by Jon	Date 98-3-11
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.63 MPa	Checked	
Part: 0	Test: 4G	TRI No.: 444	Approved TB	NGI

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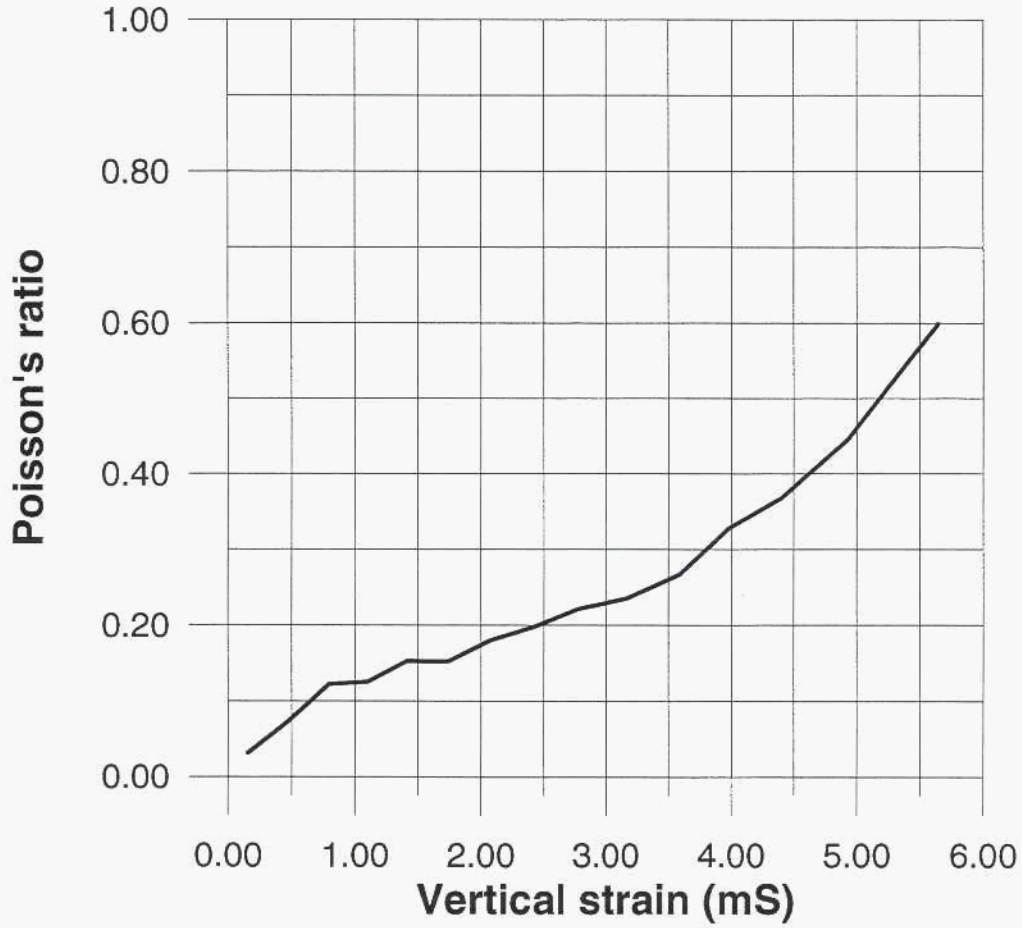

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.66 m	Drawn by: Jon	Date: 98-3-11
Stage: Shearing		σ'_{Vc} = 28.70 MPa	Checked:	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.63 MPa	Approved: TB	
Part: 0	Test: 4G	TRI No.: 444		

Report No. 981002 - 1

Figure No. 21

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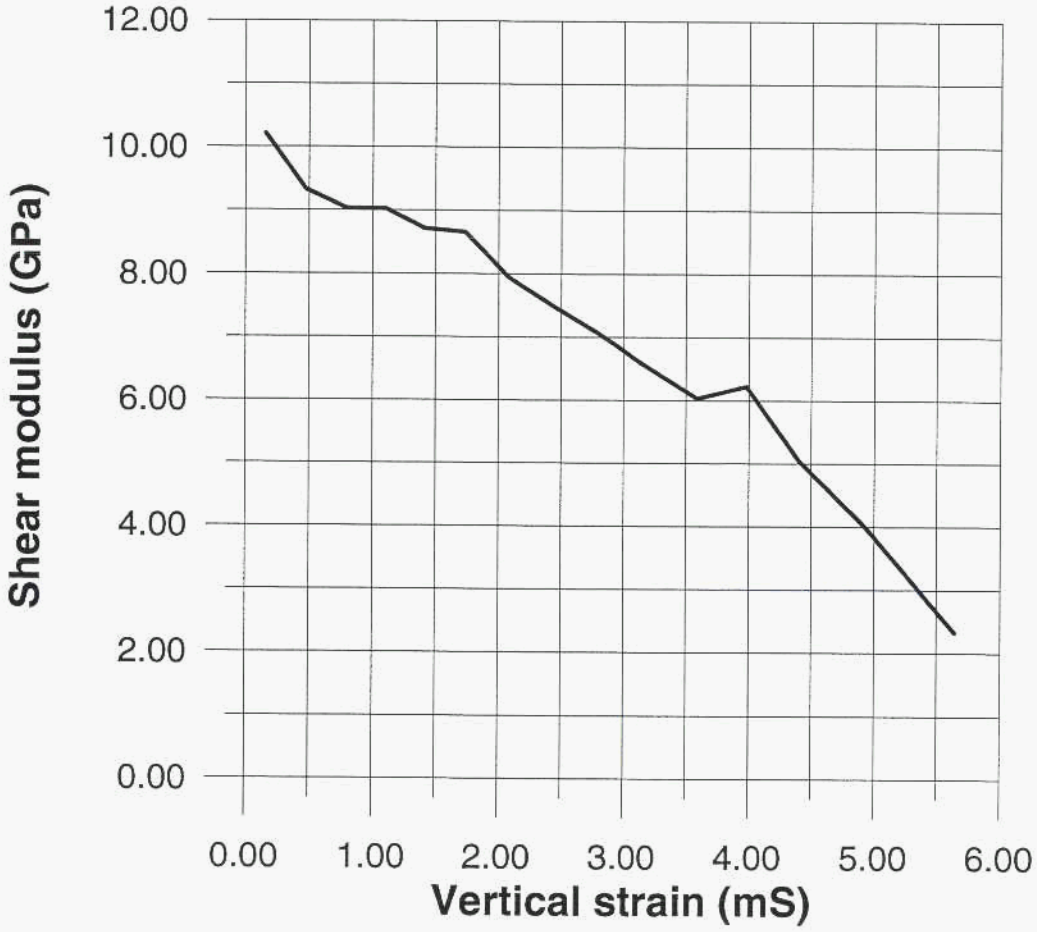

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.66 m	
Stage: Shearing		σ'_{Vc} = 28.70 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.63 MPa	
Part: 0	Test: 4G	TRI No.: 444	

Report No. 981002 – 1	Figure No. 22
Drawn by Jon	Date 98-3-11
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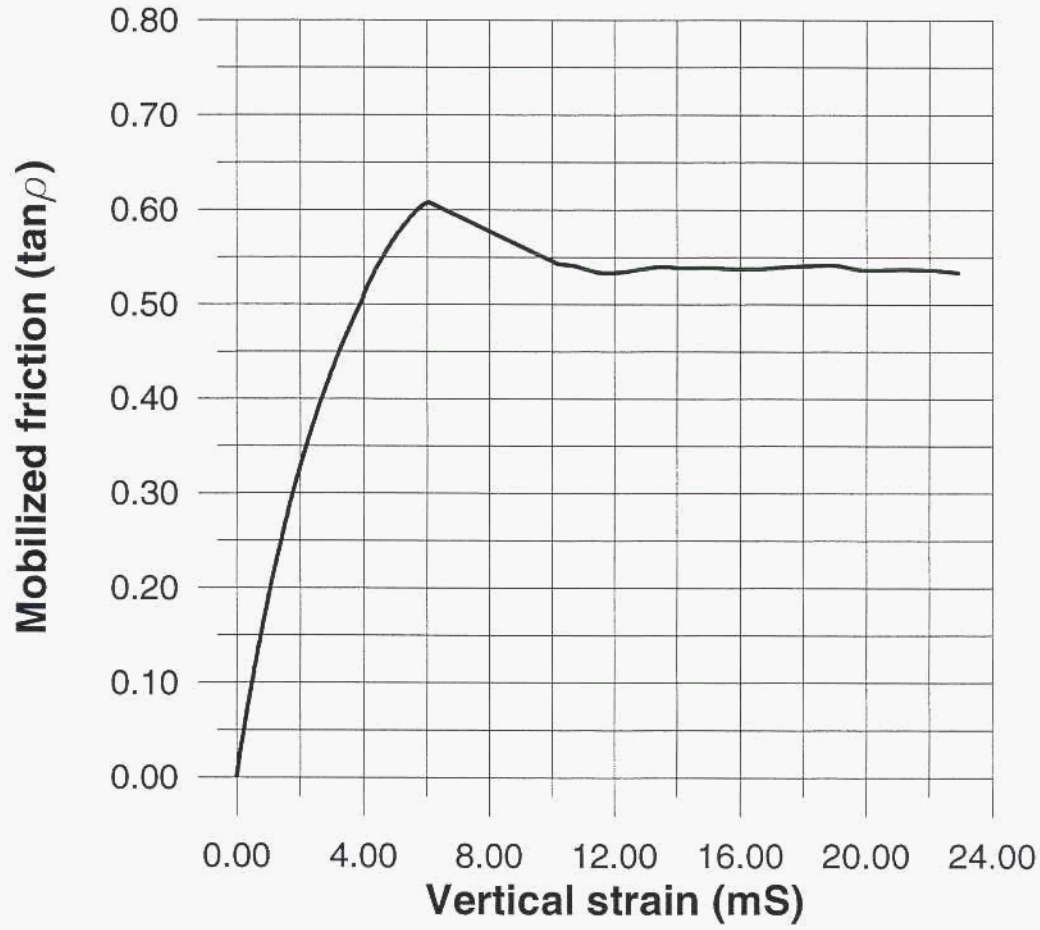

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.66 m	
Stage: Shearing		σ'_{Vc} = 28.70 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.63 MPa	
Part: 0	Test: 4G	TRI No.: 444	

Report No.	981002 ~
Figure No.	23
Drawn by	Jon
Date	98-3-11
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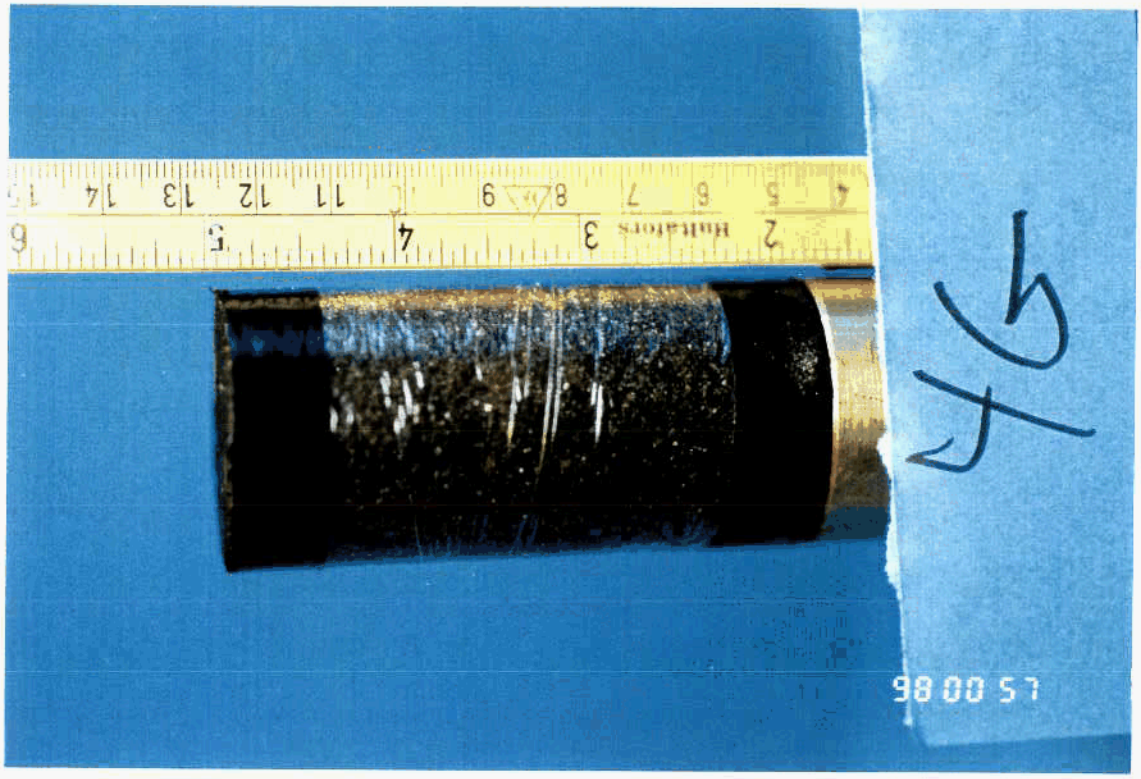

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3870.66 m	
Stage: Shearing		σ'_{Vc} = 28.70 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.63 MPa	
Part: 0	Test: 4G	TRI No.: 444	

Report No.	Figure No.
981002-1	24
Drawn by: Jon	Date: 98-3-11
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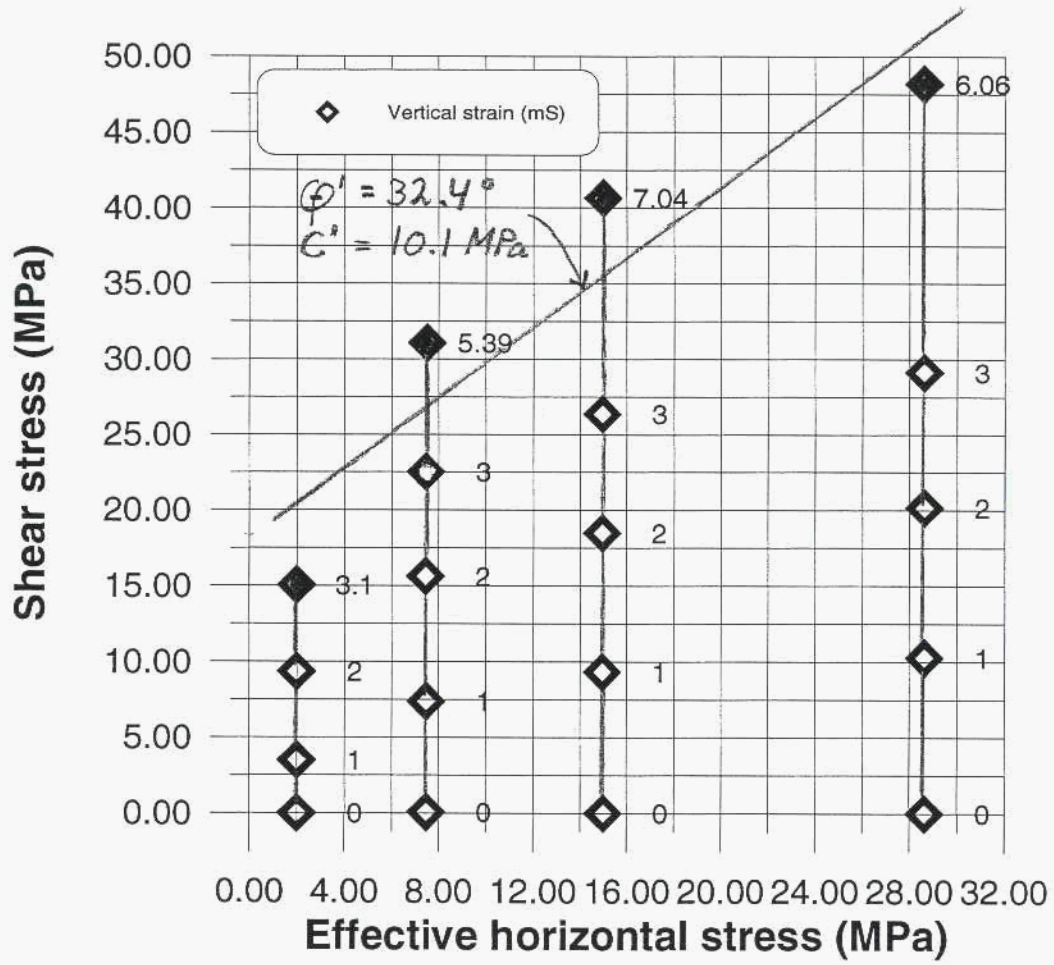

Rock Mechanical Testing. Well 15/9-19A

Triaxial tests (CID)		Depth = 3870.61 m	
Stage: Shearing		- 3870.70 m	
Bor. / Well: 15/9-19A	Tube / Plug: 0	TRI No.: 438, 440,	
Part: 0	Test: 1G-4G	441, 444	

Report No. 981002-1	Figure No. 25
Drawn by Jon	Date 98-3-11
Checked	
Approved TB	NGI

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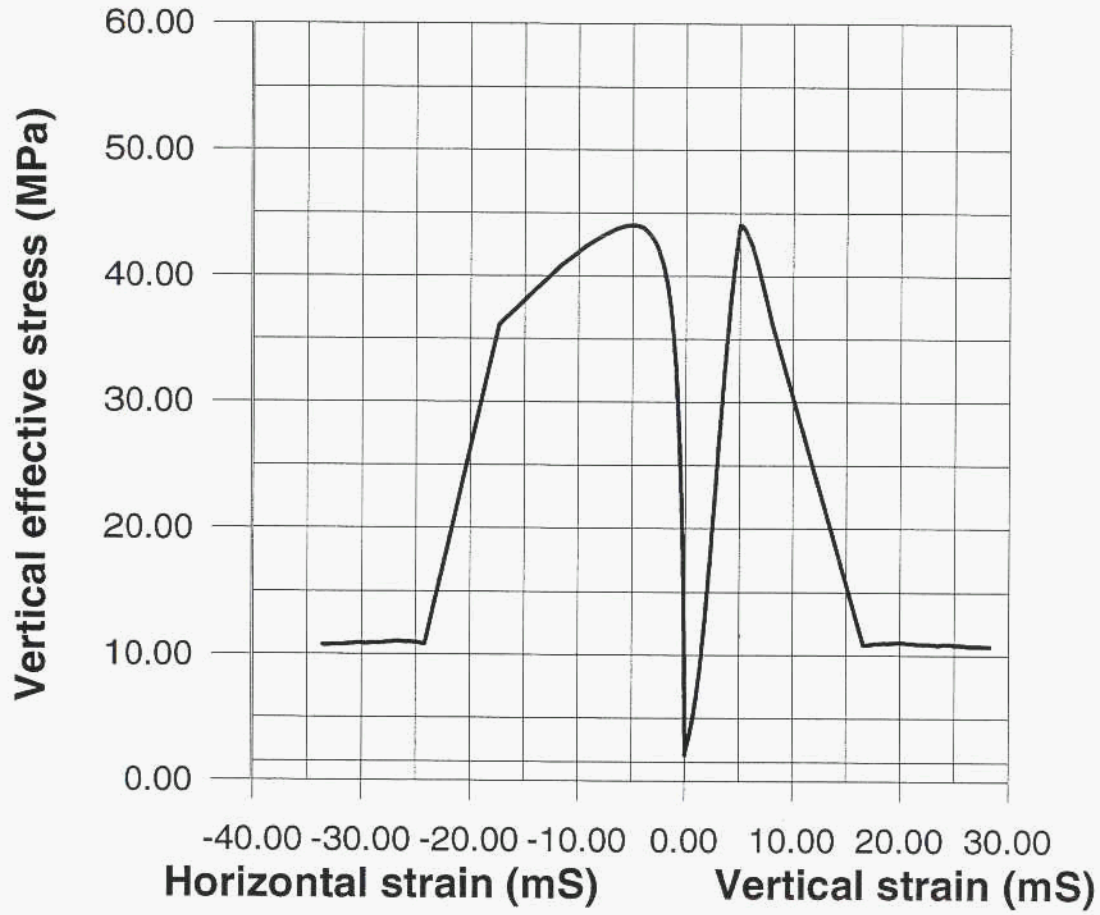

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.32 m	Report No. 981002-1	Figure No. 26
Stage: Shearing		σ'_{Vc} = 2.05 MPa	Drawn by Jon	Date 98-3-11
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.97 MPa	Checked	
Part: 0	Test: 5G	TRI No.: 445	Approved TB	NGI

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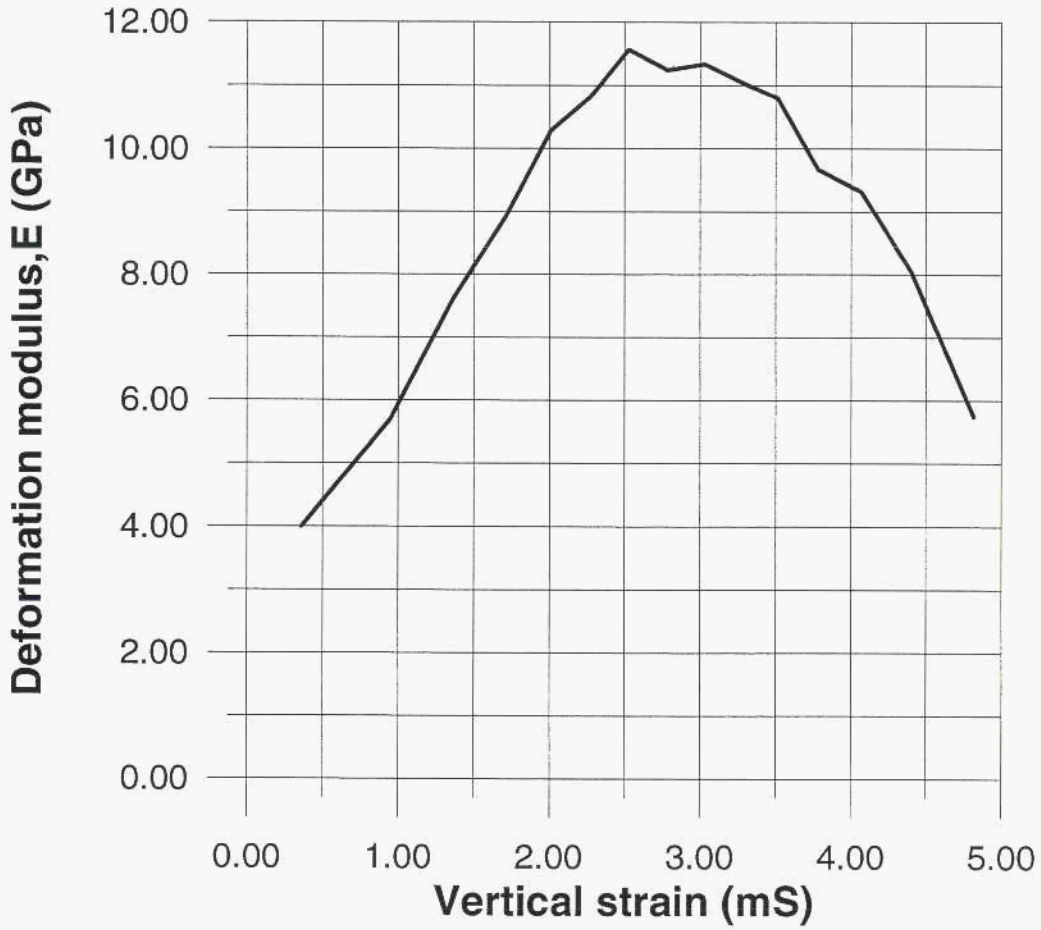

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.32 m	
Stage: Shearing		σ'_{Vc} = 2.05 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.97 MPa	
Part: 0	Test: 5G	TRI No.: 445	

Report No. 981002-1	Figure No. 27
Drawn by Jon	Date 98-3-11
Checked	
Approved TB	

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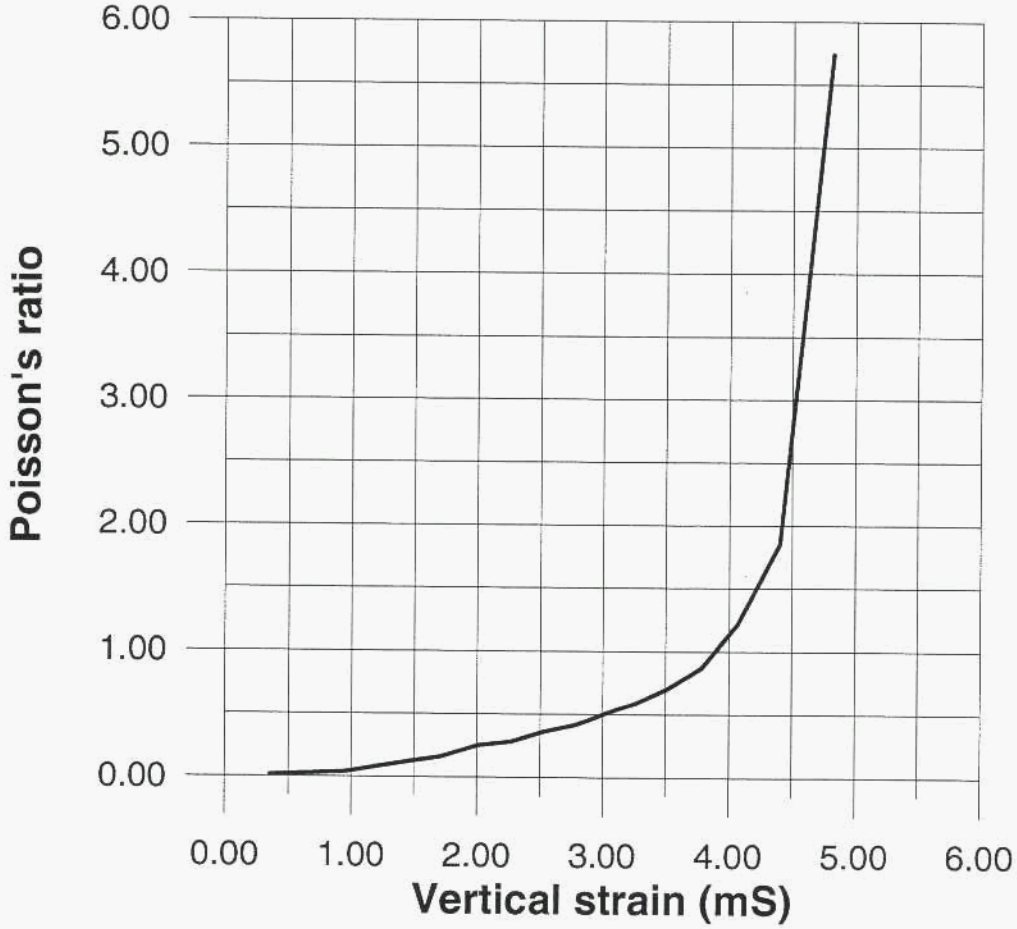

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.32 m	
Stage: Shearing		σ'_{Vc} = 2.05 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.97 MPa	
Part: 0	Test: 5G	TRI No.: 445	

Report No. 981002-1	Figure No. 28
Drawn by Jon	Date 98-3-11
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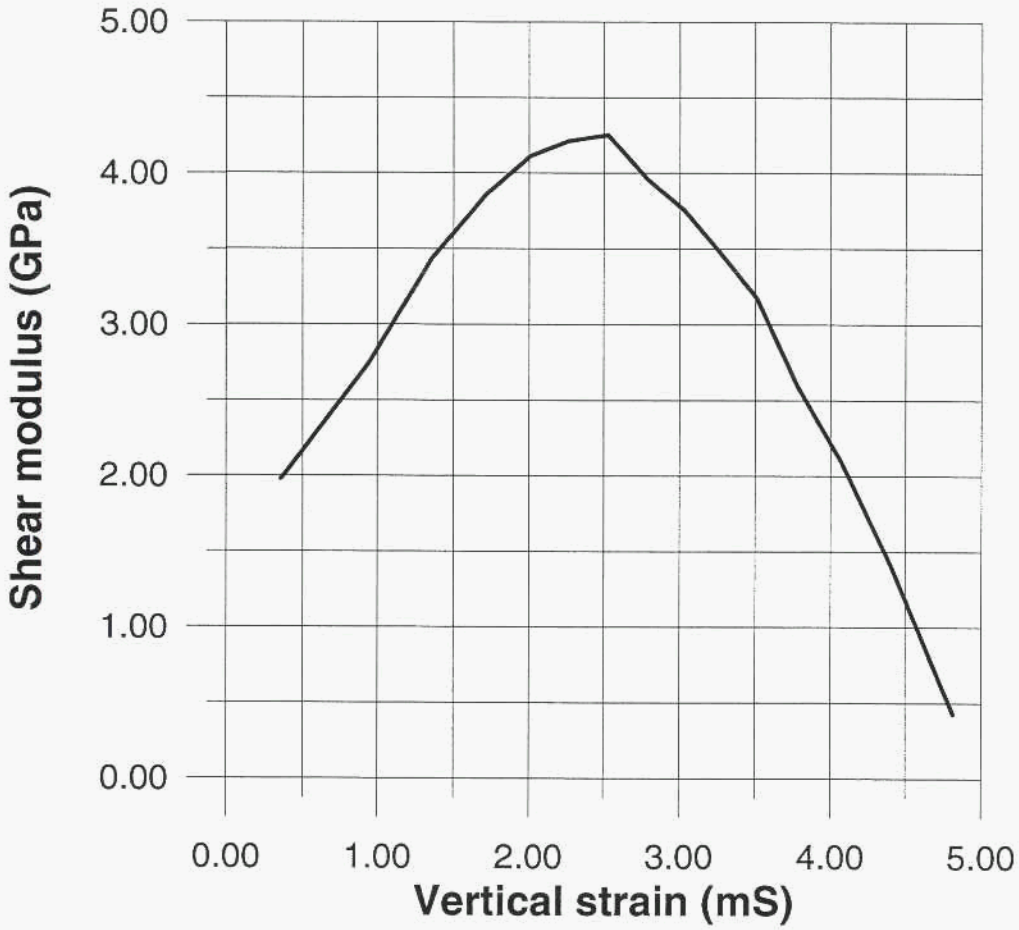

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.32 m	
Stage: Shearing		σ'_{Vc} = 2.05 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.97 MPa	
Part: 0	Test: 5G	TRI No.: 445	

Report No. 981002 - 1	Figure No. 29
Drawn by Jon	Date 98-3-11
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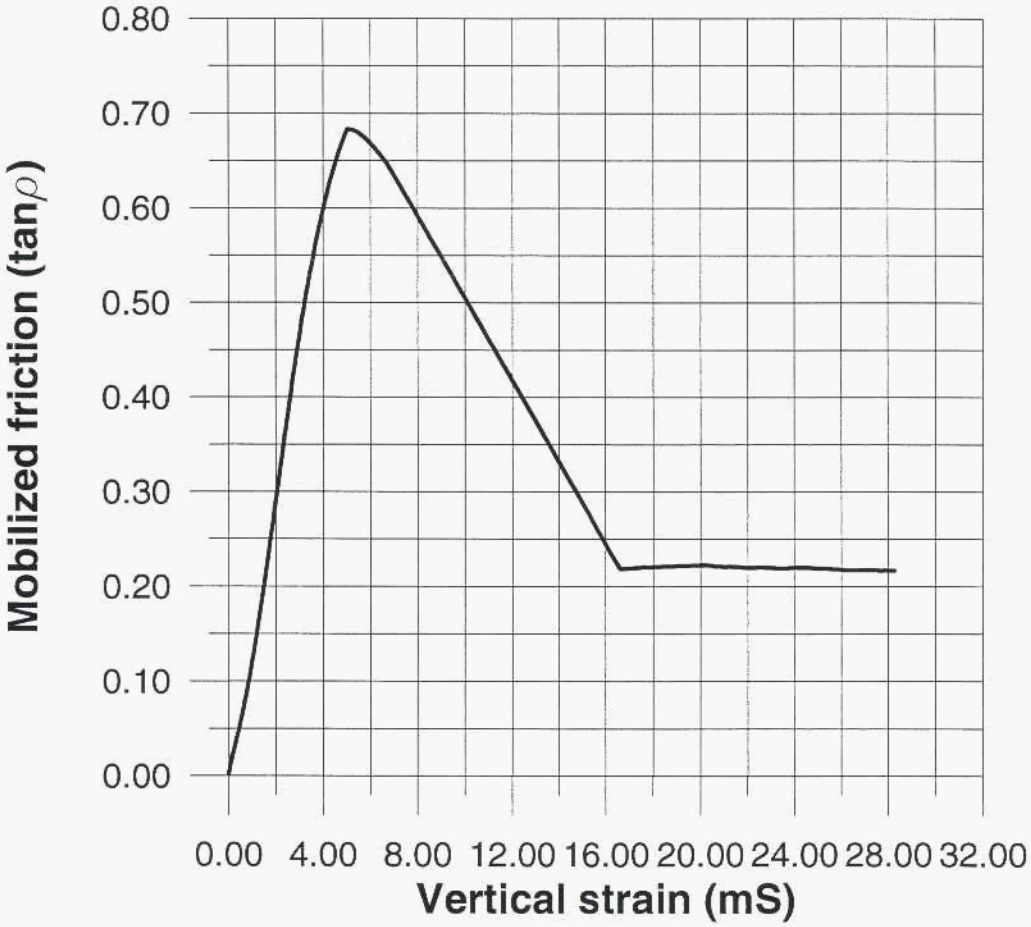

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.32 m	
Stage: Shearing		σ'_{Vc} = 2.05 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.97 MPa	
Part: 0	Test: 5G	TRI No.: 445	

Report No. 981002-1	Figure No. 30
Drawn by Jon	Date 98-3-11
Checked	
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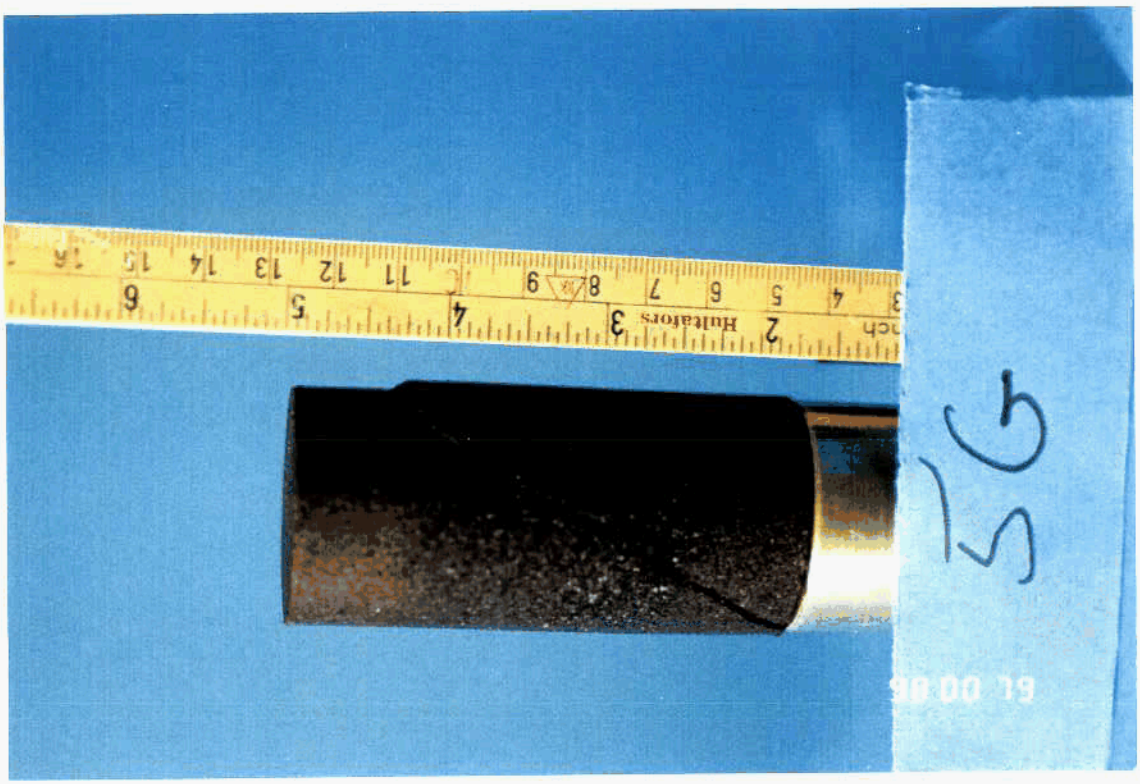

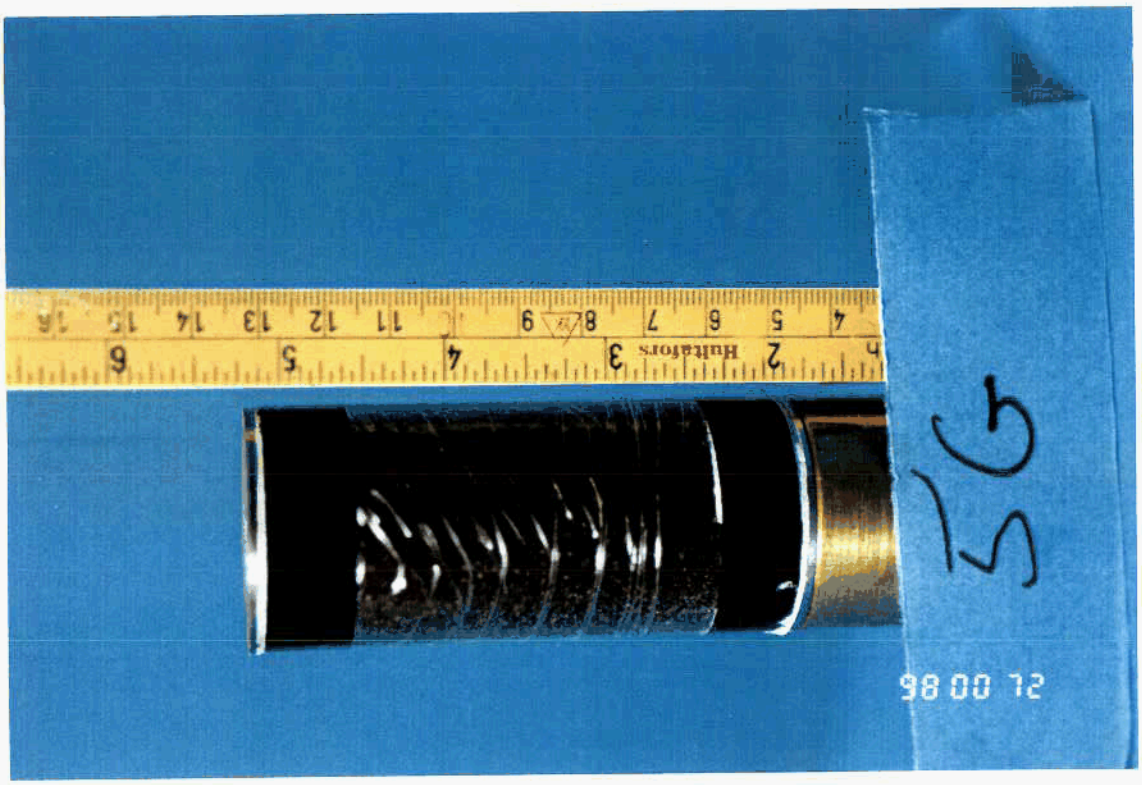

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.32 m	
Stage: Shearing		σ'_{Vc} = 2.05 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 1.97 MPa	
Part: 0	Test: 5G	TRI No.: 445	

Report No.	981002-1
Figure No.	31
Drawn by	Jon
Date	98-3-11
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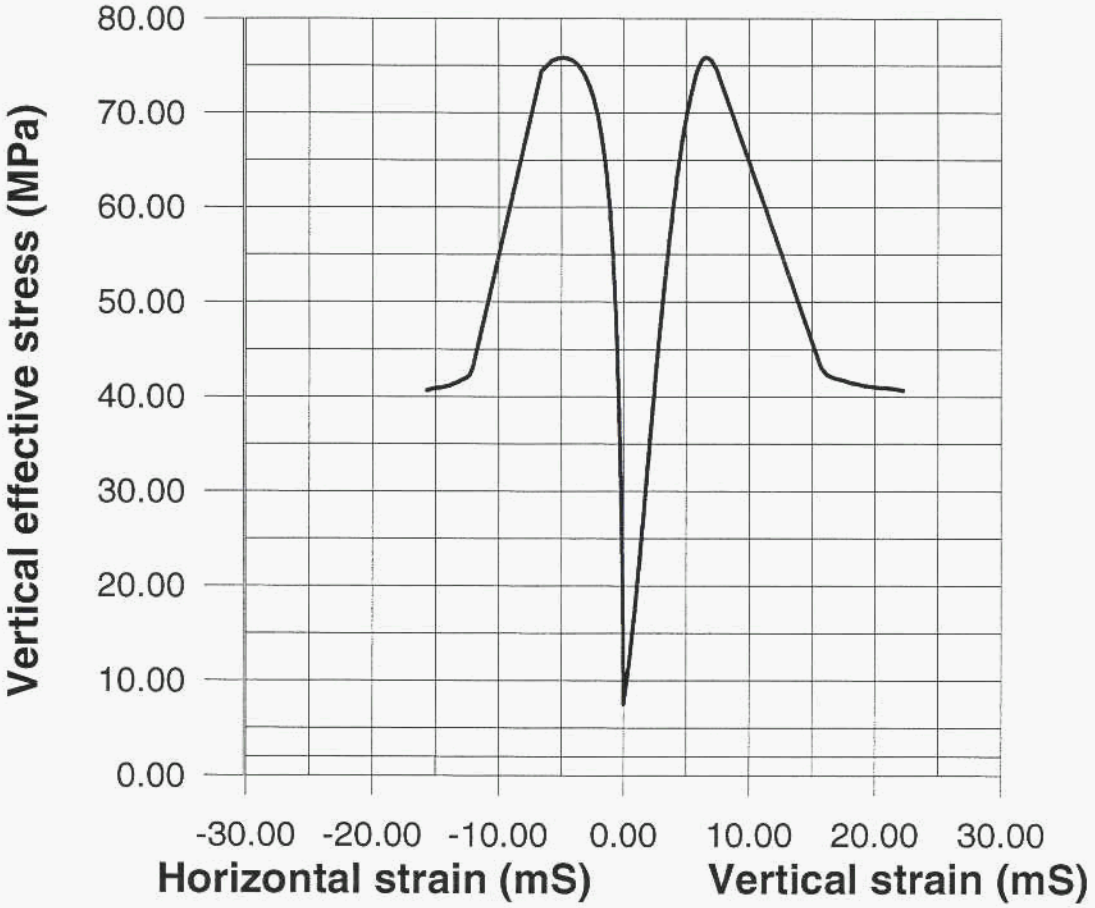

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.37 m	
Stage: Shearing		σ'_{Vc} = 7.50 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 6G	TRI No.: 446	

Report No.	981002-1
Figure No.	32
Drawn by	Jon
Date	98-3-11
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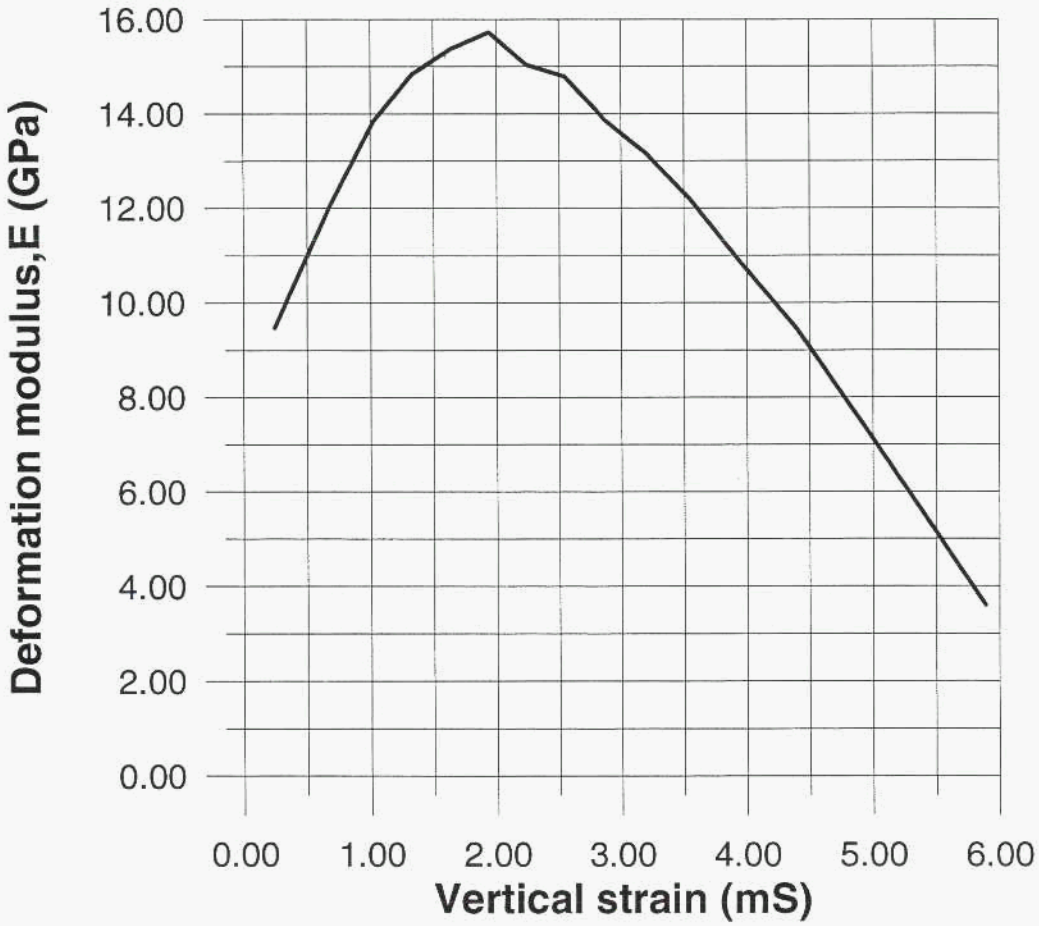

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.37 m	
Stage: Shearing		σ'_{Vc} = 7.50 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 6G	TRI No.: 446	

Report No.	981002-1
Figure No.	33
Drawn by	Jon
Date	98-3-11
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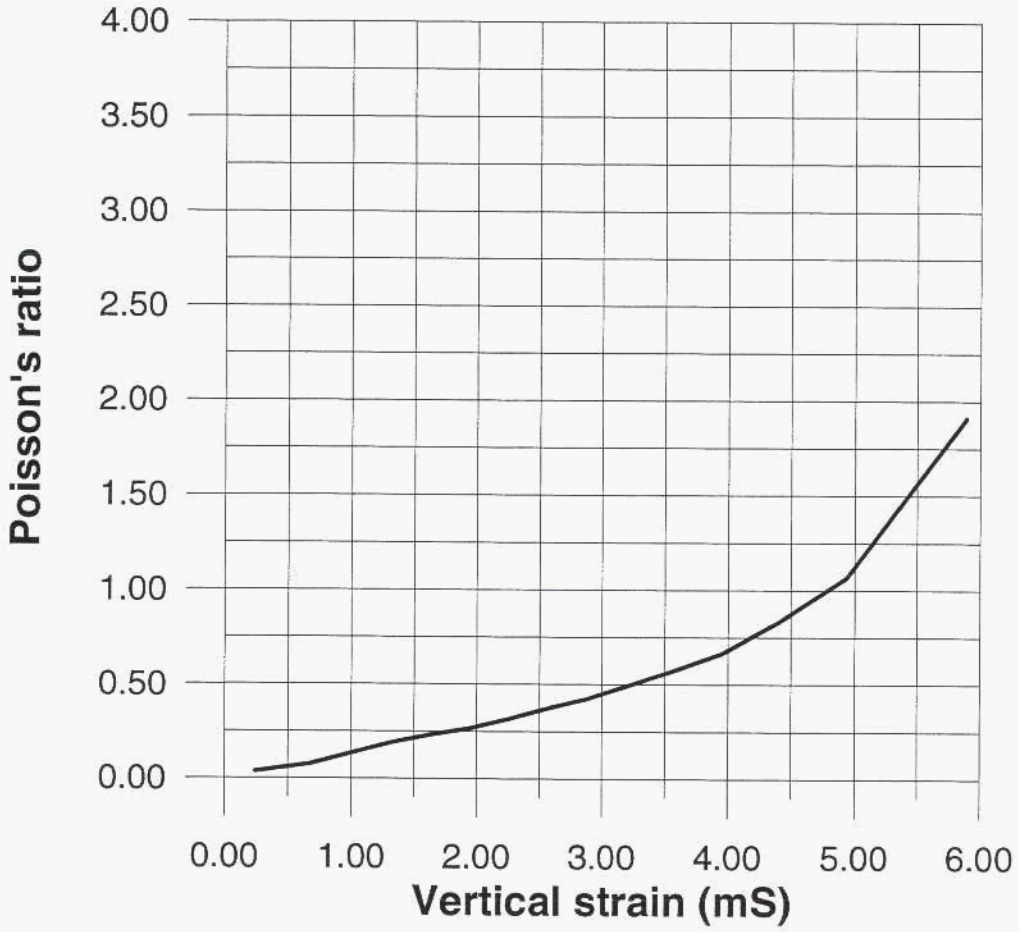

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.37 m	
Stage: Shearing		σ'_{Vc} = 7.50 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 6G	TRI No.: 446	

Report No.	Figure No.
981002-1	34
Drawn by: Jon	Date: 98-3-11
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Approved: TB	NGI

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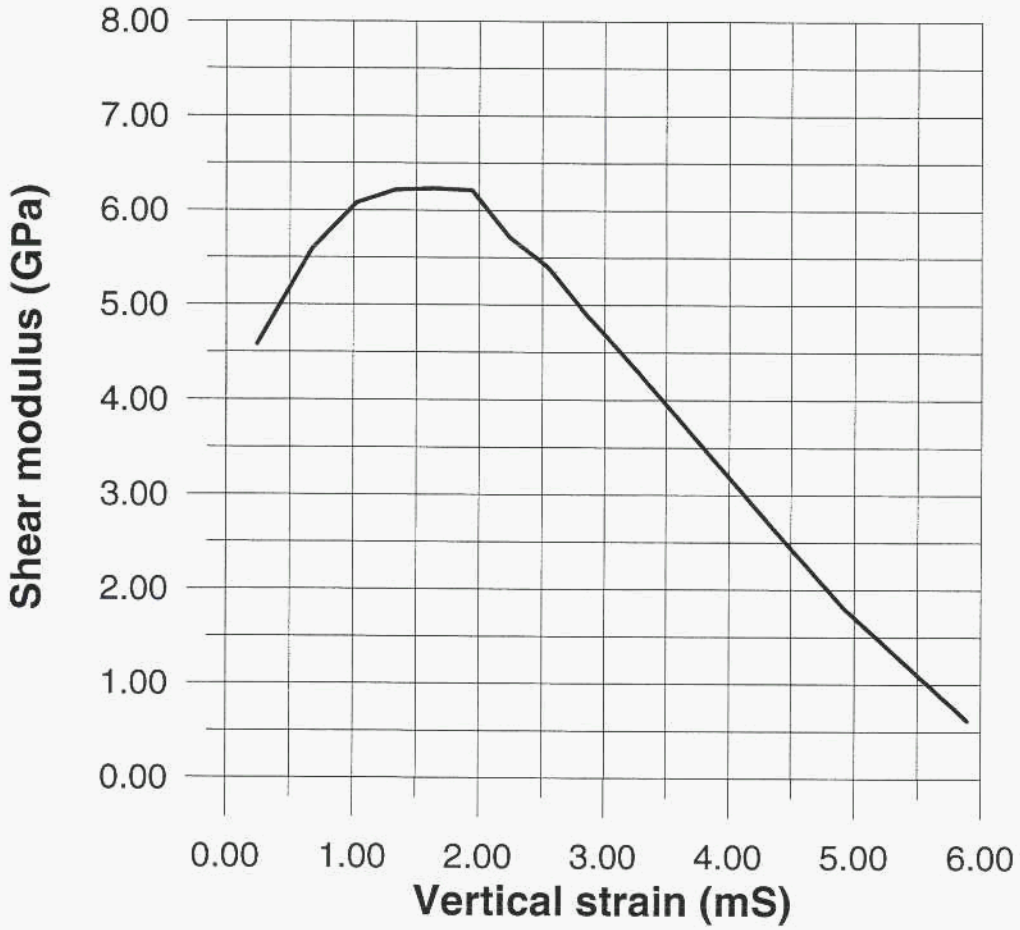

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.37 m	
Stage: Shearing		σ'_{Vc} = 7.50 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 6G	TRI No.: 446	

Report No.	981002 -1
Figure No.	35
Drawn by	Jon
Date	98-3-11
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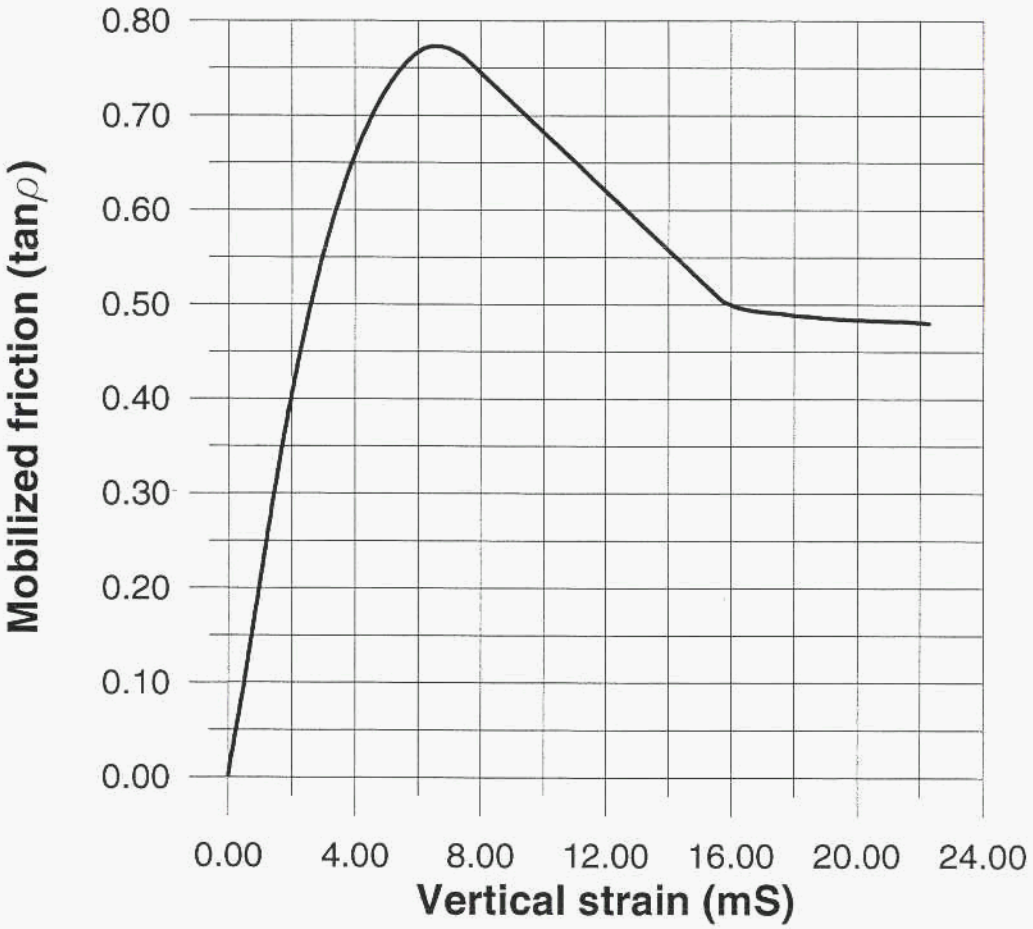

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.37 m	
Stage: Shearing		σ'_{Vc} = 7.50 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 6G	TRI No.: 446	

Report No.	981002-1
Figure No.	36
Drawn by	Jon
Date	98-3-11
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Approved	TB

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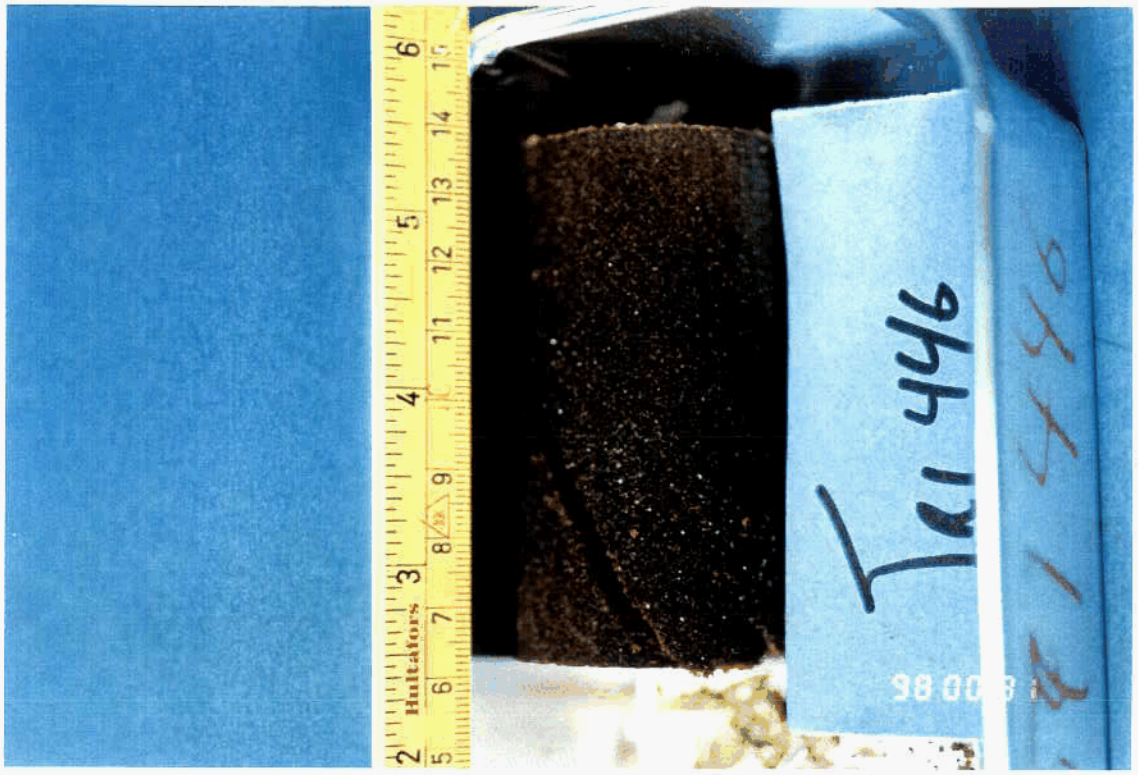

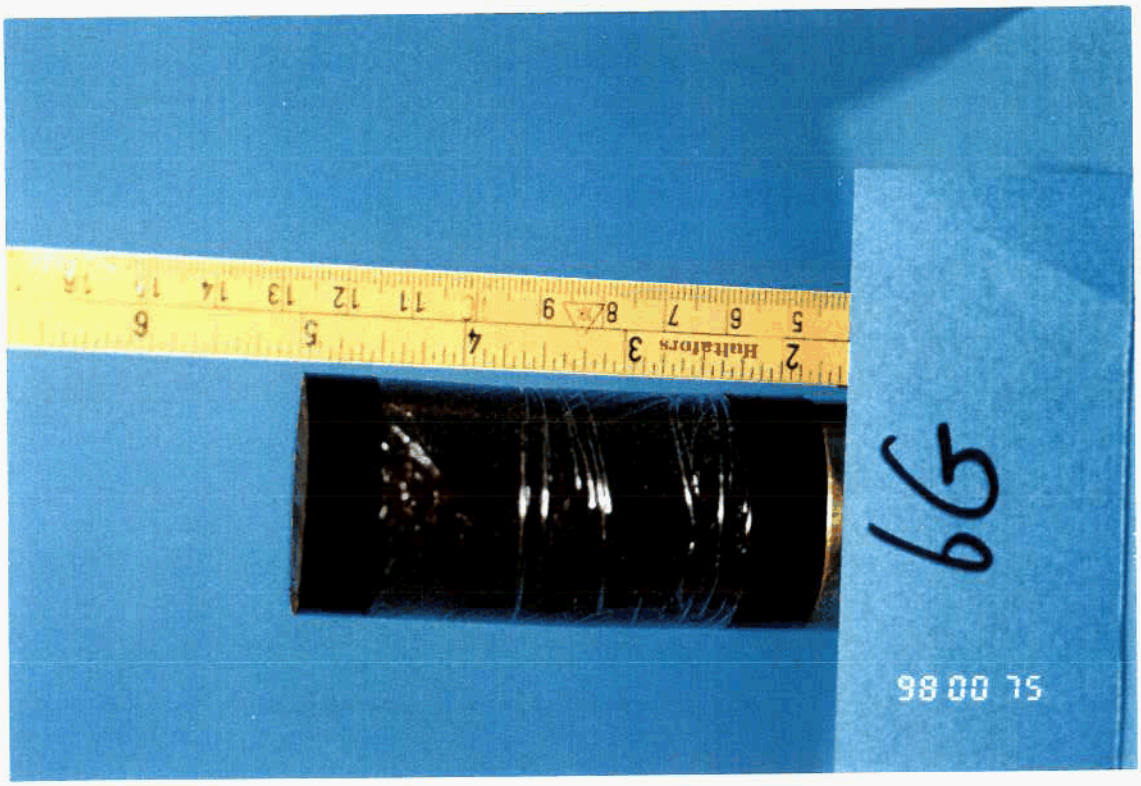

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.37 m	
Stage: Shearing		σ'_{Vc} = 7.50 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 7.46 MPa	
Part: 0	Test: 6G	TRI No.: 446	

Report No. 981002-1	Figure No. 37
Drawn by Jon	Date 98-3-11
Checked	
Approved TB	NGI

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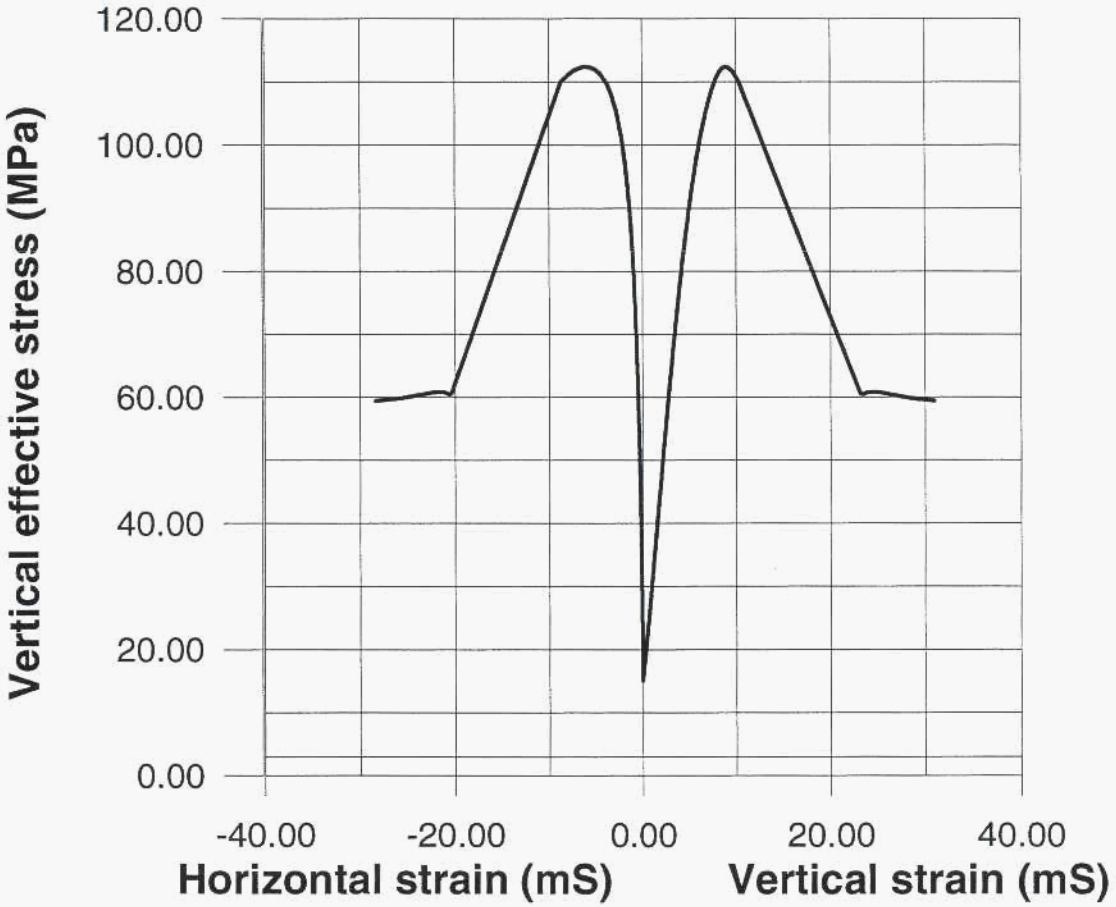

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.41 m	Drawn by: Jon	Date: 98-3-11
Stage: Shearing		σ'_{Vc} = 15.04 MPa	Checked:	NGI
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	Approved: TB	
Part: 0	Test: 7G	TRI No.: 448		

Report No. 981002-1 | Figure No. 38

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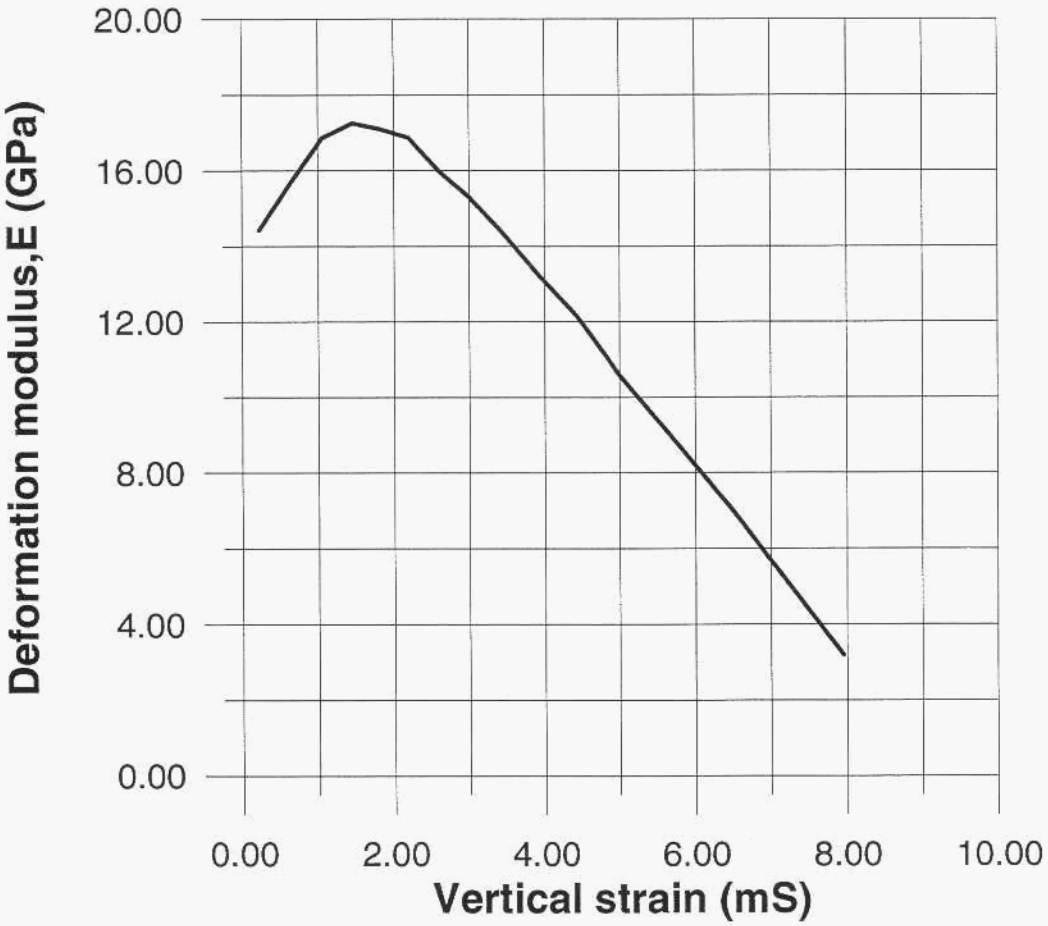

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.41 m	
Stage: Shearing		σ'_{Vc} = 15.04 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	
Part: 0	Test: 7G	TRI No.: 448	

Report No.	981002-1
Figure No.	39
Drawn by	Jon
Date	98-3-11
Checked	
Approved	TB

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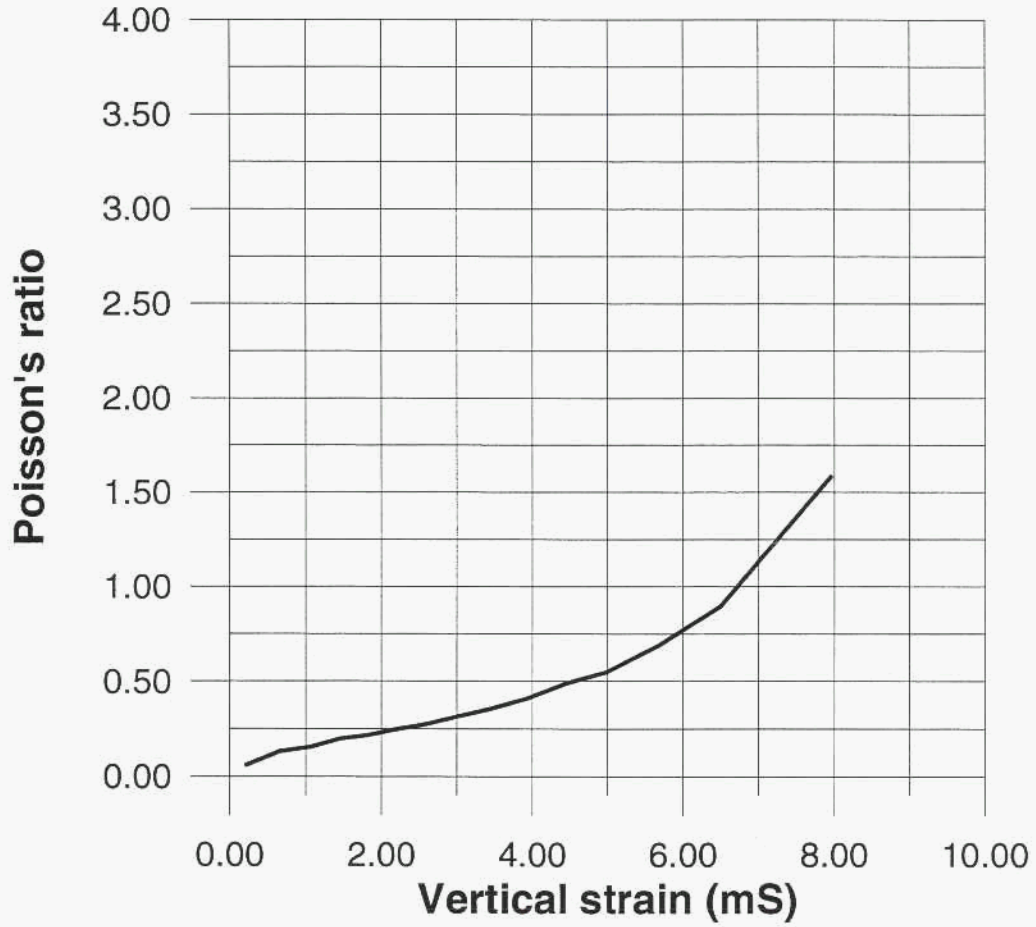

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.41 m	
Stage: Shearing		σ'_{Vc} = 15.04 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	
Part: 0	Test: 7G	TRI No.: 448	

Report No.	981002-1
Figure No.	40
Drawn by	Jon
Date	98-3-11
Checked	
Approved	TB

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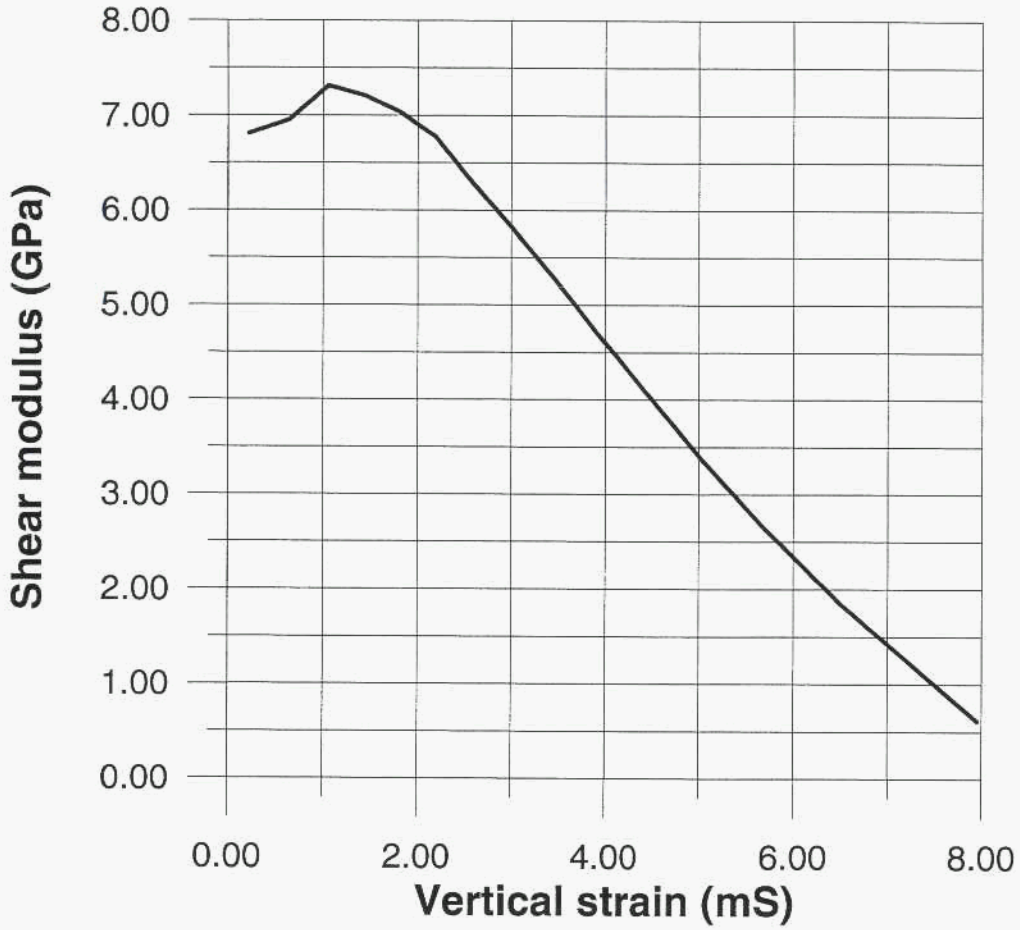

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.41 m	Report No. 981002-1	Figure No. 41
Stage: Shearing		σ'_{Vc} = 15.04 MPa	Drawn by Jon	Date 98-3-11
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	Checked	
Part: 0	Test: 7G	TRI No.: 448	Approved TB	NGI

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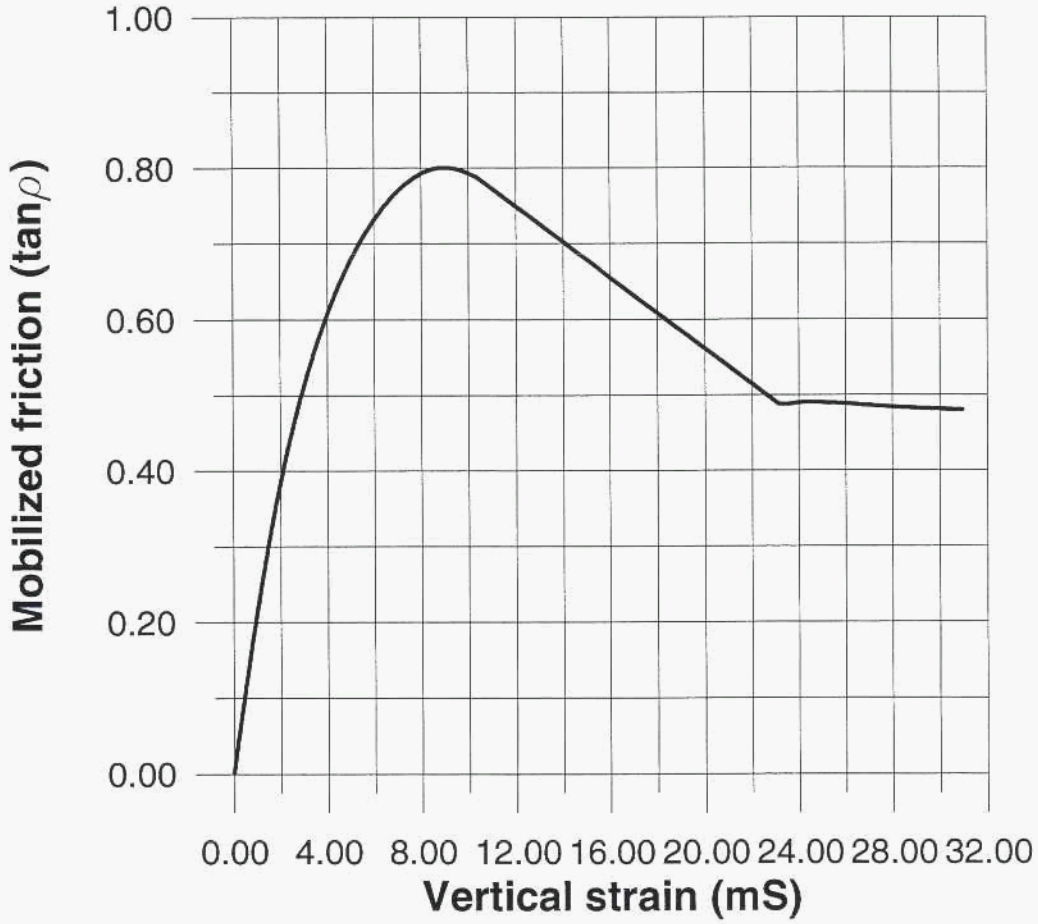

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.41 m	Drawn by: Jon	Date: 98-3-11
Stage: Shearing		σ'_{Vc} = 15.04 MPa	Checked:	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	Approved: TB	
Part: 0	Test: 7G	TRI No.: 448		

Report No. 981002-1 | Figure No. 42

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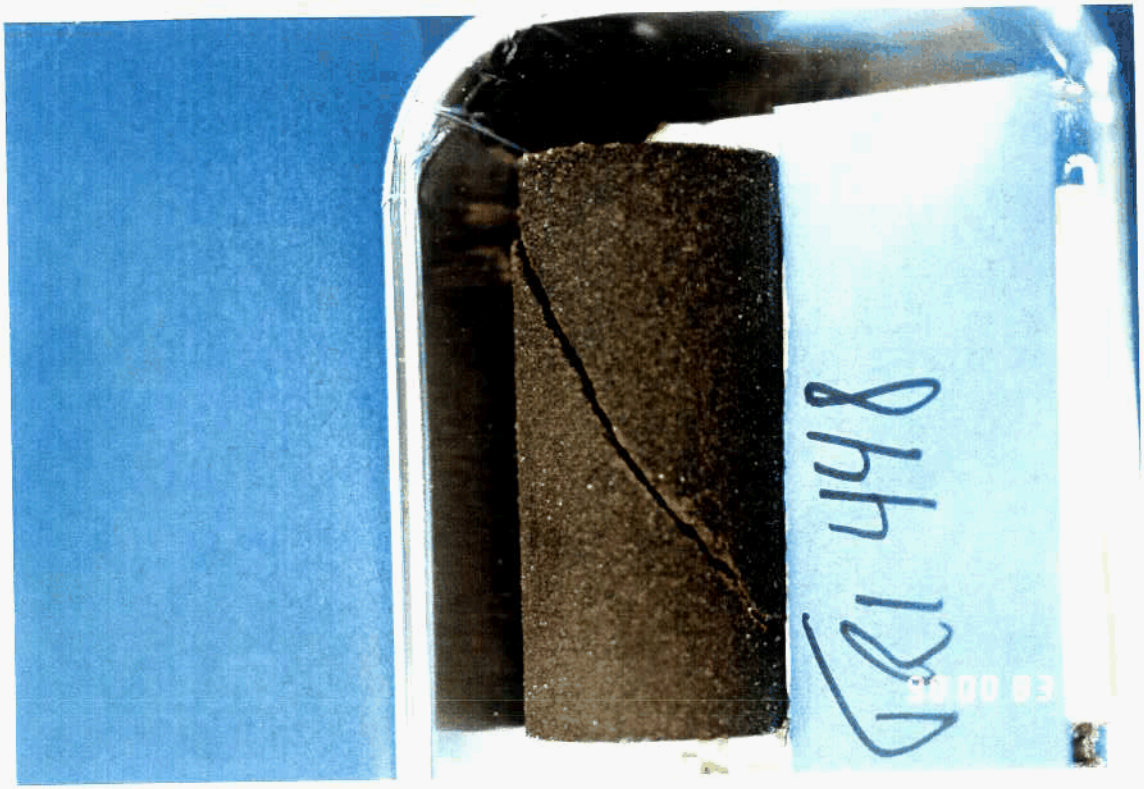

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.41 m	
Stage: Shearing		σ'_{Vc} = 15.04 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 14.98 MPa	
Part: 0	Test: 7G	TRI No.: 448	

Report No.	Figure No.
981002-1	43
Drawn by: Jon	Date: 98-3-11
Checked	
Approved: TB	NGI

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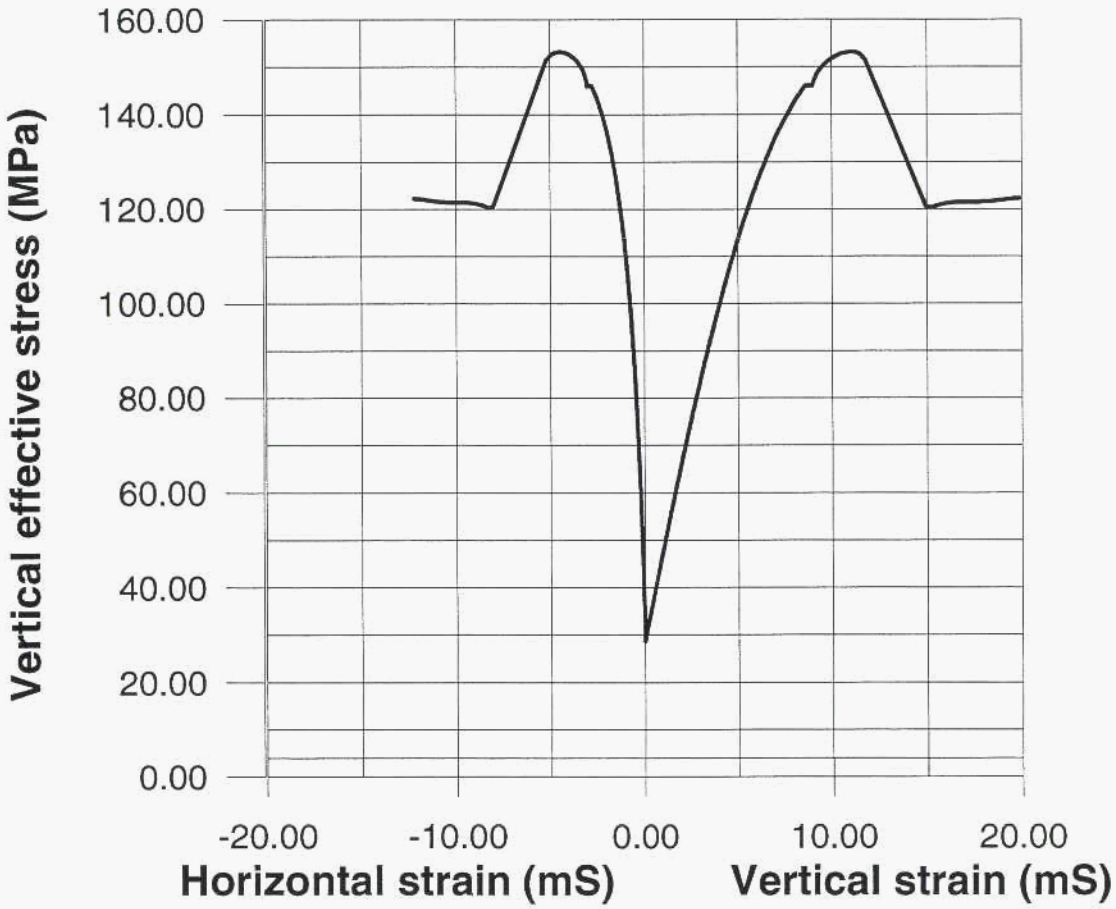

Rock Mechanical Testing. Well 15/9-19A

Report No. 981002-1			Figure No. 44	
Triaxial test (CID)		Depth = 3887.46 m	Drawn by Jon	Date 98-3-11
Stage: Shearing		σ'_{Vc} = 28.70 MPa	Checked	NGI
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.65 MPa	Approved TB	
Part: 0	Test: 8G	TRI No.: 451		

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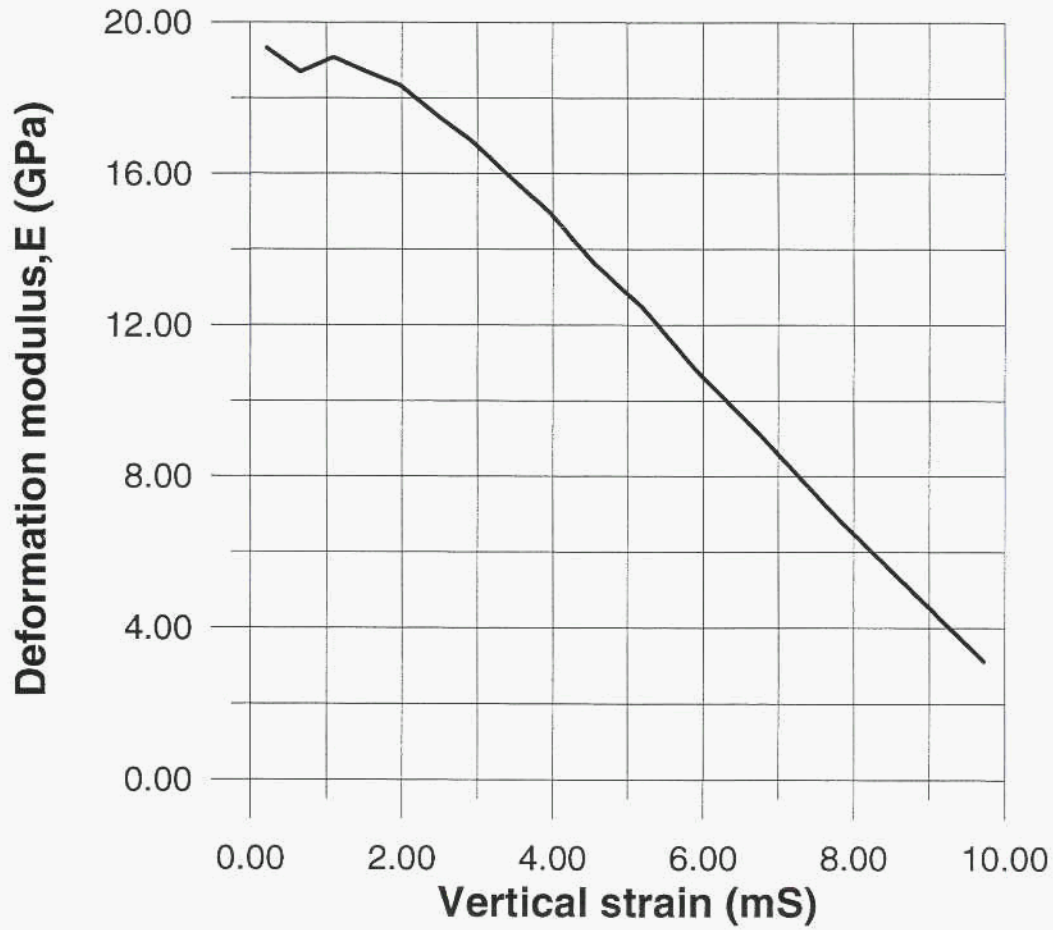

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.46 m	
Stage: Shearing		σ'_{Vc} = 28.70 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.65 MPa	
Part: 0	Test: 8G	TRI No.: 451	

Report No.	981002-1
Figure No.	45
Drawn by	Jon
Date	98-3-11
Checked	
Approved	TB

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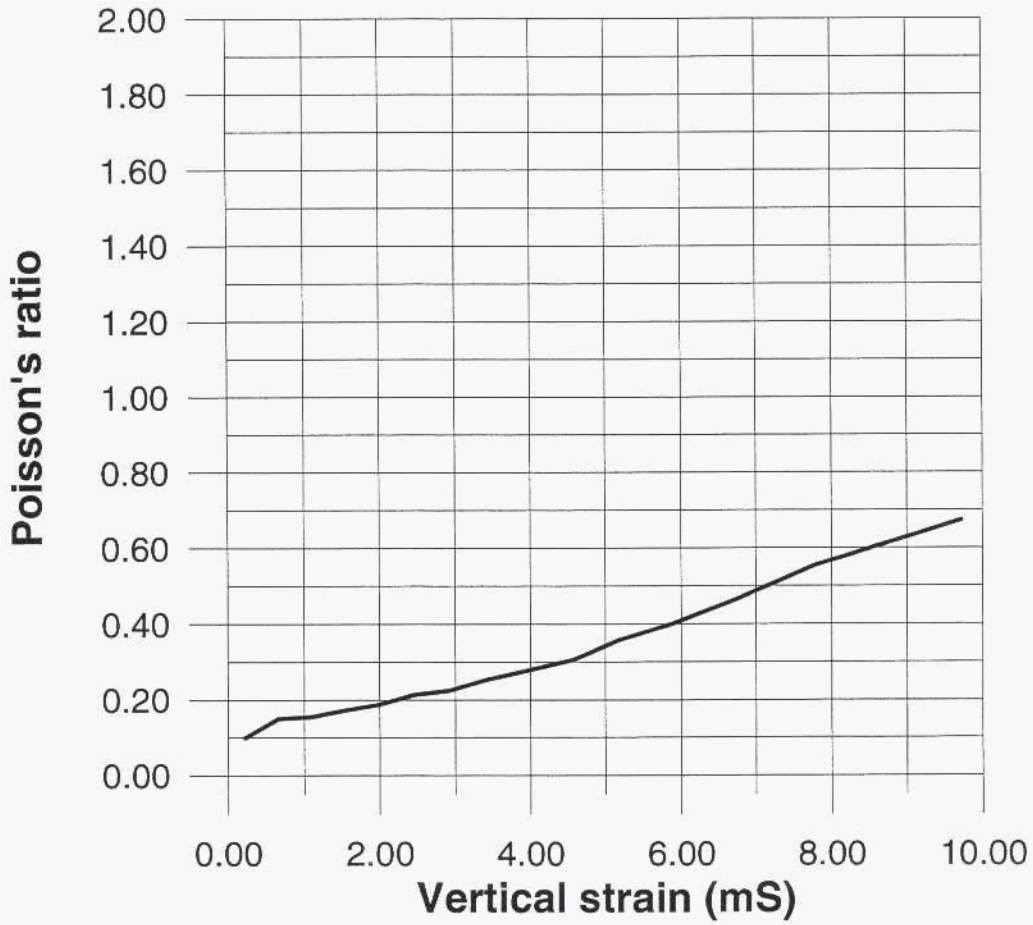

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.46 m	Report No. 981002-1	Figure No. 46
Stage: Shearing		σ'_{Vc} = 28.70 MPa	Drawn by Jon	Date 98-3-11
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.65 MPa	Checked	
Part: 0	Test: 8G	TRI No.: 451	Approved TB	NGI

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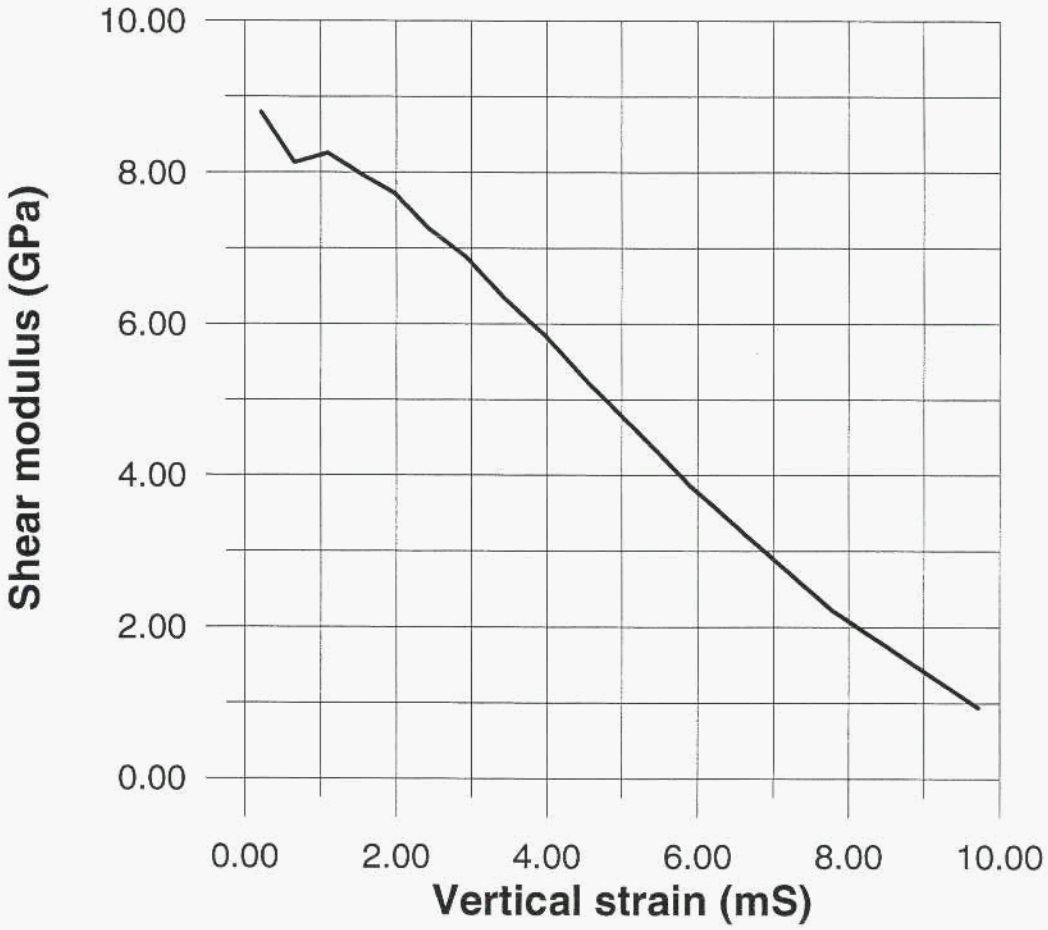

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.46 m	Drawn by: Jon	Date: 98-3-11
Stage: Shearing		σ'_{Vc} = 28.70 MPa	Checked:	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.65 MPa	Approved: TB	
Part: 0	Test: 8G	TRI No.: 451		

Report No. 981002-1 | Figure No. 47

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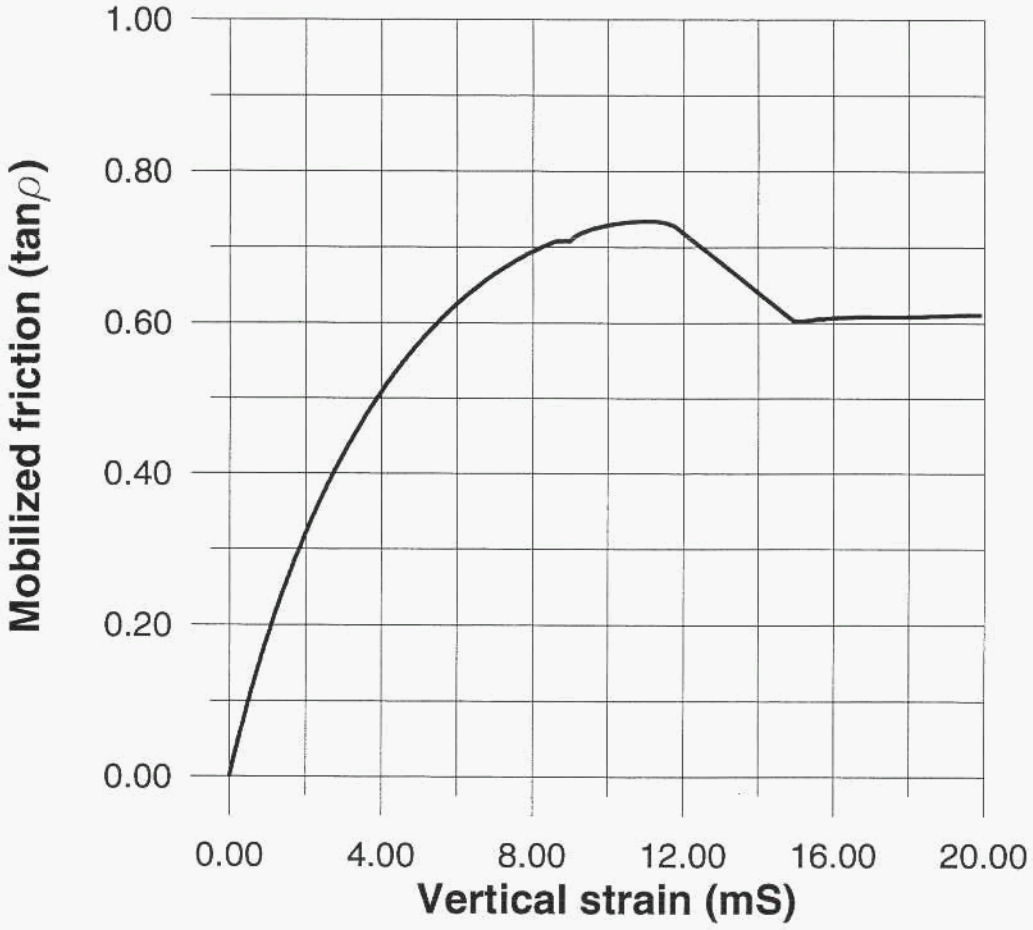

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.46 m	
Stage: Shearing		σ'_{Vc} = 28.70 MPa	
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.65 MPa	
Part: 0	Test: 8G	TRI No.: 451	

Report No. 981002 - 1	Figure No. 48
Drawn by Jon	Date 98-3-11
Checked	
Approved TB	

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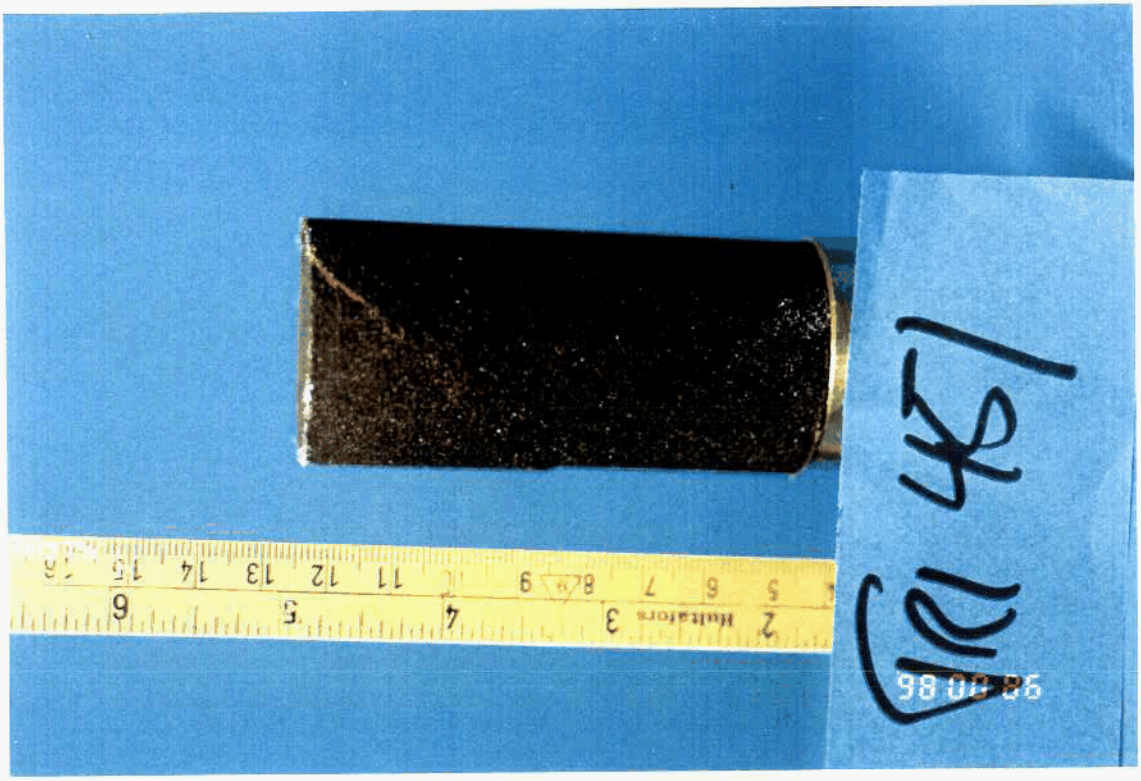

Rock Mechanical Testing. Well 15/9-19A

Triaxial test (CID)		Depth = 3887.46 m	Report No. 981002-1	Figure No. 49
Stage: Shearing		σ'_{Vc} = 28.70 MPa	Drawn by Jon	Date 98-3-11
Bor. / Well: 15/9-19A	Tube / Plug: 0	σ'_{Hc} = 28.65 MPa	Checked	
Part: 0	Test: 8G	TRI No.: 451	Approved TB	NGI

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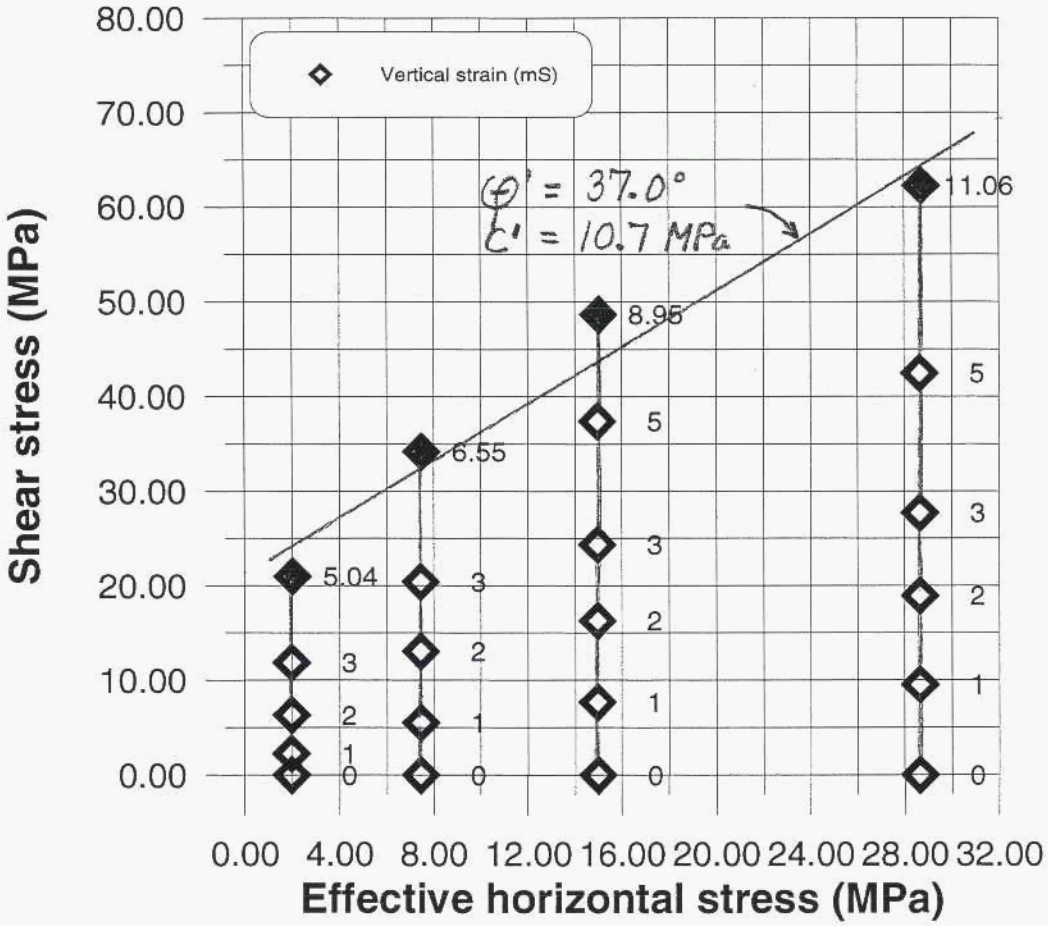

Rock Mechanical Testing. Well 15/9-19A

Triaxial tests (CID)		Depth = 3887.30 m	
Stage: Shearing		- 3887.50 m	
Bor. / Well: 15/9-19A	Tube / Plug: 0	TRI No.: 445, 446,	
Part: 0	Test: 5G-8G	448, 451	

Report No. 981002-1	Figure No. 50
Drawn by Jon	Date 98-3-11
Checked	
Approved TB	

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Kontroll- og referanseside/
Review and reference page

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Oppdragsgiver/*Client* Statoil **Kontraktsreferanse/ *Contract reference*** ANS 027467/V0003	**Dokument nr/*Document No.*** 981002-1 **Dato/*Date*** 20 March 1998
Dokumenttittel/*Document title* Triaxial tests on sandstone. Well 15/9-19A **Prosjektleder/*Project Manager*** Toralv Berre **Utarbeidet av/*Prepared by*** Toralv Berre	**Distribusjon/*Distribution*** ☐ **Fri/*Unlimited*** ☐ **Begrenset/*Limited*** ☒ **Ingen/*None***
Emneord/*Keywords* Triaxial testing. Sandstone. Acoustic measurements	
Land, fylke/*Country, County* Norway **Kommune/*Municipality*** **Sted/*Location*** **Kartblad/*Map*** **UTM-koordinater/*UTM-coordinates***	**Havområde/*Offshore area*** North Sea **Feltnavn/*Field name*** **Sted/*Location*** **Felt, blokknr./*Field, Block No.***

Kvalitetssikring i henhold til/*Quality assurance according to* NS-EN ISO9001

Kontrollert av/ *Reviewed by*	Kontrolltype/ *Type of review*	Dokument/*Document* Kontrollert/*Reviewed* Dato/*Date*	Sign.	Revisjon 1/*Revision 1* Kontrollert/*Reviewed* Dato/*Date*	Sign.	Revisjon 2/*Revision 2* Kontrollert/*Reviewed* Dato/*Date*	Sign.
KH	Helhetsvurdering/ *General Evaluation* *	29.06.98	Kll				
KH	Språk/*Style*	29.06.98	Kll				
KH	Teknisk/Technical - Skjønn/*Intelligence* - Total/*Extensive* - Tverrfaglig/ *Interdisciplinary*	29.06.98	Kll				
TB	Utforming/*Layout*	30/6-98	TB				
TB	Slutt/*Final*	-"-	TB				
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