CORE ANALYSIS REPORT

FOR

MAGELLAN PETROLEUM AUSTRALIA LTD.

PALM VALLEY 7
PALM VALLEY
PALM VALLEY

[redacted]

Western Atlas International
A Litton/Dresser Company

CORE LABORATORIES

December 10, 1990

Magellan Petroleum Australia Ltd
10th Floor
145 Eagle Street
Brisbane QLD 4000

Attention: Mr. M. Berry

Subject : Core Analysis
Well : Palm Valley #7
File : WCA-90020

Dear Sir,

Core Laboratories performed the following analysis on selected plugs from Palm Valley #7.

Helium Injection Porosity
Permeability to Air

As the results became available they were sent via facsimile to your office. This report finalizes all data.

If you have any questions concerning this report, please do not hesitate to contact us.

Core Laboratories wishes to thank Magellan Petroleum Australia Ltd., for the opportunity to have been of service.

Yours faithfully,
CORE LABORATORIES

James C. Brown
Laboratory Supervisor - Core Analysis

JCB:jc

Core Laboratories
Western Atlas International Inc. incorporated in Delaware USA.
A limited liability company
P.O. Box 785 Cloverdale W.A. 6105. Tel: (09) 353 3944. Tlx: AA 94706. Fax: (09) 353 1369

CORE LABORATORIES AUSTRALIA PTY., LTD.

Company : MAGELLAN PETROLEUM AUSTRALIA LTD.
Well : PALM VALLEY 7
Location :
Country : AUSTRALIA

Field : PALM VALLEY
Formation :
Coring Fluid :
Elevation :

File No.: WCA-90020
Date : 10-12-1990
API No. :
Analysts: J.C.B./G.A.K.

CORE ANALYSIS RESULTS

(HYDROSTATIC CONFINEMENT)

SAMPLE NUMBER	DEPTH	NOB (800 psi)		NOB (4100 psi)		GRAIN DENSITY	DESCRIPTION
		Kair	ϕ	Kair	ϕ		
	ft	md	%	md	%	gm/cc	
1	5548.6					2.84	Sst;lt gry/gry,vf,p srt,vw ind,sl calc,vert fract filled,pyr.
2	5913.1	0.093	4.8	0.014	4.2	2.72	Sst;lt gry/gry,vf,p srt,vw ind,sl calc,pyr.
3	5921.1	0.007	4.3			2.70	Sst;lt gry/gry,vf,p srt,vw ind,sl calc,pyr.
4	5924.6	0.073	2.4	0.006	1.9	2.66	Sst;lt gry,vf,p srt,vw ind,sl calc,pyr,fract.
5	5924.9	0.008	2.5			2.67	Sst;lt gry,vf,p srt,vw ind,sl calc,pyr.
6	5926.4	0.015	2.8			2.69	Sst;lt gry,vf,p srt,vw ind,sl calc,pyr.
7	5935.9	0.024	4.6	0.004	4.0	2.72	Sst;lt gry,vf,p srt,vw ind,sl calc,pyr.
8	5937.4	0.054	4.2	0.004	3.7	2.73	Sst;lt gry,vf,p srt,vw ind,sl calc,pyr.
9	5938.8	0.006	2.2			2.73	Sst;lt gry,vf,p srt,vw ind,sl calc,pyr.

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API No. :
Analysts: J.C.B./G.A.K.

CORE ANALYSIS RESULTS

(HYDROSTATIC CONFINEMENT)

SAMPLE NUMBER	DEPTH	NET OVERBURDEN (800 psi)					
		K∞	Kair	ϕ	b(He)	BETA	ALPHA
	ft	md	md	%	psi	ft(-1)	microns
1	5548.6						
2	5913.1	0.068	0.093	4.8	27.33	6.0593E12	1.27535E3
3	5921.1	0.004	0.007	4.3	57.41	7.4735E14	9.58213E3
4	5924.6	0.069	0.073	2.4	4.40	1.9124E13	3.96359E3
5	5924.9	0.006	0.008	2.5	44.96	2.7573E14	4.78367E3
6	5926.4	0.011	0.015	2.8	32.06	1.4349E14	4.81697E3
7	5935.9	0.018	0.024	4.6	26.33	7.4885E13	4.21625E3
8	5937.4	0.034	0.054	4.2	45.91		
9	5938.8	0.002	0.006	2.2	176.83		

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Coring Fluid :
Elevation :

File No.: WCA-90020
Date : 10-12-1990
API No. :
Analysts: J.C.B./G.A.K.

CORE ANALYSIS RESULTS

(HYDROSTATIC CONFINEMENT)

SAMPLE NUMBER	DEPTH	NET OVERBURDEN (4100 psi)				NOB (800 psi) BETA	NOB (4100 psi) BETA
		K∞	Kair	φ	b(He)		
	ft	md	md	%	psi	ft(-1)	ft(-1)
1	5548.6						
2	5913.1	0.008	0.014	4.2	57.82	6.0593E12	2.9859E14
3	5921.1					7.4735E14	
4	5924.6	0.002	0.006	1.9	184.99	1.9124E13	
5	5924.9					2.7573E14	
6	5926.4					1.4349E14	
7	5935.9	0.002	0.004	4.0	62.44	7.4885E13	2.0134E15
8	5937.4	<.001	0.004	3.7	228.04		
9	5938.8						

CORE LABORATORIES AUSTRALIA PTY., LTD.

Company : MAGELLAN PETROLEUM AUSTRALIA LTD.
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Field : PALM VALLEY
Formation :

File No.: WCA-90020
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ANALYTICAL PROCEDURES AND QUALITY ASSURANCE

HANDLING & CLEANING

Core Transportation	:
Solvent	:
Extraction Equipment	:
Extraction Time	:
Drying Equipment	: OVEN
Drying Time	: UNTIL DRY (CONSTANT WEIGHT)
Drying Temperature	: 110 DEG.C.

ANALYSIS

Grain volume measured by Boyle's Law in a modified U.S.B.M. porosimeter using He
Permeabilities measured on 1.5 in. diameter drilled plugs
The "OB" samples were confined in the CMS300
The "OB" samples subjected to 4100 PSI pressure

REMARKS

SAMPLE 1, EXTREAMLY TIGHT,UNABLE TO MEASURE POROSITY AND PERMEABILITY AT 800psi AND 4100psi.
SAMPLES 3,5,6, AND 9, UNABLE TO MEASURE POROSITY AND PERMEABILTY AT 4100psi. DUE TO THE LOW PERMEABILITY OF THE SAMPLES.

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CORE LABORATORIES

PORE VOLUME COMPRESSIBILITY, ULTRASONIC VELOCITY, AND DYNAMIC MODULI PALM VALLEY NO. 7 WELL PALM VALLEY FIELD

Final Report

Performed for:
Magellan Petroleum Australia, Ltd.
10 Floor, 145 Eagle Street
Brisbane Queensland
Australia 4000

January 18, 1991

Performed by:
Core Laboratories
1875 Monetary Lane
Carrollton, Texas 75006
(214) 541-2673

File: SCAL-90077

Magellan Petroleum Australia, Ltd.
File: SCAL-90077

PROGRAM PARTICIPANTS

Hydrostatic Pore Volume Compressibility Measurements and Report Preparation	John A. Kieschnick
Acoustic Velocity Measurements and Report Preparation	Richard Harting
Final Review	Carol A. Admire Laboratory Supervisor

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TABLE OF CONTENTS

SECTION 1

PROGRAM OBJECTIVE

The objective of this study was to determine specific petrophysical properties of six 2.5 inch diameter vertical core plugs and one 1.5 inch diameter horizonal core plug from the Palm Valley #7 Well. Hydrostatic pore volume reduction and acoustic properties were determined. This data was used to determine hydrostatic pore volume compressibility, predict uniaxial pore volume compressibility, and calculate the dynamic elastic moduli of the samples tested.

SECTION 2

SUMMARY/DISCUSSION

Hydrostatic Pore Volume Compressibility (PVCh) and Acoustic Velocities were measured on seven sandstone samples which range in depth from 5560′6" to 5919′1". Pore Volume Compressibility tests were conducted using net hydrostatic stresses ranging from 500 to 4500 psi. Samples 1 through 5 and sample 7 contain visible fractures, while sample 6 (5917′11.5"-5918′3.5") does not. Sample 4 appeared to be the finest grained of the samples tested. Acoustic properties were determined using a net stress of 4100 psi.

Helium porosity values for the samples at a confining stress of 500 psi range from 3.00 to 7.44 percent. At the maximum net stress used during testing (4500 psi) this was reduced to a range of 2.11 to 6.41 percent. During evaluation of pore volume compressibility data, the pore volume of each sample was normalized to its pore volume at 500 psi net stress. This helps to ensure that brine trapped in the face pores and irregularities is not included in the pore volume reduction data. Pore volume reductions during compressibility testing range from 7.6 to 30.2 percent of the original pore volume at 500 psi net stress. The least reductions in pore volume were recorded on Samples 4 and 6. Note that Sample 4 is the finest grained sample tested, while Sample 6 is the only specimen tested that does not show visible signs of fracturing. The two samples with the highest pore volume reductions and thus compressibilities (samples 1 and 2), also had numerous styolites and open fractures. The plotting of stressed porosity versus net stress revealed very similar smooth porosity reduction trends for both shaly and clean sandstones. All samples basically exhibited elastic behavior (without deformation) within the stress region tested.

Acoustic velocity measurements on the seven whole core samples from the Palm Valley No. 7 Well were performed following pore volume compressibility tests. Samples were tested fully saturated with the simulated formation brine. Compressional and shear wave velocities were determined and these values were used, with bulk density, to calculate dynamic moduli. Each sample was subjected to a net stress of 4100 psi at ambient temperature, while maintaining a pore pressure of 1000 psi.

Compressional velocities values vary from 16142 to 17749 ft/sec, while shear velocity values range from 9857 to 11643 ft/sec. Velocity data along with calculated dynamic moduli, are presented in Section 3, Table 1.

SECTION 3

EXPERIMENTAL PROCEDURES AND DATA GENERATION

PORE VOLUME COMPRESSIBILITY (PVC)

Experimental Procedures

Eight slabbed whole core pieces were obtained from the Core Laboratories facility in Perth, Australia. Verticle plug samples were obtained from each depth, keeping plug size as large as possible in order to maximize pore volume. The samples were then surface ground to obtain parallel endfaces. One sample fractured and was unsuitable for further testing. The samples range in depth from 5560′6" to 5919′1". The initial lengths, diameters, and weights of all plugs are recorded in Table 1. These samples were leached and dried in a vacuum oven until stable dry weights were achieved.

A direct pore volume (Helium) was measured with the Auto Porosimeter at an overburden of 500 psi in order to normalize the initial pressure point of the compressibility testing. The samples were then saturated overnight in the Auto Saturator with the following synthetic formation brine (g/l):

$NaCl$:	134.48
$CaCl_2$:	57.68
$MgCl_2 * 6H_2O$:	16.73
$NaHCO_3$:	0.058
KCl:	0.127

Each sample was placed in a Viton sleeve and loaded into a pressure vessel where both ends of the sample were connected by a pressure line to an FDS-210 positive displacement pump. Overburden was increased simultaneously with pore pressure so as not to exceed a net stress of 500 psi. During PVC tests, the pump maintained a pore pressure of 1000 psi while monitoring the fluid volume change. These changes are then recorded by a computer that controls both the confining and pore pressure of the system.

All samples were tested over a half-cycle of increasing net stress. Confining pressure was increased at a rate of 400 psi/24 hrs up to a confining pressure of 5500 psi, or net stress of 4500 psi. These measurements were performed over a range of stress conditions expected in the reservoir, in order to calculate hydrostatic pore volume compressibility.

Data Generation

Pore volumes were normalized to the pore volume measured in the Auto Porosimeter at a net stress of 500 psi. The calculation of hydrostatic pore volume compressibility was performed by first fitting an exponential equation to the normalized pore volume vs net stress data using TABLECURVE™ Software. The following model was used to express the half-cycle of data points at increasing net stress:

$$Vp/Vp_o = \exp(a + bx + cx^2 + dx^3 + ex^4)$$

Where: Vp = stressed pore volume
Vp_o = initial pore volume
x = net stress
a,b,c,d & e = parameters of fit (presented in tabular form in the following section)

Compressibility was determined by taking the derivative of the normal equation with respect to net stress and calculating the compressibility at each net stress point.

$$dV/dx = (b + c2x + d3x^2 + e4x^3) * (a + bx + cx^2 + dx^3 + ex^4)$$

The previous nonlinear model was chosen to predict compressibility because of its excellent fit and rapid convergence to the normalized data. Individual parameters of fit for each sample are presented in the following Section.

The prediction of uniaxial pore volume compressibility was determined by applying Teeuw's equation to the hydrostatic strain (see Appendix for further discussion). A Poisson's Ratio of 0.14 (averaged from previous Palm Valley acoustic project) was used to best fit the range of porosities tested. Once uniaxial strain was computed and plotted versus net stress, a exponential equation model was used to fit the data. The differential of that model was reported as predicted uniaxial pore volume compressibility. The same exponential model as above was selected to fit the predicted uniaxial data.

ACOUSTIC VELOCITY

Experimental Procedures

Seven 2 1/2-inch whole core samples were received for measurement following pore volume compressibility testing. Endfaces on each sample were surface ground to achieve a parallelism of within 0.0002 inches. This precision ensures a good contact between the sample endfaces and the transducers which generate and receive the acoustic waves. Samples were fully saturated with simulated formation brine when loaded into the acoustic testing apparatus.

Each sample was mounted individually into the "Automated Acoustic Velocity and Compressibility Apparatus" (AAVCA). Net stresses were created by holding the pore pressure at 1000 psi and the confining pressure at 5100 psi, resulting in a net stress on the sample of 4100 psi. The pressurization sequence involves creating an initial confining pressure of at least 1000 psi, then elevating both confining and pore pressures simultaneously to the desired levels. After allowing for pressure equilibration, compressional and shear wave acoustic signals were produced and transmitted across the samples, with the transit time determined by means of a high speed digital oscilloscope. Sample lengths were divided by transit times to calculate acoustic velocity. Using the velocity measurements and bulk density values, calculations of dynamic moduli at stress were completed for all samples. This data is included on Table 12, Section 4.

For more information concerning the methods and theory of acoustic velocity measurements and mechanical properties, please refer to the paper "Ultrasonic Velocity Apparatus and Methods" which has been included in the Appendix.

SECTION 4

TEST RESULTS

TABLES

FIGURES

NORMALIZED PORE VOLUME vs NET STRESS

PORE VOLUME COMPRESSIBILITY vs NET STRESS

POROSITY vs NET STRESS

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TABLE 1

PORE VOLUME COMPRESSIBILITY

SUMMARY OF EXPERIMENTAL PROCEDURES

Core Identification

Plug Size: Six - 2.5 inch diameter vertical core plugs,
One - 1.5 inch diameter horizontal core plug
Formation: Pacoota Sandstone
Well: Palm Valley #7
Depths: 5560'6" to 5919'1"

Physical Properties

Bulk Volume (cc): Caliper
Pore Volume (cc): Direct measurement with Helium @ 500 psi Net Overburden
Grain Volume (cc): Bulk Volume - Pore Volume
Grain Density (g/cc): Dry weight/Grain volume
Ambient Porosity (%): Pore volume/Bulk volume * 100
Stress Pore Volume (cc): Pore Volume @ 500 psi Net Stress - Volume displaced at varying net stress conditions
Stress Bulk Volume (cc): Stress Pore Volume + Grain Volume
Stress Porosity (%): Stress Pore Volume/Stress Bulk Volume x 100

Pore Volume Compressibility

Test Conditions: Ambient temperature
Saturating Fluid: Simulated Formation Brine

Test Specifications: Constant Pore Pressure at 1000 psi

Confining Stress	11 Pressure points (half-cycle)
Up Cycle	: 1500 - 5500 psi
Steps 400 (psi)	: 10

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TABLE 2

BASIC PHYSICAL PROPERTIES DATA SUMMARY

Sample I.D.	Depth '(ft) "(in)	Dia. (in)	Length (in)	Dry Weight (gms)	Bulk Volume (cm^3)	Pore Volume (cm^3)	Grain Volume (cm^3)	Porosity (%)	Grain Density, (gms/cc)	Pore Volume Reduction (%)	Lithological Description
						Lower Stairway Sand					
1	5560'6"	1.500	4.489	165.85	61.146	2.533	58.613	4.1	2.83**	23.8	Shaly sandstone, fractured, pyrite, shale laminations, quartz cementation, styolitic
2	5561'9.5"-5562'	2.467	12.145	503.66	193.654	5.808	187.846	3.0	2.681	30.2	Shaly sandstone and shaly siltstone, fractured, bedded, quartz cementation, shale laminations, very styolitic
						Pacoota Sandstone P1 Unit					
3	5894'2.5"-5894'5"	2.489	12.363	337.31	134.973	7.429	127.544	5.5	2.645	20.6	Shaly sandstone, fractured, quartz cementation
4	5904'4"-5904'6"	2.492	12.385	355.24	139.558	5.744	133.814	4.1	2.655	7.6	Shaly siltstone, fractured, quartz cementation, styolitic
*5	5910'1.5"-5910'3.5"	2.478	12.253	482.83	193.341	14.386	178.955	7.4	2.698	18.7	Shaly sandstone, fractured, bedded, fine & course grains separated by shale laminations and styolites, quartz cementation
6	5917'11.5"-5918'3.5	2.492	12.392	728.16	295.903	21.638	274.265	7.3	2.655	13.2	Clean sandstone, bedded, quartz cementation (fractures in whole core piece not evident in sample)
7	5918'10.5"-5919'1"	2.491	12.384	435.77	173.169	9.786	163.383	5.7	2.677	20.8	Clean sandstone, fractured, bedded, quartz cementation

*NOTE: This sample later splintered shale fragments on one endface which was refaced before testing.
Pore volume was recalculated by saturated pore volume at 13.327 (cm^3) which was used for normalization.

**This sample contained pyrite - observed heavy dissemination in the shale laminations.

TABLE 3

HYDROSTATIC PARAMETERS OF FIT

Increasing Stress			
Sample			
1	a = 0.0458696164	b = 8.5948e-005	c = 7.7262e-009
	d = 3.83802e-012	e = -3.082e-016	
2	a = 0.0470029182	b = -9.3157e-005	c = 1.8748e-009
	d = 7.82818e-013	e = -5.0737e-017	
3	a = 0.0350437557	b = -7.059e-005	c = 2.84427e-009
	d = 1.4466e-012	e = 3.07392e-016	
4	a = 0.0190407005	b = -4.329e-005	c = 1.18476e-008
	d = -2.8991e-012	e = 2.94997e-016	
5	a = 0.0226672363	b = -3.8734e-005	c = 1.7222e-008
	d = 3.52947e-012	e = -6.5857e-017	
6	a = 0.0370502238	b = -8.6263e-005	c = 2.54927e-008
	d = -5.2286e-012	e = 4.14429e-016	
7	a = 0.0453365367	b = -9.3561e-005	c = 5.80323e-009
	d = 7.24992e-013	e = -1.0048e-016	

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TABLE 4

PREDICTED UNIAXIAL PARAMETERS OF FIT

Increasing Stress			
Sample			
1	a = 0.0197787926	b = 3.6334e-005	c = 5.091e-009
	d = 2.64296e-012	e = -2.5816e-016	
2	a = 0.0183154198	b = -3.4226e-005	c = 6.2432e-009
	d = 2.30402e-012	e = -2.2346e-016	
3	a = 0.0148771465	b = -3.0599e-005	c = 1.51645e-009
	d = -6.2717e-013	e = 1.31541e-016	
4	a = 0.0080958813	b = -1.7655e-005	c = 3.67524e-009
	d = -6.709e-013	e = 5.71897e-017	
5	a = 0.0099584352	b = -1.728e-005	c = 7.7336e-009
	d = 1.90884e-012	e = -8.6533e-017	
6	a = 0.01741103	b = -4.1847e-005	c = 1.49178e-008
	d = -3.4866e-012	e = 3.09168e-016	
7	a = 0.0201673873	b = -4.2345e-005	c = 3.56368e-009
	d = 2.43368e-013	e = -4.9936e-017	

TABLE 5

COMPRESSIBILITY DATA SUMMARY
MAGELLAN PETROLEUM AUSTRALIA LTD.

SAMPLE: 1 DEPTH: 5560 WELL: PALM VALLEY #7

NET STRESS	CORRECTED VOL. OUT	PORE VOLUME	NORMAL PORE VOL.	POROSITY	Ch	Cu
PSI	CC	CC	Vp/Vpo	%	1/PSI*E6	1/PSI*E6
500	0.000	2.556	1.000	4.18	91.08	39.60
900	0.083	2.473	0.968	4.05	88.27	39.22
1300	0.175	2.381	0.932	3.91	83.14	37.27
1700	0.264	2.292	0.897	3.76	76.43	34.20
2100	0.333	2.223	0.870	3.66	68.77	30.45
2500	0.404	2.152	0.842	3.54	60.68	26.41
2900	0.452	2.104	0.823	3.47	52.57	22.44
3300	0.499	2.057	0.805	3.39	44.80	18.89
3700	0.546	2.010	0.786	3.32	37.66	16.09
4100	0.592	1.964	0.768	3.24	31.43	14.37
4500	0.609	1.947	0.762	3.22	26.36	14.03

TABLE 6

COMPRESSIBILITY DATA SUMMARY
MAGELLAN PETROLEUM AUSTRALIA LTD.

SAMPLE: 2 DEPTH: 5561 WELL: PALM VALLEY #7

NET STRESS	CORRECTED VOL. OUT	PORE VOLUME	NORMAL PORE VOL.	POROSITY	Ch	Cu
PSI	CC	CC	Vp/Vpo	%	1/PSI*E6	1/PSI*E6
500	0.000	5.808	1.000	3.00	94.47	38.85
900	0.215	5.593	0.963	2.89	91.26	39.87
1300	0.424	5.384	0.927	2.79	87.62	39.45
1700	0.624	5.184	0.893	2.69	83.70	37.98
2100	0.814	4.994	0.860	2.59	79.61	35.87
2500	0.994	4.814	0.829	2.50	75.47	33.46
2900	1.164	4.644	0.800	2.41	71.36	31.08
3300	1.325	4.483	0.772	2.33	67.36	29.02
3700	1.477	4.331	0.746	2.25	63.52	27.59
4100	1.620	4.188	0.721	2.18	59.89	27.04
4500	1.755	4.053	0.698	2.11	56.51	27.62

TABLE 7

COMPRESSIBILITY DATA SUMMARY
MAGELLAN PETROLEUM AUSTRALIA LTD.

SAMPLE: 3 DEPTH: 5894 WELL: PALM VALLEY #7

NET STRESS	CORRECTED VOL. OUT	PORE VOLUME	NORMAL PORE VOL.	POROSITY	Ch	Cu
PSI	CC	CC	Vp/Vpo	%	1/PSI*E6	1/PSI*E6
500	0.000	7.429	1.000	5.50	68.70	29.48
900	0.196	7.233	0.974	5.37	66.27	28.67
1300	0.395	7.034	0.947	5.23	64.25	28.02
1700	0.580	6.849	0.922	5.10	62.16	27.33
2100	0.764	6.665	0.897	4.97	59.59	26.41
2500	0.933	6.496	0.874	4.85	56.20	25.09
2900	1.088	6.341	0.854	4.74	51.68	23.19
3300	1.242	6.187	0.833	4.63	45.74	20.54
3700	1.367	6.062	0.816	4.54	38.10	16.98
4100	1.460	5.969	0.803	4.47	28.49	12.35
4500	1.529	5.900	0.794	4.42	16.54	6.46

TABLE 8

COMPRESSIBILITY DATA SUMMARY
MAGELLAN PETROLEUM AUSTRALIA LTD.

SAMPLE: 4 DEPTH: 5904 WELL: PALM VALLEY #7

NET STRESS	CORRECTED VOL. OUT	PORE VOLUME	NORMAL PORE VOL.	POROSITY	Ch	Cu
PSI	CC	CC	Vp/Vpo	%	1/PSI*E6	1/PSI*E6
500	0.000	5.744	1.000	4.12	33.47	14.46
900	0.070	5.674	0.988	4.07	27.81	12.44
1300	0.133	5.611	0.977	4.02	24.04	10.89
1700	0.179	5.565	0.969	3.99	21.64	9.71
2100	0.228	5.516	0.960	3.96	20.12	8.82
2500	0.277	5.467	0.952	3.93	19.02	8.11
2900	0.318	5.426	0.945	3.90	17.90	7.50
3300	0.356	5.388	0.938	3.87	16.33	6.90
3700	0.391	5.353	0.932	3.85	13.90	6.23
4100	0.419	5.325	0.927	3.83	10.21	5.41
4500	0.439	5.305	0.924	3.81	4.86	4.34

TABLE 9

COMPRESSIBILITY DATA SUMMARY
MAGELLAN PETROLEUM AUSTRALIA LTD.

SAMPLE: 5 DEPTH: 5910 WELL: PALM VALLEY #7

NET STRESS	CORRECTED VOL. OUT	PORE VOLUME	NORMAL PORE VOL.	POROSITY	Ch	Cu
PSI	CC	CC	Vp/Vpo	%	1/PSI*E6	1/PSI*E6
500	0.000	13.327	1.000	7.44	53.31	23.61
900	0.324	13.003	0.976	7.27	59.92	26.53
1300	0.652	12.675	0.951	7.10	63.02	27.86
1700	0.977	12.350	0.927	6.93	63.00	27.79
2100	1.288	12.039	0.903	6.77	60.26	26.51
2500	1.593	11.734	0.880	6.61	55.17	24.19
2900	1.893	11.434	0.858	6.45	48.05	21.01
3300	2.171	11.156	0.837	6.31	39.14	17.10
3700	2.294	11.033	0.828	6.24	28.58	12.60
4100	2.396	10.931	0.820	6.19	16.46	7.62
4500	2.492	10.835	0.813	6.13	2.70	2.26

TABLE 10

COMPRESSIBILITY DATA SUMMARY
MAGELLAN PETROLEUM AUSTRALIA LTD.

SAMPLE: 6 DEPTH: 5917 WELL: PALM VALLEY #7

NET STRESS	CORRECTED VOL. OUT	PORE VOLUME	NORMAL PORE VOL.	POROSITY	Ch	Cu
PSI	CC	CC	Vp/Vpo	%	1/PSI*E6	1/PSI*E6
500	0.000	21.638	1.000	7.31	64.46	29.38
900	0.525	21.113	0.976	7.15	50.67	22.33
1300	0.886	20.752	0.959	7.03	41.07	17.69
1700	1.233	20.405	0.943	6.92	34.70	14.90
2100	1.465	20.173	0.932	6.85	30.72	13.45
2500	1.766	19.872	0.918	6.76	28.42	12.83
2900	2.010	19.628	0.907	6.68	27.13	12.60
3300	2.230	19.408	0.897	6.61	26.24	12.27
3700	2.450	19.188	0.887	6.54	25.17	11.40
4100	2.669	18.969	0.877	6.47	23.37	9.57
4500	2.846	18.792	0.868	6.41	20.32	6.32

TABLE 11

COMPRESSIBILITY DATA SUMMARY
MAGELLAN PETROLEUM AUSTRALIA LTD.

SAMPLE: 7 DEPTH: 5918 WELL: PALM VALLEY #7

NET STRESS	CORRECTED VOL. OUT	PORE VOLUME	NORMAL PORE VOL.	POROSITY	Ch	Cu
PSI	CC	CC	Vp/Vpo	%	1/PSI*E6	1/PSI*E6
500	0.000	9.842	1.000	5.68	87.27	38.62
900	0.329	9.513	0.967	5.50	78.94	34.96
1300	0.623	9.219	0.937	5.34	70.90	31.38
1700	0.886	8.956	0.910	5.20	63.27	27.94
2100	1.120	8.722	0.886	5.07	56.11	24.70
2500	1.326	8.516	0.865	4.96	49.51	21.71
2900	1.509	8.333	0.847	4.85	43.52	19.02
3300	1.670	8.172	0.830	4.77	38.20	16.70
3700	1.812	8.030	0.816	4.69	33.61	14.79
4100	1.938	7.904	0.803	4.62	29.81	13.35
4500	2.048	7.794	0.792	4.55	26.85	12.43

Magellan Petroleum Australia, Ltd.
File: SCAL-90077

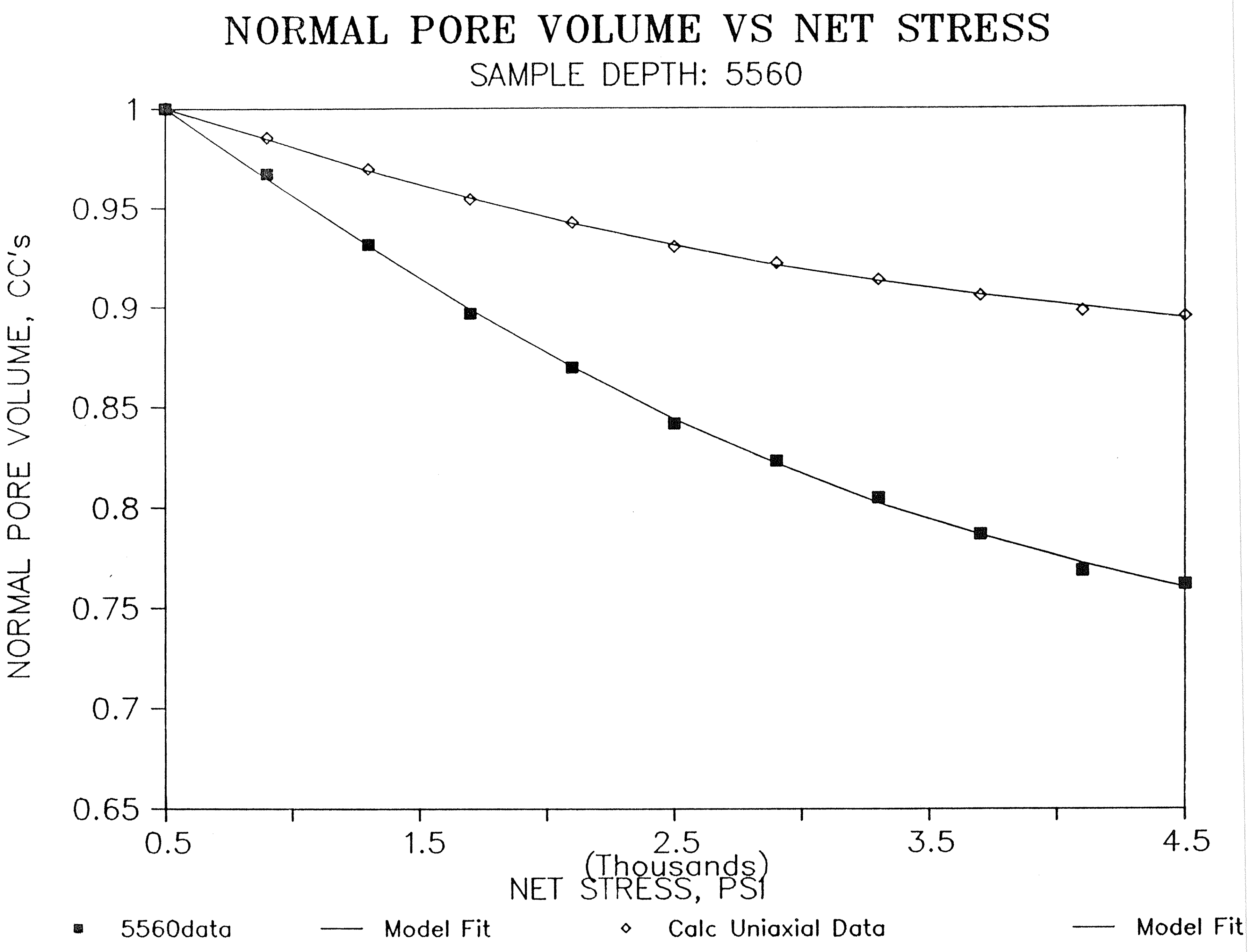
TABLE 12

ULTRASONIC VELOCITY AND DYNAMIC MODULI

Palm Valley No. 7
Lower Stairway Sand and Pacoota Sandstone P1 Unit

SAMPLE ID	DEPTH	Pc NET	BULK DENS	VELOCITY COMP	VELOCITY SHEAR	BULK MODULUS	YOUNG MODULUS	SHEAR MODULUS	POISSON RATIO
	ft	psi	gm/cc	ft/sec	ft/sec	psi	psi	psi	
				Lower Stairway Sand					
1	5560	4100	2.74	16142	9857	4.83e+06	8.62e+06	3.58e+06	0.202
2	5561	4100	2.64	17236	11015	4.80e+06	9.95e+06	4.31e+06	0.155
				Pacoota Sandstone P1 Unit					
3	5894	4100	2.57	17517	11464	4.55e+06	1.02e+07	4.54e+06	0.125
4	5904	4100	2.59	17749	11643	4.69e+06	1.06e+07	4.73e+06	0.122
5	5910	4100	2.57	17055	9966	5.48e+06	8.53e+06	3.44e+06	0.241
6	5917	4100	2.55	16233	10315	4.17e+06	8.48e+06	3.65e+06	0.161
7	5918	4100	2.59	17707	10783	5.52e+06	9.76e+06	4.05e+06	0.205

FIGURE 1



NORMAL PORE VOLUME VS NET STRESS
SAMPLE DEPTH: 5560
NORMAL PORE VOLUME, CC's
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5560data
Model Fit
Calc Uniaxial Data
Model Fit

FIGURE 2

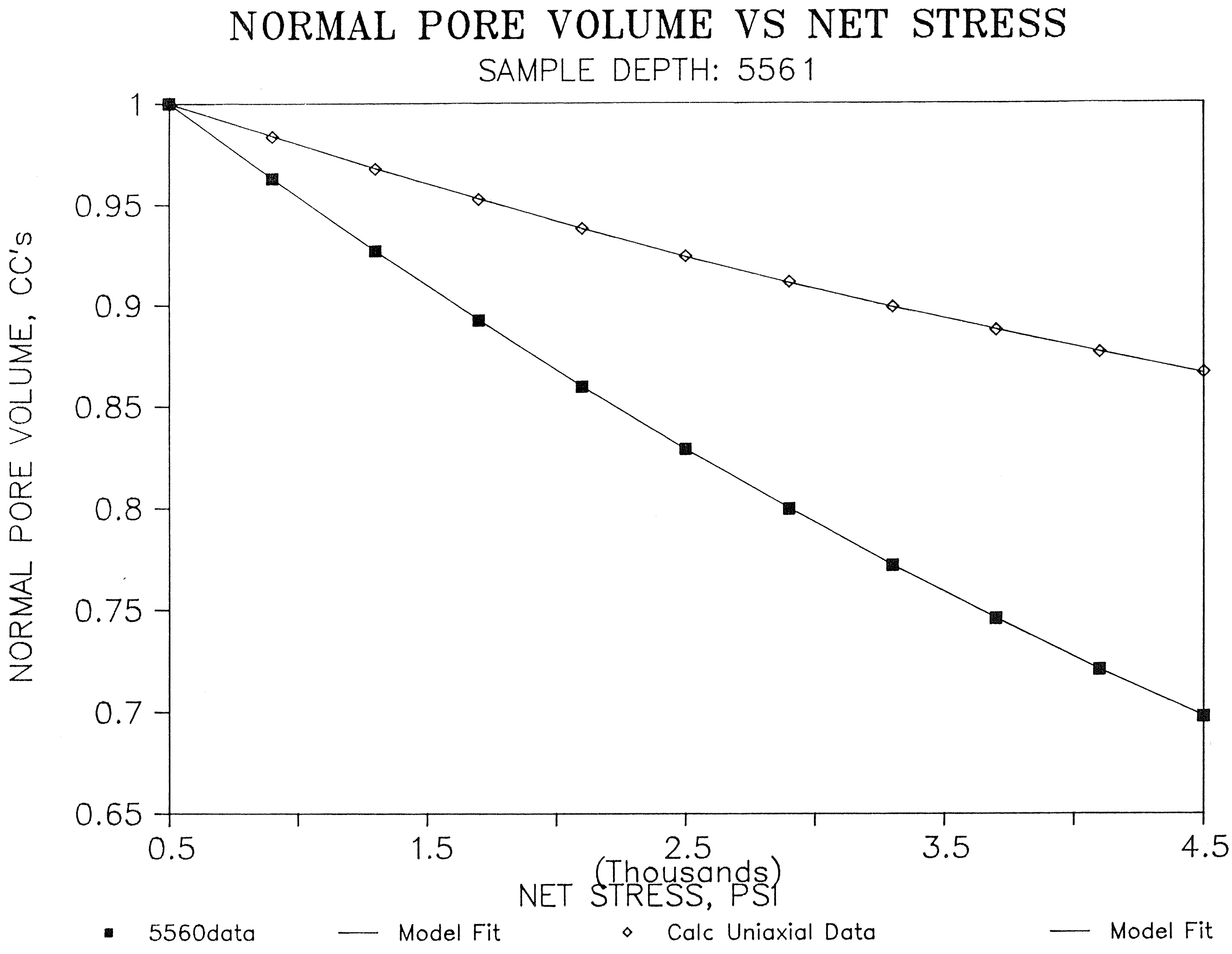

NORMAL PORE VOLUME VS NET STRESS
SAMPLE DEPTH: 5561
NORMAL PORE VOLUME, CC's
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5560data
Model Fit
Calc Uniaxial Data
Model Fit

FIGURE 3

NORMAL PORE VOLUME VS NET STRESS

SAMPLE DEPTH: 5894

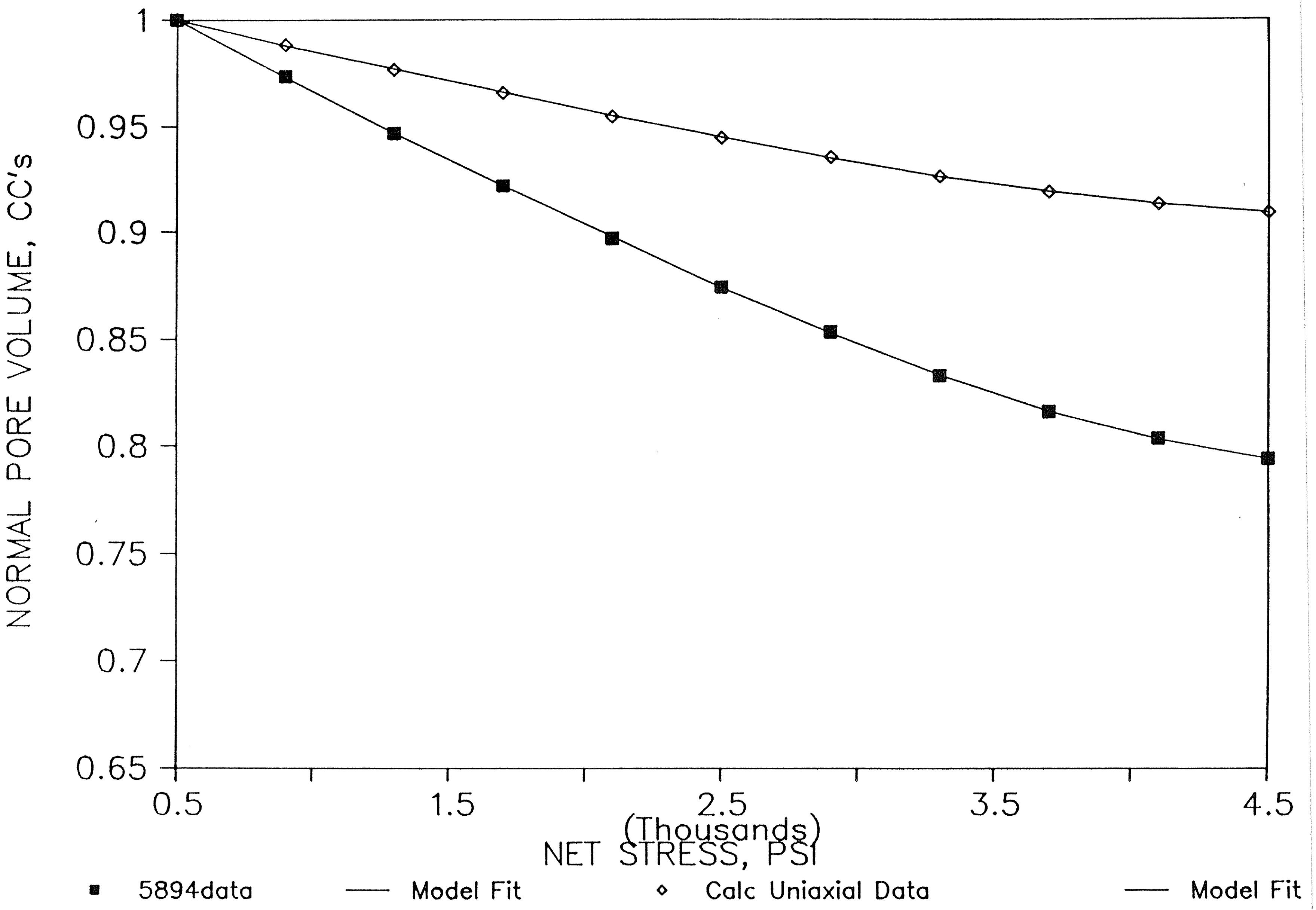


FIGURE 4

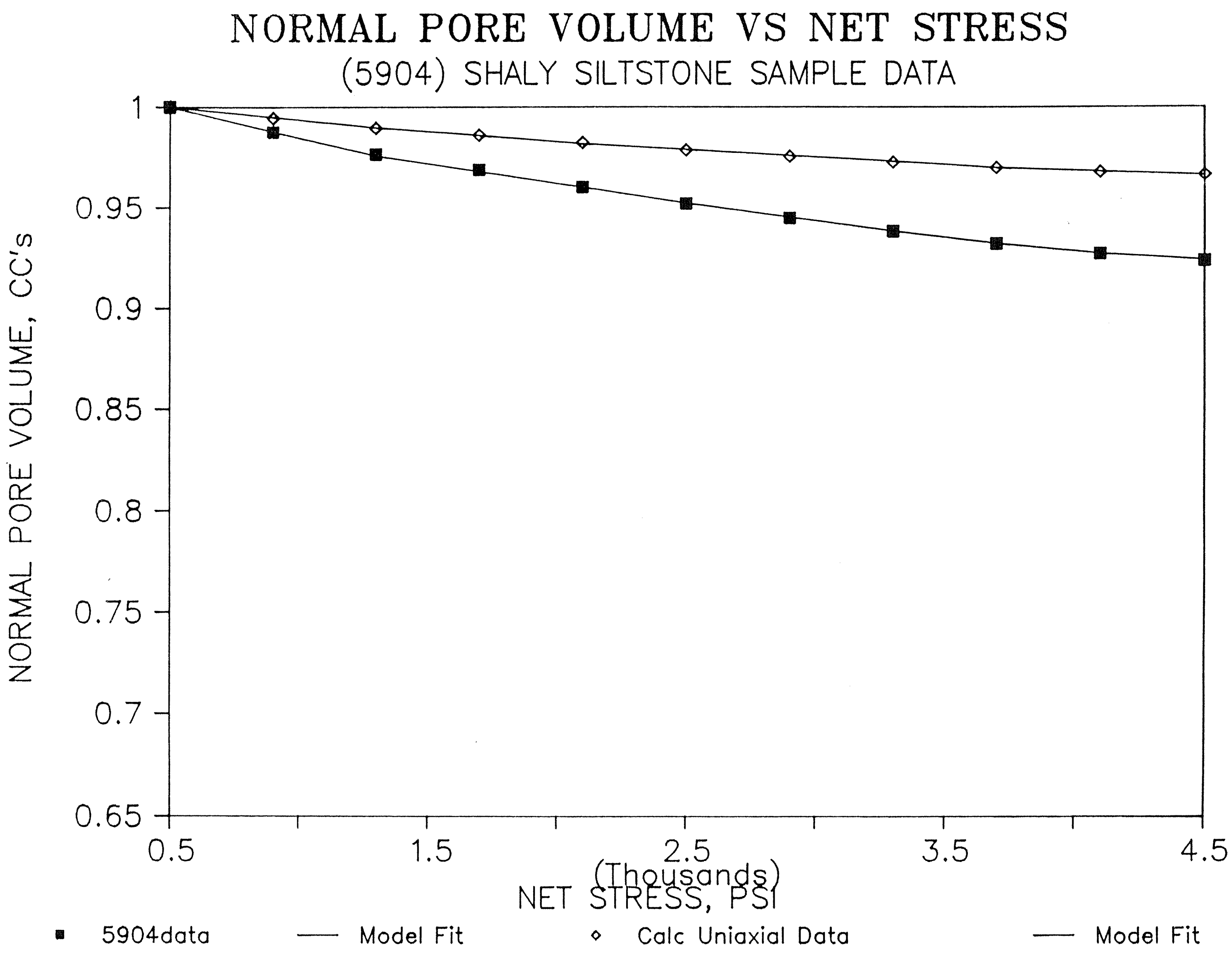

NORMAL PORE VOLUME VS NET STRESS
(5904) SHALY SILTSTONE SAMPLE DATA
NORMAL PORE VOLUME, CC's
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5904data
Model Fit
Calc Uniaxial Data
Model Fit

FIGURE 5

NORMAL PORE VOLUME VS NET STRESS

SAMPLE DEPTH: 5910

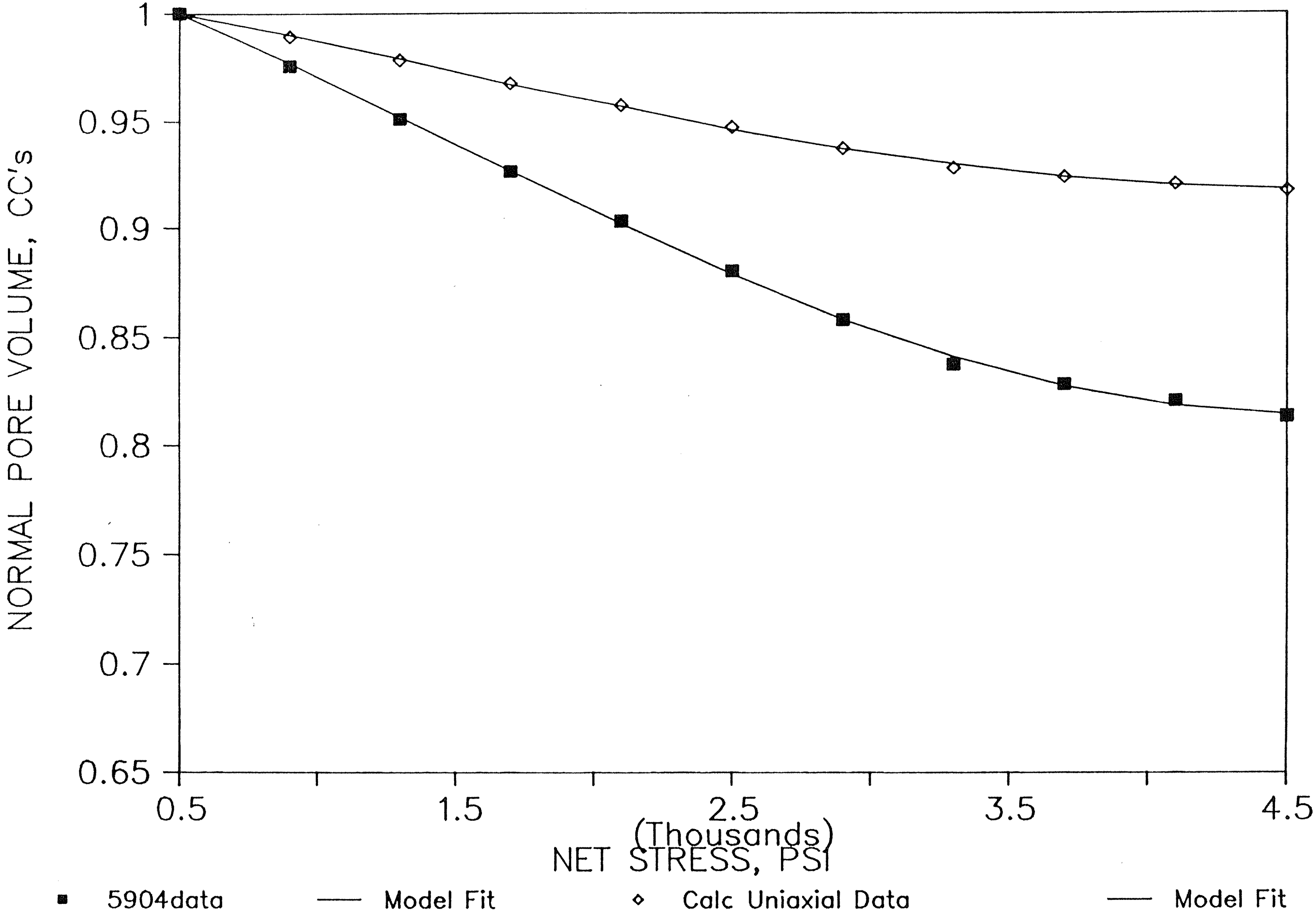


FIGURE 6

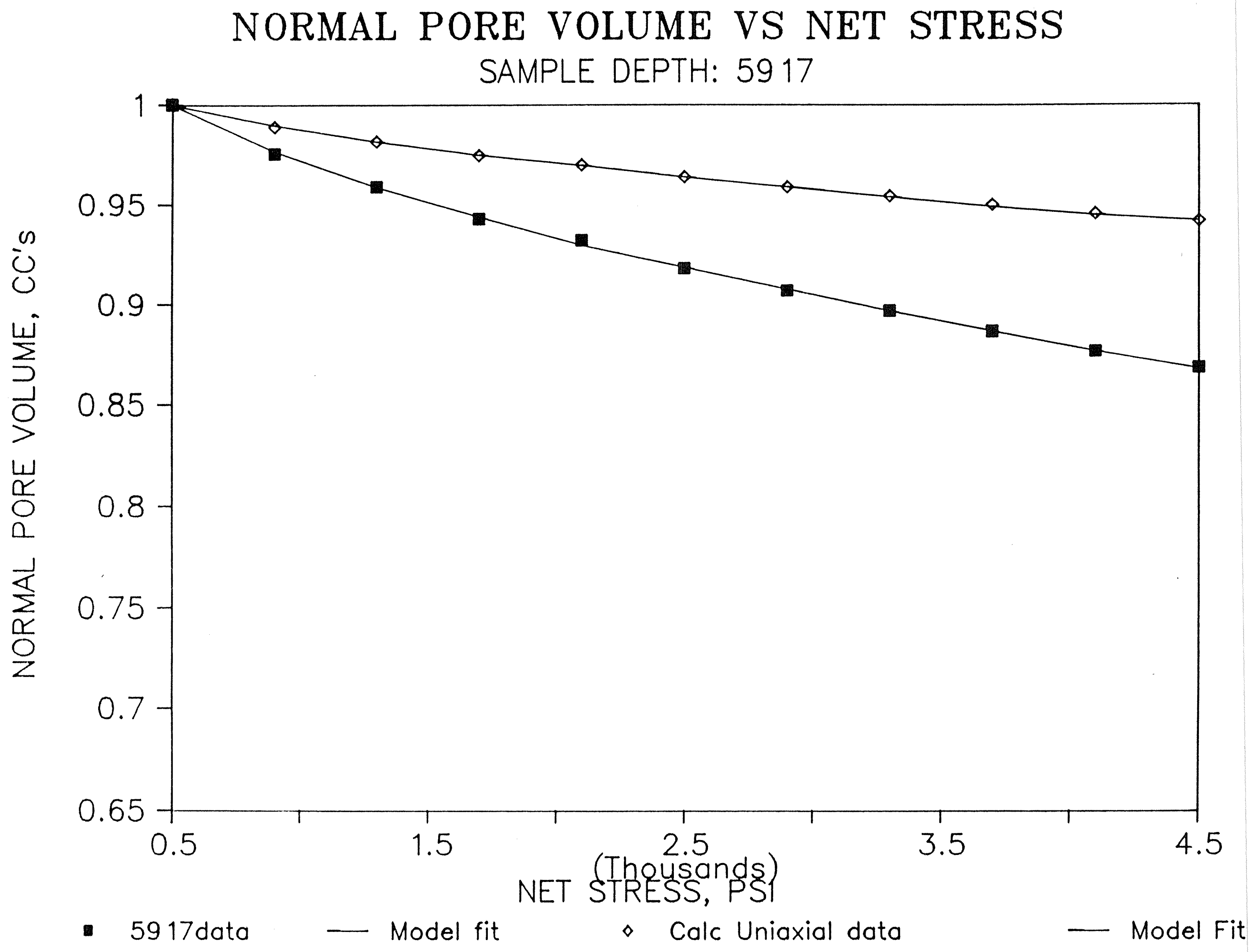
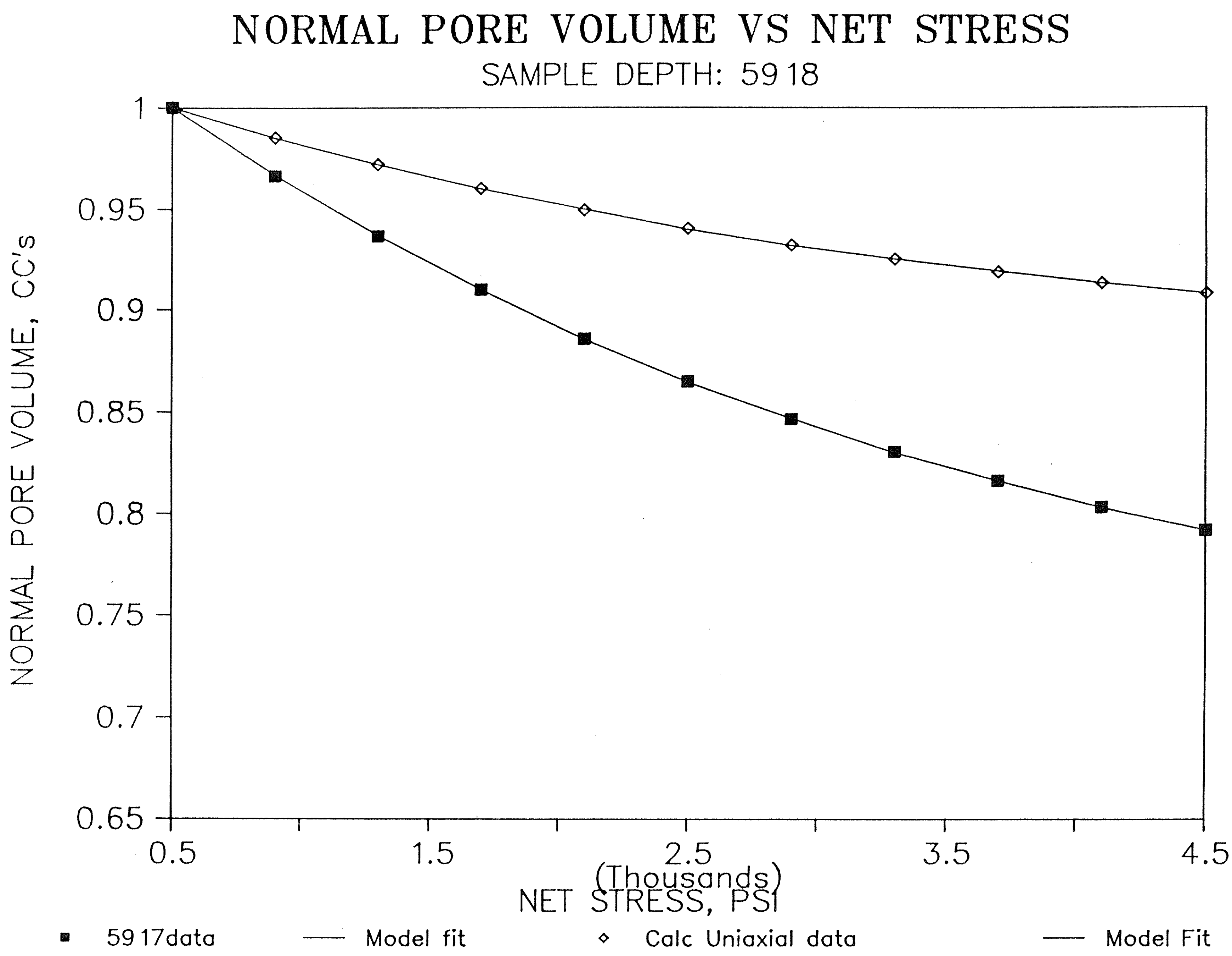
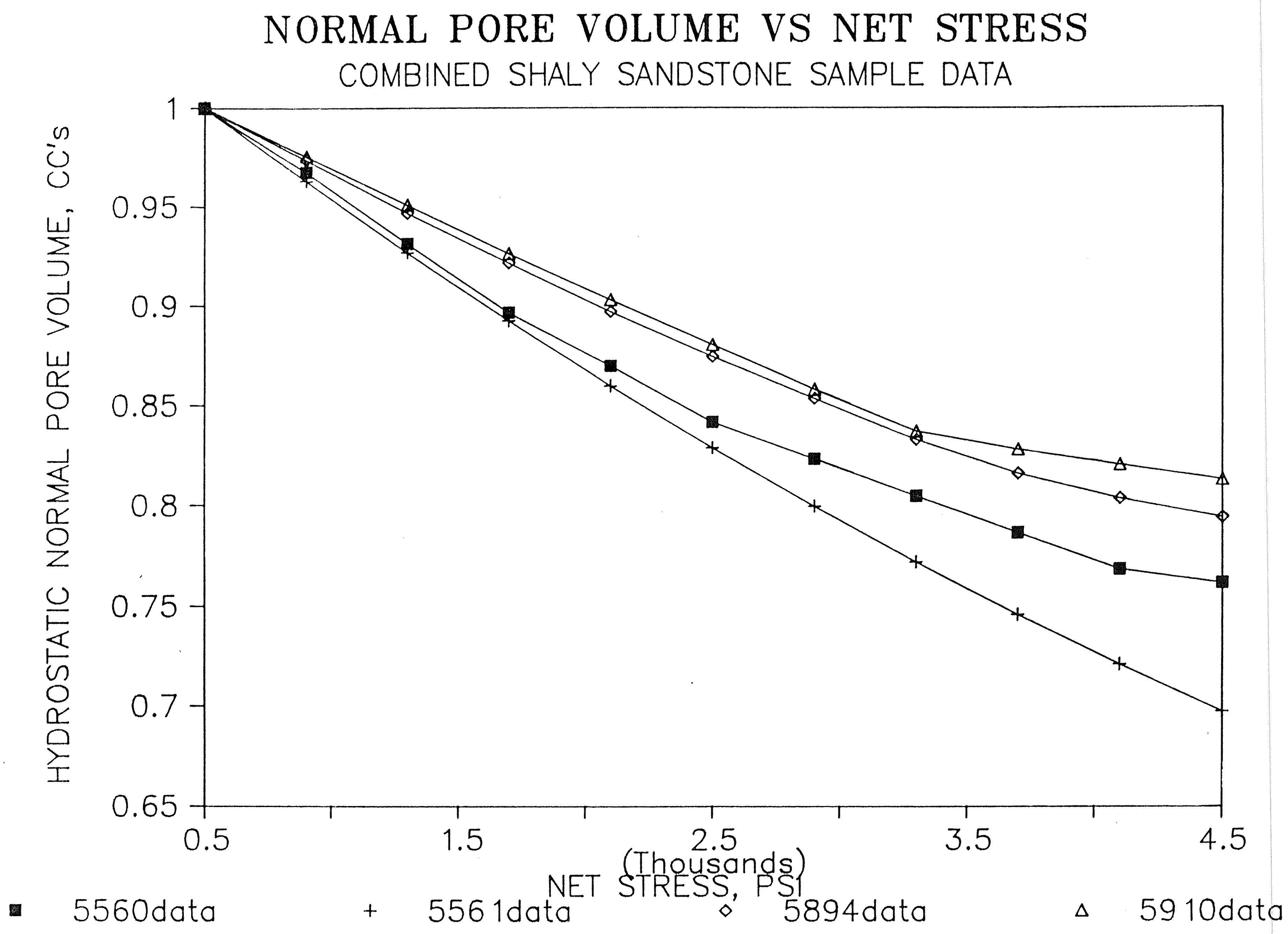

NORMAL PORE VOLUME VS NET STRESS
SAMPLE DEPTH: 5917
NORMAL PORE VOLUME, CC's
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5917data
Model fit
Calc Uniaxial data
Model Fit

FIGURE 7



NORMAL PORE VOLUME VS NET STRESS
SAMPLE DEPTH: 5918
NORMAL PORE VOLUME, CC's
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5917data
Model fit
Calc Uniaxial data
Model Fit

FIGURE 8



NORMAL PORE VOLUME VS NET STRESS
COMBINED SHALY SANDSTONE SAMPLE DATA
HYDROSTATIC NORMAL PORE VOLUME, CC's
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5560data
5561data
5894data
5910data

FIGURE 9

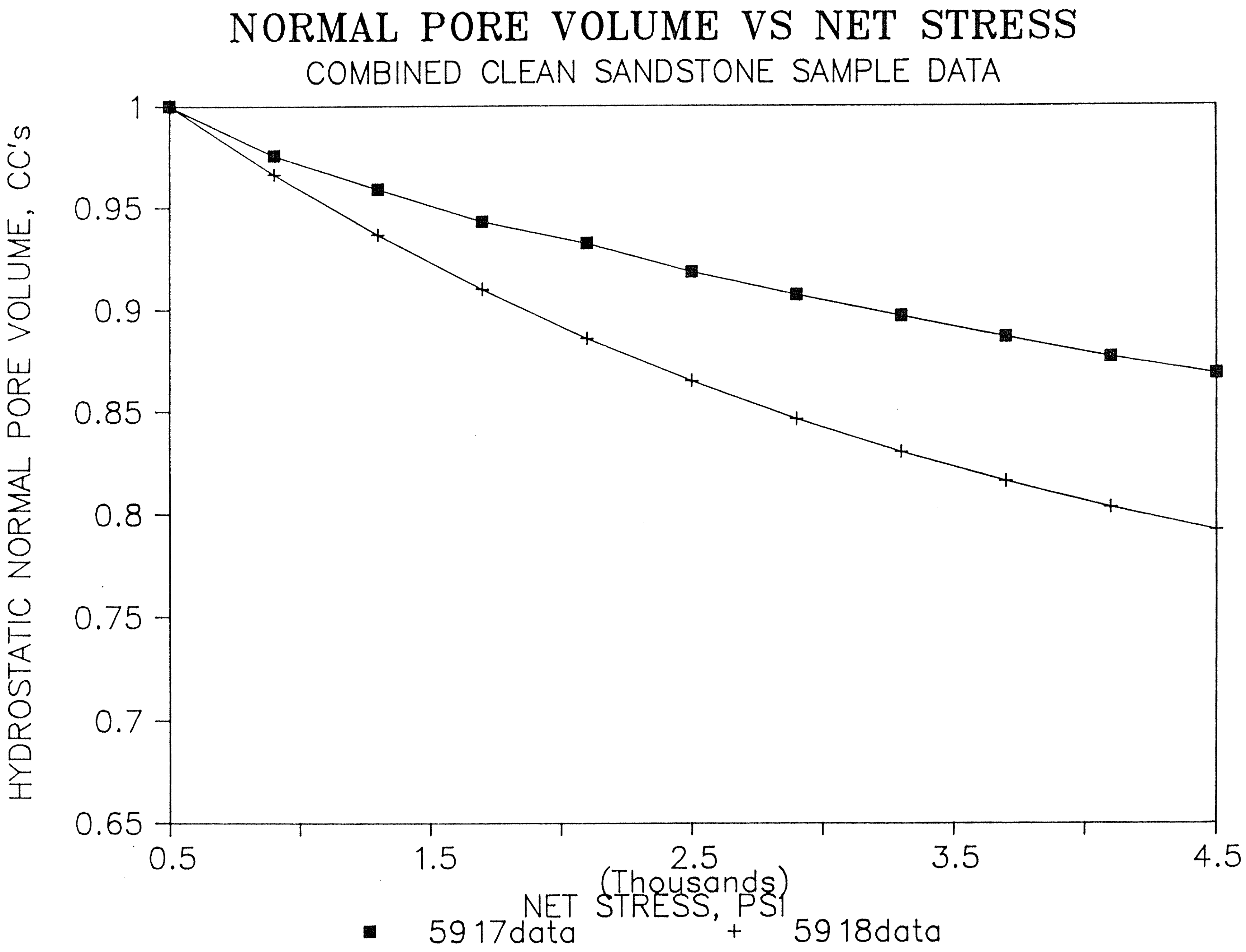
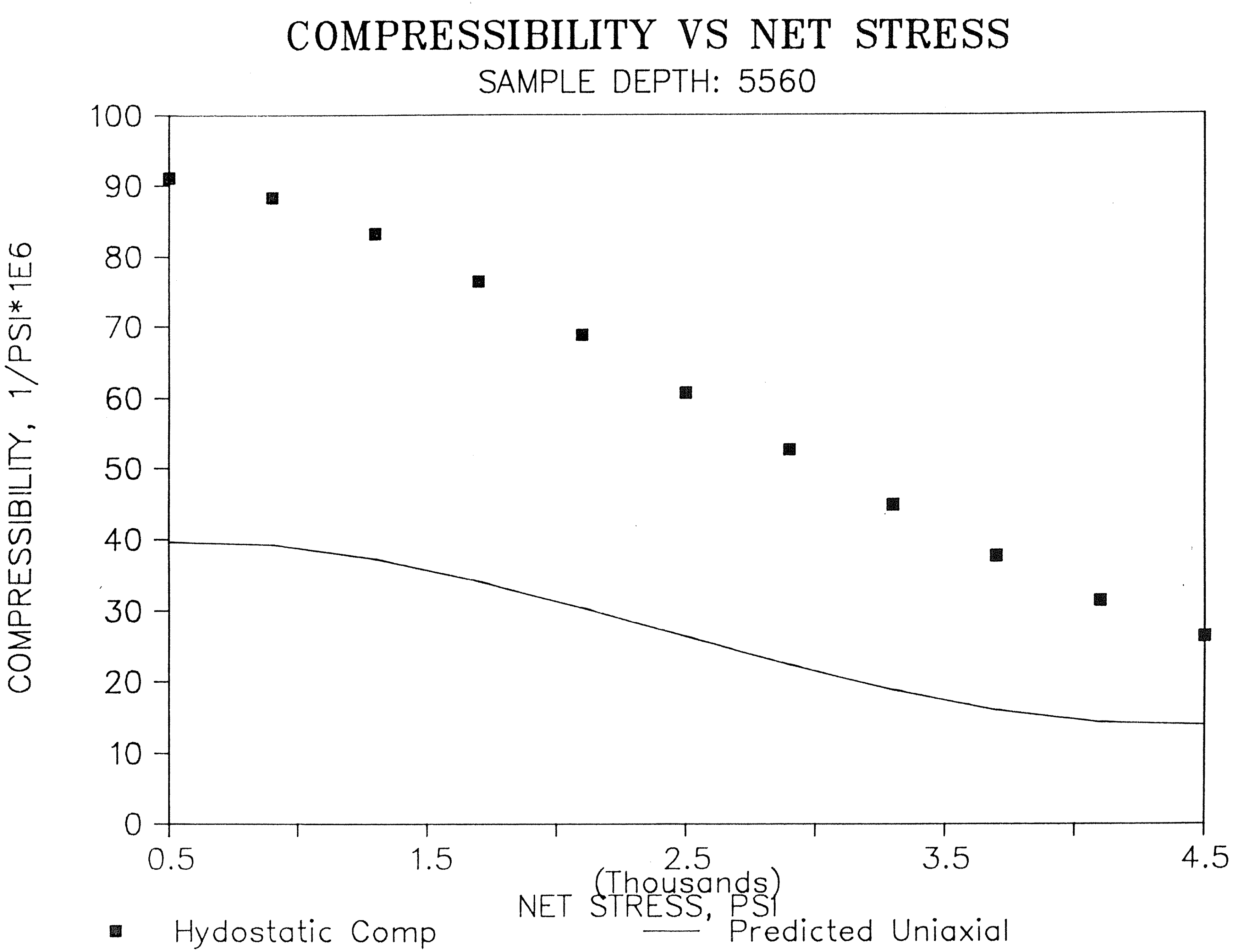

NORMAL PORE VOLUME VS NET STRESS
COMBINED CLEAN SANDSTONE SAMPLE DATA
HYDROSTATIC NORMAL PORE VOLUME, CC's
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5917data
5918data

FIGURE 10



COMPRESSIBILITY VS NET STRESS
SAMPLE DEPTH: 5560
COMPRESSIBILITY, 1/PSI*1E6
100
90
80
70
60
50
40
30
20
10
0
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
Hydostatic Comp
Predicted Uniaxial

FIGURE 11

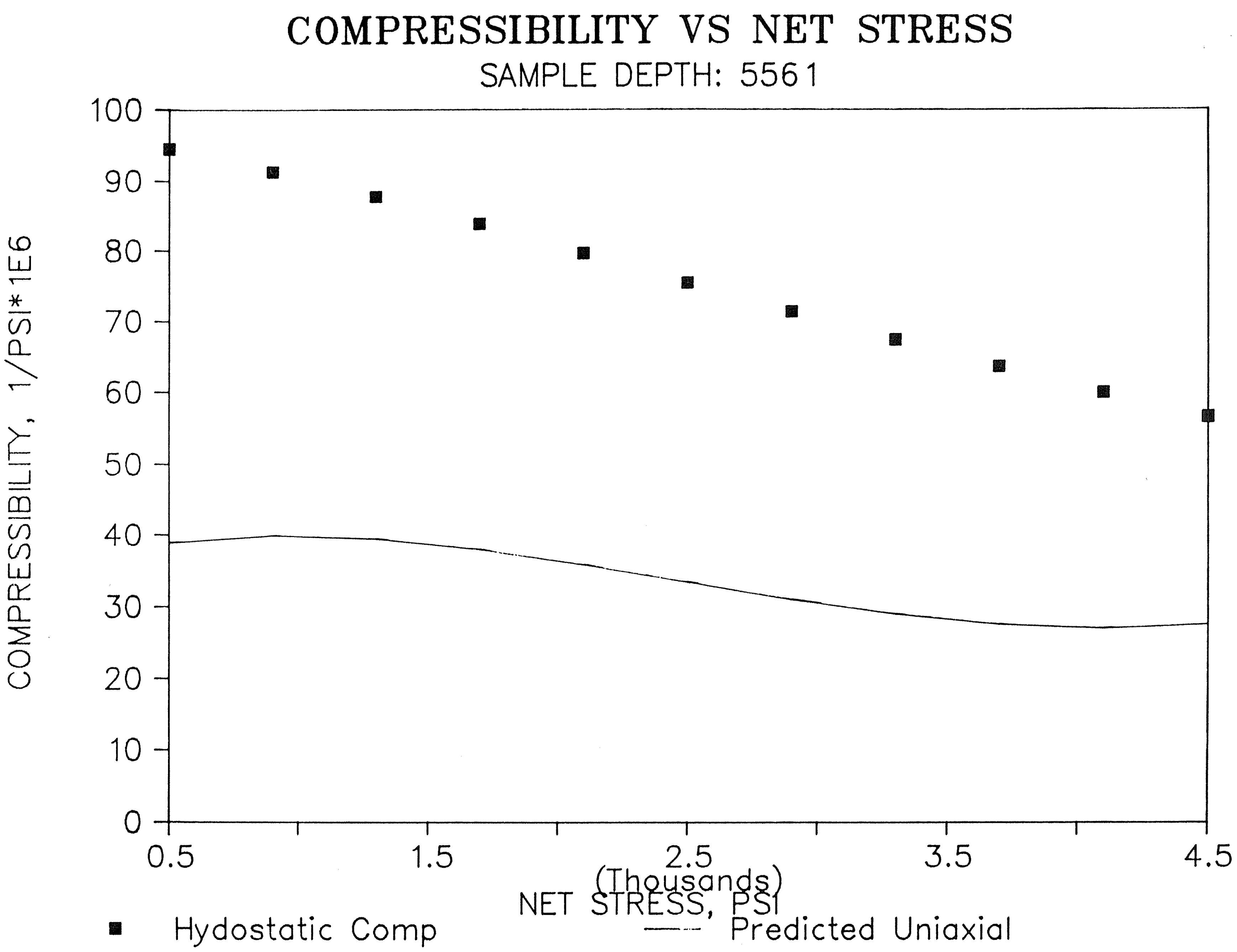

COMPRESSIBILITY VS NET STRESS
SAMPLE DEPTH: 5561
COMPRESSIBILITY, 1/PSI*1E6
100
90
80
70
60
50
40
30
20
10
0
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
Hydostatic Comp
Predicted Uniaxial

FIGURE 12

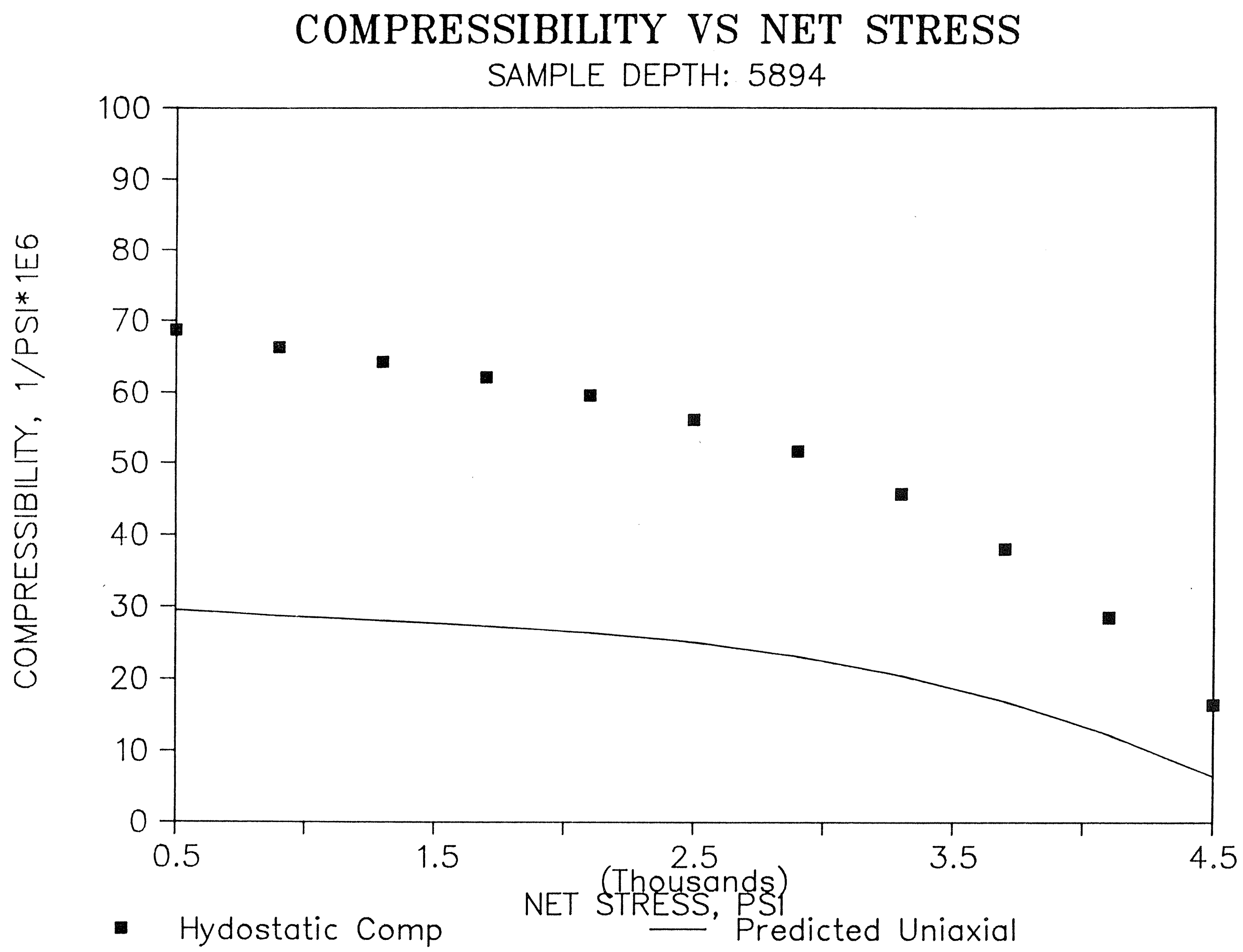

COMPRESSIBILITY VS NET STRESS
SAMPLE DEPTH: 5894
COMPRESSIBILITY, 1/PSI*1E6
100
90
80
70
60
50
40
30
20
10
0
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
Hydostatic Comp
Predicted Uniaxial

FIGURE 13

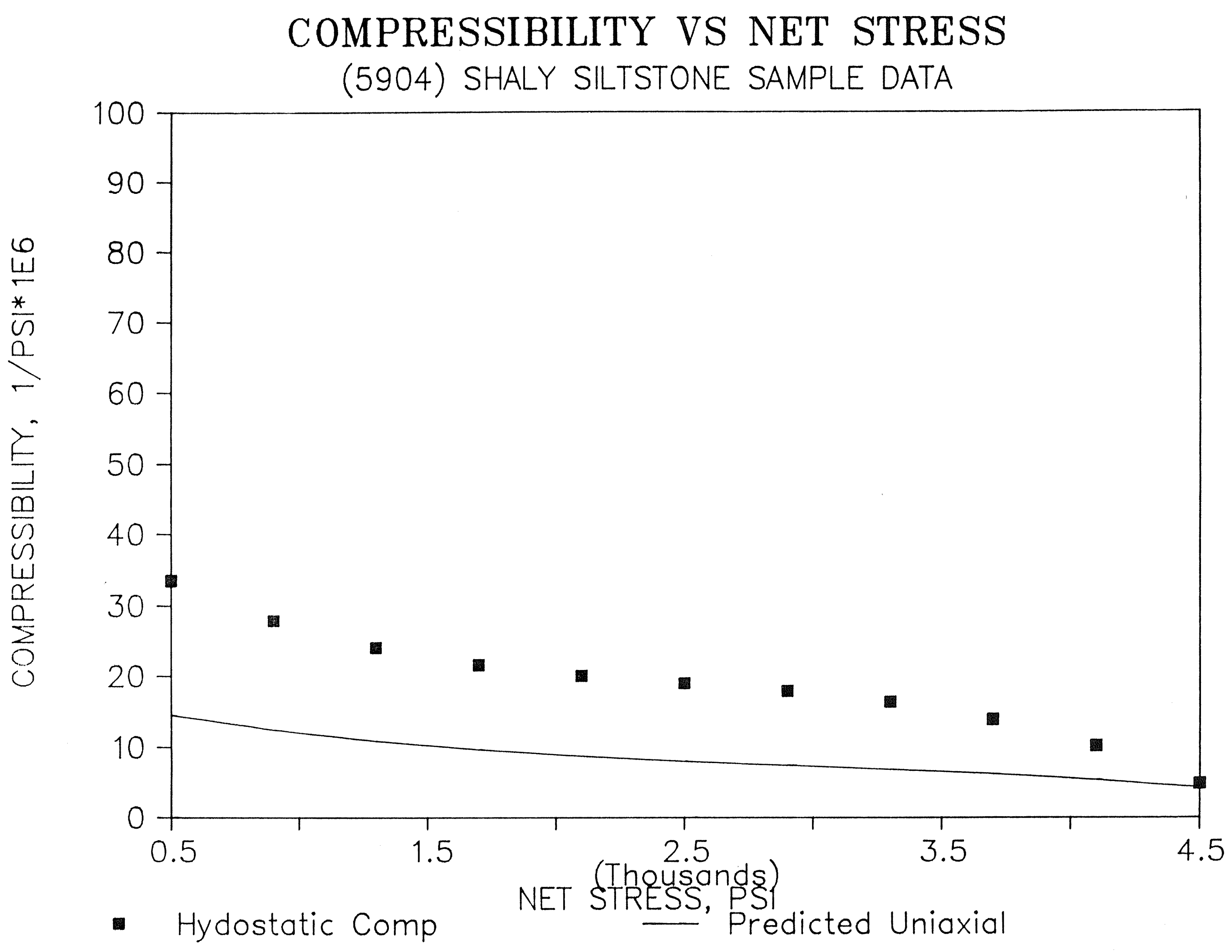
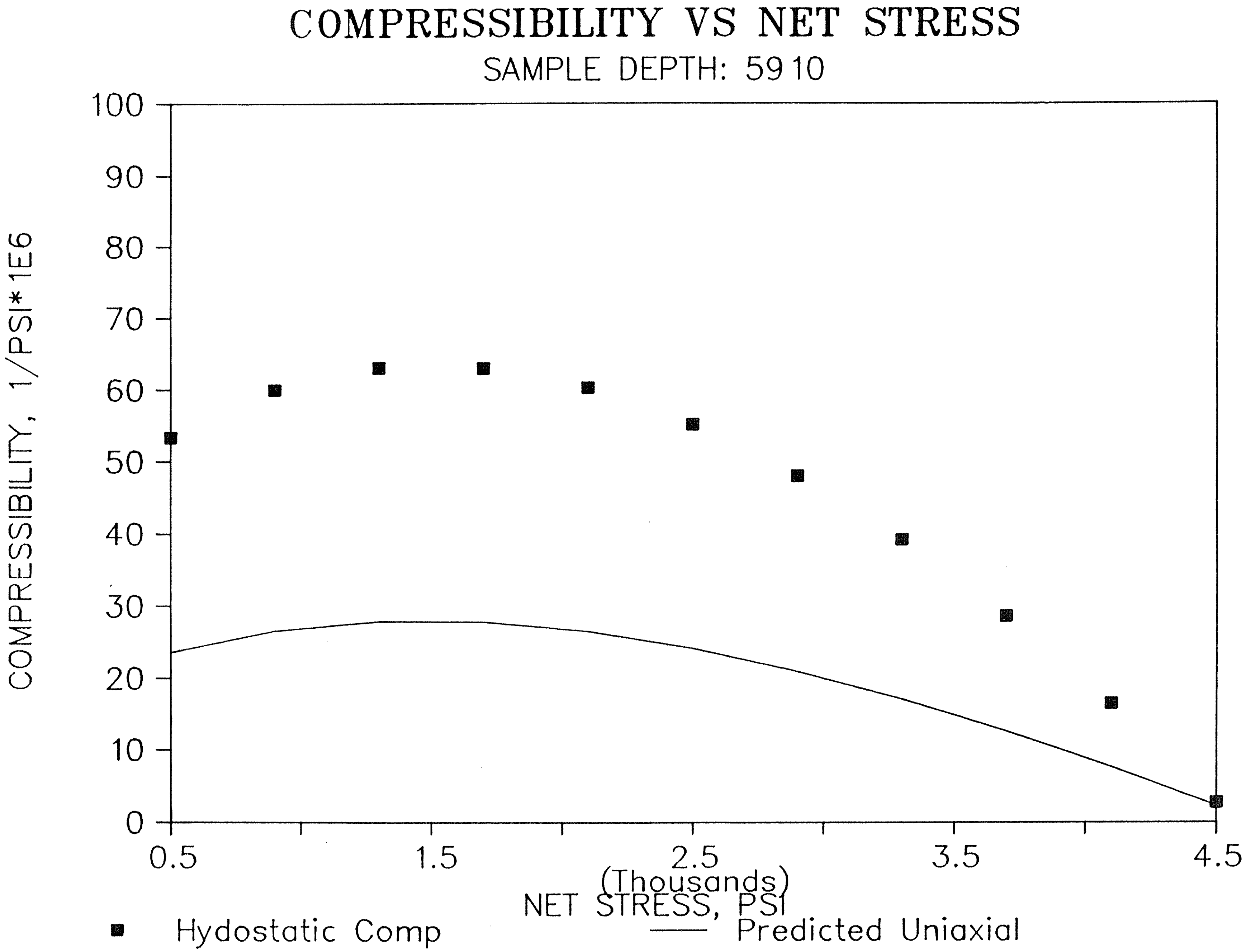
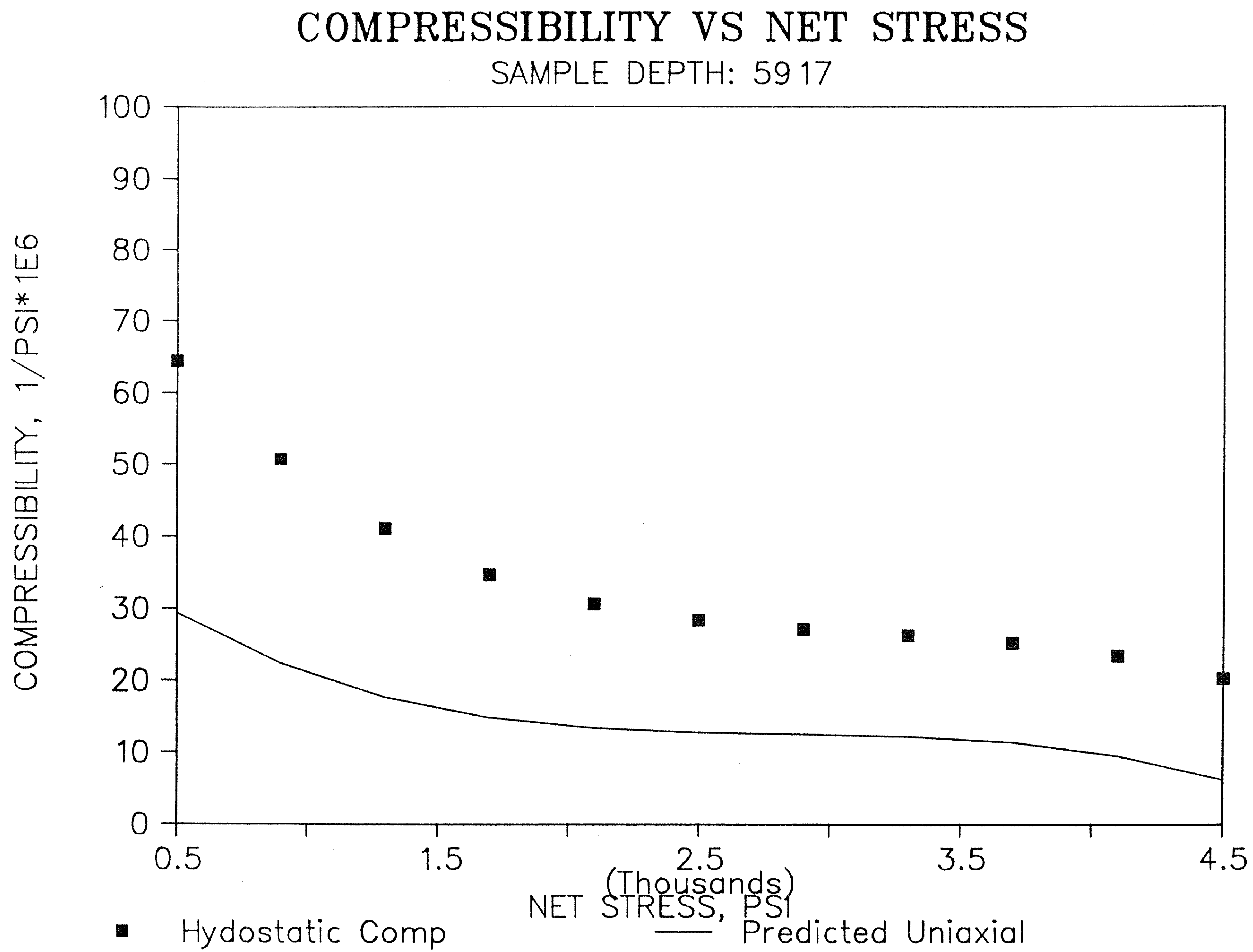

COMPRESSIBILITY VS NET STRESS
(5904) SHALY SILTSTONE SAMPLE DATA
COMPRESSIBILITY, 1/PSI*1E6
100
90
80
70
60
50
40
30
20
10
0
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
Hydostatic Comp
Predicted Uniaxial

FIGURE 14



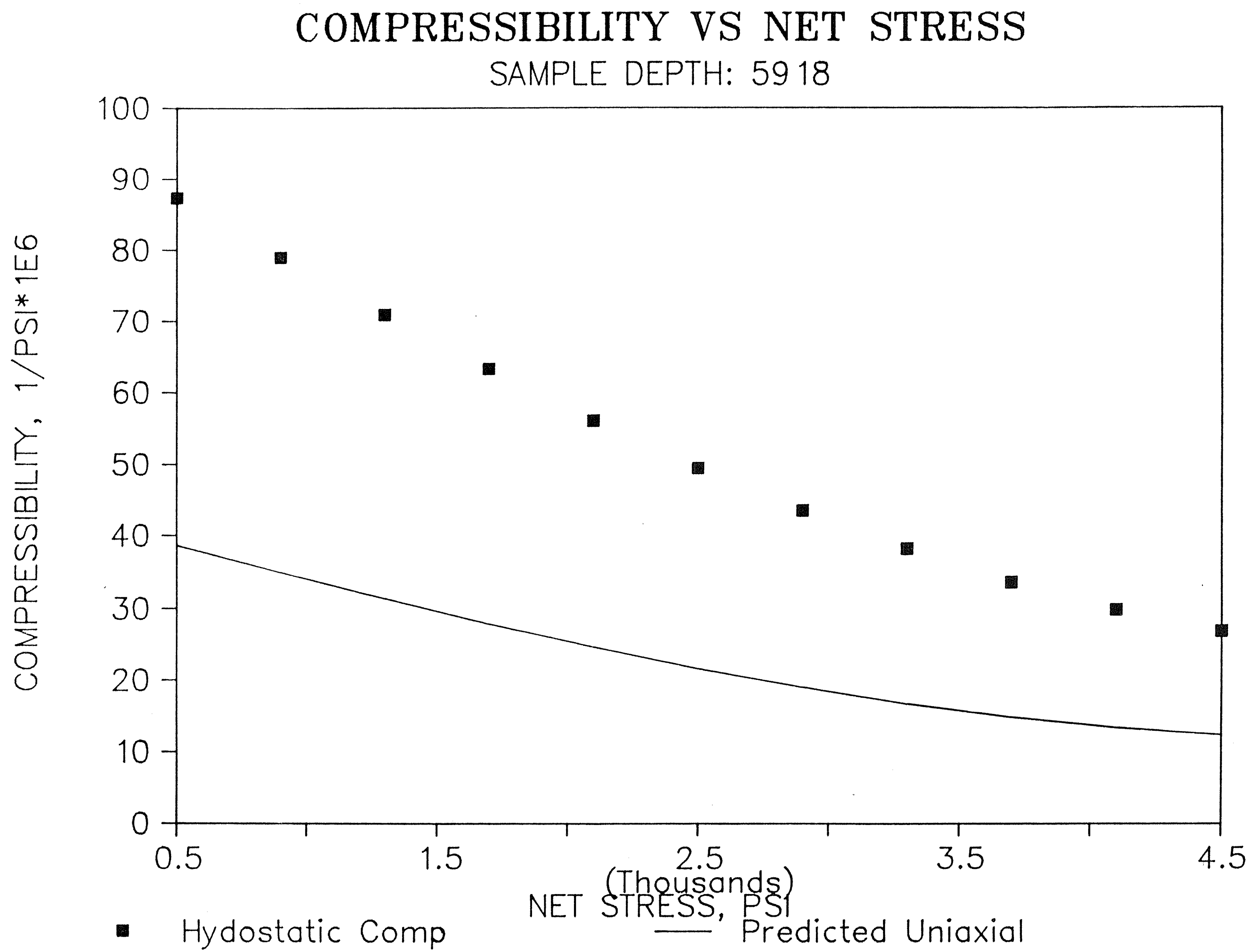
COMPRESSIBILITY VS NET STRESS
SAMPLE DEPTH: 5910
COMPRESSIBILITY, 1/PSI*1E6
100
90
80
70
60
50
40
30
20
10
0
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
Hydostatic Comp
Predicted Uniaxial

FIGURE 15



COMPRESSIBILITY VS NET STRESS
SAMPLE DEPTH: 5917
COMPRESSIBILITY, 1/PSI*1E6
100
90
80
70
60
50
40
30
20
10
0
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
Hydostatic Comp
Predicted Uniaxial

FIGURE 16



COMPRESSIBILITY VS NET STRESS
SAMPLE DEPTH: 5918
COMPRESSIBILITY, 1/PSI*1E6
100
90
80
70
60
50
40
30
20
10
0
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
Hydostatic Comp
Predicted Uniaxial

FIGURE 17

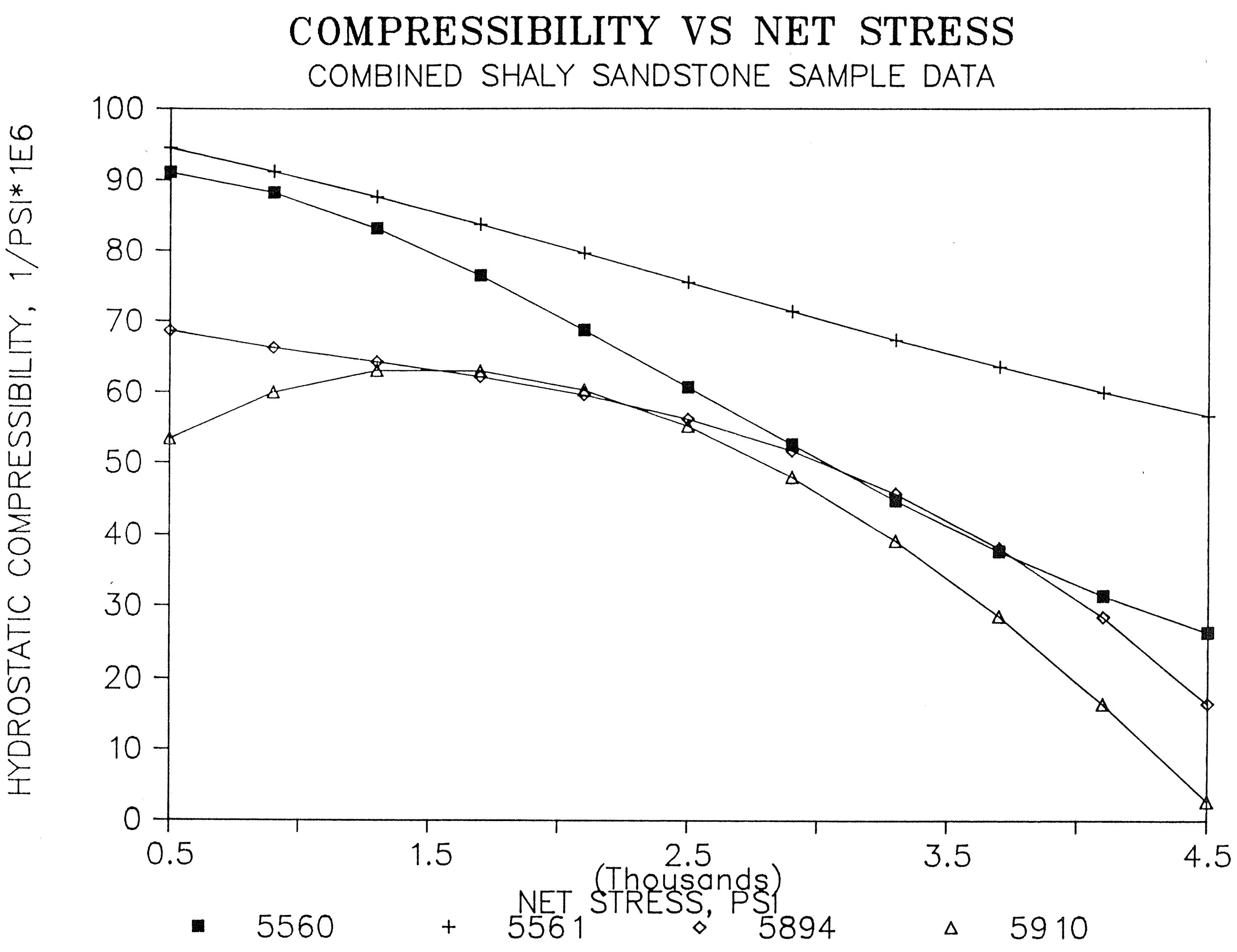

COMPRESSIBILITY VS NET STRESS
COMBINED SHALY SANDSTONE SAMPLE DATA
HYDROSTATIC COMPRESSIBILITY, 1/PSI*1E6
100
90
80
70
60
50
40
30
20
10
0
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5560
5561
5894
5910

FIGURE 18

COMPRESSIBILITY VS NET STRESS

COMBINED CLEAN SANDSTONE SAMPLE DATA

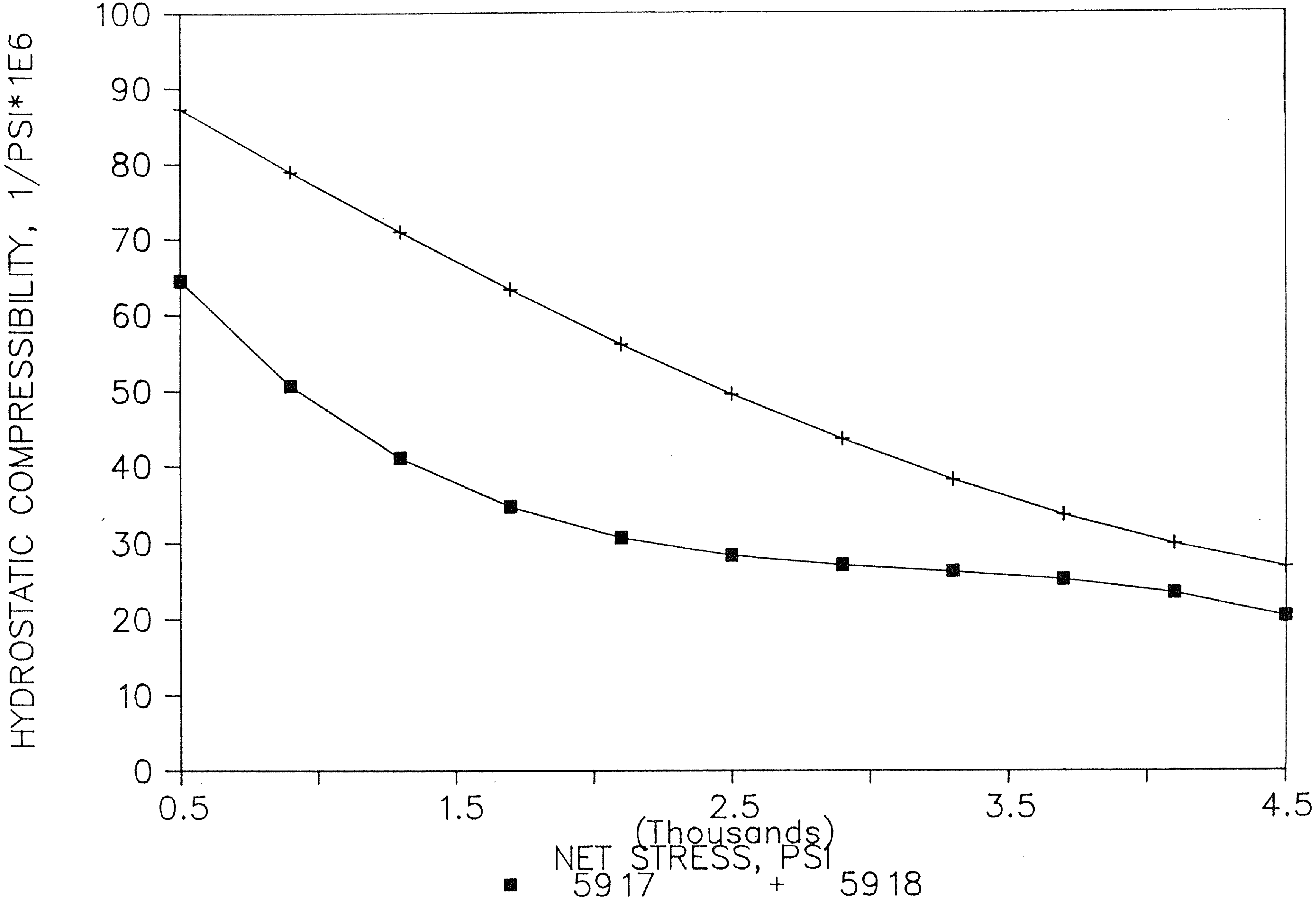


FIGURE 19

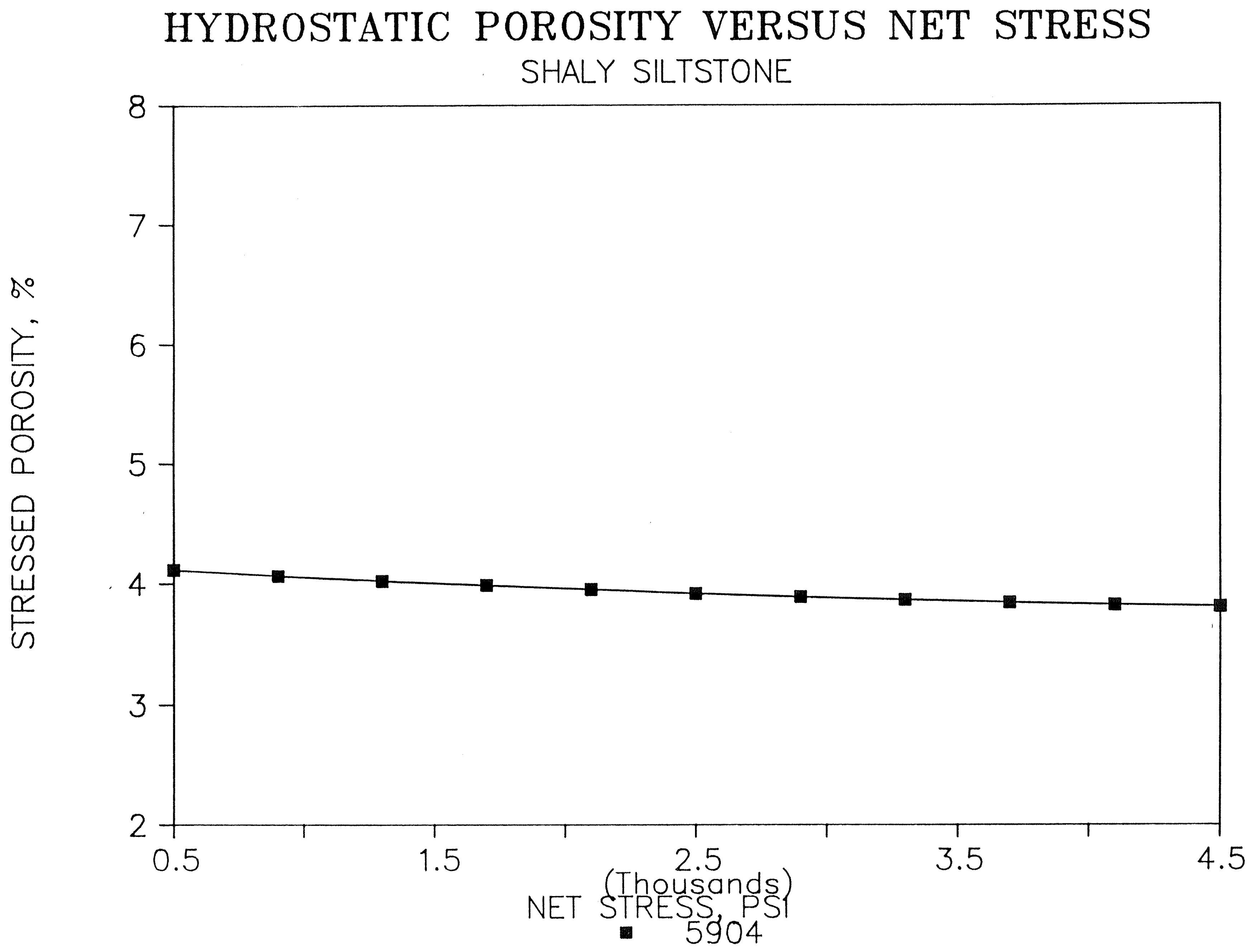

HYDROSTATIC POROSITY VERSUS NET STRESS
SHALY SILTSTONE
STRESSED POROSITY, %
8
7
6
5
4
3
2
0.5
1.5
2.5
3.5
4.5
(Thousands)
NET STRESS, PSI
5904

FIGURE 20

HYDROSTATIC POROSITY VERSUS NET STRESS

SHALY SANDSTONES

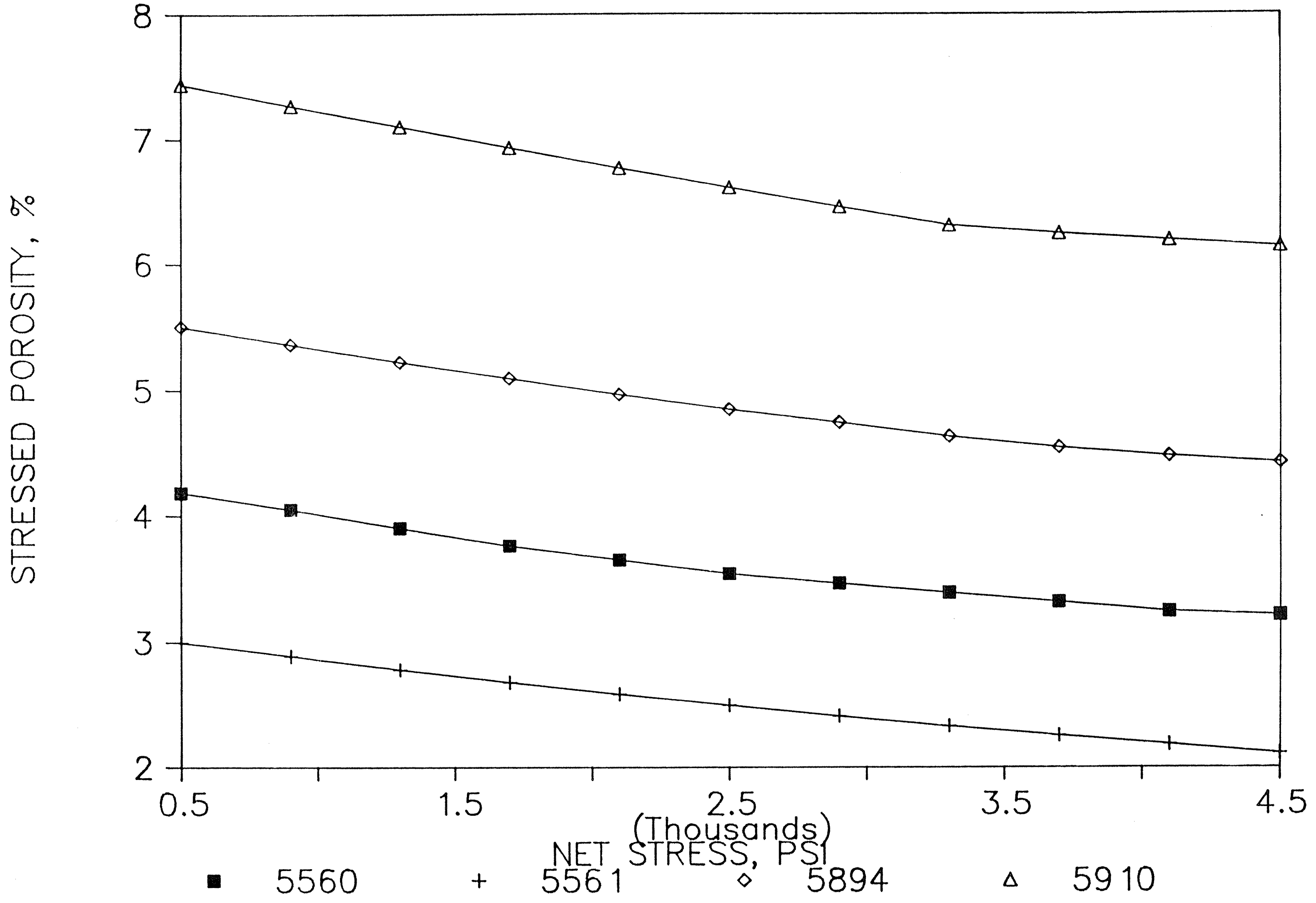
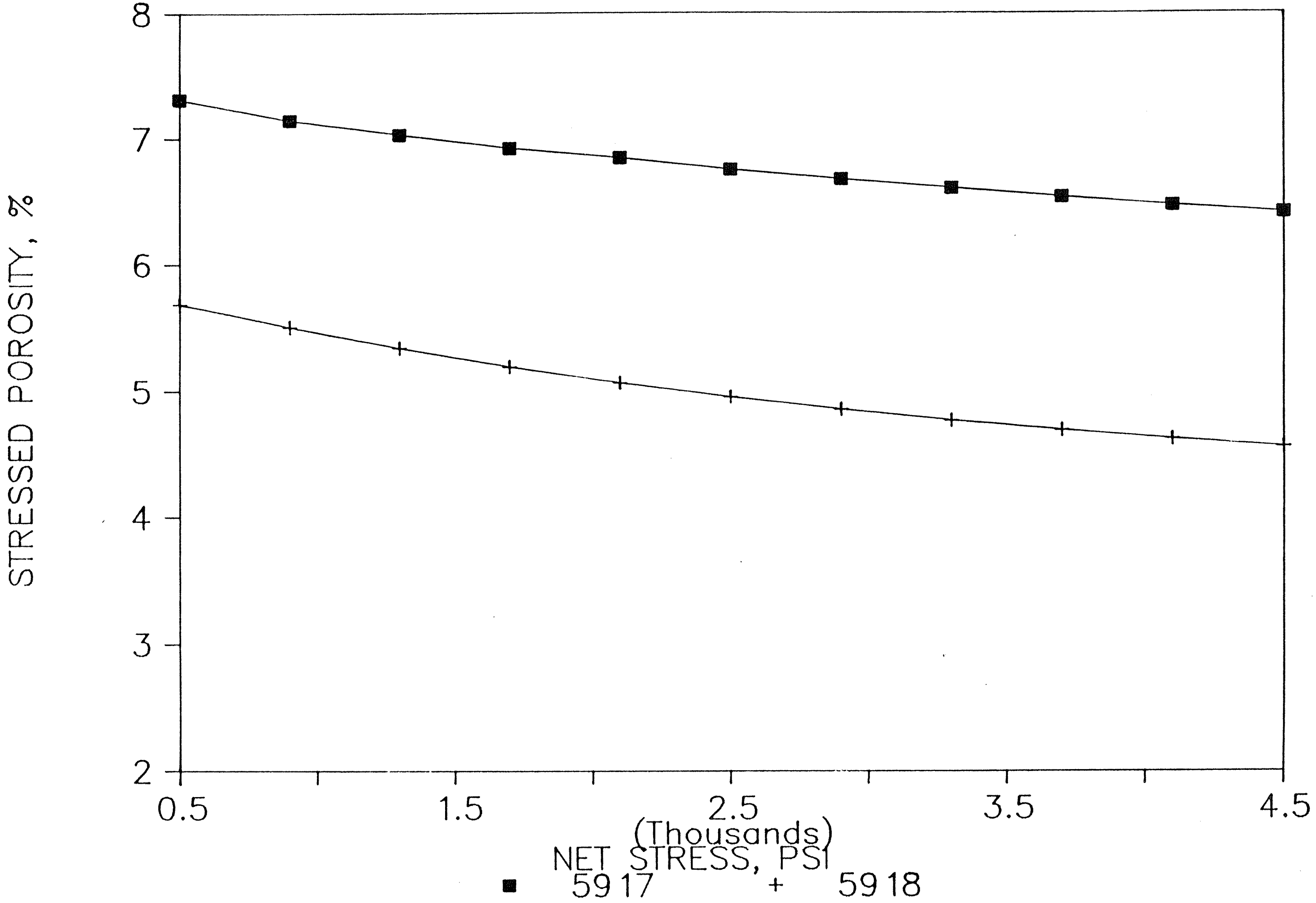


FIGURE 21

HYDROSTATIC POROSITY VERSUS NET STRESS

CLEAN SANDSTONES



Hydrostatic Pore Volume Compressibility represents the instantaneous slope of the hydrostatic strain at a specific Net Stress condition. Thus, Hydrostatic Pore Volume Compressibility can be derived by taking the differential of the exponential equation that best fits the curve of Hydrostatic Normal Pore Volume versus Net Stress.

Uniaxial Pore Volume Compressibility can thus be predicted in a like manner by taking the differential of the exponential equation (model fit) of the curve of the calculated Uniaxial Normal Pore Volume versus Net Stress.

Identical results (for the same data points) to Anderson's 3-step technique were obtained; whereas, Teeuw and Anderson applied a power law equation to model all exponential curves of Normal Pore Volume versus Net Stress. A more direct model of each curve is derived by using the software program, Tablecurve™, to achieve a least squares fit of the actual data. This is more akin to Jones' work, various papers, i.e., SPE 15380, and Anderson's paper, SPE 14213.

Ultrasonic Velocity Apparatus and Methods

Measurement Basics

In laboratory rock measurements, ultrasonic waves are generated by ceramic transducers which are specially made to exhibit "piezoelectric" properties. When voltage is applied to a piezoelectric material it expands, contracts or changes shape depending on the type of material and the polarity of the applied voltage. Conversely when the material is stressed mechanically it generates an electrical voltage. Because of this property, piezoelectric transducers are ideal for sending and receiving sound waves.

There are two types of transducers used to measure ultrasonic velocity in rock samples: compressional and shear. The compressional transducer is usually a thin round disk which, when driven by a voltage across its faces, will become slightly thicker or thinner. This expansion or contraction is less than 1 microinch but is sufficient to create a pulse which will travel through the rock sample and be detected by an identical transducer on the other side. The shear transducer responds somewhat differently to an applied voltage. In this transducer, one face moves left or right with respect to the other face. Again the displacement is very small but is sufficient to generate a "shear wave" which will travel through a solid material and be detected by another shear transducer. A diagram of compressional and shear wave transducer response to an applied voltage is shown in Figure 1.

Historical Note: The compressional wave is often called the "P" wave and the shear wave called the "S" wave. These abbreviations originated with early seismologists who noted that earthquakes generate two types of energy which arrive at distant detectors at different times. The faster moving wave was called the Primary wave and the slower one, the Secondary wave.

The frequency of sound energy generated by these two types of transducers is controlled by the thickness of the piezoelectric material. When pulsed with a high voltage square wave or spike, the transducers oscillate at their principle resonant frequency which increases as the transducer is made thinner. For a compressional disc 0.1 inch thick, the resonant frequency is about 750 kHz. For a shear plate 0.1 inch thick the resonant frequency is about 550 kHz. Both the P and S transducers in our system are of the proper thickness to generate 1 MHz sound energy. This frequency was chosen because its corresponding wavelength is usually much less than the length of our samples but greater than their grain size. Typical wavelengths (1 MHz) in rock range from 2 mm to 5 mm. The relationship between frequency (F) and wavelength (λ) is simply $\lambda = V/F$ where V is velocity.

Because shear transducers are not perfect they always produce some compressional energy which travels faster than the shear wave and causes unwanted "precursor" signal ahead of the desired shear signal. Another peculiar feature of the shear plate transducer is that the azimuthal orientation of the sender and receiver must be the same or the energy generated by one will not be detected by the other (see Figure 2A). Both of these problems can be avoided by using a circular pattern of shear plates all facing in the same rotational direction, but with opposite compressional polarizations. This configuration is called a torsional transducer and is used in all of our experiments. Because these shear plates only need to contact the outer perimeter of the plug sample, the inner space can be used for a compressional disc. The combination of a P disc and torsional S transducer is called a coaxial transducer (Figure 2B).

The displacements generated by piezoelectric transducer are very small. This means that the transducer and the rock must be in very "intimate" contact. One way to accomplish this would be to glue the transducers directly to the rock. Of course this is impractical for several reasons so the transducers are bonded to metal end plugs instead. The end plugs in our system are made of titanium which is noncorrosive and has a low density. The acoustic waves are efficiently transmitted from end plug to sample when the rock face is very flat and some pressure is applied by the confining fluid.

The determination of acoustic velocity with the system is accomplished by careful timing measurements on the digital oscilloscope. The scope is triggered by the high voltage pulser which drives the transmitting transducer. The waveform displayed is that of the corresponding receiving transducer. The travel time between trigger and the "first break" is read directly from the oscilloscope screen. An example of shear (torsional) and compressional waveforms is shown in Figure 3. This travel time also includes the end plugs so this end plug travel time must be subtracted from what is shown on the screen to obtain a rock travel time. The acoustic velocity is simply the length of the sample divided by the rock travel time. Velocity is usually reported in km/sec or mm/μsec which are numerically equivalent. Other possible units are m/sec, ft/sec, or inverse velocity (slowness) in μsec/ft.

As mentioned previously, the shear transducer also produces a small amount of compressional energy. Since the P wave always travels faster than the S wave, this P energy can show up on the shear waveform as precursor noise. In severe cases this noise can make it difficult to find the shear wave first break. Such problems usually occur in very long samples or at very low effective pressure. In such cases the waveforms are recorded on floppy discs for more intense scrutiny and comparison to subsequent waveforms recorded under higher effective stress conditions.

In addition to simply calculating and reporting P and S velocity, we can also calculate certain elastic moduli from the velocity data. An elastic material is one that strains (or deforms) in an amount directly proportional to the pressure applied to it. Most materials behave elastically when the stresses and corresponding strains are small. An elastic modulus is the number that describes how much a given material strains in response to a given stress. The theory of elasticity states that if a material is isotropic, or the same in all directions, that its elastic behavior can be completely described by only two elastic moduli. These two moduli are the shear modulus, μ, and the bulk modulus, K. Both of these can be calculated from V_p, V_s, and bulk density ρ, with the following relations:

$$\mu = \rho V_s^2$$

$$K = \rho (V_p^2 - 4/3\ V_s^2).$$

Two other elastic moduli which are often used are Poisson's ratio, ν, and Young's modulus, E, which are given by:

$$\nu = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{2\left(\left(\frac{V_p}{V_s}\right)^2 - 1\right)}$$

$$E = \frac{9\rho V_s^2\left(\frac{K}{\rho V_s^2}\right)}{3\left(\frac{K}{\rho V_s^2}\right) + 1}$$

Measurement Apparatus

The system used by Core Lab to measure ultrasonic velocity is a four sample device with automated pore pressure and confining pressure control. Figure 4 is a schematic diagram of the system. Equal hydrostatic confining pressure is applied to four jacketed samples by a hydraulic pump. A pressure transducer, the pump, and a bleed valve are connected to the Data Acquisition and

Control (DAC) unit which communicates over an IEEE 488 bus to the computer. In this way, confining pressure can be automatically continuously adjusted. Confining pressure can range from 200 psi to 15,000 psi.

The pore pressure in each sample is controlled by a separate positive displacement pump with a stepping motor drive. These four pumps are connected via the DAC to the computer. Four individual transducers monitor the pore pressure of the samples. This combination allows the computer to both control pore pressure and measure pore volume change on each sample individually. Pore pressure can range from 0 to 5000 psi.

Temperature of the system can be adjusted from ambient (about 25°C) to 100°C by a proportional controller. A thermocouple inside the oil-filled pressure vessel measures the sample temperature to 1 degree C.

There are eight compressional and eight torsional shear transducers in the system. They are switched electronically to the pulse generator or input amplifier depending on whether they are transmitters or receivers. The driving pulse is a high voltage square wave of 1 to 10 microseconds in duration. The received signal on the other side of the rock sample is amplified by 20 or 40 db and displayed on the digital scope. A reference marker is moved to the location of the first break and the time to the reference marker is digitally displayed on the scope screen. The signal can be recorded onto a floppy disc for future analysis.

A summary of the system measurement accuracy and resolution is given below:

Parameter	Accuracy	Resolution
Pressure	0.01%	0.1 bar
Temperature	1%	1.0°C
Travel Time	0.1%	0.05 μsec
Calculated Velocity*	1%	0.5%
Elastic Moduli	5%	2%
Pore Volume Change	0.1%	0.0001 cc

*Velocity accuracy and resolution are usually better than stated.

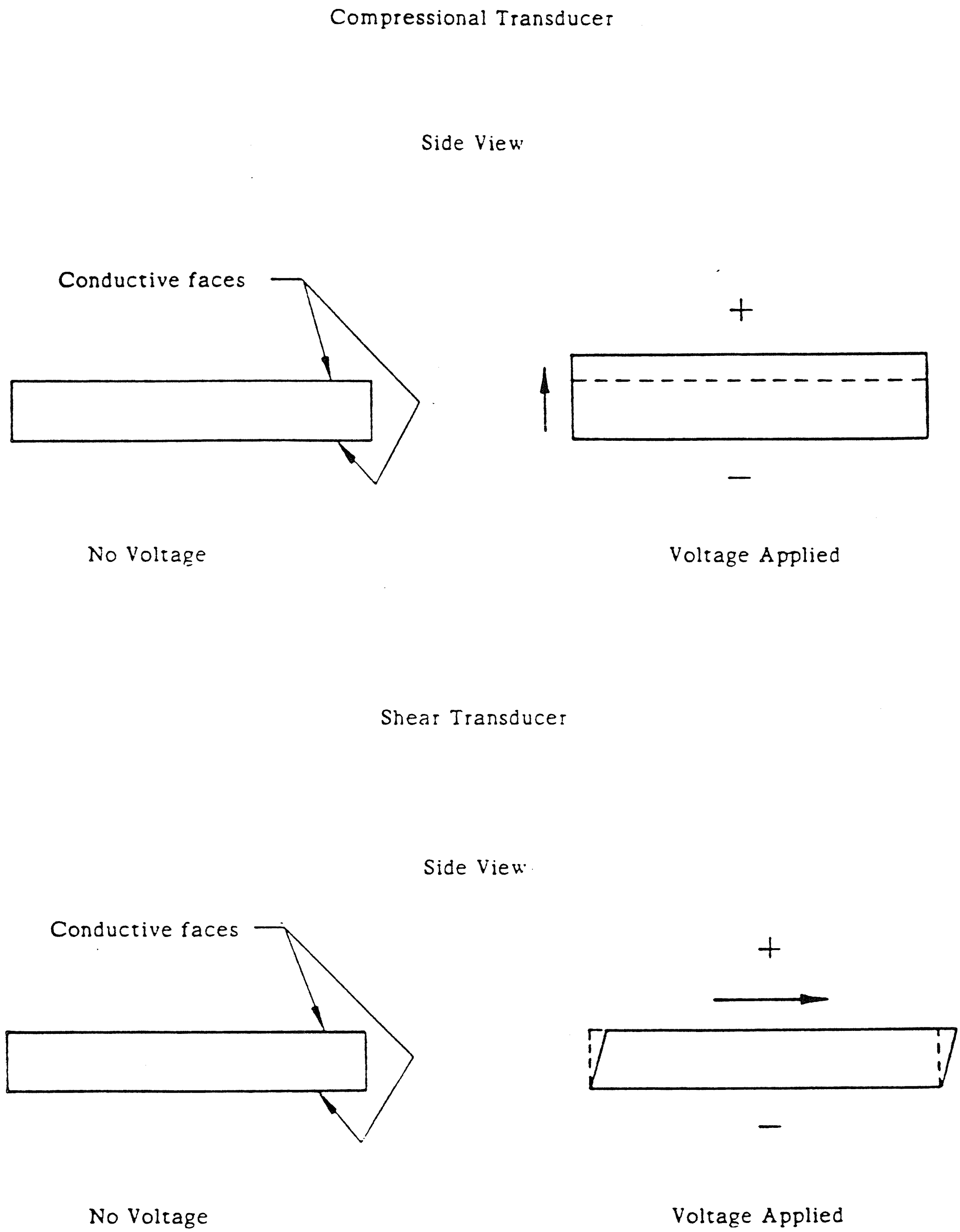


Figure 1. Shear and compressional transducer response to applied voltage.

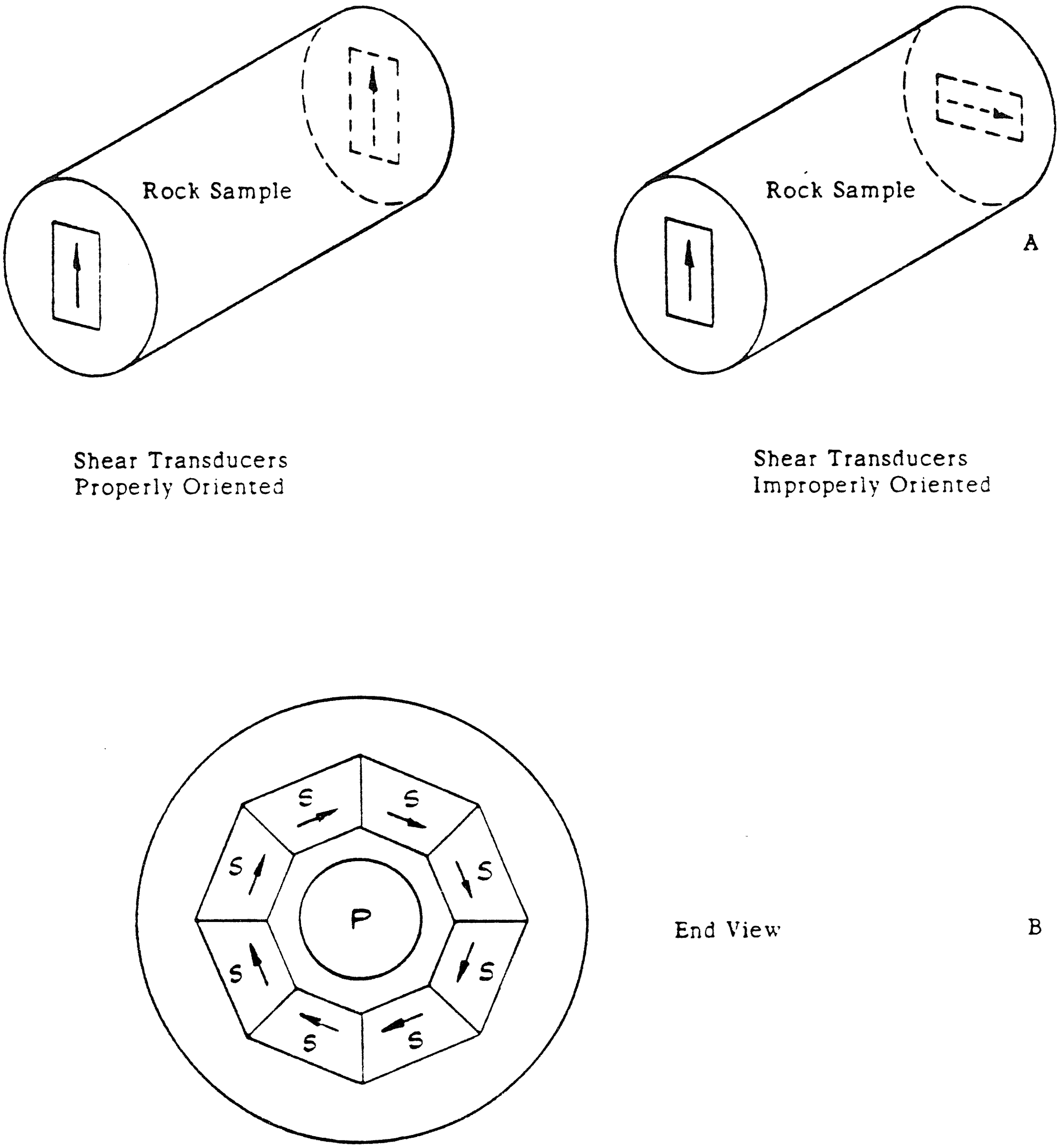
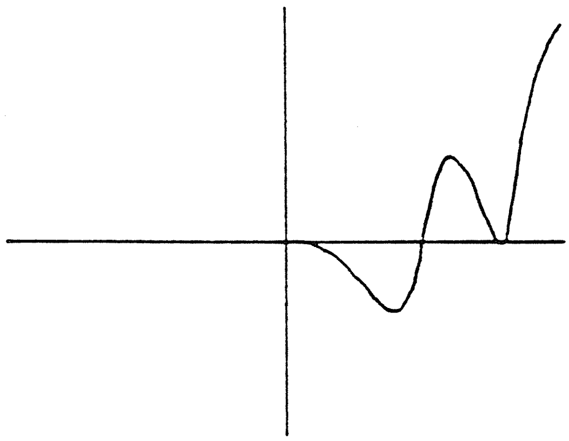
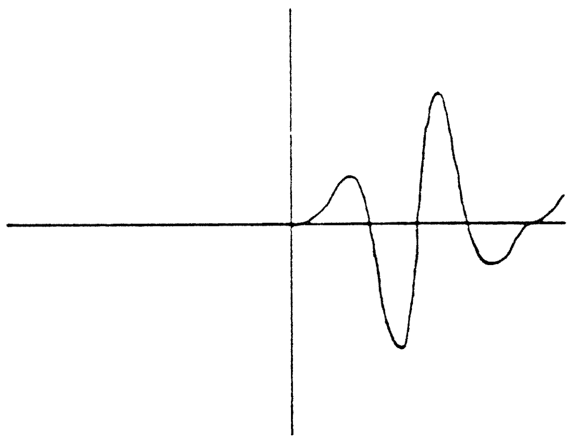


Figure 2. Coaxial P and S transducer.



TORSIONAL S WAVE SIGNAL



P WAVE SIGNAL

Figure 3. Shear and compressional waveforms.

PREDICTING UNIAXIAL PORE VOLUME COMPRESSIBILITY FROM HYDROSTATIC PORE VOLUME COMPRESSIBILITY

According to D. Teeuw's classic paper, SPE 2973, and Anderson's paper, SPE 14213, the prediction of uniaxial (often recognized as representing in-situ reservoir conditions) pore volume compressibility can be accomplished from hydrostatic pore volume compressibility tests (laboratory). These predictions of reservoir compressibility assumes 1) that the reservoir rocks act elasticly to stress, 2) that the hydrostatic and uniaxial pore volume compressibility of a porous rock is exponentially related to stress, and 3) that the Poisson's Ratio, ν, is essentially constant for all loading conditions.

Background and Purpose: (from Anderson, SPE 14213)

In order to determine the volume of hydrocarbons-in-place, early production is matched to the driving forces present in the reservoir. In addition to water drive, the other major driving force is the compression of the reservoir fluids and rock by the overburden. Overburden pressure is supported both by the rock framework and the pressure of the pore fluid. Therefore, compressibility is often reported at net overburden (or "net stress") conditions, which is the difference between the overburden pressure and pore pressure.

During reservoir production, the pore pressure generally decreases allowing the pore fluids (and or gas) to expand and provide part of the driving force for production. At the same time, the formation contracts (compacts or compresses) as the net stress increases giving the other part of the driving force for production.

Pore volume compressibility is the measure of the amount of contraction having taken place, and can be an important factor in system compressibility which is the sum of the fluid, gas, and pore volume compressibilities. The reservoir volume can be calculated from the already produced volume and the system compressibility.

The actual formation contraction as a result of production is generally considered to be in the vertical direction, and is commonly referred to as a uniaxial-strain condition.

Terminology:

Stress = Pressure

the result of which is:

Strain = Change in Pore volume

and is represented (in this case) by:

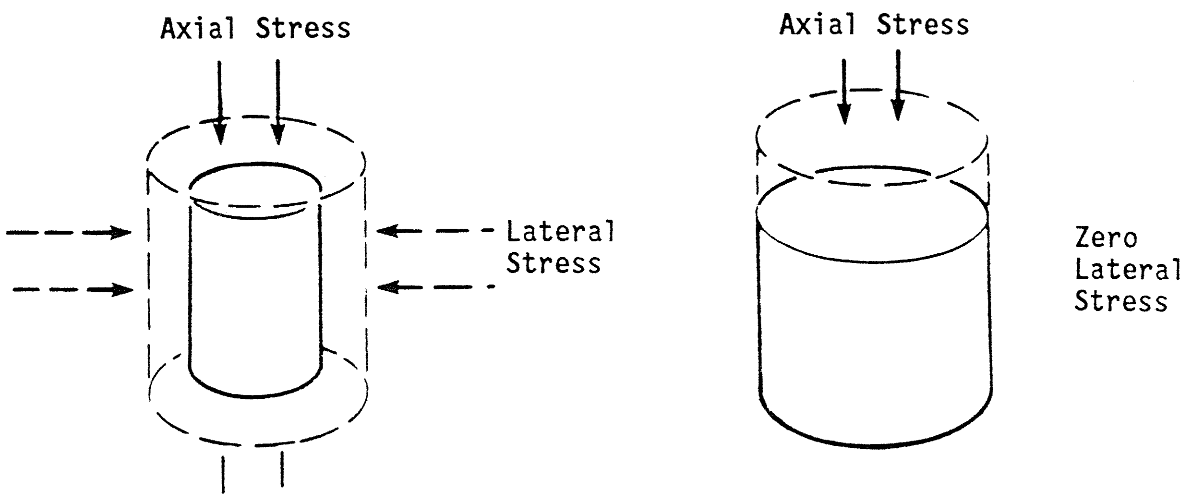
Pore Volume Compressibility

By definition the uniaxial-strain condition in the laboratory is where a stress is applied in one direction (vertical) and the confining stress in the lateral directions are adjusted to retain a zero lateral strain condition. See Figure 1.

Such uniaxial tests are costly and not as easy to perform or interpret as a hydrostatic test where both vertical and lateral stresses are the same. Therefore, being able to predict the amount of uniaxial strain from hydrostatic strain measurements can be extremely useful. Both Teeuw and Anderson present similar techniques for predicting uniaxial strain from hydrostatic strain data.

Strain as a function of stress can be easily determined by plotting the ratio of the change in pore volume (Vp) and the initial pore volume (Vpi) or more commonly referred to as the Normal Pore Volume versus the Net Stress. (Net Stress = Confining Pressure - Pore Pressure). See Figure 2.

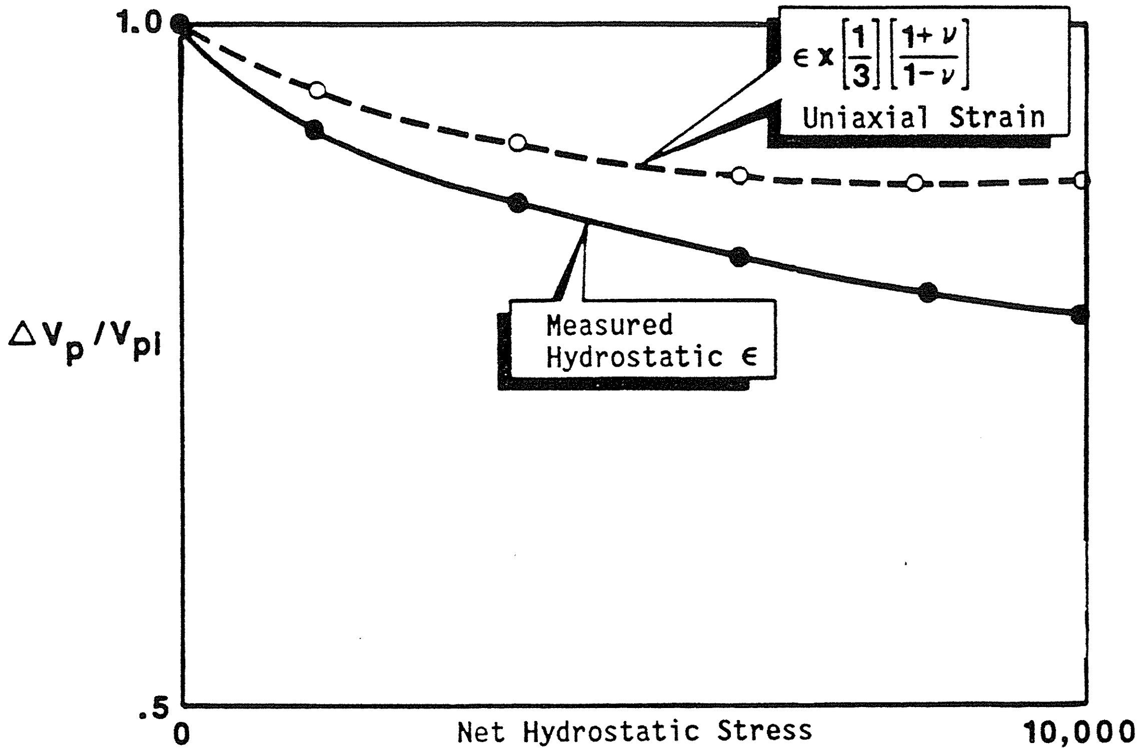
FIGURE 1



Exaggerated Hydrostatic Stress on Plug Sample

Exaggerated Uniaxial Stress Relative to a Plug Sample

FIGURE 2



Using an elastic strain approach, the hydrostatic strain (Eh) measured in the laboratory can predict (in most cases) the uniaxial strain (Eu) by applying Teeuw's equation to Strain.

$$Eu = Eh \left[\frac{1}{3}\frac{(1+\nu)}{(1-\nu)}\right] \quad \text{Where: } \nu = \text{Poisson's Ratio}$$

or simply

$$Eu = \frac{\left[\frac{1}{3}\frac{(1+\nu)}{(1-\nu)}\right] \Delta Pv}{Vpi}$$