FINAL REPORT
TASK II

DETERMINATION OF THE STRAIN RELAXATION AND THEIR RELATION TO SUBSURFACE STRESSES IN THE DEVONIAN SHALE

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SUMMARY OF TASK II

DETERMINATION OF THE STRAIN RELAXATION AND THEIR RELATION TO SUBSURFACE STRESSES IN THE DEVONIAN SHALE

Strain-relaxation tests were performed on twenty-four specimens of Devonian Shale obtained from the Columbia Well No. 20402, Lincoln County, West Virginia, for the overall purpose of identifying, among the gas-bearing shales, the prime zones for stimulation (MHF) treatment within the Devonian Shale sequence.

The results of this work provide information on the strains and stresses in only three shale zones - Upper Gray Shale, Middle Gray Shale and Middle Brown Shale - and yield the following interpretations:

1. The rate of strain relaxation is 2 to 2.5 times higher in the Middle Brown Shale zone than in the overlying Gray Shale zones, which suggest that
2. The minimum horizontal matrix-stress in the Middle Brown Shale zone could be up to 30 percent lower than the minimum horizontal matrix-stress in the upper Gray Shale zones.

From these measurements alone it appears that the upper Gray Shale zones may act as an effective barrier which prevents upward fracture propagation, thereby promoting larger lateral extension of a fracture initiated within the Middle Brown Shale, a prime gas-bearing zone.

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INTRODUCTION

The question addressed in this report is as follows: Can an inexpensive but reliable core-analysis technique be developed to provide useful information on the present-day stress distribution in subsurface reservoirs and aid in the identification and selection of prime gas-bearing zones for stimulation by massive-hydraulic-fracture (MHF)?

To provide answers to this question we have begun to use a technique that very accurately measures the small dimensional changes (strain relief) of Devonian Shale samples after they are cored and brought to the surface. The smallest dimensional change (strain) that can be detected by this technique is of the order of several micro-inches*. For example, a four-inch diameter shale sample that strained or relaxed ten micro-inches changed dimensions by 0.00004 inch.

Basically, the idea is that as a sample of any kind of rock is cored and taken from its subsurface environment, it will experience a rapid change in stresses and consequently relax and change dimensions. The amount of relaxation over a period of time after coring is related to the magnitude of the subsurface stresses or, more specifically, the magnitude of the difference between the greatest (overburden) stress and the least (minimum-horizontal) stress in the formation from which the sample was obtained.

From these relaxation measurements, however, we can only develop a qualitative estimate of the distribution of the subsurface minimum-horizontal stress-gradient and determine the relative changes, if any, in the gradient distribution from formation to formation. Nevertheless, this kind of information is useful and important because it can lead to an early recognition of anomalies in the subsurface stress gradients (usually assumed

* One micro-inch = one inch per one million inches = 10^{-6}.

to increase linearly with depth) and the identification of prime zones for stimulation and fracture-treatment.

In this report we will briefly outline the important aspects of the well-site technique of strain relaxation and its limitations. These will be followed by the description of the strain-relaxation results obtained in samples from the upper Gray Shale and Middle Brown Shale zones in Columbia Well No. 20402. Next, attention will be focused on how these results can be interpreted to provide new and useful information and, finally, how they can be applied and lead to improvements in the results of a fracture treatment program.

WELL-SITE TECHNIQUES

Strain Relaxation

The technique used at the well-site consisted of selecting small pieces of rock as soon as they were removed from the core barrel and laid out for initial geologic identification and description. The rock was slabbed with a rock saw to provide two flat, parallel surfaces and result in a test specimen two inches thick and four inches in diameter. The top surface was air dried and then washed with acetone to dissolve whatever moisture was retained at the surface of the sample. A 45-degree strain-rosette was fastened in the central part of the top surface using a quick-setting epoxy (Figure 1). Gage No. 2 (center gage) in each rosette was aligned with the reference (orientation) groove of the sample.

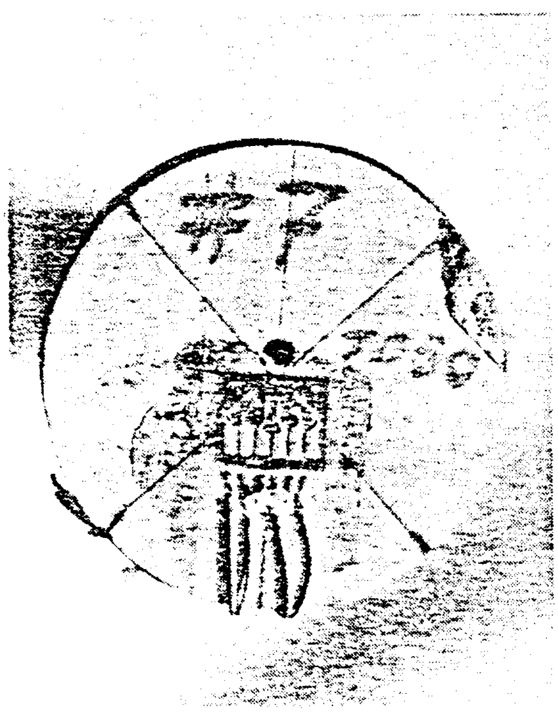

Figure 1. Core sample instrumented with 45-degree strain rosette. Gages 1, 2 and 3 are seen from left to right. The sample is Dakota sandstone cored in a western gas well.

Each of the three strain gages in the 45-degree rosette were wired into a switching unit and a strain indicator. The switching unit allowed the concurrent measurement of strain changes in as many as 12 specimens. Data were recorded manually every half-hour for the first day and every hour for all subsequent days. Three strain-time curves were drawn for each specimen to provide the basic data from which to calculate the rates and magnitudes of strain relaxation.

The limitations in reliably measuring the strain relaxation in rock samples should be clearly recognized. They are listed as follows:

1. The rock sample must be representative of the subsurface formation.
2. The rock samples must be maintained under constant moisture and temperature conditions. A change in temperature of 1°F, for example, will result in an apparent strain of about 6×10^{-6} or 6 micro-inches.
3. The rock samples should be oriented geographically to determine the directions of the major axes of strain relaxation.
4. The rock sample should be instrumented soon after removal of the subsurface stresses to assure maximum accuracy of measurement.
5. The elastic strain-relaxation, which occurs instantaneously upon coring down-hole, is not detected by this technique.

Velocity Measurements

Longitudinal (P) wave measurements were made on rock samples as soon as possible after the coring of Columbia Well No. 20402. These measurements were made in conjunction with, and with the same objective as, the strain relaxation measurements.

Figure 2 shows the technique used to obtain the transit times of the ultrasonic wave through the rock sample. A DC pulse generator was used to

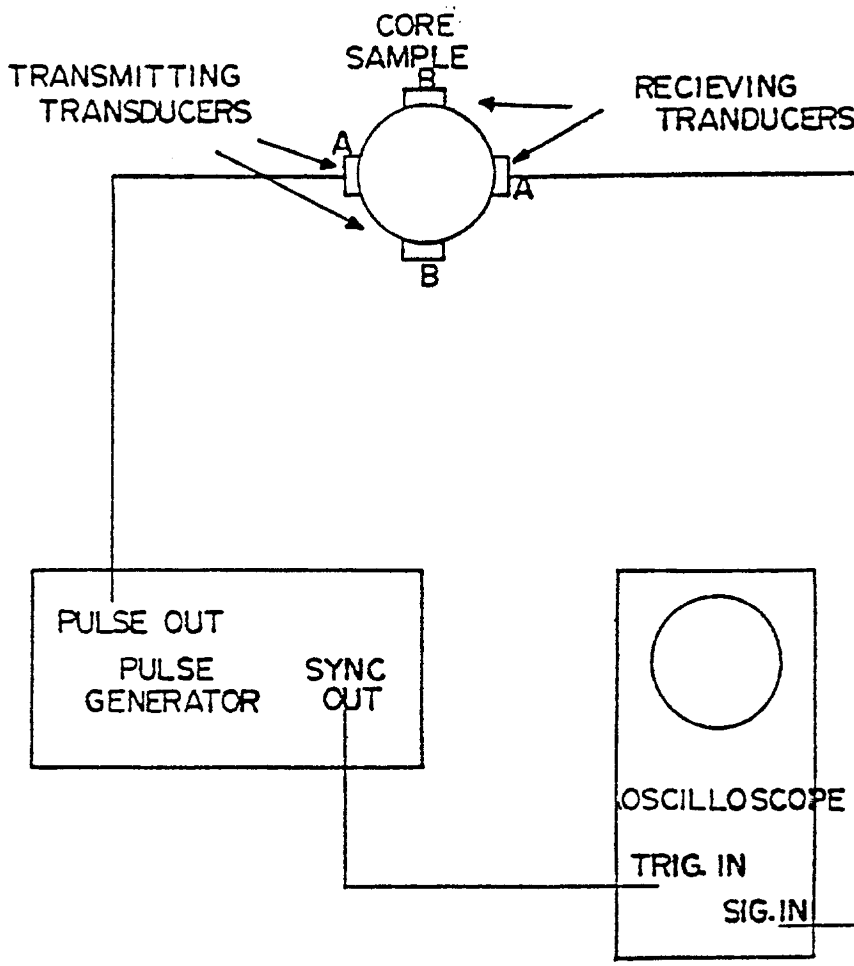

Figure 2. Schematic diagram of field equipment used to measure changes in P-wave velocity along two horizontal directions in a relaxing core.

excite the transmitting transducer and the same time to initiate the sweep on an oscilloscope. The signal produced by the receiving transducer was displayed as a vertical deflection on the oscilloscope trace. The travel times were obtained directly from the calibrated sweep speed of the trace. The accuracy of the time measurements was of the order of three percent.

The transit times were determined in two planes across the rock sample. In order to eliminate the effects of changes in the transducer to sample bonding the transducer assembly (Figure 3) was firmly attached to the rock,

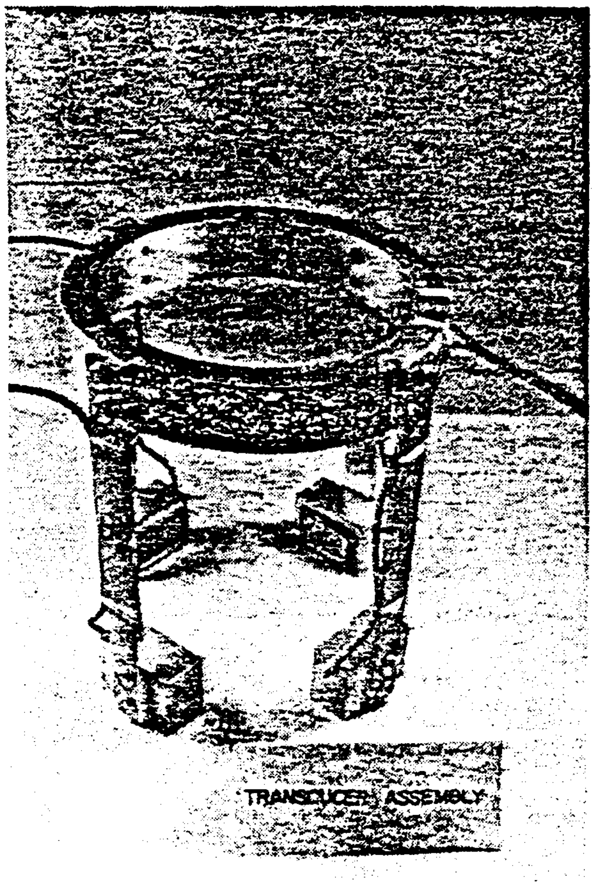

Figure 3. Photograph of sonic-transducer assembly.

and remained so for the duration of the test. The transducer elements were made from PZT-5 material and were cut to resonate at a natural frequency of 200 kilohertz.

It should be emphasized, however, that significant changes in velocity across the rock sample will occur only if the strain relaxation in the rock sample exceeds a certain minimum value, thereby causing significant changes in the elastic moduli of the rock sample. In some sandstones, for example, the lower limit of strain relaxation is about 500 micro-inches (5×10^{-4}) beyond which velocity changes can be observed.

RESULTS

Twenty-four specimens were selected from extracted cores (2686 feet to 3458 feet) in the Columbia Well No. 20402 and monitored for up to three days. Most of the specimens came from the bottom of each core run in order to capture the maximum amount of strain relaxation. Compressional P-wave velocity measurements were made on twelve specimens to check the strain relief results.

Strain Relaxation

The strain-time plots (Figures 4 through 24) form the basic data and consist of three curves. Each curve represents each strain gage in the 45-degree rosette applied to the rock surface (Figure 1). Because of the large, daily temperature variations at the well site during the measurement period, each curve has been corrected for temperature using a correction factor of $10 \times 10^{-6}/°C$ ($6 \times 10^{-6}/°F$).

With few exceptions, the data indicate that the very small strain changes with time are nearly uniform in all directions. Non-uniform, anisotropic relaxation was measured in only one specimen. Samples No. 1 (Figure 4) showed maximum horizontal, relaxation of about 240×10^{-6} along a direction (N 10° W) almost perpendicular to the predominant fracture trend (N 70° E) in the Devonian Shale. The most dramatic strain changes were observed in Sample No. 7 (Figure 7). The overall relaxation, nearly uniform in the horizontal plane ($\varepsilon_{max} = 400 \times 10^{-6}$; $\varepsilon_{min} = 350 \times 10^{-6}$), is due to the formation of a sub-horizontal fracture about 1.5 inches below the top of the specimen during the time of measurement. Velocity measurements (Table I, 2768 feet), made below the fracture, indicated no measurable changes in P-wave velocity with time.

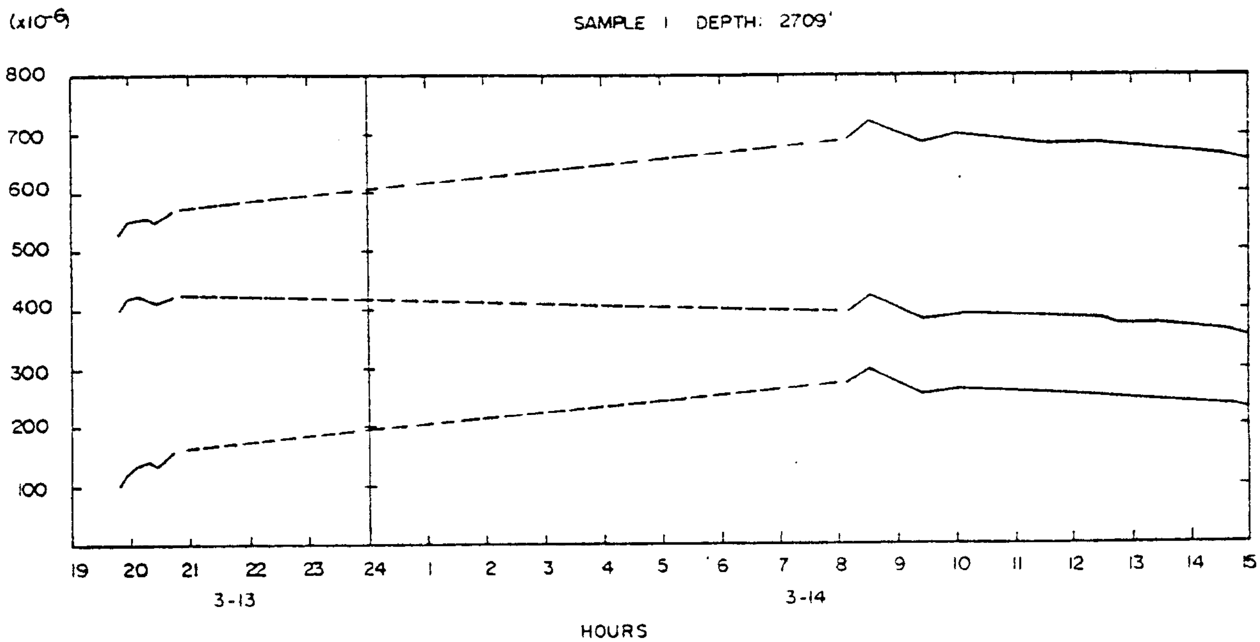

Figure 4. Strain-relaxation-time plots of Devonian Shale.

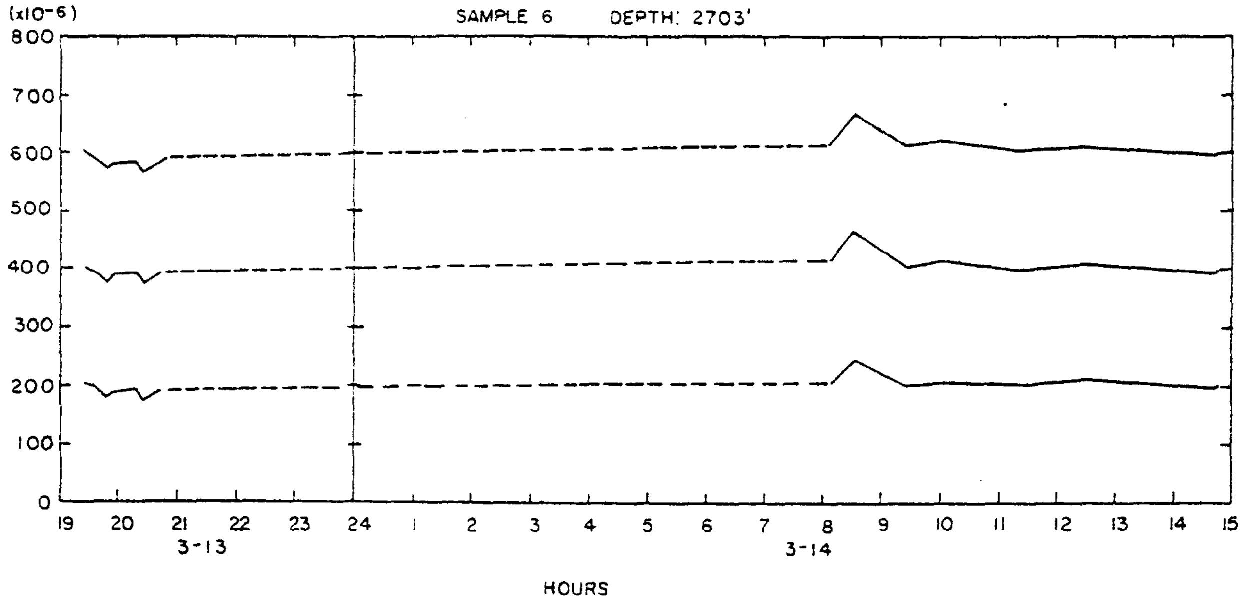

Figure 5. Strain-relaxation-time plots of Devonian Shale.

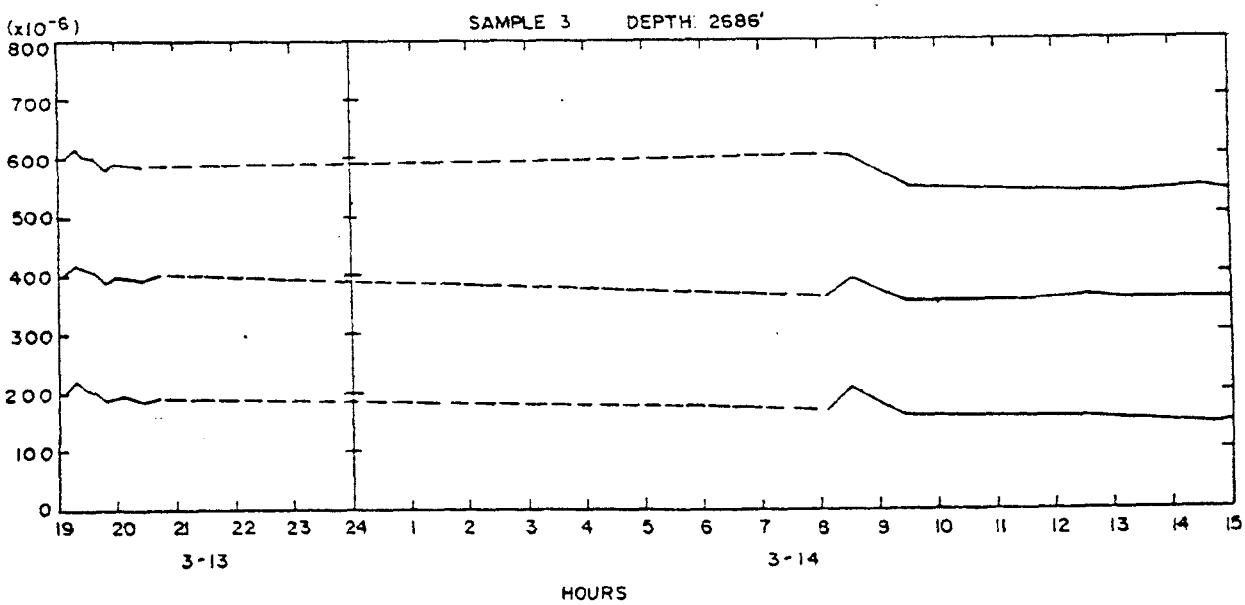

Figure 6. Strain-relaxation-time plots of Devonian Shale.

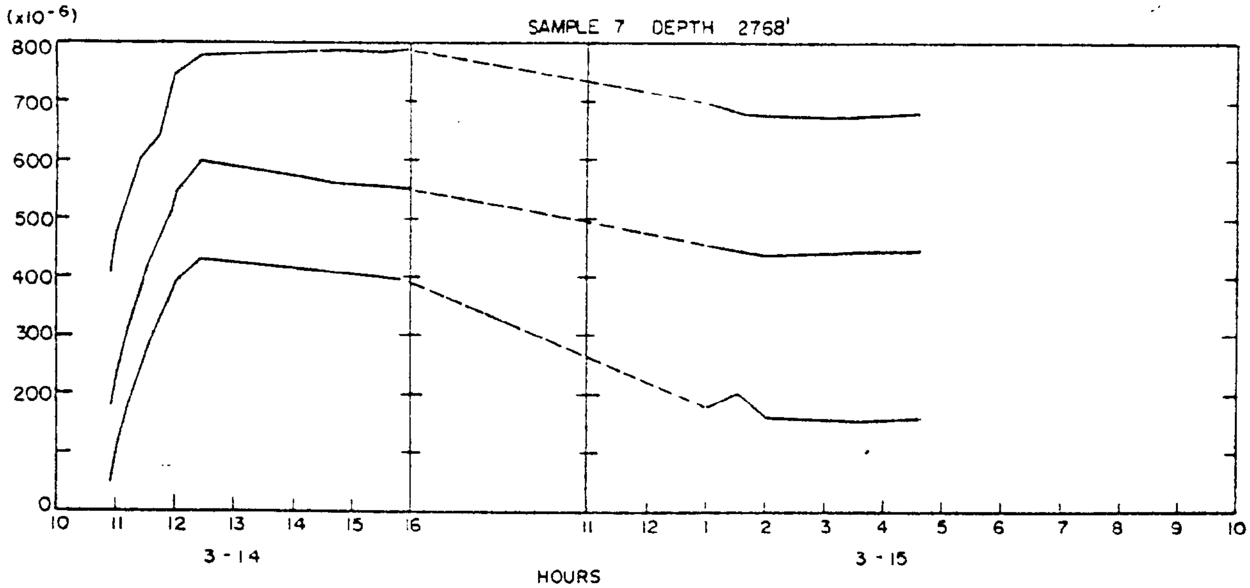

Figure 7. Strain-relaxation-time plots of Devonian Shale.

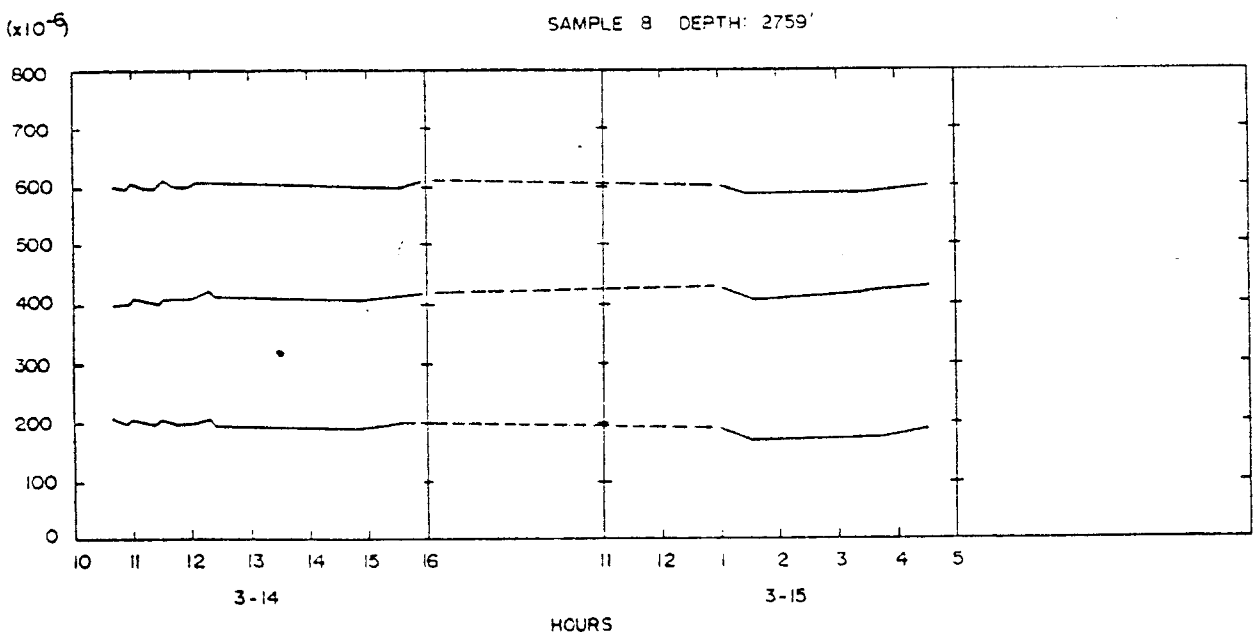

Figure 8. Strain-relaxation-time plots of Devonian Shale.

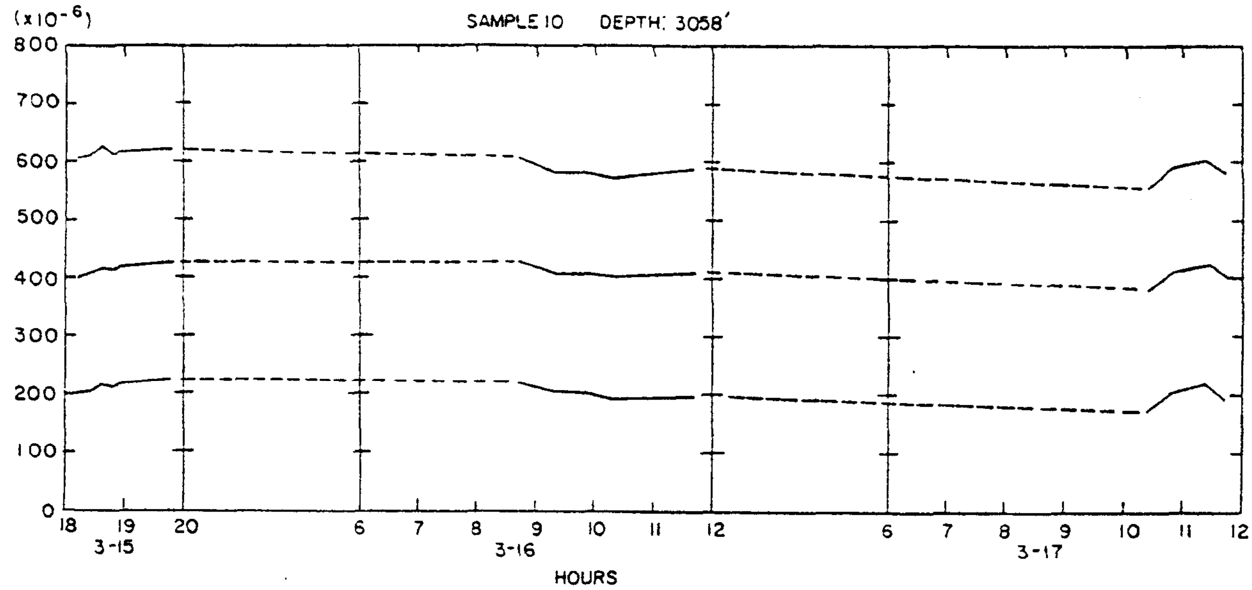

Figure 9. Strain-relaxation-time plots of Devonian Shale.

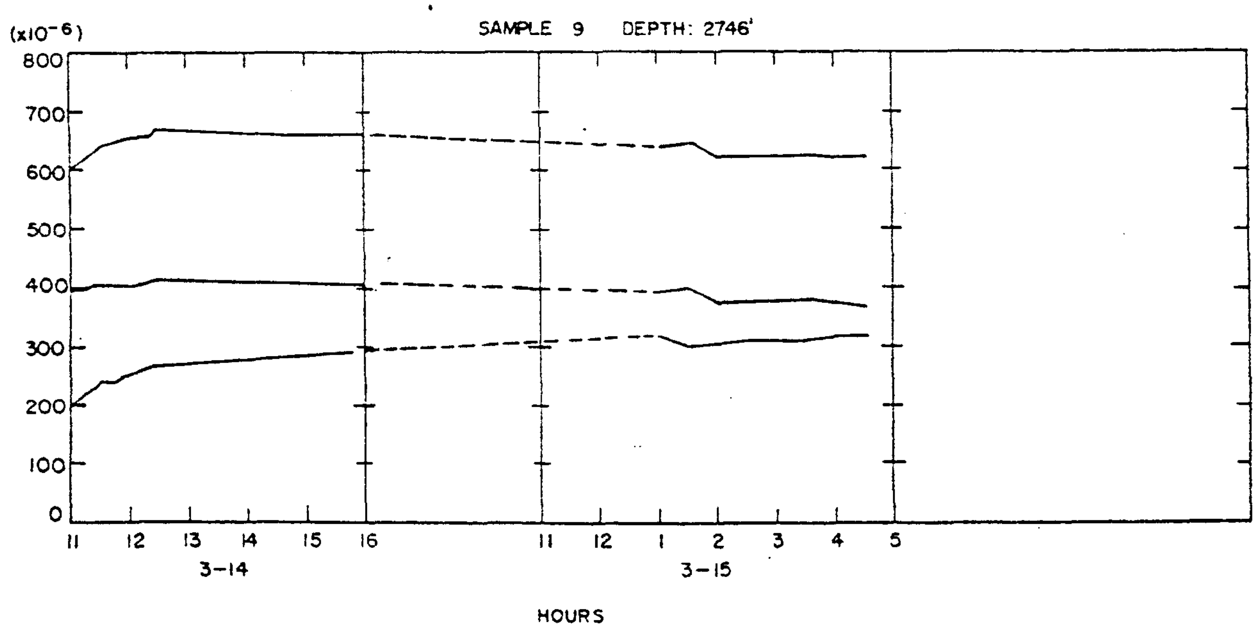

Figure 10. Strain-relaxation-time plots of Devonian Shale.

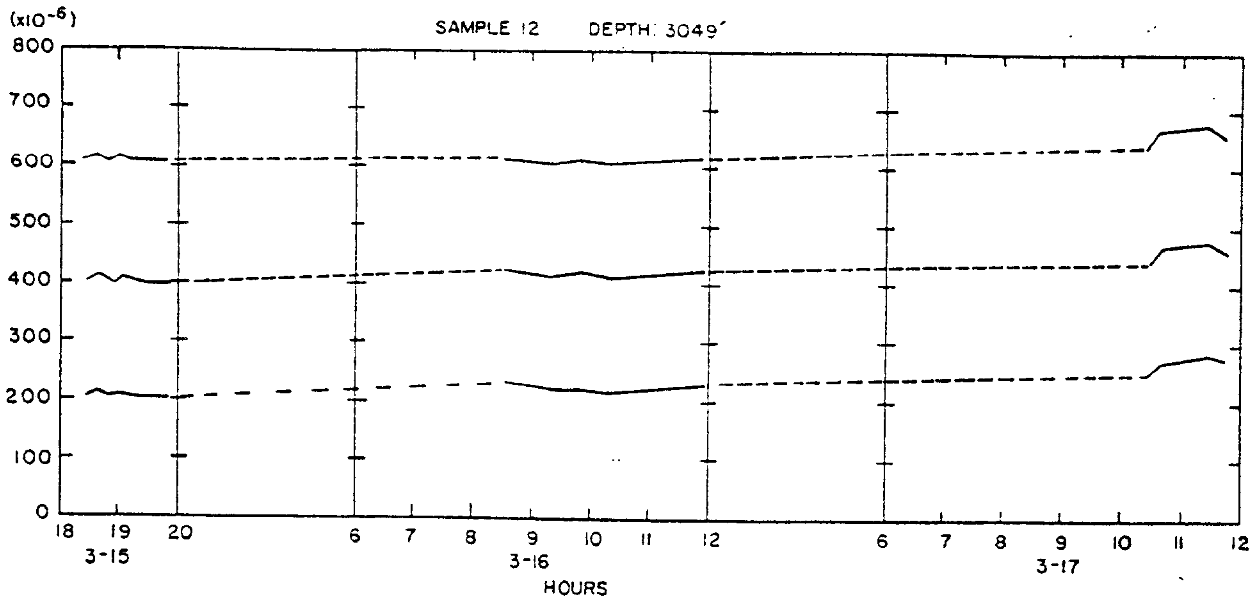

Figure 11. Strain-relaxation-time plots of Devonian Shale.

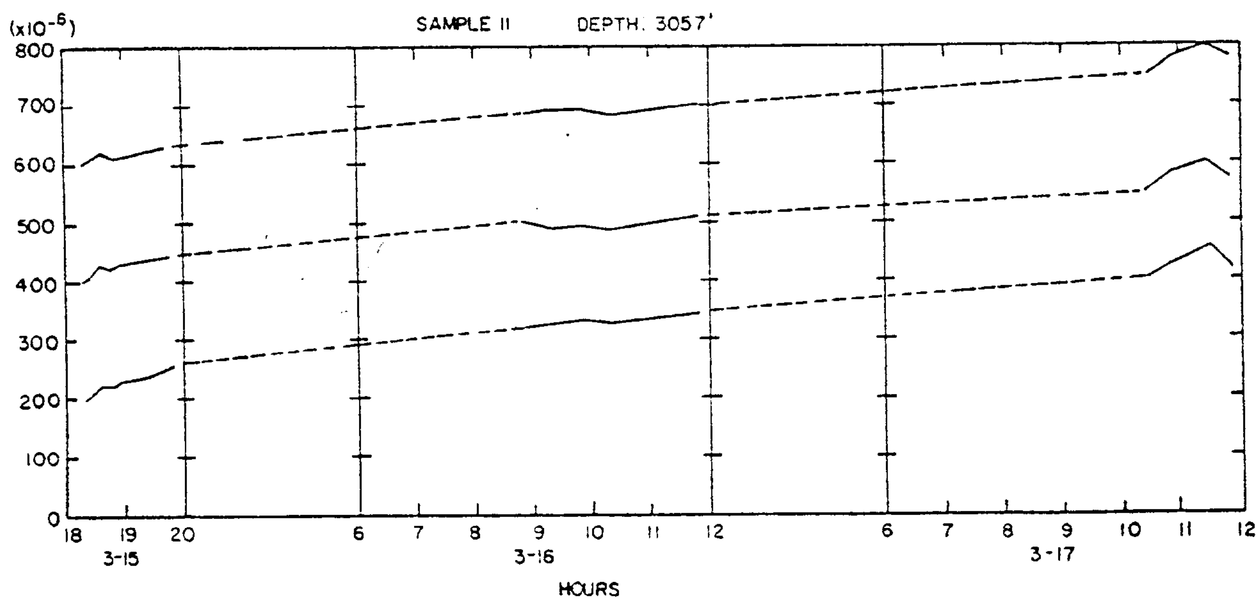

Figure 12. Strain-relaxation-time plots of Devonian Shale.

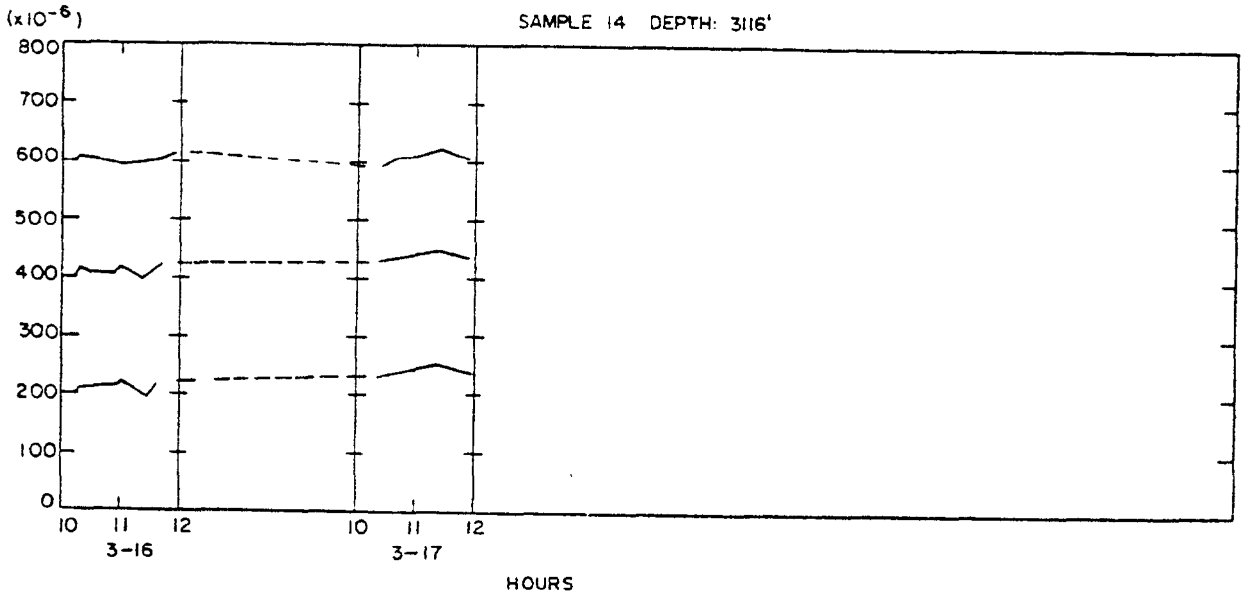

Figure 13. Strain-relaxation-time plots of Devonian Shale.

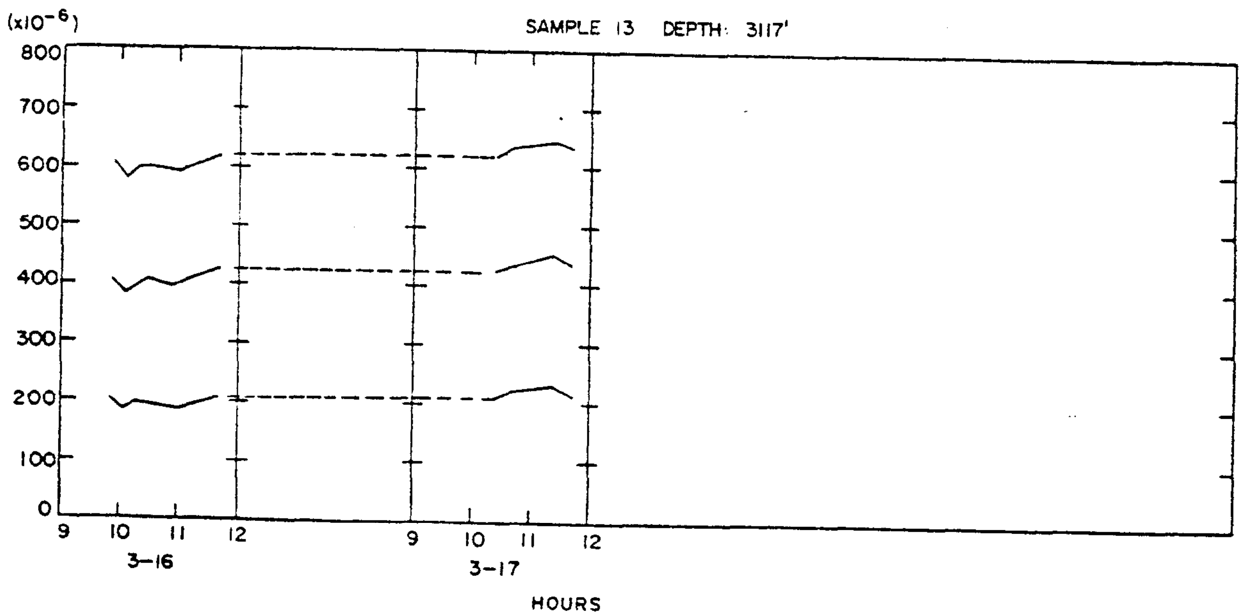

Figure 14. Strain-relaxation-time plots of Devonian Shale.

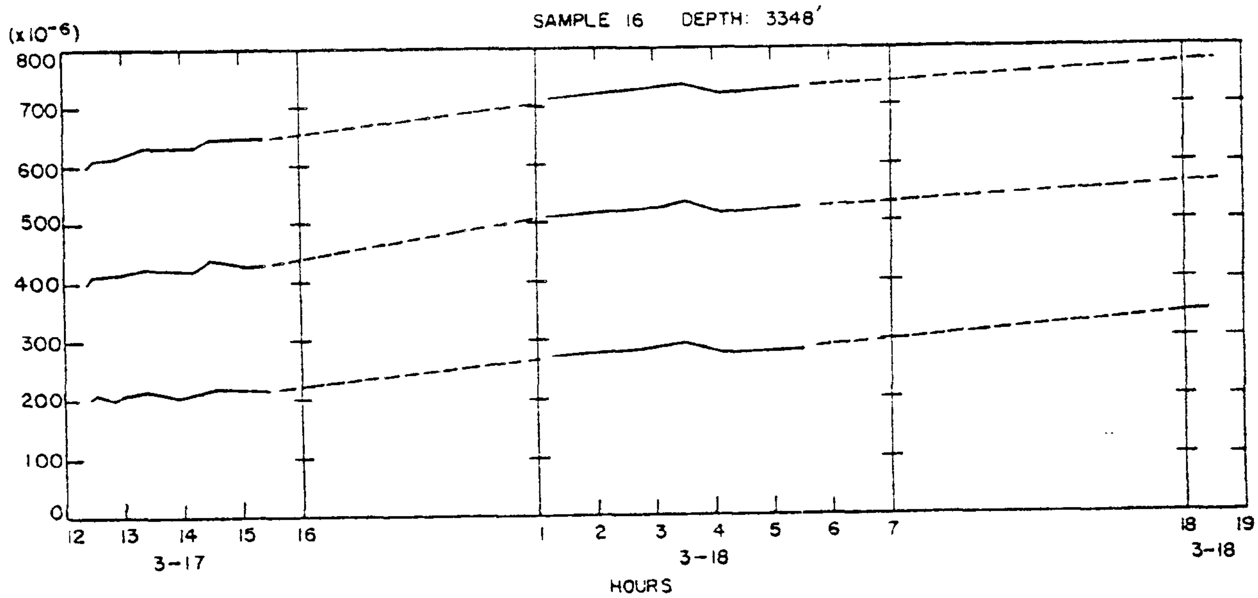

Figure 15. Strain-relaxation-time plots of Devonian Shale.

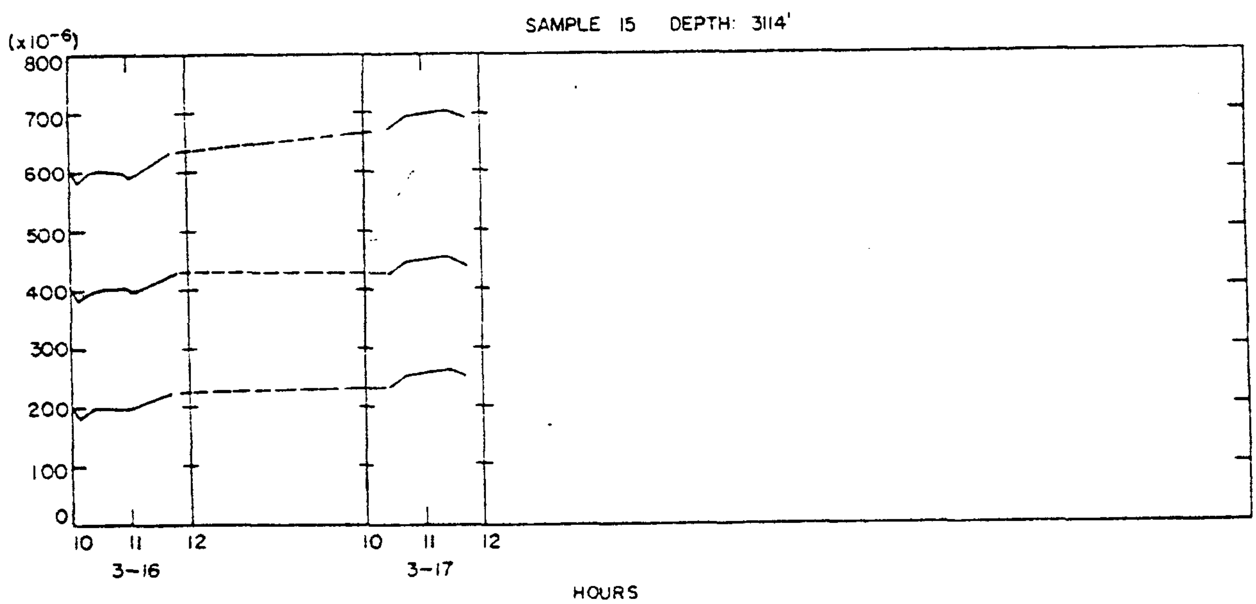

Figure 16. Strain-relaxation-time plots of Devonian Shale.

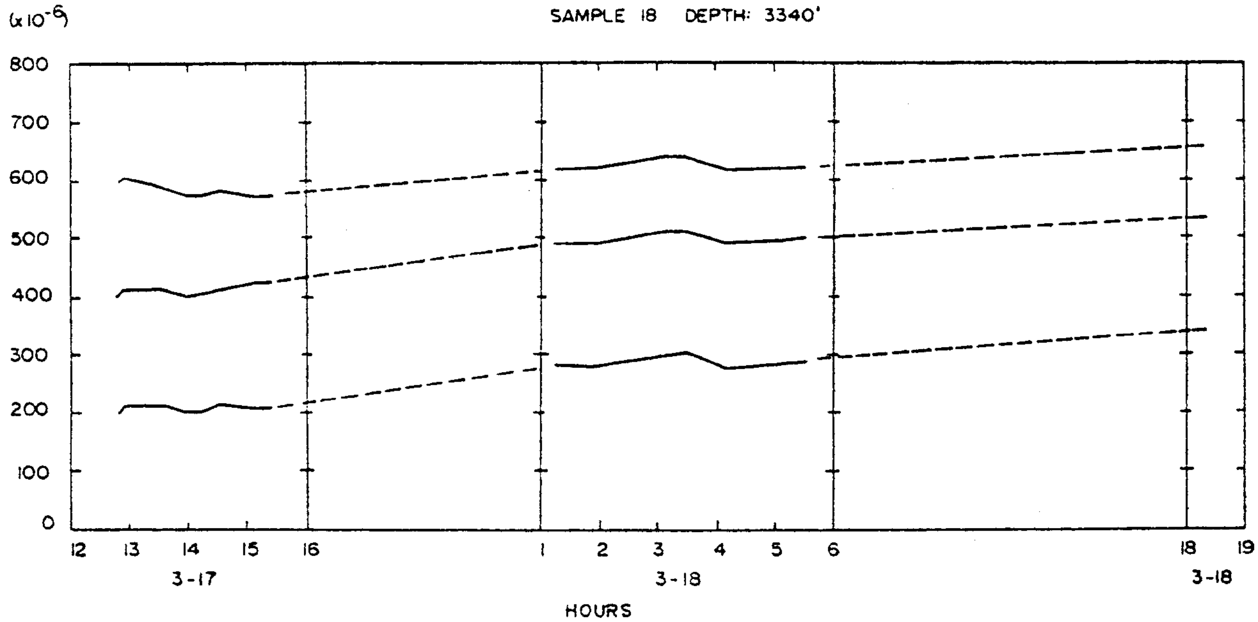

Figure 17. Strain-relaxation-time plots of Devonian Shale.

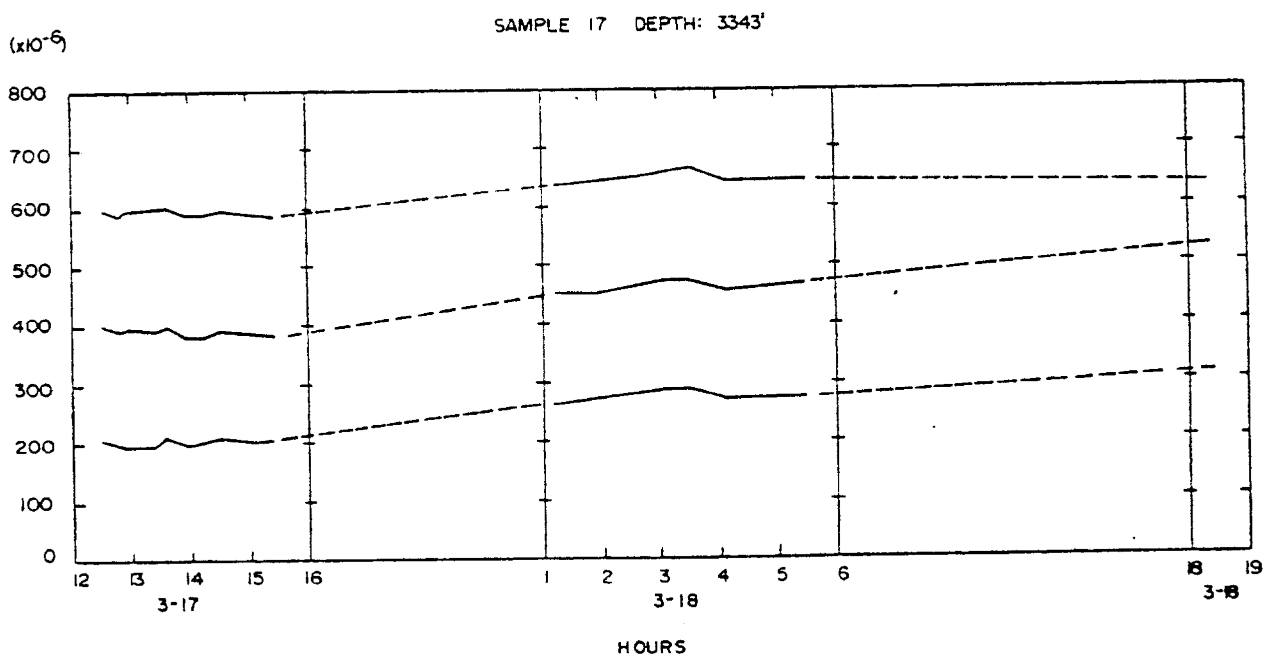

Figure 18. Strain-relaxation-time plots of Devonian Shale.

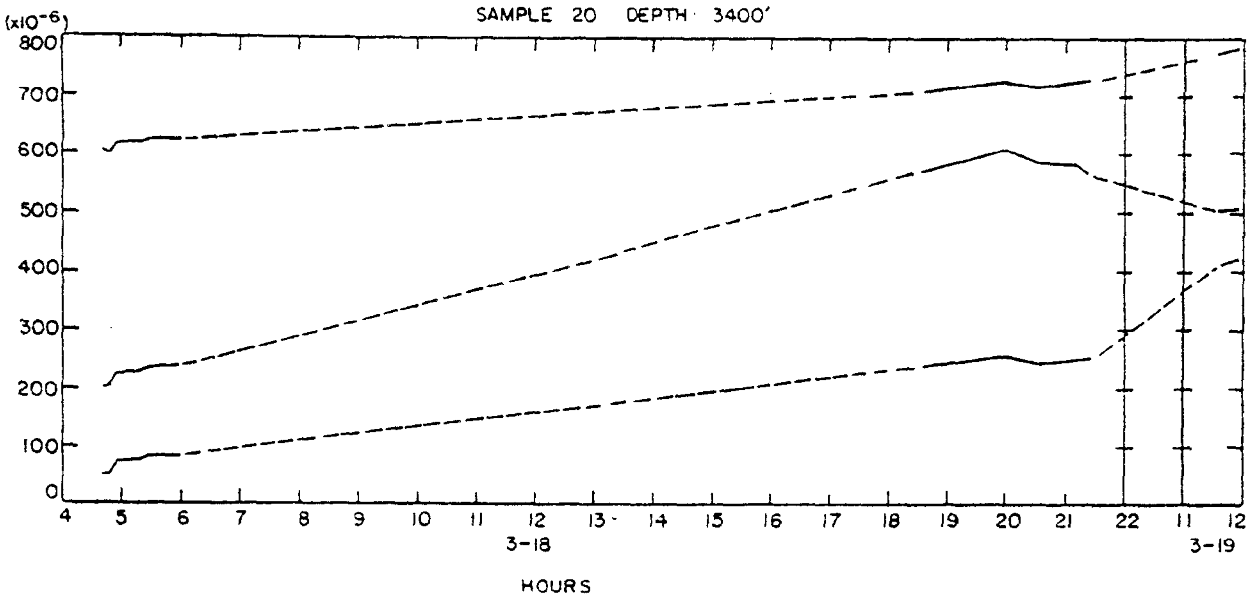

Figure 19. Strain-relaxation-time plots of Devonian Shale.

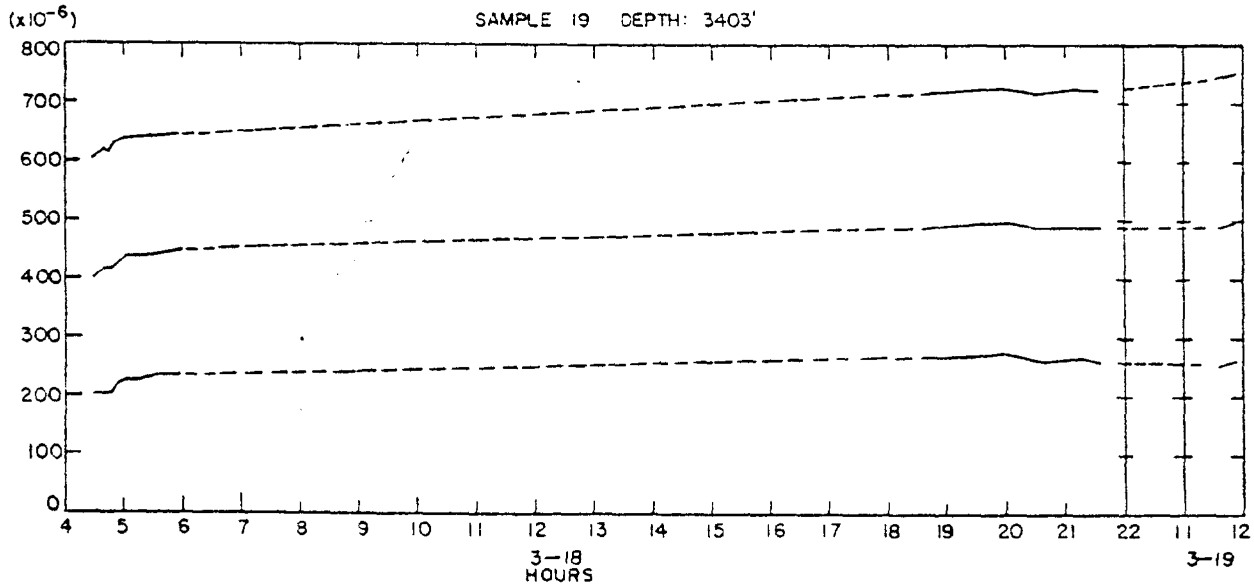

Figure 20. Strain-relaxation-time plots of Devonian Shale.

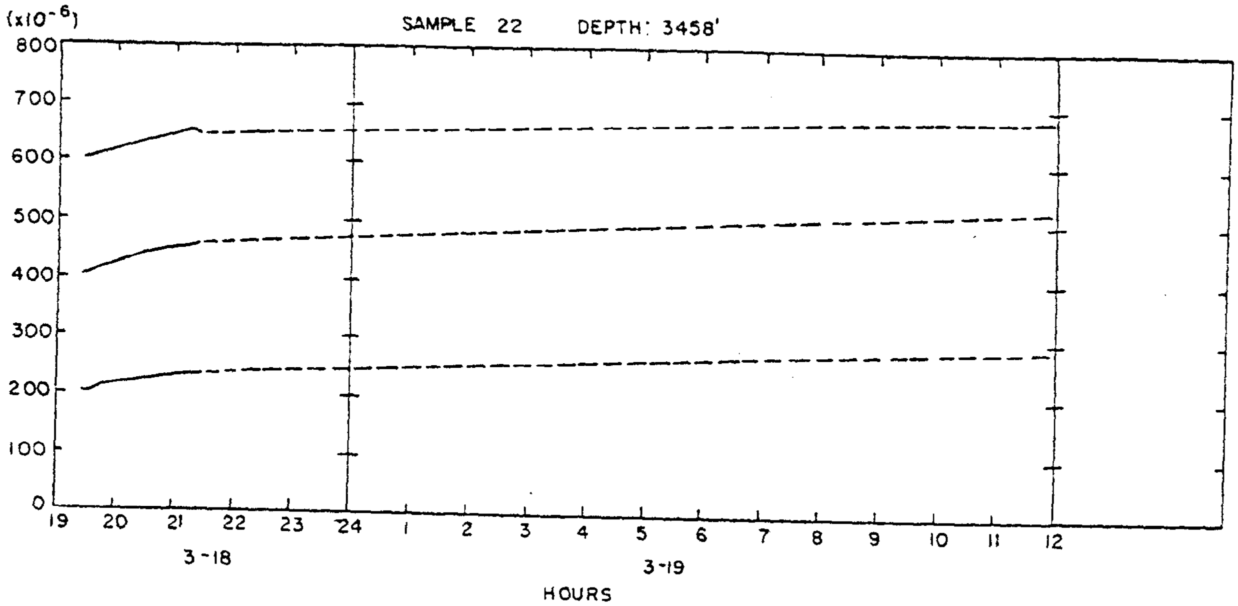

Figure 21. Strain-relaxation-time plots of Devonian Shale.

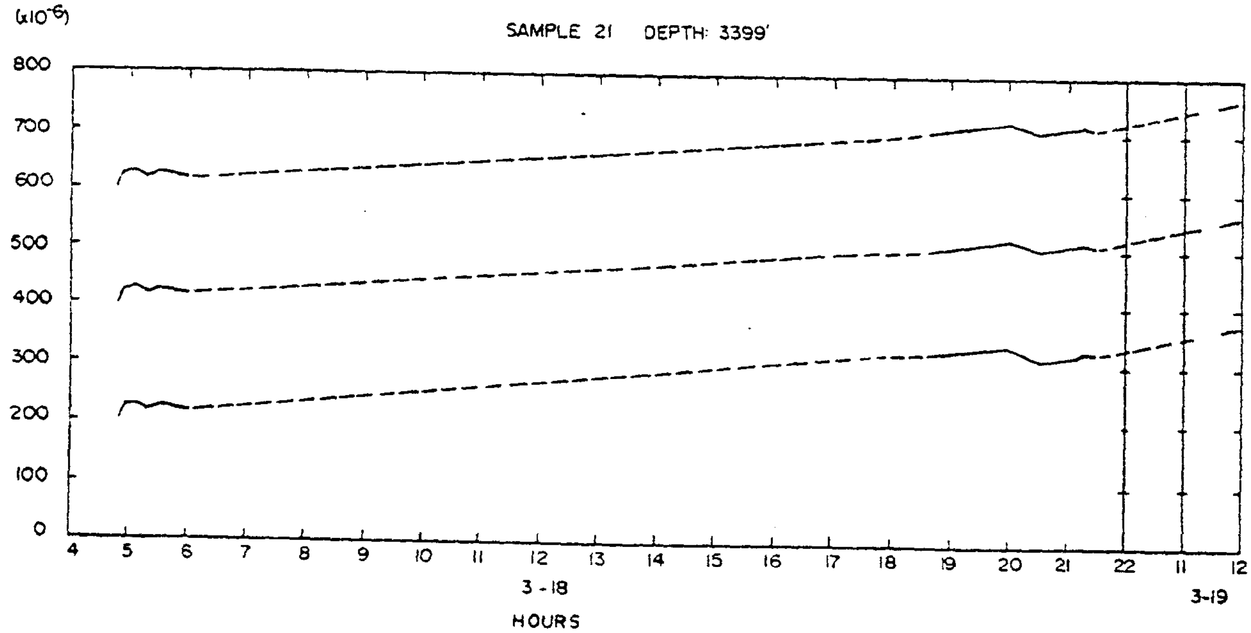

Figure 22. Strain-relaxation-time plots of Devonian Shale.

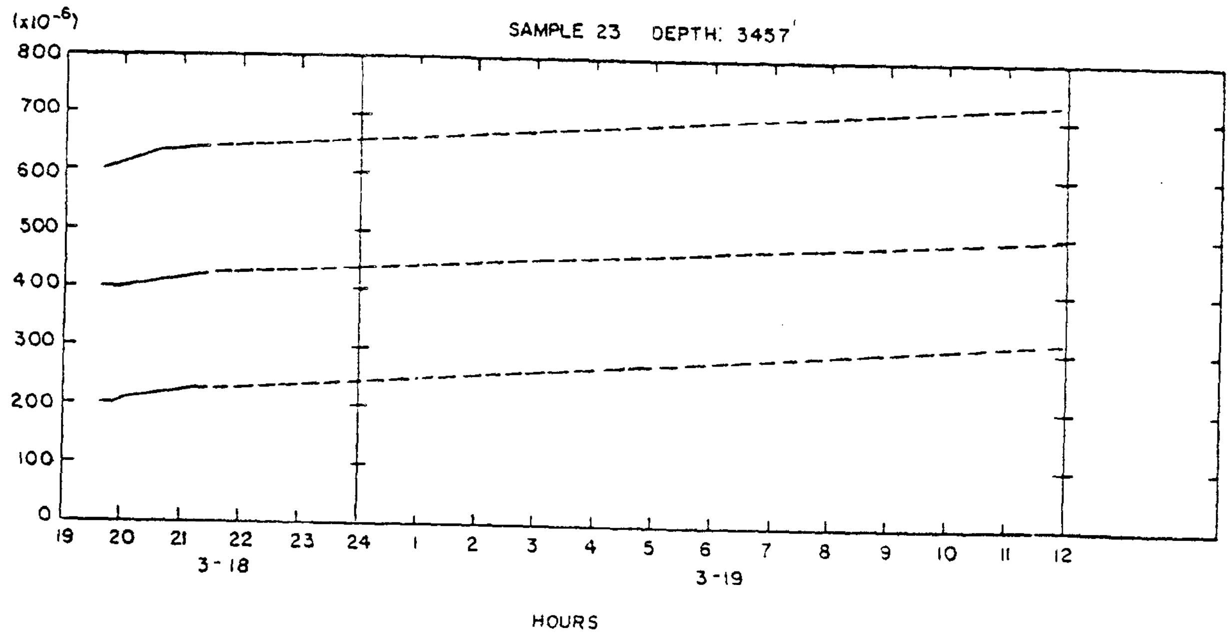

Figure 23. Strain-relaxation-time plots of Devonian Shale.

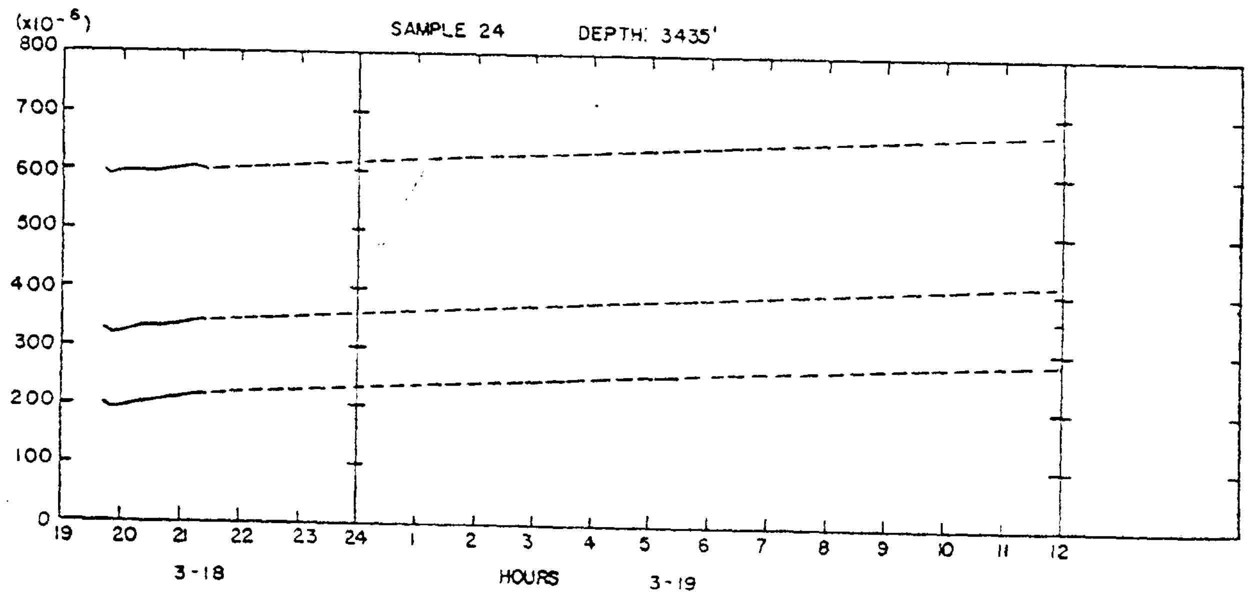

Figure 24. Strain-relaxation-time plots of Devonian Shale.

Nearly uniform or isotropic strain-relaxation was typical in the remainder of the shale specimens. Table I summarizes this information and also lists the relaxation rates (micro-inches per hour) for each specimen. Because at least three specimens were sampled from the bottom portion of each core-run and, therefore, represented a very small depth interval in the well, the relaxation rates in each group of samples were averaged and plotted against depth in Figure 25. This plot clearly shows that the relaxation rates are 2 to 2.5 times higher in the Middle Brown Shale (about 4 to 5 x 10^{-6}/hour) than those measured in the Upper and Middle Gray Shales (about 2 x 10^{-6}/hour).

<u>Velocity Measurements</u>

Ultrasonic measurements were made on a total of twelve core segments. The transducer assembly was mounted to the samples as soon as possible after coring, without interfering with the strain gaging operation. Table II is a listing of the changes in transit times at various intervals after the initial readings. The changes in transit time in all of the samples are very slight and are not considered in the discussion that follows.

TABLE I

Strain Relaxation Tests

Sample (#)	Depth (feet)	Strain Relaxation Gage (x 10^{-6}) 1	2	3	Elapsed Time (hours)	Average Relaxation per Sample (x 10^{-6})	Average Relaxation Rate per Sample (x 10^{-6}/hour)	Average Relaxation Rate per Core Run (x 10^{-6}/hour)*
3	2709	40	50	60	14	50	3.6	1.8
6	2703	0	0	0	14	0	0	
8	2759	30	0	0	15	10	0.7	2.1
9	2746	110	20	30	15	53	3.5	
10	3058	50	10	25	40	28	0.7	2.0
11	3057	150	200	150	40	167	4.2	
12	3049	50	50	35	40	45	1.1	
13	3117	25	15	10	24	17	0.7	1.2
14	3116	0	25	30	24	18	0.8	
15	3114	75	50	35	24	53	2.2	
16	3348	175	165	130	30	157	5.2	4.0
17	3343	40	110	120	30	90	3.0	
18	3340	85	130	135	30	117	3.9	
19	3403	150	110	60	32	107	3.3	4.0
21	3399	140	170	150	32	153	4.8	
22	3458	80	130	90	16	100	6.3	5.7
23	3457	90	110	100	16	100	6.3	
24	3435	70	60	80	16	70	4.4	

* This column is plotted against depth in Figure 25.

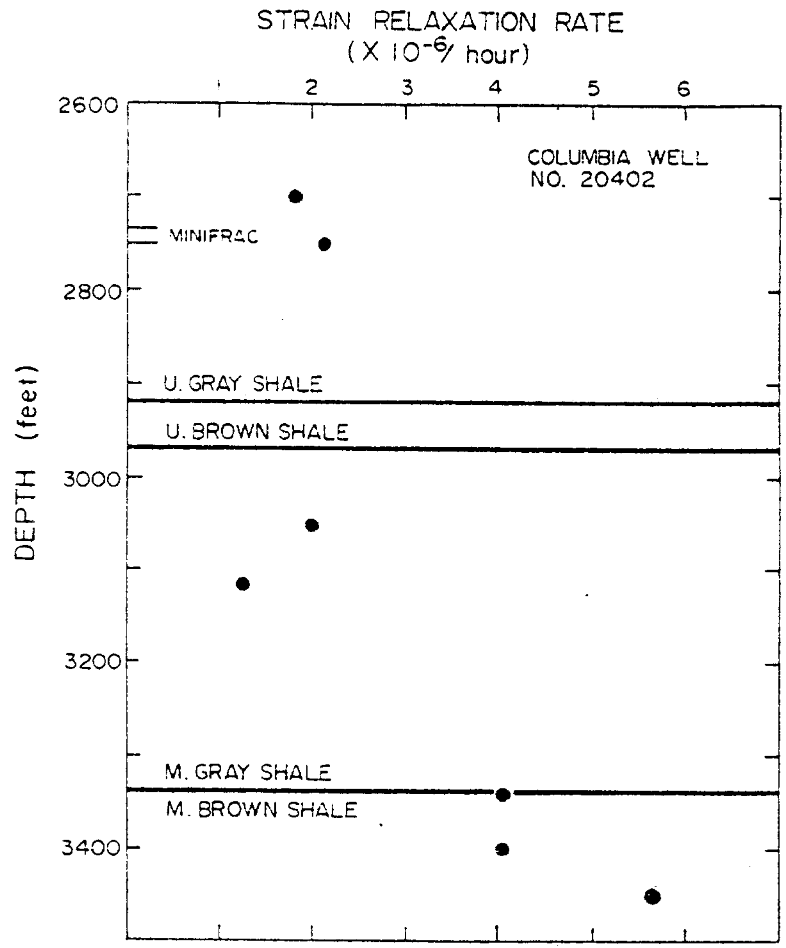

Figure 25. Plot of strain-relaxation rate against depth in Columbia Well No. 20402.

TABLE II

Change in P-Wave Transit Times with Elapsed Time on Cores Retrieved from Columbia Well #20402

Sample Depth (ft)	Elapsed Time		Normalized Transit Time (t/to)	
	Hrs.	Min.	"A"	"B"
2686		30	0.97	1.00
2686	14	10	0.97	0.98
2686	16	25	1.00	0.98
2698		30	1.00	1.00
2709		15	1.00	1.00
2709	11	30	1.02	1.00
2768		20	1.00	1.00
2768		50	1.00	1.00
2768	3	50	1.01	1.00
2768	26	20	1.01	1.00
3049		15	1.00	1.00
3049		35	1.00	1.00
3049	1		1.00	1.00
3049	13	50	0.98	1.00
3114		20	1.01	0.98
3114		40	1.03	0.98
3114	1	30	1.03	0.98
3114	24	10	1.01	0.98
3117		20	1.00	0.99
3117		50	1.00	0.97
3117	1	35	1.00	0.97
3117	24	20	0.97	0.97
3340		10	1.00	1.00
3340		40	1.01	1.01
3340	1		1.03	1.03
3340	2	10	0.99	0.99
3340	10	10	0.99	0.97
3344		25	1.00	----
3344	10	50	1.00	----
3400		20	0.97	1.00
3400	1		0.96	0.99
3435		15	1.00	1.02
3435		45	0.99	1.00
3435	1	30	0.99	1.00
3459		35	1.01	1.01
3459	1		1.00	1.01
3459	1	45	1.01	1.03

DISCUSSION

The subsurface stresses in sedimentary rocks are generally thought to increase linearly with depth: the vertical stress due to the overburden weight increases at about 1 psi per foot and the minimum-horizontal stress, on the average, increases at about 0.7 psi per foot (Figure 26).

The overburden stress-gradient of 1 psi per foot is generally accepted, although in geologically more recent environments (i.e., the Gulf Coast) this gradient is slightly less at 0.9 psi per foot. On the other hand, evidence is accumulating rapidly to suggest that the minimum-horizontal stress-gradient varies with rock type. For example, in hard rocks such as granites and quartzites the minimum stress-gradient can be as low as 0.5 psi per foot, in low-porosity sandstones it varies between 0.6 and 0.7 psi per foot and in weak shales and salt it can be as high as 0.9 psi per foot. It appears that the minimum stress-gradient decreases with increasing rock strength, but the underlying reason for this phenomenon is little understood.

The well-bore pressure gradient, required to induce and extend fractures in subsurface formations, is primarily dependent on the minimum stress-gradient and partially dependent on the overburden stress-gradient and formation pore-pressure gradient. It appears, therefore, that a good stimulation or fracture-treatment of a potential gas reservoir will, among other equally important variables, depend on the proper estimation or measurement of the stratigraphic distribution of the subsurface stress-gradients.

Estimation of Devonian Shale Stress Gradients

Within the essentially monolithic Devonian Shale sequence, is it possible to determine whether or not significant variations in the minimum stress-

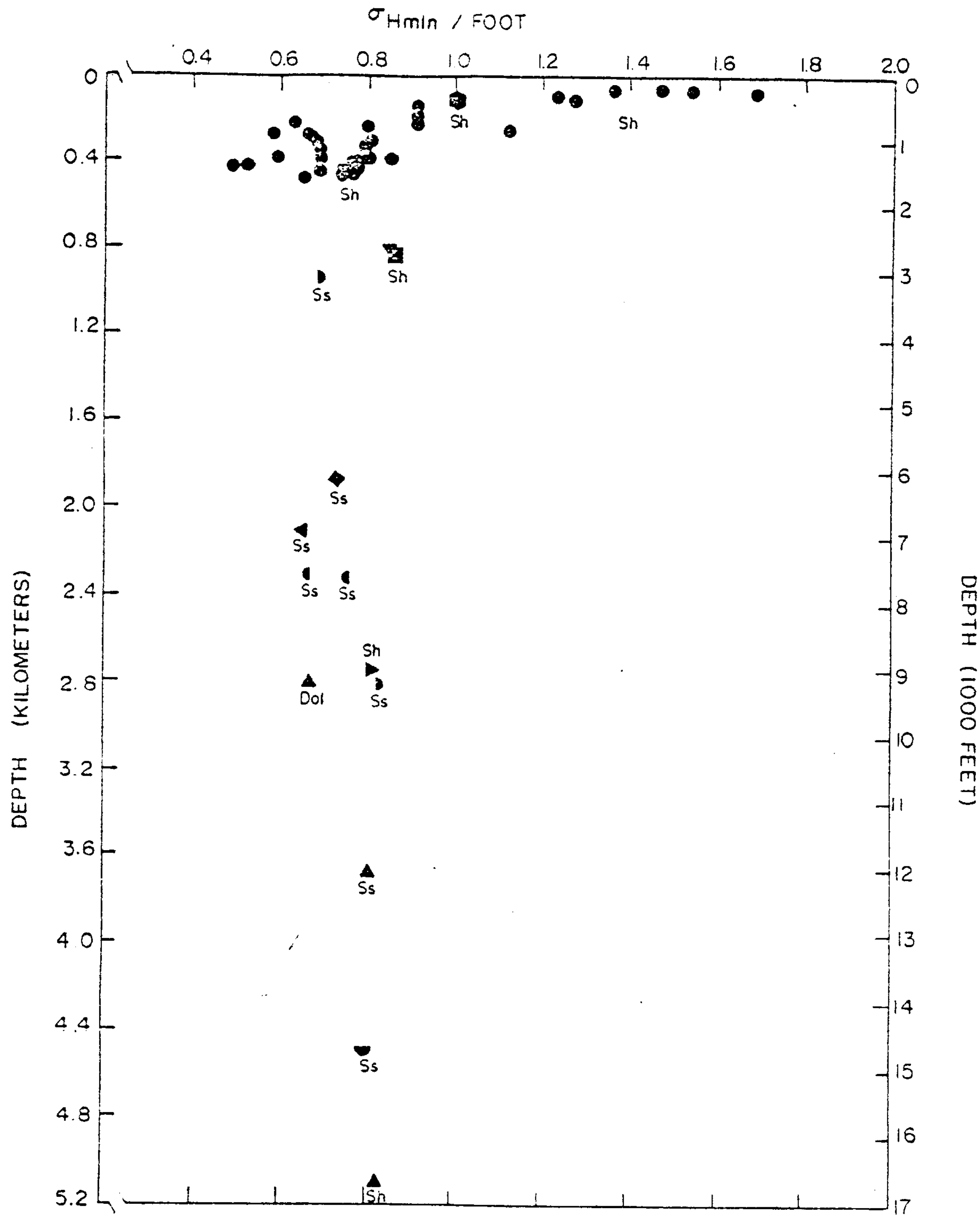

Figure 26. Vertical distribution of the minimum-horizontal-stress gradient (psi/ft) in sedimentary basins. Below a depth of 1000 feet the stress gradient is 0.7 psi/ft and increases slowly to 0.8 psi/ft at 17,000 feet. Ss - sandstone, Dol - dolomite and Sh - Shale.

gradients exist among the major shale zones and to predict whether or not the fracture-treatment of prime shale zones will be successful? A partial answer to this question is suggested by the strain-relaxation tests on cored samples from three major shale zones in the Devonian Shale.

Among the many variables that affect strain-relaxation in rock samples, the two that follow are the most influential:

- Rock type; i.e., soft versus hard rock, and
- Magnitude of local, subsurface stresses.

All of the samples were obtained from the Devonian Shale which is finely stratified and almost entirely composed of micaceous minerals (Figure 27). The compositional differences between the major shale zones are, if any, very slight and do not significantly affect the strain-relaxation results.

The limited information that is available on the behavior of rock samples under load indicates that strain-relaxation rates increase markedly, but not necessarily linearly, when higher loads are removed from the samples. An important variable in this context is the magnitude of the maximum stress difference. In the subsurface, the maximum stress difference is that between the overburden stress and the minimum horizontal stress ($\sigma_{O.B.} - \sigma_{Hmin}$).

The results of the strain-relaxation tests (Figure 25) show that samples from the Middle Brown Shale (MBs) zone relaxed at a rate 2 to 2.5 times greater than those representative of the upper Gray Shale (uGs) zones. Because the relaxation rates ($\dot{\varepsilon}$) are proportional to the local, subsurface, maximum stress differences ($\sigma_{O.B.} - \sigma_{Hmin}$), we can write for each shale zone:

$$\dot{\varepsilon}_{MBs} \propto (\sigma_{O.B.} - \sigma_{Hmin})$$

and (1)

$$\dot{\varepsilon}_{uGs} \propto (\sigma_{O.B.} - \sigma_{Hmin}) \quad .$$

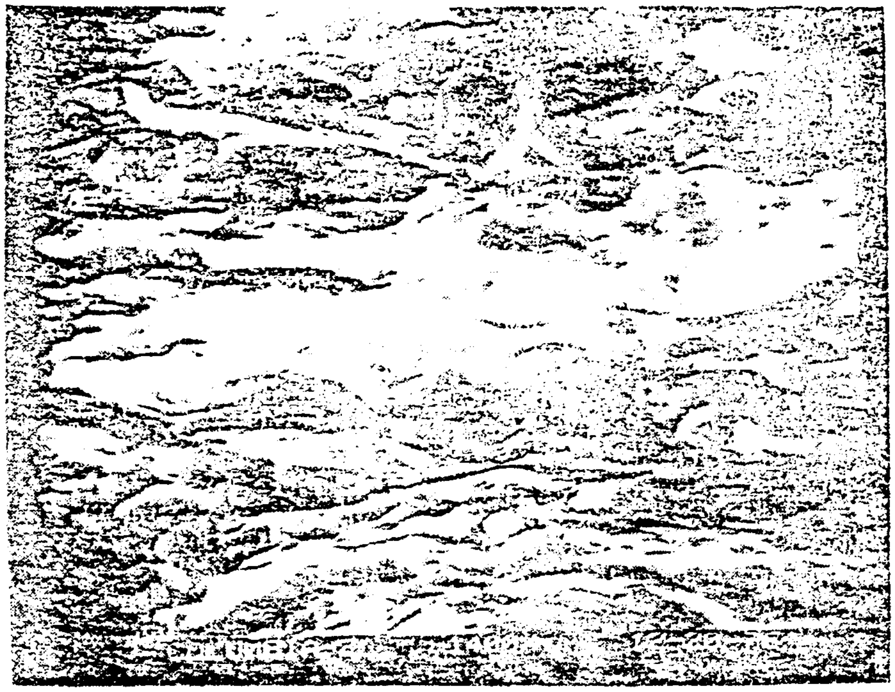

Figure 27. Scanning-electron micrograph of Middle Gray Shale (3056 ft) showing compacted clay particles. Scale: 1 cm = 20 microns.

The relaxation rates on the left of the proportionality can be written in terms of stress by multiplying $\dot{\varepsilon}$ by the Young's modulus (E) and an arbitrary time interval (t) and we get:

$$(E)\ (\dot{\varepsilon}_{MBs})(t) \propto (\sigma_{O.B.} - \sigma_{Hmin})$$

and (2)

$$(E)\ (\dot{\varepsilon}_{uGs})(t) \propto (\sigma_{O.B.} - \sigma_{Hmin}) \quad .$$

Both sides of the proportionality are now in psi units, but the stresses on either side are not exactly equal to each other because the left-hand term refers to a stress in the sample and the right-hand term refers to the stress difference in the respective subsurface shale zones. We can now normalize proportionality (2) by dividing both sides by $\sigma_{O.B.}$ or, what amounts to the same thing since $\sigma_{O.B.}$ increases by 1 psi/foot, by depth (feet):

$$(E)(\dot{\varepsilon}_{MBs})(t)/ft \propto (1 - \sigma_{Hmin}/ft)$$

and (3)

$$(E)(\dot{\varepsilon}_{uGs})(t)/ft \propto (1 - \sigma_{Hmin}/ft)$$

The relaxation rates are now proportional to the minimum-horizontal stress-gradients in each of the shale zones. For the time being we assume that the Young's moduli (E) in both shale zones are equal to 4×10^6 psi* and that (t) is equal to 100 hours. The relaxation rates in the Middle Brown Shale zone and in the upper Gray Shale zones are 4×10^{-6}/hour and 2×10^{-6}/hour, respectively (Figure 25). Upon inserting and multiplying these values on the left side of proportionality (3), reversing sides and rearranging, we get:

$$(\sigma_{Hmin}/ft)_{MBs} \propto (1 - 1600/ft)$$

and (4)

$$(\sigma_{Hmin}/ft)_{uGs} \propto (1 - 800/ft)$$

From well logs, the contact or boundary between the Gray Shale zone and the Middle Brown Shale zone in Columbia Well No. 20402 is at a depth of about 3340 feet. Upon dividing the numbers on the right side by 3340, we observe that the minimum stress-gradient in the Middle Brown Shale zone is proportional to (1 - 0.48) = 0.52 psi/ft and in the overlying Gray Shale the minimum stress-gradient is proportional to (1 - 0.24) = 0.76 psi/ft. The minimum stress-gradient in the Middle Brown Shale increases to 0.64 psi/ft if the Young's modulus (E) is reduced from 4×10^6 to 3×10^6 psi* (Figure 28).

It should be understood, at this point, that the values of the minimum stress-gradients just obtained are only estimates; they do not equal the actual subsurface stress gradients. However, these estimates serve an

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* The values for Young's modulus (E) were taken from Terra Tek Progress Report No. 3 and 4.

important purpose. They suggest that the minimum stress-gradient is higher (by as much as 30 percent) in the Gray Shales than in the Middle Brown Shale. This, in turn, suggests that an artificial fracture could be induced and extended at lower bottom-hole pressures in the Middle Brown Shale and, furthermore, if the bottom-hole treating-pressure can be kept below a peak-pressure level (1600 - 1700 psi at the well-head*), the fracture propagating into the Middle Brown Shale can be contained and prevented from propagating upward into the Gray Shale zone because of the higher stress levels in this upper zone.

Comparison with Well-Bore Data

The discussion above may appear as so much conjecture. It is necessary, therefore, to compare the results and conclusions obtained from core-analysis (strain-relaxation) work with direct down-hole measurements.

The results of the Schlumberger Synergetic Log are abstracted in Figure 28A. It appears that the fracture-pressure-gradient profile of the Devonian Shale clearly identifies shale zones in which fractures can be induced and extended at lower bottom-hole pressures; i.e., the Lower Brown Shale (Marcellus) and the Middle Brown Shale. Although stresses do not appear explicitly in the calculation of the fracture-pressure-gradient profile, the log is an estimate of the minimum stress-gradients. The correlation between the subsurface data and the core-analysis (strain-relaxation) results is remarkably good (Figures 28A and B).

The result of the minifrac experiment performed by Terra Tek is also plotted in Figure 28A. The point represents the down-hole instantaneous shut-in pressure divided by the depth at which the measurement was made (2360 psi/2745 feet = 0.86). The agreement between the minifrac result

*This upper limit in pressure is equal to the breakdown pressure plus the difference in the horizontal stresses between the upper Gray Shales and the Middle Brown Shale.

APPLICATION/SYSTEM OR SPONSORING ORGANIZATION'S NAME	MANUAL/PROCEDURE/GUIDE TITLE		
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FORM CS 4-510 CSO (4-76)

COLUMBIA GAS SYSTEM

ELECTRONIC DATA PROCESSING DEPARTMENT

ABEND/NON-ABEND ERROR OR DESCRIPTION

PROGRAM NAME	PROGRAM NUMBER	ERROR CODE
Financial Statement Format	HC2550	

DISPLAY MESSAGE

xxx,xxx,xxx,xxx- xxx,xxx,xxx,xxx-
'OUT OF BALANCE PAGE' xx 'LINE' xx 'COLUMN' z

CORRECTION BY / DETECTED IN PARAGRAPH(S)

- [ ] COMPUTER OPERATOR
- [ ] DATA CONTROL CLERK
- [ ] USER DEPARTMENT
- [ ] CURRENT SYSTEMS SECTION

CAUSE OF DISPLAY

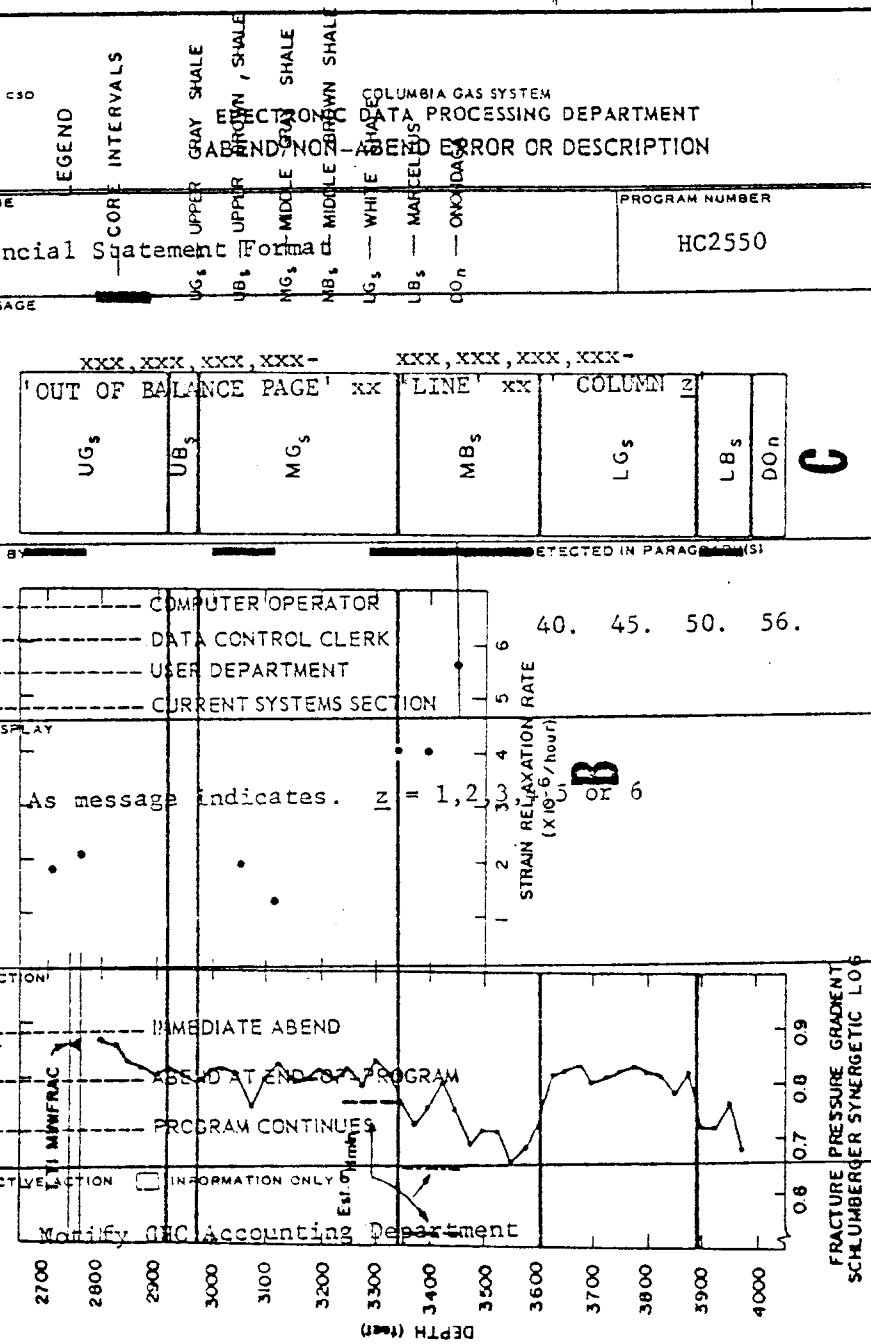
As message indicates. z = 1,2,3,4,5 or 6

PROGRAM ACTION

- [ ] IMMEDIATE ABEND
- [ ] ABEND AT END OF PROGRAM
- [X] PROGRAM CONTINUES

[X] CORRECTIVE ACTION [ ] INFORMATION ONLY

Modify CHC Accounting Department



Figur 28. A. Correlation between the minimum-horizontal-stress estimates (—— for E = 4 x 10^6 psi and ---- for E = 3 x 10^6 psi) and the fracture-pressure-gradient profile and the instantaneous shut-in pressure gradient determined down-hole.

B. Same as Figure 25.

C. Stratigraphic column of Devonian Shale in Columbia Well No. 20402.

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and the Synergetic Log which starts just below the minifrac interval is quite good. It confirms the inference that high subsurface stress-gradients are proportional to low strain-relaxation rates in cored samples.

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COLUMBIA GAS SYSTEM

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PROGRAM NAME	PROGRAM NUMBER	ERROR CODE
Financial Statement Audit	HC2530	

DISPLAY MESSAGE

'NON NUMERIC AMOUNT SUBSTITUTING ZEROS FOR PAGE' xx 'LINE' xx 'COMPANY' xx

CORRECTION BY	ERROR DETECTED IN PARAGRAPH(S)
[ ] COMPUTER OPERATOR [X] DATA CONTROL CLERK [ ] USER DEPARTMENT [ ] CURRENT SYSTEMS SECTION	87

CAUSE OF DISPLAY

As message indicates.

PROGRAM ACTION

- [ ] IMMEDIATE ABEND
- [ ] ABEND AT END-OF-PROGRAM
- [X] PROGRAM CONTINUES

[X] CORRECTIVE INFORMATION

Notify CHC Accounting Department

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RECOMMENDATIONS FOR COLUMBIA WELL NO. 20402

1. The prime, gas-bearing, candidate shale zones for fracture (MHF) treatment in Columbia Well No. 20402 which is presently shut-in are:

   The Middle Brown Shale and

   The Marcellus.

2. Fracture treatment should be confined to these two shales only, if the object is to contain the induced fractures within these shale zones and increase gas production.

3. The higher stresses in the Gray Shales and White Slate will aid in the containment of the induced fracture within the Middle Brown Shale and in the Marcellus, prevent them from propagating either upward or downward into the barrier zones, and promote the lateral extension of the fracture.

4. The bottom-hole treating-pressure (BHTP) should not be greater by 400 to 800 psi above the bottom-hole breakdown pressure, which is about 800 to 900 psi at the well-head for the Middle Brown Shale. If BHTP greatly exceeds this peak pressure the barrier zones (Gray Shale and White Slate) may breakdown as well.

5. These recommendations, based only on the strain-relaxation tests and a single mini-frac test, should be carefully checked against previous MHF experience in Wells No. 20401 and 20403, in which the potential barrier zones were perforated and fractured.

6. Unsolved, but pertinent problems remaining are, among others:

   - Exact fracture-density variation among zones
   - Secondary-porosity prediction
   - Prediction of formation breakdown-pressure.

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COLUMBIA GAS SYSTEM SERVICE CORPORATION
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SECTION TITLE: ERROR DETECTION AND CORRECTION | SECTION NO. 7 | TOPIC NO 01 | PAGE 44
TOPIC TITLE: CODED ERROR MESSAGES | ISSUED/REVISED DATE | REVISION NO. | EXHIBIT

COLUMBIA GAS SYSTEM
ELECTRONIC DATA PROCESSING DEPARTMENT
ABEND/NON-ABEND ERROR OR DESCRIPTION

PROGRAM NAME: Financial Statement Audit | PROGRAM NO.: HC2530 | REQUESTED BY: (Ira McCoy 20402)

DISPLAY MESSAGE:
RECORD COUNT OUT-OF-BALANCE FOR COMPANY XX
RECORDS READ XXXXX
RECORD COUNT FROM BAL RECORD XXXXX

[ ] COMPUTER OPERATOR
[X] DATA CONTROL CLERK
[ ] USER DEPARTMENT
[ ] CURRENT SYSTEMS SECTION

27-BAL

CAUSE OF DISPLAY:
As message indicates.

PROGRAM ACTION:
[ ] IMMEDIATE ABEND
[X] ABEND 77 END-OF-PROGRAM
[X] PROGRAM CONTINUES

[X] CORRECTIVE ACTION [ ] INFORMATION ONLY
Notify CHC Accounting Department.

PREPARED BY: Current Systems | DATE: 9/30/76

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