APPENDIX B

STRAIN-RELAXATION MEASUREMENTS IN THE MESAVERDE AND MANCOS SHALES, UINTA BASIN, UTAH

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SUMMARY

This report describes the results of field work performed at the PTS 23-25 Federal well-site to assess the subsurface stress conditions in Lower Cretaceous rocks and to evaluate the potential for creating and containing a massive hydraulic fracture(s) within the Castlegate Sandstone. The two-fold objective of the program was to:

1. Estimate the relative stress states in the barrier shales (Mesaverde and Mancos) and the payzone (Castlegate).
2. Determine the preferential direction (azimuth) of fracture extension within these rock units.

The results of this work yield the following observations:

1. The stress states in the Mesaverde and Mancos shales are very similar and approach lithostatic conditions; that is, all stress components are very nearly equal to the overburden pressure.
2. The preferred direction of fracture extension in the rock units tested is N 60°-65° W, which is parallel to the average strike of the gilsonite dikes of the Uinta Basin, Utah.

Because no core has been obtained from the Castlegate Sandstone, a comparison between the stress states in the barrier shales and the pay sandstone has not been possible.

INTRODUCTION

Strain-relaxation tests were performed on sixteen core samples of sandstone, siltstone and shale obtained from the 7466'-9209' depth interval in Pacific Transmission Supply Well No. 23-25 Federal, Uintah County, Utah. The two-fold purpose of the program was to:

1. Determine the geographic extension direction of massive hydraulic fracture to be induced into subsurface gas-bearing formations.
2. Estimate the relative subsurface stress states in the barrier shales (Mesaverde and Mancos) and in the Castlegate Sandstone.

To accomplish this task, an inexpensive and reliable core-analysis technique has been used that very accurately measures the small dimensional changes (strain relief) in rock samples after they have been cored and brought to the surface. The smallest dimensional change that can be determined by this technique is of the order of several parts per million (i.e., 10^{-6} inch per 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 or loads 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 (vertical overburden) stress and the least (minimun-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 stresses down the hole and determine the relative changes, if any, in the stress distribution from formation to formation. Nevertheless, this kind of information is useful and important because it can lead to an early

recognition of significant deviations in the subsurface stresses (usually assumed to increase linearly with depth) and the identification of prime zones for stimulation and fracture treatment without endangering the well with time-consuming tests.

An added benefit derived from the strain-relaxation measurements is the determination of the geographic direction along which a future massive hydraulic-fracture may propagate into subsurface formations. It is generally known that the hydraulic fracture will propagate along a direction perpendicular to the minimum-horizontal stress, but the accuracy of the measurement of fracture azimuth depends on how great the differences are between the principal stress components in the subsurface. Provided, therefore, that these directional measurements are correct, then the proper siting and spacing of development wells could conceivably result in substantially greater percent recovery of the natural gas resource.

In this report we will briefly outline the important aspects of the core analysis technique of strain relaxation and its limitations. These will be followed by the description of the strain-relaxation results obtained in samples from the Mesaverde and Mancos formations in PTS No. 23-25 Federal. Finally, attention will be focused on how these results can be interpreted to provide new and useful information on the subsurface stress conditions in those formations tested, and the azimuth of artificially induced hydraulic fractures.

CORE-ANALYSIS 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 oriented 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° 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. Four core samples instrumented with 45-degree strain rosettes. Gages 1, 2 and 3 in each rosette are seen from left to right on each sample. The samples are sandstone from the Mesaverde formation (7466' to 7487').

Each of the three strain gages in the 45-degree rosette was 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 until all relaxation ceased. Three strain-time curves were drawn for each specimen to provide the basic data from which to calculate the rates, magnitudes and major directions of strain relaxation.

Sixteen rock specimens were selected from four oriented cores; i.e., four specimens per core run. The first two cores (#3 and 6) were taken from the Mesaverde Formation at depth intervals of 7430' - 7489' and 8032' - 8074'. However, only the top halves of these two Mesaverde cores were oriented. The two remaining cores (#10 and 11) were taken from the Mancos Formation at depth intervals of 8990' - 9030' and 9163' - 9223'. The entire lengths of these latter cores were oriented. No cores were obtained from the Castlegate Sandstone (8820' - 8986').

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}.
3. The rock samples should be oriented geographically to determine the azimuths 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 four rock samples as soon as possible after the coring of PTS No. 23-25. 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

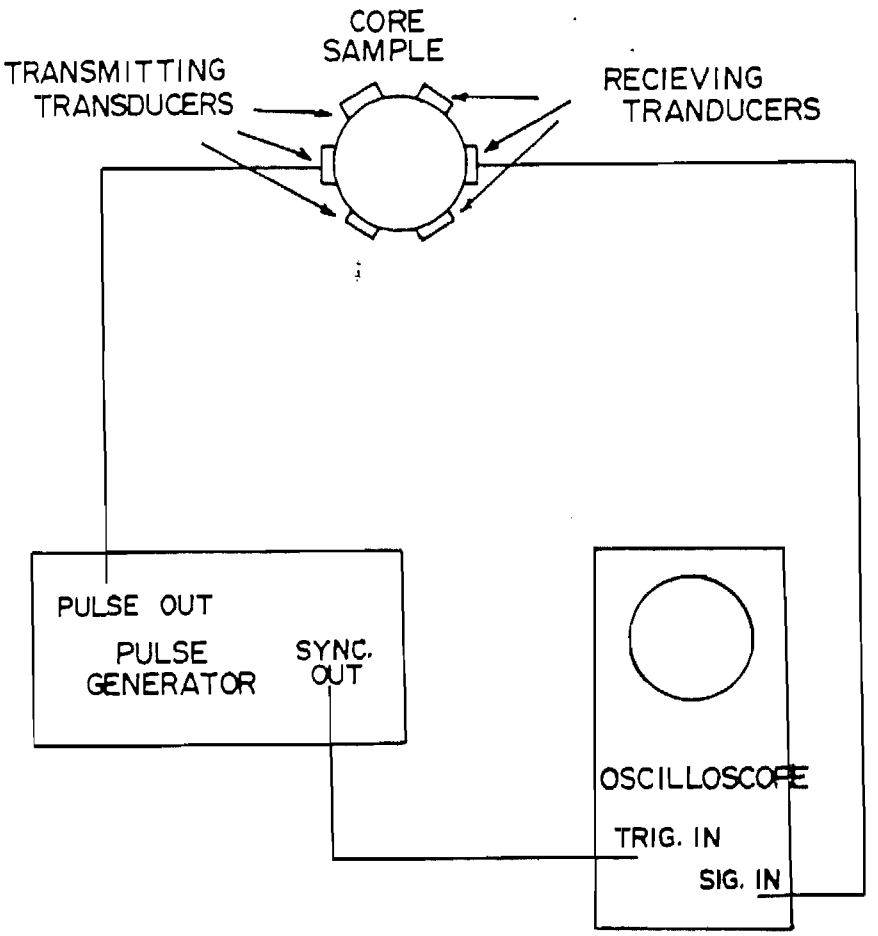


Figure 2. Schematic diagram of field equipment used to measure changes in P-wave velocity along three horizontal directions (60 degrees apart) in a relaxing core.

excite the transmitting transducer and, at 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 three 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, 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.

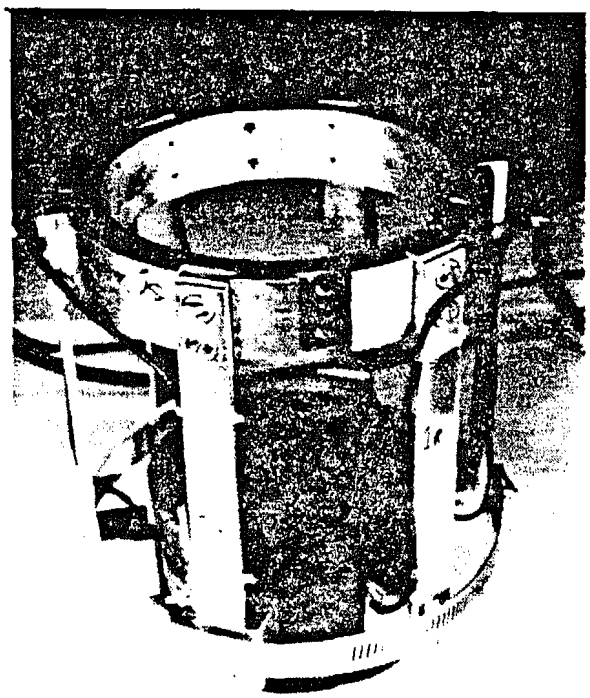


Figure 3. Photograph of sonic-transducer assembly.

RESULTS

Sixteen rock specimens were selected from extracted cores (7466 feet to 9209 feet) in the PTS Well No. 23-25 Federal and monitored for two days until all relaxation had ceased. Most of the specimens came from the bottom of each core run in order to capture the maximum amount of strain relief. Compressional P-wave velocities were made on four specimens to check and augment the strain-relaxation results.

Strain Relaxation

The results of the strain-relaxation tests are summarized in Table I. Within five hours after the tests begun the samples ceased to relax any further. The average strain relaxation in all of the samples was about 30×10^{-6} with a maximum of about 130×10^{-6} and a minimum of about 3×10^{-6}. No significant differences in the amount of relaxation have been observed between the Mesaverde and Mancos formations, although the Mancos shales and siltstone show a more pronounced anisotropy in the strains. Excessive strain relaxation occurred in at least three specimens because of outgassing of the cores (Table I, Nos 8, 9 and 14). Slowly escaping gasses were trapped between the rock surface and the gage backing, forming a noticeable bubble and causing of the gages to expand beyond reasonable limits. These particular tests were immediately discontinued.

The directions of maximum and minimum relaxation could be calculated for only a few of the specimens whose orientation were known. These are shown in Table I and in Figure 5. The orientations of maximum expansion in four Mancos specimens trend in a NE-SW direction; more or less perpendicular to the average strike (N 60°- 65° W) of the gilsonite dikes as mapped on the surface (Figure 5). The rather wide scatter in the directional data are largely due to the uncertainties in the orientation of the test specimens. Orientations of the cores in the well were obtained at intervals of about three feet and rotations

TABLE I

STRAIN-RELAXATION IN SELECTED CORE SAMPLES

Experiment No.		Depth Ft.	Core Orientation	Strain Relief e_1 10^{-6}	e_2 10^{-6}	e_3 10^{-6}	Maximum Expansion 10^{-6}	Minimum Expansion 10^{-6}	Bearing of Maximum Expansion	Remarks
1	MESAVERDE	7487	None	17	21	16	21	12	Unknown	
2		7482	"	10	4	19	26	3	"	
3		7474	"	3	6	0	-	-	"	Strains too small
4		7466	"	60	36	12	60	12	"	
5		8067	"	12	20	18	21	9	"	
6		8057	"	100	80	110	130	80	"	
7		8052	N 36° W	9	10	11	11	9	N 9° E	Direction unreliable strains too small
8		8046	N 36° W	50	-	-	-	-	Unknown	Gilsonite (?) Sample outgassing Gages destroyed
9	MANCOS	9029	N 75° E	40	-	-	-	-	"	Sample outgassing Gages destroyed
10		9026	N 60° E	-	-	-	-	-	"	Improper gage bond
11		9021	N 84° W	50	30	10	50	10	N 51° E	
12		9013	N 74° E	10	10	10	10	10	Unknown	Isotropic strain Direction indeterminate
13		9209	N 68° W	80	40	20	82	18	N 57° E	
14		9202	N 43° W	40	-	-	-	-	Unknown	Sample outgassing
15		9197	N 76° E	30	60	40	61	9	N 82° E	
16		9179	N 39° E	50	80	30	81	0	N 32° E	

as large as 105° occured between adjacent measurement points. To extrapolate the orientation of the specimen taken from within the three foot interval, a linear rotation was assumed. This assumption, however, is easily violated if sudden rotations had occured due to the breaking-off of core along weak bedding planes or pre-existing fractures.

Velocity Measurements

Ultrasonic measurements were made on three Mesaverde specimens and one oriented Mancos siltstone. The transducers were mounted as soon as possible after coring, without interfering with the strain gaging operation. Table II is a listing of the compressional P-wave velocities along three planes across each sample. Initial measurements were compared with final ones after some time had passed. Very little, if any, changes have taken place primarily because the small strain changes in each of the samples did not significantly affect reductions in the elastic moduli and changes in density. The maximum change in velocity is about 3 percent and very close to the resolution of the technique.

Anisotropy in velocity is most pronounced (9 percent) in the oriented Mancos siltstone (Table II, No. 16). The direction of maximum velocity (5.3 km/sec) is N 41° W and the direction of minimum velocity (4.8 km/sec) is N 49° E which, in turn, is close to the direction of maximum strain relaxation in the same specimen (Table I, No. 16). The magnitude of the wave speed in a rock sample is indicative of the elastic modulus in such a way that a lower velocity usually suggests a lower modulus in the same direction. At the same time, larger strain relaxation can be expected to occur parallel to the direction of lower modulus. The orientation of maximum strain relaxation, minimum velocity and lower modulus nearly perpendicular to the predominant west north-westerly trend of the gilsonite dikes now assumes some importance

in the prediction of the propagation direction of massive hydraulic fractures. These points will be disucssed in greater detail in the chapter that follows.

TABLE II

ULTRASONIC VELOCITIES IN SELECTED CORE SAMPLES

Sample No.	Depth Ft.	Core Orientation	Initial Velocity (km/sec)			Elapsed time (hours)	Final Velocity (km/sec)			Orientation	
			V_1	V_2	V_3		V_1	V_2	V_3	Maximum Velocity	Minimum Velocity
1	7487	None	3.5	3.8	3.7	14	3.5	3.7	3.7	-	-
4	7466	"	4.0	3.7	4.1	16	4.0	3.7	4.0	-	-
6	8057	"	4.9	4.9	4.8	6	4.9	4.9	4.8	-	-
16	9179	N 39° E	5.1	5.2	4.8	28	5.1	5.2	4.8	N 41° W	N 49° E

DISCUSSION

Before the present results are discussed in detail, several aspects of the work should be emphasized and clarified.

- The strain relaxations and velocity measurements in the rock samples reflect only the stress and modulus distribution in the recovered *samples*. Since large components of lithostatic stresses or pressures have been removed through coring at depth, the measured strains cannot be used to obtain absolute determinations of the subsurface stresses; this can only be done by direct downhole measurements as the mini-frac tests (Brechtel and others, 1977). The measurements on the samples, provided that they represent the subsurface formations from which they were cored, can only yield relative estimates of the subsurface conditions. Therefore, it is the difference or variation in strain-relaxation behavior from sample to sample that provides new and useful information on the subsurface conditions in each of the formations encountered in the wellbore.
- The magnitude of strain relaxation expressed in dimensionless units (10^{-6}) depends on rock type (soft versus hard rock) and the magnitude of the local and/or regional subsurface stresses. In rock of the same kind (i.e., fine-grained, well-cemented sandstone) a *small* difference between the vertical, overburden stress and the minimum-horizontal stress is reflected in *small* amounts of relaxation in the core samples and, alternatively, *larger* subsurface stress differences yield *higher* magnitudes of strain relaxation in the samples.

These diagnostics in the relaxation behavior of core samples can be used to estimate the relative subsurface stress differences in reservoir rocks and in the formations above and below them. If, for example, the maximum stress difference ($\sigma_{O.B.} - \sigma_{Hmin}$) in the reservoir rock is greater than in the bounding formations, then the following interpretation can be made. Since the overburden stress will change little over a small depth interval, the minimum-horizontal stress in the bounding formations will be larger than in the reservoir rock at the interface. The wellbore pressure necessary to extend a fracture into the reservoir rock is very nearly equal to the local minimum stress and, therefore, this pressure is less than that required to fracture the bounding, non-productive formations. By the proper choice of frac fluids, pressures and depth interval, a fracture can be created, extended and contained within the payzone.

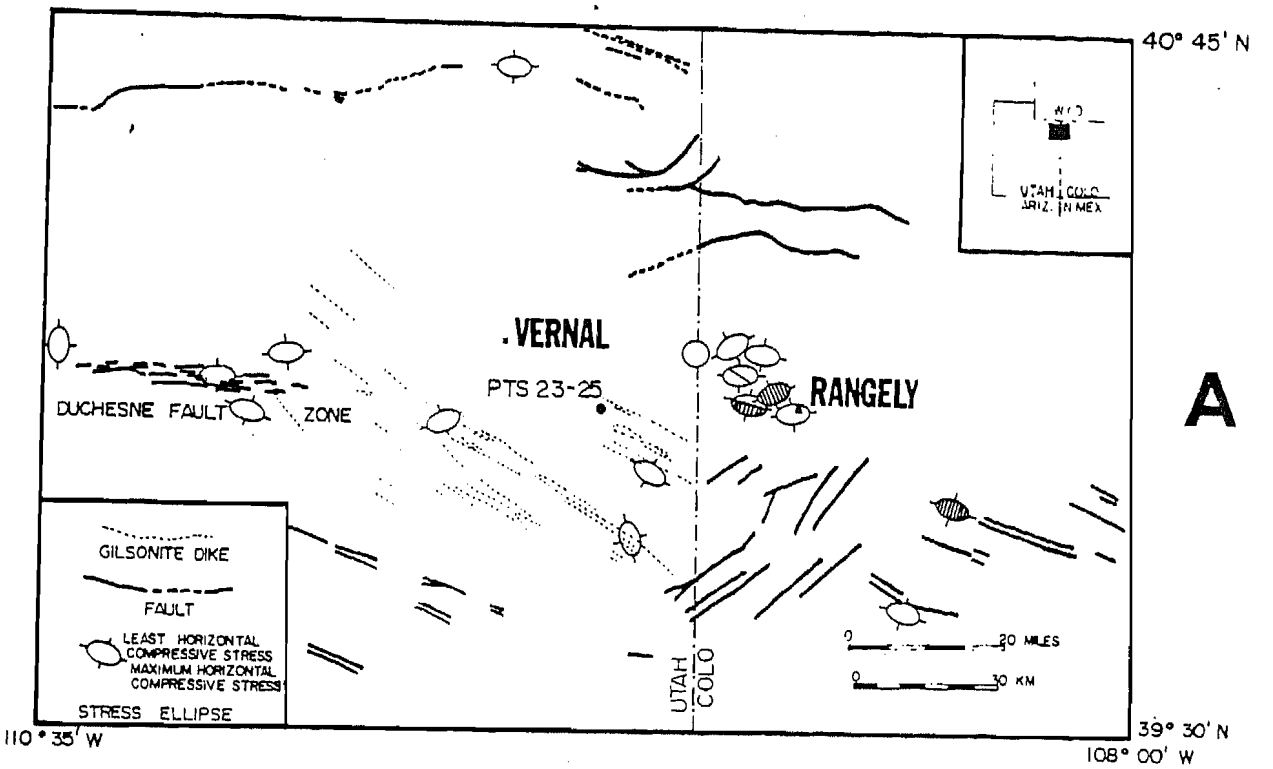
- If the strain relaxations and P-wave velocities vary in magnitude along different directions in an *oriented* core sample, then an interpretation can be made of the azimuth along which a hydraulic fracture may propagate. This interpretation can be reinforced with evidence from other direct and indirect stress measurements in and near the well and from local and regional geologic structures such as faults, folds and dykes. To illustrate this point, the following discussion will begin with a brief description of the pertinent regional structures in the Uinta Basin and surrounding areas.

Regional Stress System in the Uinta Basin, Utah

The PTS Well No. 23-25 Federal is located in the eastern part of the Uinta Basin, a sedimentary trough filled with Mesozoic and Tertiary rocks. Characteristic structures within the basin are a system of veins or dykes

filled with gilsonite (a non-volatile bitumen) and a system of normal faults (Figure 4a). The regional state of stress associated with these structures is such that the minimum-horizontal stress is oriented perpendicular to the general strike (bearing) of the dikes and normal faults (N 60°- 65° W) in the basin and the maximum-horizontal stress is parallel to their strike (Anderson, 1951; Hubbert and Willis, 1957, 1972; Hubbert, 1972). A similar reconstruction of the regional stress state based on structural analysis can be carried out in adjacent areas east of the Uinta Basin. In the uplifted Douglas Creek Arch the strikes of normal faults trend NE-SW indicating a NW-SE orientation of the minimum-horizontal stress and in the Piceance Basin of Colorado the minimum-horizontal stress orientation is back to NE-SW and perpendicular to the strike of normal faults (Figure 4a and b).

Additional evidence, supporting the generalization just mentioned, is supplied by a series of stress measurements on surface outcrops and in wells shown as ellipses in Figure 4a. The open ellipses represent surface stress measurements by Preston (1966), de la Cruz and Raleigh (1972) and Swolfs (1976) in the Uinta and Piceance basins and on the Rangely Anticline. The shaded ellipses represent hydraulic-fracture tests in wells supplemented with impression-packer surveys by Raleigh (1974) and Bredehoeft and others (1976). The direction of the major and minor axes of horizontal stress derived from these measurements are in general agreement with the orientations of the local structural elements (dikes and faults). The collective data on the prevailing, regional orientation of the minimum-horizontal stress are shown in Figure 4b. Over a broad region from west to east across Utah and Colorado, the minimum stress directions rotate from N-S (Duchesne fault zone) to NE-SW (Uinta Basin), to NW-SE (Douglas Creek Arch) and back to NE-SW (Piceance



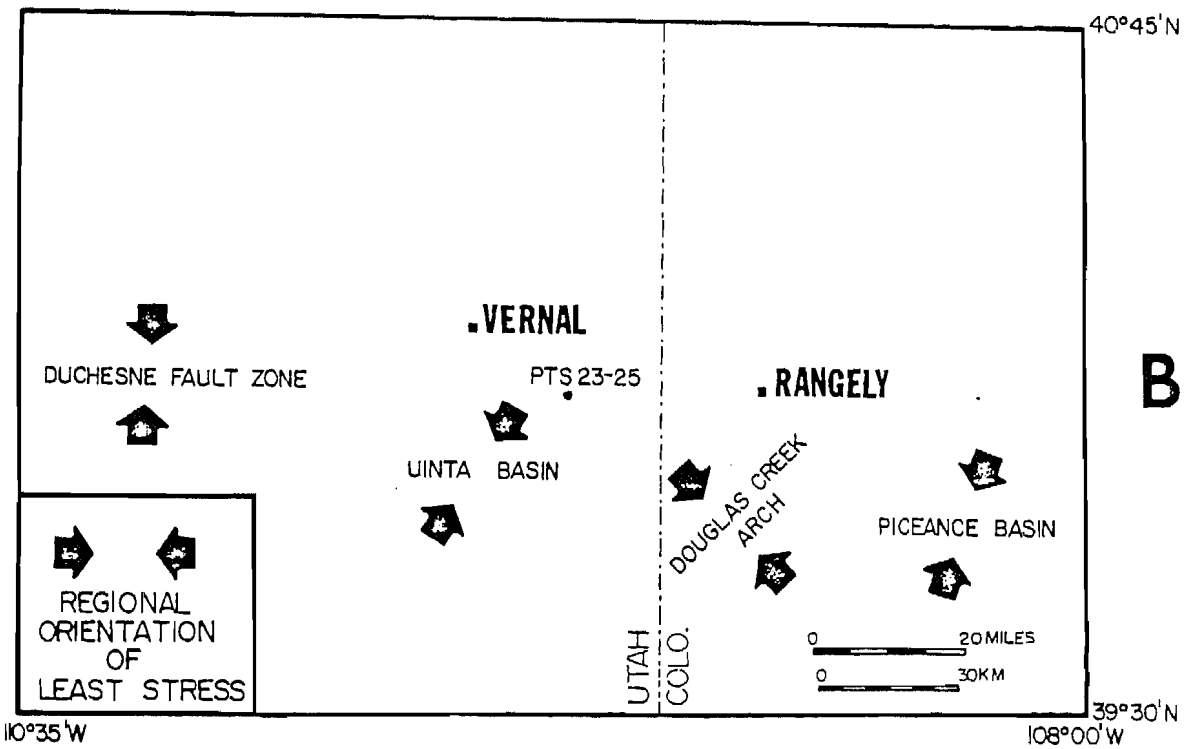


Figure 4. A. Map of the Uinta Basin region showing orientations of horizontal stresses, major normal faults, and extension fractures filled with gilsonite. (Modified after Raleigh, 1974).

B. Same map as above, but showing regional orientation of minimum horizontal stress within each structural unit (basin versus uplift).

Basin). However, within each structural unit (basin or uplift) the minimum stress direction remains fairly constant. The general information on the local stress directions within the Uinta Basin can now be compared with the results of the strain-relaxation and velocity tests obtained from PTS No. 23-25 Federal.

Direction of Hydraulic Fracture in PTS No. 23-25 Federal

Figure 5 displays the directions of maximum and minimum strain relaxation in the four oriented Mancos core samples (Nos. 11, 13, 15 and 16, Table I). Due to the uncertainties in the proper orientation of the cores the spread in the directions (50°) is rather large. Nevertheless, all the directions of maximum relaxation (Emax) lie in the NE quadrant and are more or less perpendicular to the general trend (N 60°- 65° W) of the gilsonite dikes (black rose diagram, Figure 5). The only directional velocity measurement in the Mancos cores (Table II, NO. 16) indicates that the slowest velocity and, therefore, the lowest modulus direction is N 49° E. Again, this trend is nearly perpendicular to the gilsonite dikes.

The gilsonite dikes themselves can be interpreted as natural but ancient hydraulic fractures. The physical mechanisms of their intrusion into the overlying sediments are not very different from those involved in massive hydraulic fracturing of gas reservoirs, except that the scale of the former dwarfs the attempts by man.

The data shown in Figure 5 suggest that the present-day stress directions in the subsurface are not very different from what they were several millenia ago, and that any clockwise rotation in the stress directions that may have taken place during this great time interval is small. The following conclusion, therefore, seems clear; the predominant direction of hydraulic fracture extension in the Uinta Basin will be NW-SE and nearly parallel to the gilsonite dikes.

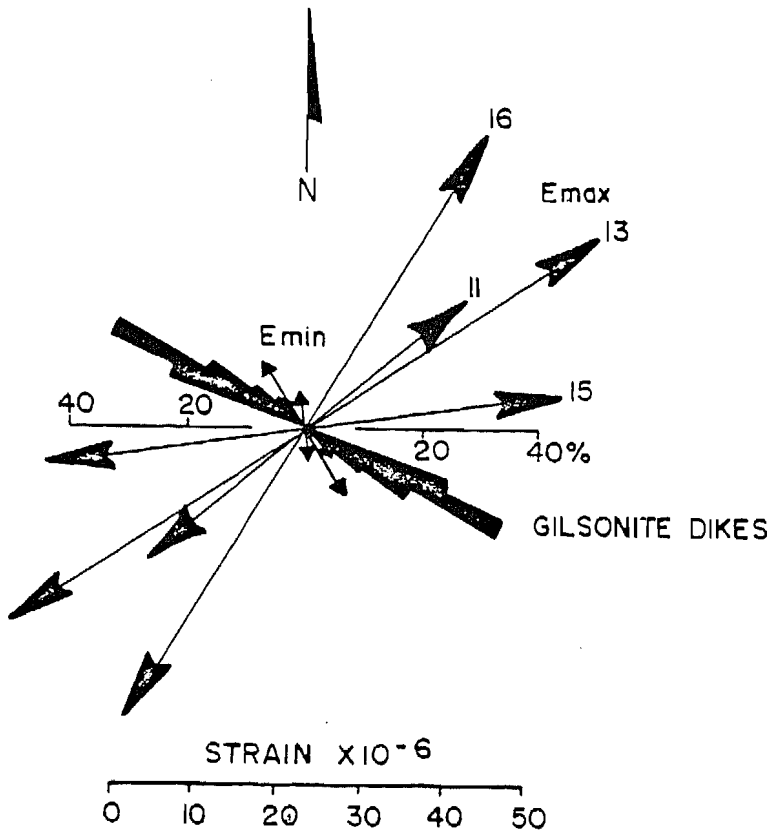


Figure 5. Relationship between the predominant trend of the gilsonite dikes (black rose diagram) and the calculated directions of maximum (E_{max}) and minimum (E_{min}) strain relaxation (arrows) in four Mancos shale samples.

Magnitude of Subsurface Stresses in the Mesaverde and Mancos Shales

It seems clear that the precise determination of the subsurface stresses is essential to the successful performance of a fracture treatment in tight, potentially gas-bearing formations. This task can be accomplished either by direct measurement or, indirectly, by making an reasonable estimate based on surface measurements on recovered cores. The hydraulic-fracturing method has been used to measure the subsurface stresses in PTS 23-25 Federal by Brechtel and others (1977). However, out of two attempts only one was successful. In order to obtain stress estimates in other formations as well (including the one tested hydraulically) we will use the strain relaxation

results presented earlier in this report.

A body of rock, buried at some depth, is subjected to loads due to gravity. Assuming, at first, that there are no horizontal displacements (Jaeger and Cook, 1969; Fertl, 1976), the stresses generated by these loads are given by:

$$\sigma_V = \rho g h \tag{1}$$

$$\sigma_H = \left(\frac{\nu}{1 - \nu}\right) \sigma_V \tag{2}$$

where σ_V and σ_H are the vertical and horizontal effective stresses, ρ is the average bulk density (obtained from formation density logs) of the sedimentary rocks, g is the gravitational acceleration, h is the depth of burial, and ν is the average Poisson's Ratio (obtained from sonic logs). Because the effective stress law states that $\sigma_V = S_V - P_f$ and $\sigma_H = S_H - P_f$, equations (1) and (2) can be rewritten as follows:

$$S_V = \rho g h + P_f \tag{3}$$

$$S_H = \left(\frac{\nu}{1 - \nu}\right) (S_V - P_f) + P_f \tag{4}$$

The total horizontal stress, S_H, is thus related to the total vertical (overburden) stress, S_V, and the formation (pore) pressure, P_f, in the sedimentary rocks.

Equations (3) and (4), however, only hold true for elastic materials. As pointed out by Price (1974), the condition of "no horizontal displacements" is untenable in sedimentary rocks and the superposition of an additional stress component, σ_t, is required. This stress component has been generated, over geologic time, by the combined processes of subsidence, uplift, tectonism, creep and other non-elastic and viscous phenomena.

Equation (4) thus becomes:

$$S_H = \left(\frac{\nu}{1 - \nu}\right) (S_V - P_f) + P_f + \sigma_t \qquad (5)$$

where the term involving Poisson's Ratio, ν, represents the stress component associated with elastic strain and the last term, σ_t, represents the stress component associated with viscoelastic (time-dependent) strain. This latter term will vary with the shale content of sedimentary rocks (Fertl, 1976). In general, it can be represented by a memory function of the form:

$$\sigma_t \equiv \int_{t_0}^{t} E\,(t - \tau)\, d\varepsilon(\tau) \qquad (6)$$

At the time (t), when the formation is cored at depth, the stresses relax to zero. The elastic strains recover immediately at depth and, therefore, are not measured at the surface. The viscoelastic strains, however, recover more slowly as a function of time and manifest themselves at the surface. Because these latter strains were accumulated [$d\varepsilon(\tau)$] over long periods of geologic time ($t - t_0$) during each deformational phase (τ) throughout the history of the rock, the relaxation process will take a finite amount of time to complete (hours to days). In order to simplify matters further, the rock is assumed to be sufficiently permeable so that the term P_f will not affect the time-dependent relaxation of the cored samples. Clearly, it is not possible to mathematically evaluate the memory function and, consequently, σ_t, because to do so one needs an accurate account of all deformational events (τ) of the rock in question.

Fortunately, the magnitudes of S_H and S_V in the Mancos shales were measured directly using the hydraulic-fracturing method. These results can help us in evaluating the relative magnitude of σ_t in this formation and then used to estimate the magnitudes of S_H in the Mesaverde formation.

By dividing equation (5) by depth (h = 9024 feet) and inserting the gradient values of S_H and S_V, Poisson's Ratio, and an assumed pore-pressure gradient of 0.5 psi/ft (listed in Table III), we get

$$\sigma_t/h = 0.03 \text{ psi/ft.}$$

The magnitude of σ_t in the Mancos shale is 270 psi or about 4 percent of the total horizontal stress, and corresponds to the measured average time-dependent strain relaxation of about 30×10^{-6} (Table I).

Because the deformational history of the Mesaverde rocks should not be very different from that of the Mancos shales (implied by the similar average amounts of strain relaxation in both formations), we can assume that $\sigma_t/h = 0.03$ psi/ft in the Mesaverde rocks and proceed to calculate the gradient values of S_H in these same rocks. Using the appropriate values for the gradients of S_V, P_f and σ_t, Poisson's Ratio (Table III), the total horizontal stress gradient in the Mesaverde section at depths of 7470 and 8070 feet (Table I) is equal to 0.73 psi/ft. This value is lower than the S_H gradient in the Mancos shales (0.83 psi/ft) and implies that fractures can be extended into the Mesaverde rocks at lower bottom-hole pressures than into the Mancos shales.

Obviously, the correction needed to estimate the S_H gradients in both sections of rock is very small and for all practical purposes negligible. On the other hand, in different rocks (such as sandstones) the average strain relaxation and the gradient of σ_t could be higher and contribute to S_H values that are significantly different (lower) from overlying shales. In this kind of situation the possibility of fracture containment in the

sandstone unit would appear to be promising and technologically and economically rewarding.

TABLE III

Formation Parameters

Formation	Depth (ft)	Density gm/cc	Poisson's Ratio	Measured Gradients (psi/ft) S_H	S_V	P_f	t
Mesaverde	7470	2.4	0.27	?	1.04	0.5	0.03
	8050	2.4	0.27	?	1.04	0.5	0.03
Mancos	9024	2.6	0.33	0.83	1.12	0.5	0.03

From the analysis of the observed data and information obtained from surface measurements on core samples, we may conclude that the subsurface stresses in the Mesaverde and Mancos sections of the Uinta Basin are fairly similar; that is, the stress states in both rock units do not differ by more than ten percent. Because no information is available on the Castlegate Sandstone, it is not possible to determine whether the stress state in this rock unit is either the same, higher or lower than those estimated and measured in the upper and lower barrier zones, respectively.

The relative fecundity of the core-analysis approach described in this report can only be established by additional work, both at the well site and in the laboratory. The relationships between rock type, history, strain relaxation, and subsurface stress states determined by further research can eventually result in a quick and cheap method of mapping the subsurface stress distribution in petroliferous sedimentary basins.

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