ONWI/SUB/87/E512-05000-T43

EVALUATION OF GEOPHYSICAL TECHNIQUES FOR IDENTIFYING FRACTURES IN PROGRAM WELLS IN DEAF SMITH COUNTY, TEXAS

REVISION 1

TOPICAL REPORT

AUGUST 1987

by

R.P. Gillespie
P.C. Siminitz

Stone & Webster Engineering Corporation
245 Summer Street
Boston, MA 02107

This report was prepared by Stone & Webster Engineering Corporation under Contract E512-05000 with Battelle Memorial Institute, Project Management Division, under Contract DE-AC02-83-CH10140 with the Department of Energy. The Contract was administered by the Battelle Project Management Division.

ABSTRACT

Quantitative information about the presence and orientation of fractures is essential for the understanding of the geomechanical and geohydrological behavior of rocks. This report evaluates various borehole geophysical techniques for characterizing fractures in three Civilian Radioactive Waste Management (CRWM) Program test wells in the Palo Duro Basin in Deaf Smith County, Texas. Emphasis has been placed on the Schlumberger Fracture Identification Log (FIL) which detects vertical fractures and provides data for calculation of orientation. Depths of FIL anomalies were compared to available core. It was found that the application of FIL results to characterize fracture frequency or orientation is inappropriate at this time. The uncertainties associated with the FIL information render the information unreliable. No geophysical logging tool appears to unequivocally determine the location and orientation of fractures in a borehole. Geologic mapping of the exploratory shafts will ultimately provide the best data on fracture frequency and orientation at the proposed repository site.

FOREWORD

The National Waste Terminal Storage (NWTS) program was established in 1976 by the U.S. Department of Energy's (DOE) predecessor, the Energy Research and Development Administration. In September 1983, this program became the Civilian Radioactive Waste Management (CRWM) Program. Its purpose is to develop technology and provide facilities for safe, environmentally acceptable, permanent disposal of high-level waste (HLW). HLW includes wastes from both commercial and defense sources, such as spent (used) fuel from nuclear power reactors, accumulations of wastes from production of nuclear weapons, and solidified wastes from fuel reprocessing.

The information in this report pertains to the Permian Basin geotechnical studies performed for the Salt Repository Project of the Office of Geologic Repositories in the CRWM Program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

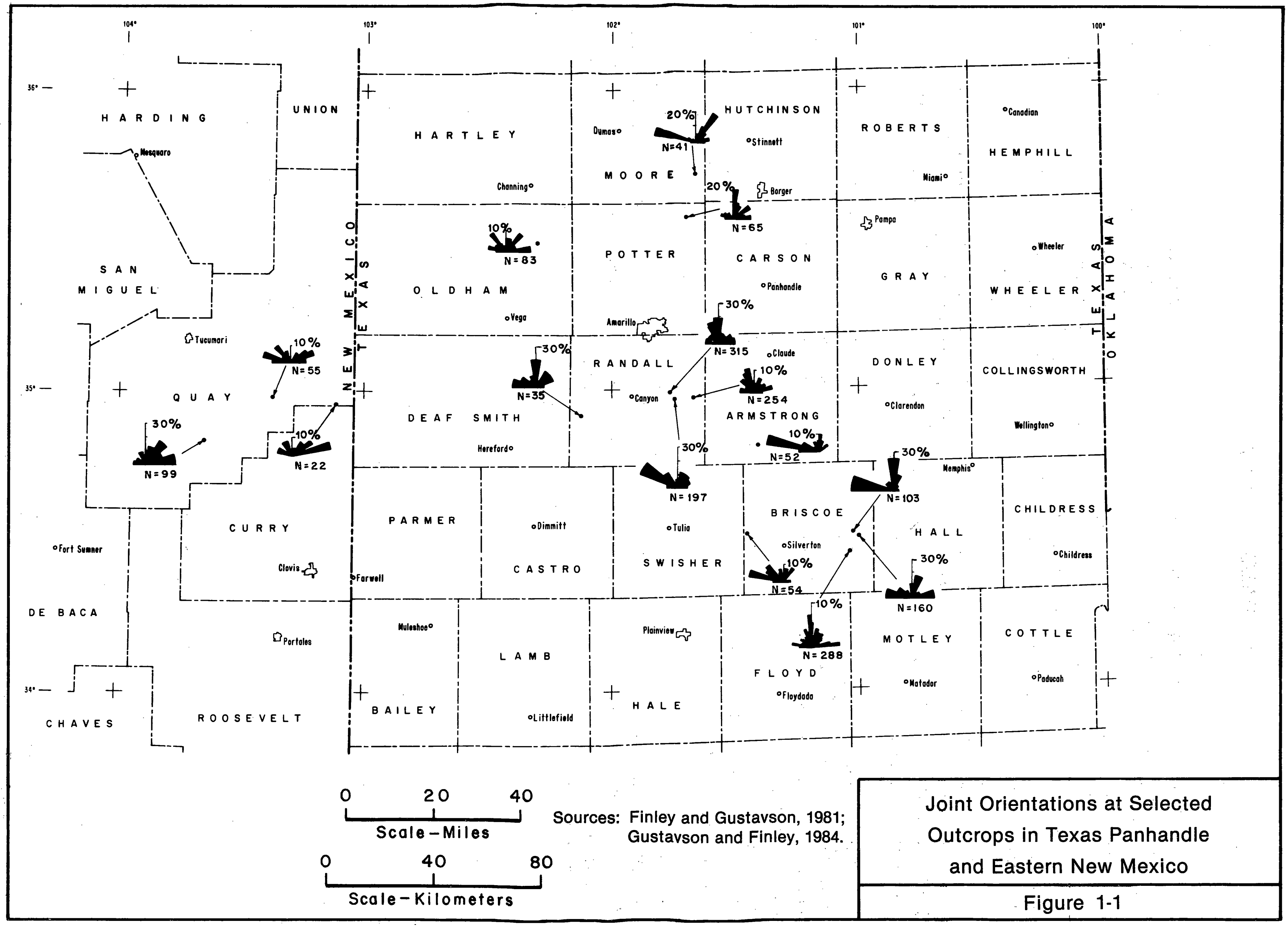
Fracturing is an aspect of the rock mass which may profoundly affect both geohydrological and geomechanical behavior. Quantitative information on the presence and orientation of fractures is essential for modeling ground-water flow and for the design of underground support and lining systems. Optimum fracture characterization results from direct observation and measurement, preferably underground, so that all orientations can be sampled. Preliminary studies in Deaf Smith County are restricted to analyses in boreholes.

Previous work on fracturing in the Palo Duro Basin of Texas has been reported by Finley and Gustavson (1981), Goldstein and Collins (1984), Collins (1984), Collins and Luneau (1985), and Gustavson and Budnik (1985). Basin-wide results from surface joint mapping are shown on Figure 1-1.

This report focuses on fracturing in the following three Civilian Radioactive Waste Management (CRWM) Program test wells in the Palo Duro Basin: the J. Friemel No. 1, the Detten No. 1, and the G. Friemel No. 1, all in Deaf Smith County, Texas (Figure 1-2). Many methods attempt to identify natural fracture systems occurring in boreholes. The scope of this study is to describe the various geophysical borehole techniques for detecting fractures. Emphasis is placed on the Schlumberger Fracture Identification Log (FIL*), which was run in the three Deaf Smith wells. The results obtained from this geophysical log are compared directly to Texas Bureau of Economic Geology (TBEG) core descriptions (TBEG, 1985a, 1985b, and 1985c). Conclusions about formational occurrence of fractures, preferred orientation, limitations of the data, and recommendations for further study are presented.

---

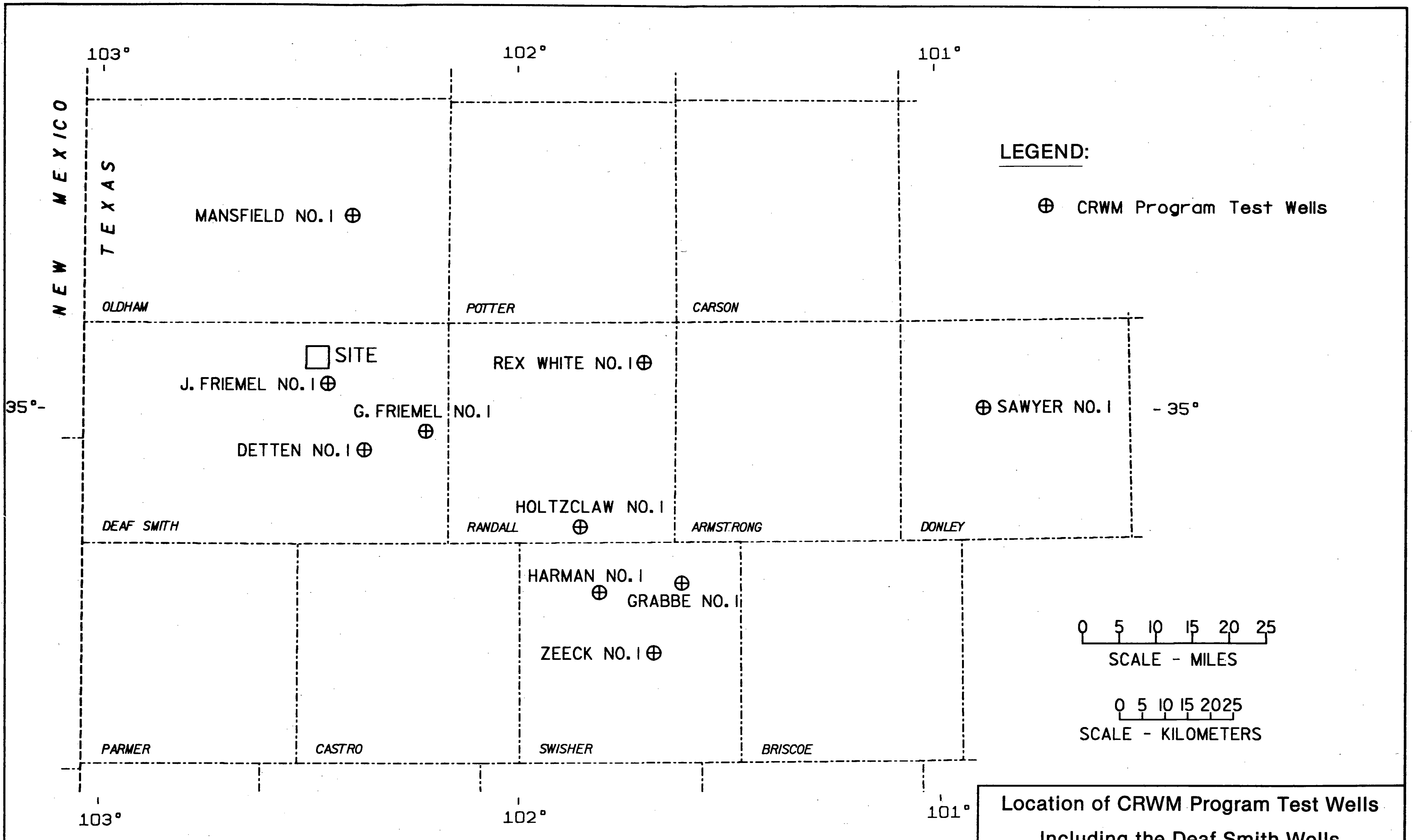
*Mark of Schlumberger



Sources: Finley and Gustavson, 1981; Gustavson and Finley, 1984.

Joint Orientations at Selected Outcrops in Texas Panhandle and Eastern New Mexico

Figure 1-1



Location of CRWM Program Test Wells Including the Deaf Smith Wells in West Texas

Figure 1-2

2.0 BOREHOLE METHODS FOR DETECTING FRACTURES

Characterizing fractures in boreholes is less reliable than fracture mapping of outcrops or large diameter shafts, owing both to the small volume sampled and to a condition known as the blind zone. The blind zone effect occurs because fractures which have a near vertical dip do not intersect vertical boreholes as often as subhorizontal fractures. Vertical fractures may be missed entirely. Cores of 4-inch (102 mm) diameter will intersect fewer fractures than the outer borehole walls of 8- to 10-inch (203 mm to 254 mm) diameter. Geophysical tools penetrate only a slightly larger volume of rock. Therefore, borehole techniques test a limited rock volume that may not represent overall rock mass conditions.

2.1 CORE

Observation of fractures in core is essential for evaluating geophysical borehole fracture identification techniques. The core allows for the direct observation and testing of the physical and mechanical properties of fracture surfaces. Oriented core was not taken in the program wells, so preferred orientation of fractures cannot be determined by direct observation. The relative orientation, separation, roughness/planarity of fracture surfaces, and fracture filling are described for the Deaf Smith wells in detail in core logs at the core depth (TBEG, 1985a, 1985b, and 1985c). This depth has been adjusted to the wireline log depth for correlation to geophysical logs. Cored intervals available for study in Deaf Smith County are shown in Table 2-1.

While direct observation of core would be the best method because it allows direct observation of fracture characteristics, there are several limiting factors which must be considered:

1. Boreholes are vertical and will not intersect many high angle fractures. Open fractures are often high angle.

2. Core is generally 4-inch (102 mm) diameter and will not be representative of the rock mass.

3. Core losses are generally high in fractured zones.

4. Core is generally not oriented.

5. Fracture apertures may change when core is removed from the ground.

6. Fractures induced by the coring or extrusion process may be indistinguishable from natural fractures.

7. Core is not obtained from the entire hole.

For these reasons, applicable borehole geophysical logging techniques should be utilized to complement direct core observations.

Table 2-1. Core Intervals Available From the Deaf Smith Wells

	Detten No. 1		G. Friemel No. 1		J. Friemel No. 1		Formation
Formation	Depth (ft)	Subtotal (ft)	Depth (ft)	Subtotal (ft)	Depth (ft)	Subtotal (ft)	Total (ft)
Ogallala					352 - 394	42	42
Dockum					394 - 1,096	702	702
Dewey Lake					1,096 - 1,187	91	91
Alibates	1,130 - 1,169	39			1,187 - 1,226	39	78
Salado	1,169 - 1,243	74			1,226 - 1,280	54	128
Yates	1,243 - 1,325	82	1,191 - 1,239	48	1,280 - 1,350	70	200
USR	1,325 - 1,421	96	1,239 - 1,312	73	1,350 - 1,464	114	283
LSR							0
Queen-Grayburg			1,727 - 1,745	18	1,846 - 1,878	32	50
USA	1,885 - 2,369	484	1,745 - 2,228	483	1,878 - 2,368	490	1,457
LSA5	2,369 - 2,571	202	2,228 - 2,433	205	2,368 - 2,563	195	602
LSA4	2,571 - 2,831	260	2,433 - 2,683	250	2,563 - 2,821	258	768
LSA3	2,831 - 2,837	6	2,683 - 2,691	8	2,821 - 2,830	9	23
LSA2							
Glorieta							0
U. Clear Fork							0
Tubb							0
L. Clear Fork							0
Red Cave							0
Wichita					5,519 - 5,582	63	63
Wolfcamp					5,582 - 6,032	50	
					6,421 - 6,537	116	176
Penn.					7,768 - 7,780	12	
					8,047 - 8,283	236	248
Total		1,243		1,085		2,583	4,911

Note: Totals include "core loss" zones.

2.2 FRACTURE IDENTIFICATION LOG

The Schlumberger Fracture Identification Log (FIL*) is a borehole geophysical log processed from the high resolution dipmeter tool. The method is based on the assumption that a mud-filled crack or fracture will register a higher conductivity than the homogeneous formation. Ideally, a vertical fracture will be picked up on two opposing pads if it passes through the center of the borehole, or on two adjacent pads if it doesn't pass through the center. A permeable bedding plane will exhibit a high conductivity on all four pads; this may be indistinguishable from a low angle fracture. Basic interpretation of the FIL is discussed in the technical papers by Schlumberger (1970), Babcock (1978), and Yost et al. (1982). A four-arm caliper tool is also run with the dipmeter which allows a determination of borehole elongation. Plumb and Singer (1983) conclude that the subsurface minimum principal stress can be correlated with the direction of borehole elongation recorded by the four-arm calipers.

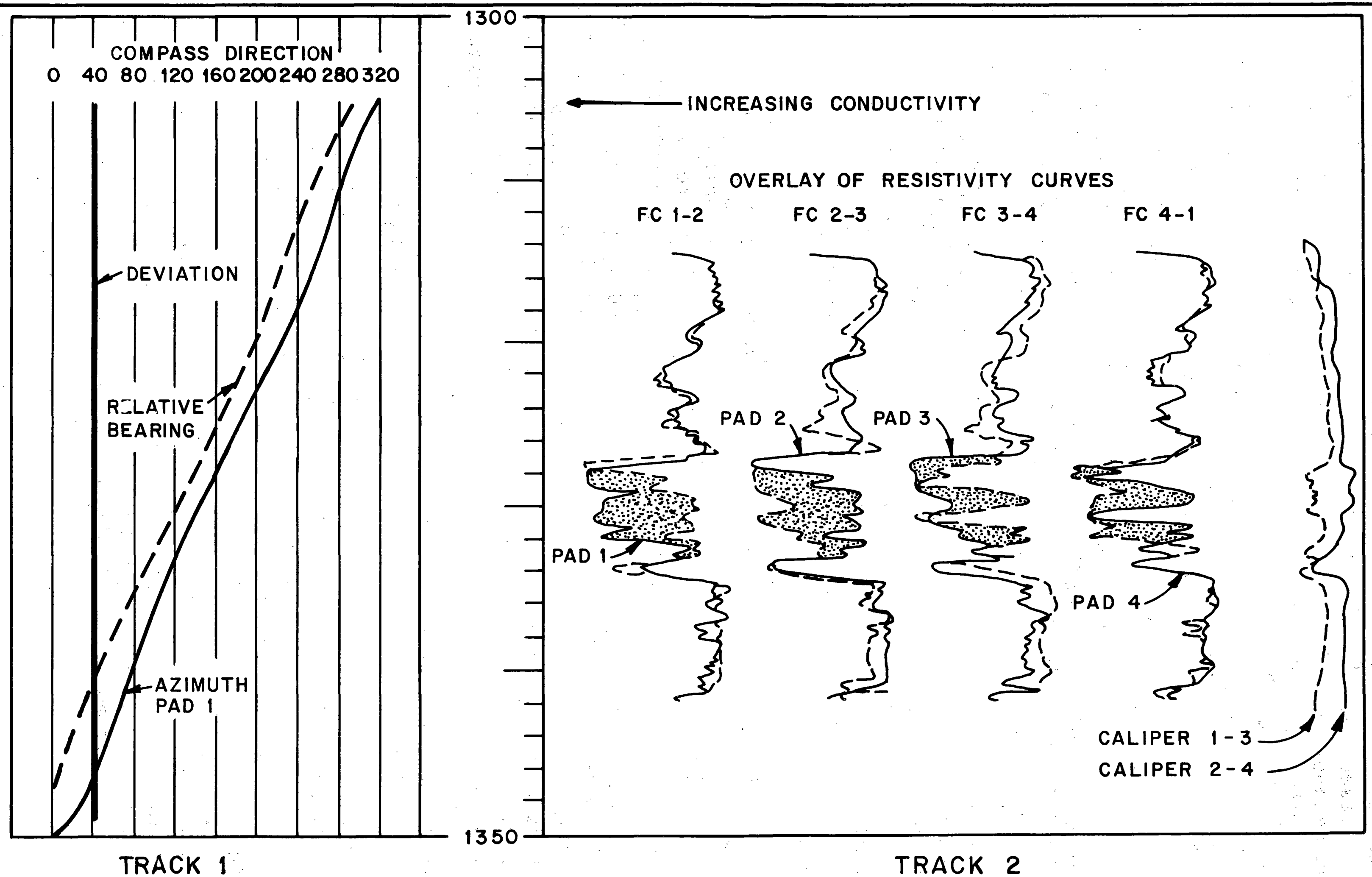
Possible fractures are identified on the FIL by the four-arm conductivity survey, which is presented as four curves in a dual-curve overlay, as follows (from left to right in track 2 of Figure 2-1 on the log): Fracture Curve (FC) 1-2 traces from pads 1 and 2, FC 2-3 traces from pads 2 and 3, FC 3-4 traces from pads 3 and 4, and FC 4-1 traces from pads 4 and 1. The four curve presentation is used to distinguish between bedding planes and vertical fractures.

Fracturing is identified as a separation or difference between the individual overlapped curve presentations. (Separations are graphically shaded as shown on Figure 2-1.) For example: a vertical fracture is identified on pad 1 and its opposing pad 3 if a separation on the overlapped logs shows higher conductivity readings on pad 1 than pad 2; higher on pad 3 than pad 2; higher on pad 3 than pad 4; and higher on pad 1 than pad 4 at a given depth in the borehole. Fractures which do not pass through the center of the borehole and intercept or are picked up on adjacent pads, such as pads 2 and 3, would show separation as follows: 2 higher than 1, 2 and 3 both high, 3 higher than 4, and 1 and 4 both low readings. Other combinations introduce multiple combination possibilities and cannot be used with much confidence for orientation purposes. High conductivity on three pads would indicate at least three possible vertical orientations, a non-homogeneous lithology, or even a low-dip fracture or bedding plane.

The orientation of the fracture can be determined since the orientation of pad 1 (reference pad) is always known with respect to magnetic north (Figure 2-2). As the tool travels up the borehole, the orientation of pad 1 is recorded as the "azimuth" curve when a low angle tool is run by the logging company, or is the sum of the "azimuth" and "relative bearing" readings when a high angle tool is utilized (Figure 2-1). The tool type used is always indicated on the bottom header of the log next to the symbol MCT. An MCT = 36 degree value indicates a low angle tool, and an MCT = 72 degree value indicates a high angle tool used primarily for boreholes deviated from vertical by more than 30 degrees (Schlumberger, 1970). Both

---

*Mark of Schlumberger

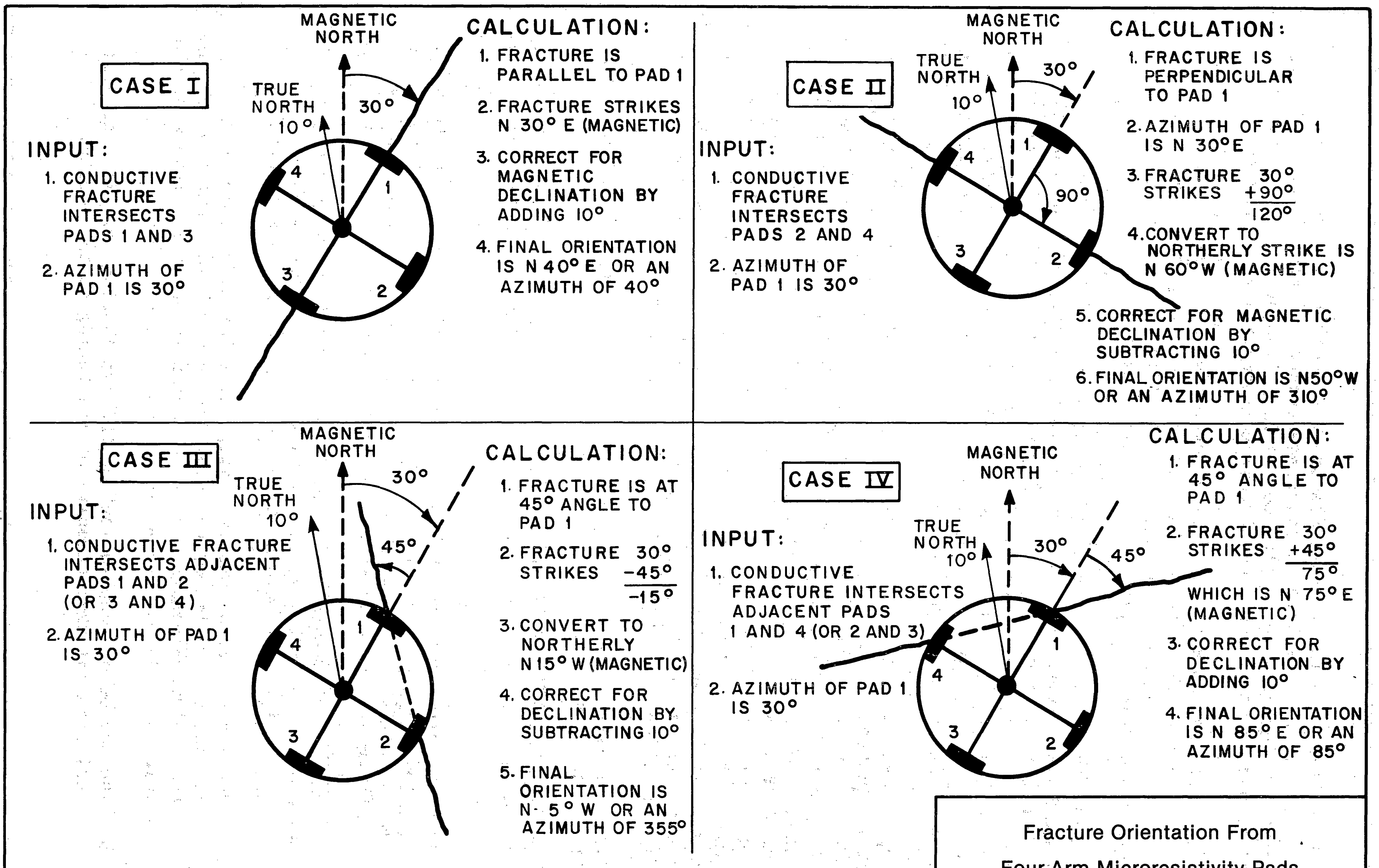


LEGEND:

Caliper ellipticity suggests fracture breakout at depth of 1326 to 1333 feet below KB. Pads 1 and 3 are consistently higher than pads 2 and 4; therefore the fracture is vertical and strikes in the direction of the Pad 1 Azimuth.

Example of Vertical Fracture Identification Log Anomaly

Figure 2-1



CASE I

INPUT:

1. CONDUCTIVE FRACTURE INTERSECTS PADS 1 AND 3
2. AZIMUTH OF PAD 1 IS 30°

CALCULATION:

1. FRACTURE IS PARALLEL TO PAD 1
2. FRACTURE STRIKES N 30° E (MAGNETIC)
3. CORRECT FOR MAGNETIC DECLINATION BY ADDING 10°
4. FINAL ORIENTATION IS N 40° E OR AN AZIMUTH OF 40°

CASE II

INPUT:

1. CONDUCTIVE FRACTURE INTERSECTS PADS 2 AND 4
2. AZIMUTH OF PAD 1 IS 30°

CALCULATION:

1. FRACTURE IS PERPENDICULAR TO PAD 1
2. AZIMUTH OF PAD 1 IS N 30° E
3. FRACTURE STRIKES $30° + 90° = 120°$
4. CONVERT TO NORTHERLY STRIKE IS N 60° W (MAGNETIC)
5. CORRECT FOR MAGNETIC DECLINATION BY SUBTRACTING 10°
6. FINAL ORIENTATION IS N50°W OR AN AZIMUTH OF 310°

CASE III

INPUT:

1. CONDUCTIVE FRACTURE INTERSECTS ADJACENT PADS 1 AND 2 (OR 3 AND 4)
2. AZIMUTH OF PAD 1 IS 30°

CALCULATION:

1. FRACTURE IS AT 45° ANGLE TO PAD 1
2. FRACTURE STRIKES $30° - 45° = -15°$
3. CONVERT TO NORTHERLY N 15° W (MAGNETIC)
4. CORRECT FOR DECLINATION BY SUBTRACTING 10°
5. FINAL ORIENTATION IS N 5° W OR AN AZIMUTH OF 355°

CASE IV

INPUT:

1. CONDUCTIVE FRACTURE INTERSECTS ADJACENT PADS 1 AND 4 (OR 2 AND 3)
2. AZIMUTH OF PAD 1 IS 30°

CALCULATION:

1. FRACTURE IS AT 45° ANGLE TO PAD 1
2. FRACTURE STRIKES $30° + 45° = 75°$ WHICH IS N 75° E (MAGNETIC)
3. CORRECT FOR DECLINATION BY ADDING 10°
4. FINAL ORIENTATION IS N 85° E OR AN AZIMUTH OF 85°

Fracture Orientation From Four-Arm Microresistivity Pads

Figure 2-2

types have been used in program wells at various times. The orientation of a high conductivity fracture which is intercepted by pads 1 and 3 is simply the azimuth value on a low angle tool. A high conductivity fracture intercepted by pads 2 and 4 would be 90 degrees from the pad 1 reading.

The resultant azimuth must be corrected for magnetic declination. The approximate declination for the Panhandle area is introduced by adding 10 degrees to all azimuth readings or subtracting 10 degrees from westerly bearings and adding 10 degrees to easterly bearings.

An enlarged hole, as indicated by separation of the caliper logs, adds a small degree of confidence to the existence of fractures at the depth in question. Additional confidence is gained by observing the relative bearing curve in track 1; within zones of fracturing, the tool tends to ride in the elongated cross section of the borehole without changing orientation, producing a near vertical azimuth trace. However, many other factors can create an enlarged or elongated hole.

In the existing literature, considerable emphasis has been placed on the determination of borehole elongation direction. Most investigators would now agree that the elongation direction (long axis) can be related to the in situ rock stress system of the area, the long axis being in the direction of minimum compressive stress. Borehole elongation or ellipticity may be severe enough to prevent normal rotation of the tool, the extended calipers acting as a rudder in the elongated direction. In this case, it is possible that the fracture orientations sampled are roughly parallel and perpendicular to the maximum horizontal stress direction and not necessarily related to the dominant fracture trend in the borehole. No attempt has been made to determine elongation directions in the present study.

The following is a summary of the general limitations and precautions which must be considered in FIL interpretation:

1. Fractures may exist in the borehole which are not swept by the tool or are indicated on only one pad. No orientation can be determined for either case.

2. Areas of fracture may be indicated where none exist due to steep bedding orientations, presence of pyrite, lack of bedding such as in breccias or conglomerates, or other geologic features that cause contrasts in resistivity from pad to pad.

3. Only about 30 percent of the borehole wall is covered by the tool pads. The tool is designed to rotate in order to obtain a statistically representative sampling of fracture orientations.

4. Representative or statistically significant fracture orientations may not be sampled by the tool due to borehole elongation causing the tool to maintain a constant orientation as it travels up the hole.

5. The degree of "separation" on the overlapping logs is a general indication of the intensity of fracturing at that depth.

6. Electrical phase shifts may produce uniform "separations" which do not indicate fracturing. Mud may cake up on certain pads and produce "separations" not necessarily related to fracturing. Extreme enlargement of the borehole may cause the tool to lose contact with the wall on one axis which produces a false separation.

7. Conductivities are so low in salt sections as to lessen the sensitivity for detecting fractures in those areas. Lack of data in salt may be due to natural healing of fractures.

8. Fracture filling material must exhibit a distinct conductivity contrast with the adjacent wall rock. Conductivity contrasts may not necessarily mean, however, that the fractures are significant from an engineering or hydrologic point of view.

9. Fractures filled with salt or other material of very low conductivity may generate orientations that are in error by 90 degrees because the interpretation assumes that the fractures are filled with drilling mud and orients the higher conductivity zone.

10. The amount of error inherent in interpolating the azimuth and relative bearing readings is about ±5 degrees, but may be much greater if the tool is rapidly spiraling up the hole.

Yost et al. (1982) performed an extensive study of natural fractures in oriented core and correlated these results to borehole logs. Their studies in shaley rock revealed that low angle fractures are not adequately defined on the FIL. However, vertical fractures of greater than 2-ft (.6 m) lengths correlated well between oriented core and the FIL.

In the Palo Duro Basin the fractures are frequently evaporite-filled. It is useful to consider the required magnitude of a discontinuity determined with an FIL. The microresistivity pads of the high resolution dipmeter tool are 1½-inch (38 mm) wide (Yost et al., 1982). Fractures less than 1/10-inch (2.5 mm) wide will probably not be detected; when the rock mass is mostly evaporitic, the conductivities are extremely low and the presence of a thin conductive fracture may be masked. In the alternate case of a mudstone with a salt-filled fracture, there will be a decreased conductivity at the fracture intersection. The fracture would have to be fairly wide to produce a conductivity contrast and knowledge of the lithology is required to properly orient these fractures.

2.3 URANIUM LOG

Dewan (1984) suggests that uranium peaks on the Natural Gamma-Ray Spectroscopy (NGRS) Log may provide confirming evidence of fractures. Uranium enrichment may result from ground-water migration through fractures. As the fractures plug up, uranium salts are deposited. Alternate explanations exist, and in fact a fracture zone may be leached of its uranium. As a result, the presence of uranium anomalies only reinforces the conclusion that a fracture exists.

Serra et al. (1980) review the use of NGRS and discuss the geochemistry of uranium; both fixation of uranium in organic complexes and precipitation of uranium salts appear to be possible in the Palo Duro Basin environment.

The uranium log may have some value as a discontinuity detector; however, distinguishing a true fracture from a sedimentary feature is not possible with the uranium log. A fracture detected by other means may only be confirmed by an anomalous uranium reading.

2.4 SONIC LOG

Fracturing of the rock mass results in a lowering of the compressional wave sonic velocity (Vp) through the mass. The interval transit time geophysical log measures these velocities for various spacings of the acoustic transmitters and receivers. Full wave form logs capture the entire acoustic signal, and refined analyses may interpret attenuation of the sonic wave in fractured zones. Morris et al. (1964) present block test data confirming sonic attenuation across saw-cut fractures. Attenuation may also result from weathering or alteration of the fracture zone.

Use of sonic logs for confirming fractures requires that the detailed lithologic interpretation of the well be completed beforehand. Lithology and porosity affect the sonic velocities significantly. Anomalously low velocities may not be a result of fractures, but may be lithology or porosity contrasts.

Conventional sonic logs appear to lack adequate resolution for quantitative fracture studies. Because the sonic log measures velocity up and down the hole, the tool is most sensitive to horizontal or low angle fractures; however, separating low angle or horizontal fractures from bedding can be difficult. A general indication of the rock mass quality may be determined, but the sonic log penetration into the borehole wall is minimal. Full waveform long-spaced acoustic logs with the measurement of tube and shear waves offer some promise for fracture studies but the techniques are not fully developed at present.

2.5 BOREHOLE TELEVIEWER LOG

The borehole televiewer and its progeny, the circumferential microsonic tool, rely on attenuation of sonic energy at the borehole wall. A very detailed map of fractures may be obtained in a fluid-filled, smooth borehole (Zemanek et al., 1969). In the typical wells of this program, a thick drilling mud is used to stabilize the borehole. Borehole surface roughness complicates the signal. Dewan (1984) concludes that fractures of less than 1/8-inch (3 mm) width will not be seen by this method. Detailed inspection of fractures identified by other means may be the appropriate application of these micro-acoustic techniques.

The one application of the borehole televiewer in the Palo Duro Basin (Borjeson and Lamb, 1987) was not successful for fracture detection. Hydraulically-induced fractures in the Holtzclaw No. 1 well in Randall County were not detectable with the borehole televiewer.

2.6 TEMPERATURE LOG

Ground-water temperatures are typically lower than drilling mud temperatures. Drilling mud is exposed to ground surface temperatures in the mud pit and is warmed by circulation through pumps and deeper portions of the borehole. Zones where cooler ground water is seeping from fractures into the borehole will show slight temperature anomalies compared to the mud temperature. Use of thick drilling muds for formation stabilization tends to mask the effect of small seepages and essentially eliminates the use of this technique. Other phenomena such as gas seeps also may produce a low temperature anomaly.

The drilling mud was too thick in the Deaf Smith wells to measure temperature anomalies with any degree of sensitivity. Dewan (1984) stated that it was doubtful that the temperature logs at the J. Friemel No. 1 well would prove to be useful.

2.7 VERTICAL SEISMIC PROFILING

Vertical Seismic Profiling (VSP) is a high resolution seismic method which was made possible by the improvement of downhole sensors and a portable recording system. A velocity geophone anchored to the borehole wall receives information coming from two opposite directions: the downgoing and the upgoing waves (the reflected waves). The advantage of this method compared to conventional seismic technique is that it is possible to separate these waves by processing and then extract detailed information from both of them. This allows for a detailed correlation to downhole logs and reflective surfaces.

Both openhole and cased hole VSPs were run in the SWEC J. Friemel No. 1 well in Deaf Smith County (Lewkowicz et al., 1983). A string of fixed wall geophones was sequentially positioned up the borehole, recording four or five "shots" at each level from the Vibroseis truck which was offset 660 ft (201 m) from the borehole. VSP data for the J. Friemel well has not been systematically reviewed at this time.

A new application of VSP is to replace the downhole geophone with a hydrophone. Beydoun et al. (1984) review the theoretical aspects of tube waves (a sonic fluid wave arrival in the mud-filled borehole) originating at fractures. Seismic energy generated at the surface compresses an open fracture and injects a fluid pulse into the borehole. Not only is the origin of the tube wave propagation identified, but the in situ fracture permeability can be estimated from the amplitude ratio of the tube wave and compressional wave. Tube wave generation is a very complex phenomenon, with multiples and reflections from the casing shoe requiring very sophisticated filtering techniques.

While the application of theoretical models to VSP problems in the Palo Duro Basin may not be fully warranted, the potential benefits are numerous. Qualitative interpretations of low angle fracture permeability may be enhanced by running hydrophone VSP surveys in the vicinity of suspected open, fluid-filled fractures identified by other means.

3.0 FIL RESULTS FOR THE DEAF SMITH COUNTY WELLS

Various geophysical tools were evaluated in the three program wells of Deaf Smith County (J. Friemel No. 1, Detten No. 1, and G. Friemel No. 1) for the characterization of fractures. Of particular interest is the Schlumberger FIL which may be useful to identify and determine the orientation of vertical fractures in both cored and uncored zones of these wells. To obtain a direct understanding of the limitations and practical uses of the FIL, a comparison was made of the fracture zones identified by the FIL to the TBEG core descriptions (TBEG, 1985a, 1985b, and 1985c). Previous studies with lithologic logs have shown that there may be up to a 5-ft (1.5 m) wireline discrepancy between the geophysical log and the core log. For this reason, the exact core depths of the FIL were not strictly adhered to when comparing FIL results with the core. Significant fractures or irregularities which occur within ±5 ft (1.5 m) of depths where fractures were indicated by the FIL were noted.

Preferred orientations of fractures from FIL data are presented on azimuth frequency diagrams. Specific results for each well follow. Table 3-1 summarizes the core descriptions in the fracture zones detected by the FIL.

Increased interval transit times, as determined from the sonic log, have been shown by others to be indicators of rock mass fracturing. This method was evaluated for units above the Glorieta Formation in the three Deaf Smith wells. An attempt was made to correlate transit times from fracture zones identified by the FIL with typical transit times for the enclosing rock type. No conclusions could be drawn from the comparisons. Among the factors which probably contributed to the inconsistent results are the following: (1) over-size and irregular hole condition frequently present, (2) frequent lithology changes and mixed lithologies, and most importantly, (3) a high percentage of shale and claystone in the column results in a high degree of variability in the "average shale" interval transit time. None of the fracture zones identified by the FIL appeared to have anomalously low interval transit times.

Similarly, uranium values (ppm) were determined for the same formations for each FIL fracture zone from the NGRS Log. These values were compared to the average uranium values for the encompassing formations. No consistent patterns could be identified. Random unfractured zones show uranium values as high or low as any in the FIL-identified zones.

3.1 J. FRIEMEL NO. 1

A total of 47 fractures (Appendix A) were interpreted from analysis of the FIL for J. Friemel No. 1 (0 to 8,200 ft); core is available for 12 of these fractures. TBEG (1985c) identified fractures in 9 of the cored intervals. Of the three intervals that showed no core fracturing, one was described as having highly disturbed bedding. TBEG (1985c) reported many more fractures in the core than were identified by the FIL. This is to be expected for several reasons: (1) the dipmeter tool may not have been in the right orientation to pick up the fractures, (2) the fractures may not have

Table 3-1. Core Description at FIL Anomaly Depths (Page 1 of 2)

FIL Anomaly Depth (ft)[(a)]	Core Description
	J. Friemel No. 1
719	No indication of fractures; cross-bedded medium sandstone noted.
746	No indication of fractures; coarse siltstone, ripple laminations and soft sediment deformation noted.
768	Microfaulted; muddy claystone, ripples and soft sediment deformation noted.
1,179	Microfaulted; siltstone, just below this depth core is broken up, rubble.
1,330	Microfaulted; fine sandstone-mudstone, laminations and ripples noted.
1,332	Mudstone with disturbed intraclastic fabric, core is highly fractured, broken and crumbly with slickensides.
1,351	Gypsum filled fractures, anhydrite matrix, disturbed intraclastic fabric at base.
5,928	Two anhydrite filled fractures, limestone matrix, fusilinids and porosity noted.
5,973	Unit is highly fractured (5,970-5,980); interbedded dolomitic wackestone and dolomitic mudstone.
6,026	Calcite-filled vertical fractures, contains scattered partially to totally filled calcite voids; slickensides noted.
6,430	Fractures from 6,427 up section, possibly due to coring, dolomitic clayshale.
8,088	No indication fo fractures; highly distorted sandstone and mudstone.
	Detten No. 1
1,169	Numerous vertically oriented cracks, laminated dolomitic mudstone.
1,195-1,196	Gypsum fracture fill, clay rich sandy mudstone. Interbeds of anhydrite with nodular gypsum replacement.
1,248-1,249	No indication of fractures; red muddy sandy siltstone.

Table 3-1. Core Description at FIL Anomaly Depths (Page 2 of 2)

FIL Anomaly Depth[(a)] (ft)	Core Description
1,913	No indication of fractures; claystone with gypsum and anhydrite nodules noted.
2,357	No indication of fractures; anhydrite-mudstone sequences noted.
2,549	No indication of fractures; layers of integrated dolomite and anhydrite noted.
	G. Friemel No. 1
1,849	No indication of fractures; banded halite, interstitial bodies of mudstone with anhydrite nodules.
2,657	No indication of fractures; limestone matrix, complex nodular lithology noted.
2,659	Halite filled fractures; limestone matrix dolomite nodules noted.

Sources: TBEG 1985a, 1985b, and 1985c

(a) Conversion factor: 1 ft = 0.3048 m

been open or mud-filled, (3) the fractures may have been open less than 1/10 of an inch (2.5 mm) (the minimum width required for observation), (4) many fractures identified (TBEG, 1985c) are actually veinlets, (5) only vertically oriented fractures were interpreted from the FIL, and (6) enlargement and roughness of the borehole may have resulted in unsuitable logs for some of those areas.

A total of 46 vertical fractures were oriented utilizing the FIL data from verified and unverified zones; one was not suitable for orientation. Azimuth frequency diagrams were prepared using (1) all the data (46 points), (2) Permian System data (39 points), and (3) Wolfcamp Series data (18 points). These are shown as Figures 3-1a, 3-1b, and 3-1c. Figure 3-1 shows a dominant west-northwest trend and a somewhat less dominant northeast trend.

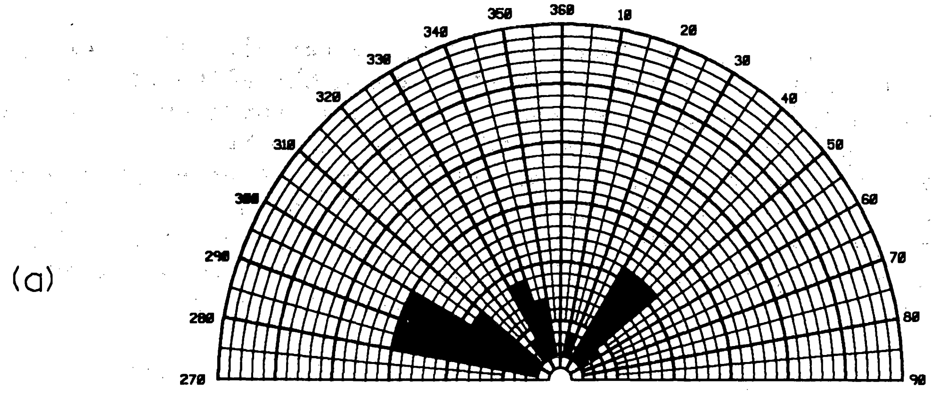
Closer examination reveals these trends to be dominated by Permian rocks, of which Wolfcamp Series fractures comprise nearly 50 percent of the data points. No viable explanation for the abundance of fractures in the Wolfcamp was evident. It may well be that Wolfcamp fracture frequency represents the "norm" while the rest of the Permian System is "under-fractured" because of the predominance of salt beds in that section. It must also be reiterated that only nine out of 47 fractures were "verified" by core, the majority not being associated with cored intervals. Many of these may not represent fractures at all. It should also be noted that there were significant intervals where the logging tool was tracking vertically up the hole, being held in one orientation by an elongated borehole. This would bias the data toward that orientation and 90 degrees from it for those intervals. Many fractures in the Permian section are filled with halite or anhydrite. It is believed that if the tool is responding to these fillings instead of a conductive mud filling, then the orientation which is calculated would be 90 degrees different from the normal calculation. Unfortunately, we have no way of knowing which fractures or veins are being read by the tool, so we don't know which readings to correct and which to leave as is. None have been adjusted in this analysis.

Clearly, little confidence or significance can be attributed to the trends indicated on the azimuth frequency diagrams.

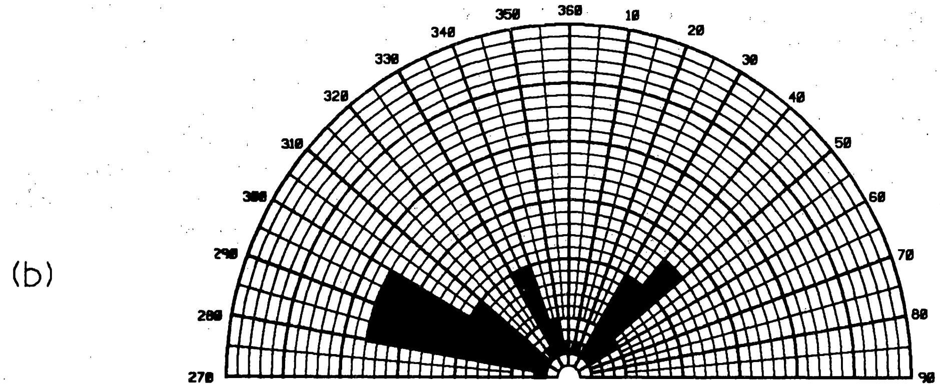
3.2 DETTEN NO. 1

Nineteen fractures (Appendix A) were interpreted by the FIL analysis of the Detten No. 1 (0 to 3,000 ft); core is available for six of these zones. Only two fracture zones identified by the FIL were "verified" in the six cored intervals. In the remaining four FIL zones, the core is described (TBEG, 1985a) as being mixtures of muddy, sandy siltstone, claystone with gypsum and anhydrite nodules, and mud clasts in anhydrite - all capable of producing conductivity contrasts across the borehole and, therefore, fracture indications.

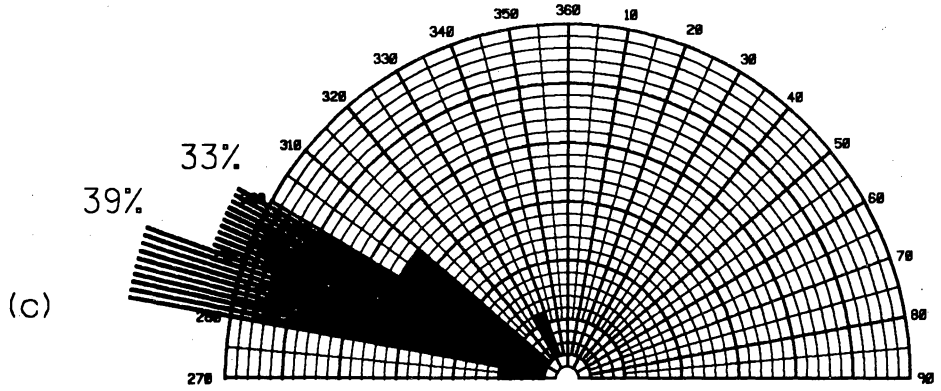
The Detten well was elongated for nearly its entire depth. The tool failed to rotate in the borehole and, hence, sampled only two potential fracture orientations, 90 degrees from each other.



Pennsylvanian - Dockum
n=46



Permian System
n=39



Wolfcamp Series
n=18

AZIMUTH FREQUENCY SCALE - FROM CENTER
TO EDGE 0 TO 30 PERCENT

FIL Fracture Orientations
for J. Friemel No. 1

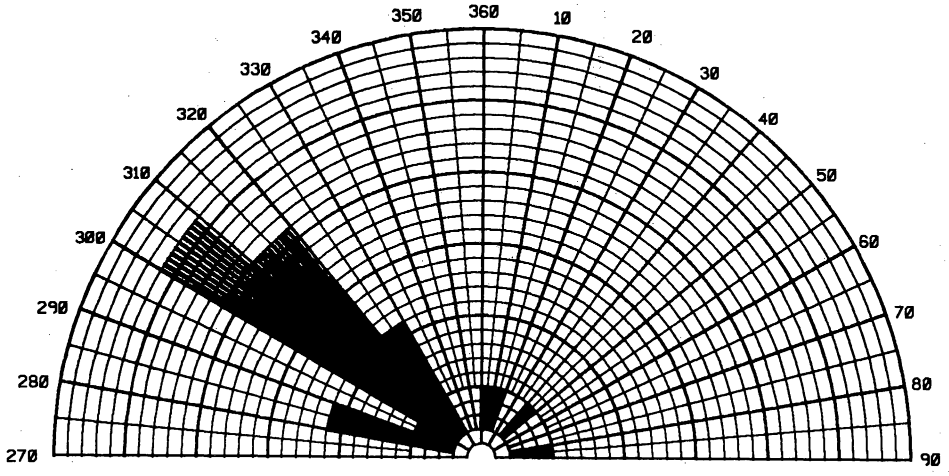
Figure 3-1

Figure 3-2a is an azimuth frequency diagram for all FIL orientations from the Detten well. All fractures were between the Alibates and Upper San Andres Formations. A strong northwest trend is evident from the diagram (Figure 3-2a). However, the diagram is strongly affected by the Queen/Grayburg data, comprising ten of the total of 19 points (Figure 3-2b). No explanation for the preponderance of fracture indications in the Queen/Grayburg was generated. Little significance should be attributed to the azimuth frequency diagrams as the underlying FIL data have been shown to be very unreliable and the sample number is too small to be statistically significant.

3.3 G. FRIEMEL NO. 1

A total of six fractures were interpreted by the FIL analysis (Appendix A) of the G. Friemel No. 1 (0 to 2,700 ft). Three of these occurred in sections where core was available but only one was "verified". Once again, the FIL zones which were not verified were typified by unusual conditions such as disturbed bedding, anhydrite nodules or mixed lithologies (TBEG, 1985b). FIL fractures, being of questionable origin and insignificant in number, were not plotted on azimuth frequency diagrams for the G. Friemel well. Tool rotation was minimal in the G. Friemel well also, further biasing the data toward one or two fracture orientations.

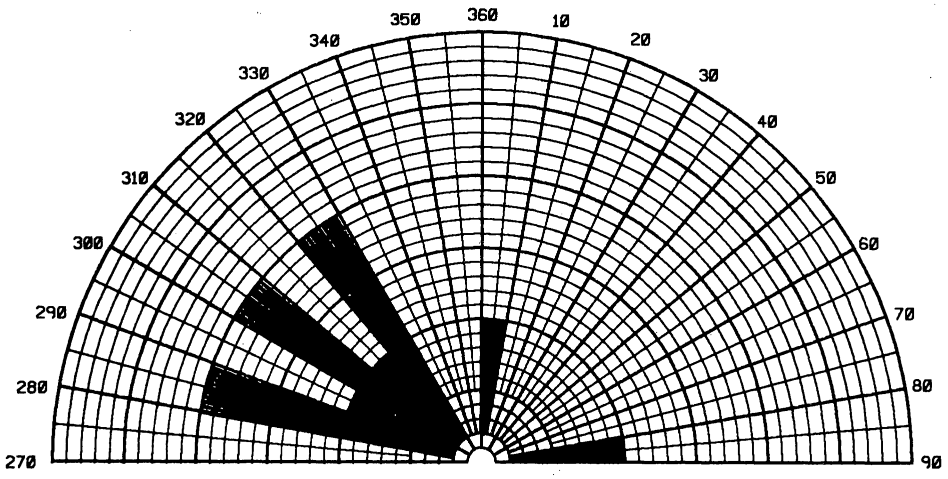
(a)



Upper San Andres through Alibates

n=19

(b)



Queen/Grayburg

n=10

AZIMUTH FREQUENCY SCALE - FROM CENTER

TO EDGE 0 TO 30 PERCENT

FIL Fracture Orientations
for Detten No. 1

Figure 3-2

4.0 SUMMARY AND RECOMMENDATIONS

It is evident that the correlation between fractures interpreted from the FIL and those identified from core logging is somewhat less than perfect. Not only does the tool indicate fractures where none exist, it misses existing fractures. Interpretation is further complicated by the fact that orientations may be in error by 90 degrees if the fracture is filled with a highly resistive material instead of conductive mud, such as frequently occurs in the Palo Duro Basin. In sections where no core is taken, the interpreter can never be sure a fracture is being read and the orientation is correct as determined or must be changed by 90 degrees. These uncertainties render the present FIL information unreliable and speculative to the point of being invalid, at least with our present understanding of the interpretation techniques.

Unfortunately, neither the uranium concentrations from the NGRS Log nor the interval transit time reduction technique from the sonic log is reliable enough to confirm the FIL. Likewise, the televiewer log and the temperature log have limitations and uncertainties which nullify their applicability to our purpose. VSP logs, run only in the J. Friemel well within Deaf Smith County, may be able to provide some confirmation of fracture existence. It won't, however, increase the confidence in the orientation results. The J. Friemel VSP log has not been analyzed in an attempt to identify fractures for comparison with the FIL.

Application of FIL results from program wells to characterize fracture frequency, conductivity, or orientation is premature and inappropriate at this time. To utilize the data as a basis for tectonic hypotheses, future dissolution trends, or structural history would be imprudent. Little reliance should be placed on FIL results published to date from CRWM program wells.

Several weaknesses are evident in our understanding of interpretation techniques as a result of this study. Confidence levels may potentially be improved with the use of newer tools. Reportedly, considerable technological improvements have been made to the dipmeter tool since the Deaf Smith County wells were logged in 1982. The high-resolution dipmeter tool (HDT), used in program wells, has essentially been replaced by the Stratigraphic High Resolution Dipmeter Tool (SHDT). The new tool takes twice as many measurements per foot as the old tool (120 versus 60), generates ten dip curves versus five, and utilizes magnetometers and accelerometers to record tool orientation instead of mechanical compasses and pendulums; all of which improve the quality of the original data on which the FIL is based. Schlumberger claims to be able to orient non-vertical fractures with the SHDT. Addition of a gamma-ray tool to the logging string would improve lithologic and depth correlations, essential when comparing the log to core intervals.

Schlumberger recently published a summary of fracture detection techniques (1987) in which they indicate a preference for utilizing borehole imaging and sonic logging techniques over the dipmeter tool. They recognize many of the problems of the FIL which were experienced in the program wells and now recommend use of their recently introduced Formation Microscanner tool for the most reliable fracture detection.

Schlumberger also has developed computer programs such as DUALDIP and FILMAP which are designed to enhance potential fracture zones of all orientations. These options may be valuable for future site-related activities and modeling efforts.

In summary, it can be stated that none of the logging tools provide data that could be used to accurately and consistently determine the location and orientation of fractures in the CRWM boreholes. Confidence levels may be improved, however, with coincidence of several techniques. Coincidence on any level for the methods discussed herein has not been achieved to date for the Deaf Smith wells. Geologic mapping of the exploratory shafts would ultimately provide the best data on fracture frequency and orientation.

5.0 REFERENCES

Babcock, E. A., 1978. "Measurement of Subsurface Fractures from Dipmeter Logs," American Association of Petroleum Geologists Bulletin, Vol. 62, No. 7, pp. 1111-1126.

Beydoun, W. B., C. H. Cheng, and M. N. Toksoz, 1984. "Detection of Subsurface Fractures and Permeable Zones by the Analysis of Tube Waves," Chapter 6 in Toksoz and Stewart (eds.) Vertical Seismic Profiling, Part B: Advanced Concepts, Geophysical Press Limited, London, England, pp. 315-336.

Borjeson, R. W., and T. J. Lamb, 1987. Geotechnical Borehole Testing Report Holtzclaw No. 1 Well (PD-10), Palo Duro Basin, Rev. 1, ONWI/SUB/87/E512-05000-T28, prepared by Stone & Webster Engineering Corporation for Office of Nuclear Waste Isolation, Battelle Memorial Institute, Columbus, OH.

Bureau of Economic Geology, 1985a. Well Report Summary Supplement, DOE-SWEC #1 Detten, Deaf Smith County, Texas, OF-WTWI-1985-20, prepared for U.S. Department of Energy by Bureau of Economic Geology, The University of Texas at Austin, Austin, TX.

Bureau of Economic Geology, 1985b. Well Report Summary Supplement, DOE-SWEC #1 G. Friemel, Deaf Smith County, Texas, OF-WTWI-1985-20, prepared for U.S. Department of Energy by Bureau of Economic Geology, The University of Texas at Austin, Austin, TX.

Bureau of Economic Geology, 1985c. Well Report Summary Supplement, DOE-SWEC #1 J. Friemel, Deaf Smith County, Texas, OF-WTWI-1985-08, prepared for U.S. Department of Energy by Bureau of Economic Geology, The University of Texas at Austin, Austin, TX.

Collins, E. W., 1984. Jointing History of the Palo Duro Basin, Open File Report OF-WTWI-1984-20, prepared for U.S. Department of Energy by Bureau of Economic Geology, The University of Texas at Austin, Austin, TX.

Collins, Edward W., and Barbara A. Luneau, 1985. Fracture Analyses of the Palo Duro Basin Area, Texas Panhandle and Eastern New Mexico, Open-File Report OF-WTWI-1983-3, Rev. 1 (Draft), prepared for U.S. Department of Energy by Bureau of Economic Geology, The University of Texas at Austin, Austin, TX.

Dewan, J. T., 1984. Geophysical Well Logging Specifications, Review and Recommendation, Document No. 13697-G112I-2, prepared by Dewan & Timko, Inc. for Stone & Webster Engineering Corporation, Boston, MA.

Finley, R. J., and T. C. Gustavson, 1981. Lineament Analysis Based on Landsat Imagery, Texas Panhandle, Geological Circular 81-5, prepared for U.S. Department of Energy by Bureau of Economic Geology, The University of Texas at Austin, Austin, TX.

Goldstein, A. G., and E. W. Collins, 1984. "Deformation of Permian Strata Overlying a Zone of Salt Dissolution and Collapse in the Texas Panhandle," Geology, Vol. 12, May, pp. 314-317.

Gustavson, Thomas C., and Roy T. Budnik, 1985. "Structural Influences on Geomorphic Processes and Physiographic Features, Texas Panhandle. Technical Issues in Siting a Nuclear-Waste Repository," Geology, Vol. 13, March, pp. 173-176.

Gustavson, T. C., and R. J. Finley, 1984. Late Cenozoic Geomorphic Evolution of the Texas Panhandle and Northeastern New Mexico: Case Studies of Structural Controls of Regional Drainage Development, OF-WTWI-1984-39, prepared for U.S. Department of Energy by Bureau of Economic Geology, The University of Texas at Austin, Austin, TX.

Lewkowicz, J. F., R. Reischman, and J. J. Walsh, 1983. "Results from Open Hole and Cased Hole Vertical Seismic Profiles," Society of Professional Well Log Analysts 24th Annual Logging Symposium (June 27-30, Calgary, AB), Paper MM, Stone & Webster Engineering Corporation, Boston, MA.

Morris, R. L., D. R. Grine, and T. E. Arkfeld, 1964. "Using Compressional and Shear Acoustic Amplitudes for the Location of Fractures," Journal of Petroleum Technology, June, pp. 623-632.

Plumb, R. A., and J. Singer, 1983. Insights into the Mechanical Properties of Tight Formations: A Study of In Situ Stress and Fracture Distribution at Auburn, New York, by Schlumberger-Doll Research, Ridgefield, CT.

Schlumberger, 1970. Fundamentals of Dipmeter Interpretation, Schlumberger Limited, New York, NY.

Schlumberger, 1987. "Fracture Detection with Logs," The Technical Review, Vol. 35, No. 1, pp. 22-34.

Serra, O., J. Baldwin, and J. Quirein, 1980. "Theory, Interpretation and Practical Applications of Natural Gamma Ray Spectroscopy," Society of Professional Well Log Analysts 21st Annual Logging Symposium, Paper Q, Lafayette, LA.

TBEG, see Bureau of Economic Geology.

Yost, Albert B., II, Karl-Heinz Frohne, Charles A. Komar, and Sam Ameri, 1982. "Techniques to Determine Natural and Induced Fracture Relationships in Devonian Shale," Journal of Petroleum Technology, June, pp. 1371-1377.

Zemanek, J., R. L. Caldwell, E. E. Glenn, Jr., S. V. Holcomb, L. J. Norton, and A. J. D. Straus, 1969. "The Borehole Televiewer - A New Logging Concept for Fracture Location and Other Types of Borehole Inspection," Journal of Petroleum Technology, June, pp. 767-774.

APPENDIX

FRACTURE IDENTIFICATION ANOMALIES IN THE DEAF SMITH COUNTY WELLS

Table A-1. Fracture Identification Log Anomalies (Page 1 of 2)

Depth (ft)[a]	Orientation (Azimuth) (degree)	Formation
	J. Friemel No. 1	
719	5	Dockum
746	10	Dockum
768	0	Dockum
930-931	340	Dockum
1,179	-[b]	Dockum
1,241	340	Salado
1,330	335	Yates
1,332	300	Yates
1,351	335	Seven Rivers
2,936	345	Lower San Andres
3,049	290	Glorieta
3,076	335	Glorieta
3,268	325	Glorieta
3,551	350	Glorieta
3,608	10	Glorieta
3,714-3,716	30	Upper Clear Fork
3,985	45	Upper Clear Fork
4,805-4,806	40	Red Cave
4,813	55	Red Cave
4,971	45	Red Cave
4,986-4,990	45	Red Cave
5,051	35	Red Cave
5,083-5,085	30	Red Cave
5,130	30	Red Cave
5,197	40	Red Cave
5,451	50	Wichita
5,928	285	Wolfcamp
5,973	335	Wolfcamp
6,026	280	Wolfcamp
6,101-6,107	280	Wolfcamp
6,115-6,117	300	Wolfcamp
6,132-6,138	300	Wolfcamp
6,154	290	Wolfcamp
6,178	290	Wolfcamp
6,196	280	Wolfcamp
6,213-6,214	290	Wolfcamp
6,247-6,248	275	Wolfcamp
6,262	290	Wolfcamp
6,308	285	Wolfcamp
6,328-6,329	290	Wolfcamp
6,362	280	Wolfcamp

Table A-1. Fracture Identification Log Anomalies (Page 2 of 2)

Depth (ft)[a]	Orientation (Azimuth) (degree)	Formation
6,416	285	Wolfcamp
6,430	290	Wolfcamp
6,675	305	Wolfcamp
7,354	320	Pennsylvanian
8,041	70	Pennsylvanian
8,088	35	Pennsylvanian
	Detten No. 1	
1,169	300	Alibates
1,195-1,196	305	Salado
1,248-1,249	40	Yates
1,562-1,564	310	Seven Rivers
1,569-1,570	310	Seven Rivers
1,606-1,608	315	Seven Rivers
1,676	300	Queen/Grayburg
1,696	320	Queen/Grayburg
1,706	310	Queen/Grayburg
1,709	305	Queen/Grayburg
1,723	295	Queen/Grayburg
1,737	285	Queen/Grayburg
1,745	285	Queen/Grayburg
1,750-1,751	5	Queen/Grayburg
1,763-1,764	320	Queen/Grayburg
1,796-1,803	80	Queen/Grayburg
1,913	305	Upper San Andres
2,357	10	Upper San Andres
2,549	0	Upper San Andres
	G. Friemel No. 1	
1,097	55	Salado
1,098	60	Salado
1,146	335	Salado
1,849	60	Upper San Andres
2,657	315	Lower San Andres Unit 4
2,659	5	Lower San Andres Unit 4

(a) Conversion factor 1 ft = 0.3048 m.
(b) No orientation determinable.