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EASTERN GAS SHALES PROJECT

CORING, LOGGING, STIMULATION, AND COMPLETION OF

EGSP TENNESSEE NO. 9 WELL

GRAINGER COUNTY, TENNESSEE

Final Report

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December 1980

Work Performed for the Department of Energy
Under Contract DE-RP-05-79MC0838

GRUY FEDERAL, INC.
Houston, Texas 77063

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EXECUTIVE SUMMARY

EGSP Tennessee No. 3 well is located in the Grainger County Industrial Park in Grainger County, Tennessee, at lat. 30°18'56"N, long. 83°24'33"W. This particular site was selected for the purpose of gathering geological information on the Chattanooga Shale and testing an exploration rationale for exploitation of the potential gas contained within the formation matrix and its fracture system. The proposed exploration rationale was based on the Chattanooga Shale being truncated by the Saltville Thrust fault, a structural setting which provides a geologically desirable site. This is due to the expected high frequency of naturally occurring, thrust-induced fractures; such a high fracture density is an essential requirement for developing productive Devonian shale wells. Another geologic factor which supports the selection of this site is that approximately 180 ft of organic shale were encountered in the EGSP Tennessee No. 7 and EGSP Tennessee No. 8 test wells located a few miles away. Both of these wells exhibited high radioactivity in the Cleveland, Lower Huron, and Rhinestreet members of the Chattanooga Shale Formation.

Falcon Drilling Company, Charleston, West Virginia, moved its air rotary rig on location and spudded the hole on January 3, 1980. Drilling and coring of the well to a total depth of 1,920 ft required 19 days. The well was cored from 1,167 to 1,865 ft, to a point 9 ft below the bottom of the Rhinestreet Member into the underlying Wildcat Valley Sandstone. The Clinch Sandstone may have been penetrated in drilling out the logging tool rathole. The stratigraphic sections encountered during the drilling and coring operations were the Cambrian Conasauga Group from 0 to 210 ft, the Rome Formation from 210 to 670 ft (both of these formations are in the upthrust block), the Mississippian Grainger Formation from 670 to 1,134 ft, and the Mississippian/Devonian Chattanooga Shale and Silurian Wildcat Valley Sandstone from 1,134 to 1,856 ft (below the thrust block).

A total of 226 feet of oriented core was cut from 1,167 to 1,865 ft in the Chattanooga Shale. The following geologic sections were penetrated:

Ohio Shale (Sunbury-Cleveland, Chagrin, and Huron members, 1,134 to 1,734 ft).

Olentangy Shale (1,734 to 1,834 ft).

West Falls Formation (Rhinestreet Member, 1,834 to 1,856 ft).

Wildcat Valley Sandstone (1,856 to 1,865 ft)

The core analysis and the open-hole logs (both dry and wet) were used to identify the Devonian strata traversed by the drilling and coring operations.

The greatest concentration of fractures noted in the cores occurs in the Lower Huron and Rhinestreet Members, an observation that substantiates the exploration rationale used to locate the test well. All natural fractures in the cores were analyzed for common structural trends. Some core barrel jamming occurred during the coring because of the fractured rocks.

A geochemical analysis of core samples of the Lower Huron and Rhinestreet shales indicated that the Lower Huron contains a high quantity of organic matter and that kerogen is the most abundant organic material.

The casing program for the well consisted of one 25-ft joint of 16-in. conductor pipe, 185 ft of 11-3/4-in. surface casing, 1,137 ft of 8-5/8-in. intermediate casing, and 1,895 ft of 4-1/2-in. production casing. All pipe strings were cemented to the surface.

On May 28, 1980, C. G. Collins Company moved their service rig on to the location for the stimulation and completion of the well. After running correlation logs, the Middle and Lower Huron intervals were perforated from 1,630 to 1,730 ft (11 shots). Two other sections also were perforated, the Upper Olentangy from 1,760 to 1,830 ft (6 shots) and the Rhinestreet Member from 1,840 to 1,850 ft (2 shots).

On June 7, 1980, the well was acidized using 6,000 gallons of 81% quality foamed acid containing 1,500 gallons of regular HF acid and 106,000 scf of nitrogen. The purpose of the acid treatment was to determine the bottom-hole treating pressure, to establish a pumping rate, to break the formation down, and to ball out the perforations. The fracture gradient was calculated to be 0.83 psi/ft, which corresponds to a stress ratio of 0.72. The following day the foam fracture treatment was undertaken. This consisted of pumping into the formation 50,000 gallons of 75% quality foam containing 12,500 gallons of water, 600,000 scf of nitrogen, 10,000 pounds of 80/100 mesh sand, and 50,000 pounds of 20/40 mesh sand. The well was immediately opened to permit backflow through progressively increasing choke sizes. All the fracturing fluid was recovered and initial gas production was established. The well continued making water, later confirmed to be formation water having a salinity of 120,000 ppm and a specific gravity of 1.086. A flow analysis taken at this time showed that only the top two perforations were producing gas.

A 2-3/8 in. production tubing string was run into the well in an attempt to unload the water and thereby allow the gas to produce naturally. The maximum gas production rate was 43,000 scf/D, measured while swabbing the tubing, but this rate could not be maintained as water continued to fill the wellbore. The gas rate gradually decreased to an unmeasurable value as water production continued. A sucker rod pumping unit would have been required to continuously remove the water and to maintain gas production. Given the measured water salinity, corrosion problems would arise in the downhole equipment as well as in surface facilities required to separate the produced fluids.

Since maintenance of downhole equipment would require frequent workovers in addition to suitable salt water disposal facilities, it was recommended that the well be plugged and abandoned. However, because high exploratory interest was expressed by operators in other geological formations in the Eastern Overthrust Belt, the Grainger County Commission decided to assume control of the well. A legal agreement was executed by the spokesman for the County to accomplish that end. The effective date of the agreement was September 30, 1980.

INTRODUCTION AND RATIONALE

Drilling and testing of the EGSP No. 9 wildcat well in Grainger County, Tennessee, was undertaken as a field demonstration project of the DOE Eastern Gas Shales Project under the Unconventional Gas Recovery (UGR) Program. The EGSP seeks to encourage commercial development of the natural gas potential of the organic-rich Devonian shales that underlie some 200,000 square miles of the eastern United States. Devonian shales are an unconventional natural gas resource in that, although they contain vast volumes of gas, they usually lack sufficient natural permeability to permit the gas to migrate to the wellbore. Historically, natural gas production at commercial rates has been obtained from the Devonian shales in isolated parts of the Appalachian, Illinois, and Michigan Basins (Fig. 1) . Most of this production can be attributed to extensive natural fracture systems that act as interconnected conduits feeding gas desorbed from the shale matrix to the wellbore. One of the primary goals of the EGSP is to develop the capability of inducing artificial fractures in the shale in order to create a permeable link between the wellbore and such natural fractures as may exist in the vicinity. However, fracture stimulation alone is not sufficient to induce gas production from the Devonian shales; natural fracture permeability must be present. Hence, another primary goal of the EGSP is the formulation of exploration rationales based on geologically controlled fracture-producing mechanisms in specific areas of the shale basins wherein these rationales could apply.

The Gruy Federal-DOE No. 1 Grainger County well tested an exploration rationale based on the anticipated occurrence of intense and intricate natural fractures in the Devonian shale in areas closely associated with the major thrust faults of the Appalachian overthrust belt. In eastern Tennessee the Devonian shale is represented by the Chattanooga Shale, a formal stratigraphic unit. Most of the shale is Upper Devonian; however, the uppermost section is Lower Mississippian in age. Within the Valley and Ridge Province (Fig. 2a) it crops out along the northwestern flanks of two isolated northeast-trending synclines, the Newman Ridge and Greendale (Fig. 2b). Both synclines are bounded to the southeast by major thrust faults of regional extent, the Clinchport and Saltville Thrust Faults, respectively. The Chattanooga Shale passes into the subsurface beneath these southeast-dipping thrusts. That the Chattanooga Shale in the Newman Ridge and Greendale synclines occurs beneath the associated major thrust faults does not invalidate the exploration rationale if one supposes the existence of bedding plane faults in the shale induced by the overlying master thrust. Indirect evidence appears to support this supposition.

WELL LOCATION

EGSP Tennessee No. 9 is located in Richland Valley, 6 miles northeast of the town of Rutledge, in the Grainger County Industrial Park (Fig. 3). The geographic coordinates are 30°18'56"N latitude and 83°24'33"W longitude, in the Avondale 7-1/2' Quadrangle. The Tennessee UTM coordinates are 710,300 N and 2,762,000 E. The site is at an elevation of 1,140 ft above mean sea level. The village of Thorn Hill lies 2-1/2 miles to the north; Knoxville, Tennessee, is 37 miles to the southwest (Fig. 3, inset).

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Fig. I Eastern gas shale deposits

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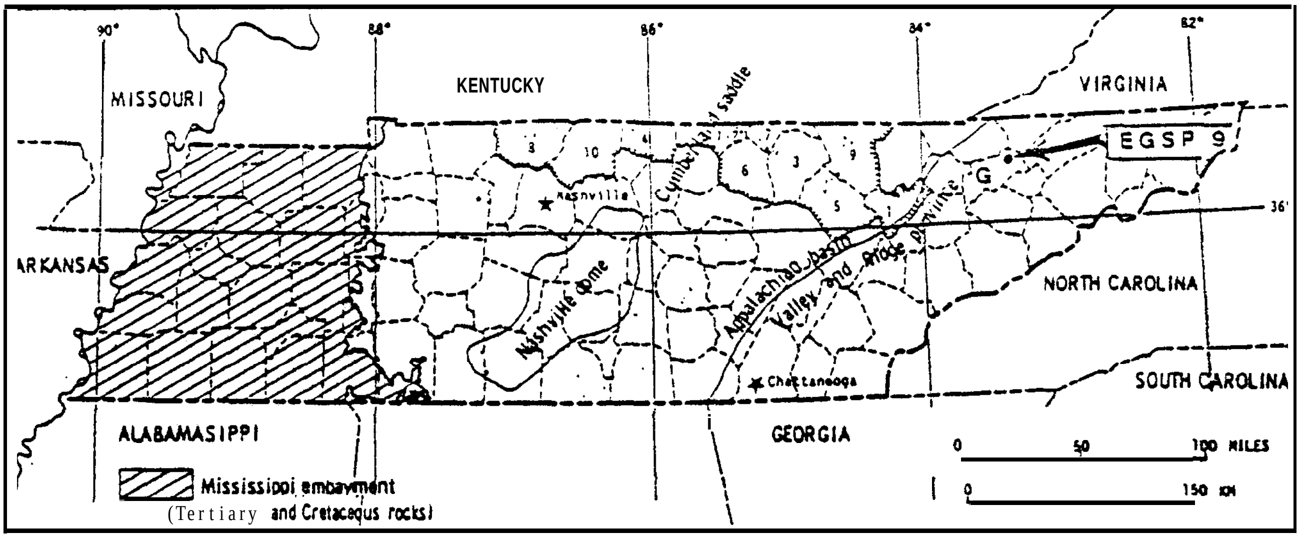

FIGURE 2 a. Tennessee. Index map, also showing major tectonic divisions and principal producing counties, past and present. County Key:

1 Anderson	3 Fentress	5 Morgan	7 Pickett	9 Scott
2 clay	4 Macon	6 Overton	8 Robertson	10 Sumner

G Grainger

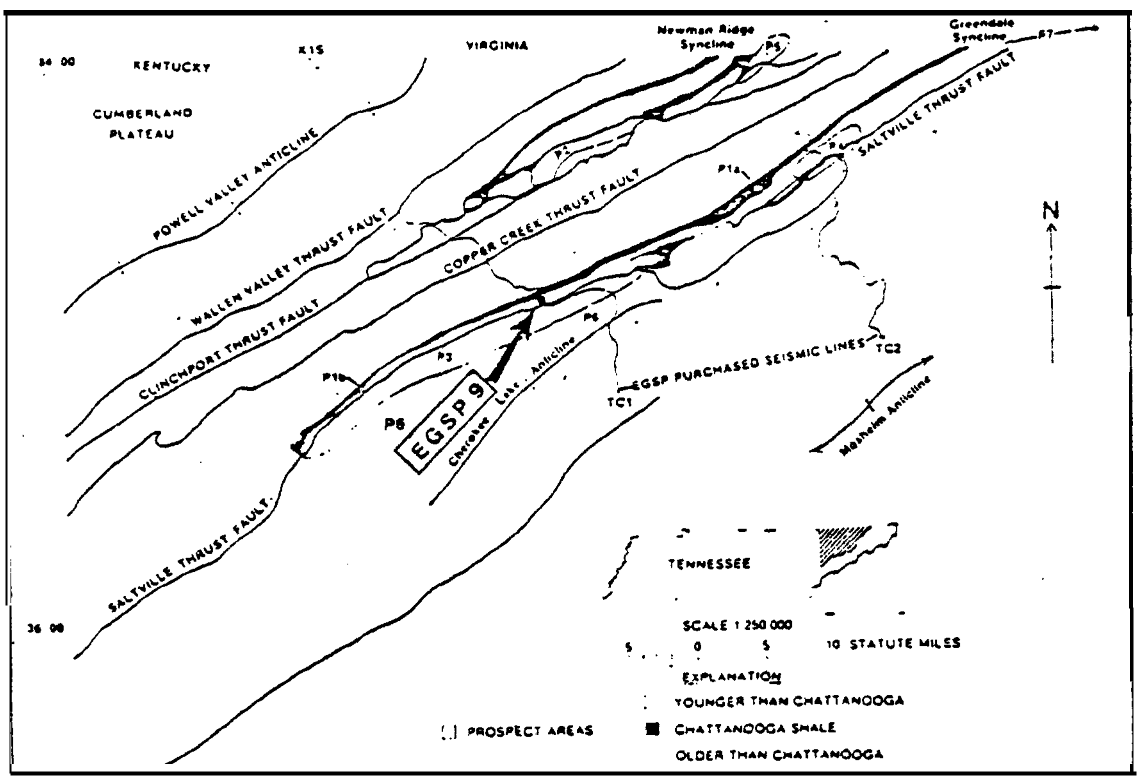

Fig. 2 b. Location of EGSP No. 9 TN core test with respect to the Clinchport and Saltville Thrust Faults, Eastern Tennessee and Southwestern Virginia

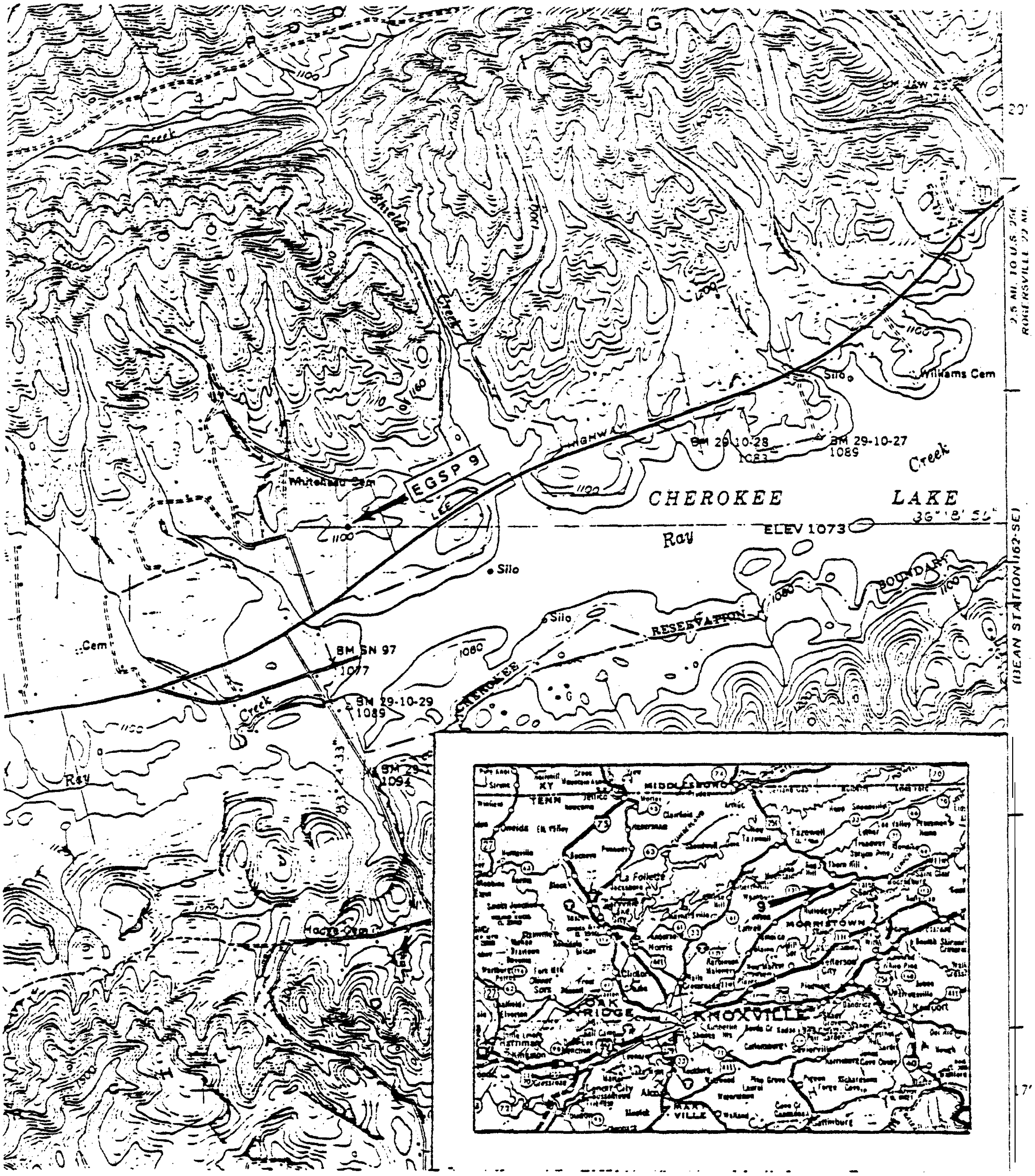

Fig. 3 Location of test well EGSP No. 9, Avondale quadrangle
NE Grainger county, Tennessee

DRILLING, CORING, AND LOGGING OPERATIONS

The well was spudded on January 3, 1980. Using a 17 1/2 in. Reed tooth bit, the hole was air drilled to a depth of 35 ft (RKB), following which one 25-ft joint of 16-in. casing (H40, 65 lb/ft) was run in and cemented to surface with 22 sacks of cement. Air drilling resumed with a 15-in. Hughes bit, type OSC/1G, to 212 ft. A total of 177 ft was drilled in 26.5 hours. After a depth of 100 ft was reached, a directional survey was undertaken, which indicated a hole deviation angle of 0.5°. An attempt was made to run the 13-3/8-in. casing into the hole, but this failed when the casing shoe would not go below 57 ft. The 13-3/8-in. pipe then was pulled, and on January 7 a string of 11-3/4-in. casing (J55, 47 lb/ft, ST&C) was successfully set at 200 ft and cemented to surface with 125 sacks of class A cement plus 4% $CaCl_2$. A 6.5-in. piece of steel which accidentally dropped into the hole during nippling up was later recovered with a magnet. A 7-7/8-in. J33 Hughes bit was used to drill the hole from 200 to 1,137 ft. Water then started entering the hole in an amount that would have precluded running the dry-hole logs. Therefore, the decision was made to ream the hole to accommodate an intermediate string of casing. The hole was reamed with a 10-5/8-in. Reed bit, type FP62, to the same depth. Both of these operations were carried out between January 8 and January 12. On the latter date Birdwell ran a set of logs in the empty hole, consisting of gamma ray, compensated density, and induction surveys. The same day, 36 joints of 8-5/8-in. intermediate casing (J55, 24 lb/ft, ST&C) were set at 1,137 ft (RKB) and cemented to surface with 300 sacks of class A cement and 4% $CaCl_2$.

On January 13 drilling resumed with a 7-7/8-in. J33 Hughes bit to 1,167 ft, the selected coring point. Coring began with a 7-27/32-in. Christensen diamond bit and a 30-ft core barrel, using foam as the circulating medium. Two cores were recovered, one from 1,167 to 1,196 ft and the other from 1,196 to 1,219 ft. Drilling then continued with a 7-7/8-in. bit to 1,610 ft, at which point water started entering the wellbore. When Birdwell ran gamma ray, compensated density, SP, and induction logs, the fluid level was at 1,410 ft. Coring the shale then resumed, and 5 cores, varying in length from 2 ft to 58 ft, were recovered from 1,610 to 1,739 ft. The major problem encountered was core barrel jamming.

The hole was drilled from 1,739 to 1,820 ft with a 7-7/8-in. bit and then cored from 1,820 to 1,865 ft, in which interval two more cores were taken. Hence, with nine core runs the aggregate recovery was 226 ft. The cored and drilled intervals are shown in Fig. 4. Coring was terminated after penetrating approximately 9 feet of the Wildcat Valley Sandstone. Fault zones encountered during the coring operation caused core jamming on four occasions. The Silurian Clinch Sandstone, the lowermost coring target, was not reached because extremely hard drilling was experienced in the overlying Wildcat Valley Sandstone. However, it is possible that the rathole may have been drilled into the Clinch Sandstone. The only coring difficulties encountered were in the Lower Huron, where an extensive fault zone caused repeated jamming of the 60-ft core barrel.

Birdwell ran a suite of dry-hole logs followed by Schlumberger dry-hole logs. The hole was later reamed out with a 7-7/8-in. bit from 1,865 to

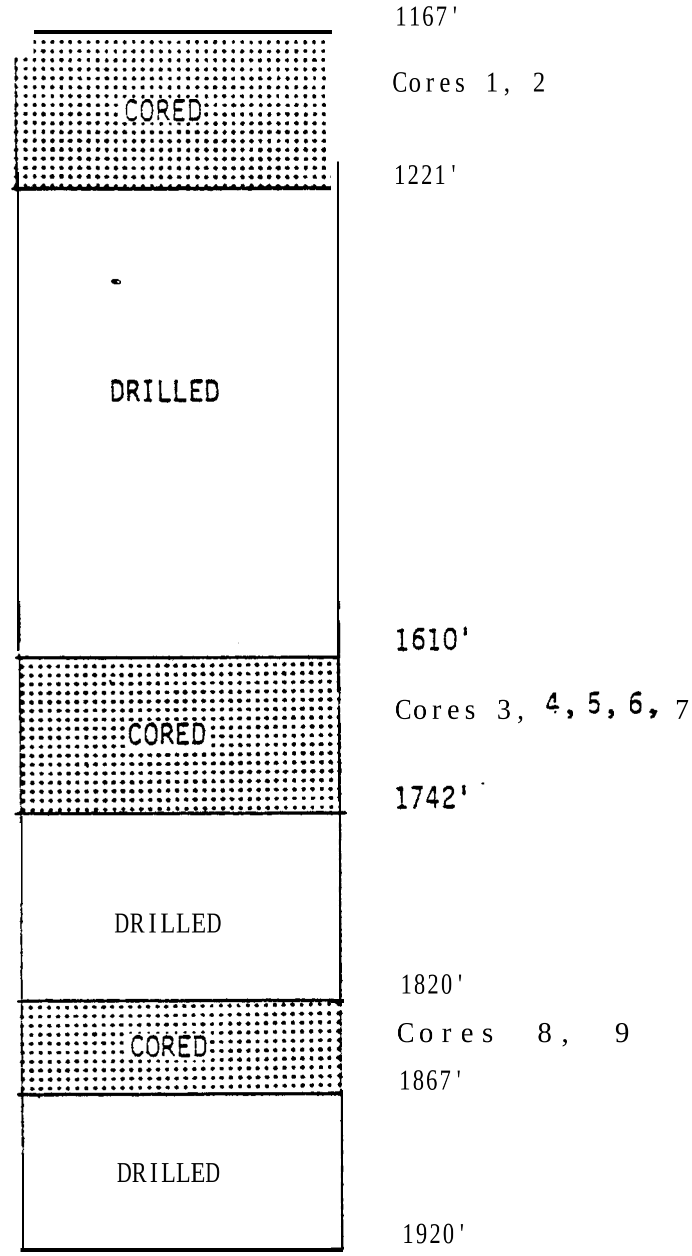

Fig.4 Cored Intervals in EGSP Tennessee No. 9

a total depth of 1,920 ft and then loaded with 45 barrels of mud to run Schlumberger's wet-hole logs. The following dry-and wet-hole wireline logs were obtained in the open hole: (i) dry hole logs: density borehole compensated, gamma ray, induction, temperature, sibilation, and spontaneous potential; (ii) wet-hole logs: gamma ray, caliper, formation density compensated, compensated neutron, borehole compensated sonic, fracture identification, spontaneous potential, dual induction-laterolog 8, variable density, and Coriband - kerogen analysis. Cased hole logs which were run during the stimulation program are: CBL-VDL, gamma ray correlation and perforation. After treatment a gamma ray log and flow analyzer survey were taken.

On January 21, 43 joints of 4-1/2 in. production casing (9.5 lb/ft, J55) were set at 1,895 ft and cemented to surface with 400 sacks of class A cement plus 2% $CaCl_2$, and the rig was released.

SAMPLE COLLECTION AND ANALYSIS

Throughout drilling operations, samples were collected at 10-ft intervals except for short intervals above each of the core points, where 5-foot samples were obtained. The latter sampling intervals were as follows: 1,137 to 1,167 ft, just before the first core point; 1,590 to 1,610 ft, just before the second core point; and 1,802 to 1,820 ft, just before the third core point.

Samples were collected at the end of the blooie line by a member of the drilling crew and transferred to heavy plastic "ziplock" sample bags before being turned over to the geologists for preparation and examination. A portion of each sample was examined wet and then dried for further study. The dry sample was examined under a binocular microscope (magnification range 10x to 40x), described, and divided into two dry sample cuts, which were rebagged for a permanent sample record. Ten percent hydrochloric acid was used to test for carbonate minerals. A fluoroscope was used to check for fluorescence in the Chattanooga Shale samples.

GEOLOGY

1. General

The surface topography in the vicinity of the well site consists of a series of northeast-southwest trending valleys and ridges resulting from overthrusting. The Saltville Fault is one of many overthrust faults associated with this major overthrust feature in the Southern Appalachian Region. The surface is underlain by rocks of the Conasauga Group (Middle Cambrian), Rome Formation (Cambrian), Grainger Formation (Mississippian-Upper Devonian), Chattanooga (Upper Devonian), Wildcat Valley Sandstone (Silurian), and the Clinch Sandstone (Silurian). The general stratigraphic section for Grainger County is shown in the lower inset on Fig. 5. The geologic nomenclature applicable to the Chattanooga Shale is given in the upper inset on Fig. 5.

The site selection for Tennessee No. 9 was based primarily on the interpretation of seismic survey TC-1, taken along US Highway 25E, approximately six miles north and along strike from the well site, and on a previous shallow (NX) geologic coring and logging program in the area. Additional local and regional geologic information was obtained from the Geologic

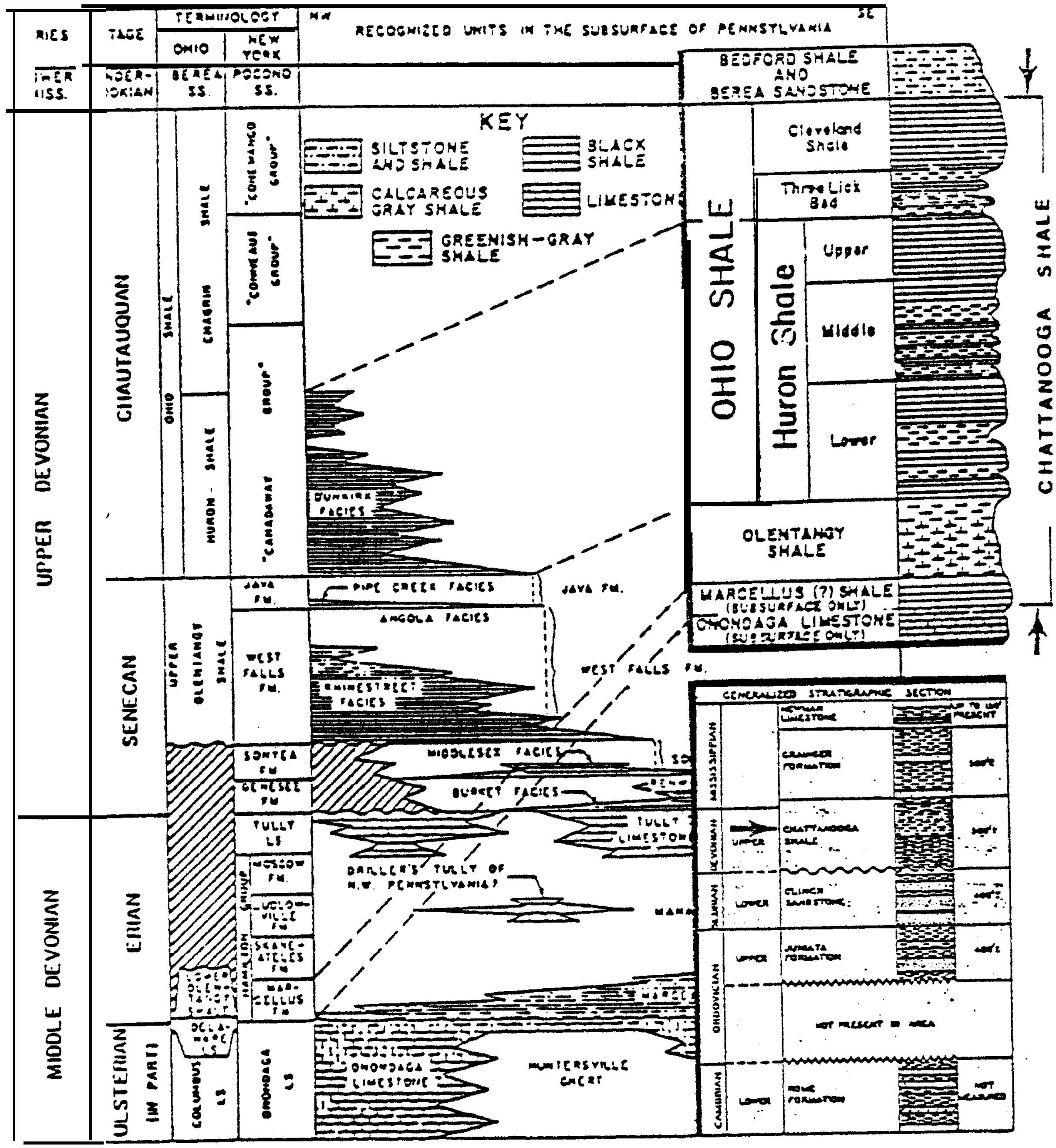

Fig. 5 Upper and Middle Devonian Stratigraphic Units in The Subsurface of Pennsylvania and Correlation with Ohio and New York Stratigraphic Section (After Oliver, and others, 1969, and Patchen, 1977).

Units of the Chattanooga Shale Shown in Upper Inset. Lower Inset Shows the Stratigraphic Section for Grainger County, Tennessee (after Jeran, 1965).

Map of Tennessee (1966) and from a study of the Grainger Formation by Hasson (1967).

The interpreted seismic line shows the Chattanooga Shale carrying back for some distance under the Saltville Thrust Fault before being truncated. This structural setting in which the Chattanooga Shale is truncated by a major thrust fault should be favorable for the development of a high degree of fracturing in the Chattanooga Shale.

The previous NX coring program along the outcrop belt of the Chattanooga Shale demonstrated that the shale is reasonably thick, ranging from 662 to 760 ft, with distinct black organic sections in the Cleveland, Lower Huron, and Rhinestreet Members. Gamma ray logs of the NX core holes show these zones to have relatively high radioactive signatures. The stratigraphic section expected in the well was the Cambrian age Conasauga Formation, Pumpkin Valley Shale, and Rome Formation in the thrust block, and the Mississippian age Grainger Formation and Chattanooga Shale beneath the fault.

Since neither driller's logs nor electric logs of the section above the Chattanooga shale were available for wells drilled in the immediate area, it was necessary to identify potential markers on the basis of outcrop lithology. Two such markers, which can be used to locate the top of the Chattanooga Shale, are the Saltville Fault "zone" and a glauconite zone in the Middle Member of the Grainger Formation.

In outcrop, the basal sandstones of the Rome Formation are similar to the massive sandstones and siltstones of the Upper Member of the Grainger. The fault "zone" varies in outcrop from less than a foot to a few feet in thickness. In drill cuttings one would expect to see a change from the micaceous Rome sandstone to non-micaceous Grainger sandstone. However, in the interval from 660 to 670 ft, the slickensided surfaces in the drill cuttings showed some shale and siltstone fragments. From 650 to 660 ft the samples contained micaceous sandstone, while the samples from 670 to 680 ft comprised a medium to dark gray siltstone. This type of evidence then permitted an accurate determination of the fault contact in the subsurface section.

Once the fault zone had been recognized, measured sections of the Grainger Formation (Hasson , 1967) obtained at outcrops located a few miles from Tennessee No. 9 (where a glauconite zone appeared in the "Middle Shale Member" of the Grainger) were used to predict that the top of the Chattanooga would be approximately 400 ft below this zone. The glauconite was clearly evident in cutting samples taken from 710 to 720 ft and from 720 ft to 730 ft. From this information it was possible to predict that the top of the Chattanooga shale would occur at 1,134 ft. A detailed lithologic description of each member of the Chattanooga Shale follows.

2. Lithology

(a) Ohio Shale: (Lower Mississippian and Upper Devonian)

The Ohio shale consists of three members, in descending order: the

Sunbury-Cleveland Member (1, 134 to 1,236 ft), the Chagrin Member (1,236 to 1,418 ft), and the Huron Member (1,418 to 1,734 ft).

(i) Sunbury-Cleveland Member:

Dean (1980) indicated that the Sunbury and Cleveland units could not be differentiated in this area. The total thickness of the Sunbury-Cleveland Member, as determined from gamma ray and compensated neutron-formation density logs, is 102 ft. Of this total, only a 52-ft section near the middle of the member (1,167 to 1,219 ft) was cored.

The cored section consists of olive-black and olive-gray, thick-bedded, shaly mudstones. Siltstones also are present as thin cross-stratified laminations. Several of the siltstones in the upper 20 feet of the core (1,167 to 1,187 ft) contain basal scour surfaces. A few of these laminations are calcareous. Vitrinite and carbonaceous fragments, some of which are partially pyritized , occur throughout . Sparse amounts of pyrite also are present in disseminated form (occasionally zonal) or as lenses and nodules. Disseminated mica, multiple calcite-cemented fractures, and an occasional lens of dolomite are present in the lower half of the Member.

The contact between the Sunbury-Cleveland Member and the underlying Chagrin Member occurred at 1,236 ft and is marked on geophysical logs by a decrease in gamma radiation and an increase in rock density.

(ii) Chagrin Member:

The Chagrin Member was not cored. The contact between the Chagrin Member and the underlying Huron Member is marked on the geophysical log by an increase in gamma radiation at a depth of 1418 ft.

(iii) Huron Member:

The Huron Member is usually divided into three informal subunits: the Upper, Middle, and Lower Huron. The Upper Huron was not cored. The contact between the Upper and Middle Huron is indicated on geophysical logs by a decrease in gamma radiation at 1,502 ft. The Middle Huron was drilled from 1,502 to 1,610 ft and cored from 1,610 to 1,632 ft. The cored portion consists of olive-black and light olive-gray shaly mudstones. Thin laminations of ripple- and cross-laminated siltstones resting on sole marks are present in the lowest 10 feet (1,622 to 1,632 ft). Vitrinite occurs throughout; carbonaceous fragments, disseminated mica, and a single conodont are present only in the top 10 feet (1, 610 to 1,620 ft) of the core. Carbonaceous spores (?) are present throughout the cored interval. Dolomite is present throughout as lenses and as a cementing agent in fractures and fault planes.

The contact between the Middle and Lower Huron is gradational in the core over approximately 9 feet (1,630 to 1,639 ft) but can be determined by a decreasing siltstone content. Well log data indicate a sharp increase in gamma radiation at this contact.

The entire Lower Huron section was cored from 1,632 to 1,734 ft. This interval consists of alternating thick and thin laminations of light olive-gray and olive-black mudstones in the upper half, and olive-gray and olive-black mudstones in the lower half. Occasional distinct shale sections were also noted. The light olive-gray and olivegray silty mudstones are restricted to the middle portion of the interval. Thinly laminated siltstones contained in the section from 1,632 to 1,706 ft are cross- and ripple-laminated and occasionally rest on scour surfaces and sole marks. In the lower half (1,664 to 1,734 ft) zones of bioturbation (mottling) occur within the olive-gray mudstones; burrow structures are present in the olive-black mudstones. These burrows are commonly pyritized and rarely mud- or silt-filled. One zone of disseminated mica and two zones of carbonaceous fragments are noted in the middle section of the interval. Carbonaceous and pyritized spore bodies are rare and are confined to the upper third (1,610 to 1,664 ft). Two concretions are present near the middle of the interval. Dolomite cement is present in many of the fractures and fault planes.

Organic-rich (kerogen) shale with numerous highly polished slickensides occur below approximately 1,680 ft. This organic-rich shale was probably injected around concretions and along fault planes while in a highly plastic state (Dean, 1980).

The contact between the Lower Huron Member and the underlying Upper Olentangy Shale is clearly marked in the core by a change from the dark shades of the Huron Member to the lighter, greenish shales of the Olentangy Shale. Well log data show a decrease in gamma radiation at this contact.

(b) Upper Olentangy Shales:

Only the upper 5 feet (1,734 to 1,739 ft) and the lower 14 feet (1,820 to 1,834 ft) of the Olentangy Shales were cored; the interval between 1,739 and 1,820 ft was drilled. The upper interval consists of alternating thin to thick laminated dark greenish-gray and grayish-black mudstones. Carbonaceous fragments (some identified as shell fragments), fish scales, and pyritized burrow structures are present throughout. The lower interval (1,820 to 1,834 ft) consists of thickly laminated to thinly bedded greenish-gray, dark greenish-gray, and dark gray, shaly mudstones. Occasional cross-laminated, light gray siltstones and thinly bedded, medium gray, limey mudstones also are present. Algal bodies, a single conodont, vitrinite, and carbonaceous and pyritized woody fragments occur throughout. Bioturbation (mottling) is present in the greenish-gray mudstones. Pyritized burrow structures and disseminated pyrite are present in the sitlstones and darker mudstones. Calcite cement is present in the fault planes and fractures. Shale breccia, associated with a fractured concretion, is present at 1,830.7 ft.

The contact between the Upper Olentangy Shale and the underlying Rhinestreet Member of the West Falls Formation is gradational over a 10-foot zone (1,830 to 1,840 ft) in the core. The light green shales of the Upper Olentangy Shale grade into the dark Rhinestreet shales. This contact is indicated by a slight increase in gamma radiation on the gamma ray log.

(c) Rhinestreet Member of the West Falls Formation:

The entire Rhinestreet Member, which is present from 1,834 to 1,856 ft, was cored. It consists of thickly laminated to thinly bedded, dark greenish-gray, dark gray, and black mudstones and silty mudstones. Occurrences of organic-rich (kerogen) shale are present throughout. Pyrite occurs in burrow structures and as disseminated grains in the darker zones. Bioturbation (mottling) is present in the greenish-gray silty mudstones. Calcite cement is present in fault planes and fractures throughout the interval.

The contact between the Rhinestreet Member and the underlying Wildcat Valley Sandstone is marked by a sharp lithologic change consisting of dark shales resting unconformably on medium gray sandstone. No well log data are available for this contact, since it occurred at the very bottom of the well beyond reach of the logging tools.

(d) Wildcat Valley Sandstone (Upper Silurian)

Nine feet (1,856 to 1,865 ft) of Wildcat Valley Sandstone was cored in the Tennessee No. 9 well. The top of the interval consists of thinly bedded, medium gray sandstone. This light gray color becomes more prominent with depth. Bioturbation and pyritized burrows are present throughout. The interval is noncalcareous at the top, changing to strongly calcareous near the base of the cored section. A shale conglomerate of subrounded particles occurs at the top of the formation along an unconformity surface. Oil staining and solution lines are present throughout the interval.

3. Fracture Analysis

Both the natural and induced fractures in the EGSP Tennessee No. 9 core were examined in detail. Because of the large number of natural fractures present the core was arbitrarily divided into four intervals to facilitate analysis.

In the entire cored section 565 natural fractures were observed. Of these, 36 percent are joints and 64 percent are faults. The distribution of these fractures throughout the cored intervals, as well as general coring data, are shown in Table 1.

The greatest concentration of fractures occurs in the Lower Huron Shale, where 3.31 fractures per foot were noted, and in the Rhinestreet Member, with 4.45 fractures per foot. High fracture frequency is not limited to these intervals but occurs throughout the drilled sections as well. Mineralization ranges from calcitic at the top of the core to dolomitic through the mid-section to non-mineralized at the bottom.

Analysis of all natural fractures in the cores served to identify three prominent structural trends :

TABLE 1

CORING DATA

Formation	Formation Interval	Formation Thickness	Geologic Sections Cored*	Avg. Coring Time MN/FT	No. of Fractures	Fractures Per Foot
Ohio Shale:						
Sunbury-Cleveland Member	1,134-1,236	102	1,167-1,219	'7	52	1
Chagrin Member	1,236-1,418	182	----		a.-	-
Huron Member:						
Upper	1,418-1,502	84	----		--	
Middle	1,502-1,632	130	1,610-1,632	7.5	46	2.09
Lower	1,632-1,734	102	1,632-1,734	7	338	3.31
Olentangy Shale:						
Upper	1,734-1,034	100	1,734-1,739	9	2	0.4
			1,820-1,834	7.5	40	2.136
West Falls Formation:						
Rhinestreet Member	1,834-1,856	22	1,834-1,856	10	98	4.45
Wildcat Valley Sandstone	1,856- **	--	1,856-1,865	25	--	-

* Individual cores: 1. 1167-1196 2. 1196-1221 3. 1610-1612 4. 1612-1670 5. 1670-1700
6. 1700-1712 7. 1712-1742 8. 1820-1844 9. 1844-1867

** Base undetermined

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Trend 1: joints, directed N30°E to N50°W, 82°-90° dip;
Trend 2: joints, N40°E to N60°E, 76°-90° dip and approximately perpendicular to Trend 1;
Trend 3: faults, N30°E to N60°E, 0°-18° dip and approximately parallel to Trend 2.

Trend 2 is orthogonal to Trend 1 and approximately parallel to Trend 3. Trend 1, which is the most dominant joint set, represents the greatest concentration of joints and contains 21 percent of the total natural fractures. The next most dominant joint set, Trend 2, contains 14 percent. Trend 3 (faults) represents 64 percent of the natural fractures. Unoriented fractures account for the remaining 1 percent.

During drilling from 212 to 400 ft, water began to enter the hole. The suspected water entry point was estimated to be at 400 ft. The ingress of water was momentarily sealed off when the intermediate 8-5/8 in. casing was cemented, but resumed during drilling from 1,221 to 1,414 ft. After the seventh core was recovered, the hole was blown dry.

When the compressor was shut off, no detectable gas was observed. However, after circulation was resumed, there was a burst of gas. This was the only occurrence of detectable gas throughout the entire drilling and coring activities.

GEOCHEMICAL ANALYSIS

Three samples were selected from the EGSP Tennessee No. 9 core as representative of the organic-rich sections : a Lower Huron Shale sample at 1,692.6 ft and two Rhinestreet Shale samples at 1,829.5 and 1,847.1 ft.

These samples were tested by J. Renton, Geochemist with the West Virginia Economic and Geologic Survey, using pyrolysis and scanning electron microscopy (SEM) techniques. The following types of data were obtained:

SEM indications :

- the presence of silicates of iron, titanium, and aluminum
- the presence of organically bonded sulfur in the Lower Huron sample
- the presence of chlorine (with sulfur absent) in the two Rhinestreet samples.

Pyrolysis indications at 550°C :

- the Lower Huron sample contained 14 to 15 times more organic material than either Rhinestreet sample
- kerogen was the most abundant organic material (80%), and was 5 to 15 times greater in quantity than any other organic substance detected in each of the three samples

- bitumen (present as long-chain compounds) was present in the Lower Huron (15%) and the upper sample of the Rhinestreet (15%), but not in the lower sample of the Rhinestreet.

STIMULATION AND COMPLETION

On May 28, 1980, C. G. Collins moved a Wilson single-pole double-drum service rig onto the location to complete the well. Schlumberger ran CB and VD logs to check the effectiveness of the cement sheath behind the 4-1/2 in. casing. The hole was subsequently swabbed dry to total depth. The Chattanooga Shale then was perforated using aluminum shaped charges on a strip jet bi-wire gun. Nineteen perforations were made at 10-ft intervals from 1630 to 1,730 ft, from 1,760 to 1,900 ft, and from 1,830 to 1,850 ft. On retrieving the perforating gun it became stuck in the casing at a depth of 1,571 ft. After the gun was jarred loose, the wire frame remained in the hole but the CCL logging tool was recovered. On May 30 the wire was recovered using a center spear. Because of the fishing activities, the scheduled stimulation treatment was postponed to a later date.

On June 7, Dowell arrived on location to proceed with the foamed acid treatment. Six thousand gallons of 81% quality foamed acid were made up using 1,500 gallons of regular HF acid and 106,000 scf of N_2. After breakdown, the interval was balled out with 30 perforation ball sealers. The instantaneous shut-in pressure was measured at 1,300 psi, corresponding to a calculated bottomhole treating pressure of 1,540 psi or a fracture gradient of 0.83 psi/ft. The following day, Dowell conducted the foam frac, which consisted of injecting 12,500 gallons of water foamed with 600,000 scf of nitrogen to make 50,000 gallons of 75% quality foam, 10,000 pounds of 80/100 mesh sand, and 50,000 pounds of 20/40 mesh sand. The foam pumping rate was 30 bbl/min, the nitrogen delivery rate 13,200 scf/min and the average wellhead treating pressure was 1,750 psi (see Tables 2 and 3). The well was immediately flowed back with progressively increasing surface choke sizes starting with a 12/64-inch choke. The well flowed back nitrogen, water, and natural gas for approximately one day. The flow then ceased and the well had to be swabbed to continue recovery of the frac water.

After two days of swabbing, the water injected during the frac was recovered, but the well continued to yield water. A chemical test of several samples indicated that the water had a specific gravity of 1.086 and a salinity of nearly 120,000 ppm (Appendix A-6). This supported the contention that formation water was entering the borehole. Steady swabbing and bailing failed to reduce the influx of water. In addition, frac sand accumulated in the borehole and on several occasions had to be pumped out.

The maximum gas rate measured was 43,000 scf/D during the cleanup period. On June 16, Basin Surveys, Inc., Crossville, Tennessee ran a gamma ray tracer log which indicated that all the perforations had been treated. A flow analyzer showed that only the two top perforations were producing gas but was not able to establish where the water was entering the wellbore.

TABLE 2

SUMMARY OF TREATMENTS

	Acid Treatment	Frac. Treatment
Regular HF Acid	1,500 Gal	
Foam Rate	8 BPM	30 BPM
Foam Quality	81 %	75 %
Sand 80/100		10,000 Lbs
Sand 20/40	•	50,000 Lbs
Surfactant Foamer F78	8 Gal	38 Gal
Surfactant Foamer F75		25 Gal
Nitrogen Used	106,000 SCF	600,000 SCF
Nitrogen Rate	5,000 SCF/mn	13,200 SCF/mn
Perf. Ball Sealers	30 (S.G.=1.3)	
Total Foam Volume	143 Bbls	1,190 Bbls
Total Water Volume		306 Bbls

TABLE 3

FRAC. TREATMENT SCHEDULE

STAGE	BBLS OF FOAM	SAND CONC. LBS/GAL	SAND LBS	SIZE	BBLS LIQUID	CUM. BBLS LIQ + SAND	SAND CONC LBS/GAL LIQ.	LIQ + SAND RATE BPM
1	238	0	0		[illegible]	[illegible]	[illegible]	7.5
2	238	1	10,000	80/100	59.5	130	4	8.868
3	476	1.5	30,000	20/40	119	281.5	6	9.552
4	238	2	20,000	20/40	59.5	362.8	8	10.236
5 displ.	30.1	0	0	0	7.5	370.3	0	7.5

In an attempt to unload the water at a faster rate and to enhance the production of gas, a string of 2-3/8 in. EU tubing (J55, 4.7 lb/ft) was run into the hole to act as a siphon string. The tubing shoe was initially set at 1,747 ft, but since no gas flowed through the tubing, it was pulled up the hole and reset at 1,624 ft, above the top perforation. Swabbing through the tubing resumed, but the downhole fluid level remained unchanged; a water influx rate of 0.42 gal/min was measured. The gas rate decreased steadily as more water accumulated in the well. The maximum recorded overnight shut-in pressure on the wellhead was 456 psi in 15.5 hours, but as water recovery work proceeded on the well, daily pressures dropped off. Work on the well was terminated on January 20, when the gas rate declined to 12,000 scf/D as the water influx continued. The wellhead tubing pressure increased to 140 psi in 12 hours while the pressure in the annulus increased to 140 psi. It was felt that if the well was allowed to produce on its own without any bailing or swabbing, it would water out, and the gas rate would drop significantly in a matter of hours.

Since the well could not be kept producing without continued swabbing, the problem of mechanical removal of water along with the gas had to be resolved. This could theoretically be accomplished by running a sucker rod pump and producing gas from the annulus while pumping water from the tubing. However, because of the high salinity of the formation water, serious corrosion problems would probably arise in the production system, particularly with the sucker rods, the subsurface pump, the surface water separation facilities and the water storage and disposal systems. Furthermore, environmental and economic considerations would have to be carefully evaluated for the proper disposal of the water. In view of these serious constraints it was decided to plug and abandon the well as noncommercial.

CONCLUSIONS

Widespread and locally intense fracturing within the Chattanooga Shale, especially within the organic-rich intervals observed in the cores and substantiated by various wireline log evaluations, was the principal exploration rationale used in siting this Devonian shale wildcat well. Since commercial gas production could not be realized during this test, a more extensive fracturing procedure would have to be undertaken to effect communication between the tight rock matrix and the fracture conduits.

The results of the flush-gas production test obtained after the stimulation were disappointing. Recovery of the frac fluid was followed by the production of natural gas accompanied by salty formation water. Steady gas production could not be sustained despite continuous swabbing efforts. Attempts to halt the water influx were unsuccessful and the maximum measured open-flow gas potential of the well was only 43,000 scf/D, a rate that abruptly declined as soon as swabbing was discontinued. No commercial gas production could be anticipated from the well unless water is withdrawn by a sucker rod pump to reduce the formation backpressure. Because the gas potential of this well remained uncertain, it was recommended that it be abandoned.

Since the shale outcrops only 1-1/2 miles from the test site, there is a strong possibility that the gas could have escaped to the surface, and was subsequently replaced by encroaching water. However, there is no evidence to support this theory.

In view of the high exploratory interest in the hydrocarbon potential of other geologic reservoirs underlying the Chattanooga Shale in the Eastern Overthrust Belt, the Grainger County Commission decided to assume control of the well.

GRUY FEDERAL, INC.

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Dean, C. S., 1980, Perspective on Devonian Shale Gas Exploration, Unconventional Gas Recovery Symposium, May 18-20, 1980, SPE/DOE Paper No. 8952, pp. 237-244.

Hasson, K. O., 1967, Lithostratigraphy of the Grainger Formation (Mississippian) in Northeastern Tennessee, unpublished Ph.D. dissertation, University of Tennessee, Knoxville, TN.

Jeran, P. W., 1965, The Structure and Stratigraphy of the Poor Valley Area Near Rutledge, Grainger County, Tennessee: Unpub. M.Sc. Thesis, University of Tennessee, Knoxville, TN.

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Gruy Federal, Inc.
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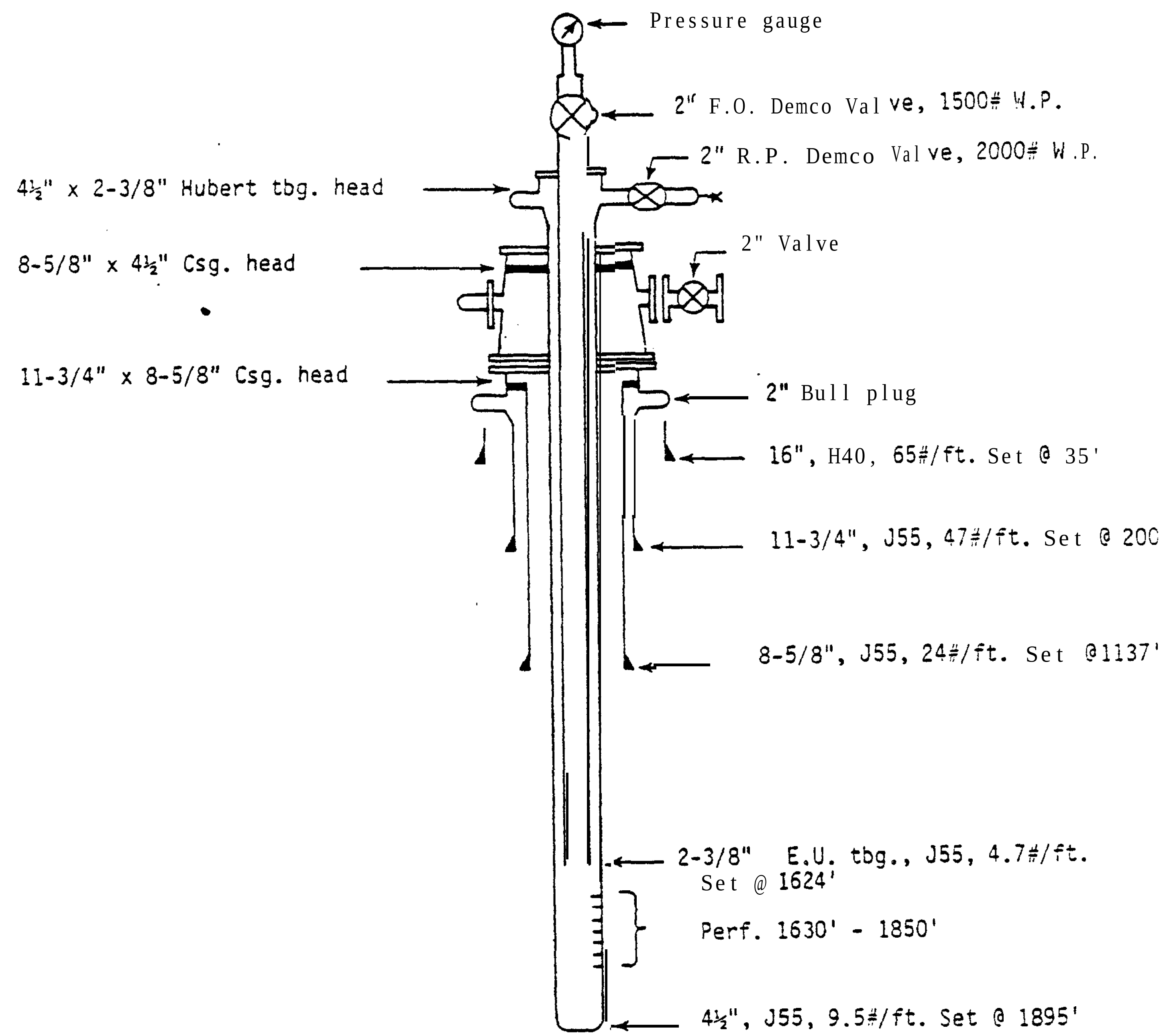
APPENDICES

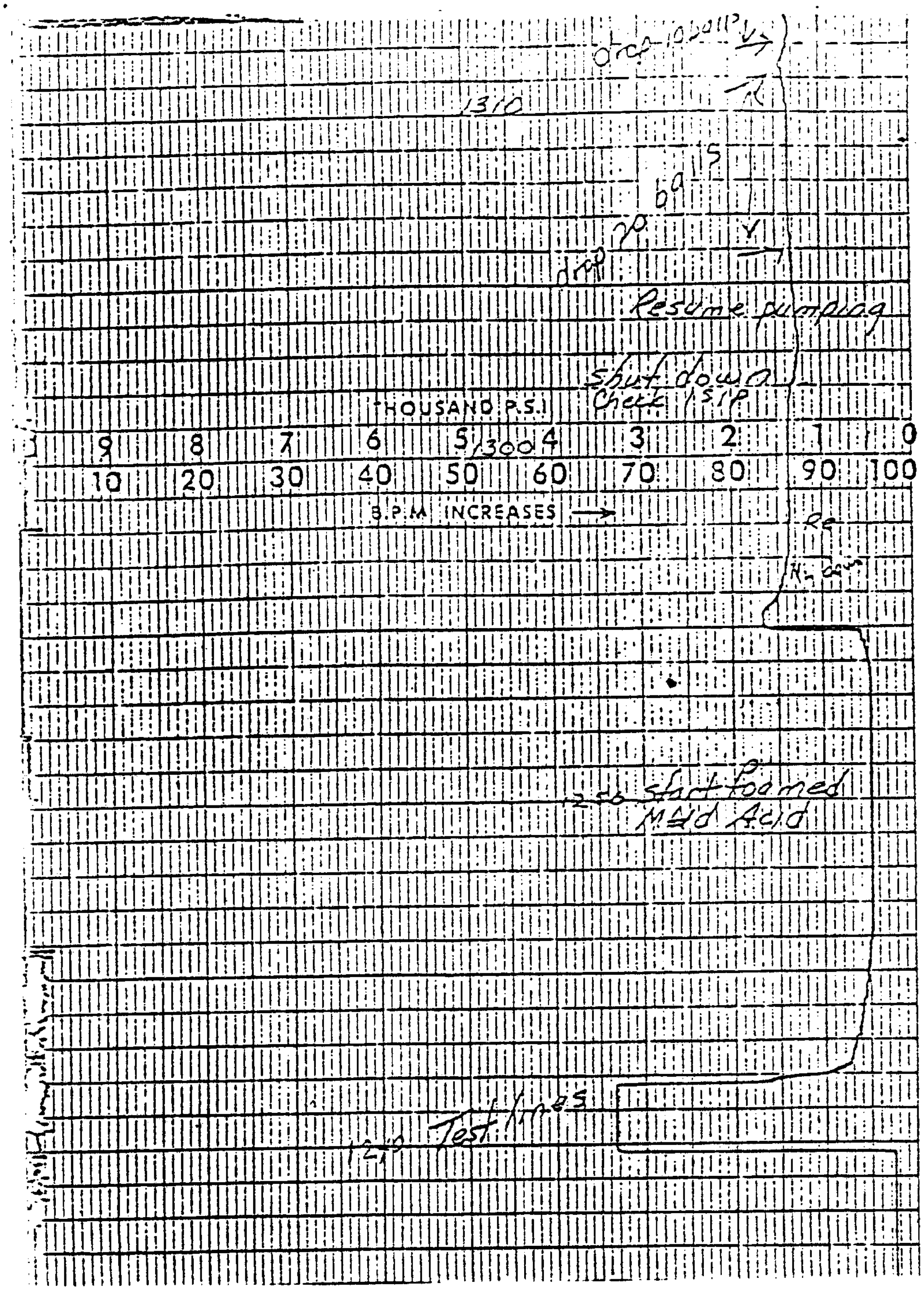
UGR File #434
Gruy Federal, Inc.
December 1980

Appendix A-1

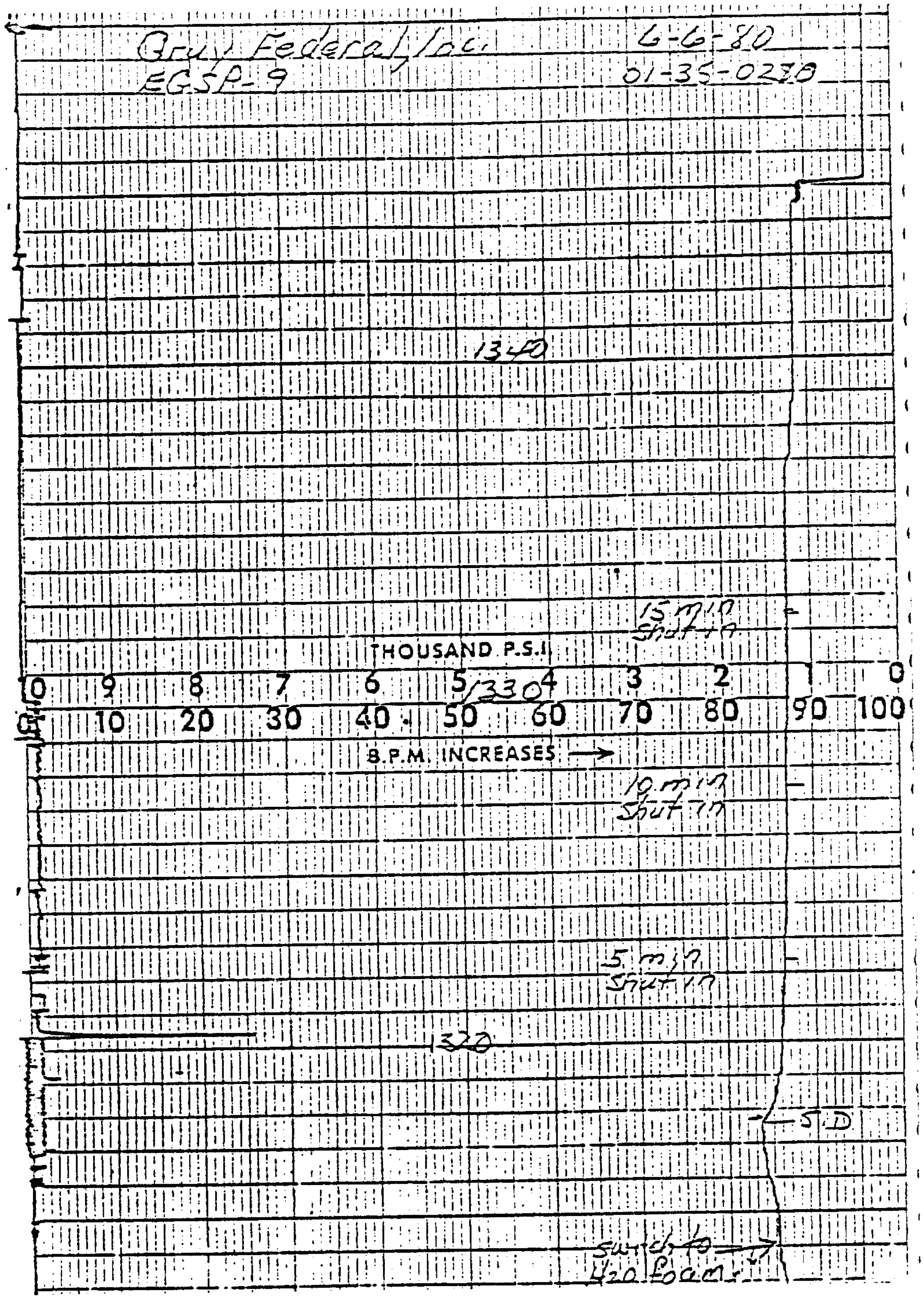
E.G.S.P. TN NO. 9

WELL DIAGRAM AFTER COMPLETION





A-2 Acid ball out treatment 1240 to 1313 (6/6/80)



A-3 Acid ball out treatment 1313 to 1350 (6/6/80)

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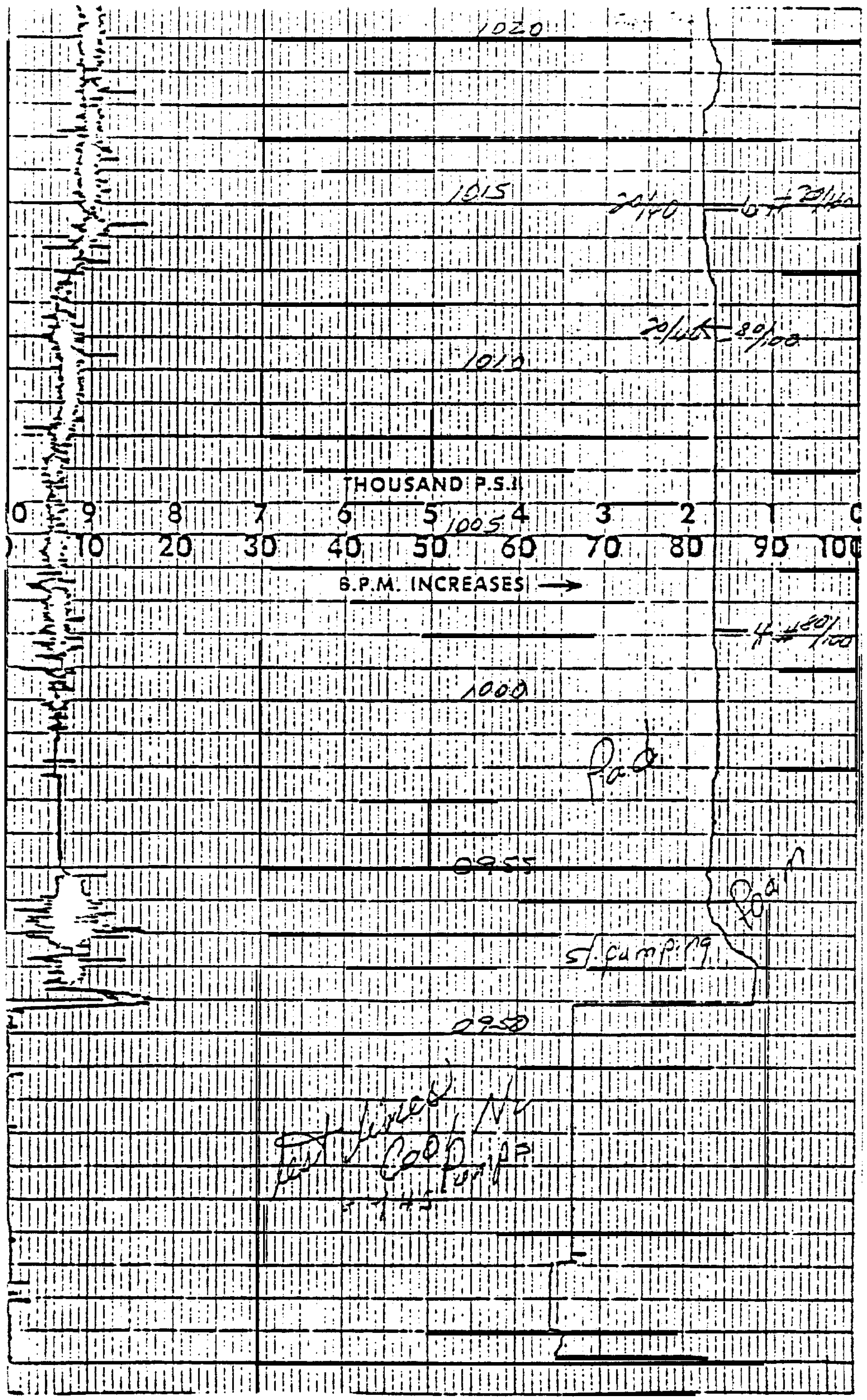

A-4 Foam fracture treatment 0939 to 1020 (6/8/80)

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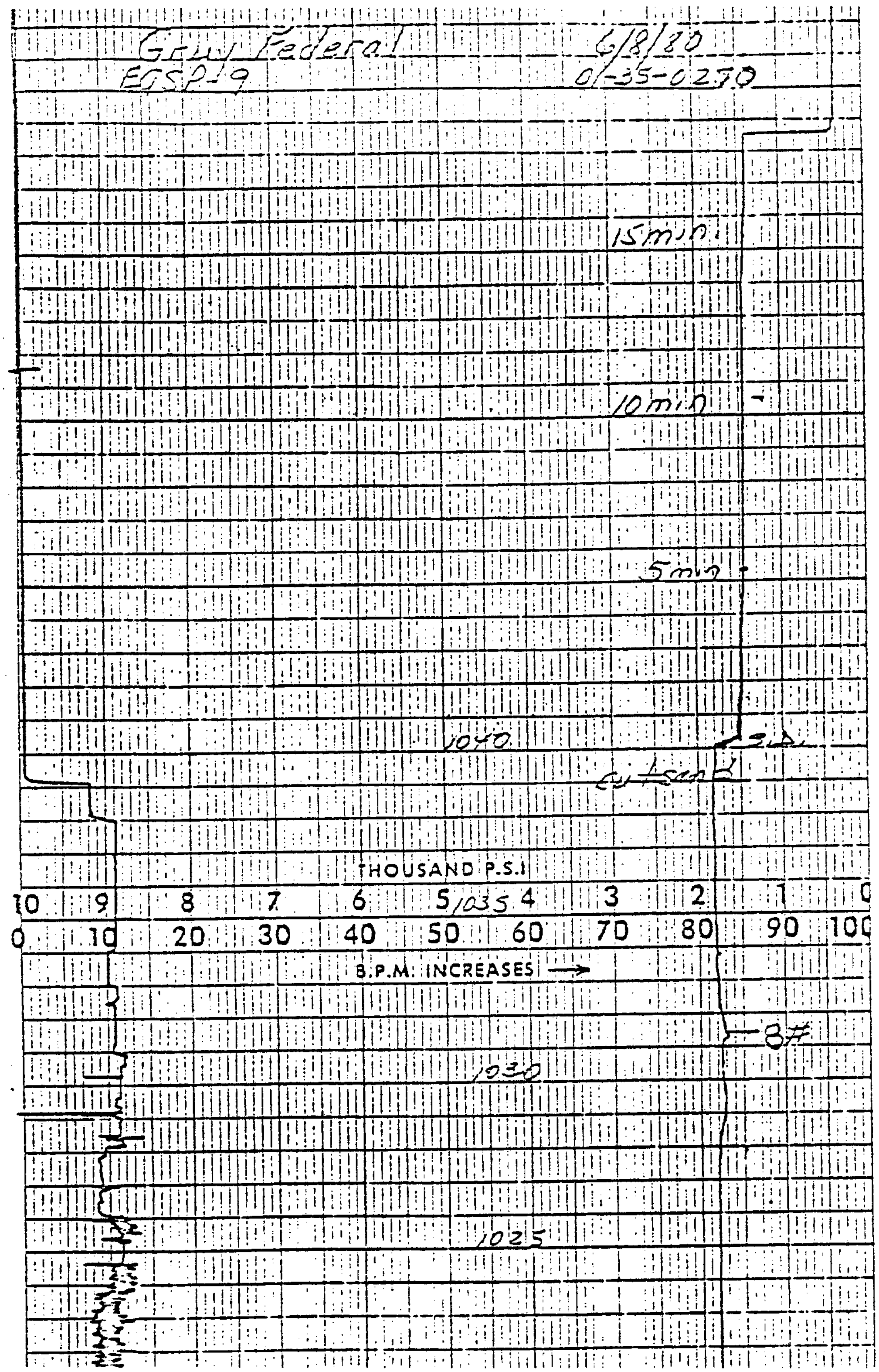

A-5 Foam fracture treatment 1021 to 1100 (6/8/80)

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GREEN INTERNATIONAL, INC.

Analytical Testing Laboratory
504 Beaver Street
Sewickley, Pennsylvania 15143
(412) 761-2770

Laboratory Analysis

Client: Gruy Federal, Inc.
Airport Office Park, Bldg. 2
400 Rouser Road
Coraopolis, Pennsylvania 15108
Attn: Ali Rdissi

Client No. 7952X15
Date Sampled Time 20/80 1630
Date Received: 6/23/80 Time: 1400
Date Reported: 6/26/80

Sample Source ennessee - Gas Well
FGSP #9

Green Sample No. 80086 1
Client Sample No. FGSP #9

Test results reported in mg/liter unless otherwise noted.

Parameter	Date	Result	Comment
Acidity - Free ($CaCO_3$)			
Acidity - Total ($CaCO_3$)			
Alkalinity M.O. ($CaCO_3$)			
Alkalinity Phe. ($CaCO_3$)			
Aluminum (Al)			
Ammonia (N)			
Arsenic (As)			
Bicarbonate ($CaCO_3$)			
Bio. Oxygen Demand (O_2)			
Cadmium (Cd)			
Calcium (Ca)		,7681	
Carbonate (CO_3)			
Chem. Oxygen Demand (O_2)			
Chloride (Cl)		76,083	
Chlorine (Cl)			
Chromate (CrO_4)			
Chromium Hexavalent (Cr^{+6})			
Chromium Total (Cr)			
Color (Pt - Co units)			
Copper (Cu)			
Cyanide - Free (CN)			
Cyanide - Total (CN)			
Dissolved Oxygen (O_2)			
Fluoride (Fl)			
Hardness ($CaCO_3$)		36,400	
Iron ( ) (Fe)			
Iron - Total (Fe)		836	
Lead (Pb)			
Magnesium (Mg)		2311	
Manganese (Mn)		32	
Mercury (Hg) ug/l			
Nickel (Ni)			
Nitrate (N)			
Nitrite ( )			
Nitrogen, Kjeldahl(N)			
Odor, Method:			

Parameter	Date	Result	Comment
Oil & Grease, Method:			
pH			
Phenol			
Phosphorus - Ortho( )			
Phosphorus - Total( )			
Potassium (K)		527	
Silica - Soluble (Si)			
Silica - Total (Si)			
Sodium (Na)		59,082	
Solids - Dissolved			
Solids - Suspended			
Solids - Total			
Solids - Nonsettleable			
Solids - Settleable			
Solids - Volatile			
Sp.Cond. 25°C umhos			
Sulfate (SO_4)		719	
Sulfide (S)			
Surfactants (MBAS)			
Tin (Sn)			
Turbidity (N.T.U.)			
Total Bacteria per 100 ml			
Total Coliform per 100 ml			
Fecal Coliform per 100 ml			
Fecal Strep. per 100 ml			
Zinc			
Specific Gravity	1.086		

A-6 Chemical analysis data for water sample

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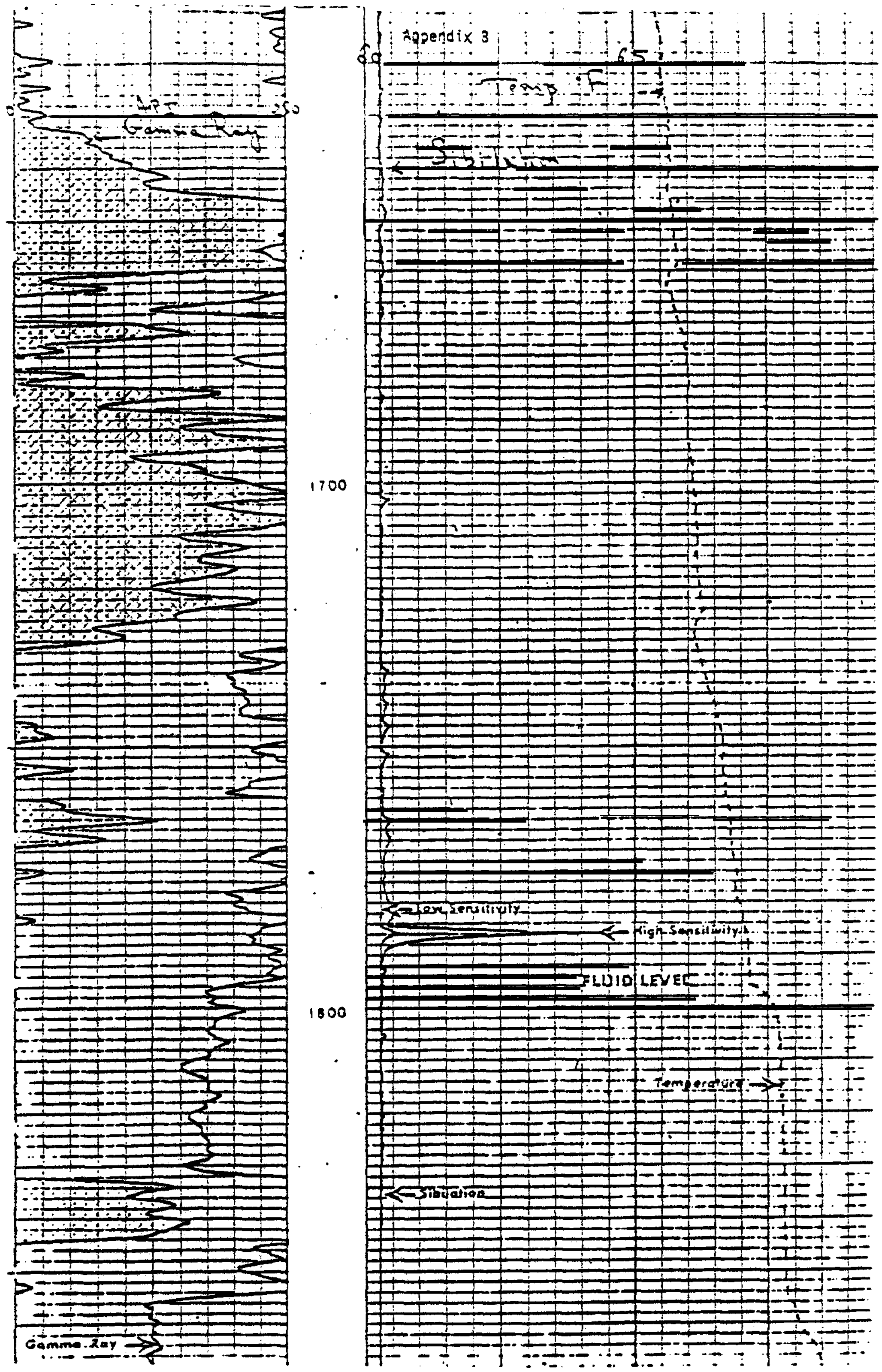
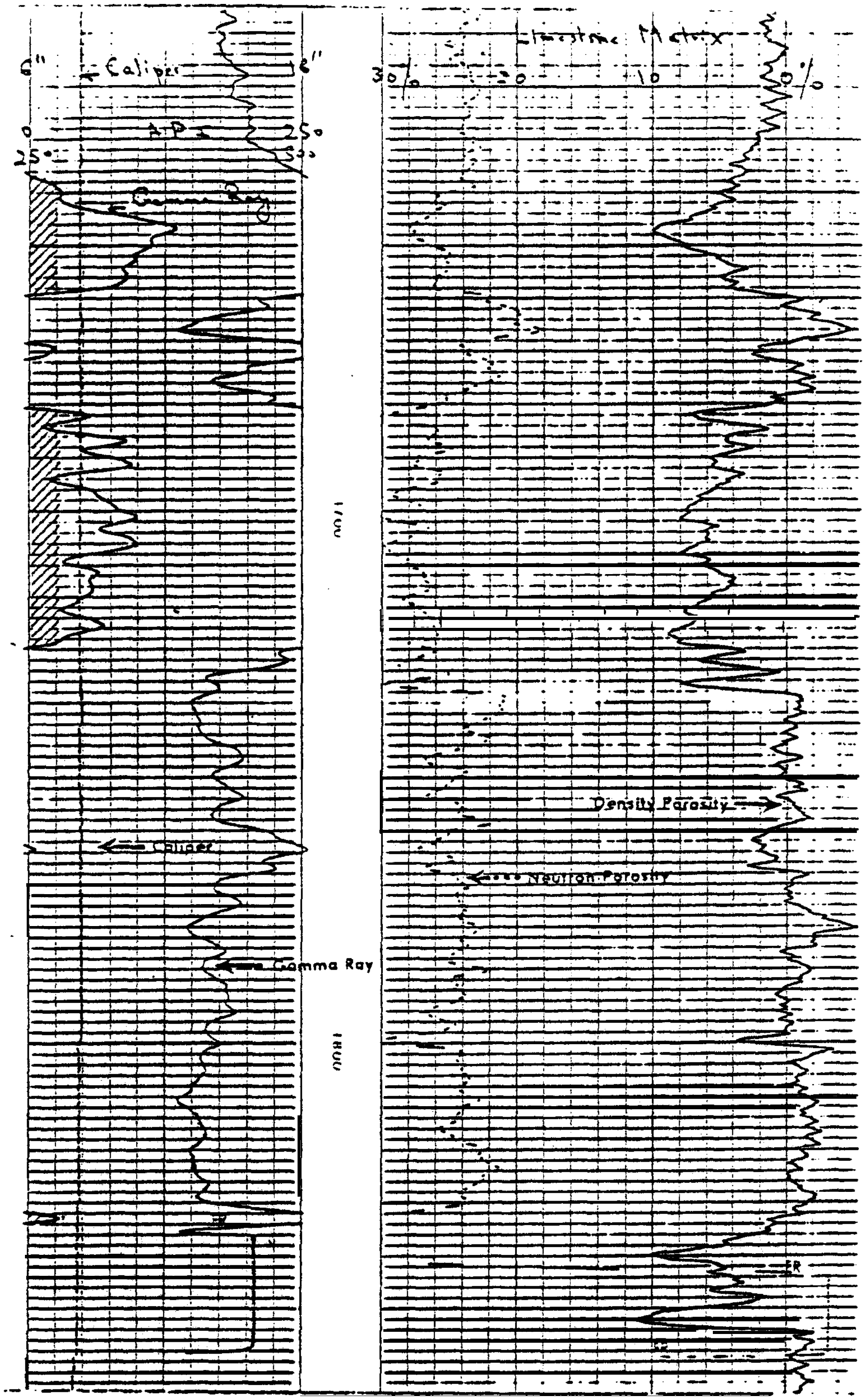
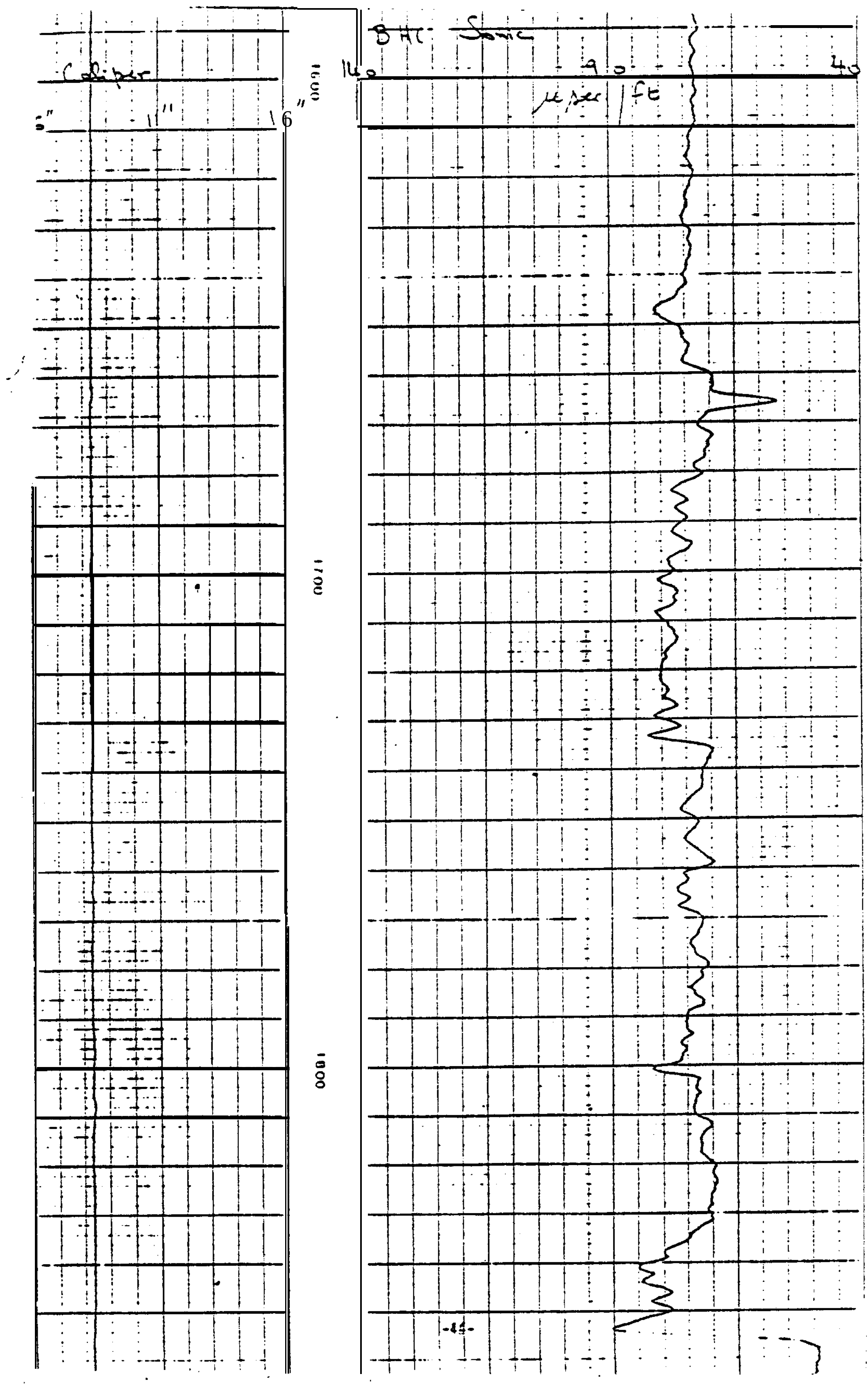


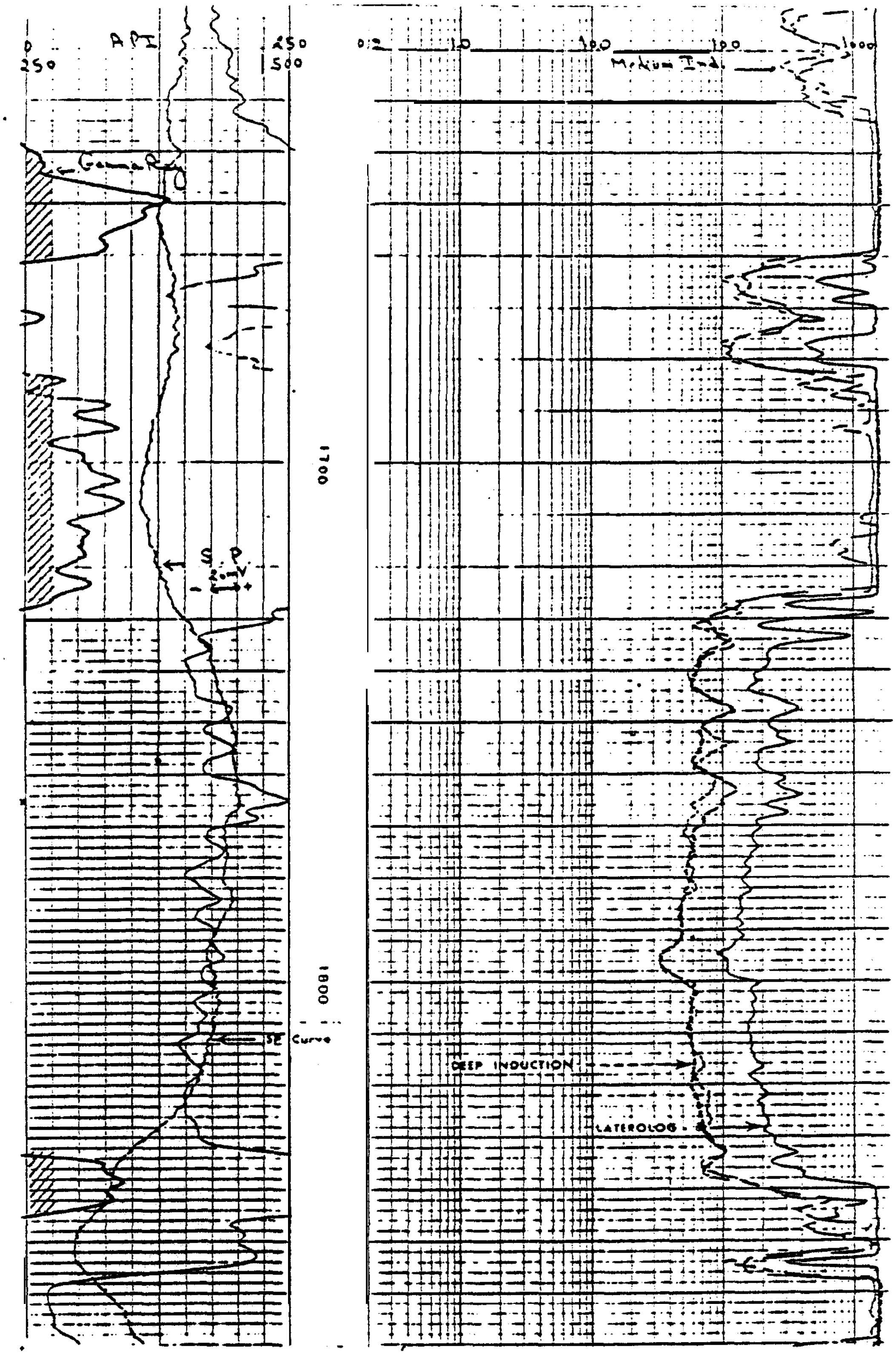
B-l Portion of Sibilation-Temperature log



B-2 Portion of FDC-CN log



B-3 Portion of BHC Sonic log



B-4 Portion of Dual Induction-LL8 log

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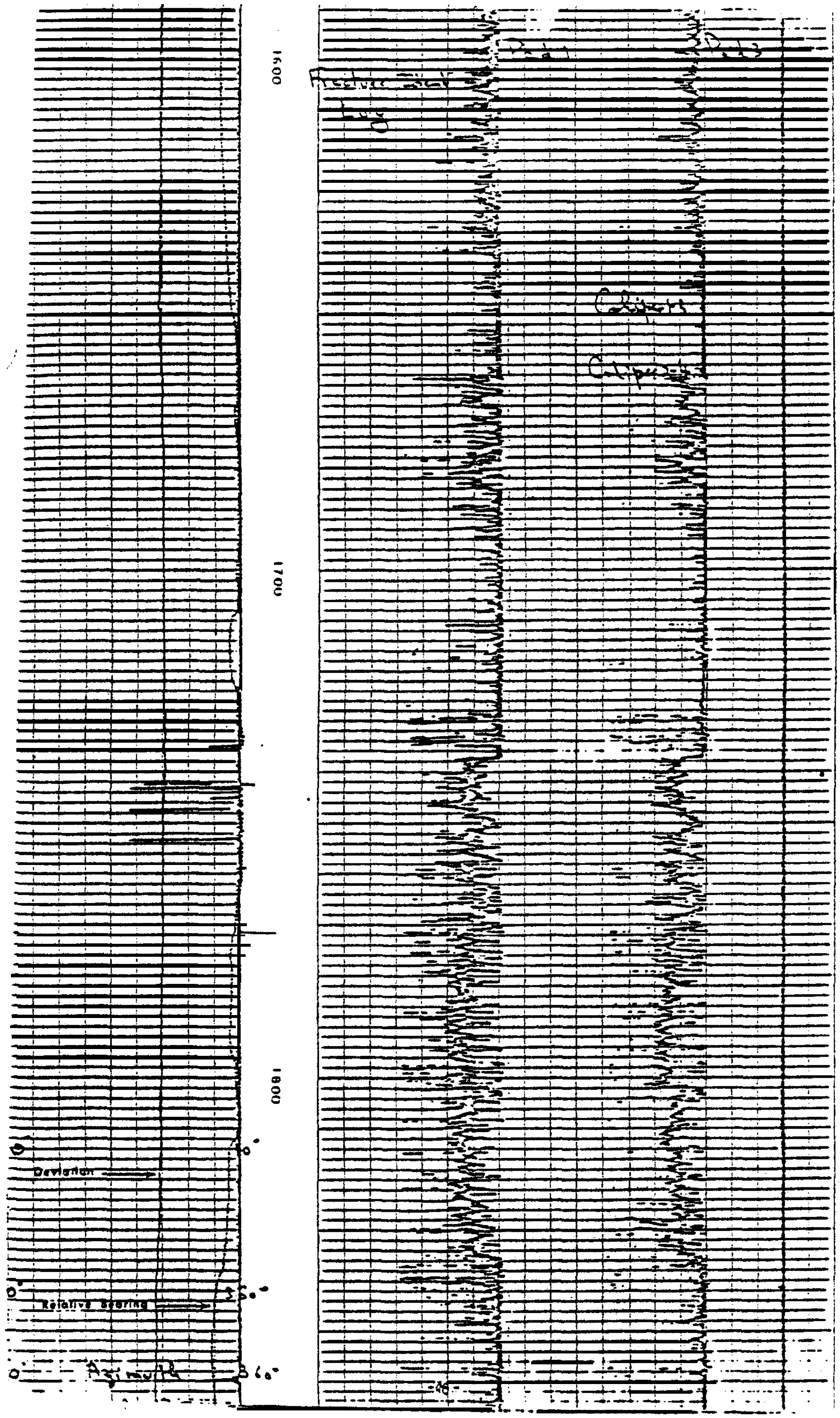
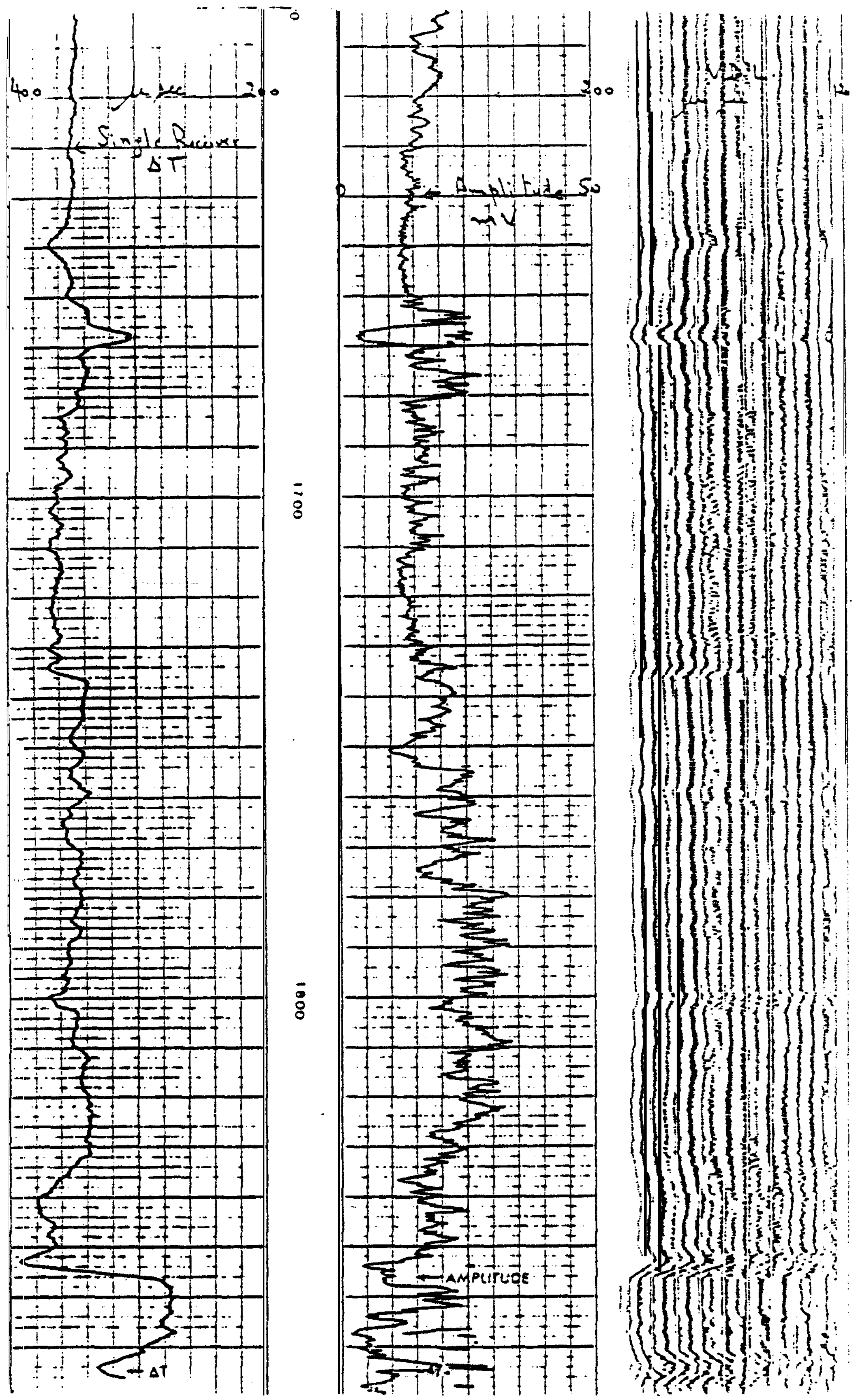


B-5 Portion of Fracture Identification log



B-6 Portion of Variable Density log

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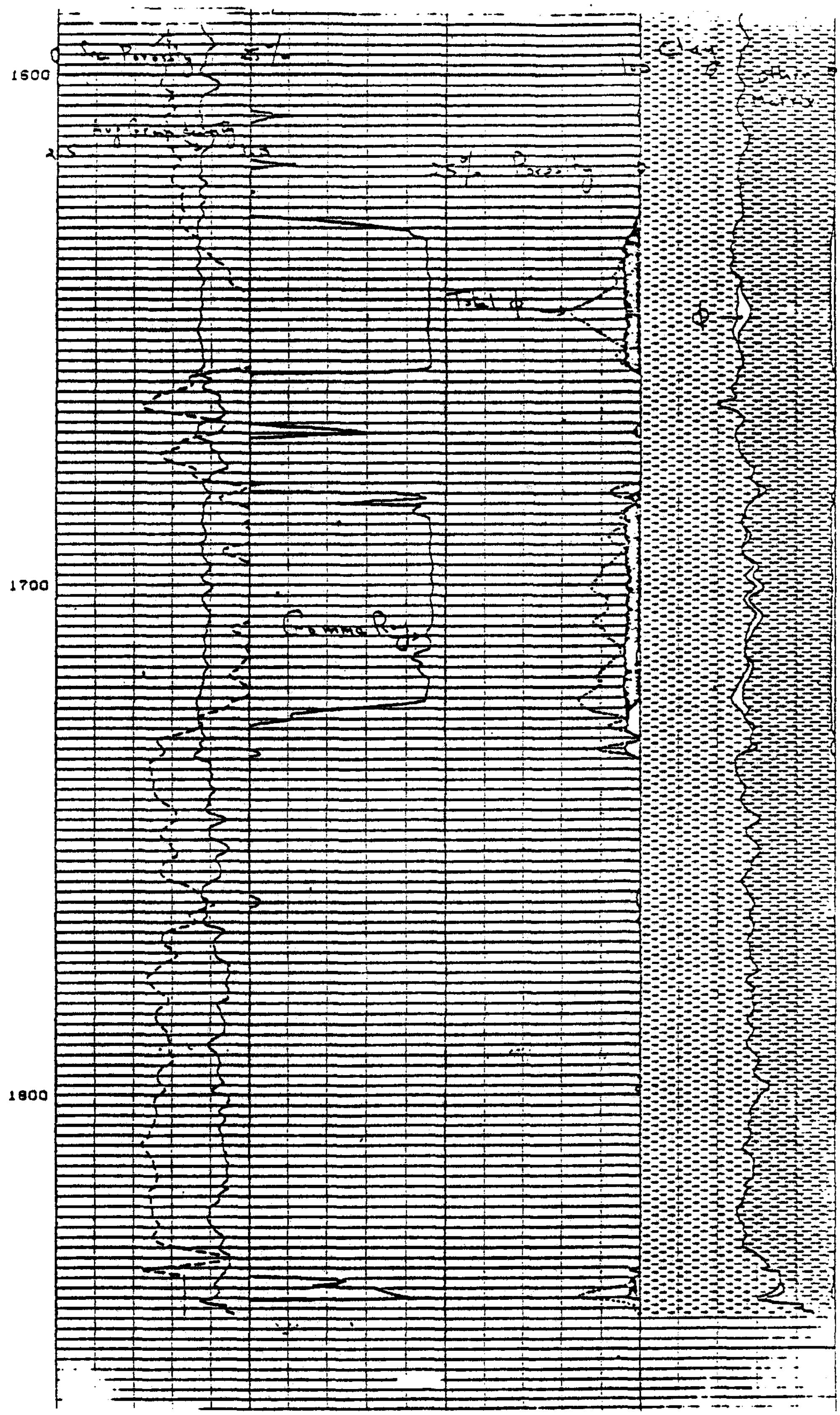

B-7 Portion of Coriband log

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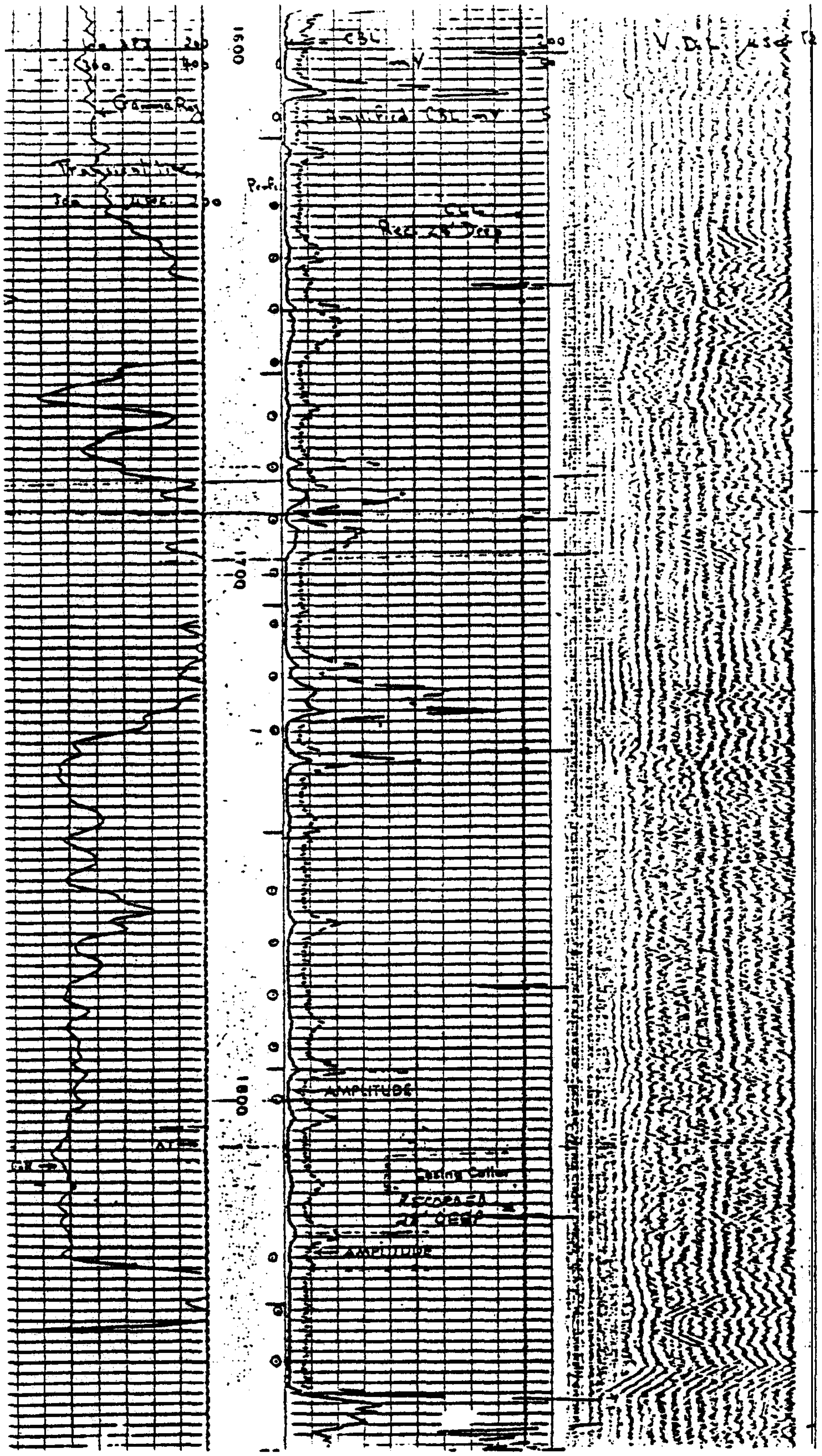

B-8 Portion of Cement Bond-VD log

UGR File #494
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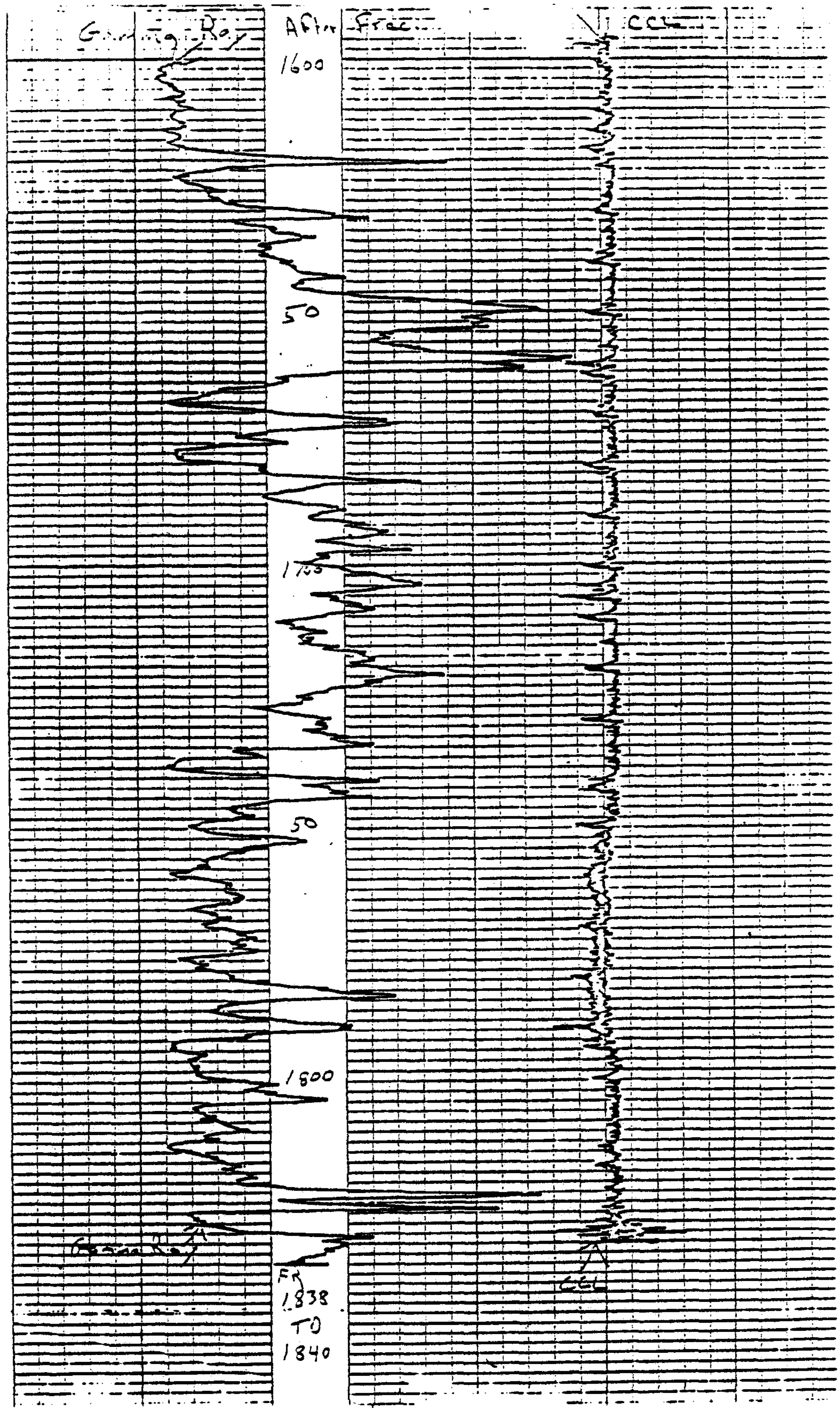

C-1 Portion of Gamma Ray log (after fracture)

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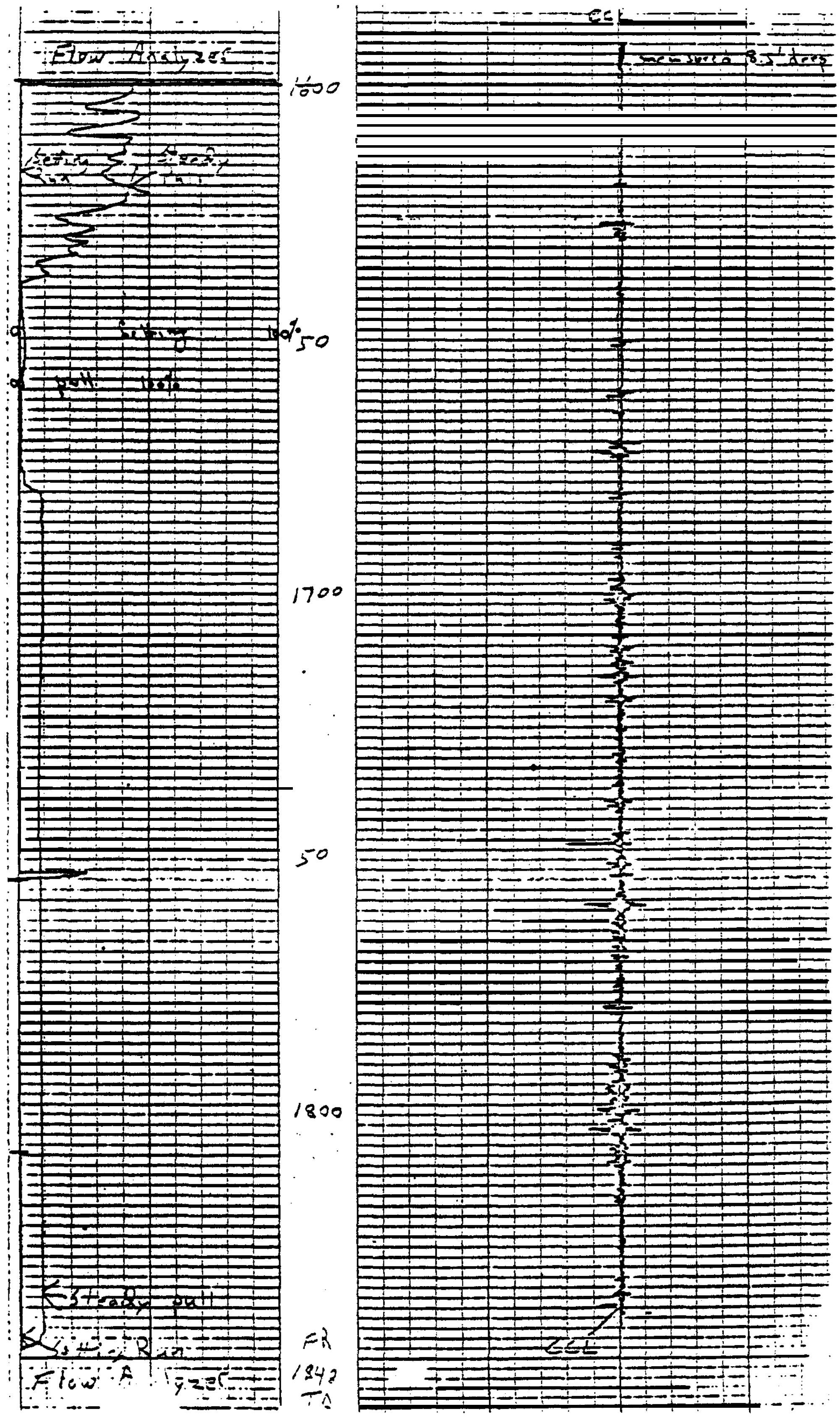
December 1980



C-Z Portion of Flow Analyzer log (after fracture)