APPLICATIONS OF THE FORMATION MICRO SCANNER* IMAGING TOOL IN THE PERMIAN BASIN

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ABSTRACT

The Formation Micro Scanner (FMS*) tool was introduced commercially in the United States in the Permian Basin in 1985. The tool is the latest development in a four pad, eight button dipmeter type tool, with an array of twenty seven buttons on two of the pads. On pads three and four, twenty seven resistivity curves are then processed into images. Since each image covers 2.8" of the borehole wall, in an 8" borehole 22% of the borehole is imaged with each logging pass. The data is presented on a 1: 5 vertical and horizontal scale or 240" per 100' versus 5" per 100' which is a normal detail logging scale.

In the Permian Basin, images have been used extensively in three major areas, High Resolution Reservoir Analysis, Stratigraphic Dip Analysis and Fracture Analysis. With High Resolution Reservoir Analysis, the type of porosity can be determined and if secondary filling of the porosity has taken place. Depositional environments and energy of environments are distinguished, stylolites are detected, and thin bed resolution is possible, all which have never before been identified with normal logging suites. When used for a Stratigraphic Dip Analysis, the data can either be used along with normal stratigraphic dipmeter computations to determine which dipmeter data should or should not be used for stratigraphic computations, or it may be used alone to compute the actual dips of the features seen on the images. Fracture Analysis with the FMS can help distinguish the difference between open and healed fractures, the number of fractures per given interval, types of fractures present (vertical or high angle) and usually if a fracture is natural or has been drilling induced.

INTRODUCTION

The introduction of the Formation Micro Scanner (FMS) in the Permian Basin made it possible to image many different types of lithologies and depositional environments. The initial FMS log images were almost exclusively obtained on wells that were partially cored so that a direct correlation could be made to the features seen on images and those present on the core. With this methodology it was possible to identify features correctly and then directly recognize these features again when seen on other wells. The tool has had several different names since it's inception - the Micro Electrical Scanning Device (MEST*), the Core Imaging Dipmeter (CID), or the Dipmeter With Images (DWI). The FMS tool is the latest in a four arm High Resolution Dipmeter-type tool which incorporates a very high resolution electrical image of the borehole which is comparable to a black and white photograph of the core.

The images are obtained from two separate arrays of buttons that are located on the caliper pads of the tool which appears very similar to the Stratigraphic High Resolution Dipmeter (SHDT*) tool (Fig. 1). The data obtained are two FMS images along with the eight SHDT resistivity curves. The SHDT data can then be processed in any of the standard dipmeter computations. The arrays, or raw image resistivities are composed of twenty seven separate resistivity buttons in four horizontal rows. Each array covers 2.8" of the borehole wall which

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equals 22% coverage of an 8" borehole per pass. Typical acquisition consists of three passes, of which the two passes that are oriented as close to the opposite sides of the borehole as possible are computed.

PROCESSING

The raw FMS resistivity data is processed in order to obtain an image of varying gray scales. The processing chain is abbreviated into the following steps: a) despiking of the noise, b) normalization of the curves for EMEX level changes, c) speed corrections utilizing accelerometers and speed button correlations, d) horizontal normalization (destripping), e) variable density display of the resistivities, (the most conductive being black and the most resistive being white), f) Hilite of the images, to either increase or decrease the image sensitivity in order to enhance the image.

PRESENTATION

Processed images are displayed on a 1: 5 vertical and horizontal scale or 240" per 100' versus the normal 5" per 100' for detail scale. According to this scale, each foot of the well is represented by 2.4" of log. Data can be displayed in several manners. The normal presentation is composed of up to four separate sections. From left to right: the depth track with the borehole direction represented by a tadpole where the body represents the drift and the large tail the orientation, and the small tail being the orientation of pad #1. Next to this is the correlation track typically containing a gamma ray curve, two perpendicular (x-y) calipers and a reconstructed resistivity curve. A dip track may be presented next, this was common on many early computed images. The main portion of the log is then composed of the 27 resistivity curves from pad #3, the images of pad #3, (if HILITED, the hilited images of pads #3 and #4), images of pad #4, and the 27 resistivity curves of pad #4. The second type of presentation is known as the BOREMAP. In this display images from several passes are merged together and presented in an azimuthal plot, where the borehole "cylinder of information" has been split on the north side and layed out flat (Fig. 4).

APPLICATIONS

In the Permian Basin the FMS images have been used extensively for three major purposes: High-Resolution Reservoir Analysis, Stratigraphic Analysis, and Fracture Analysis. To a lesser extent it has also been used to orient cores, aid in core description (missing intervals), for dip quality control, and for thin-bed analysis. Since the FMS tool was first introduced it has been used as a new and improved dipmeter and the images are used to aid in stratigraphic interpretation. It is with these images that actual crossbedding can be recognized instead of only inferred as in the past. Actual dip computations that correspond to these features can be detected on the dipmeter print

(Fig. 2). With FMS images actual types of stratigraphic features (i.e. cross bedding types) can be recognized and depositional environments are easier to infer. It is now a physical possiblity to distinguish between valid stratigraphic dips on the plots and random scatter dips when using the images to isolate and use only the data that is computed from true features. The distinction of individual sedimentary units along with their respective boundaries, whether gradational, abrupt, or erosional is now physically possible. For the first time, graded bedding sequences can be actually viewed instead of only inferred. Putting all of these stratigraphic features to work allows one to make the best interpretation of the interval and pick the most accurate offset direction possible. Images have changed the "Art of Stratigraphic Dipmeter Interpretation" into a "Science".

The ability to use the FMS tool for High Resolution Reservoir Analysis has changed the way many formations are being analyzed. In carbonate reservoirs the FMS images are being used to identify two major types of porosity, vuggy and intergranular. Vuggy porosity intervals can be divided into interconnected, which contribute to reservoir calculations, or non-interconnected (Fig. 5) which contribute very little to the reservoir calculations. Figure 5 is an Ellenburger zone with very little interconnected porosity and is therefore not found to be economic. When the porosity is not visible on porosity logs such as CNL-LDT* and sonic, images make it possible to determine why. Figure 4 shows it is possible to determine that porosity was originally present, but has since been totally filled with an anhydritic cement. This type of identification allows one to distinguish between a porosity pinch-out which terminates the reservoir extent and secondary diagenesis which may or may not define the limits of the reservoir. The determination of gypsum filled porosity is difficult with a normal logging suite because the H_2O molecules in the gypsum ($CaSO_4 \cdot H_2O$) cause the logging tools to see the gypsum as porosity. The San Andres formation in figure 3 appears to be a continuous vertical reservoir when analyzed on the Cyberlook* computation. Images of this same interval separate the reservoir into layers of effective porosity zones and layers in which gypsum filled porosity reduces or eliminates the apparent vertical permeability.

Depositional environments and other distinguishing features are possible to detect on FMS images. In figures 6 and 7 the VOLAN* computations indicate a predominate quartz matrix, in this case the quartz being chert with 15% to 25% porosity. Images of these zones show a striking contrast as figure 6 is composed of interbedded cherts and limestones and figure 7 is a chert conglomerate. Although the two zones appear similar on normal logs, production characteristics are extremely different since the primary chert has very low permeability and the conglomerate has almost infinite permeability. Thus the difference in production rates of these chert reservoir rock examples are related to the environment and not to completion practices. Stylolites are observed on images as non-planer, semi-horizontal low resistivity features (Fig. 8). Stylolites are good permeability barriers in the potential reservoir rock and need to be taken into consideration during

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completion planning. Increases in vertical permeability can be accomplished by the effects of vertical burrowing. This burrowing is common in the Delaware sandstone reservoirs of the Delaware Basin and adds good permeability to an otherwise thinnly bedded siltstone (Fig. 9). Burrowing in part destroys the original bedding characteristics causing the siltstone beds to appear speckled or mottled on the FMS images.

Fracturing is one of the easiest features to be seen with the FMS. Fracturing can be divided into the following characteristics: open or healed, vertical (greater than 75°) or high angle (less than 75°). Horizontal fractures are usually not preserved in the Permian Basin reservoirs because the overburden pressure at depths greater than 2000' will close the fractures. Open fractures are filled with drilling fluid to the depth of investigation of the FMS tool during logging. This filling of the fractures allows them to be detected as low-resistivity linear features. Healed or partially healed fractures, have the same orientations but are filled with various cements causing the fracture to have a much higher resistivity than an open fracture. Fractured reservoirs such as the Ellenburger in figures 5 and10 can exhibit both vertical and high-angle fractures. In this example fractures are used to interconnect the porosity zones present and provide increased total rock permeability. Although fracture width is impossible to measure with the FMS images at this time the vertical extent of the fractures and number of fractures per foot can be determined. By knowing if vertical fractures are present it becomes possible to engineer completions to eliminate or reduce coning problems that are commonly associated with vertical fracture systems. Fracture orientation can be obtained from the images so proper drainage patterns of wells can be properly planned. Figure 11 shows a Spraberry well with a fracture orientation of N80°E-S80°W. The vertical fractures in the Spraberry formation are in part due to hydraulic extension of the natural fracture system. Note how the fracture intersects the 2-inch shale lamination at 7816' (Fig. 11).

Orientation of full core is possible with the FMS images by detecting any of the features mentioned above on both the core and images. The easiest features to orient are fractures, large vugs, and stylolites. Once a core is calibrated to the image, any missing core intervals can be fairly well analyzed even though the core data is missing. When sidewall cores are taken in a reservoir and the reservoir is later imaged, the exact location of the cores can be identified (Fig. 12). This information allows one to identify if the sidewall core is representative of an entire interval or just a thin stringer. This answers many questions about core properties and why measured core properties sometimes vary from log measurements.

Analysis of the data on the images can be made using the Image Examiner program on a Sun™ work•station. The Image Examiner program allows actual dips to be calculated from the images themselves. With this program the apparent dip and true-dip data can be displayed for as many individual bedding planes or fractures as desired (Fig. 13)..

Another benefit of Image Examiner program is an option which allows summation of the resistivity ranges. This feature allows an accurate sand count, such as including all sands within a certain resistivity range, or to sum up the percentage of vuggy porosity in a given interval. With this system, any feature within a distinct resistivity range can be isolated and evaluated individually.

SUMMARY

The Formation Microscanner images are revolutionizing the way logs are being evaluated. Images are being utilized for detailed stratigraphic analyses, which consist of delineating the stratigraphic units, the types of bounding surfaces, and identifying the types of crossbedding within the unit. The FMS allows the type of porosity to be identified, and if secondary porosity is present, secondary cementation can be determined. Fractures can now literally be seen and no longer just indicated or inferred. Fractured reservoirs can be characterized by fracture type (vertical or high angle), fracture density, and fracture height. Numerous other features can now also be detected with the FMS log, which could only be answered in the past by full core analysis. All of the features available with the FMS now make it possible to evaluate and complete even the most complex of reservoirs efficiently.

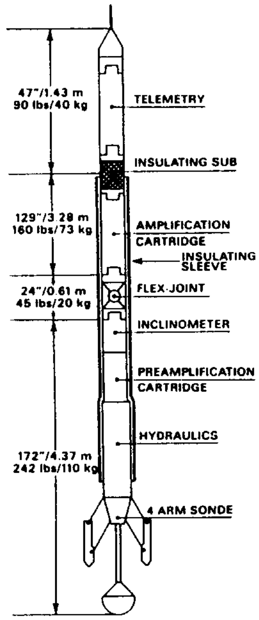
SELECTED REFERENCES

Lloyd, P.M.: "The Stratigraphic High Resolution Dipmeter Tool with Images from Micro Electrical Scanners", Schlumberger Document, 1985.

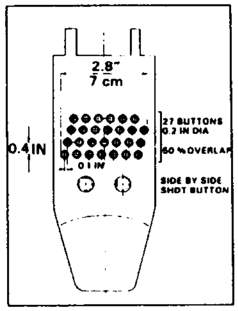
Plumb, R.A. and Luthi, S.M.: "Applications of Borehole Images to Geologic Modeling of an Eolian Reservoir", paper SPE 15487 presented at the SPE 1986 Annual Technical Conference and Exhibition.

Schlumberger: "Formation Micro Scanner Service", Document No. SMP 9100, Schlumberger Well Services, 1986.

THE TOOL



THE PAD CONFIGURATION



20% BOREHOLE COVERAGE
FROM IMAGES IN 8½" HOLE

GENERAL SPECIFICATIONS

- Length	31 ft	(9.45 m)
- Weight	537 lbs	(243 kg)
- Minimum closing diameter	5.0 inches	(127 mm)
- Minimum recommended hole size	6 1/4 inches	(160 mm)
- Maximum opening diameter	21 inches	(533 mm)
- Pressure rating	20,000 psi	(1400 bars)
- Temperature rating	350 deg F	(175 deg C)
- Logging speed		
Dip and Images	1600 ft/hr	(500 m/hr)
Dip only	3200 ft/hr	(1000 m/hr)

OUTPUTS

- ALL NORMAL DIPMETER INFORMATION.
- TWO SETS OF MICRO ELECTRICAL RESISTIVITY CURVES (2 PADS X 27 BUTTONS).
- TWO 7 cm WIDE BOREHOLE IMAGES SET AT RIGHT ANGLES TO EACH OTHER.
- (IMAGING ARRAYS ON PADS 3 + 4).

OPERATIONAL LIMITATIONS

- CONDUCTIVE MUDS ONLY.
- TOOL ROTATION RATE SHOULD NOT EXCEED 1 TURN PER 40 ft (12 m).
- HOLE DEVIATIONS UP TO 70° CAN BE LOGGED WITHOUT ANY SONDE COLLAPSE.

Figure 1 - The tool — technical specifications

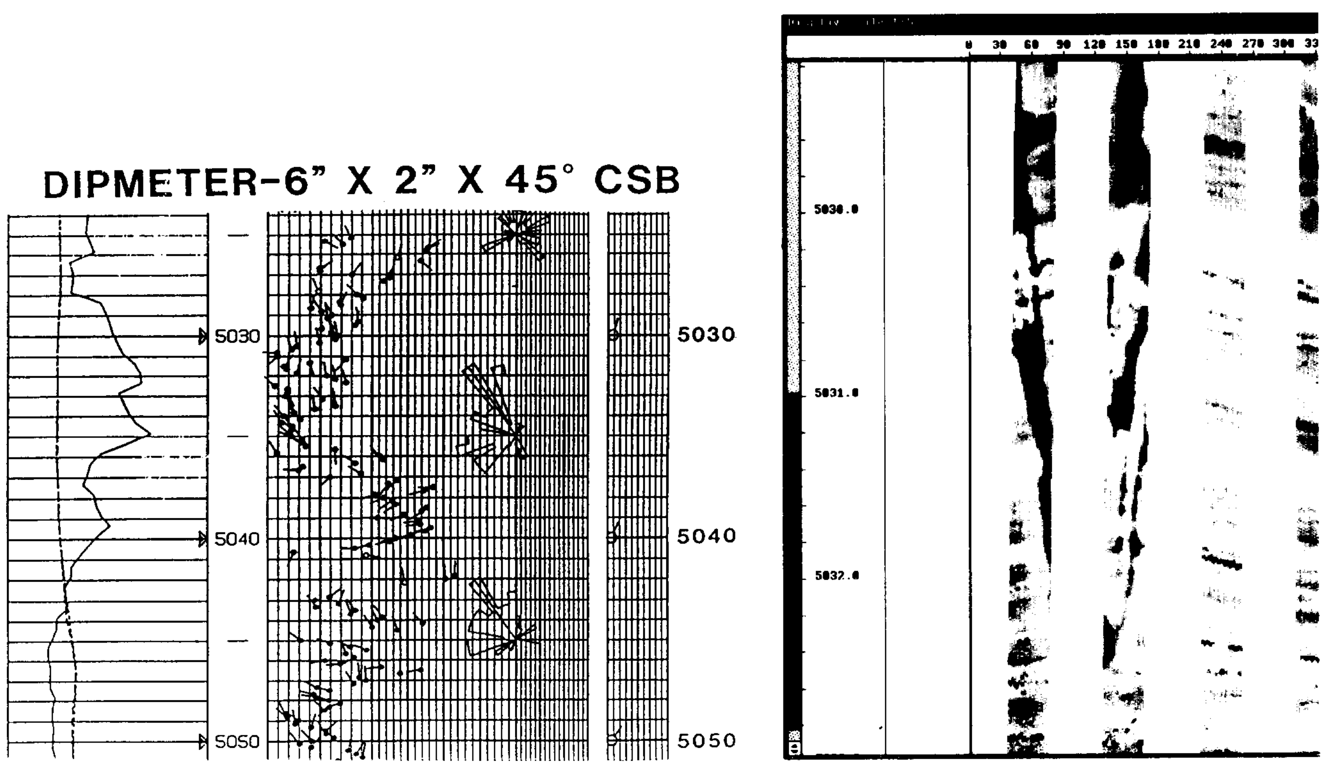


Figure 2 - Crossbedding as seen by the Stratigraphic Dipmeter
and FMS images

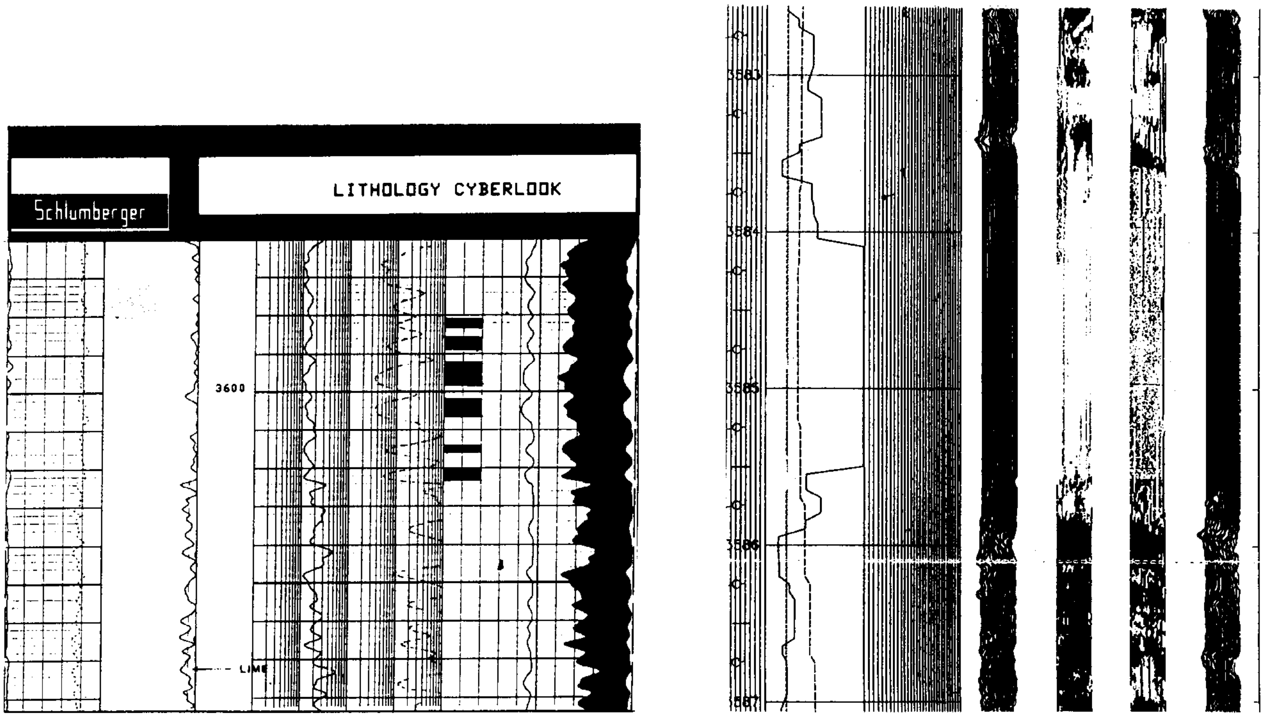


Figure 3 - Cyberlook and images of San Andres formation with layered gypsum-filled porosity zones

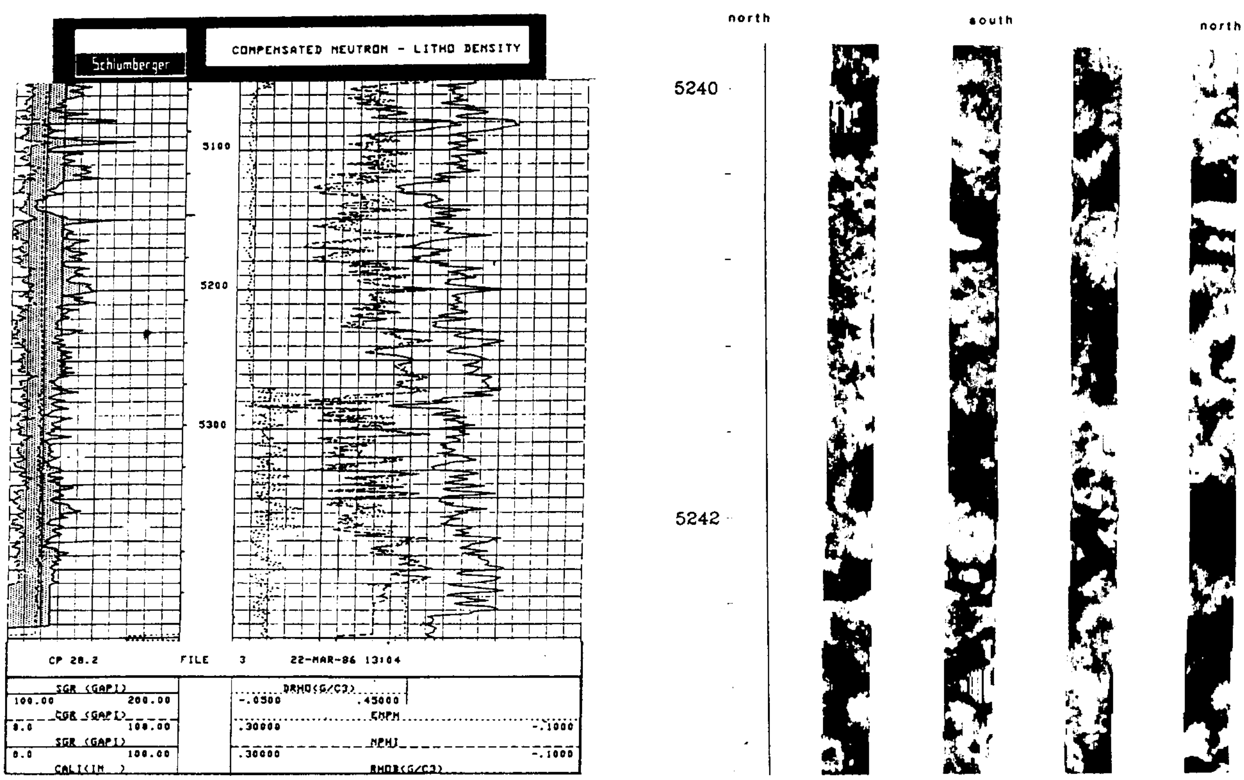


Figure 4 - BOREMAP presentation: anhydrite-filled vugs reduce effective porosity

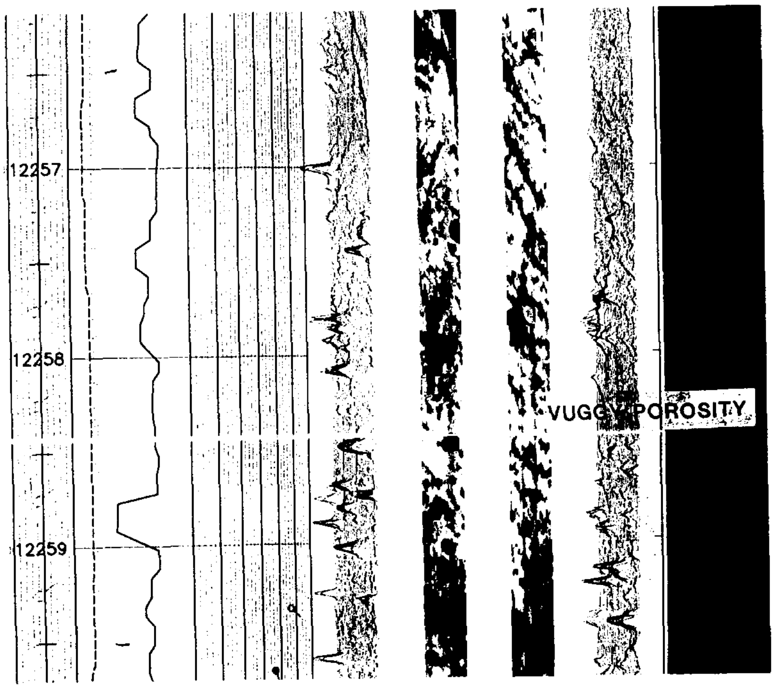


Figure 5 - Ellenberger formation exhibits
non-connected vuggy porosity
and high-angle fractures

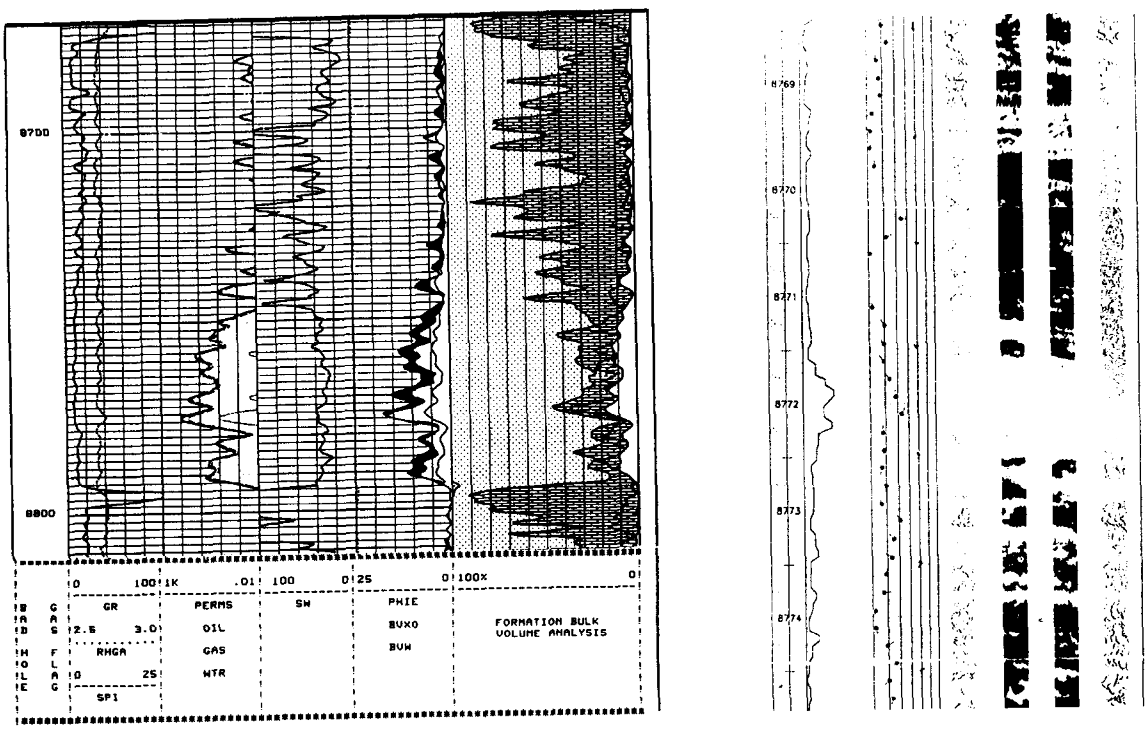


Figure 6 - Volan computation and image of a Devonian
chert with interbedded limestones

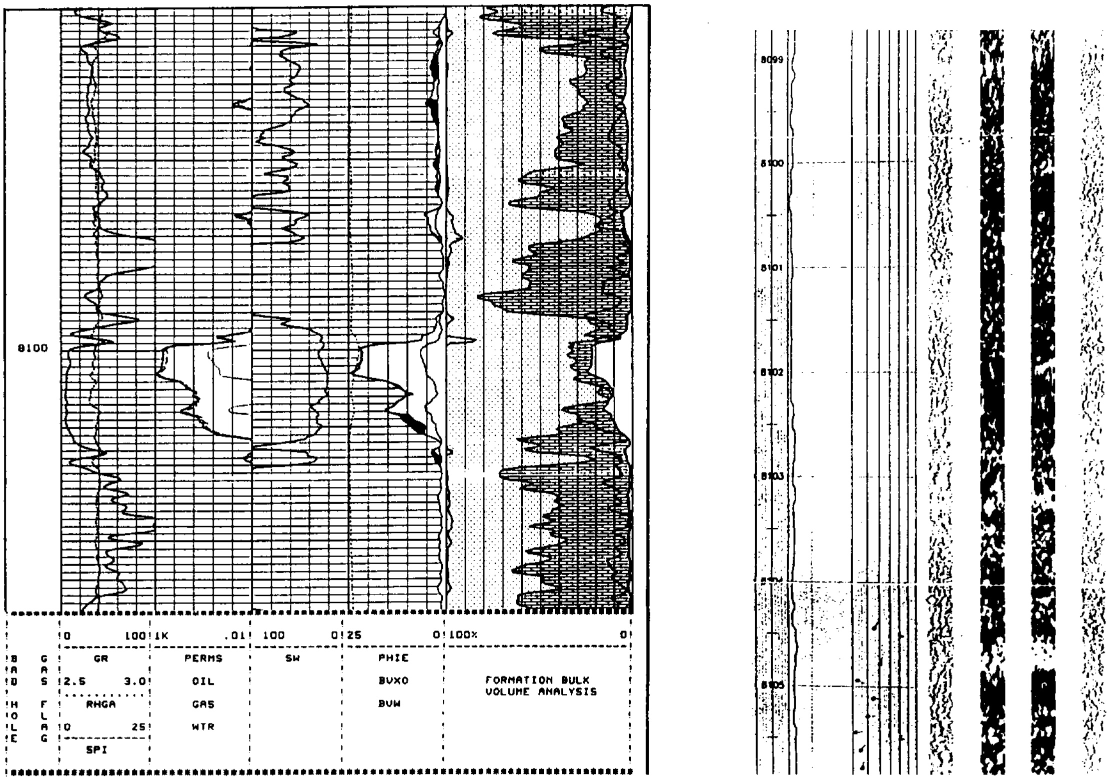
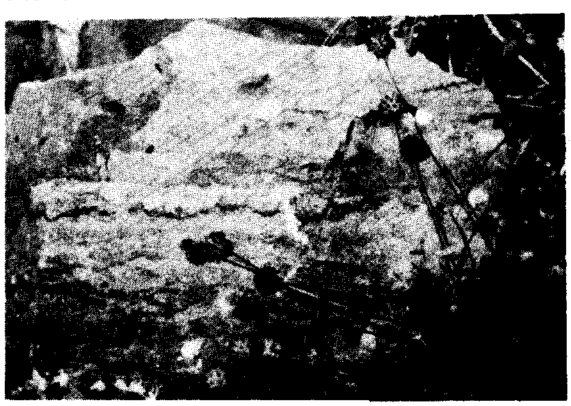


Figure 7 - Volan computation and image of a chert detrital (conglomerate)

Plate G



Limestone, glauconitic, sandy, dolomitic, with oxidized stylolites.
Cap Mountain Formation, Buffalo Creek, 2 mi SE Sandy, Blanco Co, Texas.

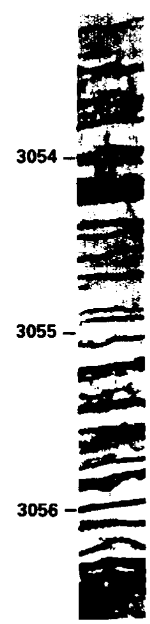


Figure 8 - Stylolites as seen in the outcrop and on FMS images

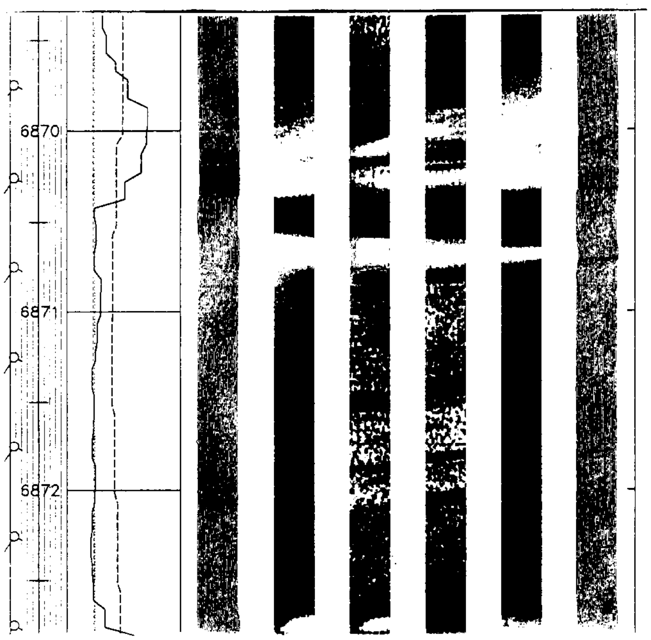


Figure 9 - Burrowing in Delaware formation
(Center images are Hilited)

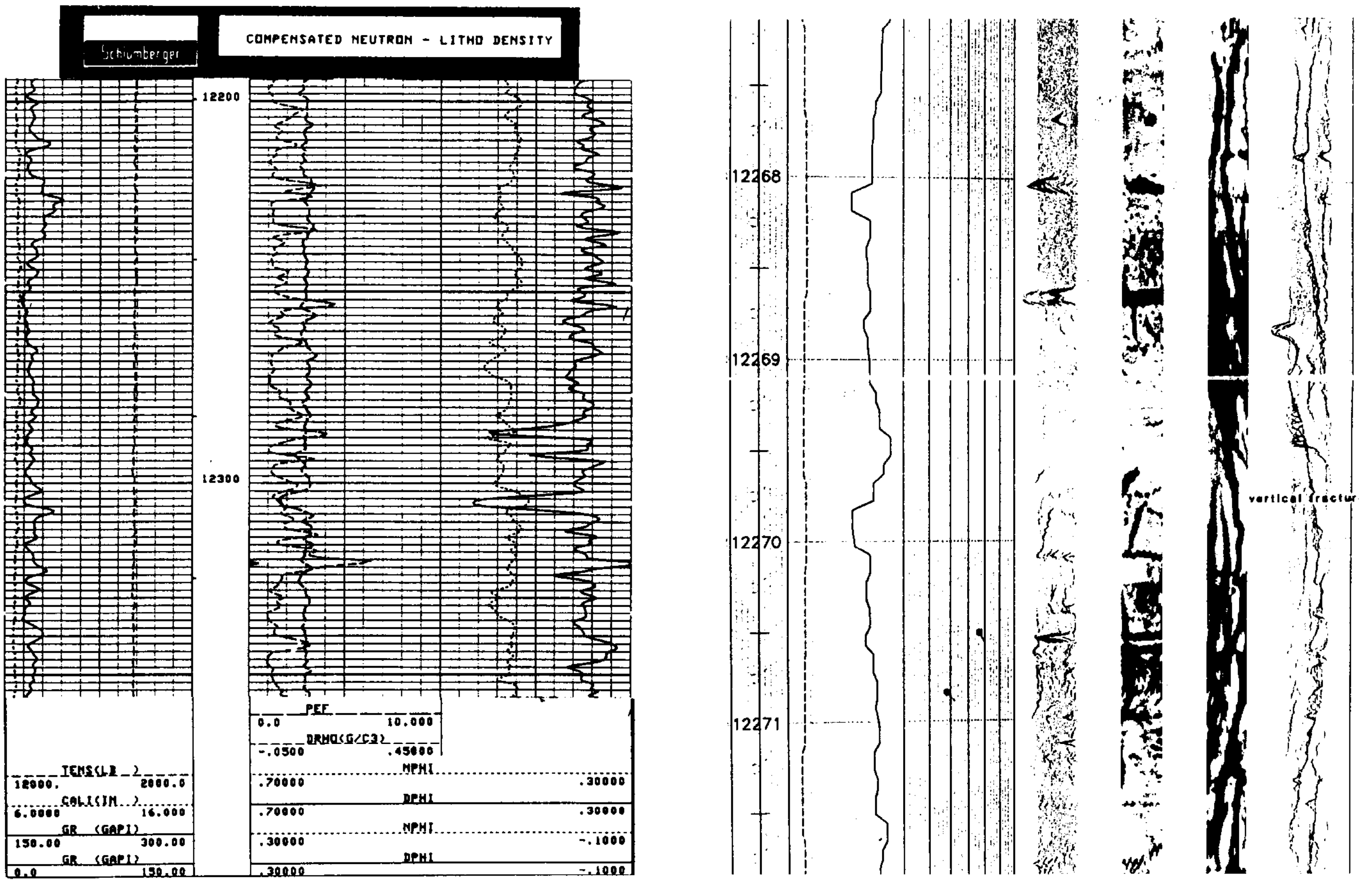


Figure 10 - Ellenberger formation with vertical fractures
(Same well as in Fig. 5)

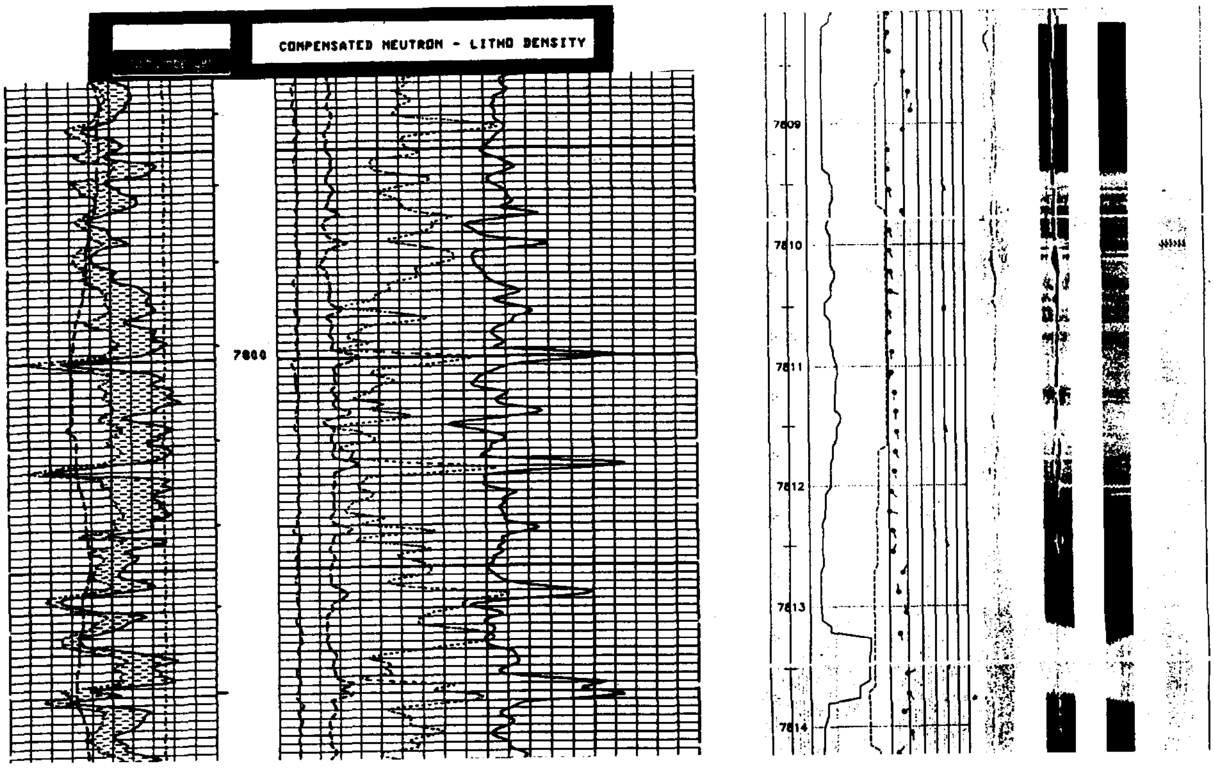


Figure 11 - Spraberry formation with vertical fracture
N80E - S80W orientation

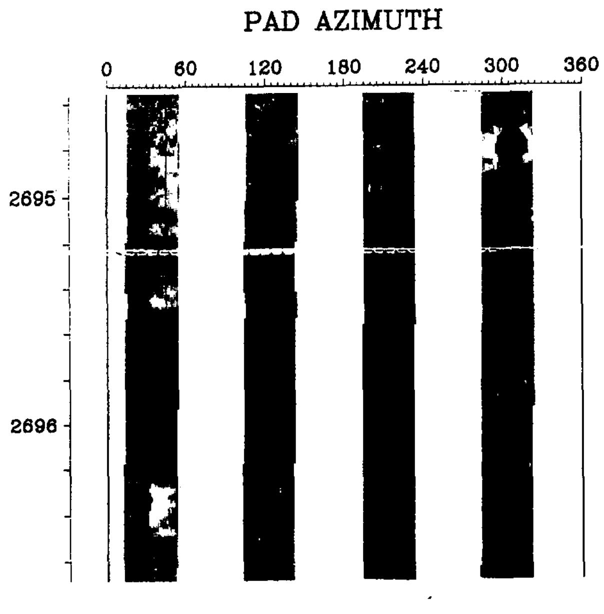


Figure 12 - BOREMAP presentation:
Sidewall cores are located at
2694.8 ft and 2696.3 ft

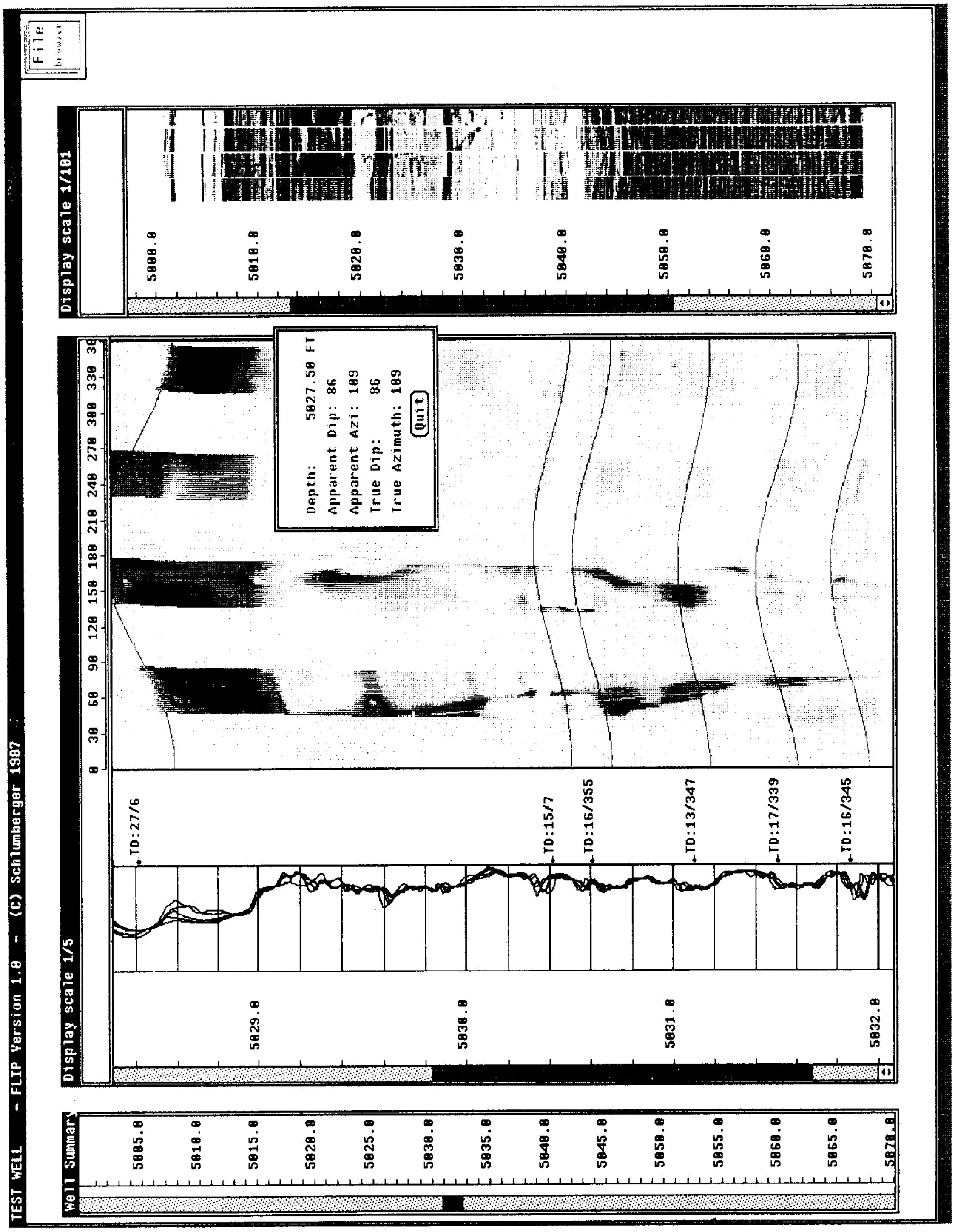


Figure 13 - Image Examiner output: Bedding plane dips are presented in depth track; fracture dip is in the box