# FORMATION MICROSCANNER* APPLICATIONS IN THE STUDY OF SUBSURFACE PALEOZOIC CARBONATE ROCKS: SOUTHWESTERN ONTARIO, CANADA

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**ABSTRACT:** The Formation MicroScanner (FMS) service, introduced by Schlumberger in 1985, has been used successfully on several Trenton - Black River (Ordovician) wells in Southwestern Ontario, Canada, to aid in structural and stratigraphic interpretation.

The FMS tool, similar to the Dual Dipmeter* tool, has arrays of microelectrodes added on two or all four caliper pads. The microconductivity, measured at a high sample rate, provides an oriented image displayed on a variable intensity grey scale. A colour image is also available when working on a SUN Workstation (FMS Image Examiner System*).

Examples of FMS images obtained in the Trenton and Black River formations illustrate open and healed fractures, secondary porosity developments, changes in porosity, and thin bedding features. The use of these images for reservoir evaluation, completion strategies, and development drilling is discussed.

## INTRODUCTION

The Trenton - Black River formations (Ordovician) of Southwestern Ontario, Canada have a long history of being good producing reservoirs. They also have the distinction of being hard to explore for. Once a well is drilled, petrophysical analysis is complex due mainly to the presence of up to three porosity systems combined with changing lithology.

The introduction of the LithoDensity (LDT*) and Electromagnetic Propagation (EPT*) tools helped with the evaluation of lithology and some of the water saturation problems. Identification of porosity type and bedding features to understand the geometry of the Trenton - Black River formations was previously only available through core analysis.

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In 1985, Schlumberger introduced the Formation MicroScanner (FMS*) service. After processing, the tool provides detailed and oriented images of the borehole wall in grey scales or colour. The interpretation of these images is similar to looking at black and white core photographs. The main difference is that the images are an electrical measurement of the formation responding to the volume of water present in the rock.

As of October 1, 1988, the FMS tool has been run on ten wells in Southwestern Ontario. The purpose of this paper is to present and discuss the results acquired to date. They include examples of open and healed fractures, secondary porosity developments, changes in porosity, and thin bedding features. Because the FMS information presented here is proprietary, the fracture and bedding geometry seen on the images will not be related to regional geology.

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*Mark of Schlumberger

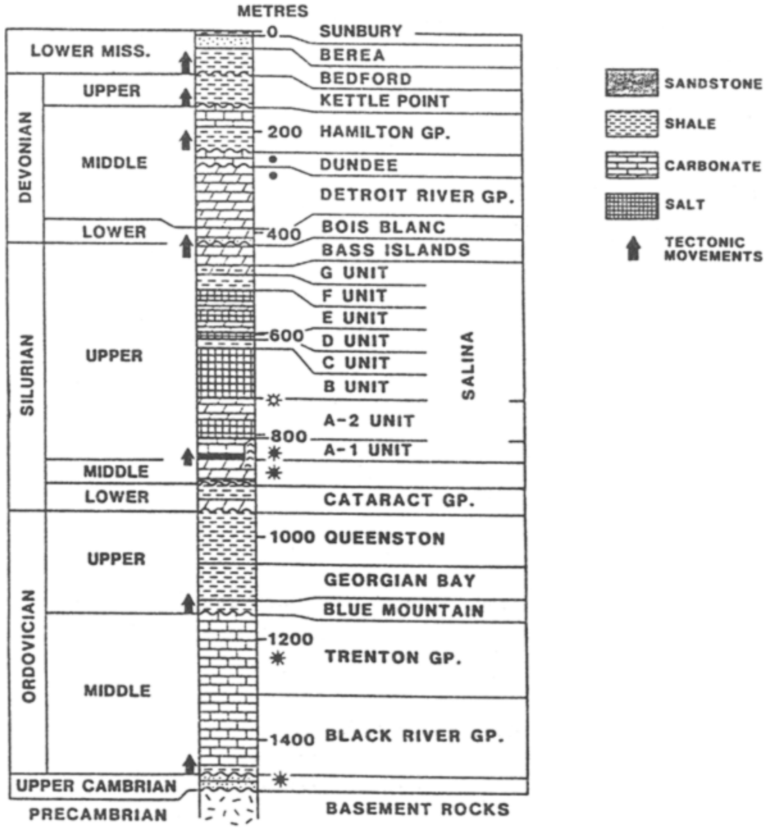


*Figure 1. Composite stratigraphic succession, southwestern Ontario.*

To better understand the examples presented, a short introduction to the Trenton Black River geology, FMS tool theory, and image presentation will be given.

## GEOLOGY

### 1. Regional Setting

Rocks of Paleozoic Age in Southwestern Ontario comprise the Ontario Sedimentary Basin. The stratigraphic sequence which ranges from Upper Cambrian, through Ordovician, Silurian, Devonian and Mississippian generally dips to the southwest and unconformably overlies the Precambrian Shield. These basins are hinged by two major basement positive structures which join the Michigan Basin to the NW and the Appalachian Basin to the SE. The two structural features which control the tectonic framework of these ancient sedimentary rocks are the NE-plunging Findlay Arch and the SW-plunging Algonquin Arch.

### 2. Trenton - Black River Carbonates

Middle to Upper Ordovician sediments occur throughout SW Ontario. The Middle Ordovician is composed of two groups of carbonates; the Trenton and Black River Groups. The Black River Group unconformably overlies the Upper Cambrian and is subdivided into the Shadow Lake, Gull River, and Coboconk Formations (Figure 1). Shadow Lake Formation rocks are dolomitic sandy, silty shales, and/or shaley and silty dolostones (Brigham, 1971).

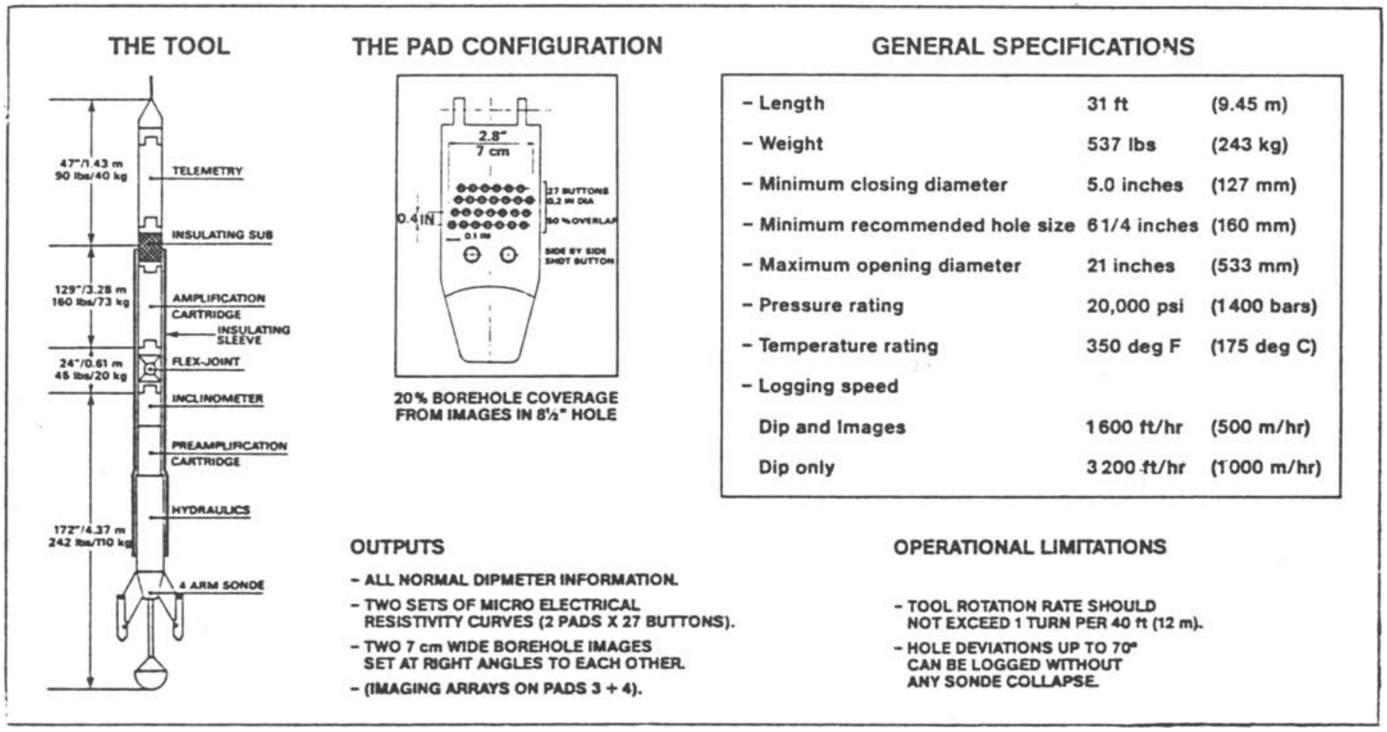
The Gull River Formation consists predominantly of lithographic limestone (variably dolomitised), interbeds of fine dolostone, and minor chert nodules. The Gull River Formation is generally less radioactive than the underlying Shadow Lake Formation rocks, giving a reliable gamma ray wireline log marker by which the formation's boundary can be picked (Sanford and Brady, 1955).

The Coboconk Formation is composed of fine-grained crystalline to cryptocrystalline limestone (variably dolomitised) and minor dolomite. Dolomitisation is possible primary; secondary where the rocks were subjected to structural deformation and fracturing near faults. The Coboconk - Gull River boundary on wireline logs is marked by an overall positive shift of the gamma ray trace and a negative shift of the neutron trace (Sanford and Brady, 1955).

The overlying Trenton Group is subdivided into the Kirkfield, Sherman Fall, and Cobourg Formations.

The Kirkfield Formation contains fragmented and bioclastic limestone (cherty and variably dolomitised) with minor interbeds of shale. On wireline logs the Kirkfield - Coboconk boundary is well defined by a thinly interbedded limestone and shale sequence at the base of the Kirkfield Formation, which overlies relatively clean limestones. This corresponds with strong traces respectively.

The Sherman Fall Formation is composed of fragmental and interbedded bioclastic limestones variably dolomitised with abundant shale partings and interbeds. The



**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**

- 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 2. General tool specifications for the two-pad Formation Micro-Scanner tool.*

Sherman Fall - Kirkfield boundary marks the change from clean Kirkfield limestones to argillaceous Sherman Fall limestones and can be identified on the gamma ray wireline log trace.

The Cobourg Formation rocks are predominately fine crystalline bioclastic limestones and are predominately dolomitised directly beneath the Collingwood Shale Formation. Generally, the Trenton - Black River rocks are tight with minor primary porosity, with the majority of the production confined to dolomitised fracture systems.

## THE TOOL THEORY

The Formation MicroScanner tool is a continuation of the Dual Dipmeter tool technology. There are currently two models of the tool in service. The first tool developed (MEST-A) has two arrays of 27 electrodes on pads three and four, as well as the Dual Dipmeter (SHDT) electrodes for dip computations. Acquisition of the data is by two modes; either as a Dual Dipmeter (SHDT) without image data or in imaging mode with all 64 electrodes being recorded with a 2.5 millimetre sample rate. The arrays consist of three rows of seven buttons and one row of six. Each of the buttons is five millimetres in diameter with the entire array 68.6 millimetres wide by 35.6 millimetres deep. With arrays on two pads, a 20 percent wellbore coverage is obtained in a 216 millimetre diameter hole with each logging pass of the tool.

A second tool design (MEST-C), recently introduced, has image arrays of 16 electrodes in two rows, on all of four pads, which gives 40 percent coverage of the wellbore. The "4-pad" FMS electrodes are slightly larger with less overlap. Field tests in Canada have indicated that in present application, the increase in wellbore coverage more than compensates for the slight loss of resolution. With this tool design, the software selects the electrodes used in dipmeter computations, which allows for a more efficient and flexible logging programme.

Both tools also contain a triaxial accelerometer to enable speed corrections to the data and three magnetometers to provide accurate tool positioning. General tool specifications for the "2-pad" tool are presented in Figure 2.

## DATA PRESENTATION

Three systems are available to present the image data from the FMS. The first system uses hard copy devices that are standard to normal log presentations. This allows for the images to be displayed in variable intensities of grey on versatec printer or film. From the film, any number of black line prints can then be made. The second method is the presentation of data on a Sun Workstation. A third option is available from a colour graphics recorder, which provides plots and continuous colour images on hard copy prints.

### 1. Grey Scale Images

After processing of the image data on a vax computer in Calgary, a variable density display is produced, representing changes in formation resistivity on a scale of 16 grey levels. The whiter the images, the more resistive the formation, indicating a low water volume in the rock. The image will darken as conductivity (water volume) increases in the rock.

The scaling of the variable intensities of grey to conductivity is relative. Thus, interpretation of the FMS images is for the most part qualitative. Quantitative data that can be derived from the tool include dip angle and azimuth determination of bedding and non-bedding features and pay thickness count.

The images are displayed on a continuous plot, usually 1:5 scale, as wrap-around picture of the wellbore from 0 to 360 degrees. Figure 3 is a typical presentation over a Black River section. The following can be noted:

i) The detailed vertical scale.
ii) The images are oriented from 0 degrees to 360 degrees (left to right).
iii) The round black dots show pinhole vugular porosity.
iv) The white indicates tight rock.

### 2. Sun Workstation (FMS Image Examiner) Colour Images

The second method of presentation is on a Sun Workstation. On this "Image Examiner" system, the image data is displayed on various scales in either straight or azimuthal orientation. With the azimuthal plot, the programme allows the interpreter to select points on a feature and the programme will compute the dip magnitude and direction of that feature and display it on the screen. If the well is deviated, the hole orientation can also be removed from this dip computation. The images can then be manipulated on the workstation screen to enhance features (normalization) and to provide "binarized" cut-off images of the higher amplitude conductivity events. With this system it is possible to enlarge the images so that detailed stratigraphic features can be studied. Comments can be typed on the screen and at any point in time, the screen image can be dumped to a hard-copy device or photographed to record the high resolution image and interpretation.

Since the interactive graphics work very fast, it is possible to analyze an entire image sequence in a short time, record pertinent data with a hard-copy screen dump, and decide on any future processing of the image data for reservoir analysis.

Figures 4 and 5 (Due to publication costs, only Figure 12 appears in color, others are gray-scale representations of the original color output. Figures appear after the text of the paper.) show a comparison between both presentations. The images at 210 and 300 degrees azimuth display evidence of some healed fracturing (the white on the fracture edges shows the cementation material).

## TRENTON - BLACK RIVER FMS EXAMPLES

Six different sets of images are presented and discussed. The examples are taken from four different wells and illustrate some of the basic geological features encountered in the Trenton - Black River formation of Southwestern Ontario. In presenting the examples, various features of the Sun Workstation will also be discussed.

### *Example 1: Brecciated and Vugular Porosity Zone*

Figure 6 shows images of a Black River sequence. The black patches at 4.2 metres are vugs of up to 8 centimetres in diameter. At 4.3 and 4.5 metres, the black bands are brecciated zones, as seen on the core.

When looking at the images of the first pad (15 degrees to 55 degrees), changes in intercrystalline porosity can be noticed. Gradual increases in porosity are shown when the images go from white (high resistivity), to yellow, to brown, and to black.

### *Example 2: Stylolites and Bedding Features*

Figure 7 shows a good example of a stylolite at 9.3 metres. Stylolites are usually caused by vertical compression and their presence can create vertical permeability barriers in carbonate reservoirs. A large number of black bands can also be noticed. These are interpreted as being argillaceous in nature with a high water volume, but no permeability.

Figure 8 is a redisplay of Figure 7 with the images enhanced. One of the options on the Sun Workstation is the ability of shifting the colour scale to enhance either low or high conductivity features. Figure 8 provides better resolution of the high conductivity beds in contrast with the more resistive features.

### *Example 3: Large Vugs and Open Fractures*

The vertical scale in Figure 9 has now been changed to 1:10. Three open fractures can be seen from 7.3 to 7.6 metres. In the DIPl column, the dip angle and azimuth is given for each fracture. One would interpret the fracture at 7.3 metres as having a dip angle of 37 degrees and an azimuth of 2 degrees with respect to North. Between 8.1 and 8.5 metres, the FMS tool is measuring an area with very high conductivity, interpreted as being a small cave (paleo Karsting) filled with drilling fluid.

Figure 10 shows another feature of the Sun Workstation called binarization. This process splits the relative conductivity scale into three variable parts of white, brown, and black. One of the uses of this feature is to calibrate the porosity, as seen by the images, to approximately match the values obtained from conventional core. This is done by adjusting the white (tight rock) to brown (intercrystalline porosity) ratio and brown to black (vugular and fracture porosity) until a good match is achieved. The same cut-offs can then be applied across uncored intervals of interest to get an approximation of the vugular and fracture porosity.

The vertical scale in Figure 11 has changed to 1:20 and includes the same interval as the previous two figures. At 8.9 and 9.6 metres, the dip angle and azimuth of two bedding planes have been included. Presented in the bottom right hand corner is a histogram plot of the dip azimuths of all the fractures processed between a specified interval in the well. In this example, the majority of the fractures are dipping from 340 degrees to 2 degrees. Based on this information, offset locations can be picked by following the strike plane (E-W) of the fractures.

### *Example 4: Heavily Fractured Zone*

Figure 12 is a good example of multiple sets of fractures in a tight carbonate. In this interval, at least six open fractures can be identified, all dipping to the North (low end of the sinusoid always indicates down dip direction). The black band at 1.6 metres is a shale bed.

In the bottom right hand corner, the azimuth directions of all fractures in a specified interval have been plotted. From the twenty dips processed, a clear pattern emerges. Most of the fractures have a dip azimuth between 340 and 10 degrees from North.

### *Example 5: Fractures in Good Intercrystalline Porosity*

The yellow and brown patches in Figure 13 represent good intercrystalline porosity. Also identified are three open fractures dipping North. A second option of the histogram plot is presented here.

Plotted is the strike direction of the 42 fractures processed in this well (No Type are also fractures). A predominant East-West strike direction is observed with one set of orthogonal fractures striking North-South.

### *Example 6: Top of the Gull River*

Figure 14 shows a tight carbonate feature between 0.3 and 0.9 metres exhibiting some minor patches of porosity and possible fracturing. The brown and black above and below the carbonate feature are shale beds.

In the top right hand corner, the last of the histogram plot options is presented. Called a Schmidt Plot, it displays dip angle and azimuth of an event by means of a dot. Dip angle is linearly scaled from 0 to 90 degrees from the centre to the outer edge of the circle. Dip azimuth is scaled the same was as a compass.

In this example, fractures in three specified intervals were plotted, each using a specific colour. Of note, each interval ended up having a specific dip azimuth, suggesting that more than one tectonic event took place.

## CONCLUSION

The high resolution images of the FMS tool have provided excellent results in attempting to better evaluate and understand the Trenton - Black River formation of Southwestern Ontario. When making comparisons with conventional core, the FMS images should be used to enhance core information concerning porosity fracture orientation, and morphology. The main uses of the FMS images in the Trenton - Black River are:

- Identification of open versus closed fractures.
- Determination of strike direction and dip magnitude of fractures.
- Recognition of type of secondary porosity between vugular, fracture, and intercrystalline.
- Identification of barriers to vertical permeability.
- Pay thickness count through porosity quantification.
- Orientation of core and extension of core analysis in uncored zones.
- Guide to completion strategy.

## ACKNOWLEDGEMENTS

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Manuscript accepted March 8, 1989

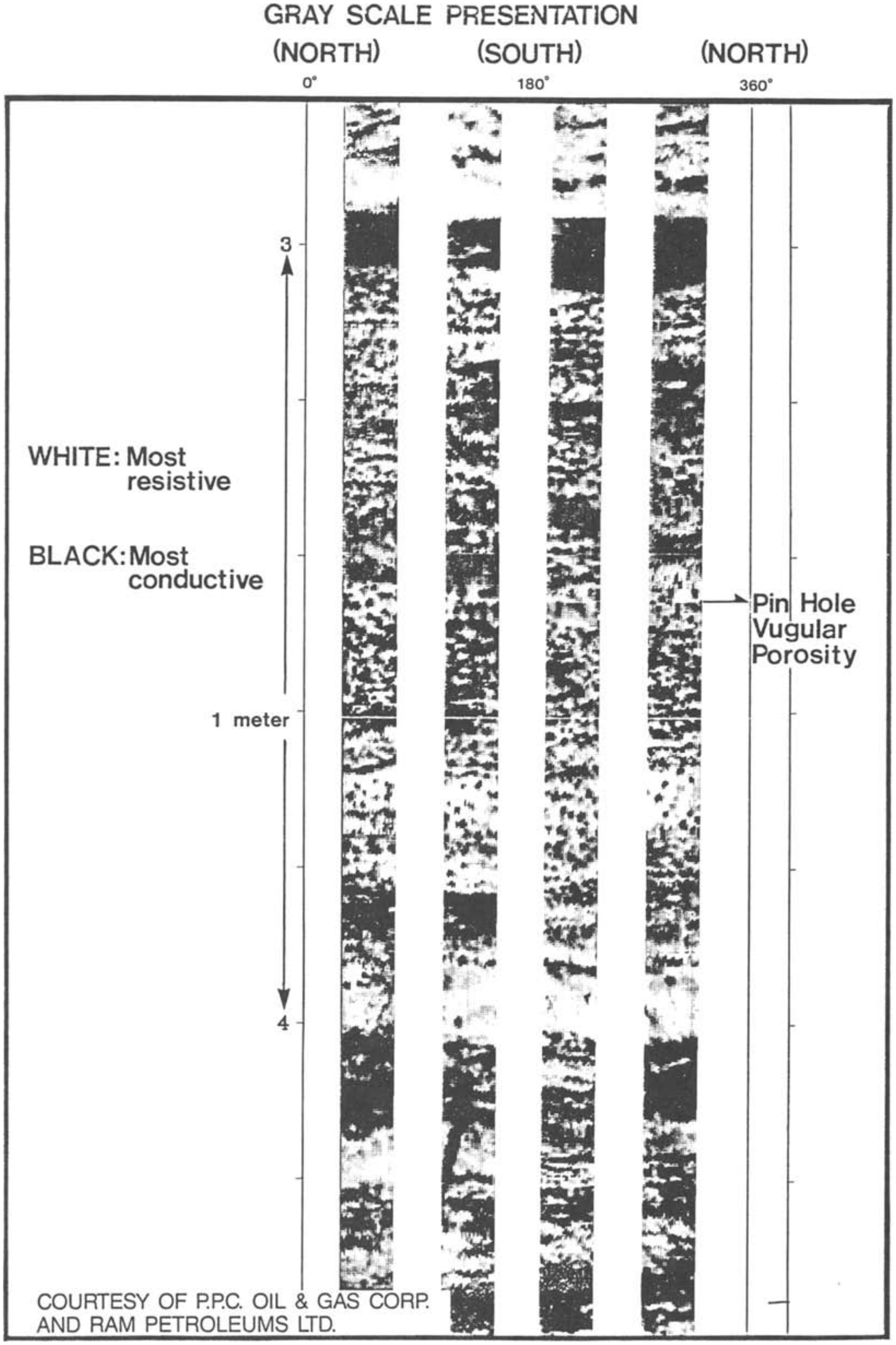


*Figure 3. A gray scale presentation over a Black River section. The image shows the comparison between tight rock (white- most resistive) and porous/permeable rock (black- most conductive). The area between 3.0 and 4.0 meters exhibits a predominantly dolomitic matrix with fair to good intercrystalline porosity and pin hole vugular porosity. Note the dark lamination at 3.0 meters, this is a laterally continuous shale marker.*

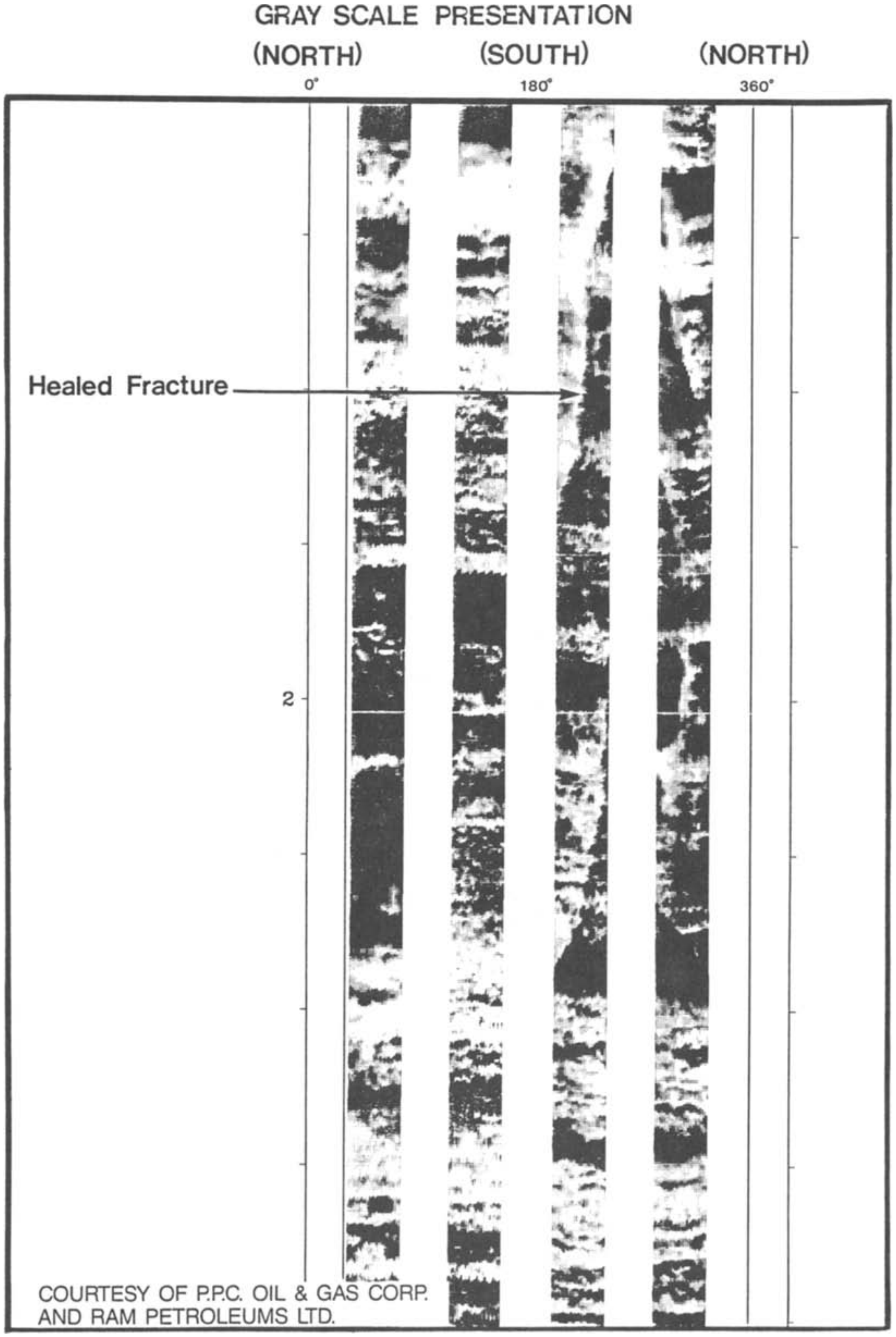
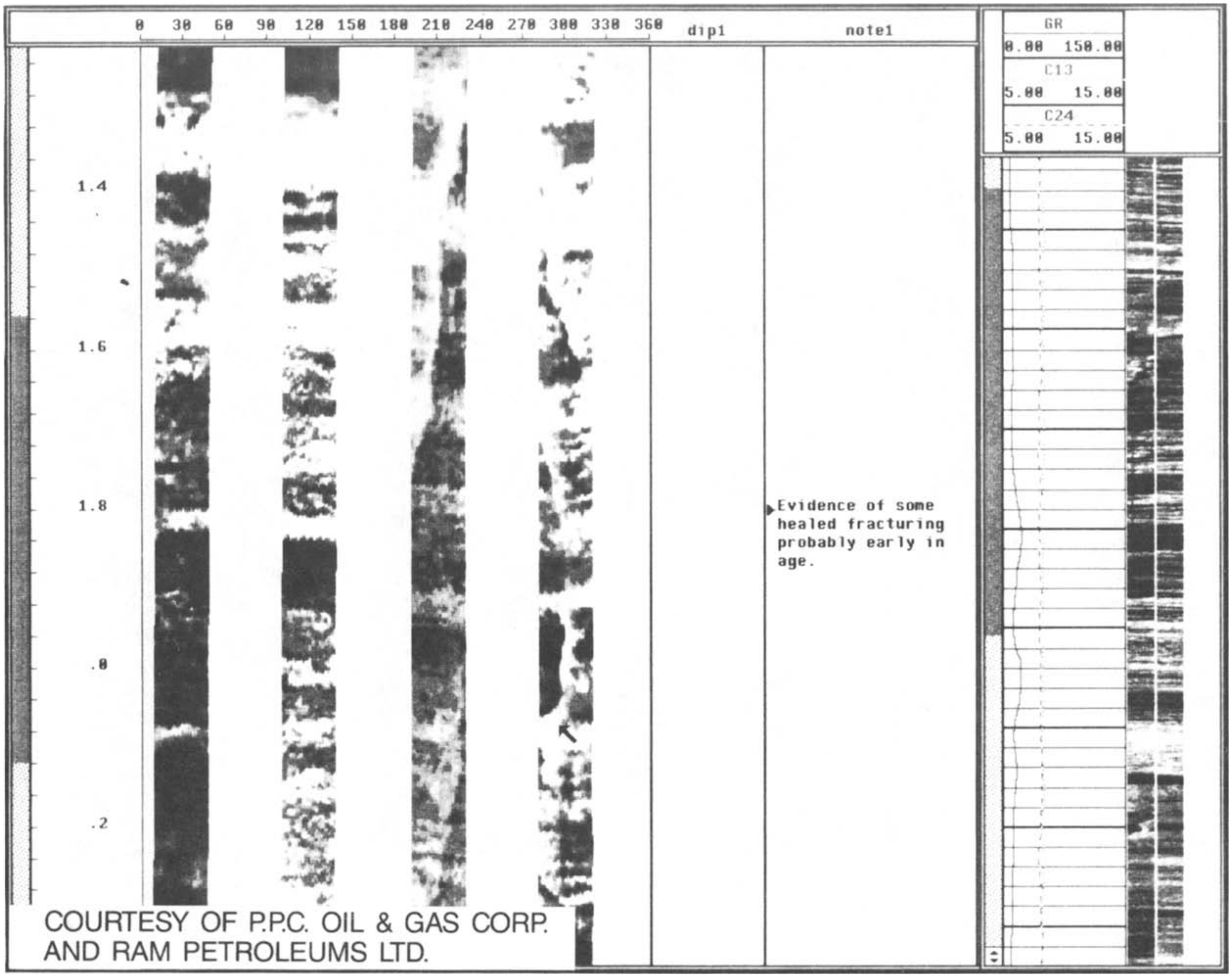


*Figure 4. Gray scale image presentation, displaying a near vertical healed fracture.*



Evidence of some healed fracturing probably early in age.

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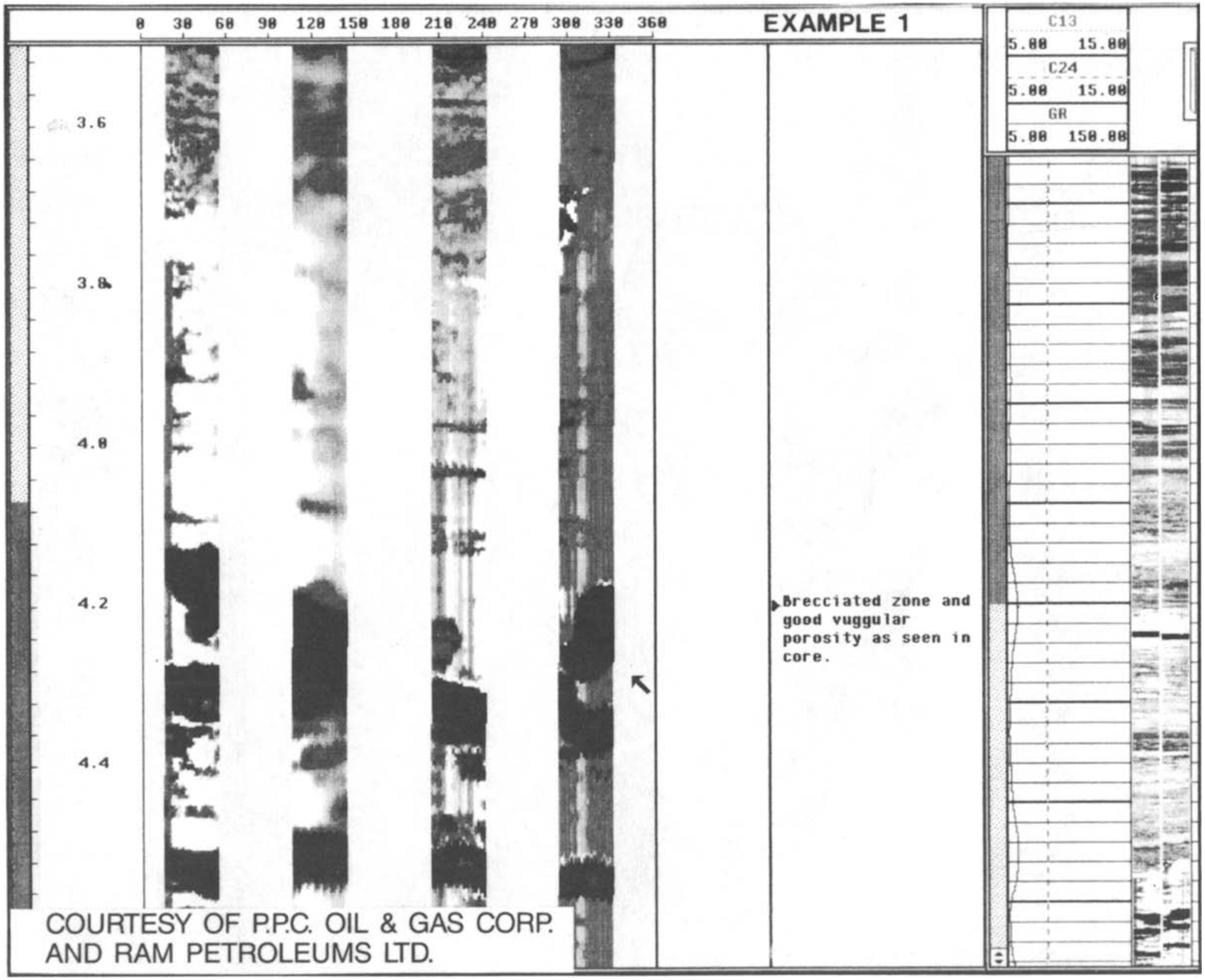
*Figure 5. Static normalization of multiple passes as displayed on the FMS Image Examiner workstation screen and then screen dumped for a hard-copy. Note the healed fracture as seen in the previous figure.*



Brecciated zone and good vuggular porosity as seen in core.

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Figure 6. A hard-copy screen image of a Black River sequence. Paleo karsting, good evidence of brecciation and collapse and vugular porosity appear in the FMS image as more conductive (darker) than the surrounding rock. These features were identically seen in the core that was cut through this sequence.

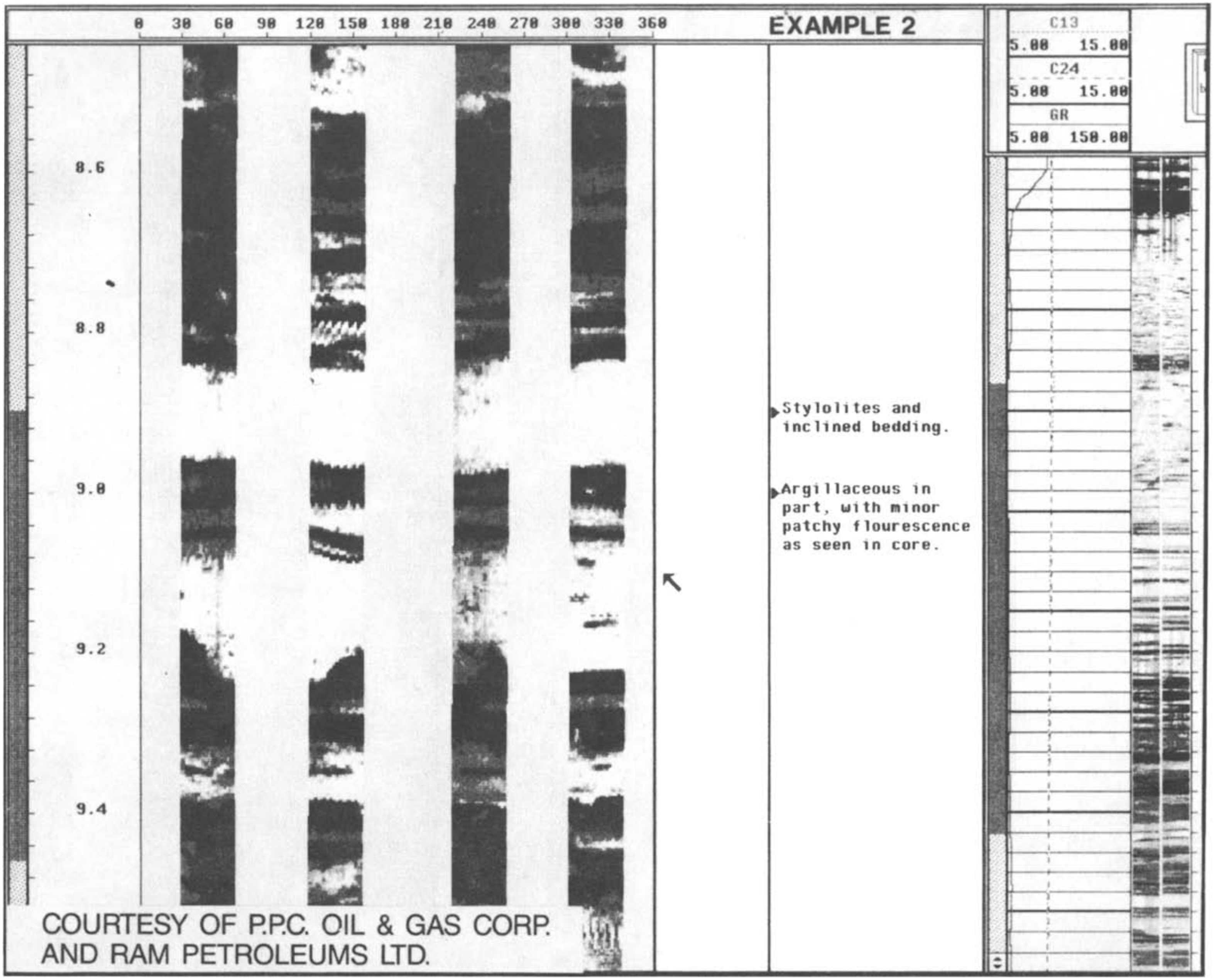
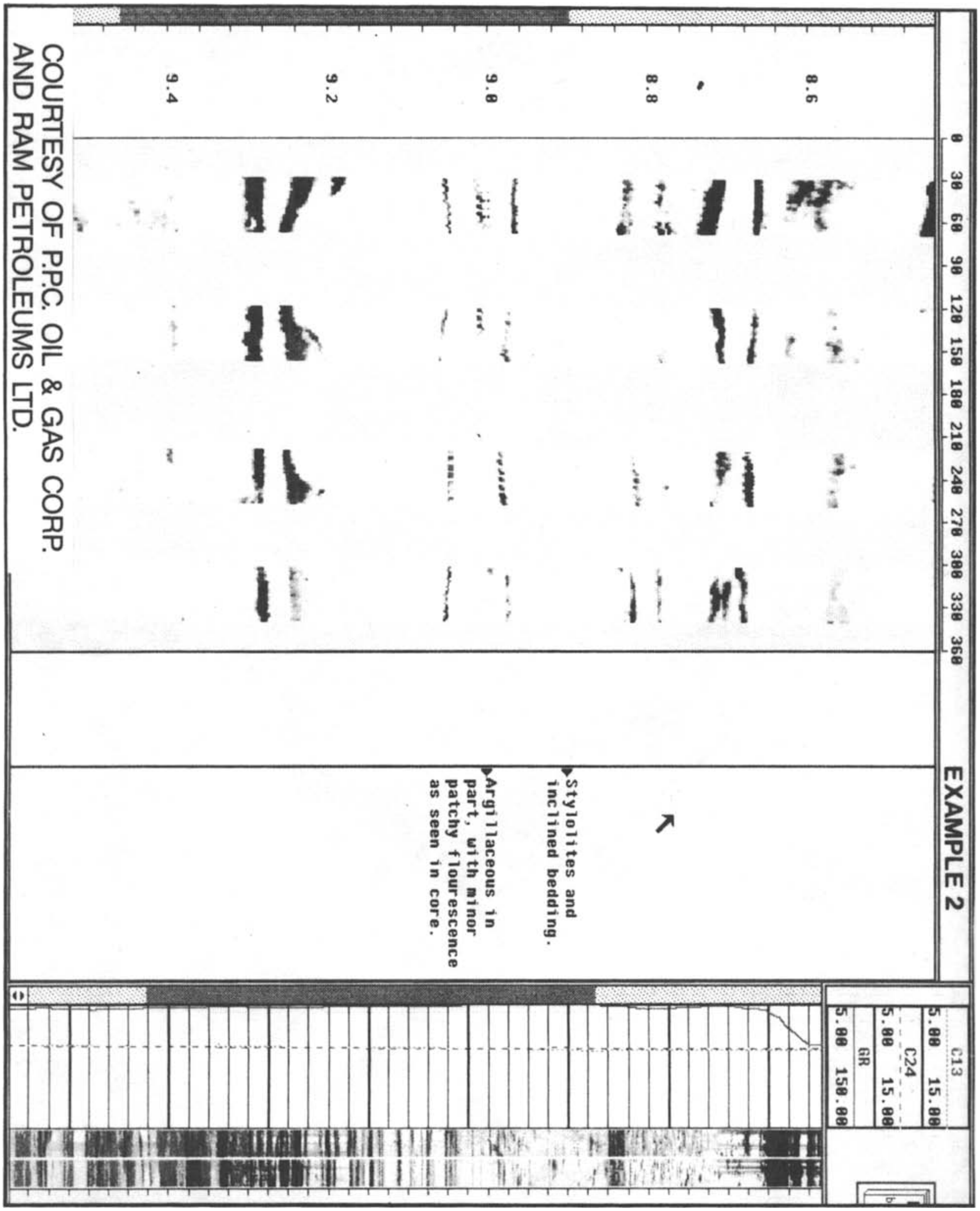


*Figure 7. Stylolites and bedding features are shown in this FMS image. Dark laminations are noted through out this sequence, these are argillaceous stringers. These features can be confirmed with open hole logs and core.*



Stylolites and inclined bedding.

Argillaceous in part, with minor patchy flourescence as seen in core.

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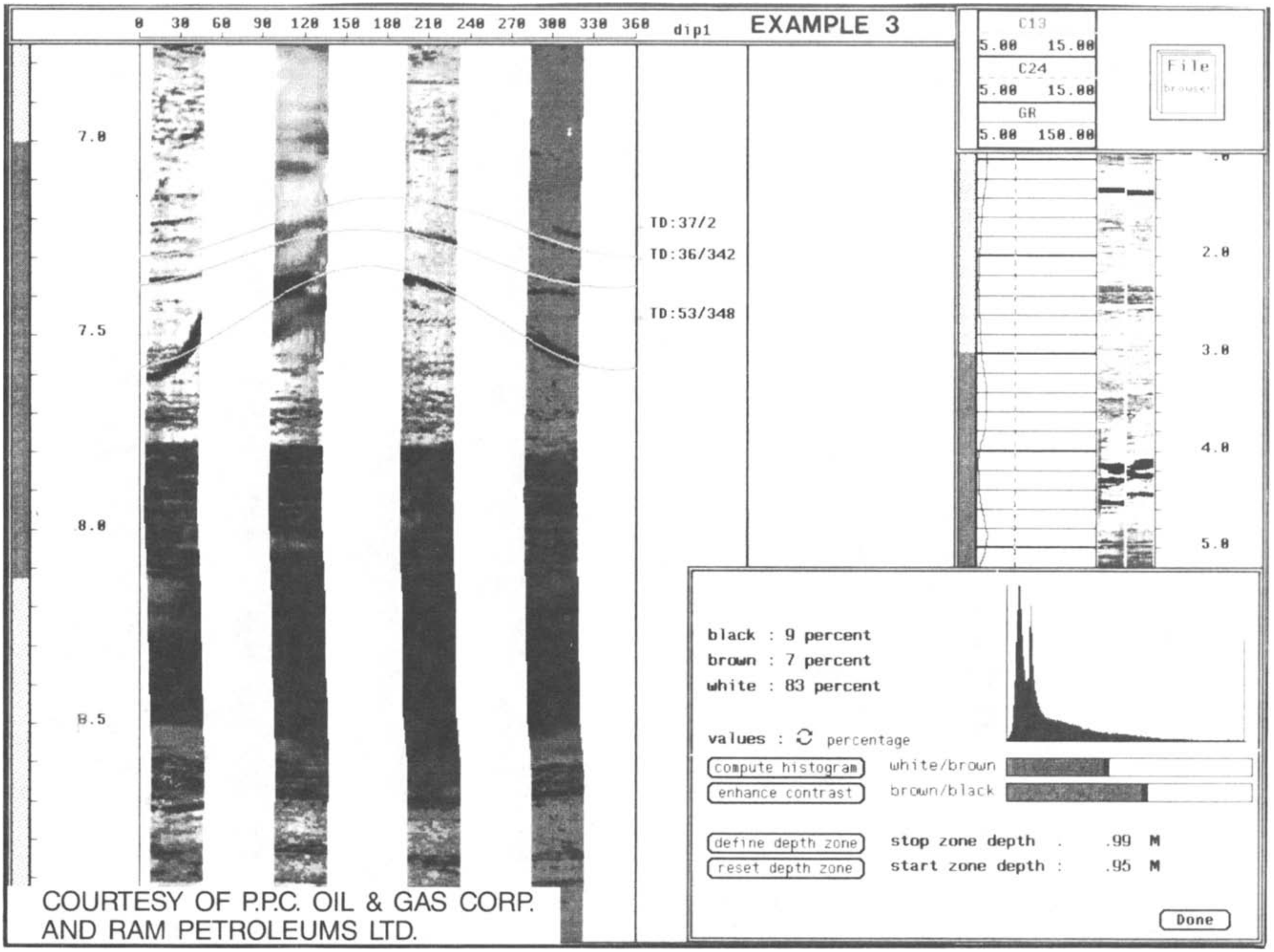
*Figure 8. A redisplay of Figure 7 but is image enhanced. This enables the interpreter to shift the colour scale on the workstation to enhance either low or high conductivity features.*



black : 9 percent
brown : 7 percent
white : 83 percent

stop zone depth . .99 M
start zone depth : .95 M

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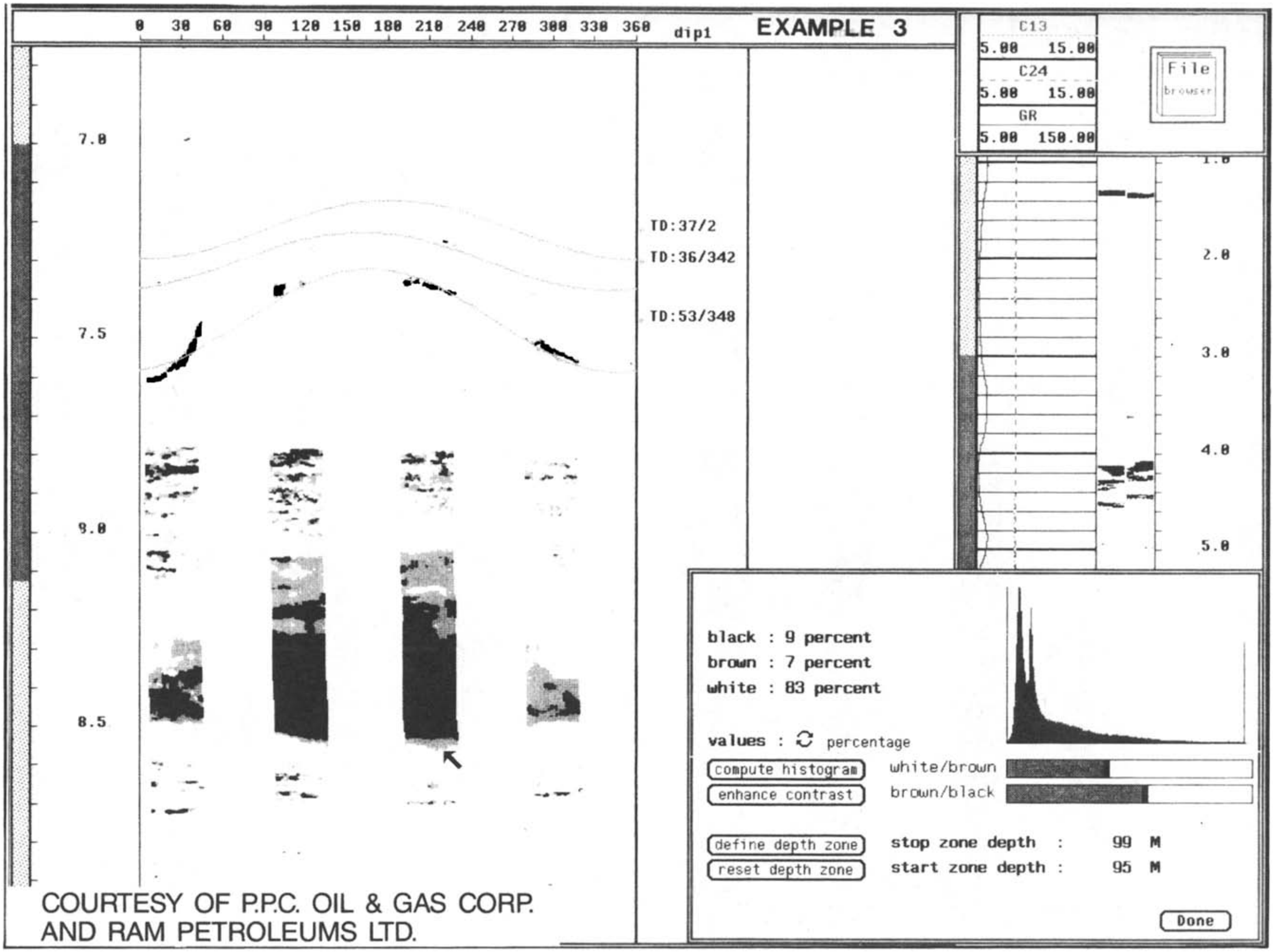
*Figure 9. Two-pad FMS log showing a spectrum of vugginess associated with fractured dolomites in a proved producing oil well in the Black River sequence.*



black : 9 percent
brown : 7 percent
white : 83 percent

stop zone depth : 99 M
start zone depth : 95 M

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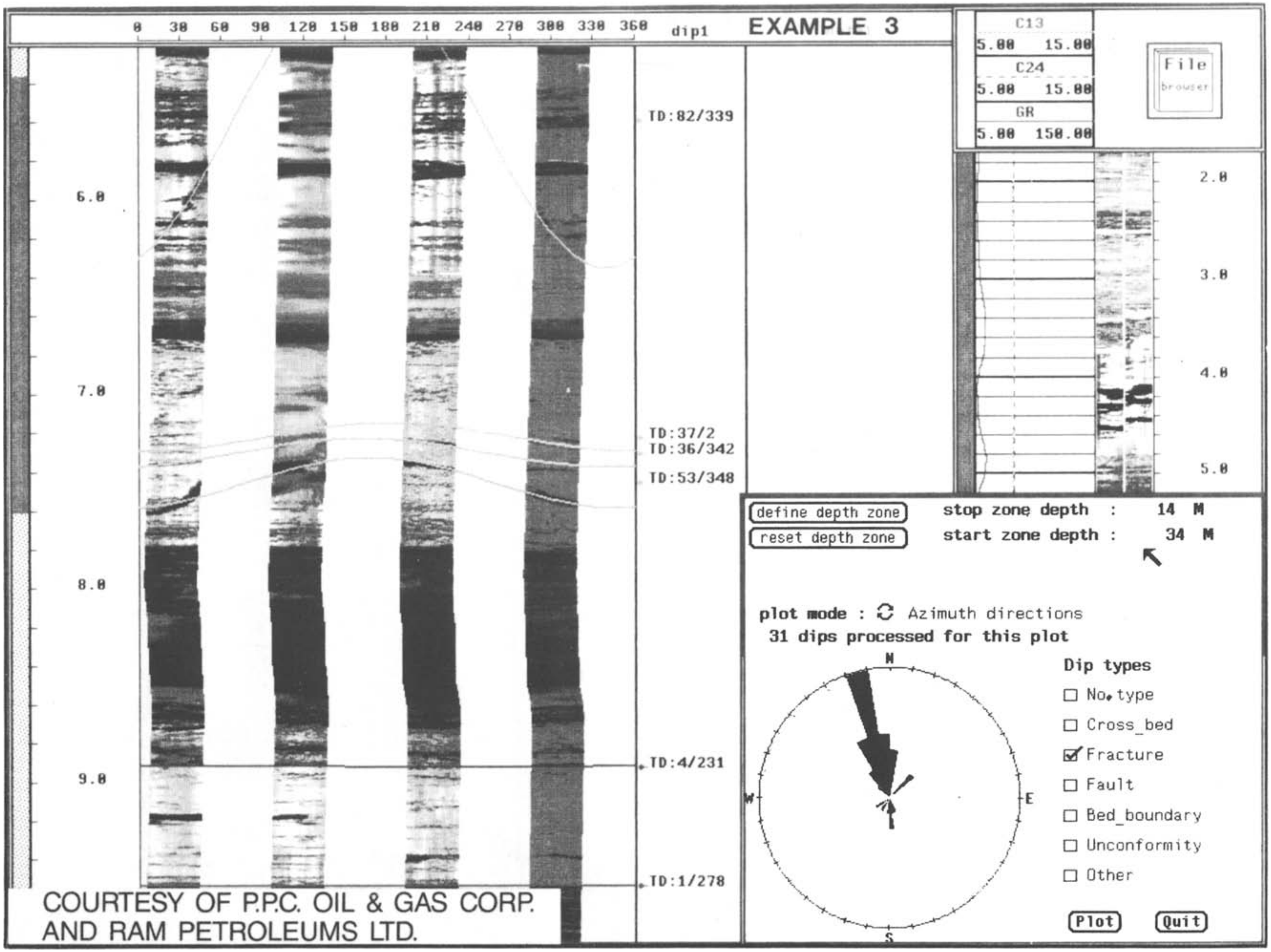
*Figure 10. A redisplay of Figure 9 showing an example of binarization. A process where true porosities as seen from open hole logs or cores can be calibrated to match and therefore porosity approximations above and below this sequence will be more accurate.*



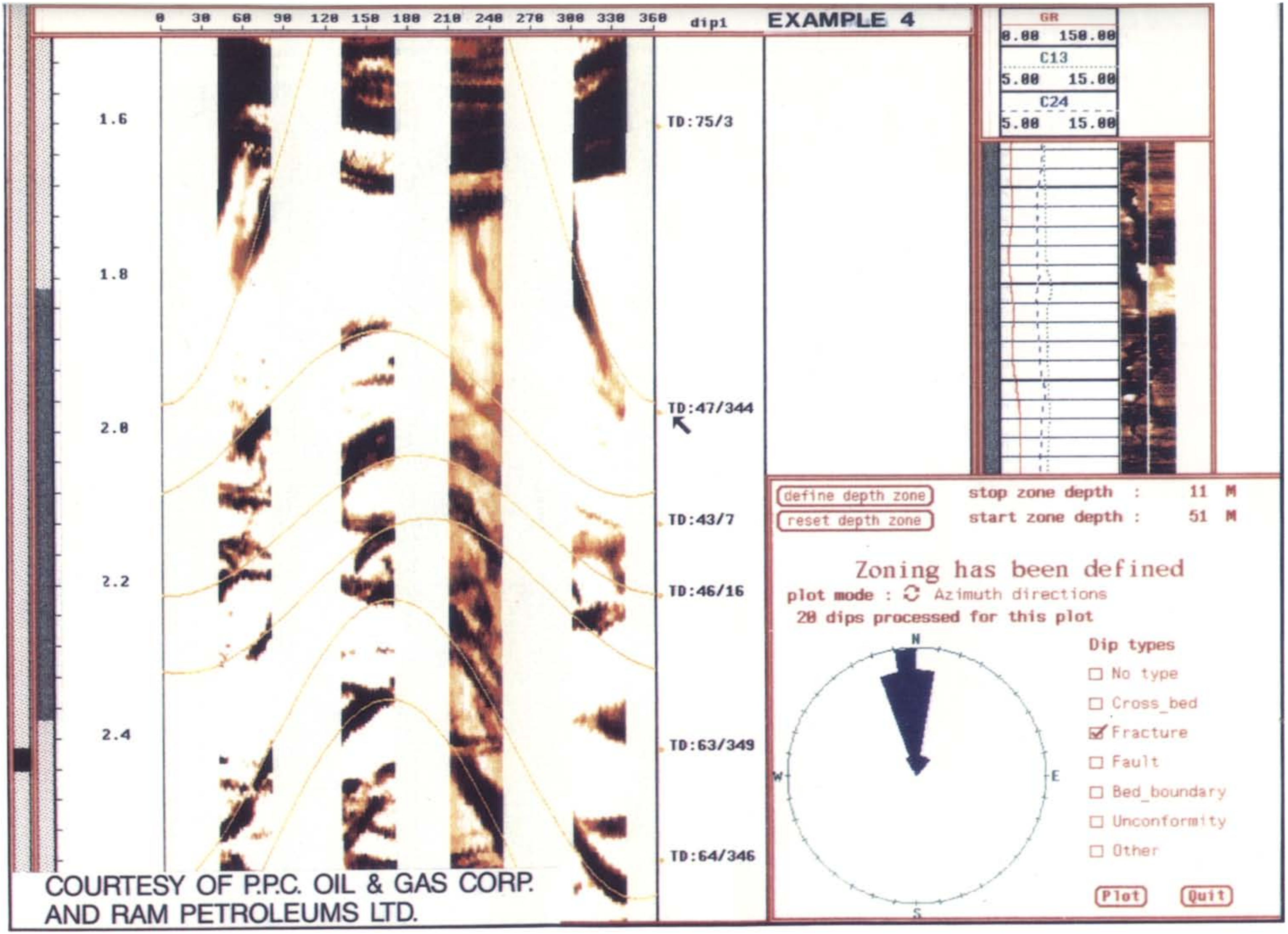
stop zone depth : 14 M
start zone depth : 34 M

plot mode : Azimuth directions
31 dips processed for this plot

**Dip types**

- ☐ No. type
- ☐ Cross_bed
- ☑ Fracture
- ☐ Fault
- ☐ Bed_boundary
- ☐ Unconformity
- ☐ Other

*Figure 11. Another redisplay of Figure 9, but the vertical scale has been changed to 1:20. Also included in the bottom right hand corner is a histogram plot of the dip azimuths of 31 fractures processed between a specified interval in the well. As identified in the histogram plot, the majority of the fractures are dipping to the NNW and striking predominately in an East-West direction.*



EXAMPLE 4

stop zone depth : 11 M

start zone depth : 51 M

Zoning has been defined

plot mode : Azimuth directions

20 dips processed for this plot

Dip types

☐ No type

☐ Cross_bed

☑ Fracture

☐ Fault

☐ Bed_boundary

☐ Unconformity

☐ Other

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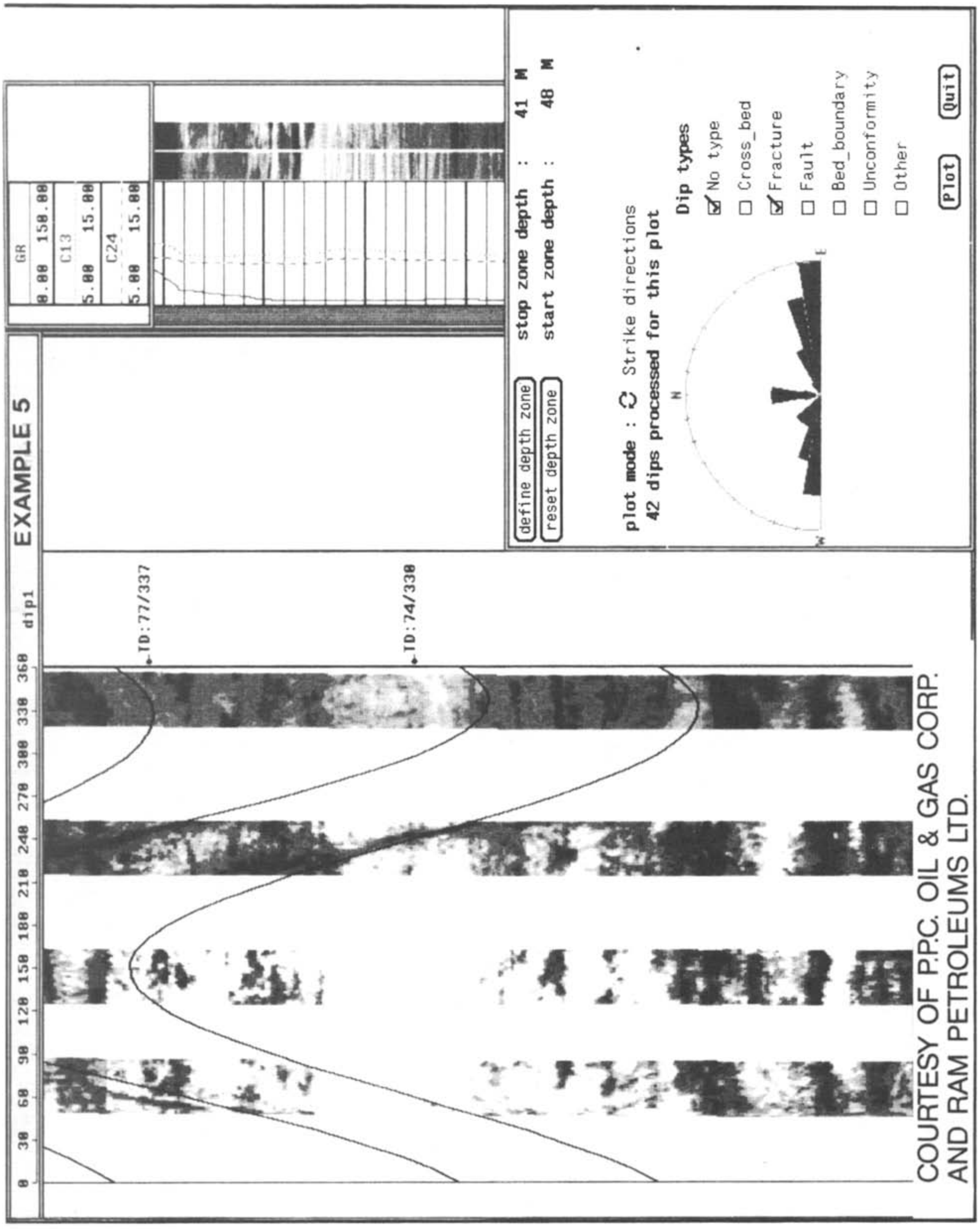
FIG.11



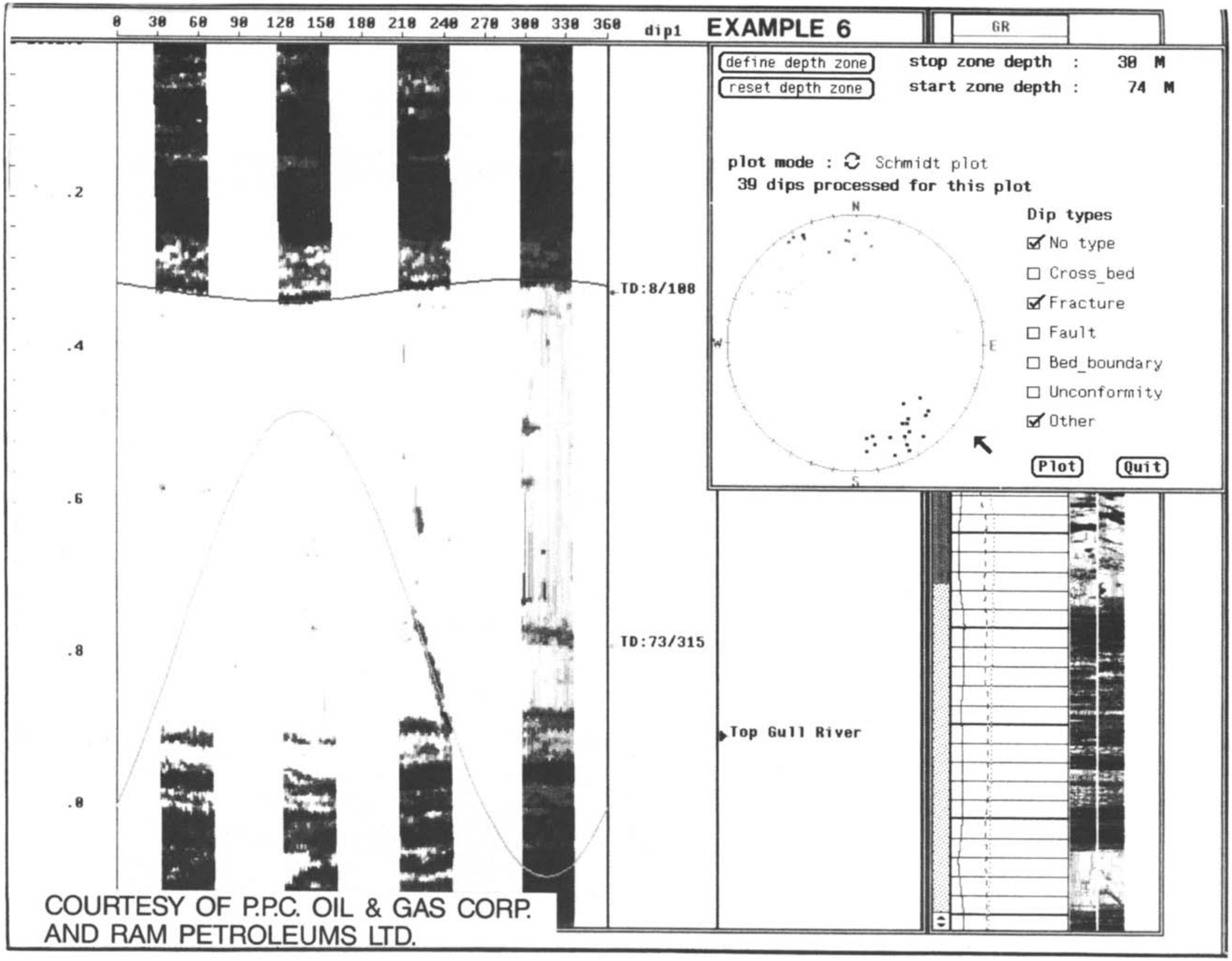
stop zone depth : 41 M
start zone depth : 48 M

plot mode : Strike directions
42 dips processed for this plot

Dip types
☑ No type
☐ Cross_bed
☑ Fracture
☐ Fault
☐ Bed_boundary
☐ Unconformity
☐ Other

*Figure 12. This image is a good example of multiple sets of fractures in a tight limestone. From open hole logs, matrix porosity is interpreted as being 3%, but fracture porosity is interpreted as being 10 to 12 %. These lower inclined open fractures exhibited hydrocarbon shows upon penetration.*

*Figure 13. Open fractures dipping North with a predominant East-West strike direction is observed in this example.*



EXAMPLE 6

stop zone depth : 30 M
start zone depth : 74 M

plot mode : Schmidt plot
39 dips processed for this plot

Dip types
☑ No type
☐ Cross_bed
☑ Fracture
☐ Fault
☐ Bed_boundary
☐ Unconformity
☑ Other

TD:8/108
TD:73/315
Top Gull River

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*Figure 14. In this display, tight limestone is seen between 0.3 and 0.9 meters exhibiting some minor patches of scattered porosity and possible fracturing. Also present in this display is the conventional Schmidt Plot. In this example 39 dip angles and azimuth points are plotted. The total 39 points calculated are from three specified intervals. Of note, each interval sampled ended up having a specific dip azimuth suggesting strongly that more than one tectonic event took place and perhaps of different age.*