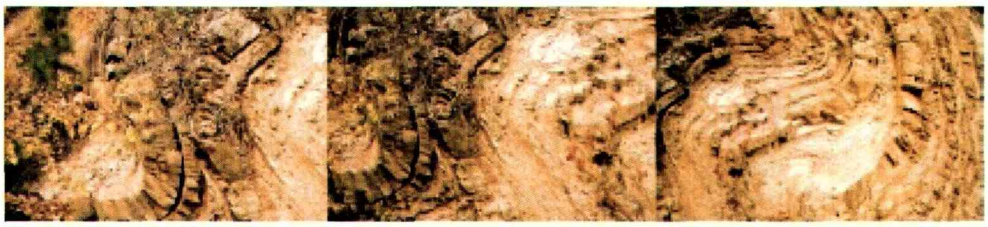
Chesapeake Operating, Inc.
Delmar Light 3H
Field: N/A
Upshur County, West Virginia
Latitude: 38.9648 N Longitude: -80.2659 W

Date Logged: 24-February-2010

Prepared by:
Brian T. David
Geologist



April 2010

FORMATION IMAGE INTERPRETATION REPORT

Formation Image Interpretation Report

Chesapeake Operating, Inc.
Well: Delmar Light 3H
Field: N/A
Upshur County, West Virginia
API: 47-097-036602

Latitude: 38.9648 N Longitude: -80.2659 W
Section: N/A Township: Buckhannon Range: Adrian

Structural Interpretation of the Delmar Light 3H

Report prepared for:
Chris Gardner
Chesapeake Energy
6100 N Western Ave.
Oklahoma City, OK 73118

By:
Brian T. David
-Geologist-
April 2010

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Formation Image Interpretation
- General Well Data -

Well Information

Company Name	Chesapeake Energy
Well Name	Delmar Light 3H
API Number	47-097-036602
Field	N/A
County	Upshur
State	West Virginia
Country	United States
Location	Lat: 38.9648 N Long: -80.2659 W

Logging Information

Service Company	Schlumberger
Type of Tool	FMI
Date Logged	March 27, 2010
Run Number	One
Permanent Datum	Ground Level - Elevation 1,745 ft
Log Measured from:	Drill Floor – Elevation 1,763 ft, 18 ft A.P.D
Bit Size	8.75 Inch
Mud Type	KCL Polymer
Mud Weight	10.00 (LBM/GAL)

Processing Information

Processed & Interpreted Interval	6,500 ft to 7,717 ft & 6,504 ft to 7,717 ft
Magnetic Declination	8 ° 35'
Source for Magnetic Declination.	National Geophysical Data Center (NGDC), National Oceanic and Atmospheric Administration (NOAA)

All Images are Oriented to Geographic North

- Executive Summary -

• The overall quality of the FMI image was very good. Quality control of the raw data showed the tool was functioning properly.

• A detailed structural analysis of the well-bore has resulted in the identification of one dip domain. Dip Domain I has an average bedding dip magnitude/direction of **2°/189° (SSW)** and covers the entire interpreted interval of 6,504 ft– 7,717 ft. There is slight scatter observed with the bedding dip direction and is most likely attributed to the very low dip magnitude.

• The Delmar Light 3H has an average *in-situ* maximum horizontal stress of **N80E-S80W** estimated from 53 centerline-tensile fractures and 99 borehole breakouts.

• There are 212 tensile enhanced fractures observed with an average strike of **N82E-S82W,** which is sub parallel to the estimated *in-situ* maximum horizontal stress observed with the borehole breakouts and centerline-tensile fractures.

• A total of 162 natural fractures have been identified within the interpreted interval of 6,504ft – 7,717 ft of the Delmar Light 3H. These fractures are divided into high-angle (≥60°) and low-angle (<60°) fractures. If the high-angle fractures have no observable displacement they are classified as joints—Mode I fractures. There are 95 joints and no high-angle faults/shears observed. There are 67 low-angle fractures, 3 of which show displacement along the fracture trace (shear fractures). The high-angle joints strike **NE-SW** with minor scatter. The low-angle fractures strike **NE-SW** and **NNW-SSE** along with some minor scattering. No low-angle faults were identified within the interpreted interval. The low-angle shear fractures have scatter. The fractures are divided according to formations, along with a brief summary, please see page 54 for the listing.

• Fracture density is highest in the Marcellus Formation (7,550 ft – 7,575 ft) where the fracture density reaches just over a 1 fracture per foot density. The lower Hamilton Formation is close to a one fracture per foot density. This increase in fracture density in the Marcellus and lower Hamilton is related mostly to the high-angle joints observed in this section of the well. Overall, the fracture density is low for the well, with an average density of 0.50 fracture per foot density. Some regions in the Sycamore (7,025 ft – 7,050 ft and 7,075 – 7,100 ft) approach a 1 fracture per foot density. The total gas curve is compared with the total fracture density. Some regions of the gas curve correlate well (as seen with the Sycamore (~7,000 ft) and other regions do not correlate very well—e.g., Marcellus. In the Marcellus the fracture is highest and the gas curve for this region is low.

- Introduction and Objectives of the Project -

This report presents the structural interpretation results for the Delmar Light 3H well based on a FMI borehole image provided by Schlumberger. The FMI imaging log was logged from 6,500 ft to 7,717 ft. Fronterra Geosciences interpreted the interval of 6,504 ft – 7,717 ft (1213 foot interval). This includes the Onondaga, Marcellus, Purcell, Hamilton, Tully, Geneseo, Sycamore, and part of an undifferentiated formation (tops were provided by Chesapeake Operating, Inc.).

The main objective is to conduct a detailed structural interpretation in order to better understand the near wellbore structure. In addition to defining structural domains, the interpretation consists of the recognition of faults and determination of the attitude and the characterization of the natural fracture system.

The orientation of the minimum and maximum horizontal stress vectors over the entire interpreted sequence will be examined based on high angle drilling induced fractures, centerline fractures, and borehole breakouts.

Overall quality of the formation image data is very good. The raw FMI data are archived together with the analysis files and the interpretation report files on the attached CD-ROM for easy access and possible future use—please see list of deliverables below.

The images are presented on 5" and 60" plots. The 5" plot displays the static image and the vectors of bedding. The dip direction of the different hand-classified bedding dips are presented as separate rose diagrams. Also, the strike of natural fractures are displayed in a separate rose diagram track. The color coding is in agreement with the color code presented in the report (Page 18). In addition, the GR, Density and Neutron curves are displayed to aid in image interpretation.

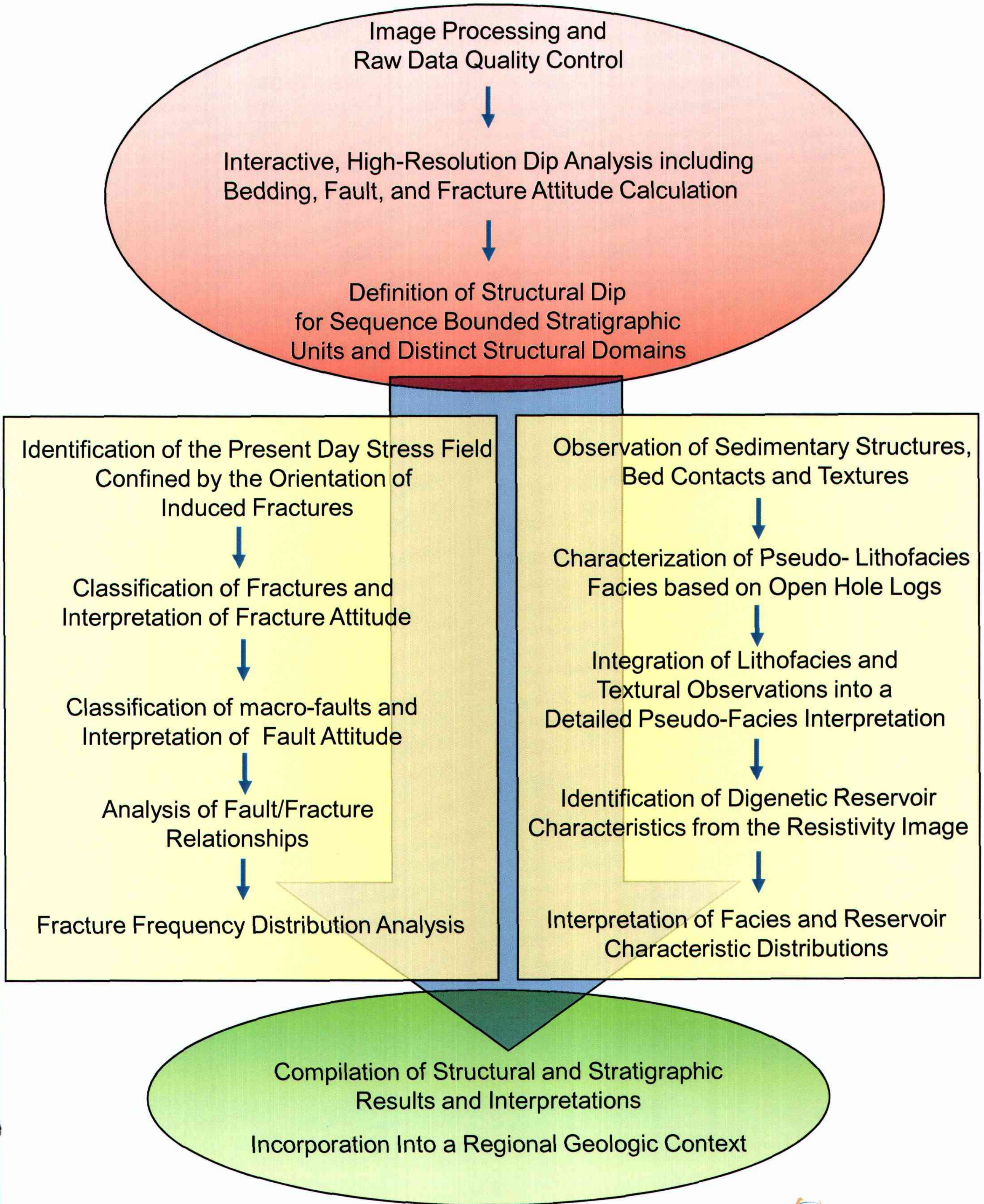
Deliverables:

1. Plots-Hardcopies
• Composite Fracture Density-Structural Plot
    - 1" fracture/joint density
    - 5" structural
• Detailed 60" Stratigraphic Plot
2. Data CD
    - Raw data
    - Report PDF
    - Digital pick files—Bedding/Fractures and Breakouts in Xcel and LAS fracture density curves
    - TS files-processed data, software specific
    - PDF's of plot files
3. Report-Hardcopy

ANALYSIS and INTERPRETATION STEPS

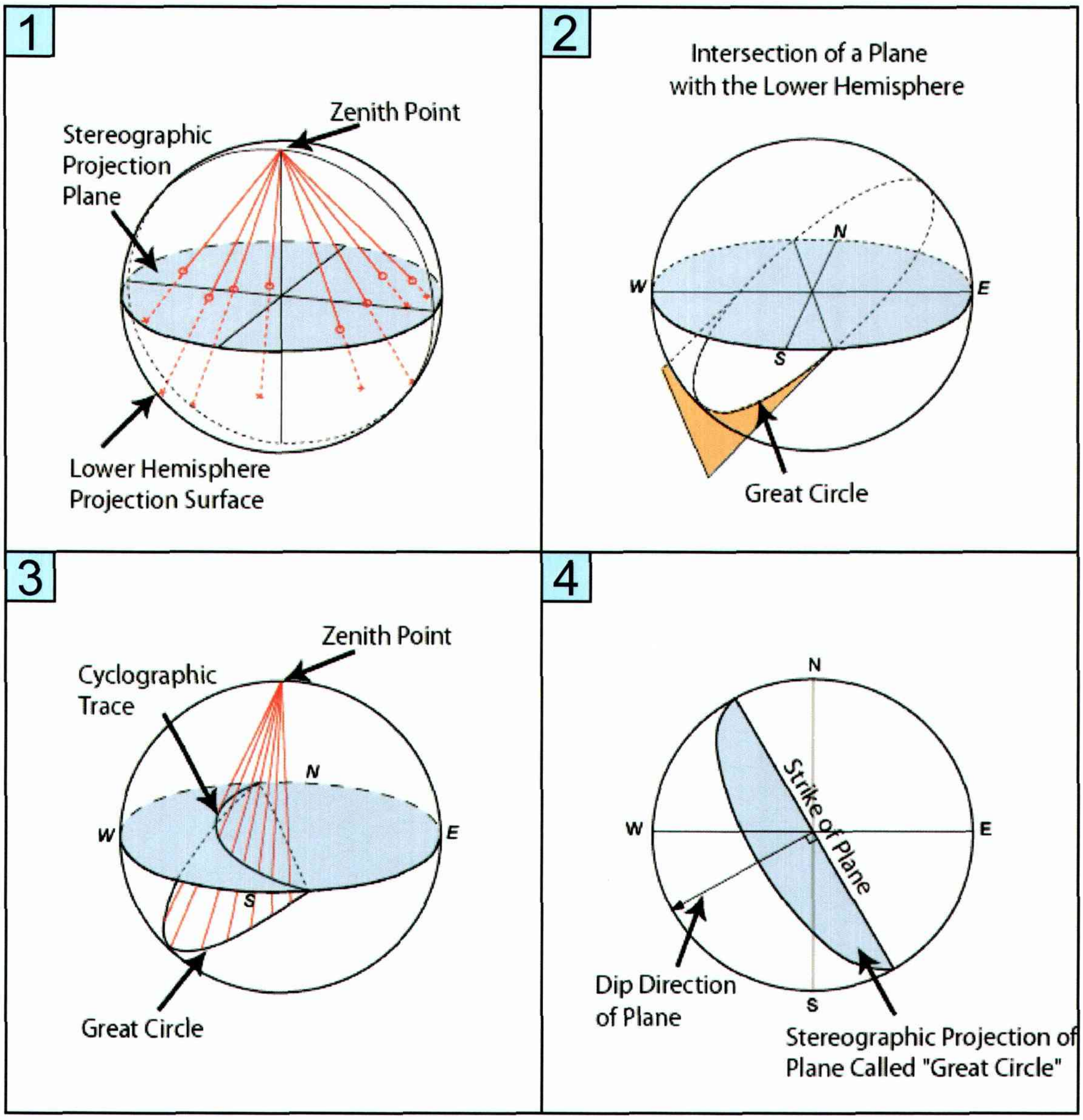
- **Methodology**
- QC raw image data and essential instrument information for accurate dip calculation
- Evaluate the near-wellbore structure and macro-faults, if present in the subject well
- Determine the orientation of the present-day stress field
- Characterization of the natural fracture system
- Analyze lithofacies of sedimentary sequences

Formation Image Analysis
- Process Flow -



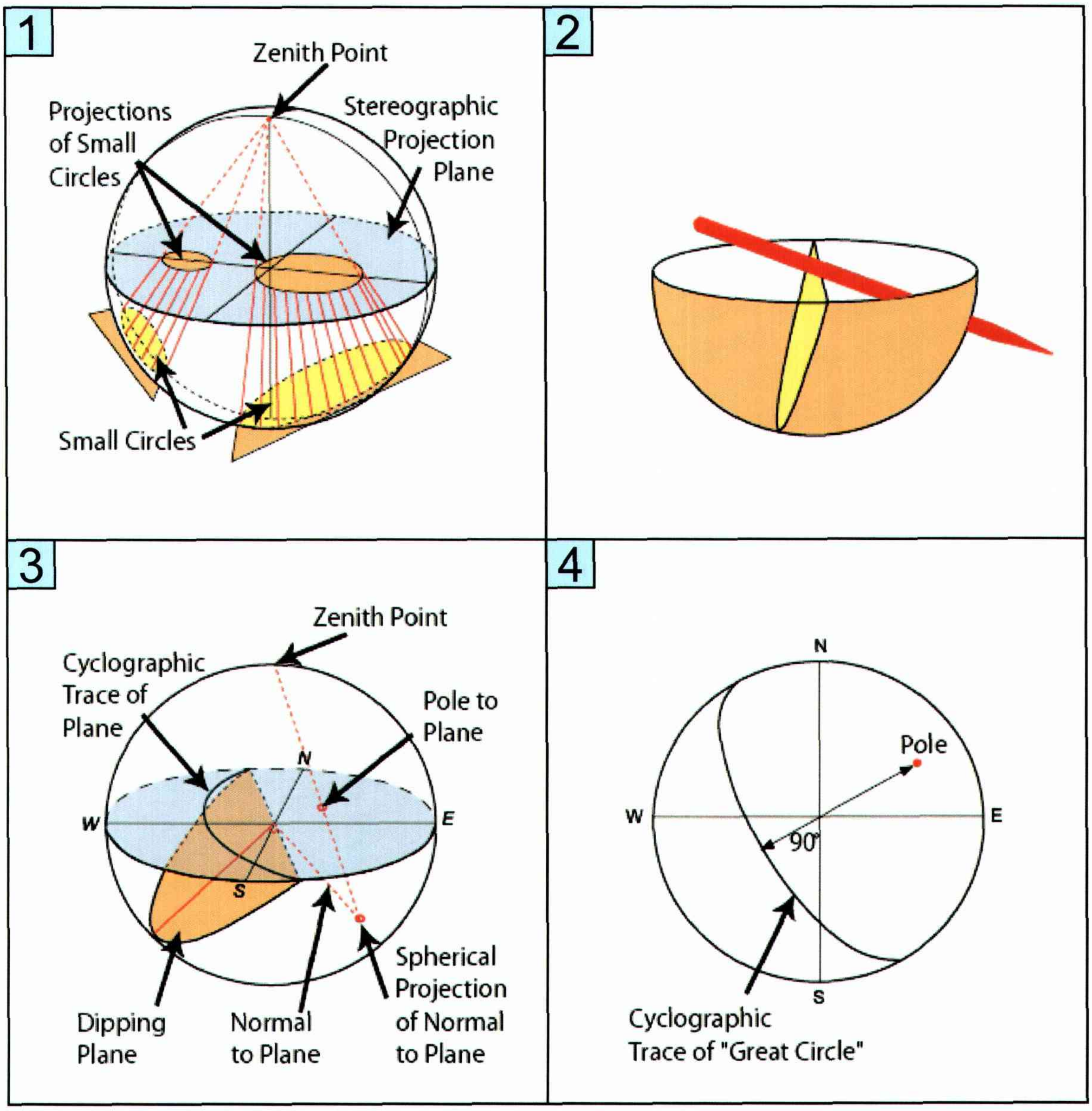
Stereographic Projection of Planes

An invaluable tool for the interpretation of structure and fracture system is the lower hemisphere pole projection. The classification of fractures as open or closed would not be very helpful if the origin and relationship of fractures to each other is not fully understood. The lower hemisphere pole projection assists in achieving that goal.



1- The projection of a point on the lower hemisphere lies along a line drawn from the point to the zenith.
2- Plane intersecting the lower hemisphere describes a great circle.
3- Lines drawn from the great circle to the zenith point intersect the equatorial projection plane describing a circular arc (the cyclographic trace).
4- The completed stereogram of a dipping plane.

Stereographic Projection of Small Circles and Poles



1- Planes that do not pass through the center of the sphere intersect the sphere in small circles. These circles project as circles (or circular arcs) on the stereographic projection plane.
2- Drawing to help visualize the meaning of a pole.
3- Projection sphere showing a dipping plane and its normal, and their projections (cyclographic trace and pole) on the horizontal equatorial plane.
4- Stereographic projection showing the cyclographic trace of a dipping plane and its pole.

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ANALYSIS and INTERPRETATION STEPS

- Methodology
- **QC raw image data and essential instrument information for accurate dip calculation**
- Evaluate the near-wellbore structure and macro-faults, if present in the subject well
- Determine the orientation of the present-day stress field
- Characterization of the natural fracture system
- Analyze lithofacies of sedimentary sequences

Formation Image Interpretation
- General Well Data -

Quality Control Checklist

Magnetometer on Depth with image	Pass
Accelerometer on Depth with image	Pass
Magnetometer Cross Plot	Pass
Accelerometer / Cosine of Deviation Plot	Pass
Depth Plot	Pass
Summary QC Plot	Pass

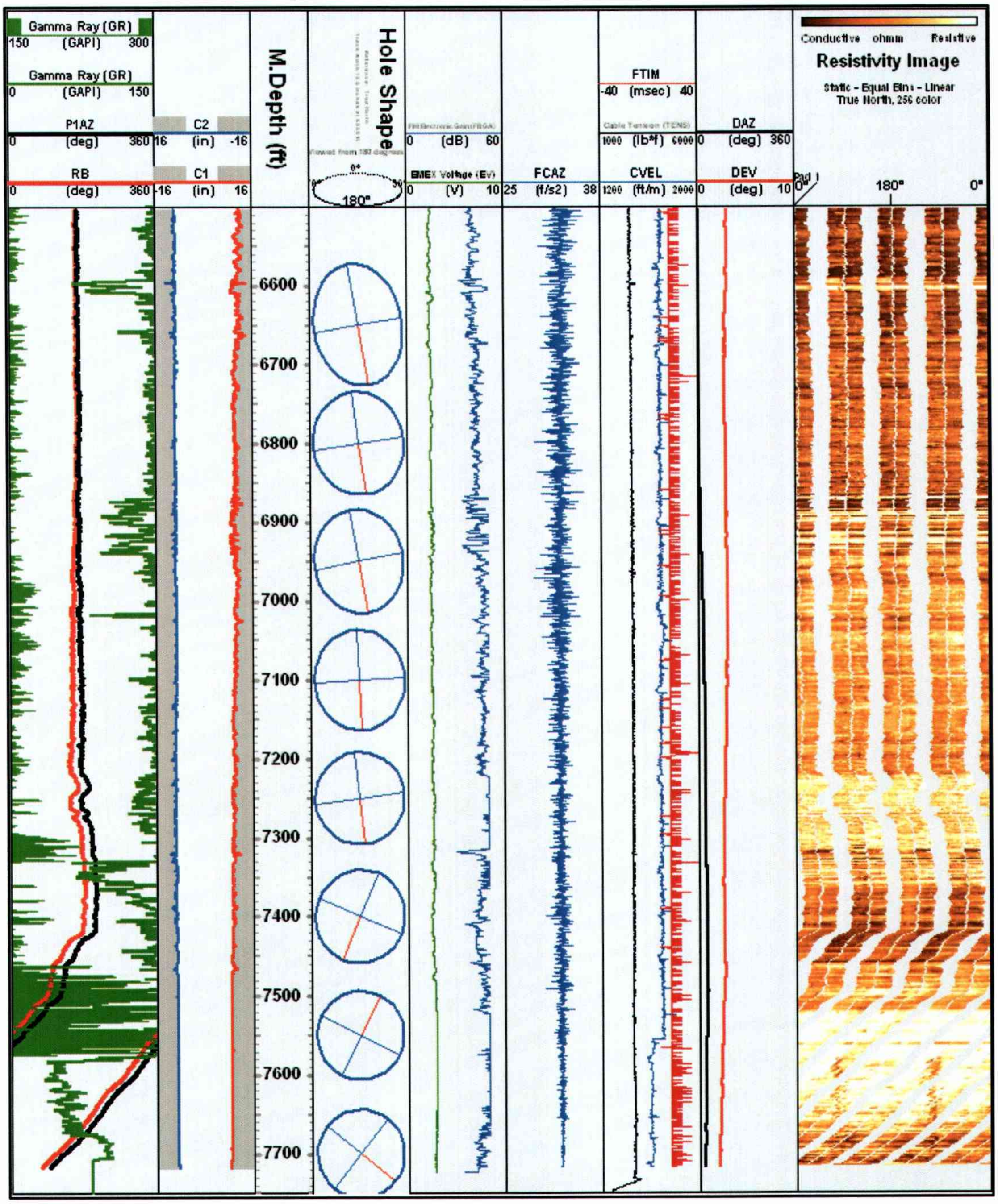
Corrections to Image

Magnetic Declination	-8.914 degrees
Speed Correction	Applied in Recall
Pad / Flap Correction	Applied in Recall
Button Equalization	None Applied
Dead Buttons	None Applied
Pad Normalization	Applied in Recall
Gain / EMEX correction	Applied in Recall

Remarks

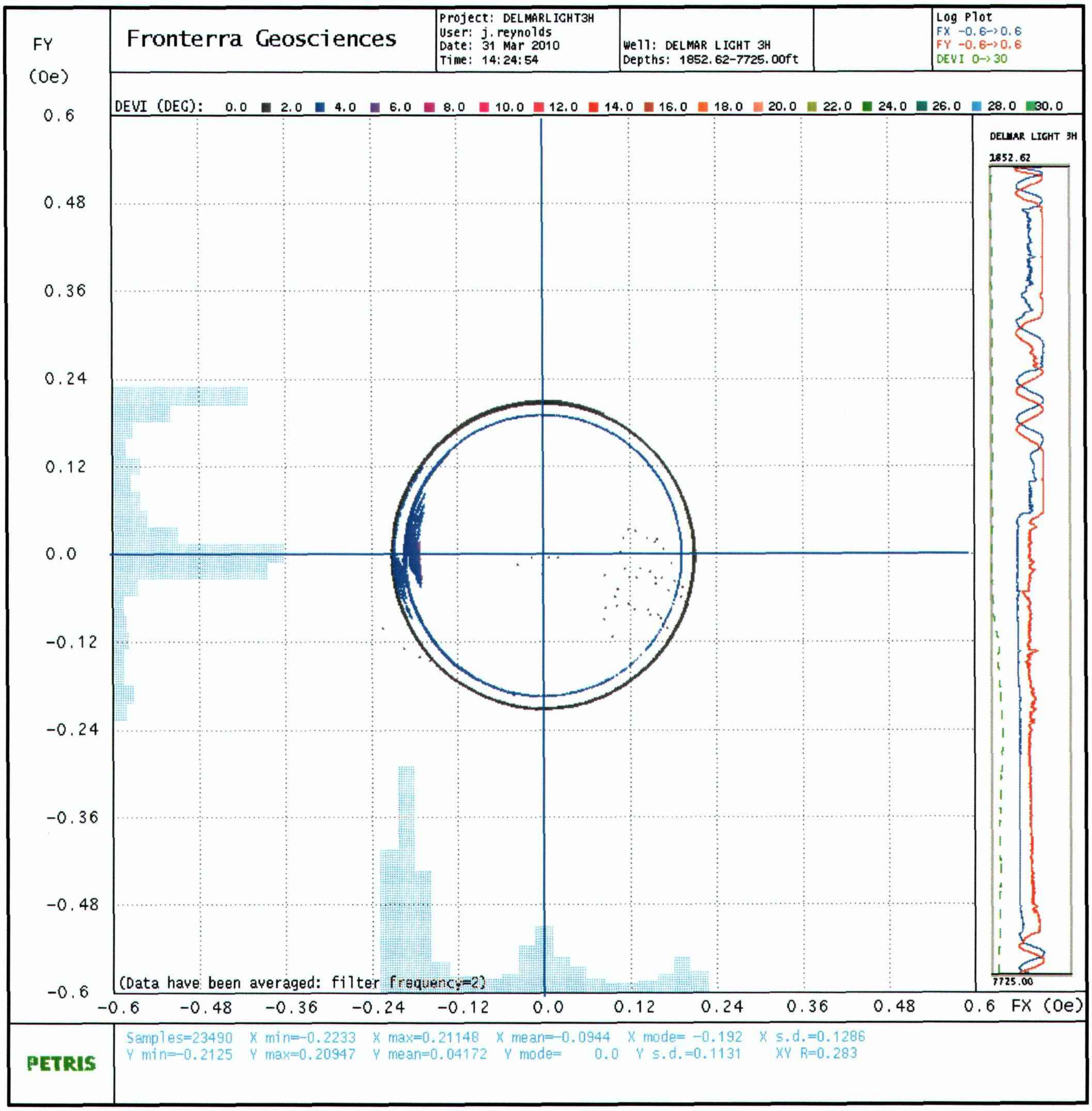
All Images are Oriented to Geographic North

Summary of all vital instrument measurements



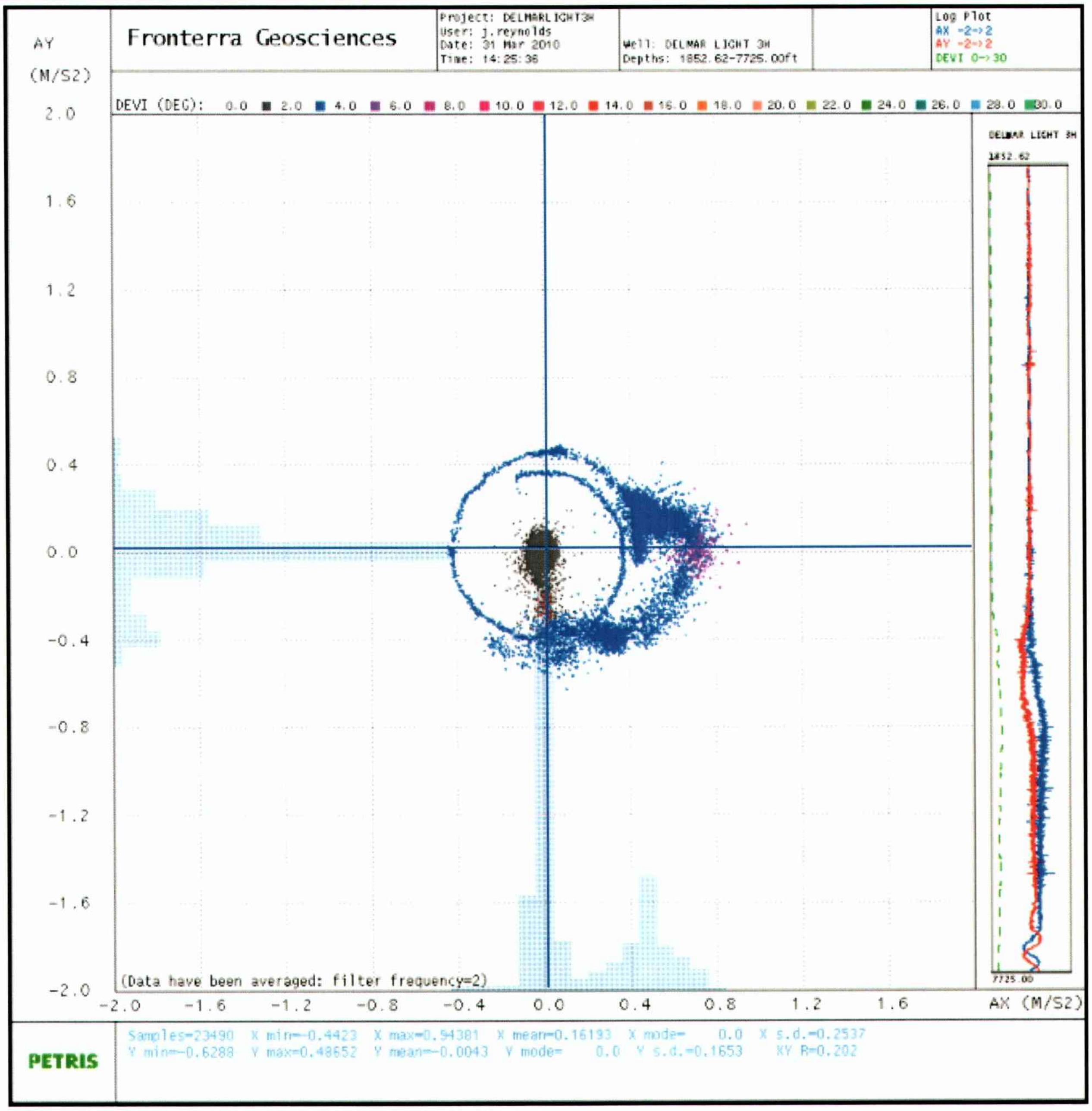
The compressed scale plot above is used as a quality check of the FMI raw data. Tool azimuth (P1AZ) and relative bearing (RB) curves in track 1 indicate normal rotation of the tool string. RB is tracking P1AZ correctly. The caliper data indicates a relatively smooth borehole circumference with very minor zones of washout. Near the top of the hole the borehole appears to be oblong. There are zones of small tool “stick and pull” identified using the Z-axis accelerometer data, cable speed (CVEL), tension (TENS) curve, and the image appearance, but these were not deemed excessive. The orientation and deviation of the borehole (DAZ and DEV) read correctly. The wellbore orientation is generally to the North. Borehole deviation is between 2 to 3 degrees for the processed interval. The image shows good contrast, indicating a properly working tool.

Formation Image Interpretation
- Magnetometer Cross Plot -



The cross plot above displays the X- and Y-axis magnetometers from the FMI data showing a circular distribution of values centered over 0, 0. In a wellbore of constant deviation these curves should plot as a circle with a center of (0,0), providing the tool rotates a complete circle and no external magnetic influences are present. The radius of the circle is affected by borehole deviation. The plot suggests good calibration and operation of the magnetometers and gives us confidence in the accuracy of pad 1 azimuth (P1AZ) and hole azimuth (HAZI).

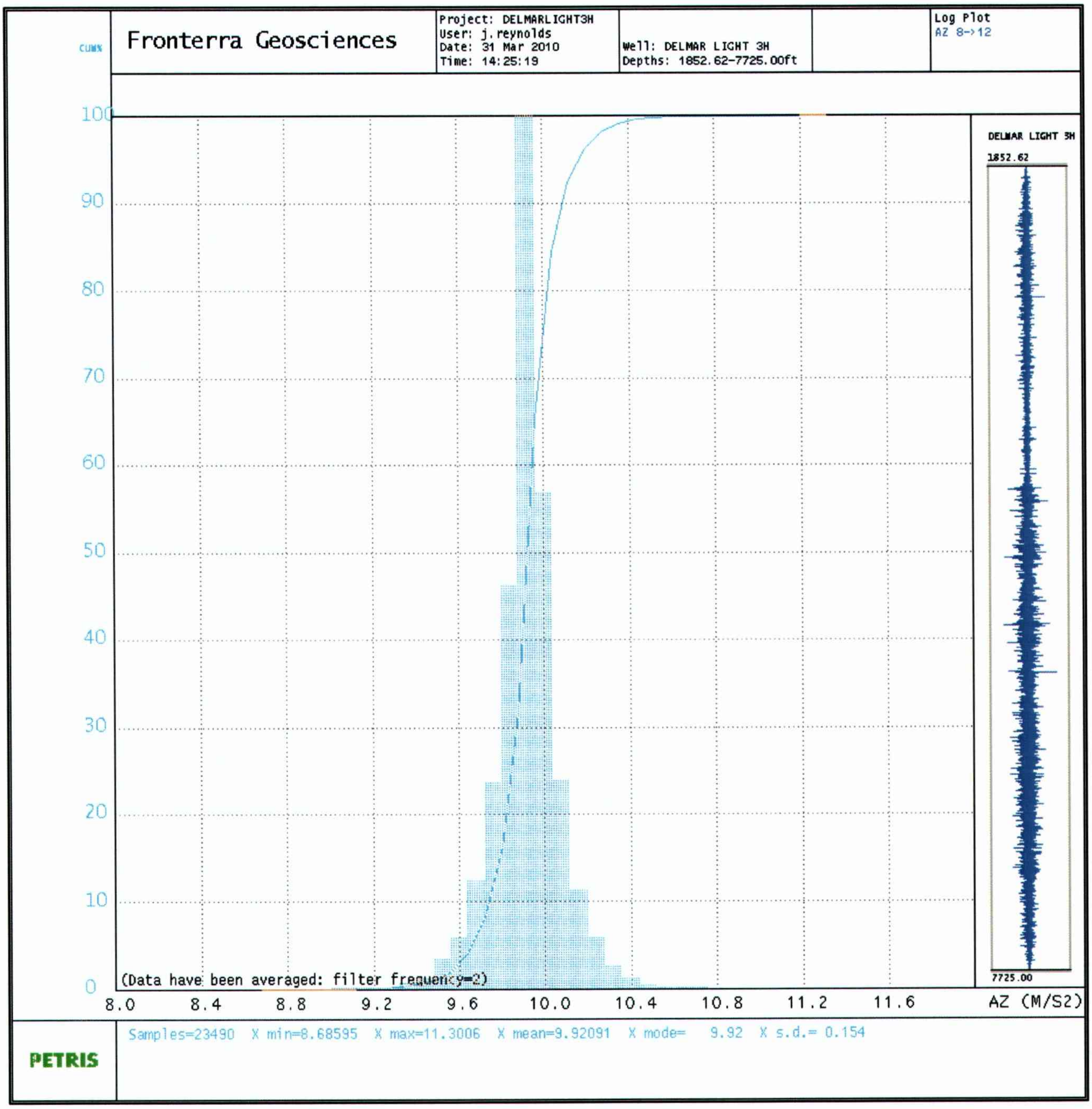
Formation Image Interpretation
- Accelerometer Cross Plot -



The cross plot above displays the X- and Y-axis accelerometers from the FMI data showing a circular distribution of values centered over 0, 0. In a wellbore of constant deviation, Accelerometers will plot as a circle with center of (0,0), providing the tool rotates a complete circle. The radius of the circle is affected by borehole deviation. The plot suggests good calibration and operation of the accelerometers and gives us confidence in the accuracy of pad 1 azimuth (P1AZ) and hole azimuth (HAZI). The deviation of this wellbore is below 4 degrees throughout the logged interval. As such the X and Y accelerometers are functioning outside of their operating range as specified by the service companies. We therefore do not provide any quality control of these curves. The Relative Bearing curve generated from these accelerometers is not used at any point in the image interpretation for this reason and the accuracy of the interpretation is not in any way compromised.

Chesapeake Operating, Inc.
Delmar Light 3H
Upshur County, West Virginia

Formation Image Interpretation
- Accelerometer Histogram -



The histogram of the Z-axis accelerometer from the FMI data confirmed the correct functioning of the instrument's accelerometer. The distribution of values indicates that the image tool encountered minor tool "stick and pull" throughout the processed interval.

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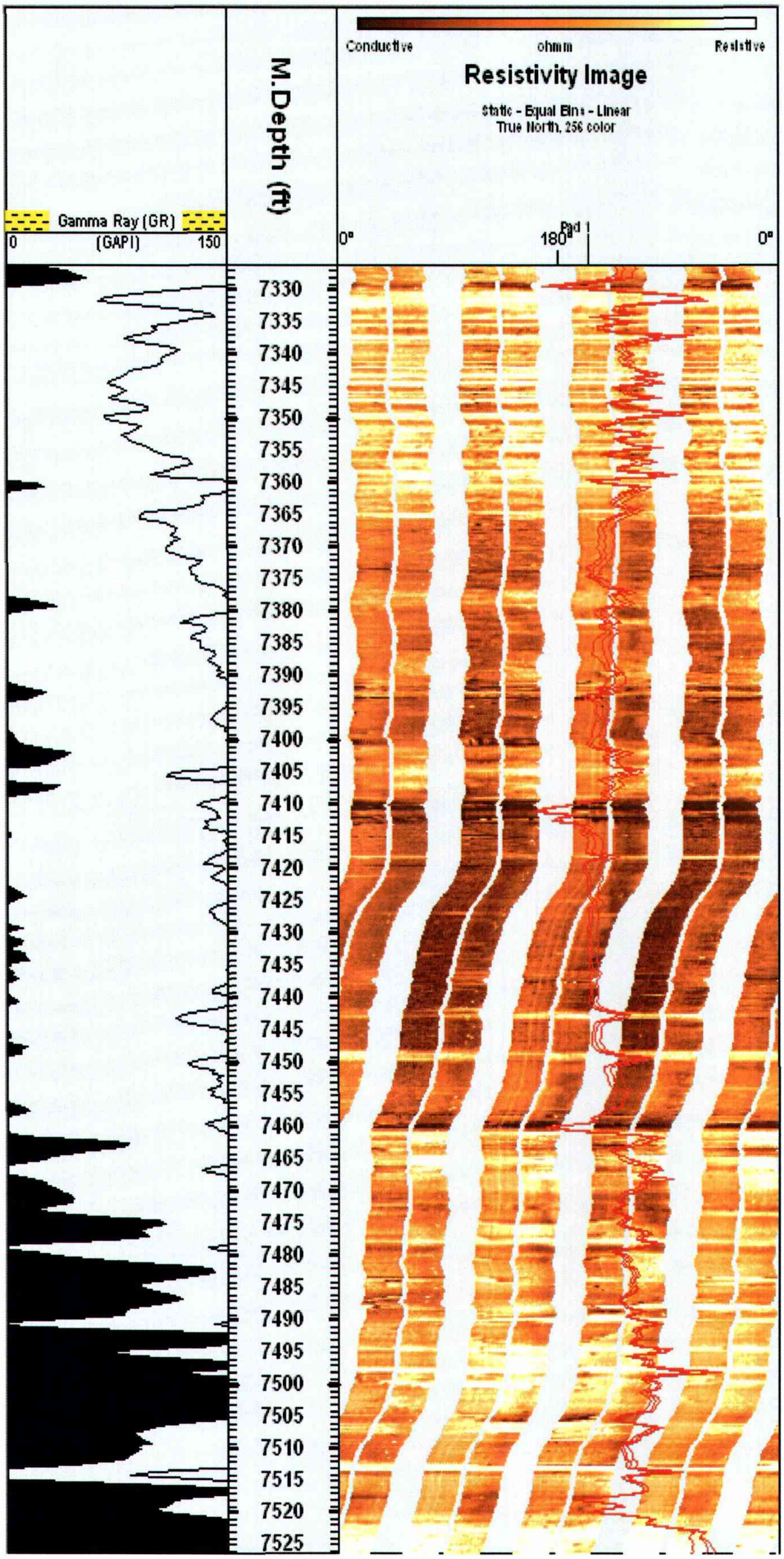
Data Quality Control
- Depth Matching –
7,325 ft ~ 7,535 ft



The interval from 7,325 ft to 7,535 ft is presented to the left to verify that the image is on depth with the open hole log data. The resistivity curves (RLA2, RLA3, RLA4, and RLA5) were overlaid onto the resistivity image to verify that the image is on depth with the open hole logs. Zones of high resistivity on the image match with high resistivity intervals on the open hole logs, and low resistivity intervals on the image correspond with low resistivity open hole response. As additional verification of depth matching, the Gamma Ray curve from the open hole logs (GR) was plotted to the left of the formation image. No depth shifting was required.

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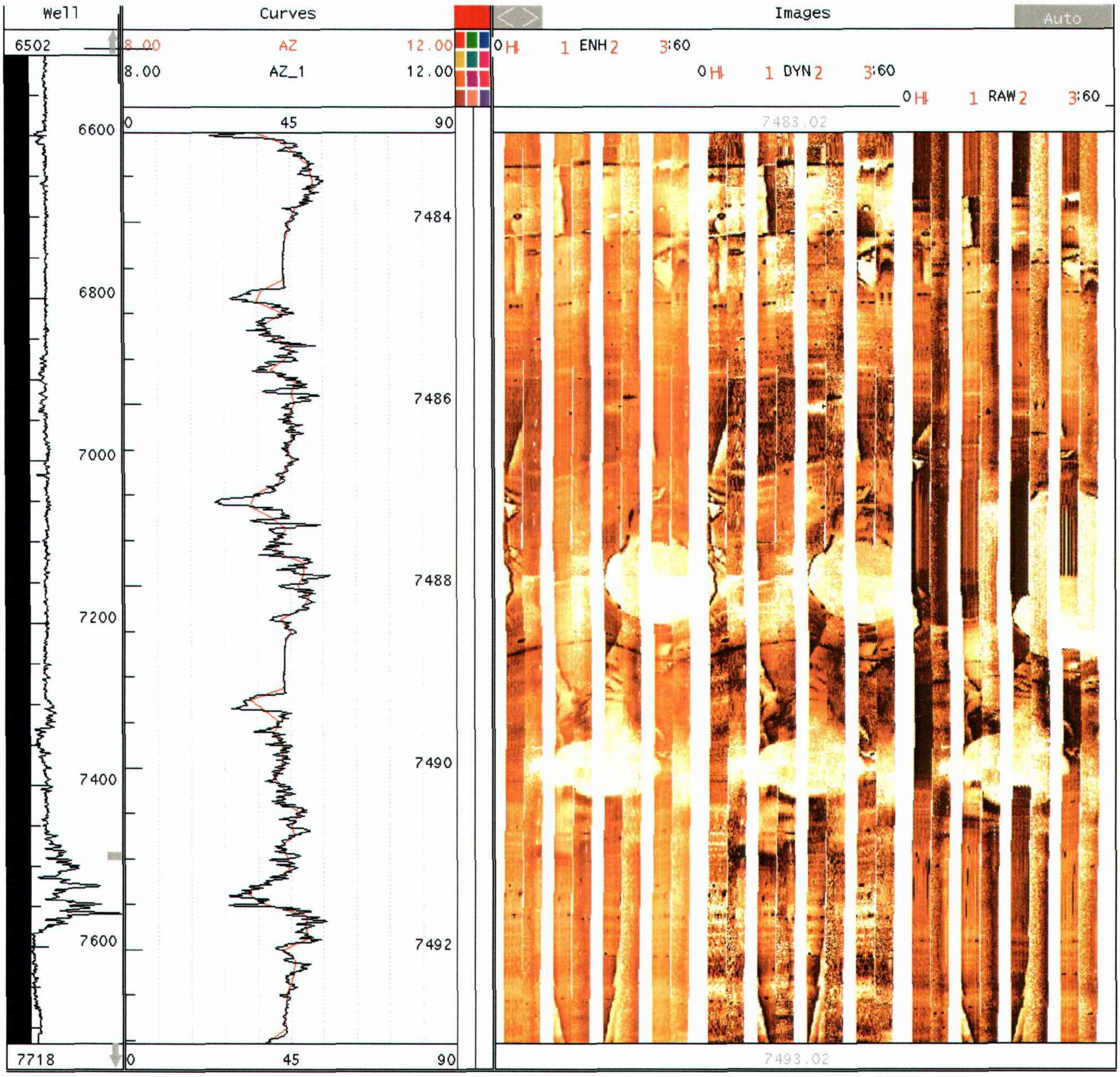
Delmar Light 3H
Upshur County, West Virginia

Data Quality Control
- Speed Correction –



The interval from 7,483 to 7,493 ft is presented to show a before and after of the speed correction of an image. The log track on the left displays the high sample rate and low sample rate Z axis Accelerometer curves. The images displayed are the static speed corrected, dynamic speed corrected and raw non-speed corrected. The wide distributions on the Z-axis Accelerometer indicate stick and pull and can be confirmed on the raw image.

Fronterra
Geosciences

ANALYSIS and INTERPRETATION STEPS

- Methodology
- QC raw image data and essential instrument information for accurate dip calculation
- **Evaluate the near-wellbore structure and macro-faults, if present in the subject well**
- Determine the orientation of the present-day stress field
- Characterization of the natural fracture system
- Analyze lithofacies of sedimentary sequences

Dip Vector Color and Symbol
- Classification Scheme -

The tadpole color and symbol scheme throughout this report as well as on the attached log prints is as follow (if present):

Stratigraphic Interpretation Dip Vector Classification:

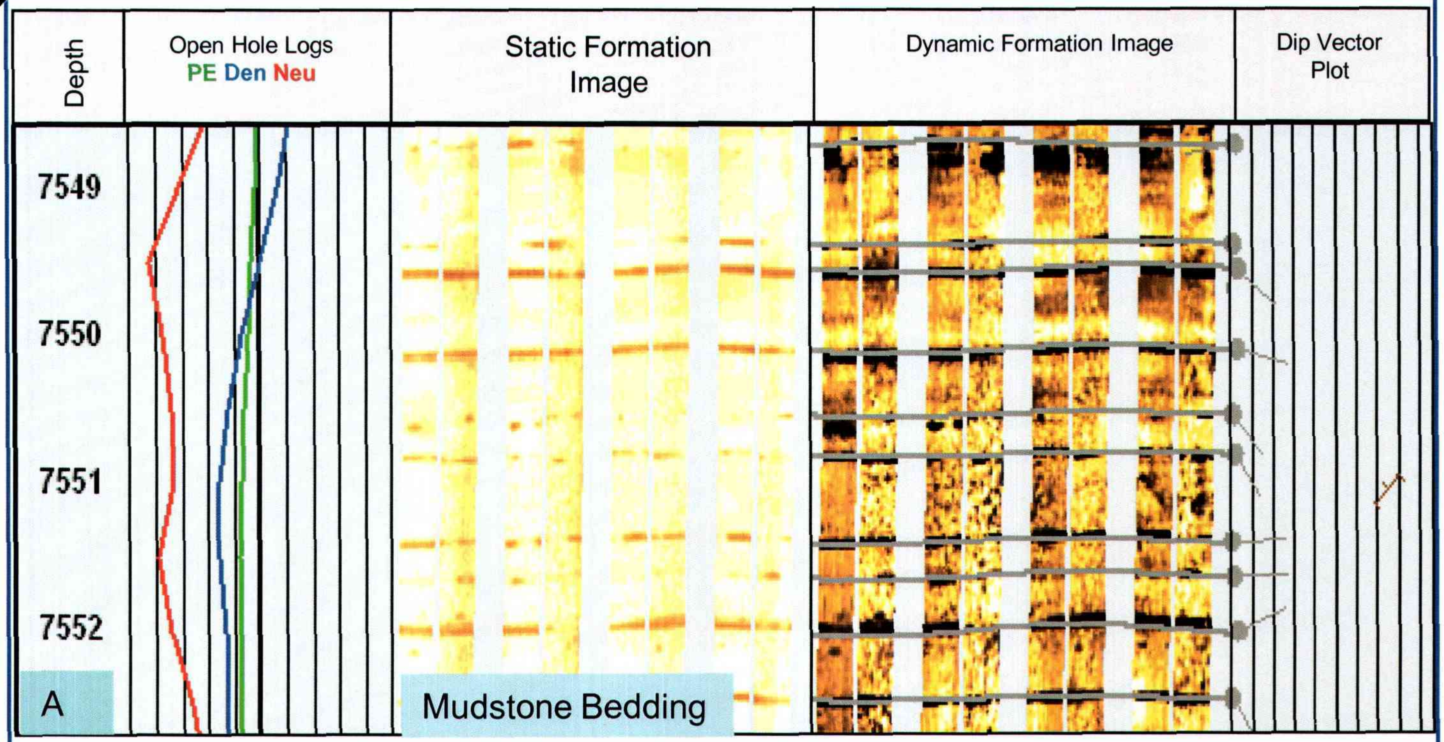
Green Tadpole	= General Bedding
Grey Tadpole	= Mudstone Bedding
Orange Tadpole	= Sandstone Bedding
Dark Blue Tadpole	= Carbonate Bedding
Red Tadpole	= Cross-Bedding
Light Steel Blue Tadpole	= Truncation Surface
Electric Blue Tadpole	= Deformed
Magenta Tadpole	= Slump
Dark Brown Tadpole	= Shale Drape/Differential Compaction
Grayish Green Diamond	= Hanging Wall Fault Drag
Olive Green Diamond	= Footwall Fault Drag
Red Triangle	= Stylolite
Light Yellow Tadpole	= Concretion

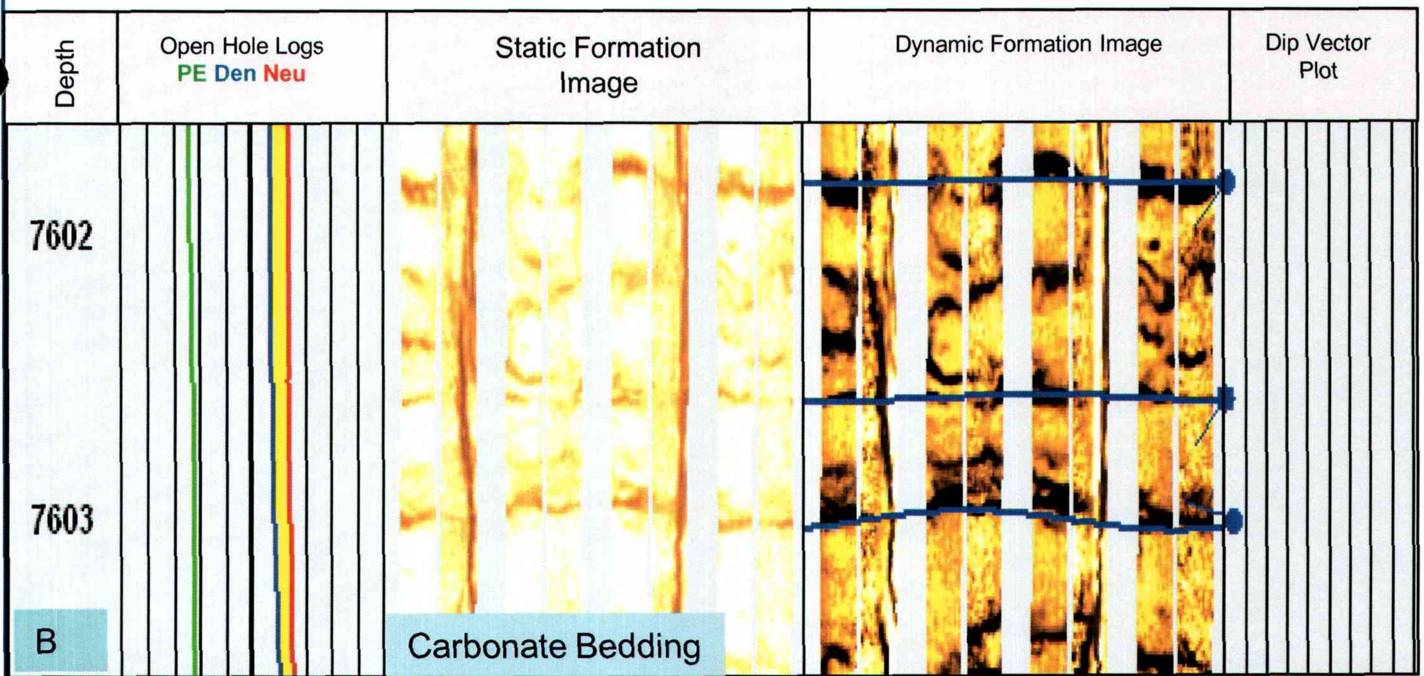
Structural Interpretation Dip Vector Classification:

Light Green Bar	= Coal Fracture
Orange Bar	= Syn – Depositional Fracture
Black Bar	= Tensile Enhanced Fracture
Brown Triangle	= Fracture, Dark High Contrast Full (Shear)
Brown Bar	= Fracture, Dark High Contrast Full (No Shear)
Brown Triangle Double Side	= Fracture, Dark High Contrast Partial (Shear)
Brown Bar Double Side	= Fracture, Dark High Contrast Partial (No Shear)
Magenta Triangle	= Fracture, Light High Contrast Full (Shear)
Magenta Bar	= Fracture, Light High Contrast Full (No Shear)
Magenta Triangle Double Side	= Fracture, Light High Contrast Partial (Shear)
Magenta Bar Double Side	= Fracture, Light High Contrast Partial (No Shear)
Purple Triangle	= Fracture, Mixed High Contrast Full (Shear)
Purple Bar	= Fracture, Mixed High Contrast Full (No Shear)
Purple Triangle Double Side	= Fracture, Mixed High Contrast Partial (Shear)
Purple Bar Double Side	= Fracture, Mixed High Contrast Partial (No Shear)
Red Triangle	= Fracture, Low Contrast Full (Shear)
Red Bar	= Fracture, Low Contrast Full (No Shear)
Red Triangle Double Side	= Fracture, Low Contrast Partial (Shear)
Red Bar Double Side	= Fracture, Low Contrast Partial (No Shear)
Brown Double Bar	= Fault, Dark High Contrast
Magenta Double Bar	= Fault, Light High Contrast
Purple Double Bar	= Fault, Mixed High Contrast
Red Double Bar	= Fault, Low Contrast
Blue Coral Double	= Centerline/Tensile Fracture
Blue Bar	= Induced Tensile Fracture, Inclined
Red Coral Double	= Borehole Breakout

Chesapeake Operating, Inc.
Delmar Light 3H
Upshur County, West Virginia

Structure Definition
Bedding Dip Types





Several different bedding types were observed in the Delmar Light 3H well. The gray tadpoles in Figure A represent mudstone bedding picked in a shale or mudstone lithology, determined from the open hole logs and the image. Usually mudstone and/or shale bedding provides the best structural dip indicator. In Figure B, the blue tadpoles represent carbonate bedding found within the processed interval, the carbonate bedding is determined from the open hole logs and image. Carbonate bedding was not included in the structural dip analysis.

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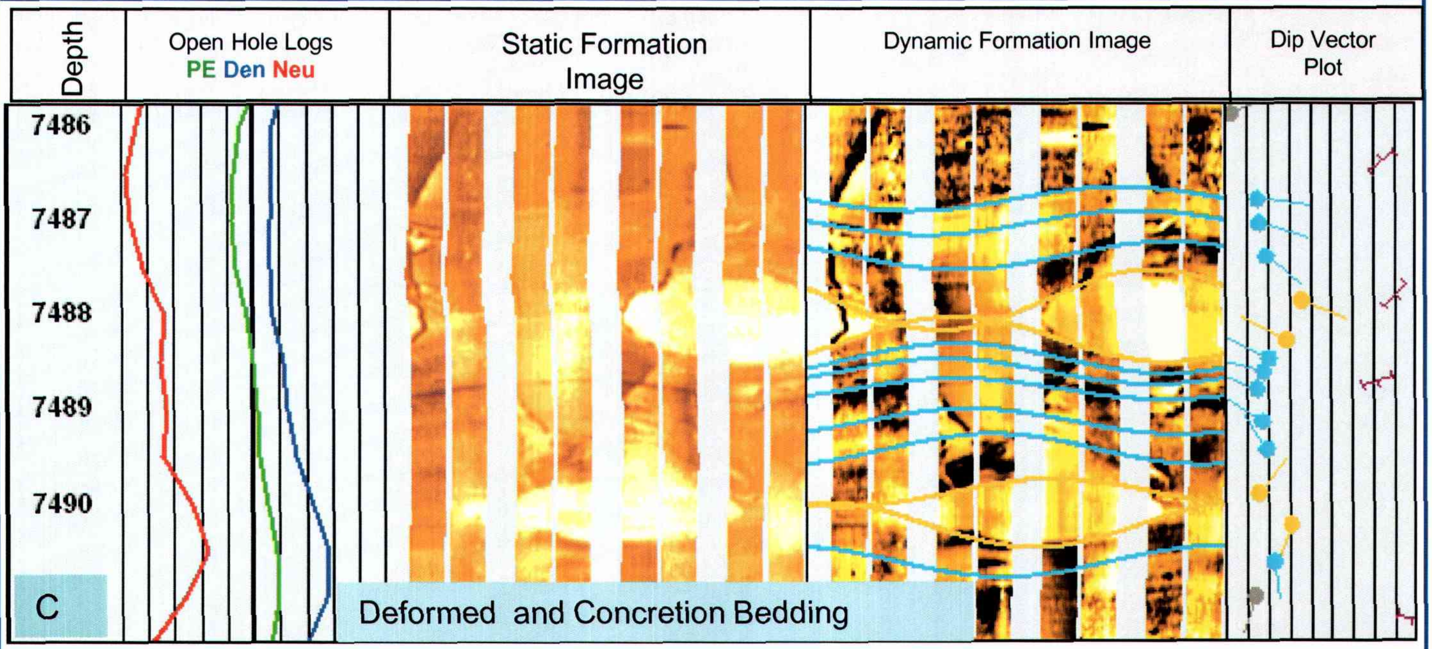
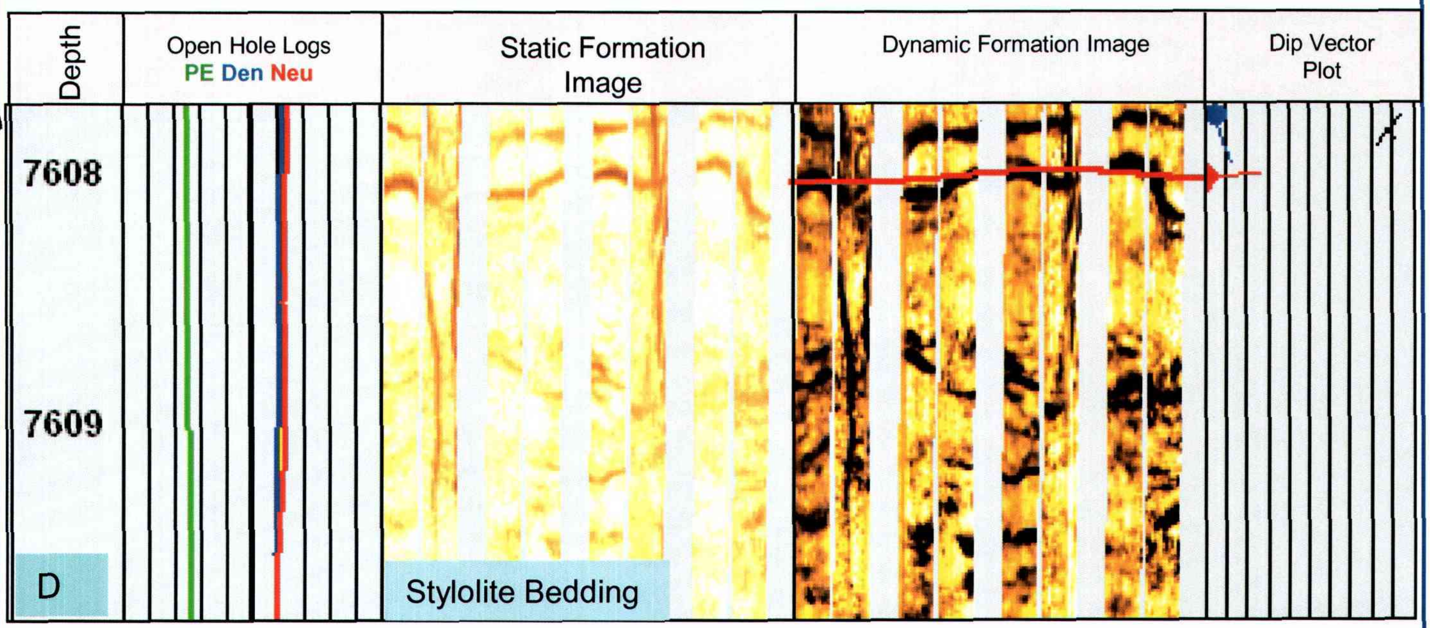
Chesapeake Operating, Inc.
Delmar Light 3H
Upshur County, West Virginia

Structure Definition
Bedding Dip Types

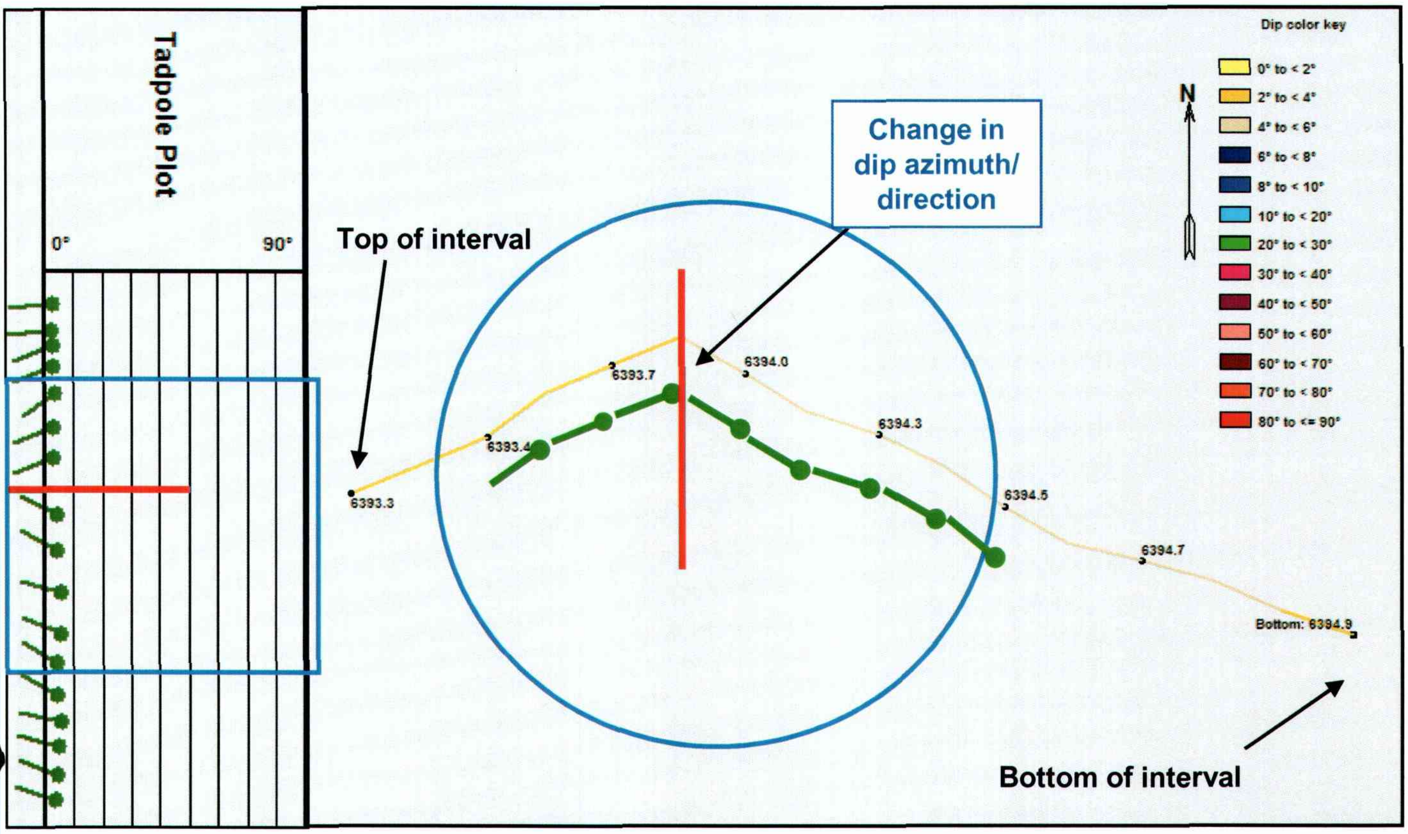




Within the Delmar Light 3H deformed and concretion bedding have been identified using the image. The yellow tadpoles represent concretion bedding and the light-blue turquoise tadpoles represent deformed bedding in Figure C. Concretion bedding are bedding planes that have been deformed due to concretions and deformed bedding has been distorted due to a change in position, orientation, shape, and/or size because of some type of tectonic or depositional anomaly. The red triangles in Figure D represent stylolites that are observed in the carbonates. Stylolites, concretion, and deformed bedding are excluded from the structural dip calculation.

Dipmeter and Formation Imaging
- Interpretation Techniques -

Example of a Schematic Dip Azimuth Walk-Away Diagram



A useful technique in structural and stratigraphic evaluation is the dip azimuth trend analysis. This is accomplished through the creation of a cumulative dip azimuth plot (above and next page). Please note the above example is not taken from the Delmar Light 3H well.

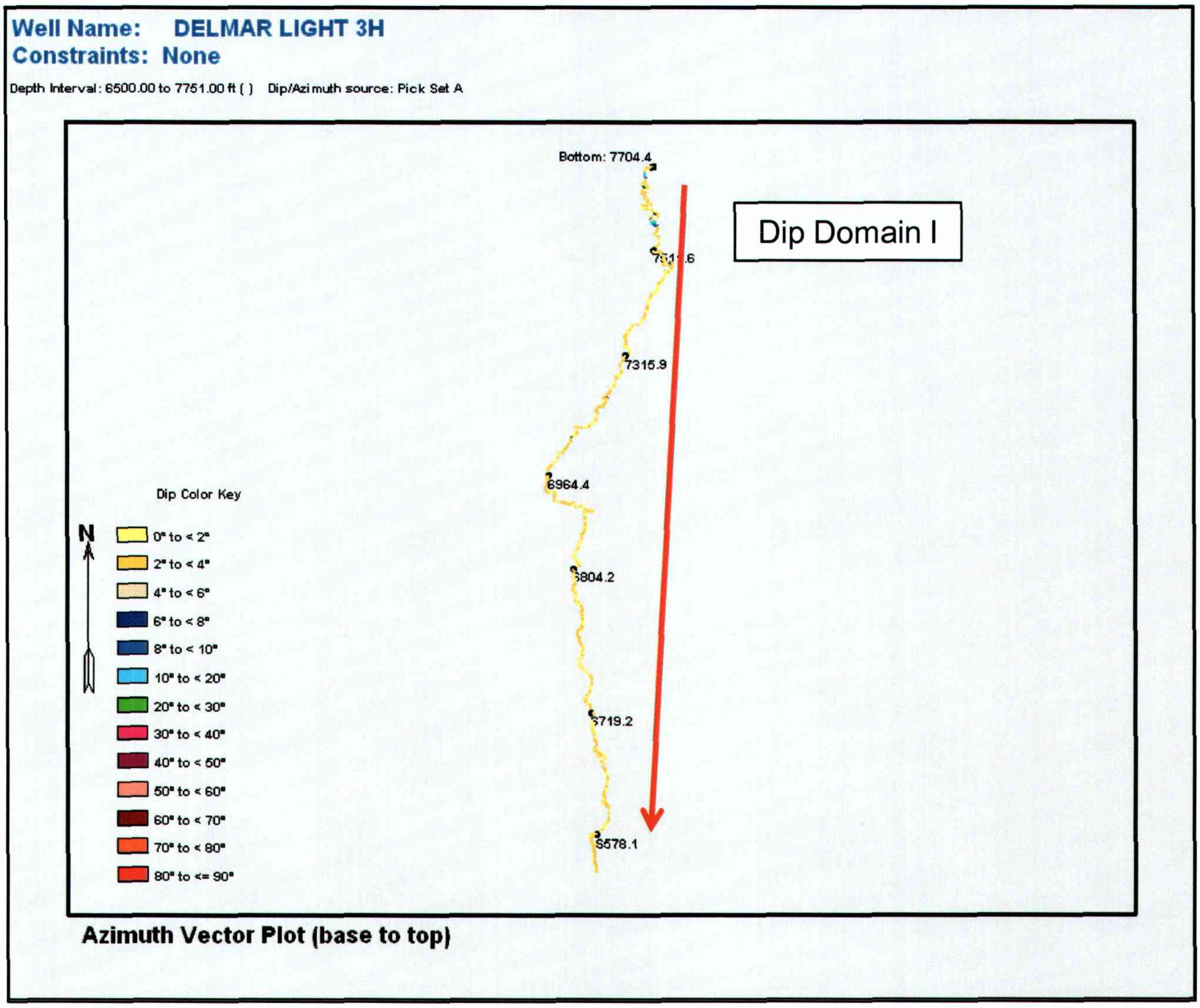
In the above example, tadpoles representing planar bedding surfaces are presented in both the Tadpole Plot (left side, plotted in a depth relationship) and in the walk-away diagram (right side in plan view). Azimuthal vectors are accumulated – end to tip – from the bottom of the well to the top. Detail within the blue circle corresponds to bedding at the depths surrounded by the blue box. A change in bedding dip azimuth is noted by the red bar in both the Tadpole Plot and walk-away diagram. Color coding indicates ranges of dip magnitude as per the legend in the upper right corner.

Inflection points in the Dip Azimuth Walk-Away Diagram represent changes in bedding azimuth which help to identify structural and stratigraphic changes.

Trend changes can be caused by one or more of the following:

- plunging fold axis,
- fault drag pattern,
- crossing fault block boundaries,
- unconformities,
- sequence boundaries, or
- stratigraphic units or compartments.

Structure Definition
-Dip Azimuth Walk-Away Diagram-
6,504 ft to 7,717 ft

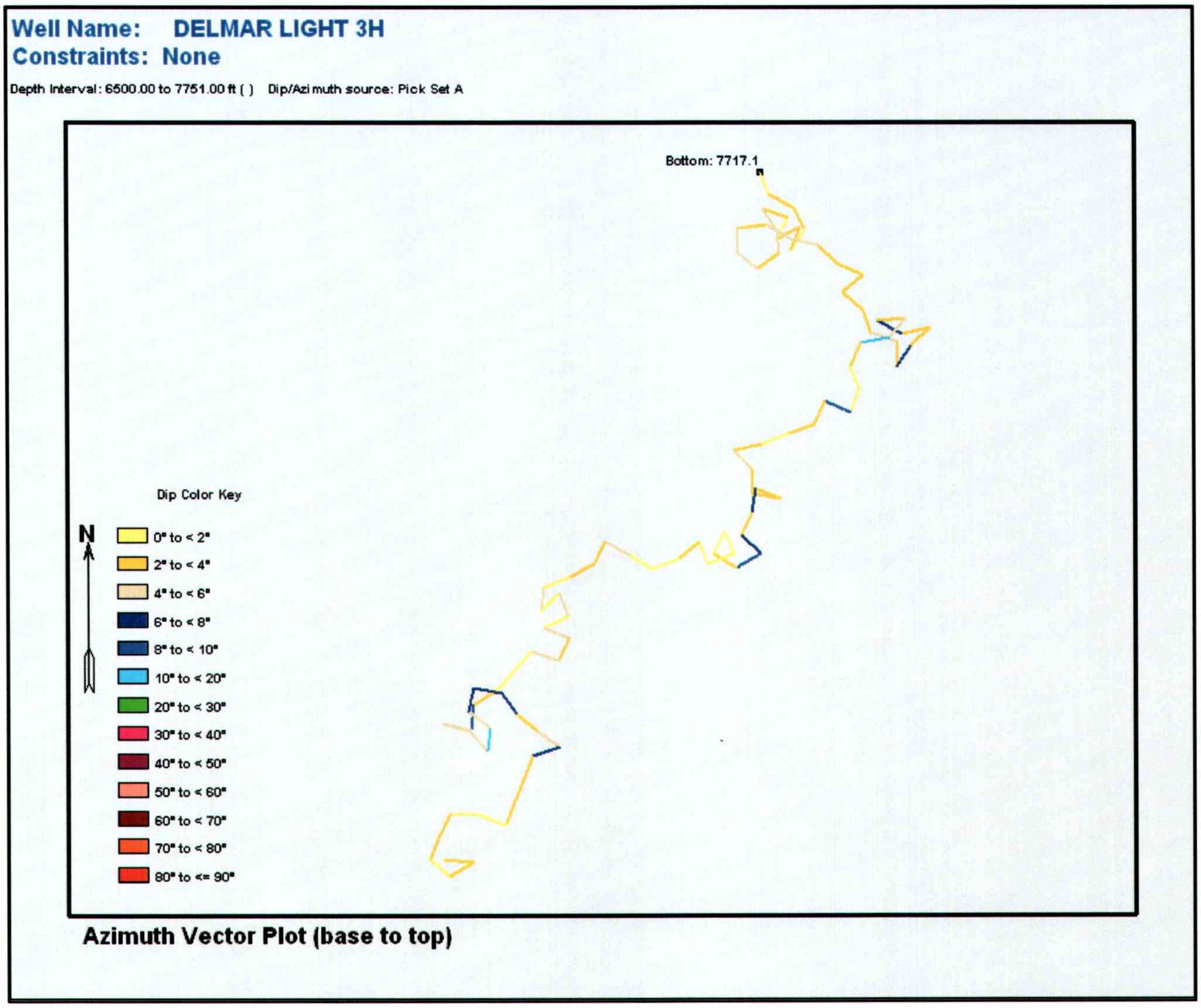


The plot above represents the dip azimuth walk-away diagram for the mudstone bedding vectors identified within the interpreted interval of 6,504 ft to 7,717 ft of the Delmar Light 3H well. This diagram is color-coded to dip magnitude, with the key displayed in the Lower left hand corner of the plot. One dip domain has been identified using changes in the structural bedding dip vectors. The dip domain is presented below:

Domain I: 6,504 ft – 7,717 ft

There were no faults observed within the interpreted interval. The wondering of the bedding dip direction is most likely the result of low dip magnitudes observed.

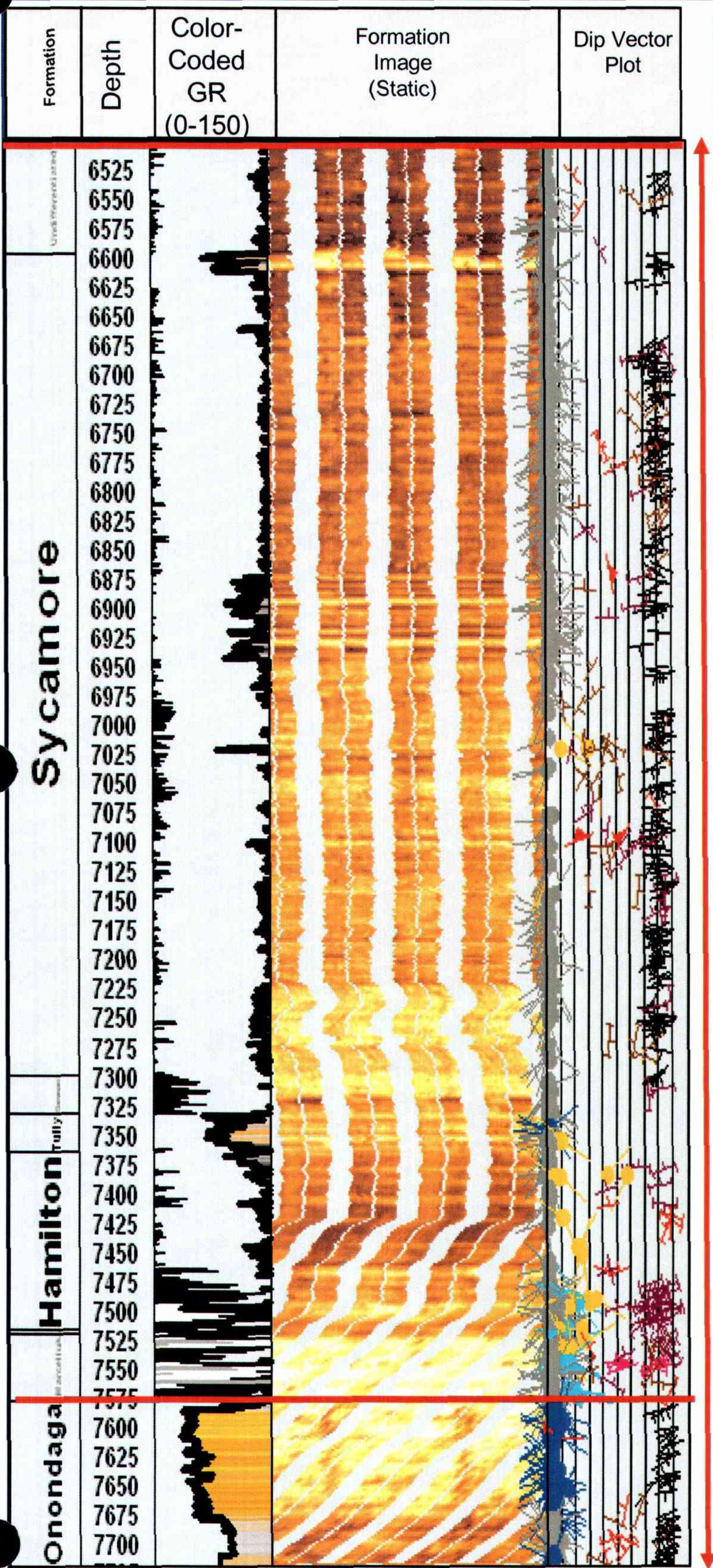
Structure Definition
-Dip Azimuth Walk-Away Diagram-
6,504 ft to 7,717 ft

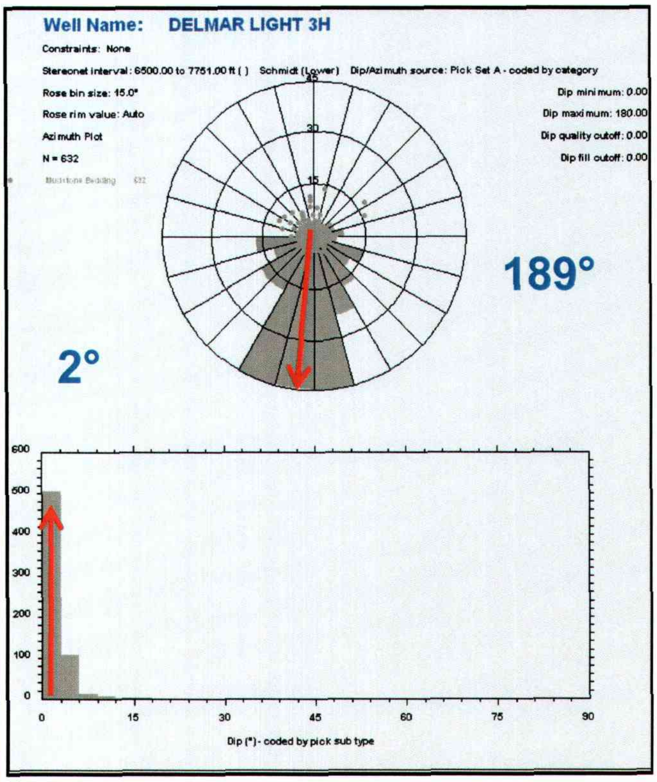


The plot above represents the dip azimuth walk-away diagram for the carbonate bedding observed within the interpreted interval of 6,504ft to 7,717 ft of the Delmar Light 3H well. This diagram is color-coded to dip magnitude, with the key displayed in the Lower left hand corner of the plot. The carbonate bedding is highly scattered and was not included in the structural dip calculation in an attempt to clean up the dip azimuth walk-away diagram. In the carbonate section there were no features—e.g., faults or shear fractures observed that would cause the observed scatter. This scatter is likely the result of the depositional environment in which the carbonates were deposited.

Chesapeake Appalachia, LLC.
Delmar Light 3H
Upshur County, West Virginia

Structure Definition
- Dip Domain I –
6,504 ft – 7,717 ft





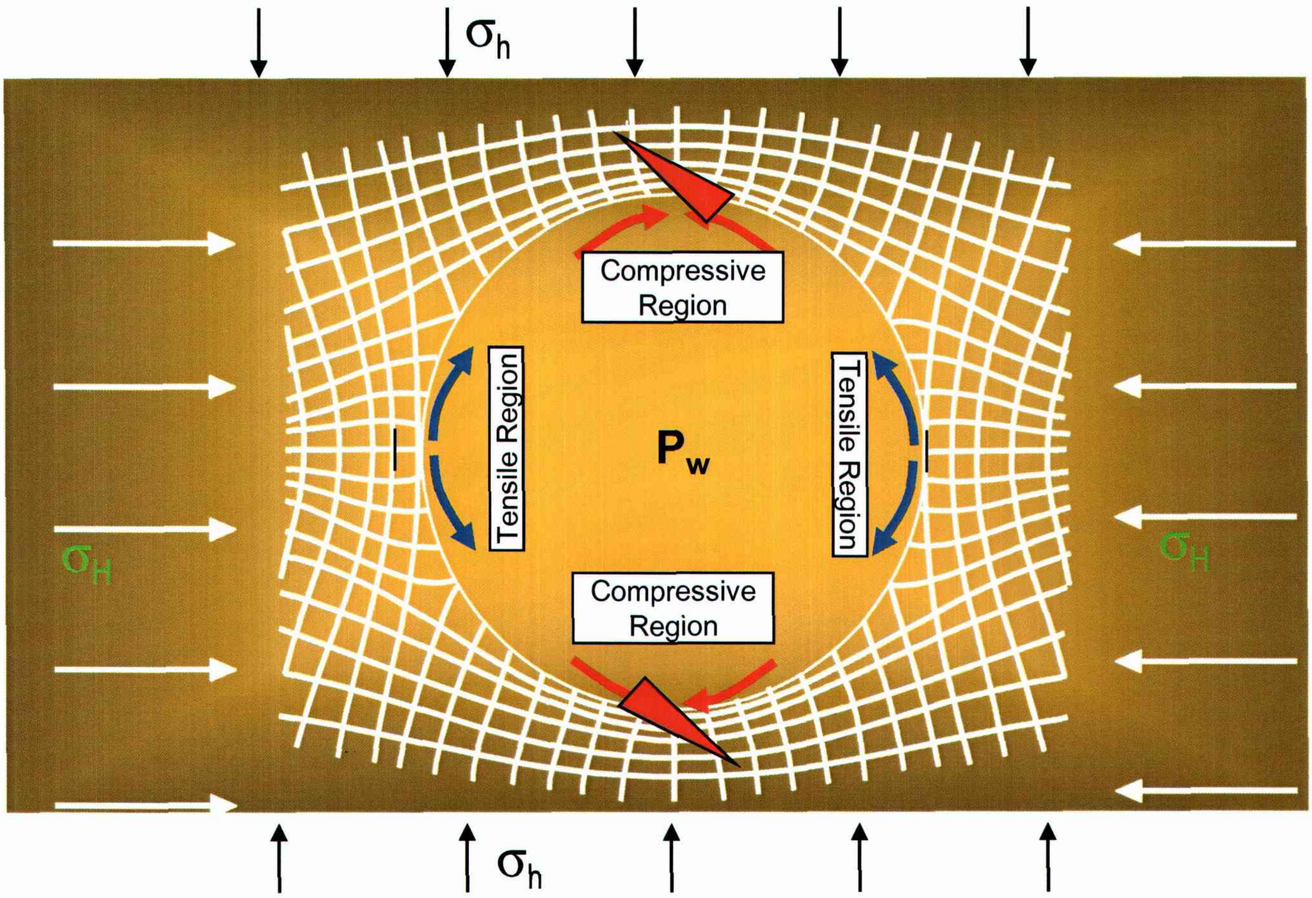
Dip domain I covers the interval of 6,504 ft – 7,717 ft. A total of 632 mudstone/shale bedding planes have a **SSW** dip of approximately **2°**. Statistical analysis of 581/632 bedding planes yields a mean dip direction of approximately **189°**. The top of the domain is bounded by top of the processed interval. Overall, there is scatter associated with bedding dip direction and this is attributed to the very low dip magnitudes.

Fronterra Geosciences

ANALYSIS and INTERPRETATION STEPS

- Methodology
- QC raw image data and essential instrument information for accurate dip calculation
- Evaluate the near-wellbore structure and macro-faults, if present in the subject well
- **Determine the orientation of the *in-situ* stress field**
- Characterization of the natural fracture system
- Analyze lithofacies of sedimentary sequences

Determination of *In-situ* Stress
Borehole Stress Concentration

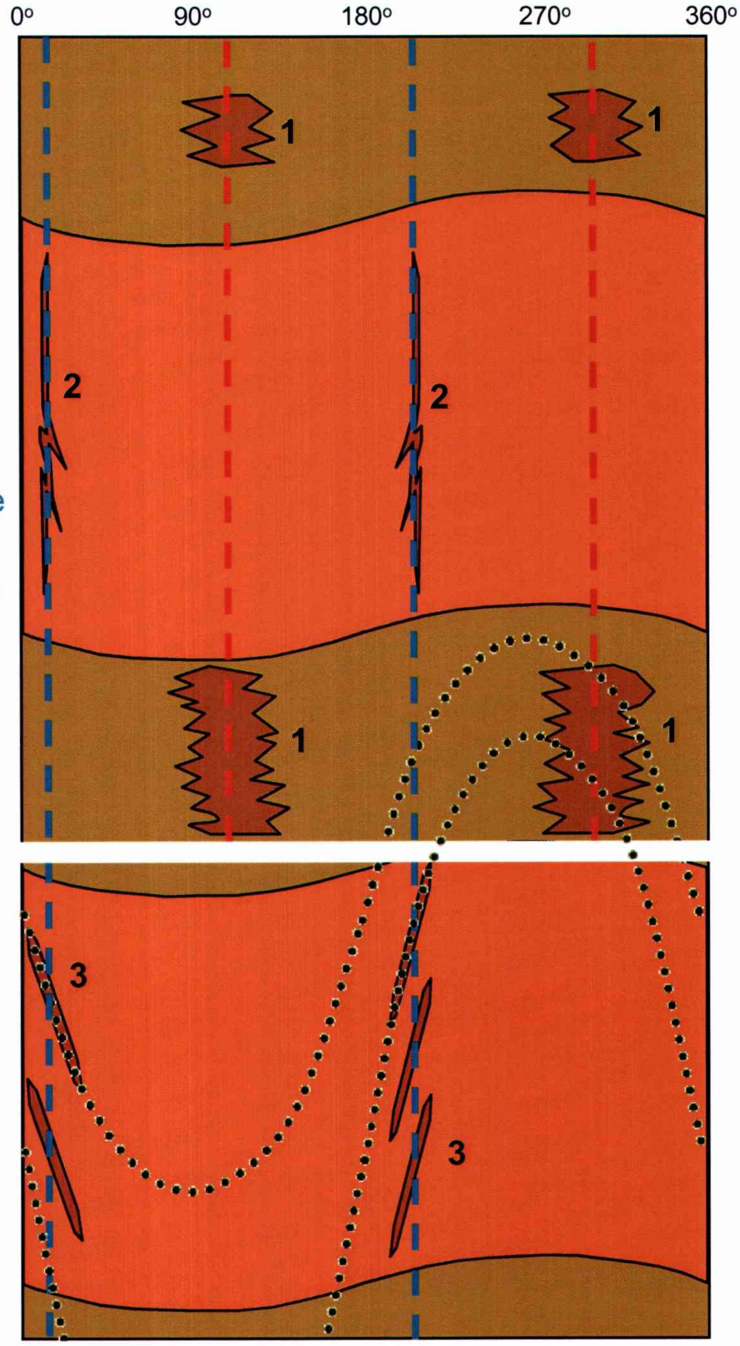


When a well is drilled in a formation, stressed solid materials are removed and replaced with drilling fluid. Since the well fluid pressure normally does not match exactly the stress which the removed solid exerted, there will be an alteration in the stress state of the formation around the well. Depending on wellbore conditions and borehole trajectory, this alteration in stress state produces indicators of the maximum and minimum *in-situ* stress directions acting on the borehole. These stress indicators are observed on the formation image log and are discussed on the following pages.

In-situ Stress Indicators Interpreted from Images

There are three dominant types of *in-situ* stress indicators commonly observed in borehole images – these are ranked below in order of best reliability:

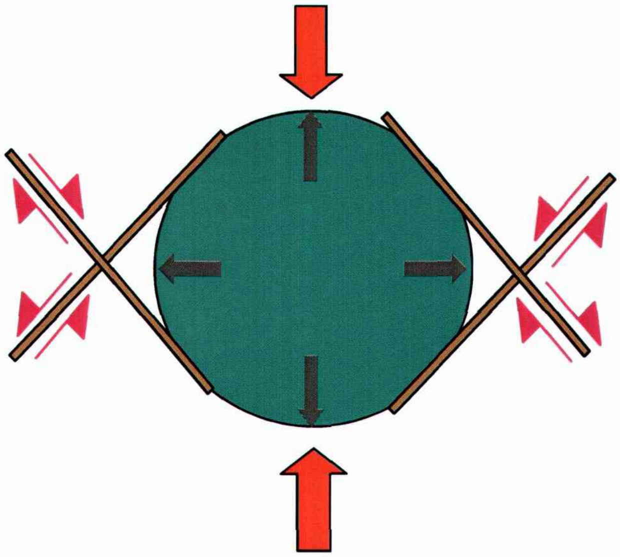
1. **Borehole Breakouts**
   - These comprise regions of damage (of varying severity) that are aligned on either side of the borehole wall (i.e. 180° apart)
2. **Drilling Induced "Centerline" Fractures**
   - These features are vertical to near-vertical (with regard to the borehole axis) and are also 180° apart, and 90° offset from the center of the borehole breakout
3. **Inclined Drilling Induced Fractures**
   - These features are distinctly inclined with respect to the borehole axis and form an *en-echelon* pattern on either side of the borehole wall (again 180° apart), with strike indicating the direction of Maximum Horizontal Stress
   - Although these fractures are seen on opposing sides of the borehole wall, they do not represent the same feature – as a result, a sine curve cannot be accurately fitted to features on both sides, and they are defined as linear features in 3-dimensional space

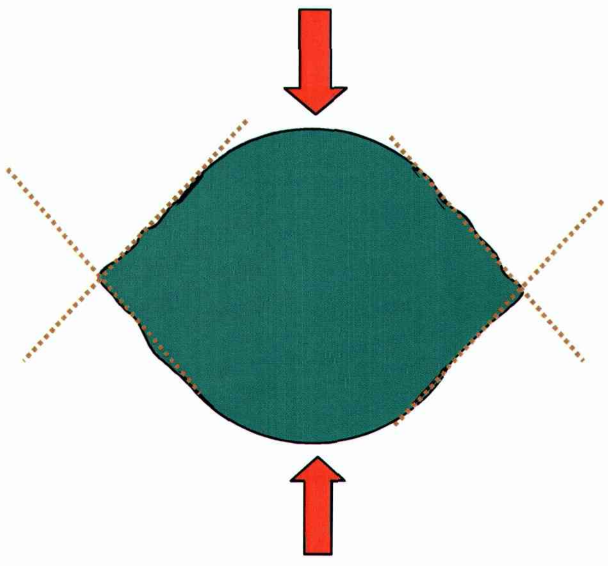


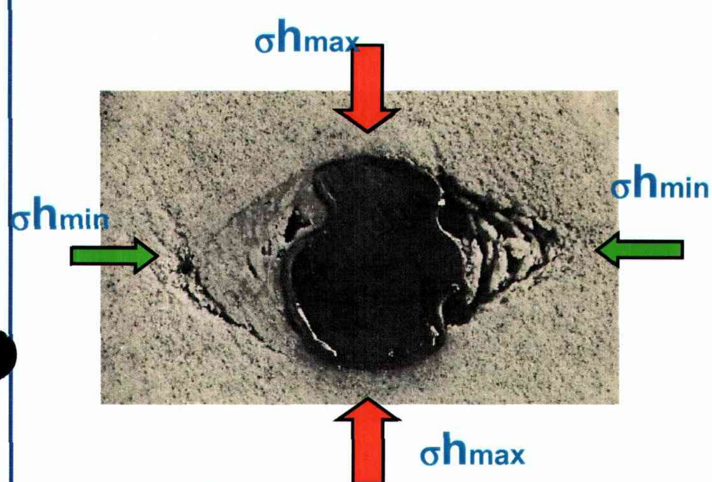
It should be noted that stress indicators 2 and 3 form due to differing relationships between borehole deviation/direction and the present-day stress field. As a result, these indicators are unlikely to occur within close proximity to each other in the wellbore.

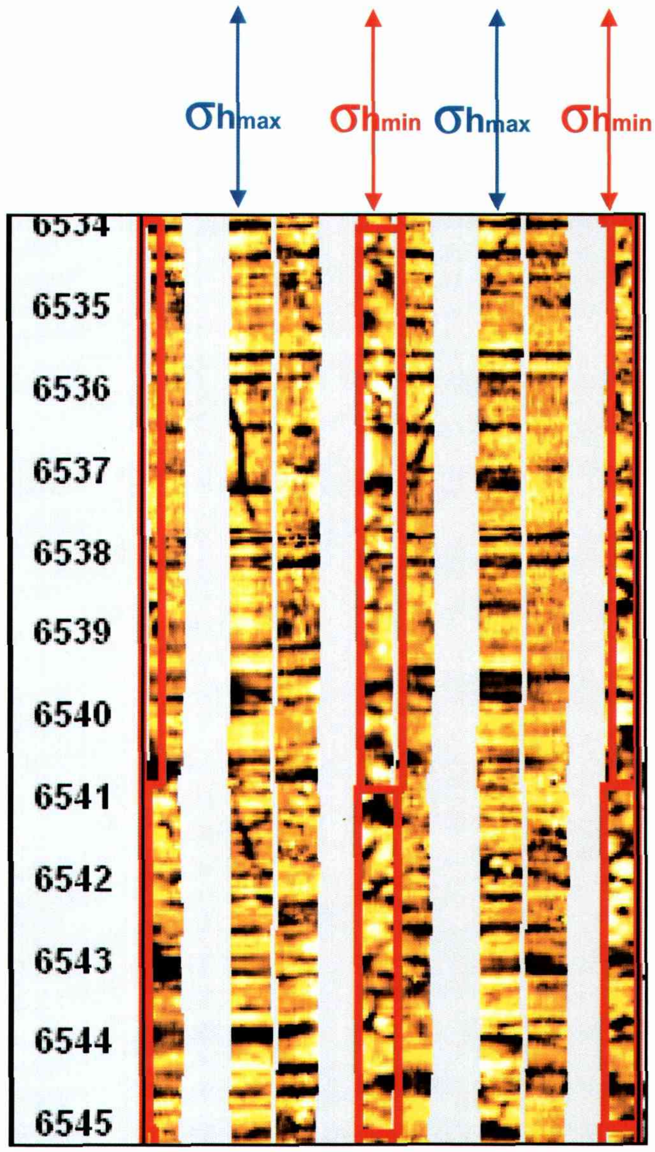
In-situ stress
Borehole Breakouts

Maximum horizontal Stress (shmax)



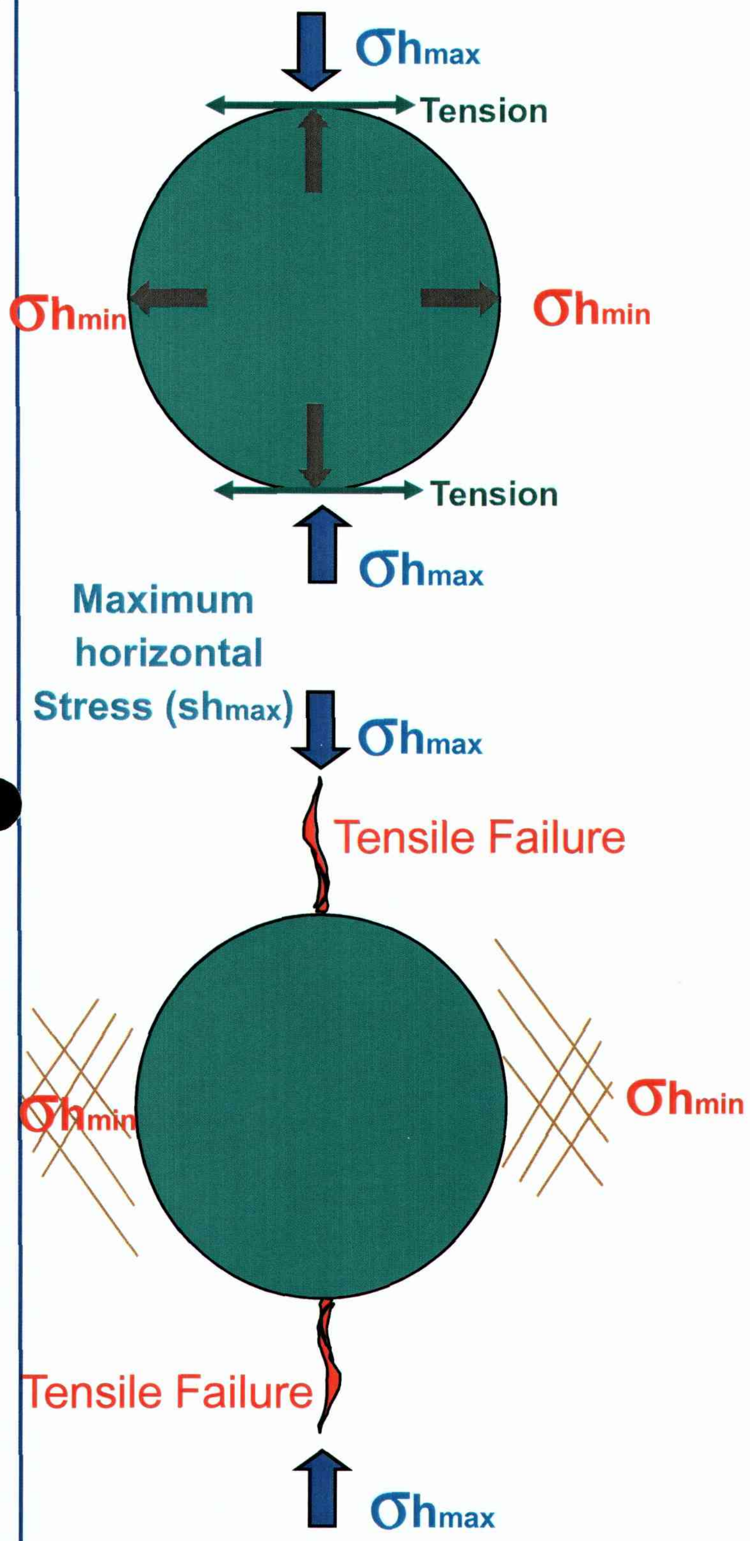




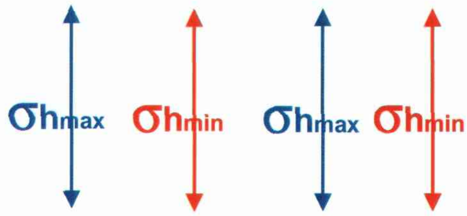


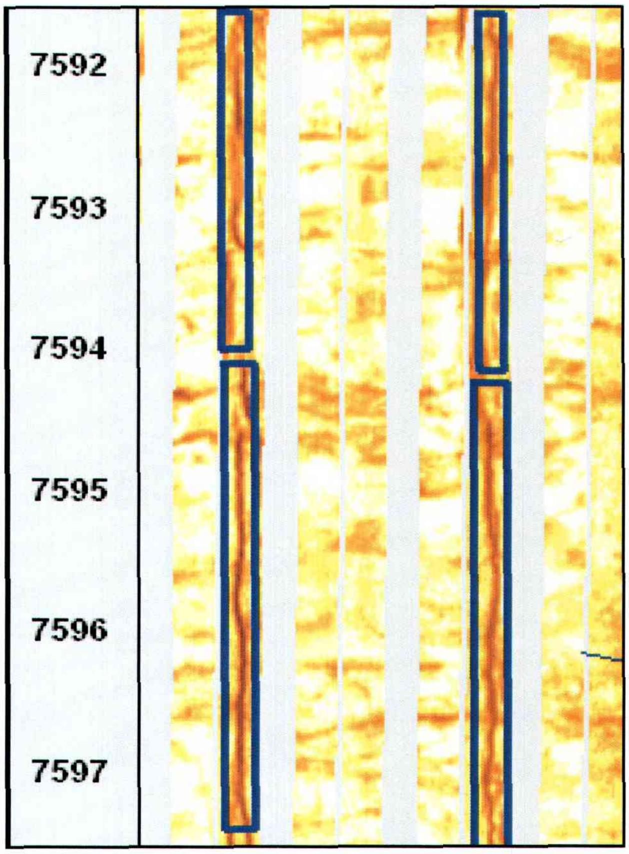
Above is an image log example of borehole breakouts observed in the undifferentiated formation. The diagrams to the left aid in explaining their formation. These features form as a result of compressive shear failure along the borehole wall. These features form 180 degrees apart from each other and are oriented azimuthally in the *in-situ* minimum horizontal stress orientation. The borehole breakouts observed within the Delmar Light 2H are not as conductive as seen in previous wells and this might be due to the mud type and/or lithology.

In-situ stress
Centerline/Tensile Fractures



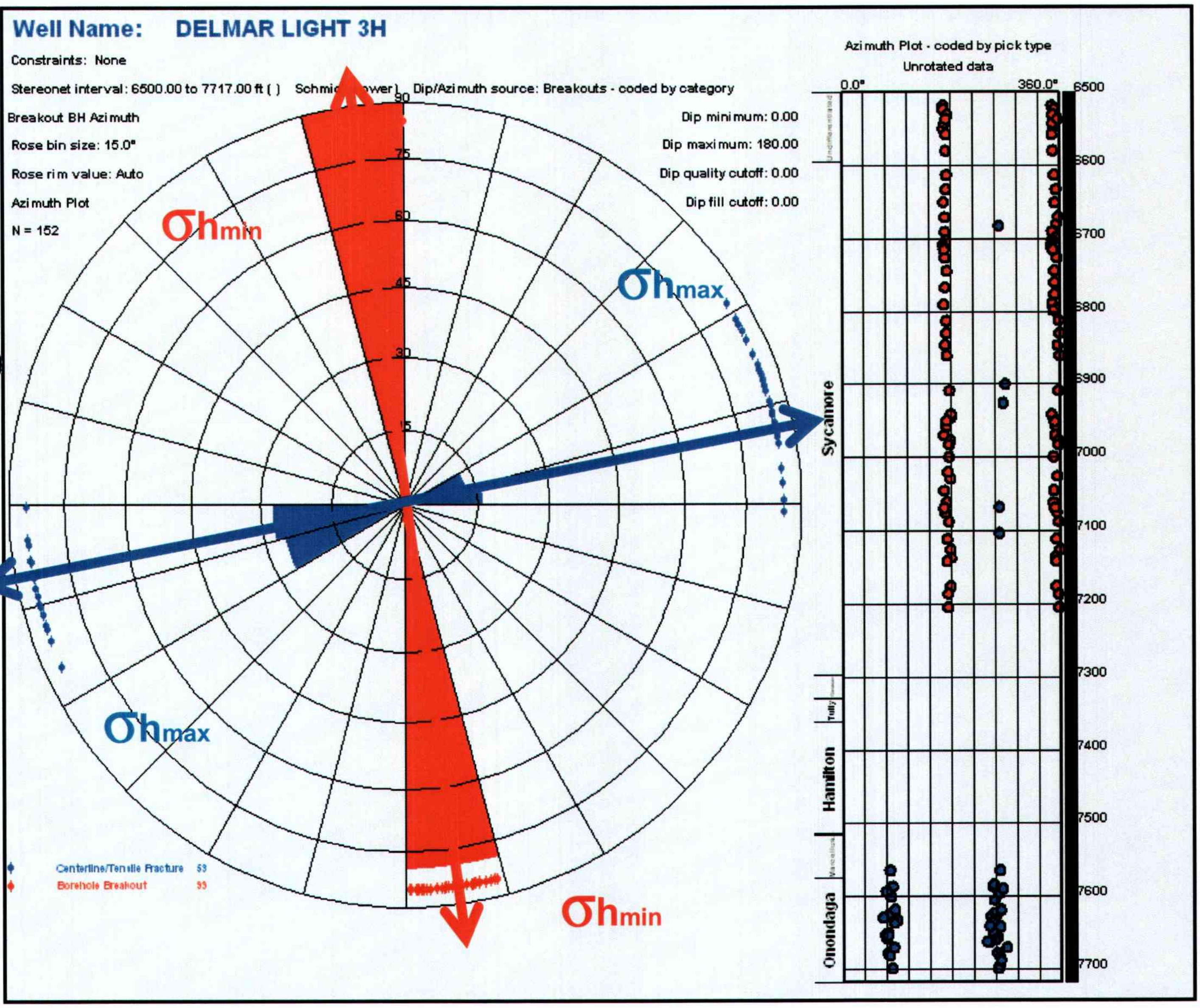
The diagrams to the left are shown to aid in explaining how centerline fractures normally form. These fractures are the result of tensile failure along the borehole wall. These features usually form 180 degrees apart from each other and are oriented azimuthally in the *in-situ* maximum horizontal stress direction.





Centerline-Tensile Fractures/Borehole Breakouts Delmar Light 3H

The lower hemisphere Schmidt plot below displays the azimuth points of borehole breakouts (direct minimum horizontal *in-situ* stress indicators) and centerline fractures (direct maximum horizontal *in-situ* stress indicators) observed within the Delmar Light 3H well. The borehole breakouts are represented as red symbols. From the borehole breakout data, the orientation of maximum horizontal *in-situ* stress has been calculated and is presented as a blue arrow below. The centerline-tensile fractures are represented as blue symbols. Both the borehole breakouts and centerline-tensile fractures are in good correlation. The azimuth plot on the right of the Schmidt plot illustrates the azimuth plots of these features as an unraveled 360° display.



Fifty-three centerline-tensile fractures and 99 borehole breakouts are identified within this well. Based on the orientations of the borehole breakouts and centerline features an *in-situ* maximum horizontal stress (**σh_{max}**) of **N80E-S80W** has been calculated for this well.

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In-situ Stress
Other Important Issues

•Some natural fractures seen in the borehole images can also give a clear indication of the "tensile region" of the borehole (i.e. the SHmax direction)

•These pre-existing, natural fractures may be modified or enhanced in the "tensile region" of the borehole

•They may vary in appearance in different sectors of the borehole and extreme caution must be used in interpretation of these features, especially where they form closely spaced, *en-echelon* fracture sets (in a vertical or along-hole sense)

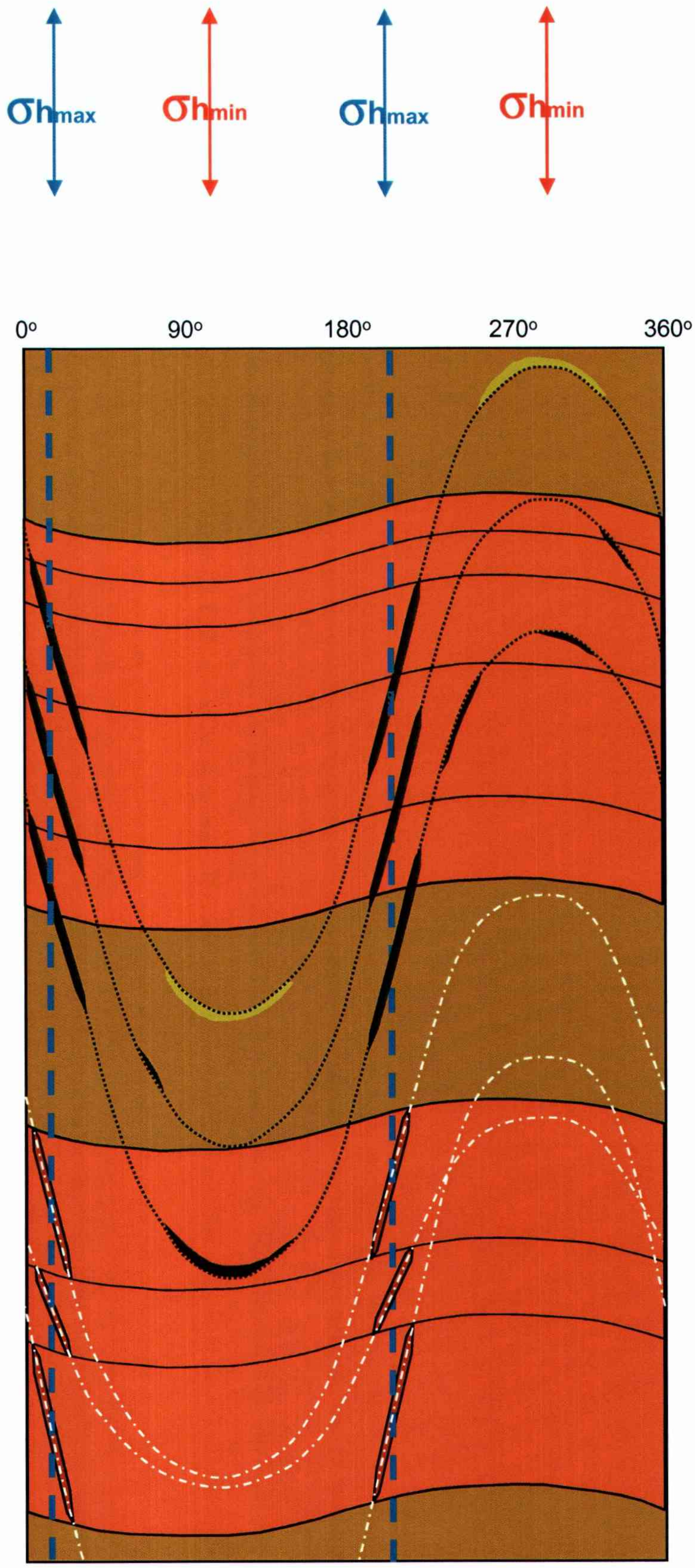
•It is important not to misidentify such fractures given the implications for their geomechanical interpretation

•Some fractures can be somewhat ambiguous in nature, especially where only the modified or enhanced part is clearly evident, or where there is interaction between natural and induced fractures and/or borehole breakout

•In general however, natural fractures that have been modified can be accurately intersected by a sine curve on both sides of the borehole (*c.f. Evans, et. al., 2004; Herman, 2005*)

•They may also show areas of resistive or conductive response (fast or slow if acoustic) elsewhere along their lengths

•Their magnitudes and azimuths may show slight to significant variability, unlike *en-echelon* induced fractures



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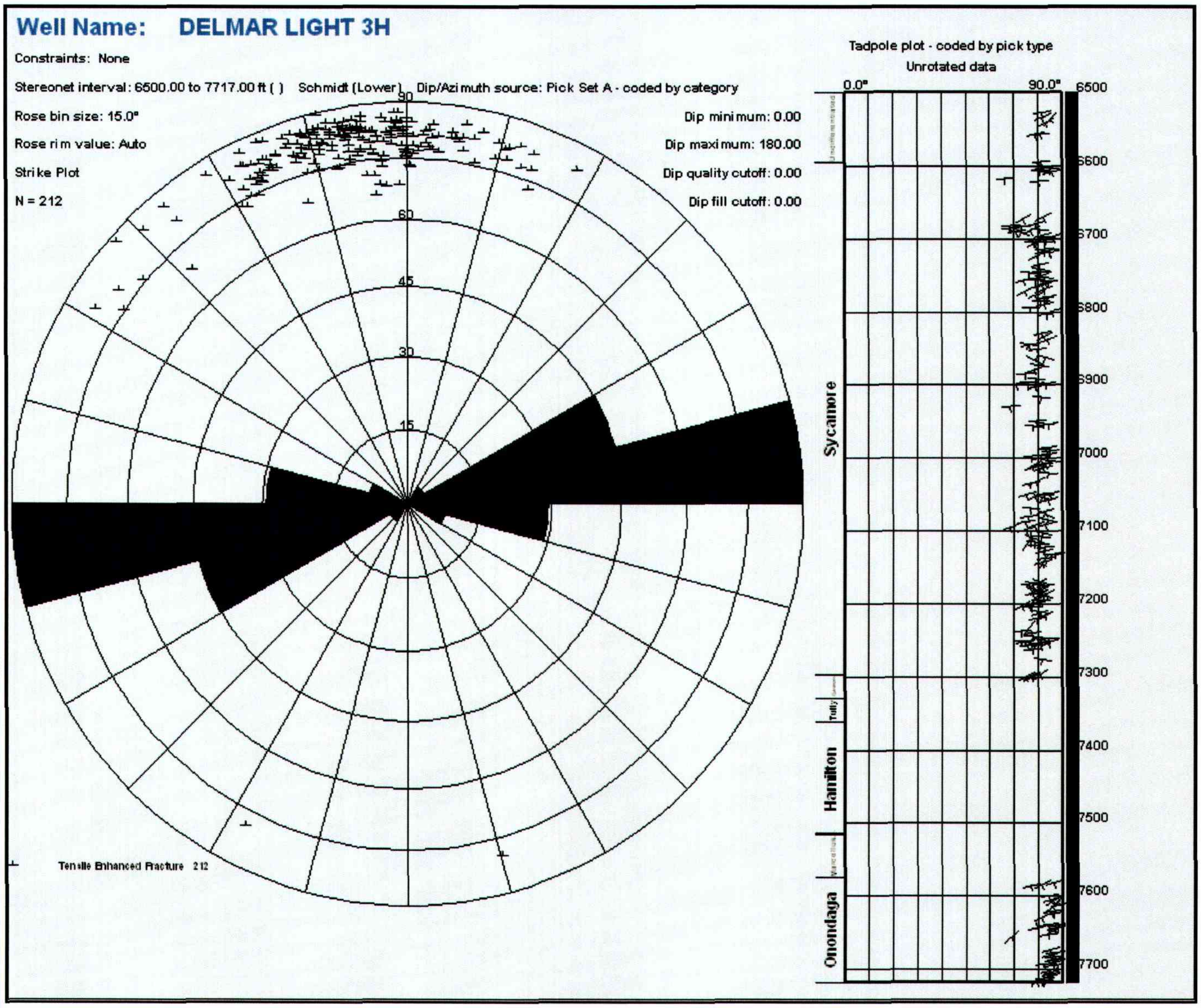
Tensile "Enhanced " Fracture Orientation



The lower hemisphere Schmidt plot above displays the tensile "enhanced" fractures (n=212) observed within the Delmar Light 3H well. The tensile "enhanced" fracture orientation trends **N82E-S82W** which is sub-parallel to the maximum horizontal *in-situ* stress estimated from the occurrence of present-day stress indicators observed within the Delmar Light 3H—e.g., borehole breakouts and centerline-tensile fractures. The orientation is based on analysis of 196 of 212 tensile "enhanced" fractures. The tensile "enhanced" fractures are pre-existing, natural fractures that may have been modified or enhanced in the "tensile region" of the borehole during the drilling process.

ANALYSIS and INTERPRETATION STEPS

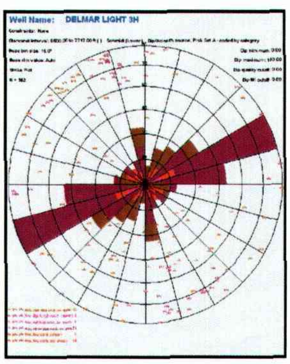
- Methodology
- QC raw image data and essential instrument information for accurate dip calculation
- Evaluate the near-wellbore structure and macro-faults, if present in the subject well
- Determine the orientation of the present day stress field
- **Characterization of the natural fracture system**
- Analyze lithofacies of sedimentary sequences

In total, 162 natural fractures have been identified over the interpreted interval (6,504 ft ~ 7,717 ft) in the Delmar Light 3H well and were analyzed with the following objectives:

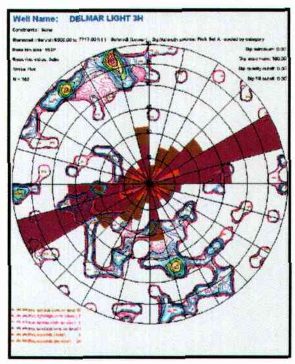
Objectives of Fracture System Interpretation

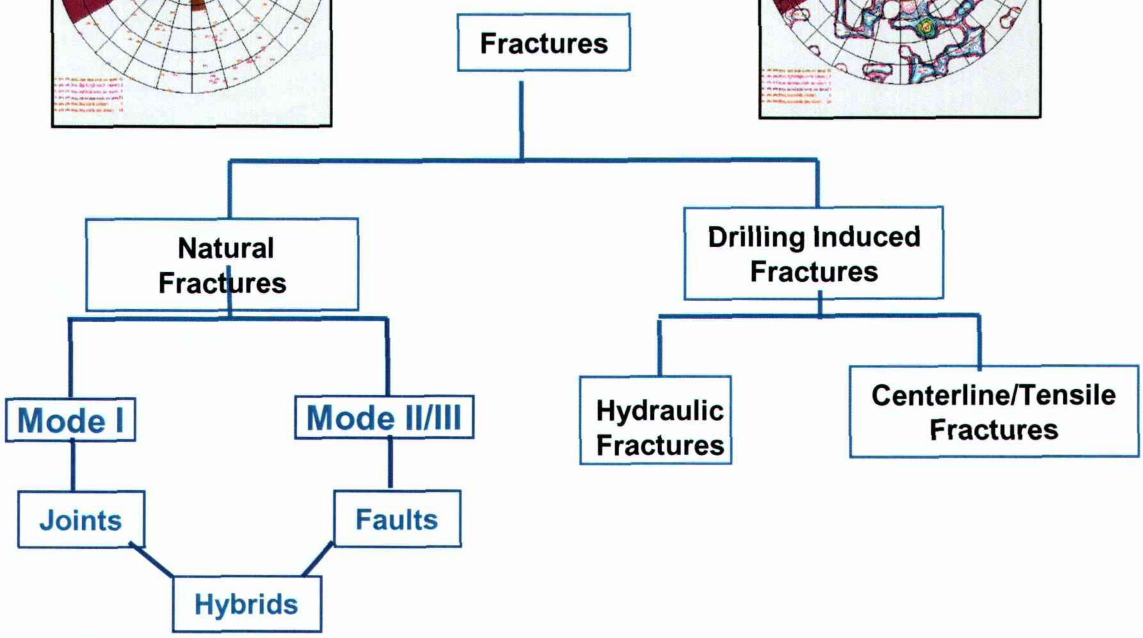
- **Type (open, closed, mineralized)**
- **Attitude**
- **Density and distribution**
- **Height**
- **Length**

Azimuth Frequency Diagram



Contour Pole Diagram





Fracture Appearance in Images

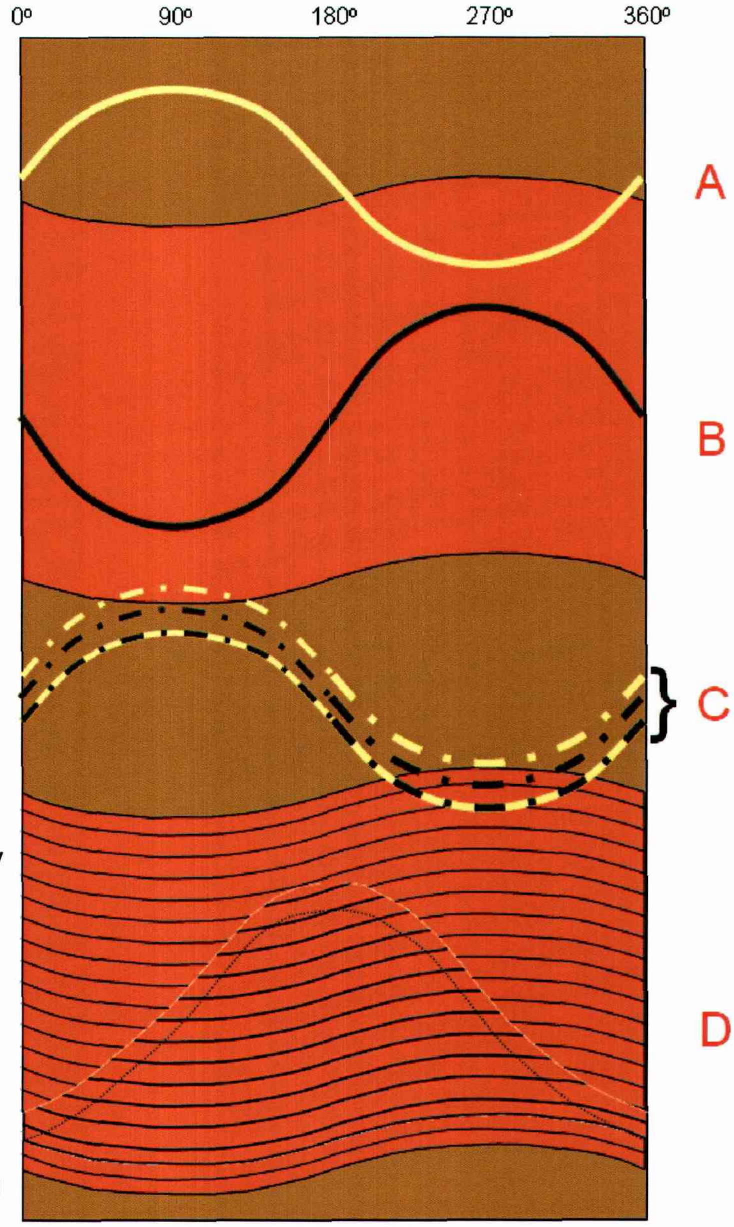
- **Fractures in image logs can be described in several ways:**
  - The main basis for fracture identification in image logs is whether they appear darker or lighter than the background formation or matrix in which they occur
  - Four principal fracture types can be described and are illustrated in the diagram below

A. **High contrast** features that are **lighter** than the background formation/matrix
   - **Resistive** in resistivity images or **high amplitude** in acoustic images (e.g. mineralized fractures, or potentially open if seen in OBM images ***only***)

B. **High contrast** features that are **darker** than the background formation matrix
   - **Conductive** in resistivity images or **low amplitude** in acoustic images (e.g. potentially open, or mineralized by conductive material such as clays)

C. **Mixed** (partially lighter, partially darker or both)
   - May be partly mineralized, partly open or both - commonly seen in carbonate lithologies

D. **Low (or no) contrast** fractures
   - Discerned from small (even very small) **discontinuities** or **offset** (shear) of bedding planes or other features
   - Often referred to as "**closed**" (i.e. no apparent mineralization and no apparent open voids/porosity)



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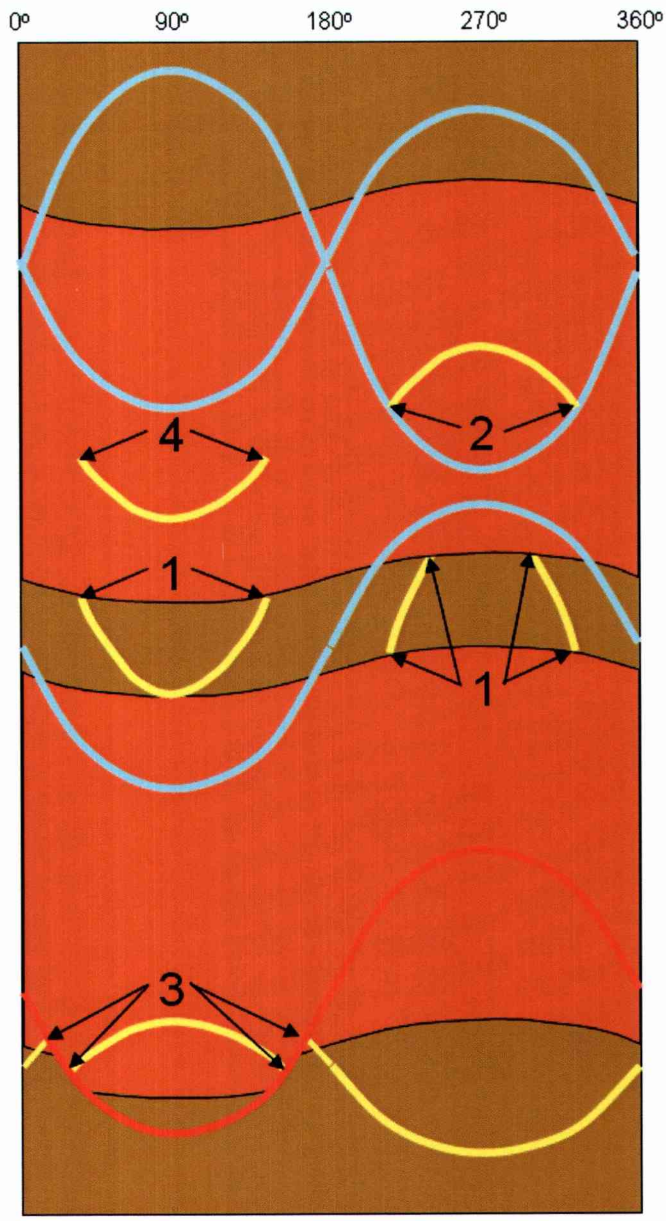
- Fractures that intersect the entire wellbore show a complete sinewave

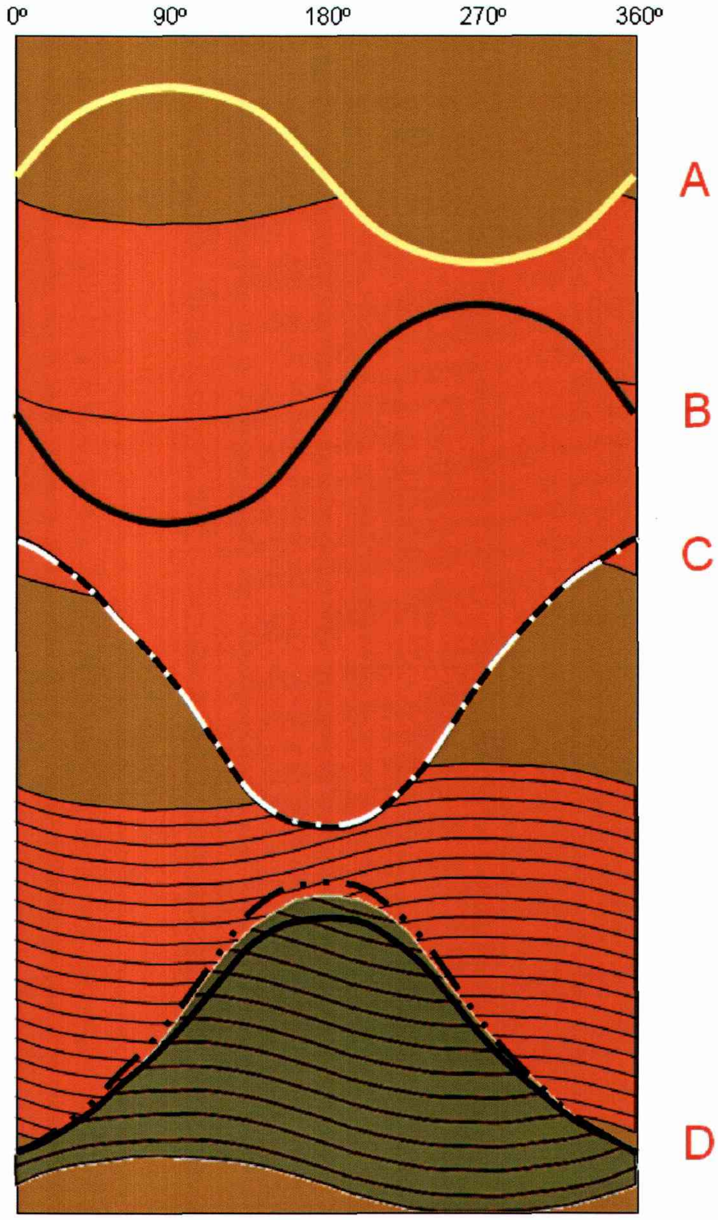
- Illustrated at right are
  - **Full sinewave** fractures with **no shear**; i.e. no offset of bedding or other fractures (**Pale Blue**)
  - **Full sinewave** fractures with **apparent shear**; i.e. that **offset** bedding and/or pre-existing fractures (**Red**)
- Some fractures however, show only:
  - **Partial sinewaves** (**Yellow**)
- These partial fractures can show a variety of **termination types**
  - **Type 1** terminates against bedding surfaces
  - **Type 2** terminates against other fractures
  - **Type 3** terminates against a shear fracture (i.e. offset by, & therefore predates, the shear fracture)
  - **Type 4** terminates within a particular bed, but not against any obvious or visible surface



Fault Definition in Images

- In image log interpretation Faults are defined as showing offset which is at least greater than the borehole diameter (i.e. the throw magnitude cannot be directly observed)

- As with fractures, the main basis for fault identification in image logs is whether they appear darker or lighter than the background formation or matrix in which they occur
- The fault plane may be
  - **A. High contrast, light**
    - May be potentially mineralized (assuming water base for a resistivity tool – may be potentially permeable/open if OBM only)
  - **B. High contrast, dark**
    - Mineralized with conductive material
    - Permeable or open (i.e. filled with conductive fluid if WBM)
    - Spalled (i.e. filled with conductive fluid, but only at the borehole edges)
    - A combination of these
  - **C. Mixed (light and/or dark)**
  - **D. Multiple** discontinuities may be seen at some fault boundaries
- Low contrast faults are not common, but in some cases the actual fault plane may not be evident due to:
  - Lack of any significant contrast
  - Major/significant damage zone or brecciation



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Formation Image Interpretation
- Fracture Type Classification -

Symbol	Appearance	Sinusoid	Shear?	Description
	High Contrast - Light	Full wellbore	X	High Contrast Light fractures represent features which exhibit a bright highly electrically resistive response on the resistivity image. This resistive response can be interpreted as the presence of electrically resistive minerals such as carbonate or silica within the fractures. These minerals may represent digenetic cements. They may or may not inhibit the flow of fluid or gas through the fracture.
			✔	
		Partial	X	
			✔	
	High Contrast - Dark	Full wellbore	X	High Contrast Dark fractures represent features which exhibit a dark, electrically-conductive response on the resistivity image. This dark response along the fracture trace is due to either the presence of drilling fluid or authigenic clay lining of the fracture. The fill material (drilling fluid or clay) cannot be determined from the image. Calibration to core is necessary to determine the fill type. If they are thought to be filled with drilling fluid then they are often considered as "open" and permit the flow of gas and fluid.
			✔	
		Partial	X	
			✔	
	High Contrast – Mixed (light &/or dark)	Full wellbore	X	A High Contrast Mixed fracture represents a feature which displays a mixed response along its trace. The response may be light in part, dark in part, or a mixture of both. This response may indicate that the feature is permeable or open over some of it's length and/or mineralized across some of its length.
			✔	
		Partial	X	
			✔	
	Low (or no) Contrast	Full wellbore	X	These Low Contrast fractures appear as subtle discontinuities that may be either slightly lighter or slightly darker than the surrounding rock matrix. In all cases however, they show little contrast difference with the background formation/matrix. These fractures show no strong evidence of being permeable or open, nor of intense mineralization and may be considered to be "closed".
			✔	
		Partial	X	
			✔	
	Tensile Enhanced Fractures			These are fractures that are only significantly apparent within parts of the borehole found to be in tension. They appear as "High Contrast, Dark" features on images and are likely filled with drilling mud. They may be seen in proximity to unequivocal drilling induced fractures, but may themselves represent drilling enhanced natural fractures.

Formation Image Interpretation
- Fracture Type Classification -

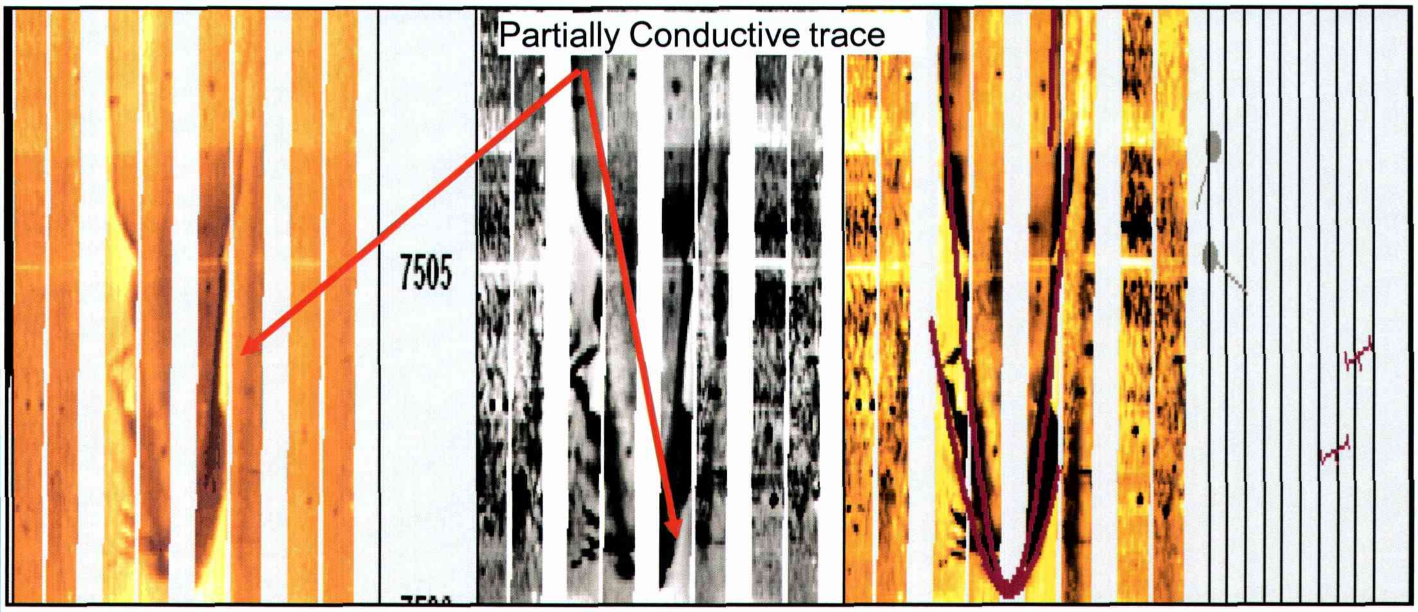
Symbol	Appearance	Description
	High Contrast - light	These features represent faults with displacement greater, or much greater than the borehole diameter. They display a bright electrically resistive response indicating the fault is lined with resistive minerals like calcite or silica. A mineralized or cemented fault may prevent fluid flow through or across the fault.
	High Contrast – dark	These features represent faults, again with throw greater, or much greater than the borehole diameter. These faults display dark electrically conductive traces on the image. They are either open and filled with drilling fluid or are closed and filled with authigenic clay. This cannot be determined from the image only. If the faults are open then they could be conduits to fluid flow. If they are filled with clay they could behave more like cemented faults and prevent fluid flow.
	High Contrast Mixed	These features represent faults with displacement greater than, or much greater than the borehole diameter. These faults display a mixed response along their traces. The response may be light in part, dark in part, or a mixture of both. This response may indicate that the feature is permeable or open over some of it's length and/or mineralized across some of its length.
	Low Contrast	These features represent faults with displacement greater than, or much greater than the borehole diameter. These represent faults that appear as subtle discontinuities that may be either slightly lighter or slightly darker than the surrounding rock matrix. In all cases however, they show little contrast difference with the background formation/matrix. These faults show no strong evidence of being permeable or open, nor of intense mineralization and may be considered to be "closed".

Fracture System Interpretation
Fractures by Type
6,504 ft to 7,717 ft

Fracture Trace Appearance	Fracture Interpretation	No Shear/ Shear/ Fault	Total # of Fractures
Light, high contrast	Cemented/ Resistive	Shear	0
Light, high contrast	Cemented/ Resistive	No Shear	8
Mixed, high contrast	Partially Open/ Conductive	Shear	0
Mixed, high contrast	Partially Open/ Conductive	No Shear	71
Low contrast	Closed/ Non-conductive	Shear	3
Low contrast	Closed/ Non-conductive	No Shear	24
Dark, high contrast	Open	Shear	0
Dark, high contrast	Open	No Shear	56

The above chart lists the fracture types observed in the Delmar Light 3H. Four fracture types were observed and are as follows; Light, mixed, dark, and low contrast. These fracture types are further explained on the following pages.

Fracture System Interpretation
- Partially Open Fractures-



Static Image Black and White Dynamic image Color Dynamic Image

The snapshot above is an image log example of mixed high contrast fractures that were interpreted to be partially open fractures (purple trace/sinusoid). The partially open fractures are identified by its partial conductive traces which cuts across the bedding planes. The partially conductive trace represents a fracture which displays a mixed response along its trace. The response may be light in part, dark in part, or a mixture of both. This response may indicate that the feature may be permeable or open over some of it's length and/or mineralized across some of its length. The mixed fracture type was chosen because the fracture trace appeared conductive along certain portions of the fracture trace and faint along other portions as well as resistive in some portions on the static image.

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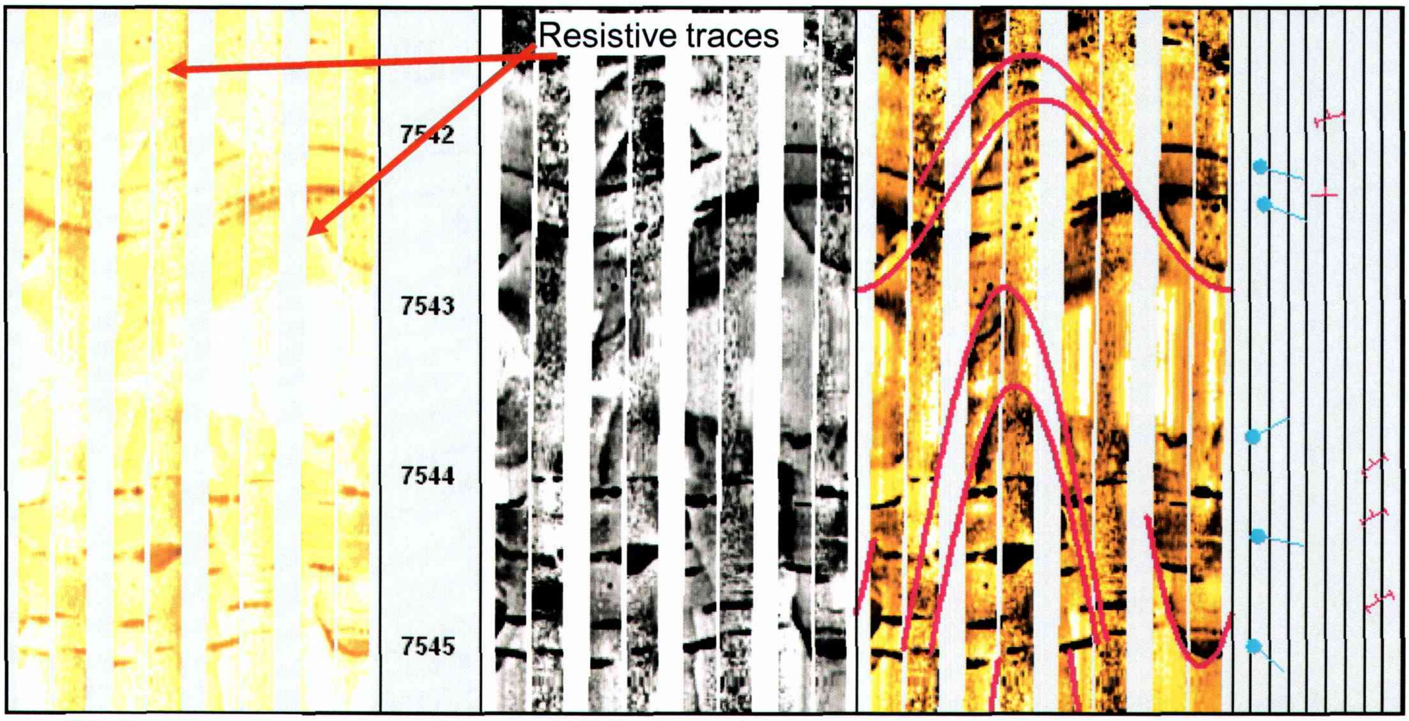
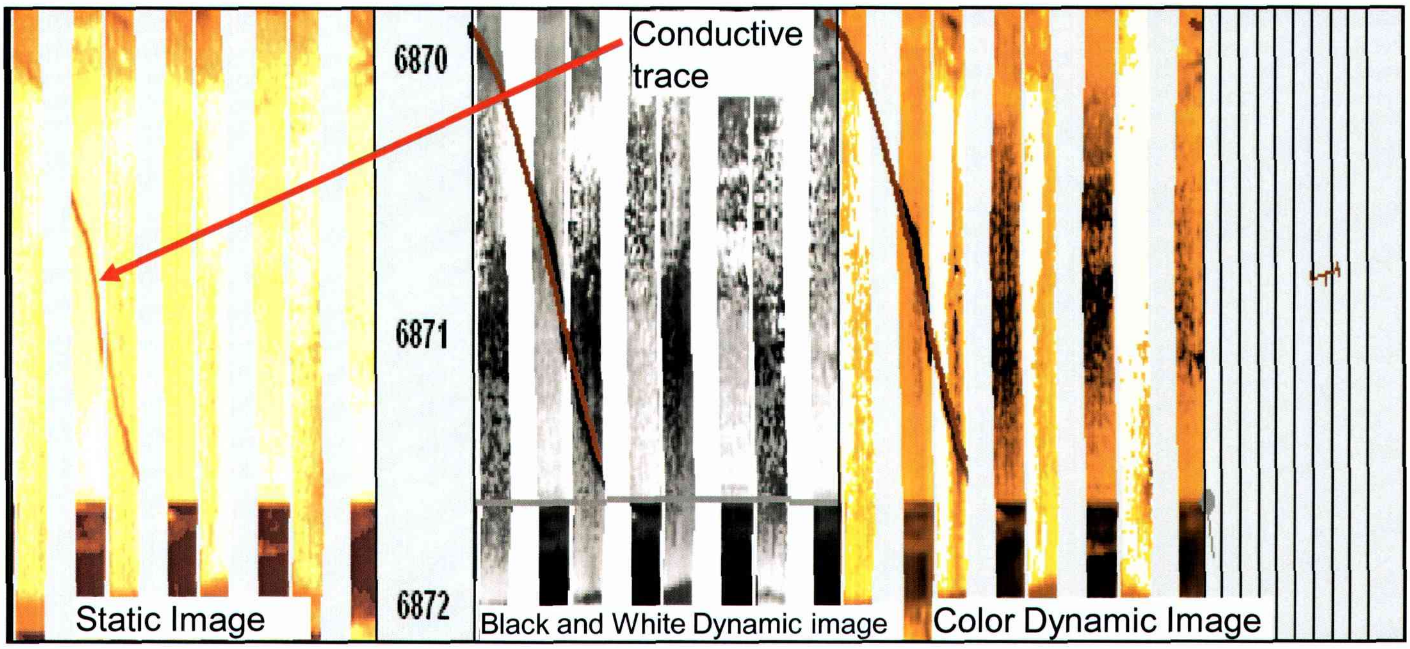
Fracture System Interpretation
- Cemented Fractures-



Static Image Black and White Dynamic image Color Dynamic Image

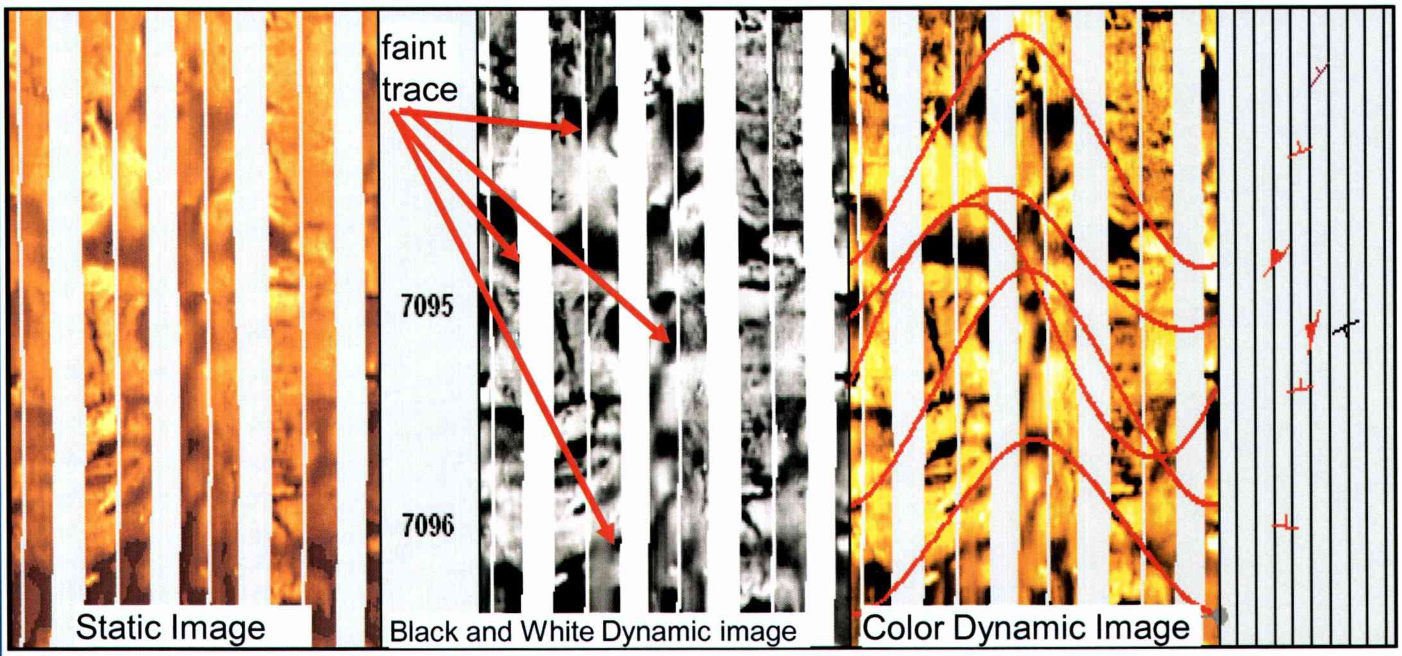
In the snapshot above is an image log example of light high contrast fractures that are interpreted to be cemented fractures (magenta traces/sinusoids). These cemented fractures are identified by the highly resistive fracture trace that cut across the bedding planes. The cemented trace represents a fracture which may be interpreted as the presence of electrically resistive minerals such as carbonate or silica within the fractures. These minerals may represent digenetic cements. They may or may not inhibit the flow of fluid or gas through the fracture. The static image is used to determine the resistive trace of a fracture. The cemented fractures identified in the above snapshot are high-angle (>60°) fractures.

Fracture System Interpretation - Open Fractures-



The above snapshot is an image log example of a high contrast dark fractures identified in the Delmar Light 3H well. The high contrast dark fractures are interpreted to be an open fractures (brown trace/sinusoid). The open fractures were identified by the conductive traces that cut across the bedding planes. The conductive trace may be caused by an infill of conductive drilling mud or because the fracture is lined with a conductive mineral—e.g., pyrite. The image alone cannot make this distinction. The open, conductive fracture identified in the above snapshot consists of a high-angle fracture that extends from the tensile region to the compressive region of the borehole. Please note that only one limb of this fracture is visible on the image.

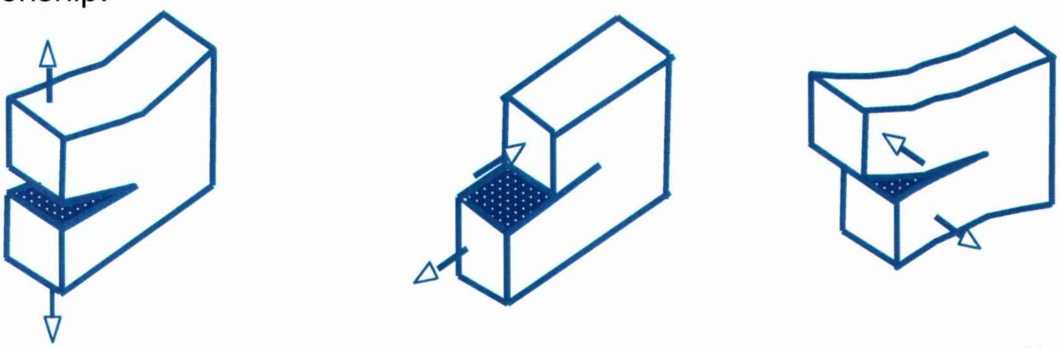
Fracture System Interpretation -Closed Fractures-



The snapshot above is an image log example of low contrast fractures interpreted to be closed/non-conductive fractures (red traces/sinusoids) identified within the Delmar Light 3H well. Closed fractures exhibit faint traces at the rock-to-rock contact, which have cut across bedding planes. These low contrast fractures display a relatively faint or slightly conductive appearance, which cut across bedding planes at the rock-to-rock contact. The slightly conductive traces may be the result of clay or drilling mud. The image alone cannot make this distinction. The closed fracture identified in snapshot consist of both low-angle shear fractures (<60°) and high-angle (>60°) joints.

Fracture Classification on the Basis of Displacement Discontinuity

Formation image fractures are classified into the three groups displayed below based on the observation of bed boundary displacements or the lack of it. Mode I fractures do not show displacement of rock along the fracture and are, therefore, interpreted as extension joints. Mode II and III fractures are recognized by displacement of geological features along the fractures. These fractures are interpreted as fault related shear fractures. In addition, dip magnitude of the fractures and their spatial organization provide additional classification criteria. The discrimination of Mode II from Mode III fractures is not straight forward and often requires a larger data set that allows detailed statistical analysis in order to recognize distinct fracture sets and their respective spatial relationship.



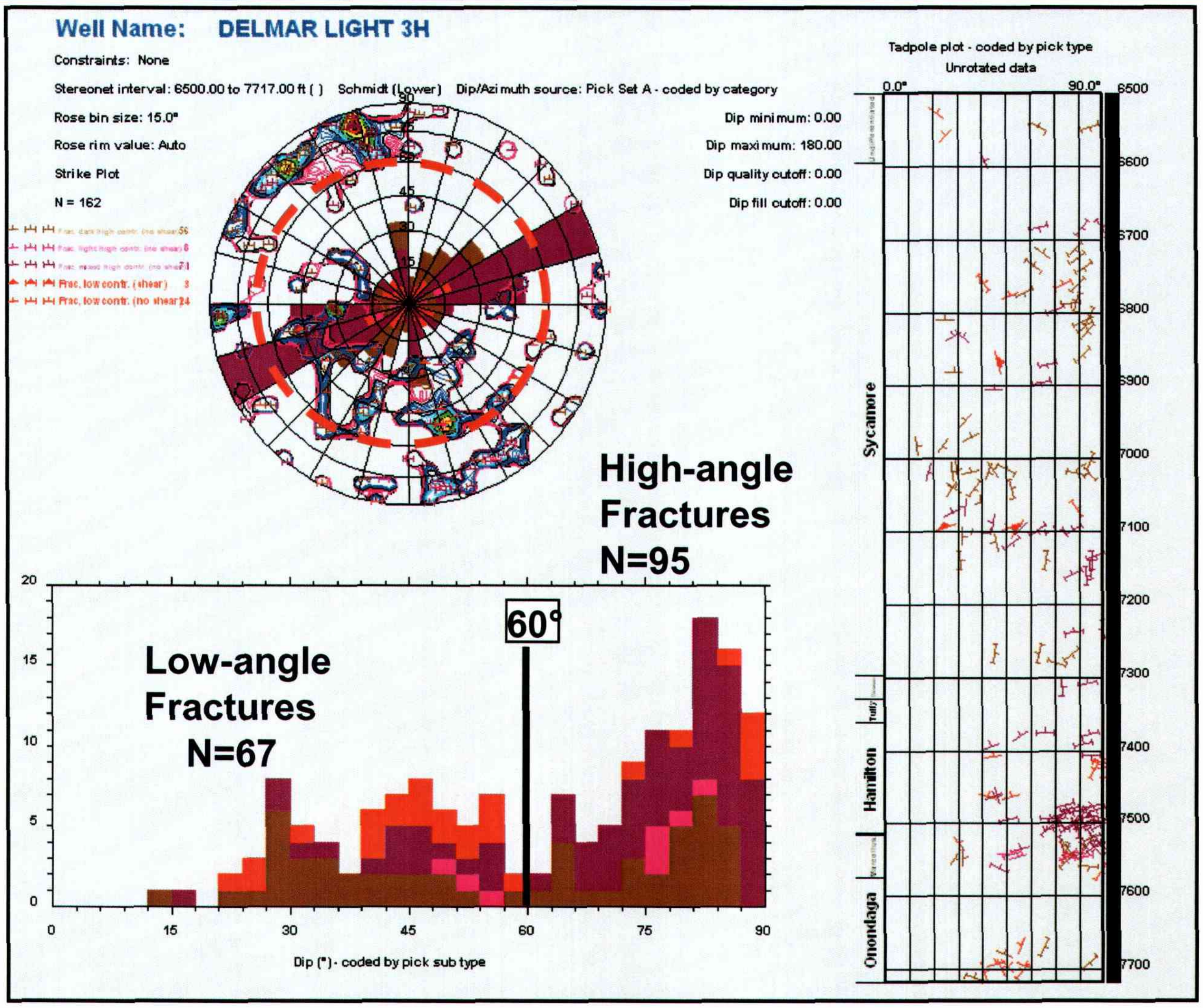
mode I | **mode II** | **mode III**

opening → Joint, Vein

closing → e.g. solution surface (stylolite in limestone)
compaction band (in sandstone)

Shear Fractures (mode II, mode III) → e.g. normal or reverse faulting, bedding plain fault, growth fault, deformation band

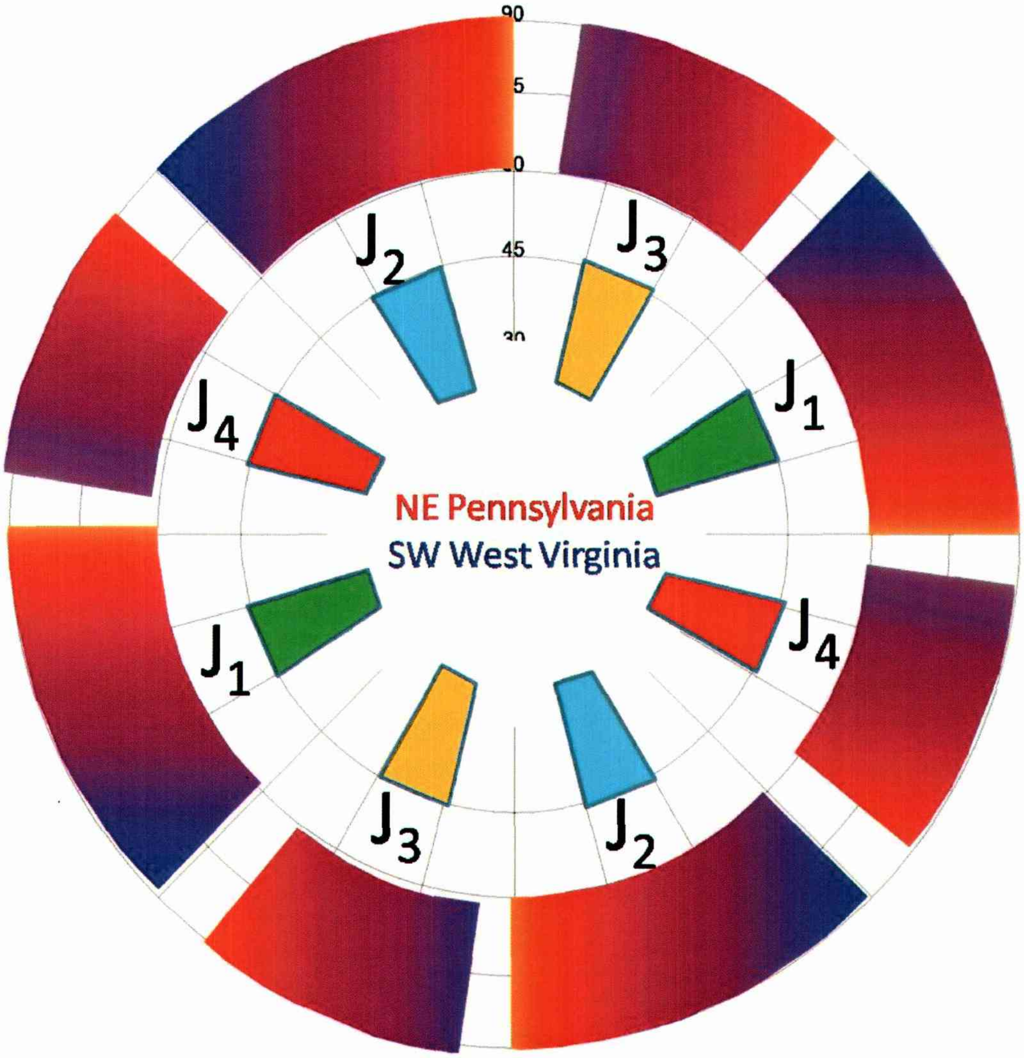
Fracture System Interpretation
6,504 ft to 7,717 ft



A total of 162 natural fractures are identified within the interpreted interval of 6,504 ft – 7,717 ft of the Delmar Light 3H well. Natural fractures are defined by those fractures that are related to the deformation of the rock and include such features as faults, joints, veins, and cracks (Ameen, 2003). All the natural fractures are termed mesofractures, fractures that can be fully characterized using a borehole imaging tool (Ameen et al., 2010). The fractures are plotted on a lower hemisphere contoured Schmidt plot above by fracture type along with the spatial distribution to the right. The observed fracture types include mixed and dark high contrast, light high contrast and low contrast. The fractures are divided into low-angle fractures and high-angle fractures based on a dip magnitude of 60°--i.e., low-angle fractures have a dip magnitude of less than 60° and high-angle fractures have a dip magnitude of 60° or greater. There are 67 low-angle fractures (some low-angle fractures show displacement along the bedding planes) and 95 high-angle fractures that were observed within the interpreted interval—no high-angle fractures showed displacement along the fracture trace. Thus the high-angle fractures are classified as mode 1 fractures—i.e., joints. Both fracture types are further discussed on the following pages.

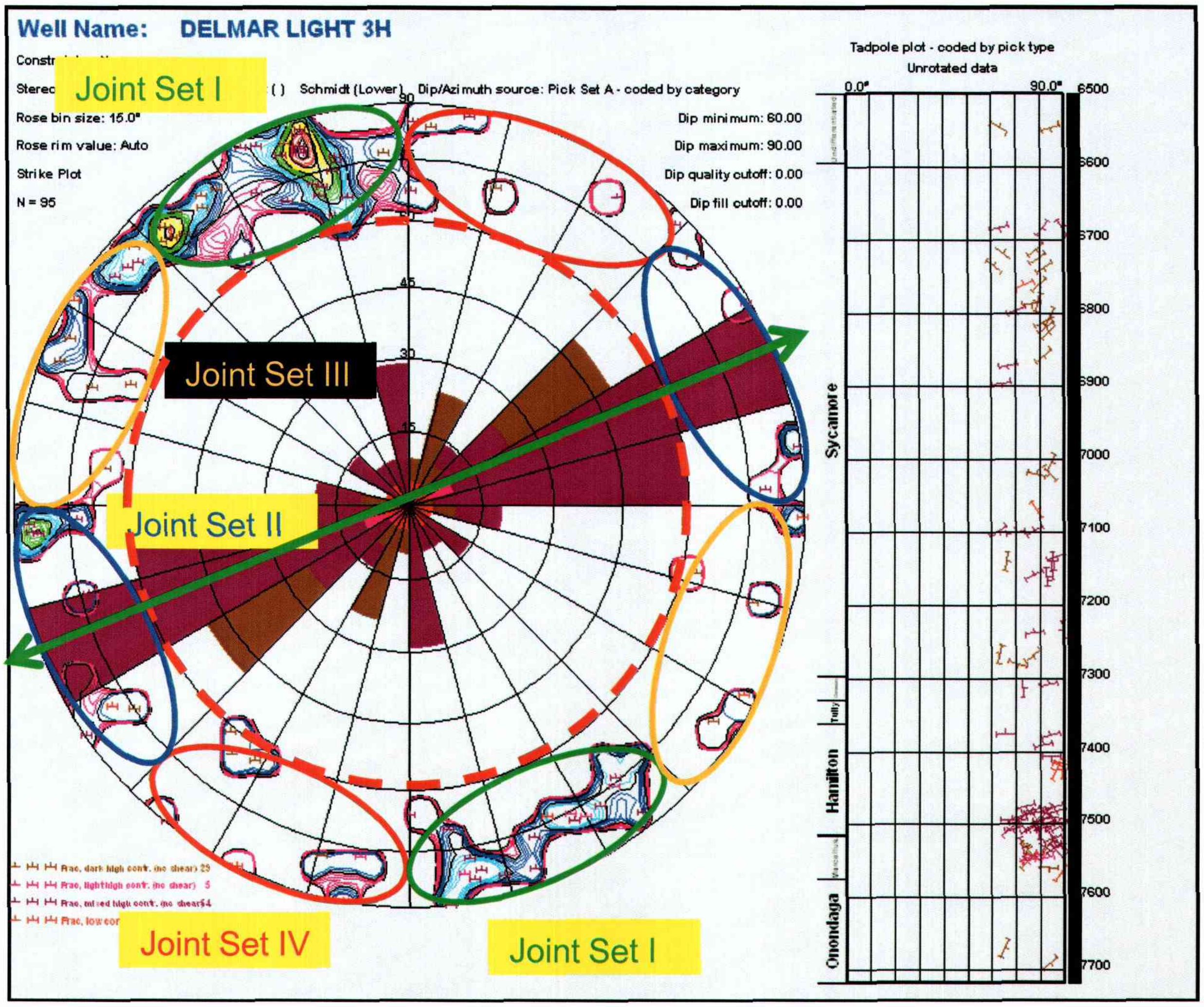
The dashed red-circle denotes the 60°circle on the Schmidt Plot.

Regional Joint sets: Marcellus Wells



The above diagram displays the strike orientation of 4 common joint sets that have been observed in previously interpreted Chesapeake Marcellus wells. The above diagram was created in order to try and establish consistency among the various reports that are written for the Marcellus Group at Chesapeake. Previous work in the Marcellus Formation has shown there are two well-documented joint sets, these joints are referred to as Joint Sets I and II. Joint Sets III and IV are sets that Fronterra Geosciences have observed in Marcellus formation images and have been named based on order in which the sets were observed in the wells. The naming of the joint sets III and IV does not suggest any structural or tectonic timing. The exact strike is not necessarily consistent from well to well, due to basin dimensions, changes in regional paleo-stress, and possible post-formational rotation due to external forces such as faulting and folding. The colored spectrum (red-purple) indicates documented regional rotation while the colored petals (red, blue, green and orange) indicate colors used by Fronterra Geosciences in the classification of these sets.

Fracture System Interpretation—Mode I
6,504 ft to 7,717 ft



The fracture contour diagram displayed above is used to aid in the identification of natural joint sets (>60° dip magnitude) within the interpreted interval (6,504 ft to 7,717 ft) of the Delmar Light 3H. A total of 95 joints have been identified within the processed interval and consists of light, mixed, and dark high contrast and low contrast joints. No high-angle shear fractures and high-angle faults were observed within the interpreted interval. Most of the joints occur in Joint Set I and the rest of the joint set regions have minor quantities of joints. The attitudes of Joint Set I is listed below:

Joint Set I (Green): **N67E-S67W**, Mean Dip 78°NW, 78°SE

Joint Set II (n=13), Joint Set III (n=15), and Joint Set IV (n=15) have a small population of joints and thus the attitudes of these joint sets were not calculated. Joint Set I has 52 joints.

Dashed red line represents the 60° cutoff.

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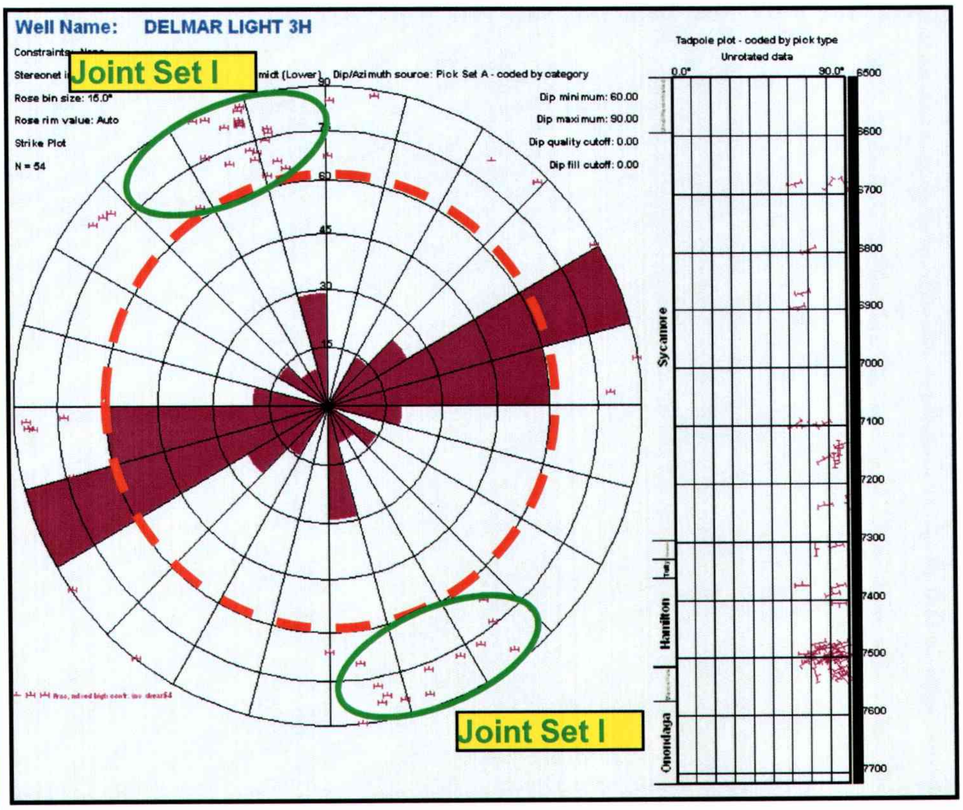
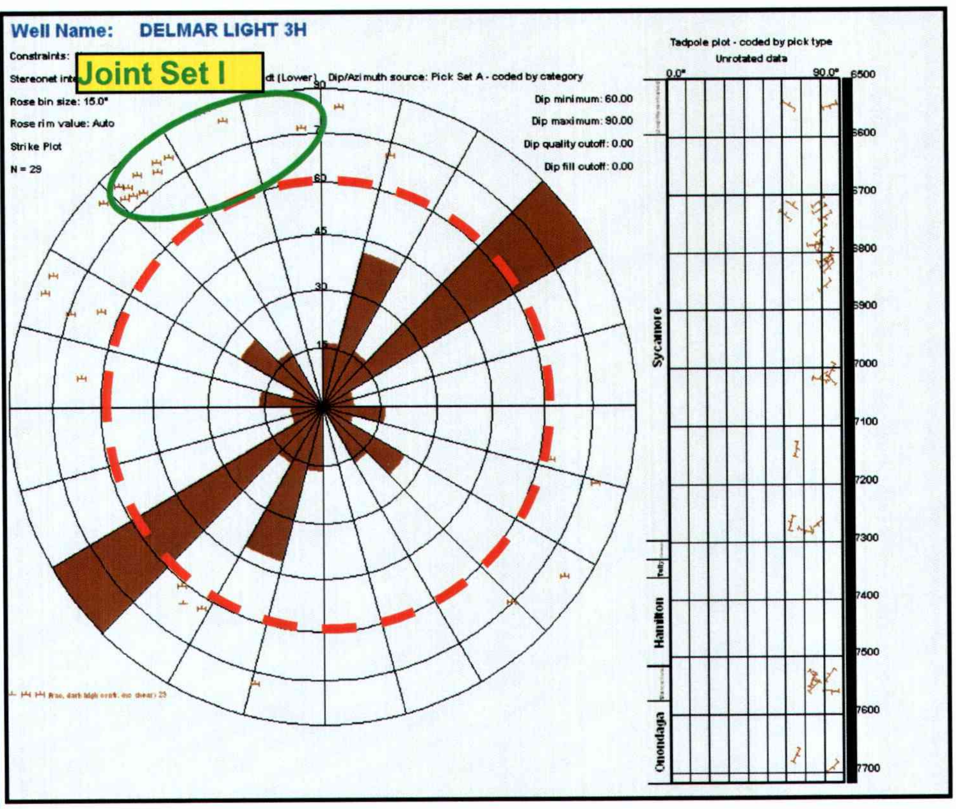
Fracture System Interpretation
Partially Open/Open Joints
6,504 ft to 7,717 ft



Fifty-four mixed high contrast joints (partially open) have been identified within the interpreted interval. The partially open joints strike **NE-SW** and very minor to the **NNW-SSE** and are mostly related to Joint Set I. The partially open joints are mostly joints that terminate into bedding planes or other fractures. There is only one complete partially open fracture observed.



Twenty-nine dark high contrast (open) joints have been observed within the interpreted interval. These open joints mostly terminate into bedding planes or other fractures. There is only one complete open joint observed in the interpreted interval. The strike orientation is **NE-SW**. There is a minor **NW-SE** orientation as well.

Dashed red line represents 60° cutoff between joints and low-angle fractures.

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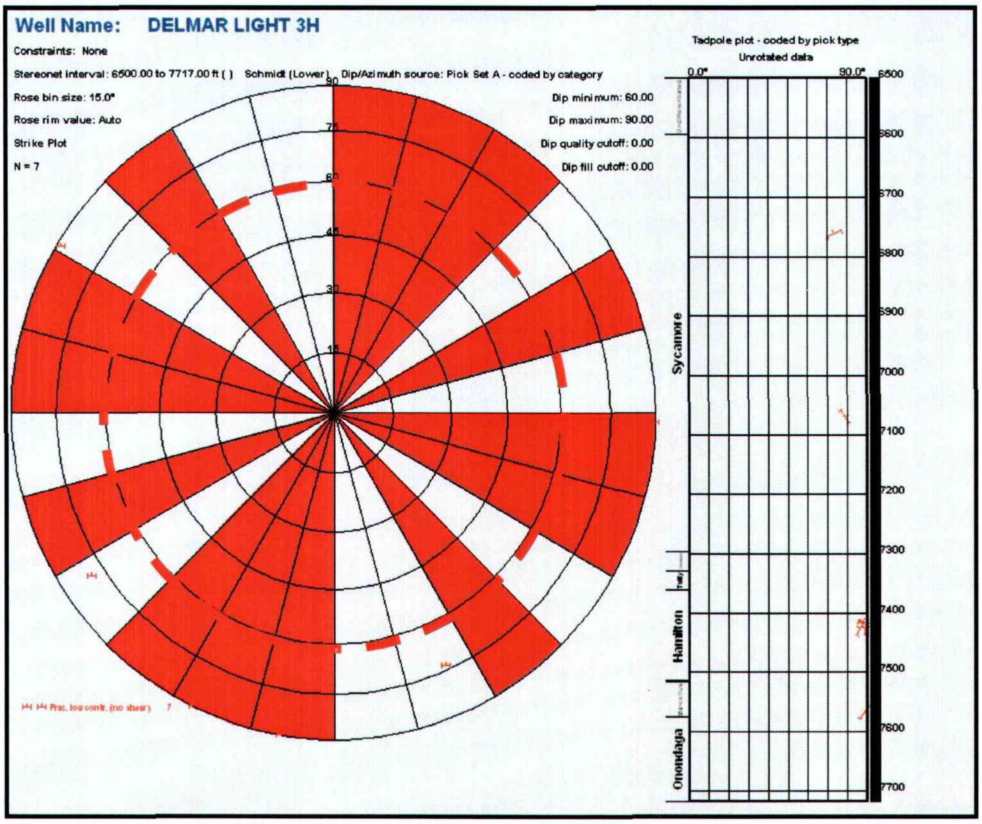
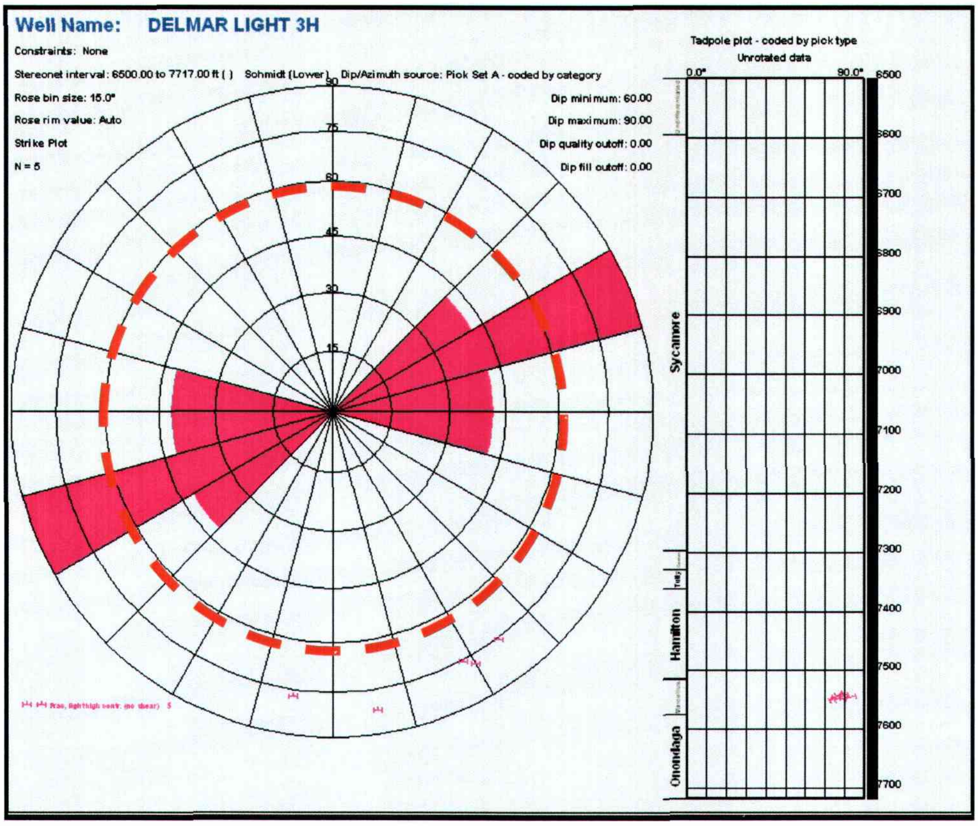
Fracture System Interpretation
Closed/Cemented Joints
6,504 ft to 7,717 ft



Seven low contrast (closed) joints are observed within the interpreted interval. These closed joints are scattered and all terminate into bedding planes or other fractures.

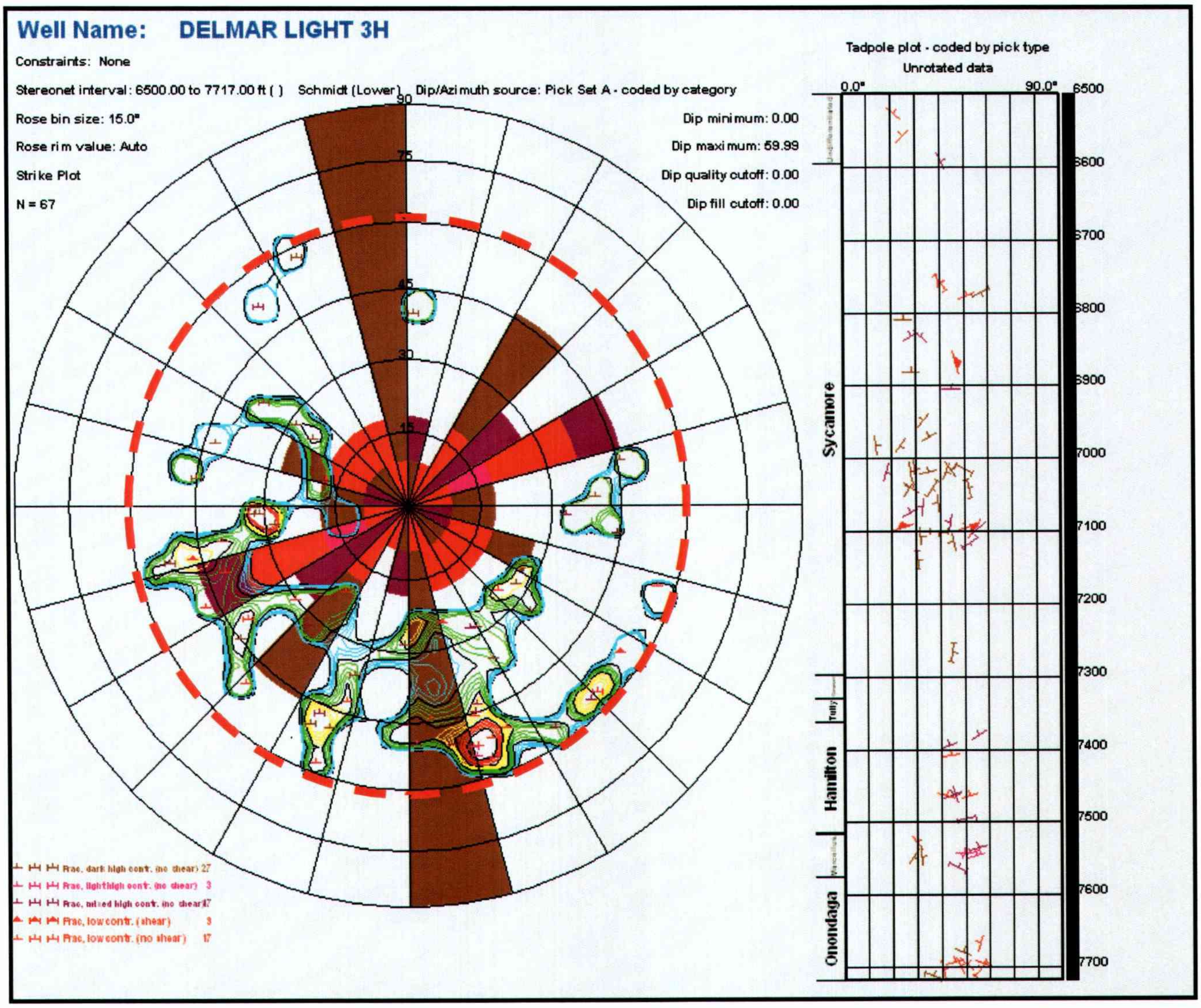


Five light high contrast joints (cemented) are observed within the interpreted interval. These cemented joints strike **NE-SW**. All of the cemented joints terminate into either bedding planes or other fractures.

Dashed red line represents 60° cutoff between joints and low-angle fractures.

Chesapeake Operating, Inc.
Delmar Light 3H
Upshur County, West Virginia

Fracture System Interpretation
Low-Angle Fractures (<60°)
(Mode II and/or III) 6,504 ft – 7,717 ft

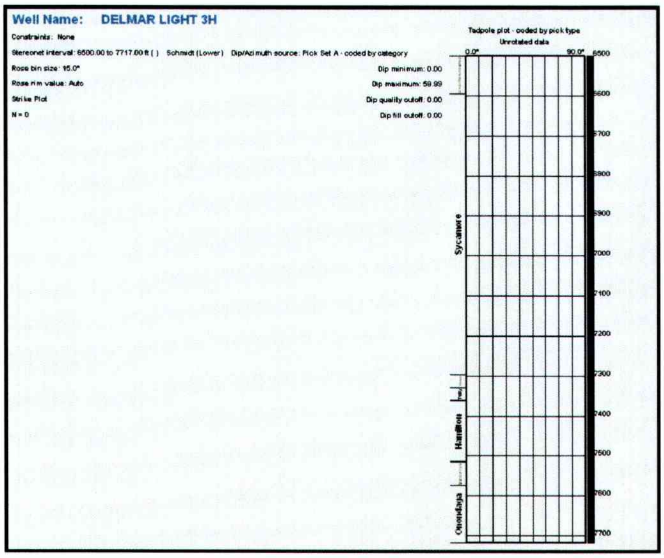


The fracture contour diagram displayed above was used to aid in the identification of 67 low-angle natural fractures (<60° dip magnitude) within the interpreted interval 6,509 ft to 7,717 ft of the Delmar Light 3H well. The type of low-angle fractures observed are mixed (N=17), dark (n=27), light (n=3), and low contrast (n=20). The observed low-angle fractures have two main orientations a **NE-SW** and a **NNW-SSE**. There are 3 low-angle fractures that have observable displacement that can be seen along the fracture trace. Please note that not every low-angle fracture with displacement along the fracture trace can be seen due to the resolution limits of the image tool. There were no low-angle faults identified within the interpreted interval.

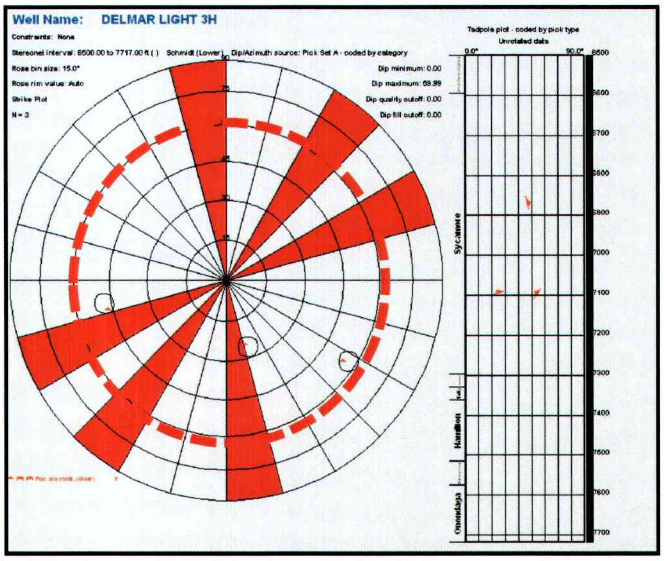
The dashed red line represents the 60° cutoff between joints and low-angle fractures.

Chesapeake Operating, Inc.
Delmar Light 3H
Upshur County, West Virginia

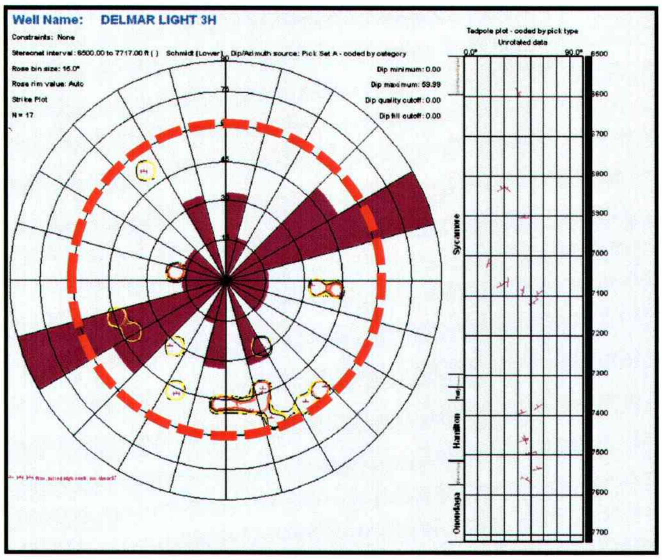
Fracture System Interpretation Low-Angle Fractures with Displacement Vs. No Displacement (6,504 ft to 7,717 ft)



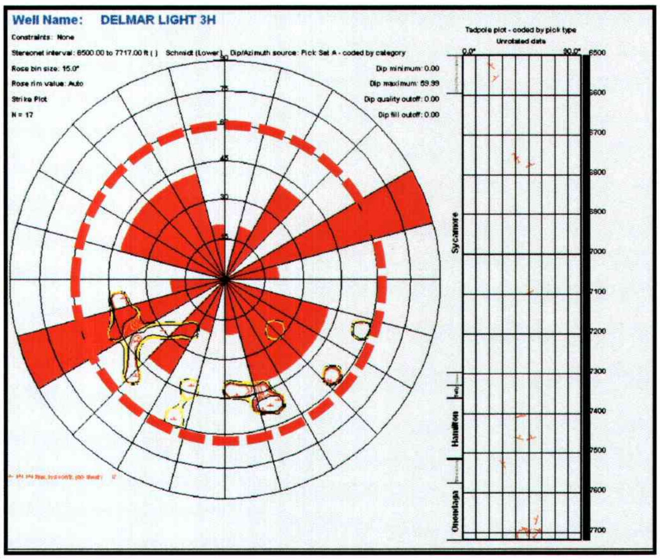
Low-Angle Partially Open Fracture with Shear



Low-Angle Closed fractures with Shear



Low-Angle Partially Open Fracture with No Shear



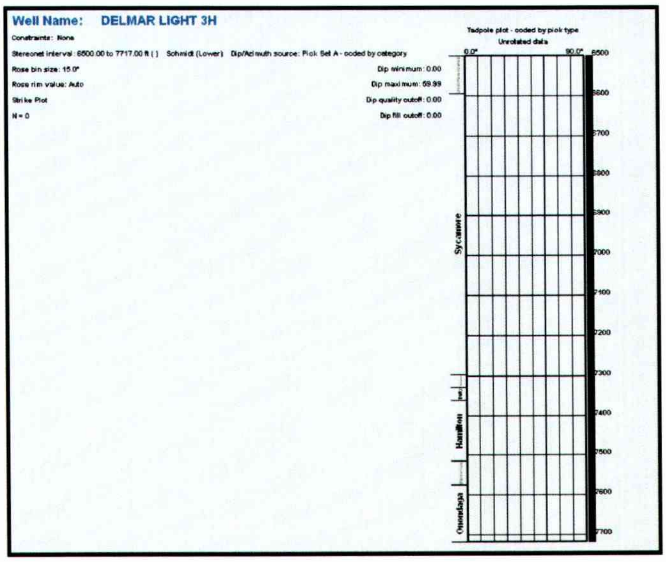
Low-Angle Closed Fractures with No Shear

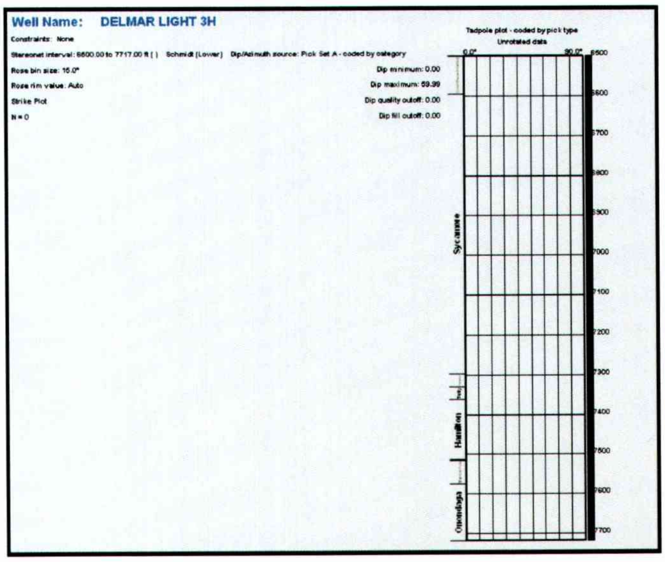
A total of 17 mixed high contrast (partially open) low-angle fractures have been identified in the interpreted interval. The partially open low-angle fractures do not show shearing (no observable displacement) along the fracture trace. The strike orientation is **NE-SW** and a minor **NNW-SSE**.

The Delmar Light 3H contains 20 low contrast low-angle fractures (closed) with three having observable shearing along the fracture trace. The closed low-angle fractures (with no observable displacement) strike orientation of **NW-SE** and **NE-SW**. The three low-angle closed fractures with shearing strike **NNW-SSE** and **NE-SW**.

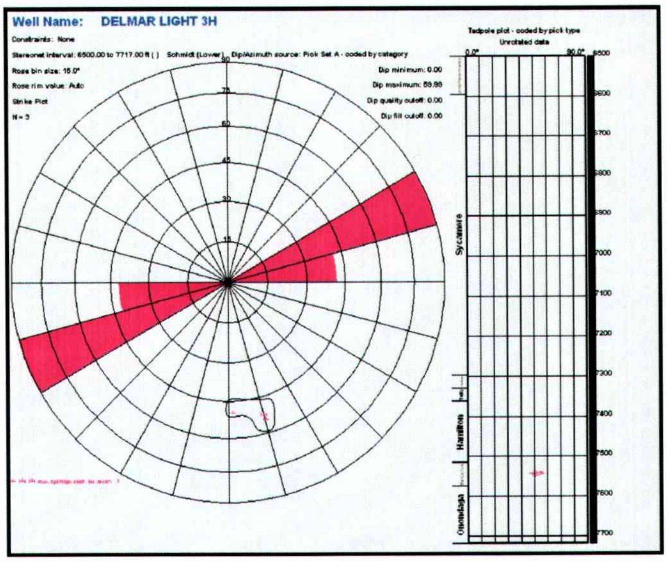
Chesapeake Operating, Inc.
Delmar Light 3H
Upshur County, West Virginia

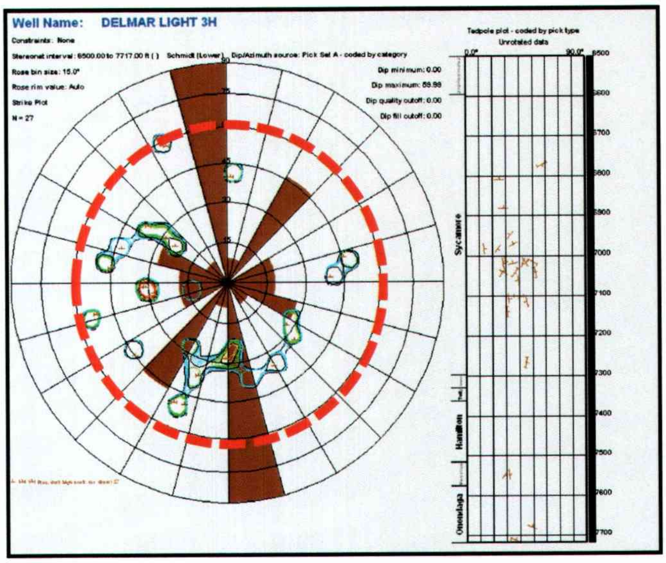
Fracture System Interpretation Low-Angle Fractures with Displacement Vs. No Displacement (6,504 ft to 7,717 ft)





Low-Angle Cemented Fractures with Shear **Low-Angle Open Fractures with Shear**





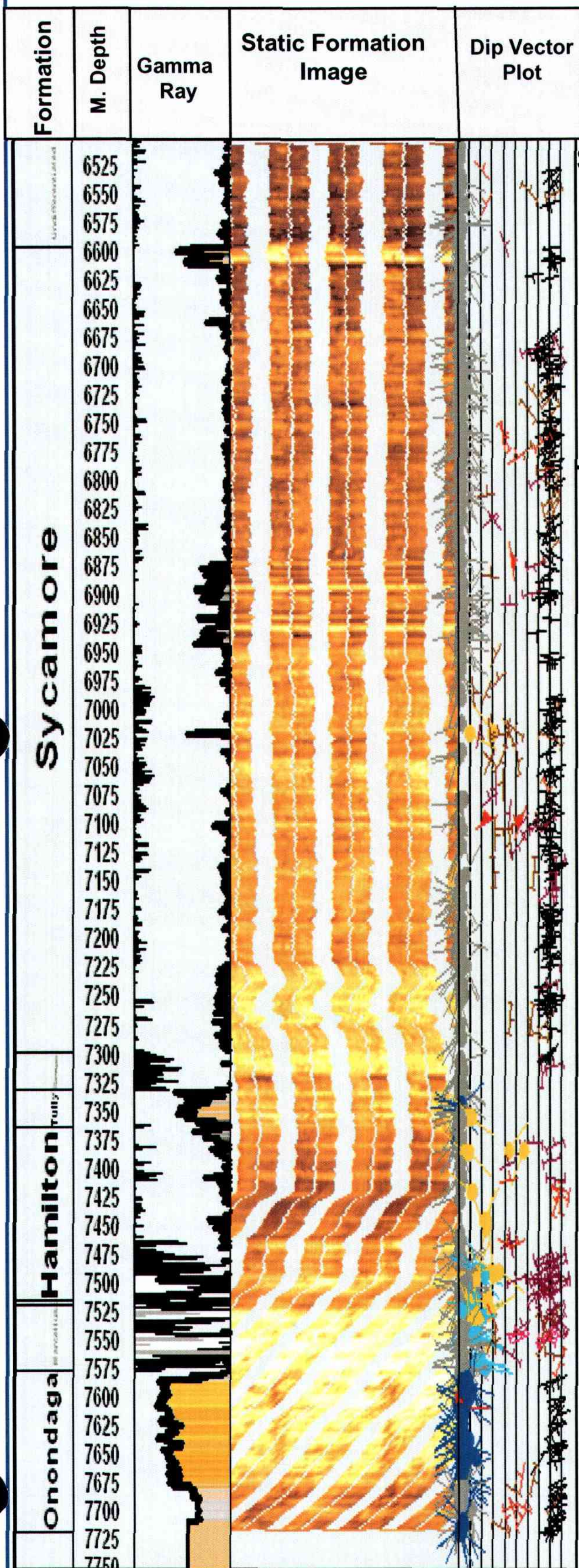
Low-Angle Cemented Fracture with No Shear **Low-Angle Open Fractures with No Shear**

The Delmar Light 3H contains 27 dark high contrast (open) low-angle fractures. The low-angle open fractures (with no displacement) strike **NNW-SSE** and have a minor **NE-SW** orientation. None of the open low-angle fractures have observable shearing along the fracture trace.

There are three low-angle light high contrast (cemented) fractures observed within the interpreted interval these fractures strike **NE-SW**. There were no cemented fractures with observable displacement (shearing).

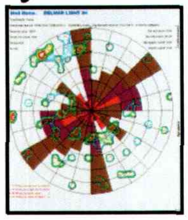
Chesapeake Operating, Inc.
Delmar Light 3H
Upshur County, West Virginia

Fracture System Interpretation High-Angle Joints (≥60°) and Low-Angle Fractures (<60°) by Formation



Low-angle Fracture and Joint Orientation by Formations

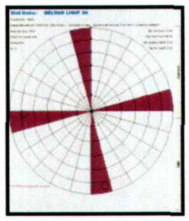
Sycamore/Undifferentiated FM (Tot. Fracs (N=82))



Joints (N=40) **NE-SW** (some scatter)
Low-angle fractures (N=42)
NW-SE strike (some scatter).

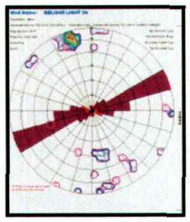
Fracture types observed are partially open, open, and closed.

Tully and Geneseo Formations (Tot. Fracs (N=2))



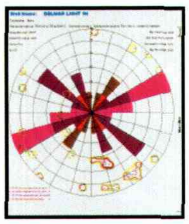
Joints (N=2) strike **ENE-WSW** and **NNW-SSE**.
Low-angle fractures (N=0)
Fracture types observed include partially open.

Hamilton Formation (Tot. Fracs (N=40))



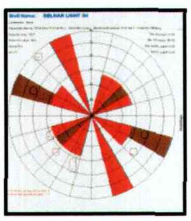
Joints (N=32) **NE-SW** strike.
Low-angle fractures (N=08). Strike **NE-SW** along with scatter.
Fracture types observed include partially open and closed.

Marcellus/Purcell Formation (Tot. Fracs (N=27))



Joints (N=19)
NW-SE and **NE-SW.**
Low-angle fractures (N=8)
NE-SW strike (scatter).
Fractures observed are open, partially open, closed and cemented.

Onondaga Formation (Tot. Fracs (N=11))



Joints (N=2)
NE-SW strike.
Low-angle fractures (N=9)
NW-SE and **NE-SW** strike (scatter).

Fracture types observed are open and closed..

Fracture System Interpretation
-Fracture Density Curves Explanation-

- Total Fractures (AD10F)—This Curve includes all fracture types observed within the interpreted interval. This includes both high- and low-angle fractures and shear and non shear fractures. The fractures excluded in this curve are drilling induced fractures—e.g., tensile enhanced and centerline and/or borehole breakouts.

- Cemented Fractures (HLD10F)—This curve includes all cemented fractures determined from the image. This curve includes both non-shear and shear cemented fractures and high- and low-angle cemented fractures.

- Closed Fractures (LRD10F)—The LRD10F curve includes all fractures that are determined to be closed using the image. This includes both non-shear and shear closed fractures and high- and low-angle closed fractures.

- Partially Open Fractures (HMD10F)—This curve includes all fractures that are classified as having a mixed appearance along the fracture trace—i.e., partially resistive and partially conductive and/or partially conductive and partially closed. This includes both non-shear and shear mixed fractures and high- and low-angle mixed fractures.

- Open Fractures (HDD10F)—This includes fractures that are determined to be open (conductive) and could be filled with drilling mud or conductive minerals—e.g., pyrite. This includes both non-shear and shear open fractures and both high- and low-angle fractures. The image alone cannot determine the cause of conductivity, an image to core comparison would need to be conducted.

- Total Joints (TJ10F)—Includes all fracture types that have a dip magnitude equal to or greater than 60 degrees and show no observable displacement along the fracture trace.

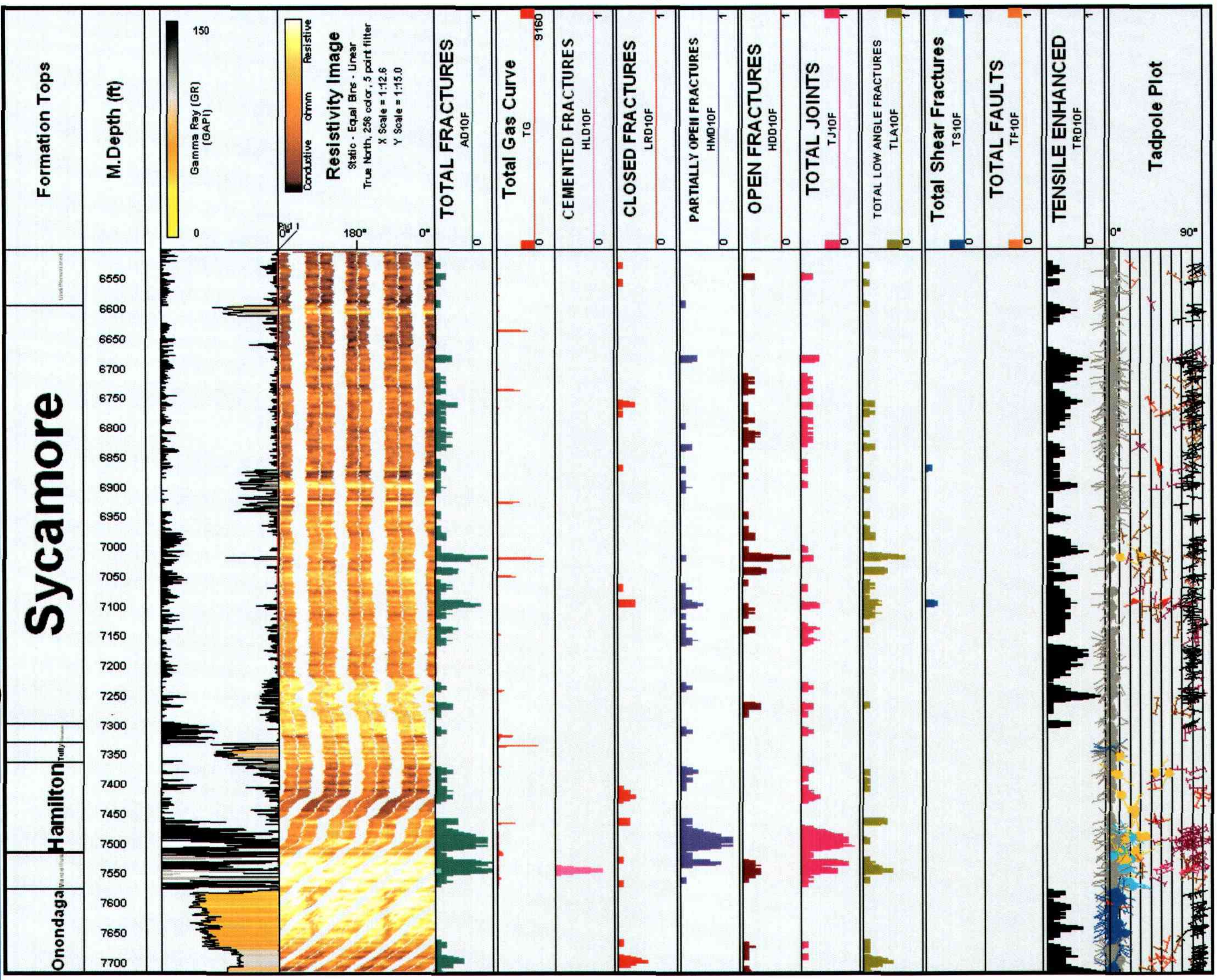
- Total Low Angle (TLA10F)—This curve includes all low-angle fractures that have a dip magnitude of less than or equal to 59.99 degrees. In addition, these low-angle fractures do not show any displacement along the fracture trace.

- Total Shear Fractures (TS10F)—Includes all fracture types regardless of dip magnitude that show observable displacement along the fracture trace. This displacement is less than the well-bore diameter.

- Total Faults (TF10F)—This includes all fracture types with displacement that is greater than the well-bore diameter.

- Tensile Enhanced (TRD10F)—These are fractures that are only apparent within parts of the borehole found to be in tension. They appear as "High Contrast, Dark" features on images and are likely filled with drilling mud. They may be seen in proximity to unequivocal drilling induced fractures, but may themselves represent drilling enhanced natural fractures.

Fracture System Interpretation
-Fracture Density-
(6,504 ft to 7,717 ft)



Fracture density has been computed using a 10 ft sample window for all natural fractures observed in the Delmar Light 3H well and is presented above by fracture type and total. Fracture density is highest in the Marcellus Formation (7,550 ft – 7,575 ft) where the fracture density reaches just over a 1 fracture per foot density. The lower Hamilton Formation is close to a one fracture per foot density. This increase in fracture density is related to mostly high-angle joints observed in this section of the well. Overall, the fracture density is low for the well, with an average density of 0.50 fracture per foot density. Some regions in Sycamore (7,025 ft – 7,050 ft and 7,075 – 7,100 ft) approach a 1 fracture per foot density. The total gas curve is compared with the total fracture density. Some regions of the gas curve correlate well (as seen in the Sycamore—7,000 ft) and other regions do not correlate well—e.g., Marcellus.

Reference List

Ameen, M.S., 2003, Fracture and *in-situ* stress characterization of hydrocarbon reservoirs: definitions and introduction, *in* Ameen, M.S., ed., Fracture and *In-Situ* Stress Characterization of Hydrocarbons Reservoirs: Geological Society (London) Special Publication 209, p. 1-6.

Ameen, M.S., Buhidma, I.S., and Rahim, Z., 2010, The function of fractures and *in-situ* stresses in the Khuff reservoir performance, onshore fields, Saudi Arabia: American Association of Petroleum Geologists Bulletin, v. 94, No. 1. p. 27-60.

Fronterra
Geosciences

5100 N. Brookline Ave, Suite 750

Oklahoma City, OK 73112

Office: 405.942.7677

fronterra@fronterrageo.com