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SUCCESSFUL APPLICATIONS OF NON-SEISMIC METHODS TO FIND AND EVALUATE PROSPECTS

FRACTURE DENSITY AS A GUIDE TO PETROLEUM EXPLORATION AND DEVELOPMENT

Ronald J. Staskowski[1], Cynthia K. Dacre[1], and John R. Everett[2]. (1) Geological Exploration, Earth Satellite Corporation, 6011 Executive Boulevard, Suite 400, Rockville, MD 20852, phone: 301-231-0660, fax: 301-231-5020, rstaskowski @ earthsat.com, (2) Chief Geologist, Earth Satellite Corporation, 6011 Executive Boulevard, Suite 400, Rockville, MD 20852

ABSTRACT

In areas as diverse as Western New York, Central Texas, the Powder River Basin, and Central China, there is a strong correlation between high density fractures mapped from remotely sensed data and hydrocarbon production. Where accumulation is related to fracture porosity and permeability (e.g., Texas and China) the relationship is anticipated. However, in areas with other structural and stratigraphic traps, the relationship also persists.

Faulting and fracturing influence the location of channels and offshore bars; differential compaction over buried sand or carbonate bodies may produce higher fracture density. Alteration related to vertical migration of hydrocarbons along fractures may make the fractures more obvious. Vertical fractures may constitute critical pathways for fluid migration from generating source beds to reservoirs. Thus, traps are preferentially charged in the vicinity of fractures. Some of these fractures may be the product of the over-pressuring of source beds during generation and expulsion.

Both density and orientation of fractures are important factors. Areas of high fracture density are the most attractive, and wells that encounter relatively open-standing fractures (those parallel to maximum principal compressive stress in most areas) are the most prolific. Digital technology allows one to rapidly digitize fractures, compute and map fracture density, and analyze fracture orientation.

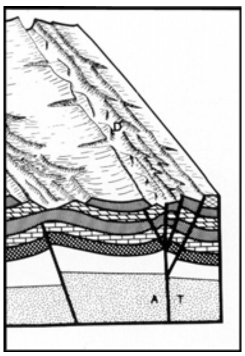
The approach is useful for identifying new exploration targets, extending producing trends, choosing optimal location for development wells, and selecting the orientation of horizontal well bores. Fracture analysis is relatively inexpensive and, like all other tools, is best used in concert with sound geologic thinking and other conventional tools and techniques.

SURFICIAL EXPRESSION OF SUBSURFACE FEATURES

TECTONIC-RELATED

(Left) Diagram of a strike-slip fault and associated fracturing resulting from tectonic stresses (from Berger, 1994).

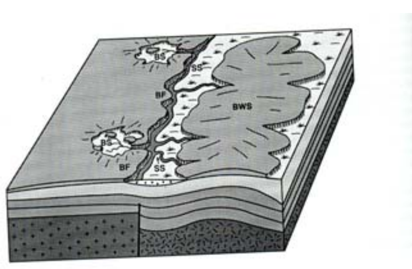
(Right) Landsat TM image of strike-slip faulting and fracturing from tectonic activity near Los Angeles, California.

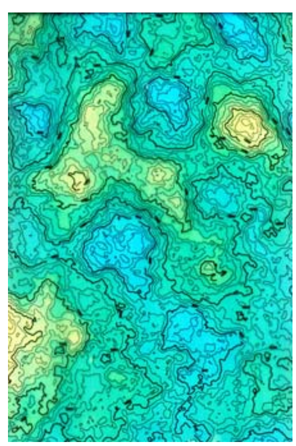


STRUCTURAL CONTROLS ON STRATIGRAPHY

(Left) Schematic block diagram of structural control on fluvial system (from Berger, 1994).

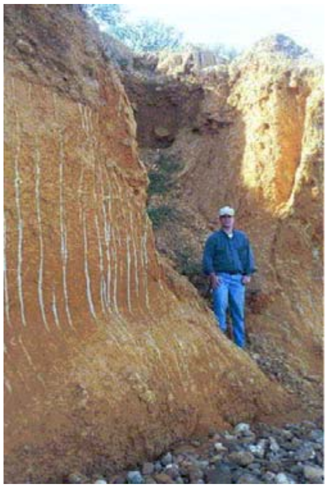
(Right) Fracture density contours from an area with channel sand production (Wyoming).





DIAGENETIC PROCESSES RELATED TO FRACTURES

Near-surface fractures with alteration related to hydrocarbon microseepage (Venezuela).



FACTORS IN PLANNING A SUCCESSFUL FRACTURE DENSITY ANALYSIS

SELECTION OF WORK SCALE

An appropriate work scale will depend on the resolution needed to meet the project objectives, the size of the study area, and any cost considerations. A detailed analysis at a scale of less than 1:50,000 is usually recommended for uses such as well siting and other field development tasks. A more general analysis is typically appropriate for determining regional trends over large areas. For these applications a work scale of roughly 1:100,000 may be preferred. However, depending on the area an even smaller scale (such as 1:250,000) may still be appropriate.

SELECTION OF IMAGERY

Multispectral satellite imagery such as Landsat TM has the advantage of providing data for a large area at a relatively low cost. In addition the multispectral capabilities mean that the data can be processed to enhance features such as subtle differences in vegetation that can be used to identify fractures. Landsat TM data's resolution of about 28 m is sufficient for most regional studies for exploration trends.

For studies that will be used for detailed analysis or that cover a small area, higher resolution data such as aerial photographs or CORONA declassified satellite data (resolution about 2 m) may be preferred. Another advantage of these data sources is that stereopairs may be obtained. Stereo interpretations are extremely useful when detailed fracture analysis is required.

MAPPING BASE

Because fracture density analysis is used to evaluate geologic characteristics of particular locations, it is critical that the fractures be plotted on a spatially-accurate base map. Most satellite imagery can be orthorectified and used as a mapping base prior to picking fractures. However, portions of stereo images, such as stereo aerial photographs and CORONA data, are spatially distorted. Therefore, fractures picked from these sources must be replotted onto an orthorectified image (such as processed Landsat TM data).

INTERPRETATION OF RESULTS

The correlation between productivity and fracture density varies depending on the geologic regime. For many settings, the best production is directly in areas of high fracture density. However, there are certain locations where productivity is best along the edges of the high fracture density trends, or even between fracture density highs (for example, where fracture cementation is an issue).

Because the ease of identifying fractures varies throughout a given mapsheet, the fracture density values should be interpreted relative to surrounding values in localized portions of the map. For example, a value between 1100 and 1300 (light green) may represent a high density in one portion of the mapsheet, or a low density in another portion of the mapsheet.

EXAMPLE -- POWDER RIVER BASIN

In the Powder River basin, fracturing is important for oil and gas exploration in several ways. Faulting and associated fracturing influenced the location of channels and long-shore bars during deposition of several of the productive Lower Cretaceous units. Fracturing enhances the permeability and bulk porosity of several productive sand intervals. It is possible that increased fracture density, by virtue of differential compaction over buried sand bodies, may mark the location of potentially productive sand bodies. Furthermore, most of the hydrocarbon production in the Powder River basin comes from stratigraphic or fracture-enhanced reservoirs that are not related to traditional structural traps such as anticlines or domes and consequently are not easily observable on seismic data.

Considering the importance of fracturing, a fracture density analysis of the Powder River Basin was completed to look for exploration targets. Orthorectified Landsat Thematic Mapper imagery was selected as the data source and mapping base. A mapping scale of 1:100,000 was used to provide basin-wide coverage of fracture trends. The fracture analysis was done blind (i.e., without reference to geologic maps or maps of existing hydrocarbon production). The fractures were then digitized, input into a Geographic Information System, and rasterized. Fracture density was calculated using standard algorithms, fracture density values were contoured, and Rose Diagrams were generated. This analysis indicated that the fractures in the Powder River basin generally trend N35^{o}-55^{o}W and N40^{o-}60^{o}E. There are also two other prominent sets of fractures, one oriented roughly north-south and another oriented east-west.

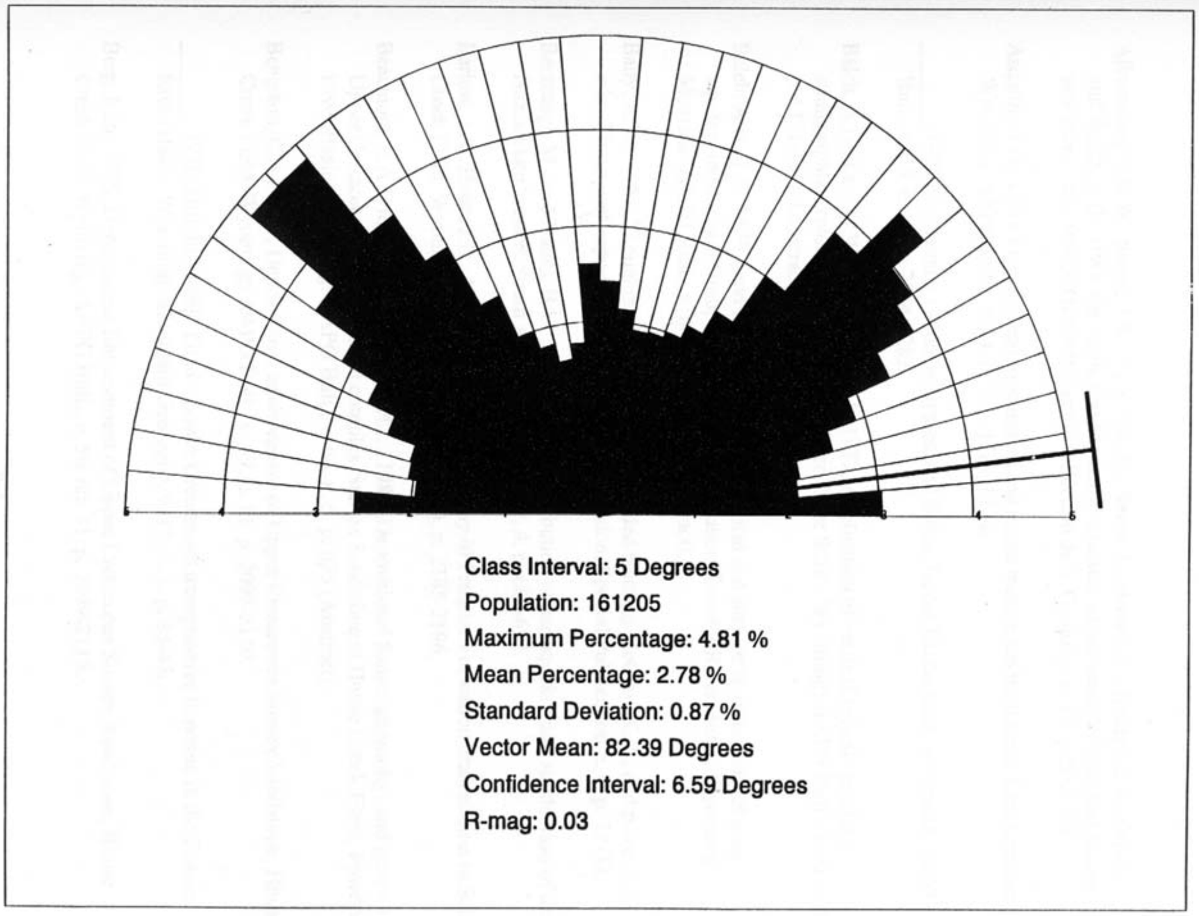
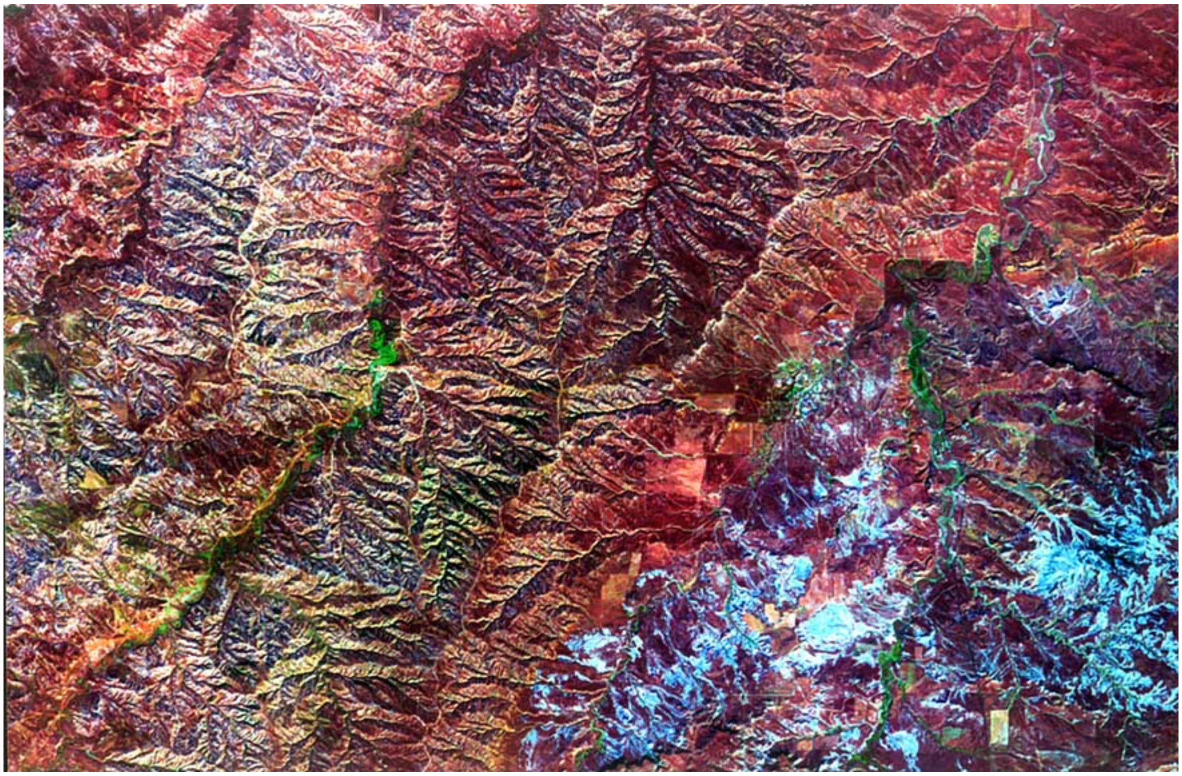


Figure 5.6 Rose diagram for entire Powder River Basin.

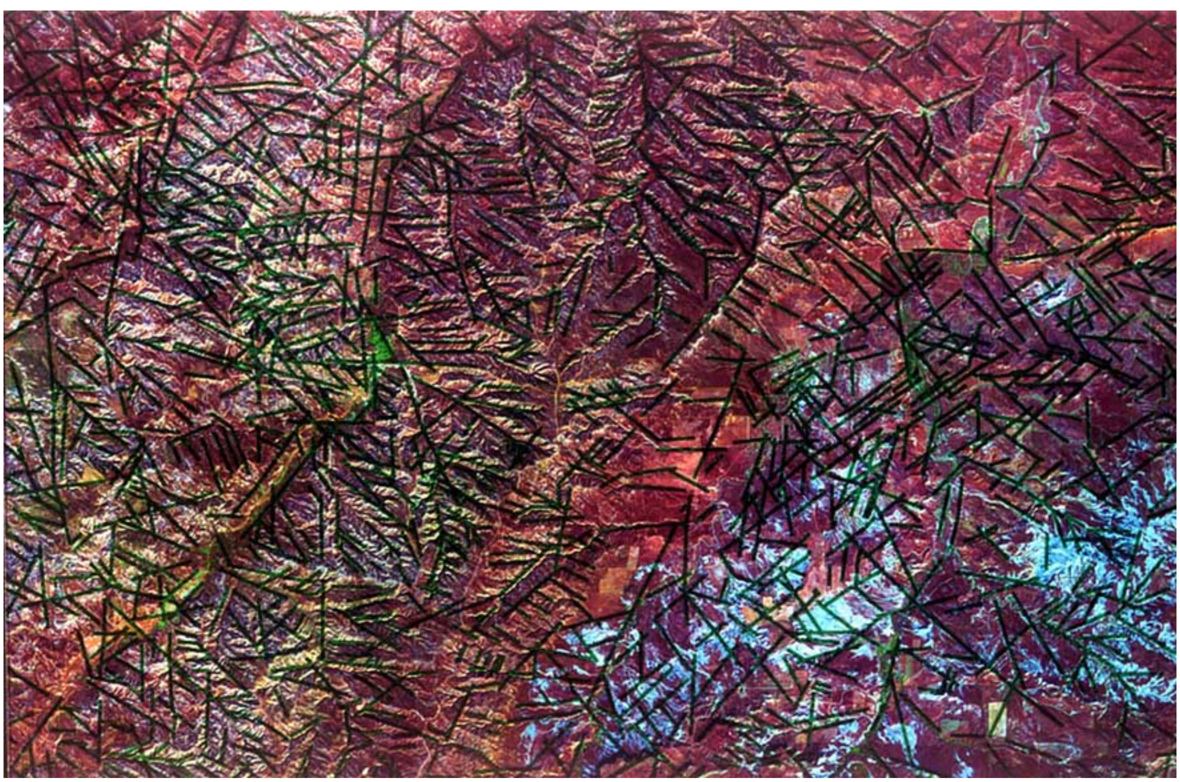
Fracture density values were then compared to existing limits of production based on the 1996 Wyoming Geologic Survey's Oil and Gas Map. These fracture directions are coincidental with the orientation of sand bodies and oil fields in this region. At several locations, there is also a strong congruity between fracture distribution and production. Examples of the thirty-five fields that show a strong positive correlation with fracture density highs in the study area include: House Creek, Kitty, Dead Horse Creek, Fiddler Creek, Clareton, Lance Creek, Kaye, Poison Draw, Teapot Dome, and Big Muddy fields. For several fields with Frontier production there appears to be an inverse correlation between fracture density and production.

As the figures below show, both Kaye Field and Lance Creek Field show a correlation between the extent of production and fracture density even though these fields produce from different formations. Production at Lance Creek is predominantly from the Jurassic Canyon Springs Sandstone. Canyon Springs Sandstones are apparently a beach and near-shore marine sandstone complex. Kaye Field produces predominantly from the Teapot sandstones of the Mesa Verde Group, deposited as delta front and barrier bars during a regressive cycle. In each of these formations, deposition of reservoir-quality sands was apparently controlled by fractures or small faults.

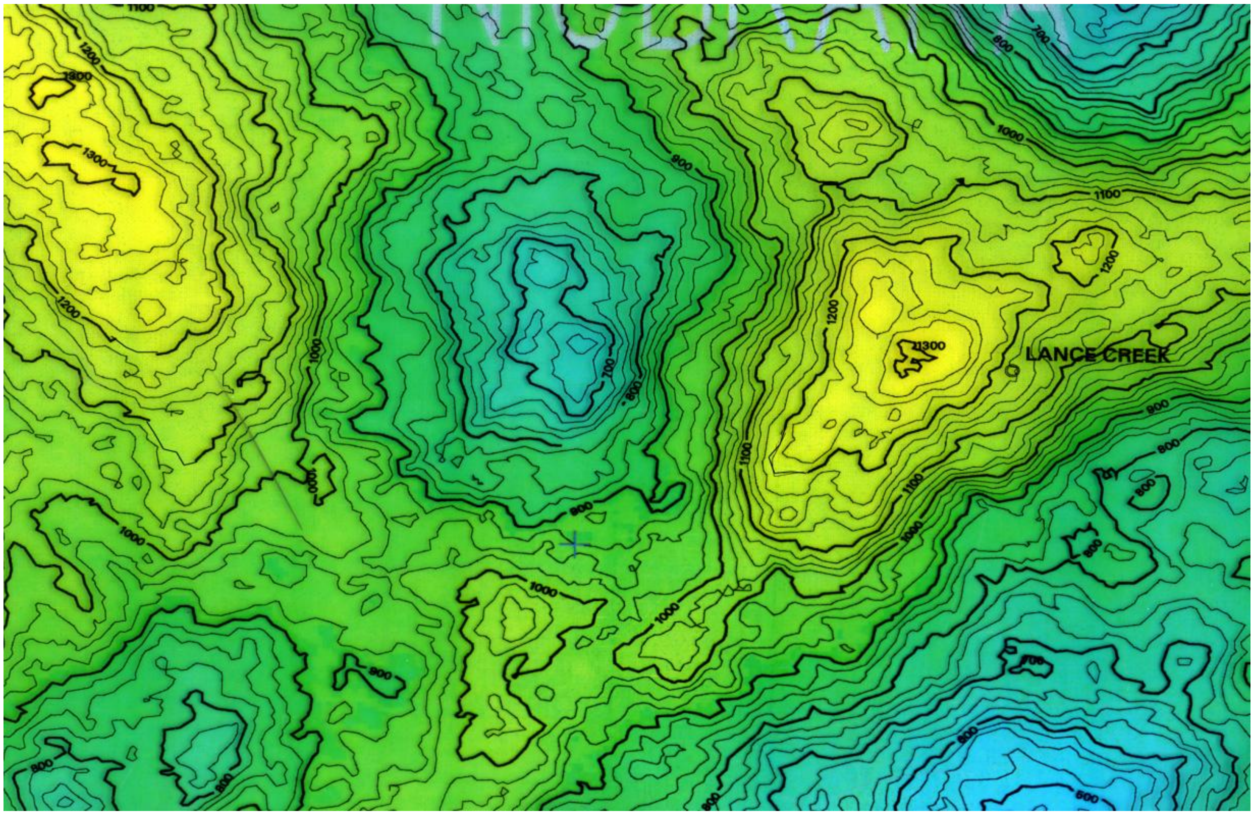
Landsat TM Image Over Kaye And Lance Fields



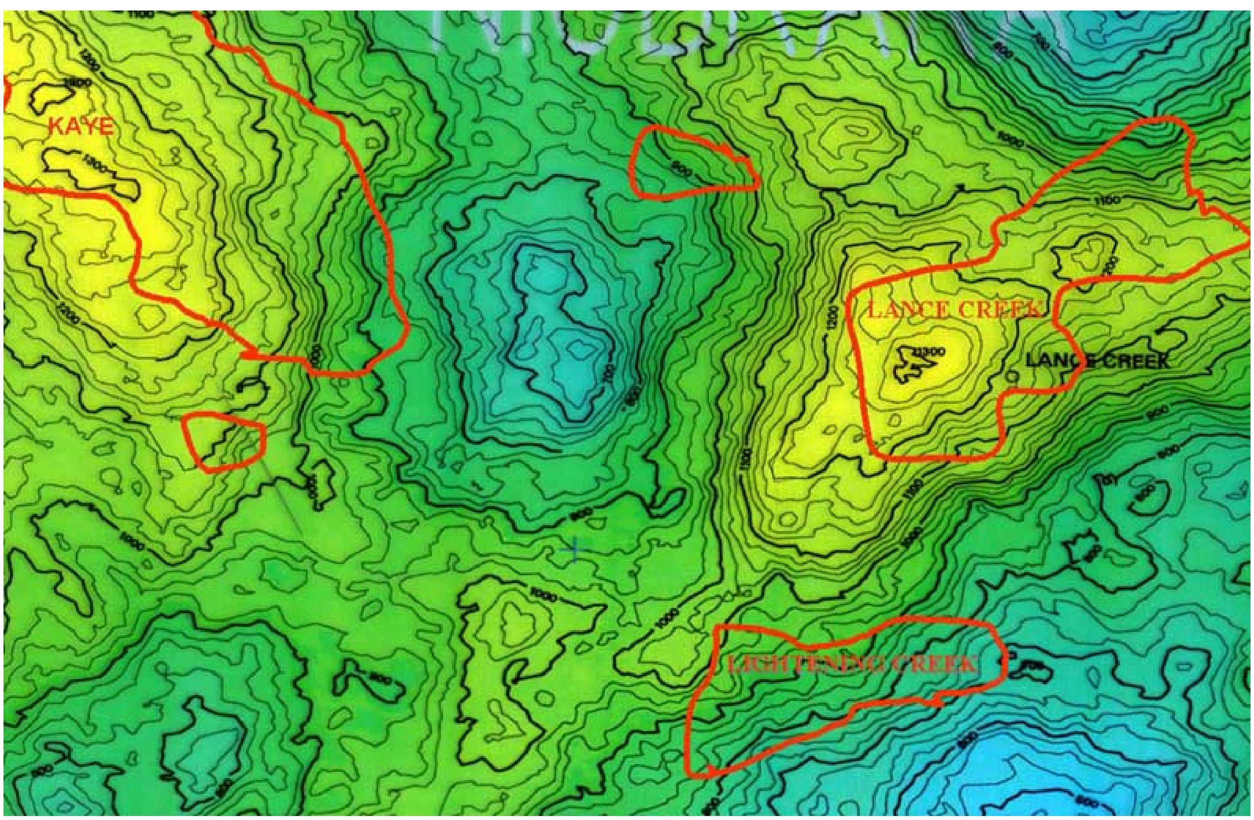
Landsat TM Image Over Kaye And Lance Fields With Fracture Interpretation



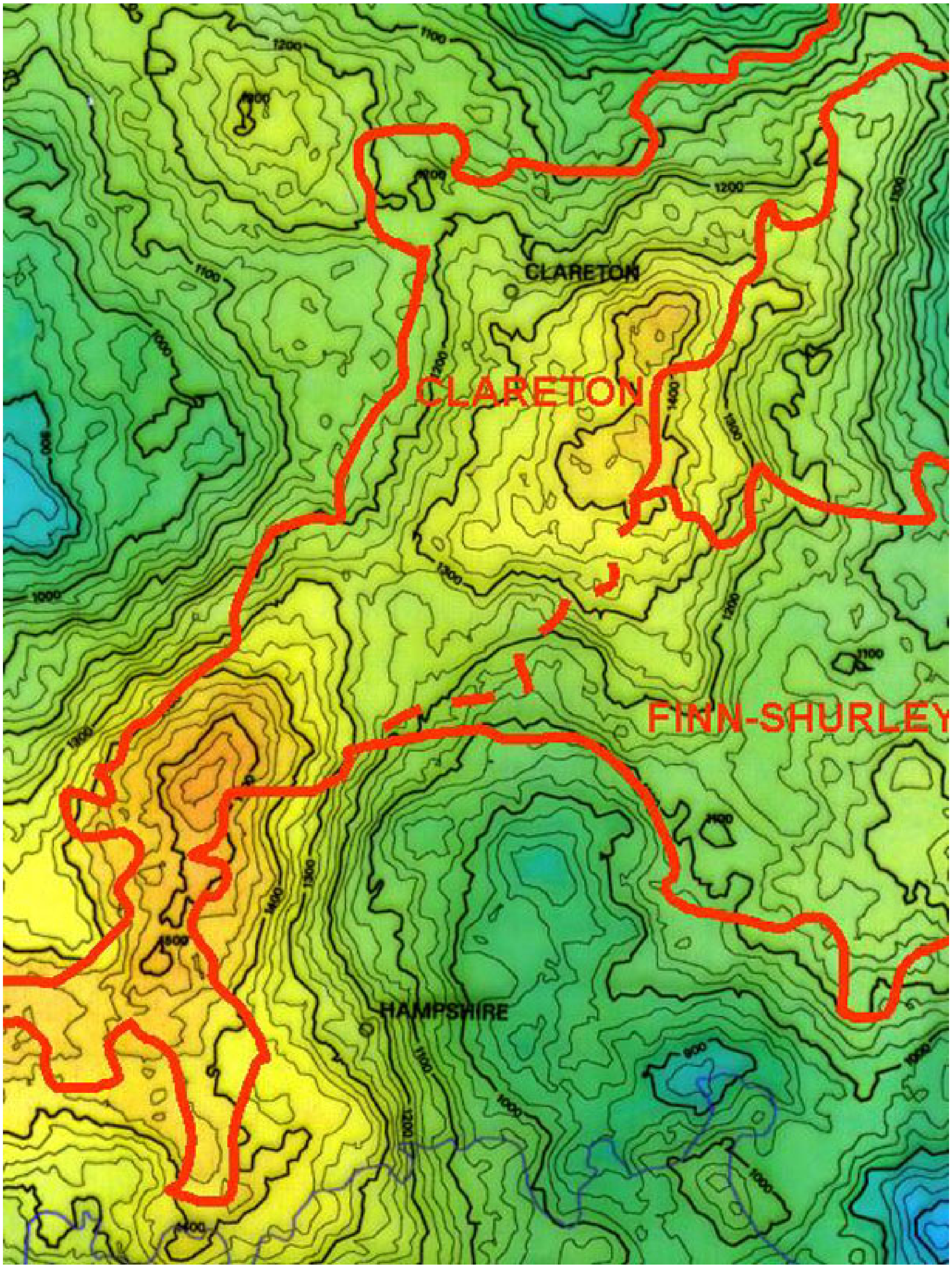
Fracture Density Contours Of Interpretation Over Kaye And Lance Fields



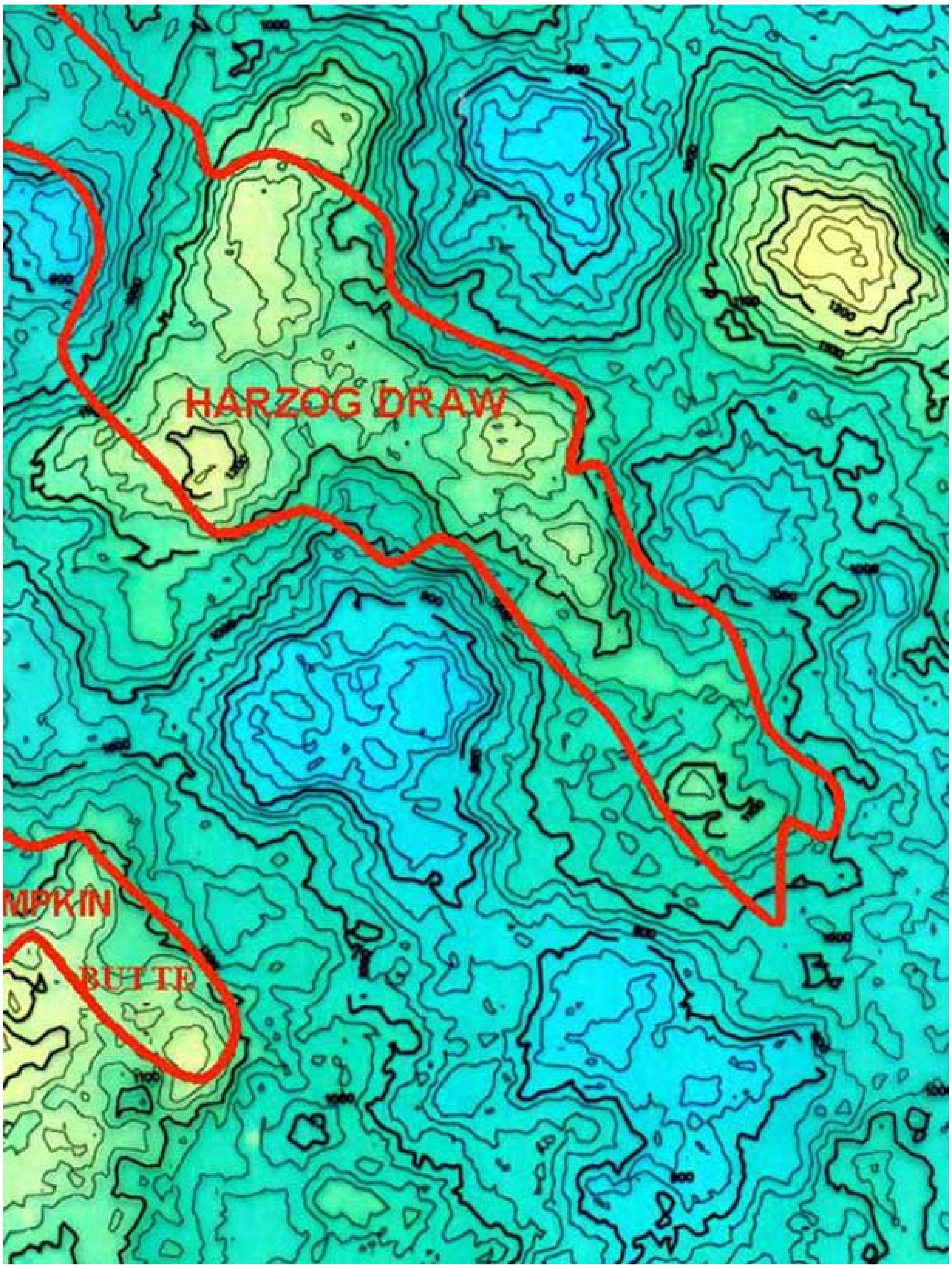
Fracture Density Contours Over Kaye And Lance Fields And Field Outlines



Another example from the eastern Powder River Basin is the comparison between the extent of production at the Clareton field and fracture density (see next page). At Clareton production is from Lower Cretaceous formations such as the Muddy, which were deposited in a complex fluvial and marginal marine environment. The Lower Muddy channel sandstone at Clareton field is localized along the downthrown side of northeast-trending faults.



The figure below shows an example from the western Powder River Basin. Harzog Draw produces predominantly from the Upper Cretaceous Shannon formation. Sandstones of the Shannon formation are interpreted as offshore marine sands that were initially deposited by long-shore currents on the continental shelf. These sands were later reworked into discrete sand bodies by storm waves and tidal currents. At Harzog Draw, the traps are largely stratigraphic where the permeable sand lenses change updip to impermeable sandstone, siltstone, or shale. The range of fracture density values in this area is less than in the other examples, but even in this case, it is still apparent that the fracture density trends correlate with the extent of productivity.



SUMMARY

Fracture density analysis uses satellite or aerial imagery data and geographic information systems to explore for:

- Highly fractured areas due to tectonic stress;
- Fractures related to diagenetic processes; and
- Depositional features controlled by basement block faulting.

In addition, fracture density analysis has found new use in planning field development measures such as hydrofracing.