Gulf Publishing Company
www.worldoil.com
November 2003

EXPLORATION TECHNOLOGY

Nov. 2003 Vol. 224 No. 11
Feature Article

Fracture and satellite hyperspectral analysis for petroleum exploration

Correlating fracture density and productivity, orienting horizontal wells, finding vegetation differences related to fracture zones and focusing seismic surveys are some of the uses for this remote sensing technique

John R. Everett and Ronald J. Staskowski, Earth Satellite Corporation, Rockville, Maryland; and
Robert D. Jacobi, University at Buffalo, The State University of New York

Although the importance of fracture porosity and permeability to producibility has long been recognized, 30 years ago one seldom intentionally explored for fracture targets. Times have changed, and companies are pursuing a variety of fracture plays like the Barnett shale, Niobrara, Austin chalk, coal bed methane, and "hydrothermal" dolomite plays. Understanding fractured reservoirs has evolved to the point that they now constitute an intentional exploration target.

Before horizontal drilling and 3D seismic acquisition, fractured reservoir targets were notoriously difficult to explore for and drill successfully. It is still costly and frustrating to explore for these targets without some method of focusing the acquisition of seismic data. Two research projects by Earth Satellite Corp. in 1997 and 2002 for the New York State Energy Research and Development Authority (NYSERDA) focused on Devonian shale reservoirs and the fractured carbonate reservoirs of the Trenton-Black River sequence.[1,2] These demonstrated that careful analysis of satellite data can provide guidance for seismic data acquisition and orientation of horizontal boreholes. The research produced several practical observations:

- There is good correlation between areas of high fracture density and petroleum production from fractured Devonian shales and Ordovician carbonates.
- Prominent fracture zones mapped from satellite data match mapped fault zones (e.g. Clarendon-Linden), previously unmapped fault zones, fracture intensification domains, and known and suspected basement faults.
- ASTER satellite data is useful for locating major fracture zones and detecting subtle differences in vegetation, soils and rocks related to the presence of hydrocarbons.
- Fieldwork verified the location and orientation of fractures seen in satellite data and the differences in vegetation within and outside of fracture zones.
- Ground geochemical surveys by the University of Buffalo verified the presence of hydrocarbons along specific satellite-defined fracture zones[3].

Fracture Density and Production

The relationship between areas with a relatively high density of fractures and production from fractured reservoirs has been known or suspected for a long time. The exact nature of this relationship may be different from place to place. In the Powder River basin of Wyoming, small displacement faults and fracture zones controlled the deposition of reservoir facies, (e.g. channel sands of the Muddy formation or the coast-parallel marine sands of the Shannon and Sussex formations). The upward propagation of these fault and fracture zones, some of which define edges of structural blocks, produces the high density of fractures visible at the surface that coincide with the fields.

In other areas, like the Bass Island Trend and Devonian shales of New York, much of the fracture related production occurs along the traces of post-depositional “blind” thrust faults. Fracturing in these reservoirs and fracturing seen at the surface are both related to structural events that occurred after deposition of the reservoir and source rocks. Productivity in Devonian shales is in part the result of geologic good fortune. When the east-northeast-trending fractures formed, they were compressive fractures and tightly closed. Since the Alleghenian orogeny, the stress field has been reoriented nearly 90°, so that the east-northeast fractures are extensional and relatively open standing, and consequently productive.

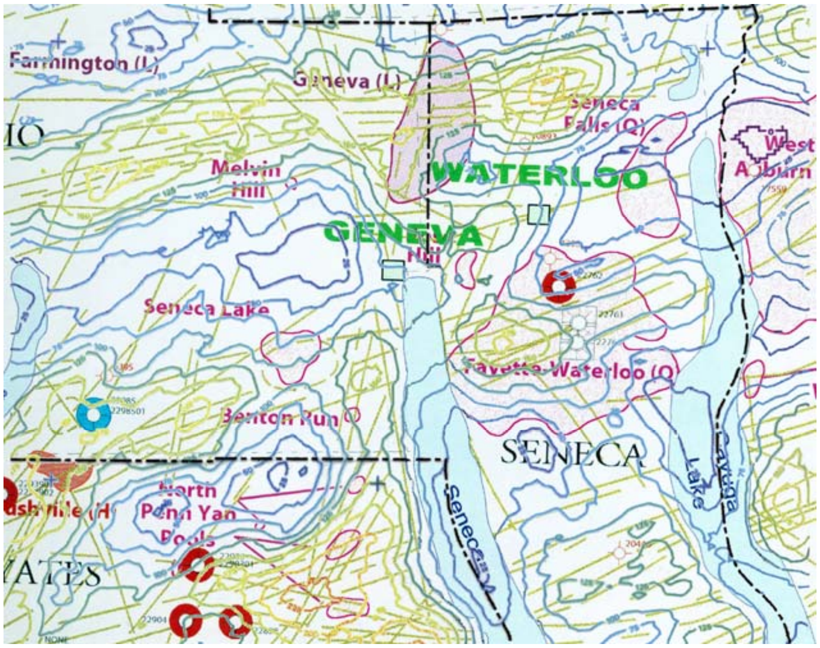
A third possible relationship is when major fault or fracture zones have acted as channels for fluid movement out of basins or generating source rocks. Fractured carbonate fields (a.k.a. hydrothermal dolomite fields) like the Trenton-Black River Glodes Corners Road, New York and Stony Point and Albion-Scipio fields, Michigan, are end members of a continuum that includes Mississippi Valley type (MVT) lead-zinc deposits at one extreme, and oil and gas fields at the other extreme.

Both oil fields and MVT deposits involve the movement of large volumes of relatively low temperature fluids (~ 70ºC < 200ºC; most range 70ºC-150ºC). As a result, fractured carbonate rocks have undergone a substantial amount of dissolution, dolomitezation, and mineralization (PbS, ZnS, CaF_2), with porosity and permeability confined to solution enhanced fracture systems and dolomitized wall rock immediately adjacent to the fracture system. (Interestingly enough, the 70-200º temperature range is also the range associated with the generation and expulsion of hydrocarbons from source rocks). Once the dissolution and dolomitization (which produces a 14% reduction in rock volume and concomitant increase in porosity) occur and the hydrocarbons wet the fracture surface, it is unlikely that later mineralization or changes in stress regime will close the fractures and destroy porosity and permeability.

Other possible relationships between fractures at the surface and production at depth include: differential compaction over buried traps (anticlines or salt domes), active extensional tectonics, or auto-hydrofracing related to generation and expulsion of hydrocarbons from source rocks. It is possible that hydrocarbons escaping vertically from an accumulation may simply enhance the visibility of fractures by virtue of surface rock alteration, mineralization, or geobotanical effects resulting in a higher apparent density of fractures over accumulations.

Mapping fracture-density in New York involved carefully interpreting Landsat satellite images for fractures, digitizing the fractures, and then sampling the density of fractures by moving a circular kernel of a given diameter over the digital fracture map and recording the total length of fractures within the kernel at each point on the sampling grid. These values were then contoured producing a map of *length of fracture per unit area* for each point on the map. When this map was compared to maps of existing production in central New York State, it revealed a strong correlation between zones of higher fracture density and production (Fig. 1).

Fig. 1. Correlation of production from Devonian wells and fields (in red), Ordovician wells & fields (in purple), and areas of higher fracture density (red, yellow, & green contours).



Comparison of fracture density maps to cumulative production indicated that many wells with large cumulative production also lay within a satellite mapped fracture or in areas of high fracture density. Additional comparison of the satellite-derived fractures and fracture density maps to existing geologic mapping, subsurface data, and earthquake records revealed that satellite-mapped fractures coincided with all of the major mapped faults (e.g., Clarendon-Linden and the faults controlling the Bass Island trend).

Several seismic events not associated with known faults lay along mapped fractures or trends of high fracture density, suggesting that seismic events may have occurred along the edges of deep-seated structural blocks. Synthesis of subsurface and other data with the fracture density mapping demonstrated or strongly suggested the existence of several previously unrecognized faults, (Fig 2).[4]

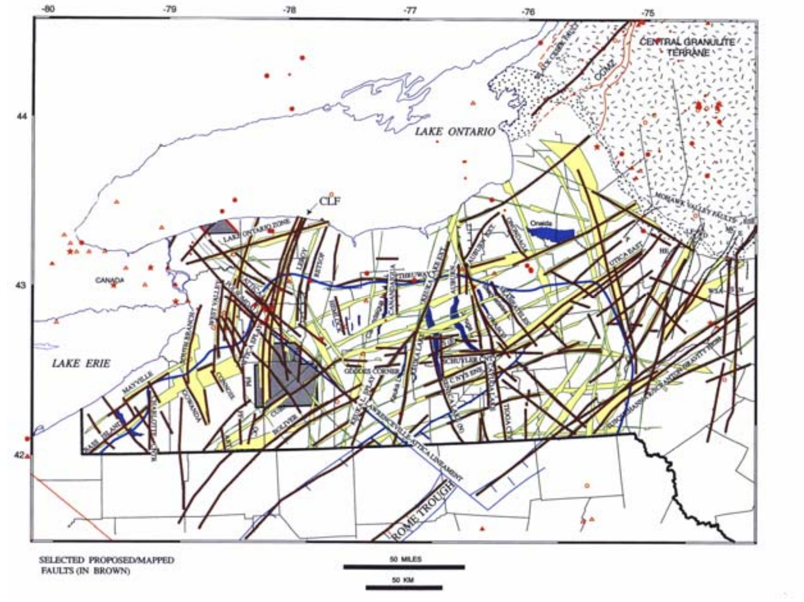


Fig. 2. Correlation of Landsat/ASTER fracture density highs (in yellow) with proposed/mapped faults (in brown); after Jacobi (2002).

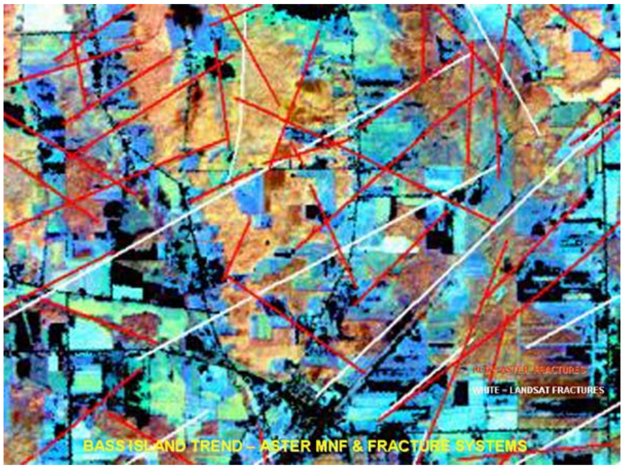


Fig. 3. ASTER MNF image with fracture analysis.

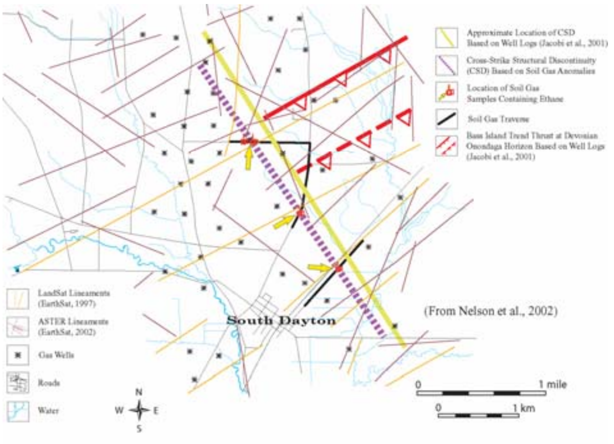


Fig. 4. ASTER & Landsat fracture analyses, production, and soil gas transects; same area as Fig. 3.

Leaking Hydrocarbons and ASTER

The ASTER satellite looks at the earth in 14 different spectral bands. Two of these bands are visual (yellow and red); one band is infrared that grasshoppers and other insects see; six bands are shortwave infrared, which differntiate several minerals (e.g., kaolinite, gypsum, limestone, doloite) that may be related to the presence of hydrocarbons; and five bands detect heat or thermal infrared energy, which can differntiate a number of different rock types.

Like the Landsat imagery, ASTER imagery of the Bass Island trend revealed many fractures and fracture systems (Fig. 3). Many of the Landsat fractures (white lines) and ASTER fractures (red lines) were collocated. Several of the satellite-mapped fracture systems coincided with fracture systems of the Bass Island structural trend and with fracture intensification domains (FID) mapped by University of Buffalo geologists. Spectral anomalies marked some of the fractures. A soil gas survey by the University of Buffalo[5] crossed several of these Landsat and ASTER fractures and FIDs (Fig. 4). The survey showed that soil gas values (C_1 - C_2) are elevated in the satellite mapped fracture systems and FIDs.

Field checking in the Glodes Corners Road field area during the Fall of 2002 confirmed that at every location with reasonable outcrops, there were joints and small faults that coincided with the fractures mapped in the imagery.

As can be observed in Fig. 5, much of this area of New York is forested (i.e., vegetated). Vegetated areas are particularly challenging in the search for hydrocarbons. The response of vegetation to hydrocarbon in the soil is strongly location-specific and depends on climate, drainage, soil type, and available vegetation communities, to list a few. Because hydrocarbon microseepage occurs for long periods of time relative to the life span of vegetation, the hydrocarbons do not actually produce vegetation "stress" in the usual sense. Rather, the presence of hydrocarbons produces structural changes in the vegetation community, such as changes in species, plant distribution, crown density, leaf structure, apparent vigor (dwarfs or giants). These changes in the vegetation community, over an actively seeping area, in turn produce subtle changes in the spectral reflectivity of the area.

In the Glodes Corners Road field area, the fall colors of the leaves revealed that the tree communities within the fracture zones marked by spectral anomalies were very different from the tree communities outside the fracture zones. Oak hard wood forests constitute the majority of the forests in the area. Within the fracture zones mapped on the ASTER data, maples, green ash, poplars, and basswood with their bright fall colors are common. This difference in color and tree species is obvious in the fall when the leaves have turned, but the ASTER imagery was acquired in the summertime when tree color and species differentiation were not as

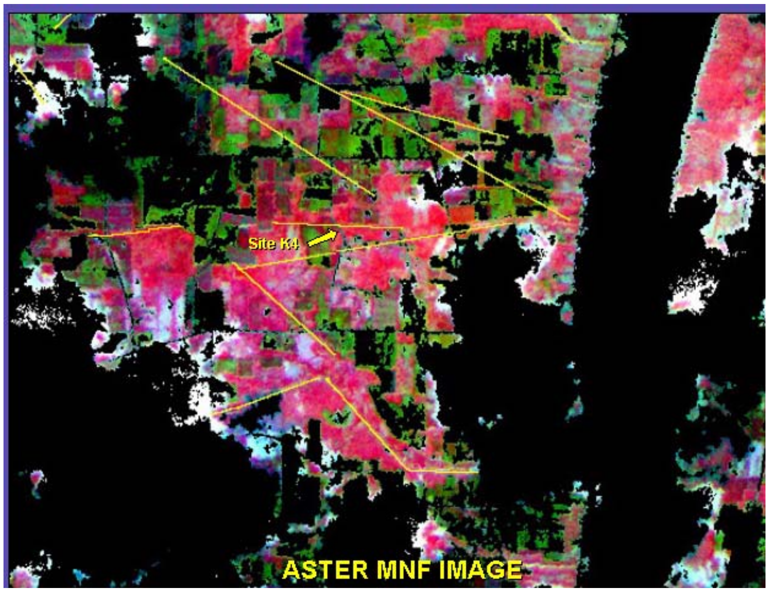


Fig. 5. ASTER MNF image of Site K4.

obvious to the unaided eye. The difference in forest types extended beyond the creek bottoms and drainage features that marked many of the fracture zones and was not solely related to differences in soil moisture. Apparently the ASTER data were detecting subtle differences in the spectral characteristics of the different forests.

In the Geosat Report[6], Barry Rock noted the same type of anomalous vegetation associated with the Lost River gas field in West Virginia. The explanation is that mycorrhizal fungi have a symbiotic relationship with the trees. The fungi are crucial to the uptake of nutrients for the trees. In poplars, beeches, basswood, and some maples, the fungi are internal to the root structure. In oaks, these fungi are in external nodes on the roots making oaks less tolerant to water - saturated or gas-saturated soils. Consequently, where there is an absence of oaks or an abundance of poplar/maples away from water-saturated areas, one might suspect the presence of hydrocarbons in the soil.

In the Glodes Corners Road field area, this appears to be the situation over many of the ASTER fractures. In these fractures there is usually a topographic break with a corresponding lowland, creek, or stream. However, the maple/ poplar community covers a much wider area than the stream bed or adjacent saturated area. Fig. 5 shows a fracture in the ASTER data. On the aerial photo in Fig. 6, the ASTER fracture system appears as a dark alignment in the forest. On the ground, the dark area is a very small stream, Fig. 7. As seen from the road in Fig. 8, there is a profound difference in vegetation inside and outside the fracture zone.

This area is roughly on-trend with Glodes Corner Road field. These same types of spectral anomalies and vegetation patterns are present throughout the area. In this area, where natural oil seeps and production along some of the fracture zones that spectral anomalies highlighted, is a natural oil seep located in an ASTER fracture that trends N85°E. Production occurs adjacent to this fracture zone and oil seepage and the vegetation anomaly marking this fracture zone trends almost east-west.

Fig. 6 Aerial photo of Site K4.

Fig. 7 Ground photo of Site K4, looking due west.

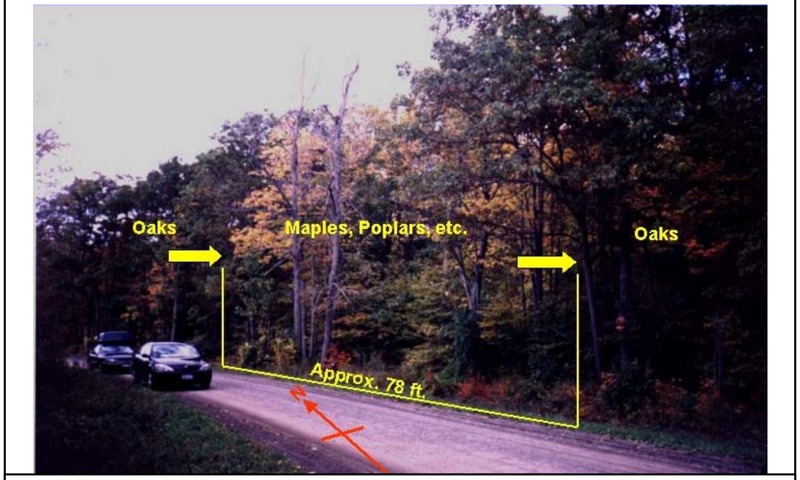


Fig. 8 Glodes Corners Road vegetation anomaly, Site K4.

Conclusion

All of the evidence suggests that one can use satellite data to focus more expensive exploration tools (e.g., ground geochemical or seismic surveys) in the search for fractured reservoirs. Some of the faults or structural block boundaries identified or implied by the fracture data may be new exploration fairways. Areas of high fracture density may indicate potential exploration targets.

Literature Cited

[1] Earth Satellite Corp. (EarthSat), "Remote Sensing and fracture analysis for petroleum exploration of Ordovician to Devonian fractures in New York State," New York State Energy Research and Development Authority (NYSERDA), Albany, NY, 1997.

[2] Earth Satellite Corp. (EarthSat), "Assessing the contribution of satellite hyperspectral data to petroleum exploration, New York State Energy Research and Development Authority (NYSERDA), Albany, NY, 2002.

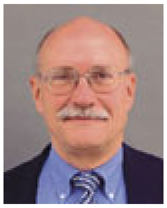
[3] Jacobi, R.D., Fountain, J. and Loewenstein, S., "Demonstration of an exploration technique integrating EarthSat's Landsat lineaments, soil gas anomalies, and fracture intensification domains for the determination of subsurface structure in the Bass Island Trend, New York State," Final report: New York State Energy Research and Development Authority (NYSERDA), Albany, NY, 2001.

[4] Jacobi, R. D., "Basement faults and seismicity in the Appalachian basin of New York State, *Tectonophysics*, Vol. 353, Issues 1-4, 23 August 2002, p. 75-113. "The use of soil gas surveys to delineate subsurface structure: Cross-strike discontinuity locations for the Bass Island Trend in western New York, in poster session*:* Northeast Section, Geological Society of America, thirty-seventh annual meeting, Springfield, MA, March 25-27, 2002.

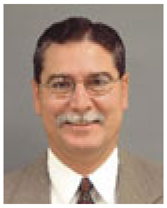
[5] T. Nelson, J. C. Fountain, R. D. Jacobi, T. Witmer, and R. Bieber, "The use of soil gas surveys to delineate subsurface structure: Cross-strike discontinuity locations for the Bass Island Trend in western New York," in poster session: Northeast Section, Geological Society of America, thirty-seventh annual meeting, Springfield, MA, March 25 - 27, 2002.

[6] Lang, H. R., J. B. Curtis, and J. S. Kovacs, "Lost River, West Virginia, Petroleum Test Site Report: *in* The NASA/Geosat Test Case Project Final Report, Part 2, Vol. II, section 12, American Association of Petroleum Geologists, Tulsa, OK, 1985.

The authors



Dr. John R. Everett, is a vice president and chief geologist at Earth Satellite Corporation. He is responsible for the technical aspects of geological projects. Dr. Everett received a BS in geology at the University of Oklahoma and a MA and PhD in geology at the University of Texas.



Ronald J. Staskowski is a vice president and the Director of Geology and Hydrology at Earth Satellite Corporation. He joined EarthSat in 1980 after completing course work for a MS in Remote Sensing / Geologic Applications at the University of Michigan. Mr. Staskowski also holds a BS degree in earth sciences from the University of California, Santa Cruz, and a BA in psychology from the University of New York, Potsdam.

Dr. Robert D. Jacobi is a professor at the University at Buffalo, The State University of New York. He specializes in sedimentology, fault and fracture systems, and stratigraphy. Dr. Jacobi received a BA in geology at Beloit College and a MPhil and PhD in geology at Columbia University.

EARTH SATELLITE CORPORATION (EarthSat)
6011 Executive Boulevard, Suite 400,Rockville, MD 20852
Telephone: (240) 833-8200 FAX: (240) 833-8201
rstaskow@esarthsat.com or jeverett@earthsat.com
www.earthsat.com
EARTHSAT