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## Fracture Analysis For Petroleum Exploration Of Ordovician To Devonian Fractured Reservoirs In New York State Using Satellite Imagery

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**Abstract**

Fracture analysis and geologic interpretation of digitally-enhanced, Landsat Thematic Mapper images covering virtually all of New York State showed a strong correlation between sites of high fracture density and production from Devonian and Ordovician reservoirs. The 1:250,000 scale interpretation focused on mapping surface fractures and structures indicative of fractured reservoir conditions at depth and identifying any tonal or vegetation anomalies potentially associated with the seepage of hydrocarbons. Integration of the geological analysis, fracture density contour maps, and production data in an ARC/INFO GIS led to the selection of twenty-one exploration fairways.

Mapped surface faults (e.g., Clarendon-Linden) are clearly delineated and recent research has revealed that many of the interpreted fracture zones correlate with previously unmapped surface faults and known or suspected basement faults. East-northeast trending bands of high fracture density coincide with fracture intensification domains, soil gas anomalies, and the axes of Appalachian folds and thrusts. In the ambient stress field, these fold/thrust parallel fractures are open-standing, enhancing production from the otherwise tight Ordovician to Devonian limestones and shales. In combination with an analysis of the stress history and the thermal maturation and migration history of source rocks, fracture density contour mapping is a useful guide for exploration of fractured reservoirs.

**Introduction and Methodology**

In New York State and adjacent regions, hydrocarbon production from Ordovician to Devonian reservoirs depends on fracture permeability and porosity.

The goal of this project was to create a series of interpretative and analytical geologic tools in electronic format to assist in the assessment of large portions of New York State for exploration of fractured-reservoir, hydrocarbon production.

The base for this assessment was a detailed (1:250,000 scale) geologic interpretation of ten digitally enhanced, Landsat Thematic Mapper (TM) images covering all of New York State except for New York City and Long Island. In addition to this analysis, the ten images were digitally mosaicked into a single picture of New York State (1:500,000 scale) to provide a coherent view of the entire area. The digital mosaic was divided into four 1:250,000 scale image map sheets based on the 1:250,000 scale, Geologic Map of New York (1970), for ease in data integration with other data sets. The geologic interpretation focused on the interpretation of fractures and structures that may indicate fracture reservoir conditions and any tonal or vegetation anomalies that may indicate the seepage of hydrocarbons. Integration of this interpretation with a careful synthesis of the literature and other existing data produced additional data layers and insights critical to basin wide evaluation of the potential for fractured reservoir production. Some of the items of information that were particularly useful for this basin-wide study analysis were the distribution and depth of source/reservoir rocks as derived from well logs, oil and gas field production statistics, well location maps, the ambient state of stress and stress history, and the history of thermogenic generation and maturation of hydrocarbons.

The geologic interpretation was digitized and fracture density contour maps and rose diagrams were created for the entire study area and each of the four mapsheets. The combination and integration of all of the data sets in an ARC/INFO GIS led to the selection of 21 exploration fairways of high exploration potential for fractured reservoir production. All of the data layers (including the Landsat TM images and mosaic) were delivered in both hard copy and digital formats.

The study was designed to provide tools and information that are practical and useful at the basin level of exploration for commercial, fractured reservoir accumulations of oil and gas. To make the information interpreted from the remotely sensed data more useful, an examination of the stress history of the region has been undertaken in relation to the onset of maturation and generation of hydrocarbons. In most situations, the extensional fractures, that is those lying parallel to the ambient Maximum Principal Compressive Stress (MPCS) direction, are the most open-standing fractures, and consequently constitute the best reservoirs for hydrocarbon. However, there are areas where the onset of generation and migration occurred under stress conditions different than those now present. In these areas the open standing fractures at the time of generation may constitute good reservoirs either because they were enhanced by solution at the time of first migration or that wetting by hydrocarbons has prevented re-cementation. In order to know which fracture systems or which portions of a given fracture system are potential targets, one needs to know the distribution and depth of potential reservoir rocks. This study focused on the organic-rich, black and brown shales of Ordovician to Devonian age and the closely associated sandstones and siltstones. However, the work has obvious application to Ordovician carbonate reservoirs like the Trenton Black River portion of the section. These units would be susceptible to solution and dolomitization (the presence of base metal sulfides in these units may indicate the presence of hydrocarbons at least at the time of mineralization). Rocks of equivalent age and composition are prolific producers from fractured reservoirs in the Michigan basin and the area to the south in Ohio and Indiana and in the Devonian shale basin further south in the Appalachian basin.

**Results**

Statistical analysis of the fracture orientations mapped during this project reveals that the predominant fracture orientations for the entire study area trend N60º-65ºE (N50º-80ºE for the broad maximum), with minor maxima centered at N15ºE, N10ºW, and N85ºW. For the Niagara region (western New York), the predominant fracture directions trend N55º-70ºE, N25º-30ºE, N30º-50ºW, and E-W. In the Finger Lakes region (central New York), the predominant fracture orientations turn more easterly to N55º-80ºE (predominant maximum), N15º-20ºE, N5º-15ºW, and E-W. For the Adirondack region (northeastern New York), the wide variation in fracture directions is indicative of the fact that this area contains the northeastern-most portion (mostly Ordovician section) of the Appalachian basin, the St. Lawrence Lowlands portion of the study, and the anorthosites of the Adirondack Mountains. The predominant fracture directions in this region trend N60º-70ºE, N50º-55ºE, N20º-30ºE, N10º-20ºW, N30º-45ºW, and N55º-65ºW. In the Hudson region, the effect of basement reactivation of trends associated with the Taconic orogeny is evident (N5º-20ºE and N5º-20ºW trends) as are the trends associated with the eastern-most portion of the Appalachian basin (N45º-55ºW N25º-40ºE, and N45º-60ºE trends).

In pursuing fractured reservoirs, one of the most critical questions is: "What is the open-standing fracture direction?" In many reservoirs, it is the fracture zone perpendicular to the least compressive stress, or parallel to the maximum horizontal stress (Figure 1). Over much of eastern North America today, the maximum horizontal compressive stress trends east-northeast to northeast. Thus, the open fractures parallel that trend. Many of the Devonian shale fields lie on fracture density highs of this orientation.

However, with rocks that are susceptible to solution, dolomitization, or mineralization, one needs to consider both the stress history and the thermal history of maturation/ generation/ and expulsion of the source rocks as well as the current state of stress. This is so because the early expulsed fluids from source rocks are highly corrosive and can greatly enhance the porosity and permeability of fractures through which they pass by virtue of solution and dolomitization. Conversely, the orientation of the fractures used for initial migration or the orientation fractures created by autohydrofracing related to the overpressuring associated with the conversion of kerogen to hydrocarbon is determined by the stress field at that time.

In central and western New York State, the maximum principal compressive stress was oriented northwest to west-northwest during the Taconic, Acadian and Alleghenian orogenies. Thus, northwest to north-northwest fractures would have been open (Figure 2) at those times. Folds and thrusts from all three orogenies would strike northeast. The folding and thrusting produced an abundance of fractures parallel to fold axes or thrusts.

Generation and expulsion may have begun by Acadian, but was certainly underway by Alleghenian time. Consequently, the porosity and permeability of north-northwest fracture systems may have been enhanced and preserved (once a surface is wetted with hydrocarbons, secondary mineral growth is unlikely).

Figure 3 shows fractures that may have served as fluid migration pathways. Considering the tectonic and hydrocarbon generation history in this area, one might expect good production rates from Trenton-Black River reservoirs along north-northwest (fracture C) or east-northeast-trending fracture systems (fracture A). For Devonian reservoirs, the east-northeast fractures (fracture A) would be the first choice as a target.

Combining the well information, production statistics, fault and fracture interpretations, and fracture density contour maps in the ARC/INFO GIS facilitated identifying, characterizing, and highlighting those fracture zones, orientations of fractures, and specific areas that are of particular interest for exploration of hydrocarbons in fracture reservoirs. The tectonic history; ambient states of stress in the upper crust; hydrocarbon generation, maturation, and migration history; oil and gas show data; and knowledge of existing fracture-related production contributed to selection of the exploration fairways. Combination of the exploration fairways; the Devonian and Ordovician oil and gas field and well location data; the zero edge of the Silurian Salt; and the oil and gas data produced an "Exploration Fairways" data set.

Figures 4 through Figure 9 show the Geologic Structure Interpretation, Fracture Density Contour Analysis, and Exploration Fairways for the western two sheets of the study area (i.e., 6 of the 12 sheets presented during the poster session).

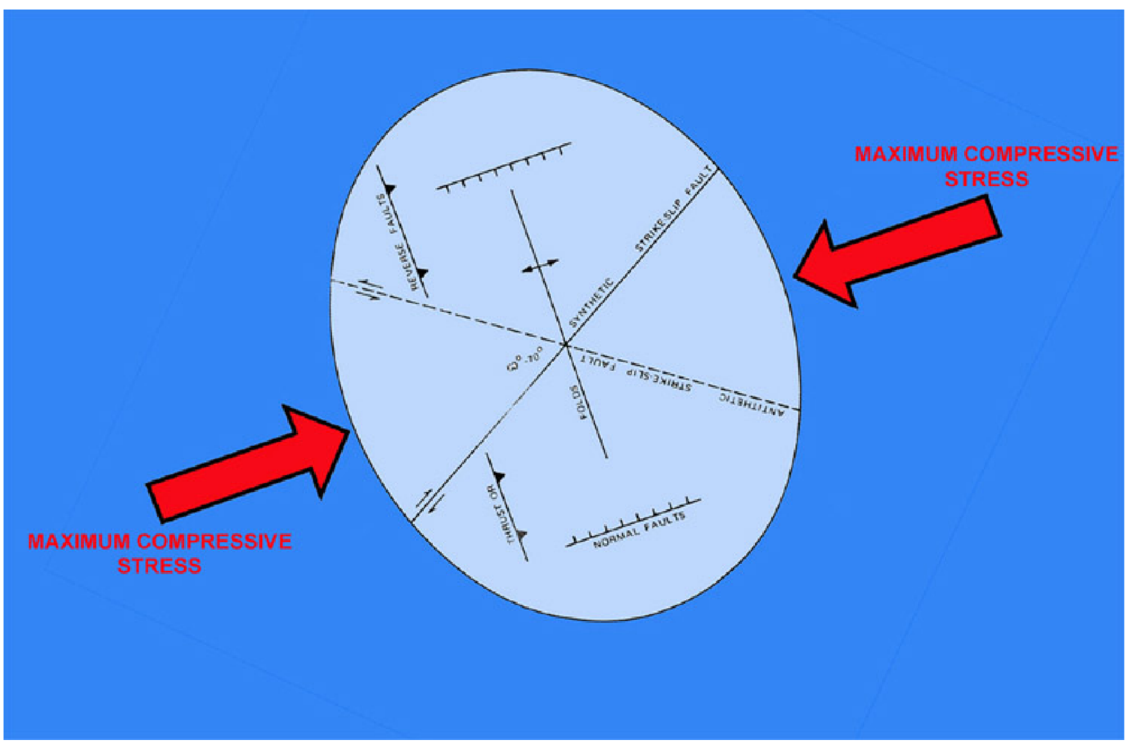


**Figure 1:** Current maximum compressive stress in eastern North America.

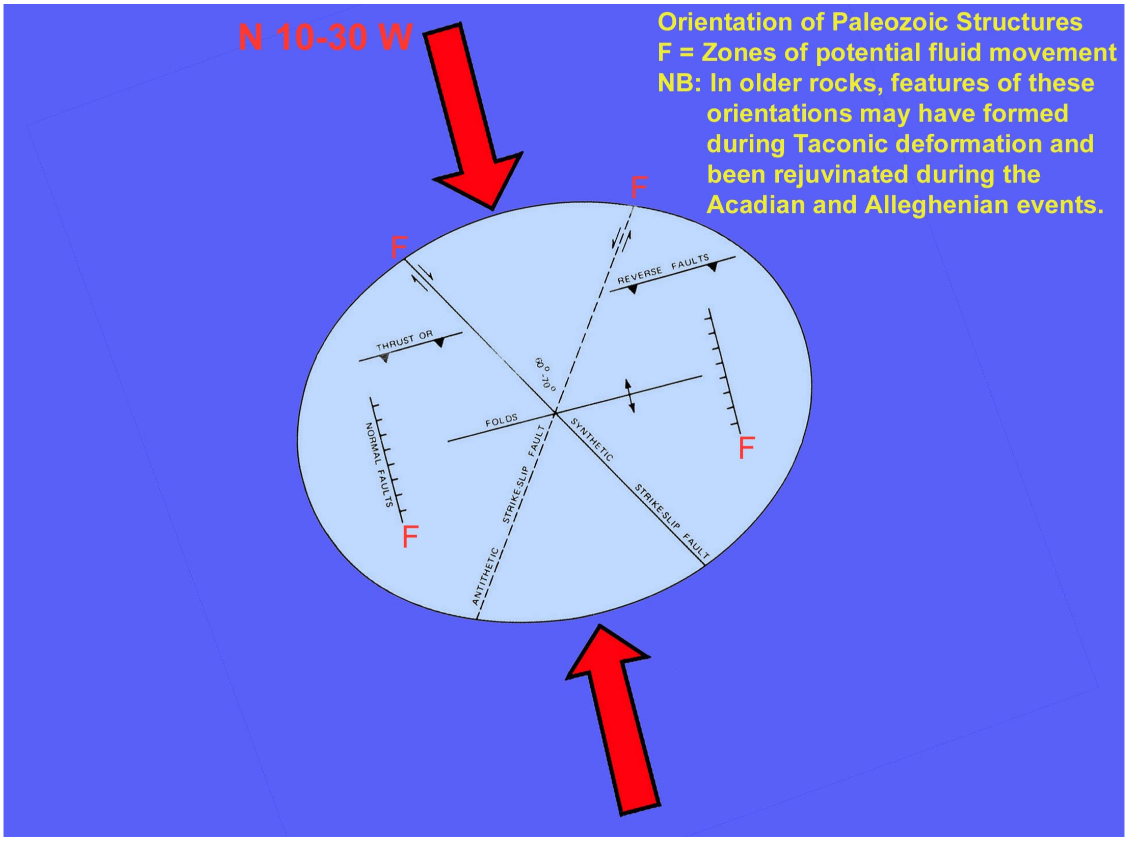


**Figure 2:** Maximum compressive stress during the Taconic, Acadian and Alleghenian orogenies.

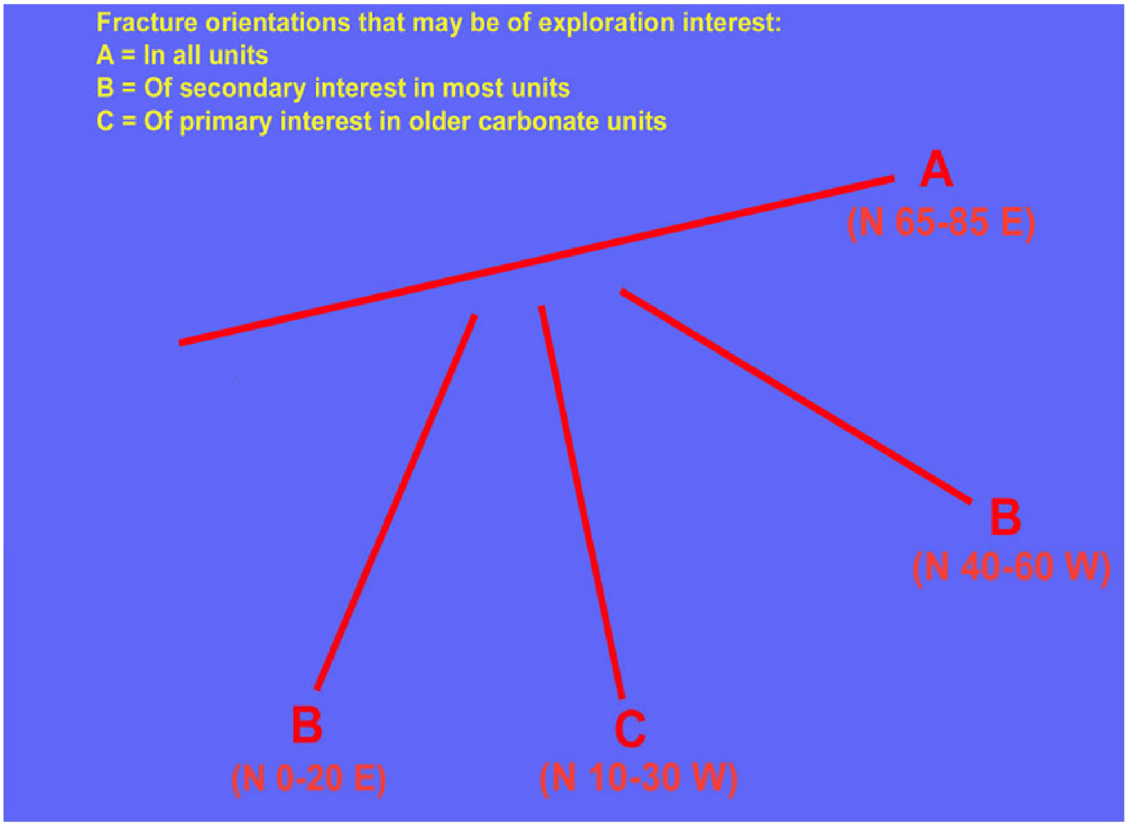


**Figure 3:** Fracture orientations of exploration interest.


**Figure 4:** Niagara Geologic Interpretation

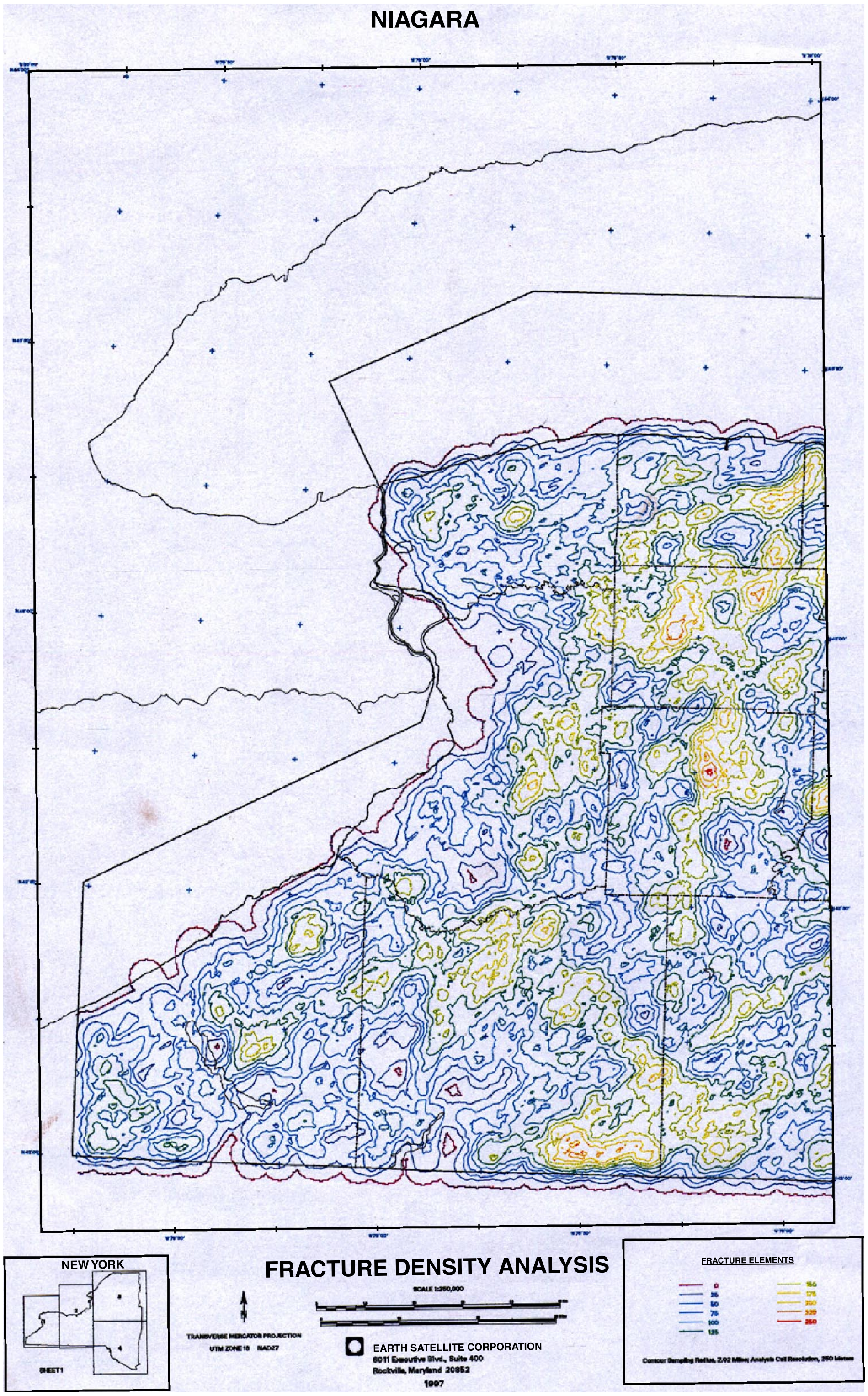


**Figure 5:** Niagara Fracture Density Analysis

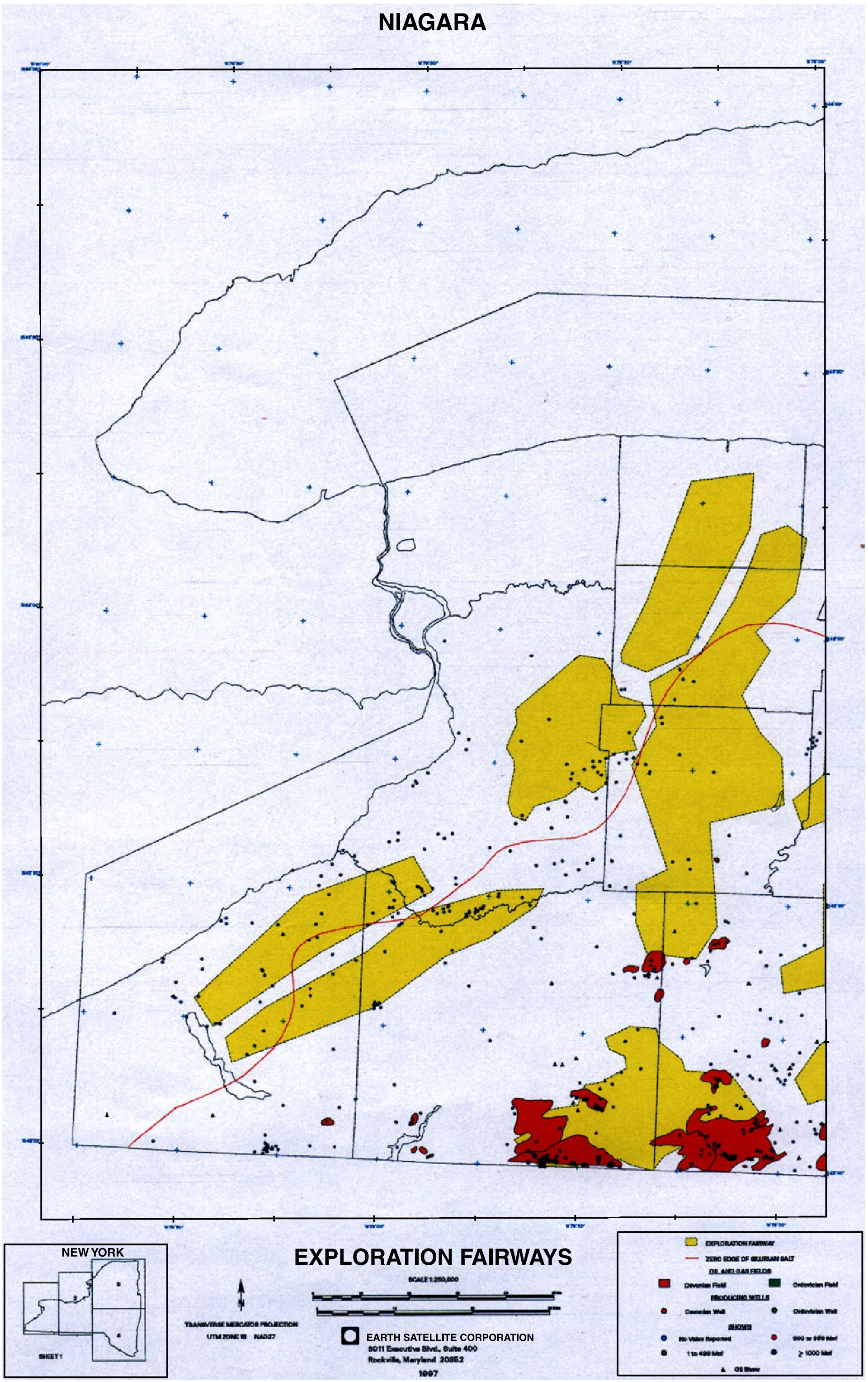


**Figure 6:** Niagara Exploration Fairways


**Figure 7:** Finger Lakes Geologic Interpretation.

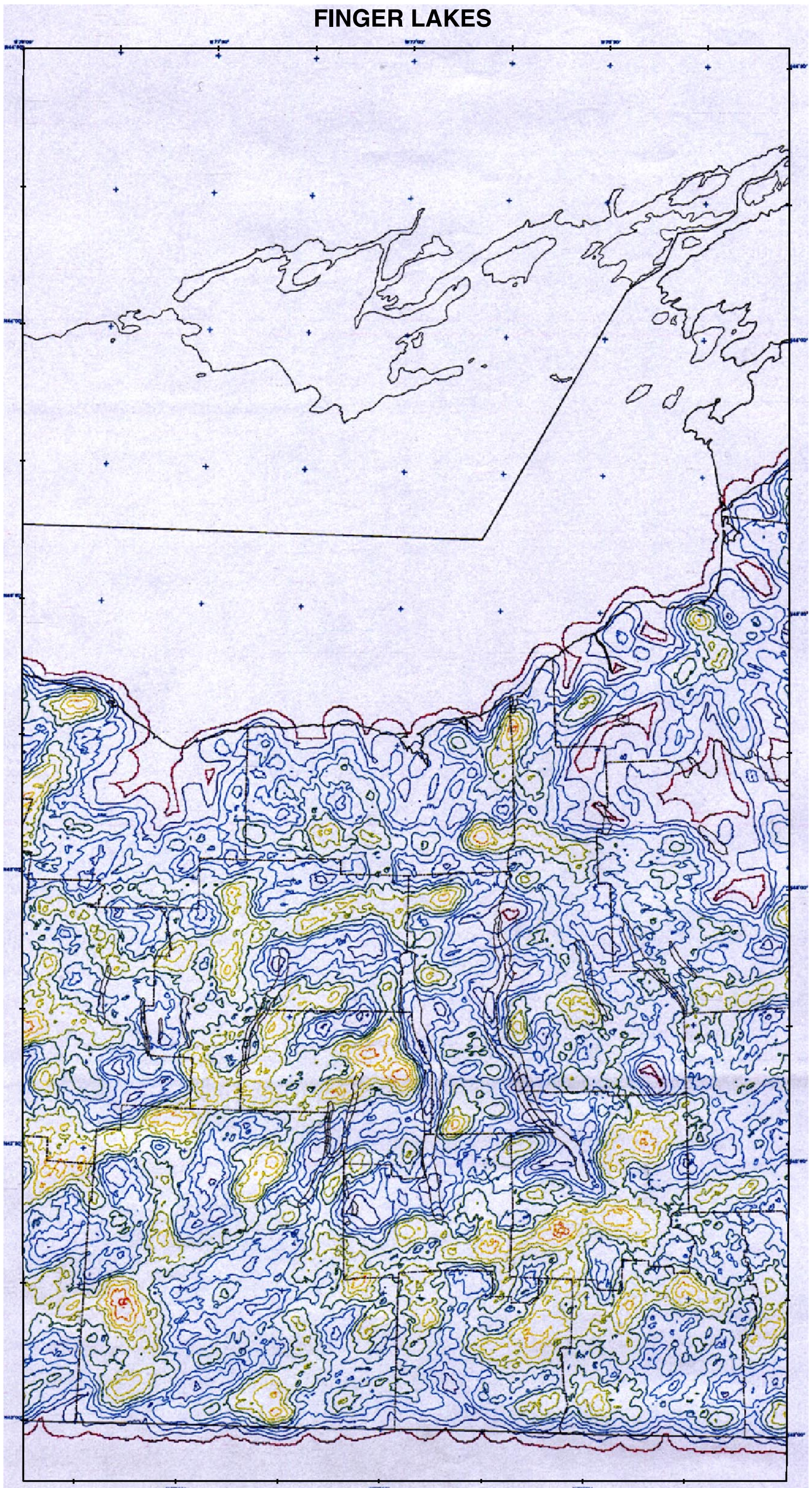


**Figure 8:** Finger Lakes Fracture Density Analysis

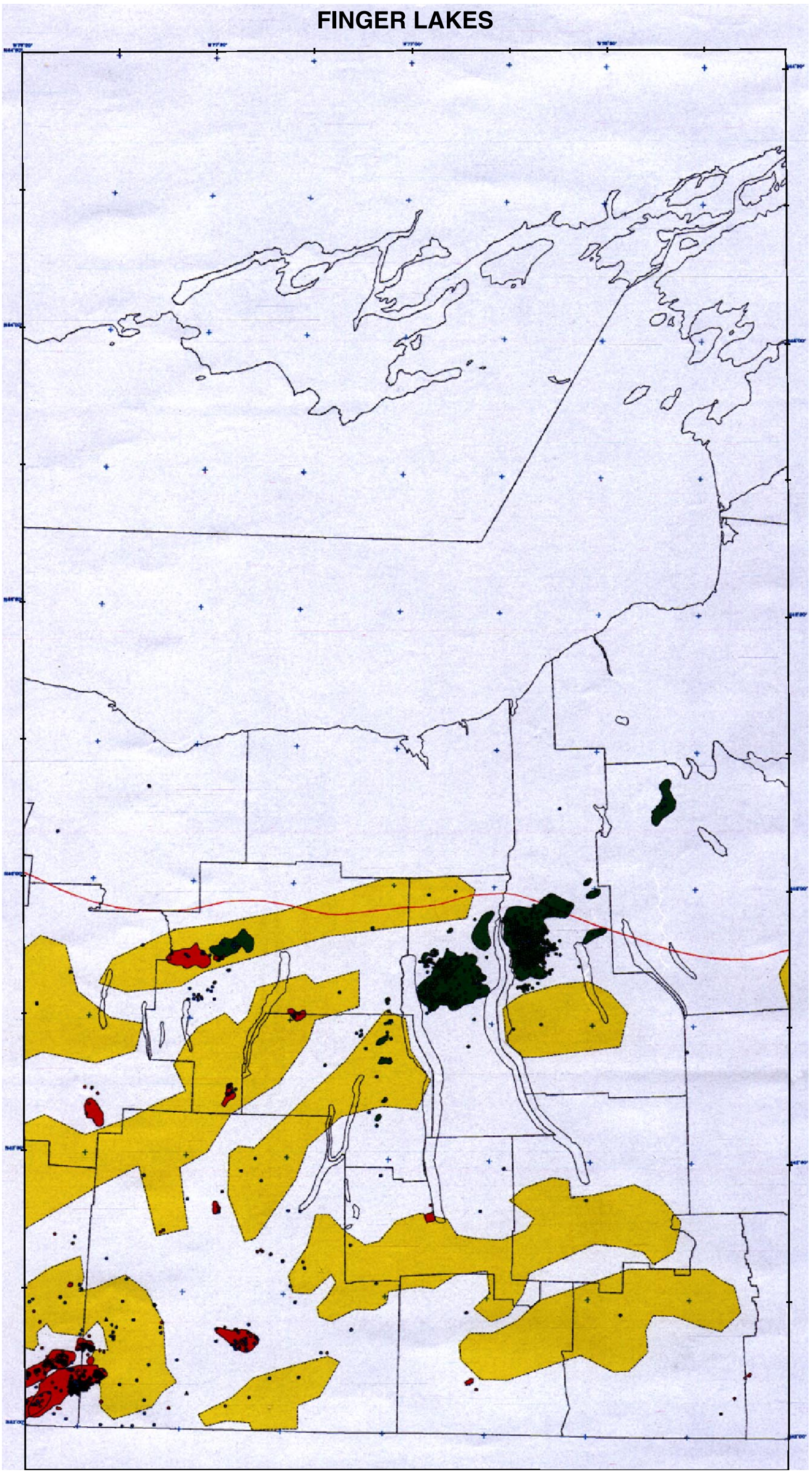


**Figure 9:** Finger Lakes Exploration Fairways