INNOVATIVE METHODOLOGY FOR DETECTION
OF
FRACTURE-CONTROLLED SWEET SPOTS
IN THE
NORTHERN APPALACHIAN BASIN
SEMI-ANNUAL TECHNICAL PROGRESS REPORT

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Dr. Robert Jacobi, Principal Author

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CONTRACTOR:

Research Foundation of State University of New York
P. O. Box 9
Albany, New York 12201
on behalf of:
University at Buffalo
The State University of New York
Suite 211, The UB Commons
520 Lee Entrance
Amherst, New York 14228

Dr. Robert Jacobi, Project Director
Dr. John Fountain, Co-Principal Investigator

Mr. Stuart Loewenstein, President, Subcontractor
Quest Energy, Inc.
63 Kenmore Ave.
Amherst, NY 14226

Dr. Bruce Hart, Subcontractor
McGill Seismic Research Group
McGill University
Montreal, QC, CANADA H3A 2A7

Dr. Edward deRidder, Subcontractor
Pearson, deRidder and Johnson, Inc.
12640 West Cedar Drive, Suite 100
Lakewood, CO 80228

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ABSTRACT

In the structure task, the goals for this reporting period were to: 1) complete analyses of field work on the NNW-SSE transect along the west side of Cayuga Lake. We have completed data input and analyses for this goal, and discuss the results. The additional data from the 2002 field season (and additional revised data from the previous season) demonstrate that zones of closely-spaced E-striking fractures bear a close spatial correlation with the E-striking Firtree Anticline. East-striking EarthSat (1997) Landsat lineaments also occur in the same general region as the Firtree Anticline. However, one E-striking lineament occurs where we have no sites with a high E-striking fracture frequency. ENE-striking closely-spaced fractures occur where ENE-striking lineaments occur. From the Seneca lake transect, these fractures intensification domains and lineaments are thought to mark zones of reactivated Trenton/Black River faults.

In the advanced seismic analyses task, the goals for this reporting period were to complete analyses of the seismic data. We have completed data the data analyses and find that high porosity zones can be recognized along some of the Trenton/Black River fault zones.

These data continue to demonstrate that integration of aeromagnetic and Landsat lineaments, surface structure, soil gas and seismic allows us to extrapolate Trenton-Black River trends away from confirmatory seismic lines.

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1.0 INTRODUCTION

3-D seismic analysis is unquestionably one of the premier methods for obtaining information concerning deep structure, including predictions of enhanced fracture porosity in reservoirs. However, the high cost of 3-D seismic makes it economically unfeasible in many basins with *perceived* marginal gas reserves. However, without some advanced technology like 3-D seismic, the deep structure in many basins (like the Appalachian Basin of New York State) cannot be critically evaluated because available seismic reflection profiles and deep well logs provide insufficient control.

This research project demonstrates a cost-effective alternative to 3-D seismic. The project demonstration is a combination of low-cost, innovative technologies that, when integrated, yield near-3-D quality on a regional scale for identification of fractured reservoir prospects. The study area covers about 760 sq. miles, an area that would cost about \$22 million for 3-D seismic coverage alone; our proposal is a fraction of that cost.

The basic premise is that highly productive zones in tight reservoirs are associated with discrete zones of intense fracturing, termed “fracture intensification domains” (FIDs, Jacobi and Fountain, 1996, Jacobi and Xu, 1998). These zones can be identified by integration of surface geology, lineaments, well log data, seismic data and soil gas anomalies. FIDs in the northern Appalachian Basin have been shown to be indicative of fault zones at depth (Jacobi and Fountain, 1996, Jacobi and Xu, 1998). Thus, by identifying and tracing FIDs, we can predict the location of zones of increased fractures in the subsurface.

Because large gas discoveries (estimated 3 bcf/well) have been made recently along fault zones in the New York State portion of the Appalachian Basin, it is important to be able to recognize FIDs. Because of vegetation and surficial deposits, the FIDs cannot be traced continuously in outcrop. In order to trace the FIDs, we have developed an integrated program that involves:

1. surface structure,
2. soil gas analyses,
3. remotely-sensed lineaments,
4. existing (2-D) seismics, and
5. aeromagnetics.

Structural studies on outcrops allow identification of FIDs; then lineaments from aeromagnetic and remotely-sensed data are used to trace the FIDs between outcrops. Soil gas anomalies can confirm that the lineaments are associated with fracturing. Existing well log and seismic data are used to confirm the interpretations. Many of the fault systems in the northern Appalachian basin can be traced with aeromagnetics because the surface faults are reactivated deep faults that are located in the Precambrian basement.

The study area is located in the northern Appalachian Basin in the Finger Lakes region of central New York State, primarily between Seneca and Cayuga lakes. The target is the Ordovician Trenton/Black River groups, although fractured tight sands above the Trenton also occur in this area. The most prolific gas play in New York State today is the Glodes Corners Road Field, an

Ordovician Trenton/Black River play that is located west of Keuka Lake. This field was developed by Columbia Natural Resources (CNR), who estimates that the yield/well is 1.3 bcf. The east-northeast trend of the Glodes Corners Road Field suggests that the Glodes Corners Road Field is located along faults that are reactivated structures related to the older Cambrian Rome Trough, which is assumed to trend approximately east-northeast in regions south of the play (Jacobi et al., 1999). Well logs from the Glodes Corners Road Field indicate a narrow fault zone that increases in stratigraphic offset upsection, increasing to 6 m in the Trenton.

On seismic reflection profiles, the Trenton plays occur along fault zones that appear as narrow (~2000') grabens with small regional offset. These grabens are thought to be a result of a combination of

- ◆ solution collapse,
- ◆ reverse flower structures (along strike-slip faults), and
- ◆ seismic pull-down from the lower velocities associated with dissolution and fault brecciation.

In order to procure and analyze the data necessary for the demonstration project, the integrated research project was divided into seven tasks. These tasks include:

- ◆ Traditional and innovative analyses of fractures (Jacobi),
- ◆ Stratigraphy/well log analyses (Jacobi and Loewenstein),
- ◆ Lineaments (Jacobi),
- ◆ Soil Gas Analyses (Fountain),
- ◆ Seismic Data Acquisition and Interpretation (Loewenstein and Jacobi),
- ◆ Advanced Seismic Analyses (Hart), and
- ◆ Aeromagnetic Survey and Analyses (deRidder).

During the third reporting period, we made significant progress, as outlined in the “Results and Discussion” section.

2.0 EXPERIMENTAL

2.1 FRACTURE ANALYSES SUBTASK

Jacobi and graduate students (Lugert and Wehn) used an abbreviated methodology to collect outcrop structural data during the second field season. In the abbreviated methodology, Jacobi and assistants identified the fracture sets in the outcrop, and measured the spacing among a minimum of three fractures for each systematic fracture set. They also measured the strike and dip of the fractures, and collected information concerning the abutting relationships, length/height, character of fracture trace (e.g., straight, curvy), and offset along the fracture. They constructed a sketch map in their field notebooks that showed the location of the outcrop and a sketch map of the fracture traces on the outcrop. They indicated the general site location in the field by tying an annotated ribbon to an overhead tree. The sketch map of the site also includes sufficient geographical markers to be able to identify the site location on the topographic base. They annotated the site of the outcrop on the enlarged topographic map base.

Jacobi and graduate students (Lugert and Wehn) entered all the site data and the fracture data in Excel data spreadsheets (Appendix 1 for sites, Appendix 2 for fracture data). For each site, the next step is to calculate the fracture frequency for each set. As most fractures are very steeply dipping ($80^{\circ}+$), modified rose diagrams can be used to portray the results. In these rose diagrams, fracture frequency is displayed in the top half of the diagram. We generally show three orders of magnitude on the diagram as successively larger concentric circles, with the inner circle representing 0.01 fractures/m, the middle ring representing 0.1 fracture/m, and the outer ring representing 1 fracture/m. Thus, long petals indicate a relatively high number of fractures, as did the old rose diagrams. The advantage of this modified diagram is that it is compatible with scanline data that we collected the first year. We use the lower half of the rose diagram to indicate other features of the fracture sets, commonly either abutting relationships, or length (which is a proxy for abutting relationships). The longest petals in the lower half indicate the master set; the next longest petals indicate the set that abuts the master set, but that is itself master to another fracture set, which is portrayed by even shorter petals.

Advanced analysis techniques, including fractal analysis and geostatistics (see Jacobi et al., 2001, for a review) will be carried out where these techniques will add to the understanding of the fracture development and significance of fractures for identifying deep structure. However, from the first two field seasons, the fracture data look to be very robust, so these techniques may not be necessary. The extent of outcrop was far greater than we had expected, and so the need for these special techniques that we developed especially for areas with limited outcrop, may not be necessary.

2.2 STRATIGRAPHY/WELL LOG ANALYSES SUBTASK

Jacobi and Loewenstein will provide the project with 1) structure contours on bedrock marker beds that outcrop in the study area, and 2) subsurface structure contour maps based on distinctive units identified in well logs. Such maps shall aid in determining fault locations and offset. The construction of these maps is funded by an ongoing NYSERDA project. The contouring will be

accomplished by a subroutine package in Geographix. The stratigraphic tops picked from well logs will follow the industry practice for recognizing each unit top; van Tyne and Foster's (1979) study illustrates such picks.

Jacobi and assistants will provide geological cross-sections across prominent surface structure where outcrops of marker units allow such constructions. The elevations of the marker units will be determined from topographic maps, and/or from altimeters, and/or from surveying from a known elevation.

2.3 LINEAMENTS SUBTASK

Jacobi and Loewenstein will combine lineaments recognized in Landsat images and in 7.5' topographic quadrangle maps. They will integrate Earthsat's (1997) pick of Landsat lineaments in the demonstration area with a reanalyzed Landsat data set. They will also analyze 7.5' topographic maps for lineaments following Jacobi and Fountain's (1996) methodology.

Jacobi will contribute an analysis of digital elevation data available from USGS for the study area. This analysis will include edited topography, a high-pass of the topography, and a horizontal gradient of the high-pass of the topography. We will compare lineaments observed in these gradient maps to those lineaments observed on the Landsat and 7.5' quadrangle maps.

The resulting series of maps of the demonstration area will include 1) Earthsat's Landsat lineament map, 2) our interpretation of lineaments from the Landsat data, 3) lineaments from 7.5' topographic quadrangle maps, 4) lineaments from gradient maps of Pearson, deRidder and Johnson, Inc. and 5) a map integrating all 4 data sets. We will compare the lineaments with the preliminary FID map. Where coincidence occurs between lineaments and FIDs observed in outcrop, we will extend the observed FID along the lineament. After the first iteration, we will compare the lineament/FID map with the soil gas analyses discussed below.

2.4 SOIL GAS ANALYSES

Soil gas surveys will be conducted along primarily north-south profiles, following existing seismic lines, and the general techniques and rationale of Jacobi and Fountain (1996) and Fountain and Jacobi (2000). In this research plan, traverses are conducted along the edge of roads and samples are collected at a distance of 3 to 10 meters from the road, depending on road construction, to avoid the roadbed fill material.

Samples are obtained by driving a stainless steel probe to a depth of 60 cm using a hand-held sledge hammer. Twenty cubic centimeters of air, slightly more than one probe volume, is withdrawn from the probe and discarded with an air tight syringe to purge atmospheric air from the probe. An additional 60 cc of air is then withdrawn with the syringe and injected directly into a gas chromatograph (GC) equipped with a flame ionization detector for analysis (a Century OVA 128 GC). Gas enters the probe through an array of holes approximately 5 cm above the tip; the holes are covered by a loose sliding collar that minimizes plugging during insertion.

Samples are collected at 10 m intervals. This distance is somewhat arbitrary; however, the results of over 10,000 analyses established that most anomalies are more than 10 m wide (Fountain and Jacobi, 2000), confirming that a 10 m spacing will detect most anomalies.

Linear response of the gas chromatograph is determined by analysis of standard gasses at the start of each day, after four hours of analyses, and at the end of each day. Samples are analyzed in duplicate every 10 samples.

All samples with 10 ppm or greater total organic vapor content are returned to the laboratory for analysis on a laboratory gas chromatograph to determine ethane/methane ratios. The GC is calibrated daily for response and elution times using standard gas mixtures.

2.5 SEISMIC DATA ACQUISITION, REPROCESSING, AND INTERPRETATION

Loewenstein will purchase available seismic lines and subcontract with seismic processors to reprocess the records where necessary. He will evaluate the reprocessing effort and be especially cognizant of statics problems. If such problems appear to exist, he will request that the processor reprocess any section that may exhibit such problems. Loewenstein and Jacobi will interpret the seismic lines for prominent stratigraphic reflectors and faults. Where recognizable, they will pick the reflectors that represent the Tully, Onondaga, Trenton, Black River and Precambrian/Cambrian contacts. They will use accepted industry practices for the reflector recognition (e.g., Jacobi and Fountain, 1996; Jacobi et al., 2000). The interpretation of the 2-D seismic will be displayed along the seismic line in depth (time) sections that show potential faults. These depth displays will be integrated with the surficial FID/soil gas/lineament maps in two ways: 1) the location of surficial FIDs/soil gas anomalies and lineaments will be shown above the depth section for ease in spatial correlation, and 2) the locations of deep structure (faults) as interpreted from the seismic line, will be entered in Geographix so that their locations can be compared in map view with the locations of the surficial FIDs/soil gas anomalies and lineaments.

2.6 ADVANCED SEISMIC ANALYSES

The seismic expression of faults is a function of several variables, including the fault offset and the frequency content of the seismic data. On migrated seismic lines, faults are most easily recognized by reflection offsets, changes in dip, changes in amplitude, etc. Subtle faults are most easily detected in 3-D seismic volumes by deriving and analyzing “horizon” attributes, such as dip, edge detection and azimuth, or “coherency” attributes (e.g., Hart et al., 1996). Additionally, complex trace attributes (e.g., instantaneous frequency, reflection strength) can be useful for fault detection. In the manner described above, Hart will analyze critical sections of the seismic profiles procured in the preceding subtask.

2.7 AEROMAGNETIC SURVEY AND ANALYSES

Aeromagnetic prospecting is a powerful methodology that can define the basement fault block patterns with detail on a basinal scale. Pearson, deRidder and Johnson, Inc. will acquire, process, and interpret an aeromagnetic survey of the study area. Using both widely available techniques and proprietary methods, Pearson, deRidder and Johnson, Inc. and Jacobi will delineate basement-related structural elements that serve as bounding structures on intra-basement lithology blocks, supra-basement structural relief, and zones of strike-slip faulting that may be associated with fracture swarm development. In addition, the proprietary profile data interpretation tool, STARMAG, licensed by Texaco exclusively to Pearson, deRidder and Johnson, Inc., will be amended, using local constraints, to allow for improved models of magnetic lineaments related to fracture swarms.

Specifications shall be as follows:

Survey area:	710 square miles
Line spacing:	1/3- mile N-S x 1-mile E-W
Line mileage:	3,600 line miles
Ground clearance:	500' above ground level, or as to be decided
Acquisition subcontractor:	Airmag Surveys, Inc., Philadelphia, PA

The data will be processed using an equivalent source method, which compensates for elevation differences at line intersections, taking into account anomalous vertical magnetic gradients. Both profile and grid based interpretation methodologies will be employed to derive the maximum information content of the data set. The resulting maps can be used to infer lineaments related to faults in the basement, and can, in some cases, be used to determine approximate amount of offset on basement. Jacobi and Loewenstein will integrate the aeromagnetic lineaments with the FID/lineament/soil gas maps and seismic attribute studies. Spatial coincidence among aeromagnetic lineaments and the FID/lineament/soil gas/seismic line fractures (seismic attribute) maps will be taken as defining probable fault systems that affected the entire sedimentary section, including the Ordovician targets.

2.8 DRILLING AND TESTING OF VERIFICATION WELL

If at the Decision Point, it is determined to all parties' satisfaction that the project will continue to Task 2.8, the subcontractor, Loewenstein, shall 1) drill an exploratory well at the site judged most likely to exhibit FIDs at depth, and 2) conduct a logging program that shall determine the nature of the intersected fractures. The offeror (Jacobi), subcontractor (Loewenstein), and the Government shall select the drill site, based on all the integrated maps that portray the FIDs in the study area (including outcrop FIDs integrated with topographic and magnetic lineaments, soil gas anomalies and fracture systems suspected from the reprocessed seismic data). The offeror (Jacobi), subcontractor (Loewenstein), and the Government shall locate the drill site along a east-northeast trending FID. If north-striking FIDs are found to intersect the east-northeast FIDs, after discussion with the Government at the Decision Point, the offeror (Jacobi) and subcontractor (Loewenstein) may choose the intersection point as the optimal drill site.

The subcontractor (Loewenstein), shall conduct the following logging program

- ◆ Mud Logging – Sample description and gas detection information that identifies

mineralogies indicative of healed and partially healed fractures, as well as detection of gas entry points in the well bore at the time of drilling that might indicated fractured zones.

- ◆ Temperature and Acoustic Logs – Identify gas entry points in the well bore to correlate with other logging information.
- ◆ Formation imaging (Schlumberger Formation Micro Scanner) – “Direct” detection of fractured zones.
- ◆ Combinable Magnetic Resonance Logging – Identify zones of higher permeability and movable fluids.

The subcontractor (Loewenstein) shall be responsible for selective coring in the target. The subcontractor (Loewenstein) shall be responsible for obtaining sidewall cores for fracture and reservoir characterization. The offeror (Jacobi) shall digitally image the cores and characterize the fracture spacing, intersections and form (e.g., stylolitic) for each set that occurs in the cored interval.

3.0 RESULTS AND DISCUSSION

3.1 FRACTURE ANALYSES SUBTASK

We had one primary objective for this reporting period: complete analyses on the NNW-SSE transect along the west side of Cayuga Lake (for general location, see Figure 3.1-1). Jacobi and undergraduate student (Wall) analyzed data collected along the Cayuga Lake NNW-SSE transect. Much of these data had been entered into Excel by another undergraduate student (Stroup) and reported in the previous Progress Report. However, the modified rose diagrams had not been constructed for the 2002 field season data and had not been located on maps. Additionally, problems we encountered that centered on a particular graduate student's data (lost structure data for sites in the 2001 field season and discrepancies in 2001 field site locations) have all been resolved. The data were recovered and the field site locations were determined. These 2001 and 2002 data have now been added to the NNW-SSE transect (Figs. 3.1-2 and 3.1-3). Rose diagrams constructed from the 2001 and 2002 data have been added to the detailed maps along the west side of Cayuga Lake (Figs. 3.1-4 to 3.1-23).

In the southern half of the NNW-SSE Cayuga Lake transect (Figs. 3.1-3 and 3.1-24), a number of zones with closely-spaced fractures (fracture intensification domains, FIDs) that strike east occur between 8 and 16 km (Fig. 3.1-24). East-striking Landsat lineaments (EarthSat, 1997) also occur in this same area. To the west, this same packet of E-trending lineaments is located on the previously recognized E-striking, Alleghanian Firtree Anticline (Fig. 3.1-25). Although an exact one-to-one correlation between lineaments and E-striking FIDs is not observed for the Firtree Anticline at Cayuga Lake (Fig. 3.1-24), lineaments related to the anticline do occur in the same region as E-striking FIDs with fracture frequencies greater than 10 fractures/meter (for E-striking fractures). On Inset J (Fig. 3.1-13), Site 1-157 has a very high fracture frequency for E-striking fractures, and this site is approximately on-strike with a set of discontinuous E-striking lineaments to the west of Inset J (Fig. 3.1-2). (Although Inset K covers region that includes these E-striking lineaments, we have no outcrops in the specific areas of the lineaments in Inset K). Another E-striking lineament passes through Inset M (Fig. 3.1-2). Site 153 (Fig. 3.1-16), which has a high E-striking fracture frequency (about 10 fractures/m), occurs in the region where the E-striking lineament was recognized by EarthSat (1997). Farther north in Inset M, site 1-249 also exhibited a high E-striking fracture frequency. In all three sites, the high frequency E-striking fractures post-date the Alleghanian cross-strike fractures; i.e., the fracturing associated with the Alleghanian Firtree anticline post date the development of the cross-strike fractures.

The southern-most series of E-striking FIDs with fracture frequencies of greater than 5/meter does not correspond to recognized Landsat lineaments. Between this lineament/FID and the Firtree Anticline lineaments/FIDs, another zone of E-striking FIDs occurs (at 5.5 km to 6.5 km along the transect; Fig. 3.1-24). This FID zone does not coincide with any Landsat lineaments, but the number of sites with high fracture frequencies suggests that there is an E-striking Alleghanian structure (fault) in this region.

The northern half of the NNW-SSE transect along the west side of Cayuga Lake is characterized

by generally low E-striking fracture frequencies. Only at 27 km along the transect (Fig. 3.1-24) and northward do fracture frequencies approach 5/m (or greater). No Landsat lineaments were recognized in this region by EarthSat (1997). The only E-striking Landsat lineament in the northern half of the transect occurs in a region where no sites show any evidence of E-striking FIDs (between 21 and 24 km on the transect; Fig. 3.1-24). This lineament passes through Insets E and F (Fig. 3.1-3), where no E-striking FIDs were found (Figs. 3.1-8 and 3.1-9), and in fact, only one site displays any E-striking fractures (at 1 fracture/m). The lack of fractures to support the lineament, and the lack of coinciding topographic lineaments, suggests that this lineament may not reflect important subsurface features in this region. Both the lack of support for this lineament, and the lack of lineaments where we do have high frequency fractures, point up the need for verification of the Landsat lineaments, and the usefulness of fracture studies as a means of verification, as well as an indicator of structure not recognized in the Landsat data.

The distribution of ENE-striking FIDs and Landsat lineaments on the NNW-SSE transect along the west side of Cayuga Lake is shown in Figures 3.1-3 and 3.1-26. The two northern packets of ENE-striking lineaments (between 21 and 16 km and between 28 km and the end of the transect, fig. 3.1-26) both correspond to regions where ENE-striking FIDs occur. These ENE-striking lineaments and FIDs are thought to reflect the Trenton/Black river structures, since they are coincident with reactivated Trenton/Black River structures observed on a seismic line along the Seneca Lake transect (reported in earlier progress reports). In Inset A (Fig. 3.1-4), an ENE-striking FID observed at Site 1-307 is coincident with an ENE-trending Landsat lineament (compare Fig. 3.1-4 with 3.1-3) and with a stream. The fracture intersections between ENE-striking fractures and cross strike fractures in this region are complicated. For example in Inset E (Fig. 3.1-8) at many sites the ENE-striking fractures and FIDs are master to the cross-strike (NNW-striking) fractures (e. g., sites 1-279, 1-286). However, they also intersect the cross-strike fractures (same sites). The inference is that some ENE-striking fractures and FIDs predate the cross-strike fractures, while other ENE-striking fractures may be contemporaneous with the cross-strike fractures (or may have developed when the cross-strike fractures were "tight"). In some regions, the ENE-striking FIDs postdate the cross-strike fractures (e.g., Site 1-233A in Inset F, Fig. 3.1-9). This range of relative ages is consistent with the observations on seismic lines that some of the Trenton/Black River faults have been multiply-reactivated.

The central packet of NE to ENE-striking lineaments passes through Insets I, J, K, and L (Fig. 3.1-3) and corresponds to high fracture frequency in ENE-striking fractures (Fig. 3.1-26) as well as NE-striking fractures (e.g. site 1-226 in Inset I, Fig. 3.1-12). The same range of intersection relationships is observed here as to the north. The southern zone of ENE-trending lineaments passes through insets Q and R (Fig. 3.1-7). Sites 1-188 and 1-297 in Inset R (Fig. 3.1-21) exhibit ENE-striking FIDs that coincide with the location of a Landsat lineament (compare Fig. 3.1-3 with Fig. 3.1-21). At this area, the ENE-striking fractures both predate and postdate the Alleghanian cross-strike fractures.

Other fracture trends that exhibit FIDs include N-, NW-, and NE- striking fractures. For example, N-striking FIDs are common in the southern part of the transect. For example, note the number of N-striking FIDs in Inset M (Fig. 3.1-16). This high number of sites with N-striking

FIDs may indicate a N-striking fault in the region of Inset M. Inset M is approximately on-strike

with N-striking Landsat and topographic lineaments that extend north of Cayuga Lake (Fig. 3.1-3). Northwest-striking FIDs occur throughout the transect region (e.g. Insets A and R, Figs. 3.1-4 and 3.1-21, respectively). NE-striking FIDs are rare (other than discussed above), but do occur (e.g. Site 1-199, Inset A, Fig. 3.1-4).

To summarize the general fracture relationship, established from numerous outcrops between the two transects: FIDs related to the Firtree Anticline generally postdate the Alleghanian cross-strike fractures, whereas the FIDs related to the Trenton/Black River faults generally predate the Alleghanian cross-strike fractures. These relationships suggest that the ENE-striking Trenton/Black River faults were reactivated before fractures related to the Firtree anticline developed.

3.2 STRATIGRAPHY/WELL LOG ANALYSES SUBTASK

The results were reported in previous progress reports.

3.3 LINEAMENTS SUBTASK

The results were reported in previous progress reports.

3.4 SOIL GAS ANALYSES

The results were reported in previous progress reports.

3.5 SEISMIC DATA ACQUISITION, REPROCESSING, AND INTERPRETATION

The results were reported in previous progress reports.

3.6 ADVANCED SEISMIC ANALYSES

The Advanced Seismic Analysis task, supported by Kamal Al Atroshi and Bruce Hart of the McGill Seismic Research Group (MSRG, McGill University) continued to refine stratigraphic and structural analyses of the seismic data in 2002-2003. inverted one of the seismic lines for which wireline log data had become available to directly image physical properties of the productive fault zones on that line. MSRG undertook structural and attribute analyses of the seismic data, and log analysis in support of the inversion work. MSRG's objectives were: a) To use advanced analyses to identify and interpret faults, and b) To integrate the seismic data with log data to distinguish the hydrothermal dolomite systems from the surrounding limestones. MSRG compared inversion results on line SCNYRC1 with those from line EGI004 from

1. Available data:

- Seismic data of the line SCNYRC1 (time migrated)
- Well log data from the Campion #1 well including GR (gamma ray), CALI (caliper), SP (spontaneous potential), RXO (flushed-zone resistivity), HLLD (deep resistivity),

HLLS (shallow resistivity), HART (computed true resistivity), NPHI (neutron porosity), SPHI (sonic porosity), DPHI (density porosity), PEF (photoelectric factor).

- Fluid shows and test data.

2. Seismic Markers:

Seismic interpretation of the North- South oriented line SCNYRC1 shows the following markers (Fig.3.6-1&2);

- 1- Top Trenton (Yellow marker); represents a high amplitude, continuous reflection peak. The marker extends from 1.078 sec TWT (deepest) South to 0.798 sec TWT North (shallowest).
- 2- Top Black River (Green marker); represents a zero crossing +/- peak to trough reflection. Top Black River extends from 1.190 sec TWT in the South to 0.898 sec TWT in the North.
- 3- Knox Unconformity (Blue marker); represents a reflection peak. The marker shows variable reflection amplitude and continuity from South to North. Depths range from 1.290 sec TWT at the South to 0.959 sec at the north. No phase change has been observed along the marker save at structural deformation zones, where some phase distortion can be identified.
- 4- Crystalline Basement (Violet marker); represents a reflection peak, the top basement shows lateral variations in reflection amplitude and continuity. The marker lies at 1.365 sec TWT at the South and shallows to 1.024 sec TWT at the north.

A reflection strength display clearly shows the seismic character variations between the major picked four markers (Fig. 3.6-3).

Marker flattening has been helpful in studying the time thickness variation of three main seismic packages bounded by the four main markers. Upon flattening the Basement (Fig. 3.6-4), the interval Basement/ Knox shows visible thinning at the North and South, while maximum thickness covers the central part and composed of 6 relatively concordant, continuous variable amplitude reflectors. This variation can either be attributed to accommodation variations provided by basement blocks, or can as well be due to erosional truncation at the Knox level

Flattening of Knox (Fig. 3.6-5) shows significant time thinning of the Black River section from South to North. Additional thinning occurs at our target intervals bounded by closely spaced normal faults (graben-like features). The Black River section TWT thickness variation ranges from 0.128 sec at the South to 0.052 sec at the North. Section thinning seems to be gradual and starts immediately North of a major fault located at CMP 850. However, some major additional Black River thinning can as well be observed at CMPs 230, 300, 311, 480, 487, 604 and 710. These collapse zones could be considered as potential targets, at least from a structural perspective. Seismically, the Black River interval is composed of a sequence of low amplitude, low frequency and discontinuous reflections that become chaotic at the central part of the sequence, mainly at the thickest section in the South.

Upon flattening the Black River marker (Fig-6), the overlying Trenton sequence shows a more regular time thickness variation. Trenton time thickness is greatest at the North and keeps an

average time isopach of 0.101 sec from the start of the line then southward to CMP 320 where a significant time thickness reduction to 0.085 sec occurs within the graben that extends from CMP 320 to CMP 600. Time thickness increases southward attaining 0.099 sec down to CMP 860. This point marks the beginning of second graben where the Trenton isochron reduces back to 0.085 sec.

3. Structural interpretation:

Structurally, the area has undergone a significant extension, possibly accompanied by wrenching (Figs. 3.6-7, 8, 9), giving rise to a sequence of structural grabens and horsts of different sizes. 22 gravity faults have been interpreted in the sequence extending from the basement to the top of the Trenton. These faults show variable dips and throws. Fault frequency increases at the northern segment with visible rollover events near fault shoulders. 7 small size Grabens associated with thickness reductions in the Black River section have been interpreted. Those collapse structures dominate the structurally higher northern sector of the area and are bounded by CMPs 220- 240, 240-250, 300-310, 310-330, 424-430, 477-490 and CMP 596 to CMP 609.

4. Seismic Attribute Analyses:

In order to identify possible fault associated fractures systems, as well as other subtle variations, seismic data have been processed in order to extract complex (analytic) trace attributes via sample-by-sample computation.

□ Instantaneous amplitude processing (s-10, 11, 12):

This attribute, also known as reflection strength, is amplitude independent of phase. It is proportional to the total energy of the seismic signal at each instant in time. The instantaneous amplitude is the envelope function of the seismic trace. The envelope reflects low frequency filtering of the amplitude variations with time. Values are always greater than or equal to zero. The mathematical expression is:

$$e(t) = [r^2(t) + q^2(t)]^{1/2}$$

Where:

$e(t)$ = energy envelope,

$r(t)$ = real seismic trace, and

$q(t)$ = quadrature seismic trace or the imaginary part of the seismic trace.

Strong energy reflections can be associated with major lithologic changes as well as, in some settings, oil and gas accumulations. Lateral energy variations can quantify changes in acoustic rock properties and bed thickness. Seismic line SCNYRC1 shows significant lateral variations in the instantaneous amplitude attribute, reflectivity dimming occurs at top Black River within

some of the faulted and collapsed graben shaped units (CMPs 477-490, 596-609, and 800-850). This event can be attributed to possible fracturing or higher secondary porosities at the upper Black River level.

- **Instantaneous phase (Figs. 3-6- 13, 14):**

This attribute shows phase independent of amplitude. It is a measure of continuity of events on a seismic profile. The output relates to the phase component of the wave propagation. Instantaneous phase is mathematically defined as:

$$p(t) = \tan^{-1}[q(t)/r(t)],$$

Where:

p(t) = instantaneous phase trace,
q(t) = quadrature seismic trace, and
r(t) = real seismic trace.

The target area at top Black River level shows a lateral phase change with phase inversion at some positions. These phase distortions occur near and within the faulted and collapsed top Black River.

- **Instantaneous frequency (Figs. 3.6-15, 16, 17):**

Instantaneous frequency is the rate of change of instantaneous phase. This attribute corresponds to the average frequency of the amplitude spectrum of the seismic wavelet and can be an indicator of fracture zones dominated by lower frequencies. Mathematically, instantaneous frequency can be defined by:

$$dp(t) / d(t)$$

Where:

p(t) = instantaneous phase trace

The southern part of the line shows no instantaneous frequency anomalies, however, the crestal part at the North shows a significant low frequency anomaly zone immediately beneath the top of the Black River (CMPs 130-150) where instantaneous amplitudes also dim. Structurally, this unit has not undergone any visible faulting; therefore, the anomaly can be possibly attributed to localized fracturing or hydrothermal alteration effects. Seismic inversion (see below) could be used in order to confirm the validity of this interpretation,. Other anomalies have also been interpreted along some major faults, however, some of these anomalies extent upwards into Trenton, therefore, no possible seal can be provided for the Black River (CMP 325).

- **Seismic Coherency Processing (Fig. 3.6-18):**

Coherency is a geometrical attribute that is useful for detecting faults and other seismic event terminations. The processing was been carried out on the SCNYRC1 2-D seismic line for. However, results were not encouraging as this processing was developed for 3-D data rather

than 2-D (results are commonly looked at in timeslices). Nevertheless, results were helpful in confirming some of the interpreted faults.

4. Campion #1 well log Analyses (Figs. 3.6-19, 20, 21,22, and 23):

MSRG undertook log analyses in order to help establish the relationships between seismic-derived and log-derived physical properties. Two well composite logs have been prepared covering the Trenton and Black River intervals. Logs used were; NPHI, SPHI, DPHI, PEF, RXOZ, HLLD, HLLS, HART, GR, SP and Caliper.

4.1. Log Response Analyses:

- Upper Black River interval (7055- 7185 ft) defines a clean and porous (vuggy) dolomitic interval (7081-7100 ft) showing signs of hole over-gauging. No signs of shale can be detected from the FMI and GR logs. The interval shows high deep and shallow resistivities, therefore no indication of filtrate invasion. An average of 14% NPHI & 3% DPHI has been recorded at the over-gauged section which can probably be related to intensive dolomitization. No gas shows were recorded during drilling. At lower levels, some possible gas bearing units have been detected via NPHI & DPHI log signatures, these are located at 7113-7119ft, 7126-7130ft, and at 7155-7159 ft.
- Middle Black River interval (7185- 7315 ft) is more argillaceous and shows lower RXO& HLLD resistivities. Average Nphi level is 10%, the interval shows a log gas signature at 7212ft and 7225 ft as well as a gas kick recorded at 7290 ft.
- Lower Black River (7315- TD), is composed of 3 clean compact intervals separated by 2 shale barriers at 7390 and 7440 ft. The dolomitic intervals show high deep resistivity but lower RXO values indicating high filtrate invasion. A gas signature can be observed at 7350, 7455 and 7550 ft. Seismic inversion results (discussed below) did not support any possible reservoir quality within this interval.

4.2. Facies characterization & Cross-Plot Analyses:

- NPHI & SPHI Plot (Fig. 3.6-24); the plot has identified a typical cluster trend for Trenton (blue envelope) showing a linear relationship and 4 different clusters for the Black River interval. The majority of the Black River facies are located within the red cluster facies envelope; a low sonic porosity and a variable neutron porosity evolution levels characterize this cluster. Gas recorded kicks as well as log gas signatures are located within these facies. The red cluster defines the clean dolomitic Black River intervals. The second dominant facies (violet cluster envelope) defines a similar characteristic trend but with a higher sonic porosity average value. A third minor facies has been identified (dark blue cluster); this marks the more shaly dolomites. The blue cluster envelope identifies the shale barriers within the Black River unit.
- NPHI& DPHI Plot (Fig. 3.6-25); This plot defines two major distinct clusters, the light blue envelope with red and red points for Black River and a violet envelope with blue points for Trenton. Black River facies show a NPHI range from 0.4%

to 14% including gas kick and gas log signature zones (red points) and variable density porosities. Fig. 3.6-26 shows an association of porosity, resistivity and GR& caliper logs with a NPHI vs. DPHI cross-plot for the Black River interval 7050-7250ft. The discrimination of the gas log response zones within the interval indicate an anomaly cluster (colored points) with an average NPHI of 0.09 to 0.12 corresponding to variable DPHI values up to 0.23. Figure 3.6-27 shows a gas signature of a compact dolomite unit. The FMI log has been incorporated with the facies discrimination analyses (Fig. 3.6-28), the thick and porous upper dolomite unit has proven to be dry, however, some thinner and probably less porous lower intervals have proven to be gas bearing due to drilling and log analyses results. The lower Black River shows a gas signature of a dolomitic unit within a thick shaly section at 7550 ft and 7620 ft within the lowermost clean dolomite (Fig. 3.6-29).

- NPHI & True Resistivity Plot (Fig. 3.6-30); Two major facies cluster trends are identified showing an inverse relationship axial trends. The Black River facies tend to be more resistive and mark some possible gas bearing zones (green points and green intervals). This interval marks a higher resistivities and lower NPHI values.
- True Resistivity (Hart)& RXOZ plot (Fig. 3.6-31, 32); this plot has been incorporated with the FMI composite log. The discrimination objective is to identify porous zones marking considerable divergences between deep and shallow resistivity logs. These divergence intervals have shown best fitting with the units of best porosities within the Black River section, units indicate filtrate invasion zones in dolomites.
- GR& True Resistivity Plot (Fig. 3.6-33): Both Trenton facies (light blue) and Black River facies (red) show inverse relationship in terms of GR and true Resistivity plot. The Black River facies cluster envelope (violet) indicates clean and resistive facies at the upper and middle part of the formation. Shale intervals (green cluster envelope) can be discriminated at the lower part of the formation.
- Caliper & GR Plot (Fig. 3.6-34); the relationship defines 3 different clusters within the Black River, the violet cluster envelope defines the upper and part of Middle Black River over-gauged hole section characterized by low shale content. The red cluster defines the cleanest gauged Black River section while the blue cluster is related to shale units. It seems that hole over-gauging occurs at the clean dolomitized zones of the Black River that indicates intensive fracturing within a near fault well position.

5. Seismic Inversion:

In order to proceed to seismic inversion, MSR&G needed to transfer seismic picks (Top Trenton, Top Black River, Knox U, and the top basement) that were picked on the line SCNYRSC1 from GeoGraphix to the Hampson-Russell software (Fig. 3.6-35). Log to seismic calibration as well as

the generation of synthetic traces marked a reasonable (but not high) correlation coefficient of 64% and the composite log showed an acceptable match. A P-wave impedance log has been generated from the Campion #1 well sonic and density logs, the impedance log was then correlated with the synthetic traces as well as with the rest of the logs (Fig. 3.6-36). This log was used as the basis for calculating the impedance model utilized for the later seismic inversion process (Fig. 3.6-37). The computed acoustic impedance log shows three main AI sequences with tops at 995 ms TWT (Top Black River) then at 1018 ms, and at 1040 ms. the anomalously low impedances represent the intra-Black River shale dominated intervals. The upper and lowermost intervals represent the clean dolomites; the middle interval is a shaleier dolomitic facies.

Prior to seismic Inversion, an attempt has been made to use the integrated absolute amplitude attribute processing in order to study the seismic amplitude behavior at the zone of interest (Figs. 3.6-38, 39, 40). This attribute refers to a continuous trend calculation of seismic instantaneous amplitudes in time and space. It is sometimes known as a “bandlimited” (or recursive) inversion. The results seem very helpful in checking for the zone of structural and/or stratigraphic anomalies. Actually the results supported the location of the well within the low amplitude trend. Moreover, other new graben-related zones of interests have been observed on the section; CDP 554, 582, 604, and 638. At the Campion well location, the attribute has proven that the anomaly extends upwards within the Trenton section, which might mean that reservoir seal is absent thus supporting the dry results of the well. However, at CDP 554 (South of the Campion well), another anomaly shows a state of a good seal conditions that could be tested by drilling.

Seismic inversion results (Figs. 3.6- 41, 42, 43) show that the Campion well has effectively penetrated the near-fault collapsed but relatively tight zone (light blue interval) with AI range of 56000-57000 ft/s*g/cc. This high AI level extends laterally to the North and South of the well. These results are consistent with the poor results obtained from the well: although the well penetrated an otherwise seismically attractive target, no porous dolomite facies (that would be associated with a low AI values from the inversion) were developed there. Results of inversion work on EIG004 (last year) clearly showed that productive (low AI) zones at the Muck Farms and Glodes Corners fields may be recognized using seismic inversion.

Inversion has shown a second possible target (green spot with AI 47000 ft/s*g/cc) at CDP 604, which was previously indicated as an anomaly during the seismic attribute analysis. This target marks interesting characteristics in terms of acoustic impedance value as well as to its confined nature. Moreover, results indicate the existence of an excellent seal facies. Other near top Black River AI anomalies has been identified at CMPs (120, 236, 398, 605).

A second inversion has been ran based on a model using impedance values generated from a modified and corrected density log as well as a generated sonic log from inverse Gardner equation (Fig. 3.6 44). This step was undertaken because inversion of line EIG004 (last year) needed to be done without a measured sonic log. Density log modification was to remove “spikes” associated with bad hole conditions. The new inversion slightly enhanced the resolution

of inverted data but did not significantly modify conclusions derived the previous inversion results at the level of top Black River target.

In order to calibrate the seismic inversion data with FMI images and porosities as well as with lithofacies in depth, the Campion well (e-log) impedance data in TWT and depth has been calibrated with the FMI log (Figs. 3.6-45 and 46). Results have shown that the upper Black River dolomitized and porous interval falls within the time window of 996-998 ms TWT. This window matches with a relatively tight zone according to the inversion results (Fig. 3.6-47).

A third seismic inversion has been carried out using an impedance model based on impedance values generated from a corrected density log and the original sonic log from the well Campion #1 (Fig. 3.6-48). Inversion results have widely improved inversion resolution and added more details to the upper Black River interval, especially at the well site. AI log has been used to calibrate the FMI log in time and depth for both the upper porous and middle shaly intervals (Figs. 3.6- 49 and 50). The upper time-calibrated unit was then projected on the inverted data. Inversion results indicated that the porous interval is located in a tight zone showing an AI range of 56000 ft/s*g/cc, (Fig. 3.6-51). The same procedure has been applied to the middle Black River shaly interval (Fig. 3.6- 52).

6. Interpretation of Seismic Lines SCNYR6& SCNYR7:

The integrated absolute amplitude processing as well as structural interpretation has been applied on the two remaining seismic lines SCNYR6 and SCNYR7. Anomaly trends have been observed on both lines, these anomalies are fault associated, however, no thickness reduction can be identified within the Black River section, therefore, these are considered to be risky drilling targets (Figs. 3.6- 53,54,55,56,57).

3.7 AEROMAGNETIC SURVEY AND ANALYSES

Pearson, deRidder and Johnson, Inc. completed their task, and the final results were reported in a previous progress report.

3.8 DRILLING AND TESTING OF VERIFICATION WELL

The subcontractor (Loewenstein) has built a consortium that this summer will drill a well which will pass through the Trenton/Black River. If this well is deemed suitable, the verification part of the research will be accomplished with this well. At present, DOE funds associated with the verification phase have not been expended.

4.0 CONCLUSIONS

During this reporting period, we analyzed fracture data in order to fill in gaps in the earlier data sets and to define the structure traces between the two N-S transects. In structure, these new data showed that most of the Landsat lineaments recognized by EarthSat (1997) correspond to FIDs. Further, it is possible to discriminate between FIDs related to the shallow Alleghanian Firtree Anticline and those related to the Trenton/Black River faults. The Trenton/Black River-related FIDs trend ENE in the study area and generally predate the Alleghanian cross-strike fractures. In contrast, the Firtree Anticline-related FIDs trend E-W and postdate the Alleghanian cross-strike fractures in the study area. This discrimination ability allows the Trenton/Black River faults to be recognized and extrapolated away from the seismic lines. Advanced seismic analyses show that faults in the Trenton/Black River section can be recognized through a series of analyses, and that some of the faults do exhibit zones of probable high porosity.

FIGURE CAPTIONS

FIGURE 3.1-1. Map showing location of Cayuga Lake and selected Trenton/Black River fields. Landsat lineaments from EarthSat (1997).

FIGURE 3.1-2. Inset location map for the Cayuga Lake transect. Green lineaments are Landsat lineaments from EarthSat (1997).

FIGURE 3.1-3. Transect location map. Orange line indicates location of transect shown in Figures 3.1-24 and 26.

FIGURE 3.1-4. Inset A. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-5. Inset B. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-6. Inset C. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-7. Inset D. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-8. Inset E. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-9. Inset F. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-10. Inset G. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-11. Inset H. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-12. Inset I. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

- FIGURE 3.1-13. Inset J. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-14. Inset K. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-15. Inset L. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-16. Inset M. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-17. Inset N. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-18. Inset O. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-19. Inset P. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-20. Inset Q. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-21. Inset R. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-22. Inset S. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.
- FIGURE 3.1-23. Inset T. For location, see Figure 3.1-2. Modified rose diagrams show fracture frequency in the upper half and fracture intersection relationships in the lower half.

FIGURE 3.1-24. Transect along the west side of Cayuga Lake that compares E-striking fracture frequency to E-striking Landsat lineaments from EarthSat (1997). For location of transect, see Figure 3.1-3.

FIGURE 3.1-25. Structure contours at the base of the Devonian Rhinestreet Shale and Landsat lineaments from EarthSat (1997) for the Seneca Lake region.

FIGURE 3.1-26. Transect along the west side of Cayuga Lake that compares ENE-striking fracture frequency to ENE-striking Landsat lineaments from EarthSat (1997). For location of transect, see Figure 3.1-3.

FIGURE 3.6- 1. Northern part of seismic line SCNYRC1, interpreted. Line overlaps with Figure 3.6-2.

FIGURE 3.6-2. Southern part of seismic line SCNYRC1, interpreted. Line overlaps with Figure 3.6- 1.

FIGURE 3.6-3. Reflection strength (instantaneous amplitude) version of seismic line SCNYRC1.

FIGURE 3.6-4. Line SCNYRC1 flattened at basement horizon to emphasize thickness trends.

FIGURE 3.6-5. Seismic line SCNYRC1 flattened on the Knox Unconformity to emphasize thickness trends.

FIGURE 3.6-6. Seismic line SCNYRC1 flattened on the Black River pick.

FIGURE 3.6-7. Fault interpretations superimposed on reflection strength display of line SCNYRC1.

FIGURE 3.6-8. Close-up of a small graben feature, line SCNYRC1

FIGURE 3.6-9. Close-up of a small graben feature, line SCNYRC1.

FIGURE 3.6-10. Reflection strength display, line SCNYRC1. Alternate color display.

FIGURE 3.6-11. Close-up, reflection strength display, line SCNYRC1.

FIGURE 3.6-12. Close-up showing dimming and thickness reduction of Black River horizon, line SCNYRC1.

FIGURE 3.6-13. Instantaneous phase display, part of line SCNYRC1.

FIGURE 3.6-14. Instantaneous phase display, part of line SCNYRC1.

FIGURE 3.6-15. Instantaneous frequency display, line SCNYRC1.

FIGURE 3.6-16. Close-up, instantaneous frequency display, line SCNYRC1.

FIGURE 3.6-17. Close-up, instantaneous frequency display, line SCNYRC1.

FIGURE 3.6-18. Coherency processing, line SCNYRC1.

FIGURE 3.6-19. Log display, Campion #1 well.

FIGURE 3.6-20. Annotated log display, Campion #1 well.

FIGURE 3.6-21. Comparison of logs with borehole imagery. Campion #1 well.

FIGURE 3.6-22. Comparison of borehole imagery log (right) with driller's log (left), Campion #1 well.

FIGURE 3.6-23. Comparison of conventional borehole logs and image log.

FIGURE 3.6-24. Crossplot of neutron porosity versus sonic porosity, Campion #1 well.

FIGURE 3.6-25. Density porosity versus neutron porosity, Campion #1 well.

FIGURE 3.6-26. Log response for the interval 7050' – 7250', Campion #1 well.

FIGURE 3.6-27. Gas signature, Campion #1 well.

FIGURE 3.6-28. Gas signature crossplot (Fig. 29) and image log, Campion #1 well.

FIGURE 3.6-29. Gas signature in shaly section, lower Black River, Campion #1 well.

FIGURE 3.6-30. Neutron porosity versus true resistivity, Campion #1 well.

FIGURE 3.6-31. Flushed zone resistivity (RXO) versus true resistivity (HART), Campion #1 well.

FIGURE 3.6-32. Flushed zone resistivity versus true resistivity, Campion #1 well.

FIGURE 3.6-33. Gamma ray versus true resistivity, Campion #1 well.

FIGURE 3.6-34. Caliper versus gamma ray plot, Campion #1 well.

FIGURE 3.6-35. Line SCNYRSC1, imported into Hampson-Russell software.

FIGURE 3.6-36. Synthetic seismogram display, Campion #1 well.

- FIGURE 3.6-37. Initial acoustic impedance model, based on logs from Campion #1 well and seismic picks, used for inversion of line SCNYRSC1.
- FIGURE 3.6-38. Close-up at Campion #1 well location, integrated absolute amplitude processing, line SCNYRSC1.
- FIGURE 3.6-39. Close-up, integrated absolute amplitude processing, line SCNYRSC1.
- FIGURE 3.6-40. Close-up, integrated absolute amplitude processing, line SCNYRSC1.
- FIGURE 3.6-41. Close-up, inversion results at Campion #1 well location and South, line SCNYRSC1. See FIGURE 3.6- 43 for color scale.
- FIGURE 3.6-42. Close-up, inversion results at Campion #1 well location and North, line SCNYRSC1. See FIGURE 3.6- 43 for color scale.
- FIGURE 3.6-43. Flattened inversion result, line SCNYRSC1.
- FIGURE 3.6-44. Inversion result, line SCNYRSC1, generated using sonic log derived from density log via Gardner equation
- FIGURE 3.6-45. Comparison of borehole image log and acoustic impedance log, Campion #1 well.
- FIGURE 3.6-46. Comparison of borehole image log and acoustic impedance log, Campion #1 well.
- FIGURE 3.6-47. Close-up of inversion result, line SCNYRSC1, with p-wave impedance and image logs overlain, Campion #1 well location.
- FIGURE 3.6-48. Inversion result, line SCNYRSC1, derived using edited density log.
- FIGURE 3.6-49. Time-depth calibration, acoustic impedance and borehole image logs, Campion #1 well.
- FIGURE 3.6-50. Time-depth calibration, acoustic impedance and borehole image logs, Campion #1 well.
- FIGURE 3.6-51. Close-up, inversion result shown in Fig 48, with log overlay.
- FIGURE 3.6-52. Close-up, inversion result shown in Fig 48, with log overlay.
- FIGURE 3.6-53. Close-up, integrated absolute amplitude processing, line SCNYR6.
- FIGURE 3.6-54. Line SCNYRS7, structural interpretation.

FIGURE 3.6-55. Reflection strength display, line SCNYRS7.

FIGURE 3.6-56. Integrated absolute amplitude processing, line SCNYRS7.

FIGURE 3.6-57. Comparison of structural interpretation and integrated absolute amplitude processing, line SCNYRS7.

FIGURE 3.1-1

CAYUGA LAKE LOCATION MAP FOR INSETS

FIGURE 3.1-2

FIGURE 3.1-3

FIGURE 3.1-4

FIGURE 3.1-5

FIGURE 3.1-6

FIGURE 3.1-7

FIGURE 3.1-8

FIGURE 3.1-9

G

FIGURE 3.1-10

FIGURE 3.1-11

FIGURE 3.1-12

FIGURE 3.1-13

FIGURE 3.1-14

FIGURE 3.1-15

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FIGURE 3.1-23

FIGURE 3.1-24

FIGURE 3.1-25

FIGURE 3.1-26

Figure 3.6-1. Northern part of seismic line SCNYRC1, interpreted. Line overlaps with Figure 3.6-2.

Figure 3.6-2. Southern part of seismic line SCNYRC1, interpreted. Line overlaps with Figure 3.6-1.

Figure 3.6-3. Reflection strength (instantaneous amplitude) version of seismic line SCNYRC1.

Figure 3.6-4. Line SCNYRC1 flattened at basement horizon to emphasize thickness trends.

Figure 3.6-5. Seismic line SCNYRC1 flattened on the Knox Unconformity to emphasize thickness trends.

Figure 3.6-6. Seismic line SCNYRC1 flattened on the Black River pick.

Figure 3.6-7. Fault interpretations superimposed on reflection strength display of line SCNYRC1.

Figure 3.6-8. Close-up of a small graben feature, line SCNYRC1.

Figure 3.6-9. Close-up of a small graben feature, line SCNYRC1.

Figure 3.6-10. Reflection strength display, line SCNYRC1. Alternate color display.

Figure 3.6-11. Close-up, reflection strength display, line SCNYRC1.

Figure 3.6-12. Close-up showing dimming and thickness reduction of Black River horizon, line SCNYRC1.

Figure 3.6-13. Instantaneous phase display, part of line SCNYRC1.

Figure 3.6-14. Instantaneous phase display, part of line SCNYRC1.

Figure 3.6-15. Instantaneous frequency display, line SCNYRC1.

Figure 3.6-16. Close-up, instantaneous frequency display, line SCNYRC1.

Figure 3.6-17. Close-up, instantaneous frequency display, line SCNYRC1.

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Figure 3.6-20. Annotated log display, Camion #1 well

Sonic Porosity, Neutron and Density
porosity response of the Porous upper.
Black River

Fig- 21

Figure 3.6-21. Comparison of logs with borehole imagery. Campion #1 well.

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Figure 3.6-42. Close-up, inversion results at Campion #1 well location and North, line SCNYRSC1. See Figure 3.6-43 for color scale.

Figure 3.6-43. Flattened inversion result, line SCNYRSC1.

Figure 3.6-44. Inversion result, line SCNYRSC1, generated using sonic log derived from density log via Gardner equation.

Fig-45

Figure 3.6-45. Comparison of borehole image log and acoustic impedance log, Campion #1 well.

Figure 3.6-46. Comparison of borehole image log and acoustic impedance log, Campion #1 well.

Figure 3.6-47. Close-up of inversion result, line SCNYRSC1, with p-wave impedance and image logs overlain, Campion #1 well location.

Figure 3.6-48. Inversion result, line SCNYRSC1, derived using edited density log.

Figure 3.6-49. Time-depth calibration, acoustic impedance and borehole image logs, Campion #1 well.

Figure 3.6-50. Time-depth calibration, acoustic impedance and borehole image logs, Campion #1 well.

Figure 3.6-51. Close-up, inversion result shown in Fig 48, with log overlay.

Figure 52. Close-up, inversion result shown in Fig 48, with log overlay.

Figure 3.6-53. Close-up, integrated absolute amplitude processing, line SCNYR6.

Figure 3.6-54. Line SCNYRS7, structural interpretation.

Figure 3.6-55. Reflection strength display, line SCNYRS7.

Figure 3.6-56. Integrated absolute amplitude processing, line SCNYRS7.

Figure 3.6-57. Comparison of structural interpretation and integrated absolute amplitude processing, line SCNYRS7.