Use of Remote Sensing Technologies to Detect Surface and Near-Surface Stray Gas Occurrence and Potential Migration Pathways in Tioga County, Pennsylvania*

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Abstract

Shell has an active program of Marcellus Shale gas development in NE Pennsylvania. Ongoing gas production in Pennsylvania depends on industry's ability to drill and complete gas wells in a safe and environmentally responsible manner. Key to protection of fresh groundwater resources is avoidance of pre-existing natural and man-made conduits of methane coupled with proper drilling and well construction techniques to ensure zonal isolation.

In Tioga County, Pennsylvania, Upper Devonian gas-bearing sandstones of the Catskills Formation occur at or near the surface across most of Tioga County. In addition to naturally occurring methane surface seeps seen across this region, historical oil/gas and water well construction practices have in some cases resulted in vertical conduits for methane migration from shallow gas-bearing sandstones into freshwater aquifers. Methane injected into the Oriskany Sandstone for storage, has also been detected by USGS researchers in freshwater aquifers. Finally, imperfect zonal isolation by the surface and intermediate casing and cement intervals can result in a potential conduit for methane getting into groundwater.

In August 2011, Shell contracted with NEOS GeoSolutions to conduct a remote-sensing survey of our Tioga County operating area in Pennsylvania. A fixed-wing aircraft was used to collect band-specific hyperspectral, magnetic, gravity, electromagnetic and radiometric data over all of Tioga County. In addition, a helicopter system was used to collect high-resolution band-specific hyperspectral, magnetic, electromagnetic (EM) and radiometric data over a project specific area. Key project objectives were:
1) Detection of surface hydrocarbon seeps and potential indirect hydrocarbon indicators.
2) Detection of abandoned/derelict oil and gas wells not found in state agency or commercial databases.
3) Mapping of resistivity anomalies in the near-surface to provide an indication of potential aquifer salinity variations and locations of shallow gas sands in the Upper Devonian Bradford Group.
4) Definition of surface lineaments and fracture corridors and identification of fault networks that can be extended from the surface into the subsurface when integrated with 3-D and 2-D seismic.

5) Developing a hyperspectral-derived image of surface geo-hazards and geo-botanical variations.

References Cited

Carter, K.M. and J.A. Harper 2002, Oil and gas prospects in northeastern Pennsylvania, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of Northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 15 - 31.

Williams, J.H., L.W. Taylor, and D.J. Low, 1998, Hydrogeology and ground-water quality of the glaciated valleys of Bradford, Tioga, and Potter counties, Pennsylvania: Pennsylvania Geological Survey, 4th series, Water Resource Report 68, 89 p.

AAPG

The Shell-NEOS neoPROSPECTOR Project in Tioga County, NE Pennsylvania:

Use of Remote Sensing Technologies to Detect Surface and Near-Surface Stray Gas Occurrence and Potential Migration Pathways

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American Association of Petroleum Geologists
Annual Convention & Exhibition
Pittsburgh, PA May 21, 2013

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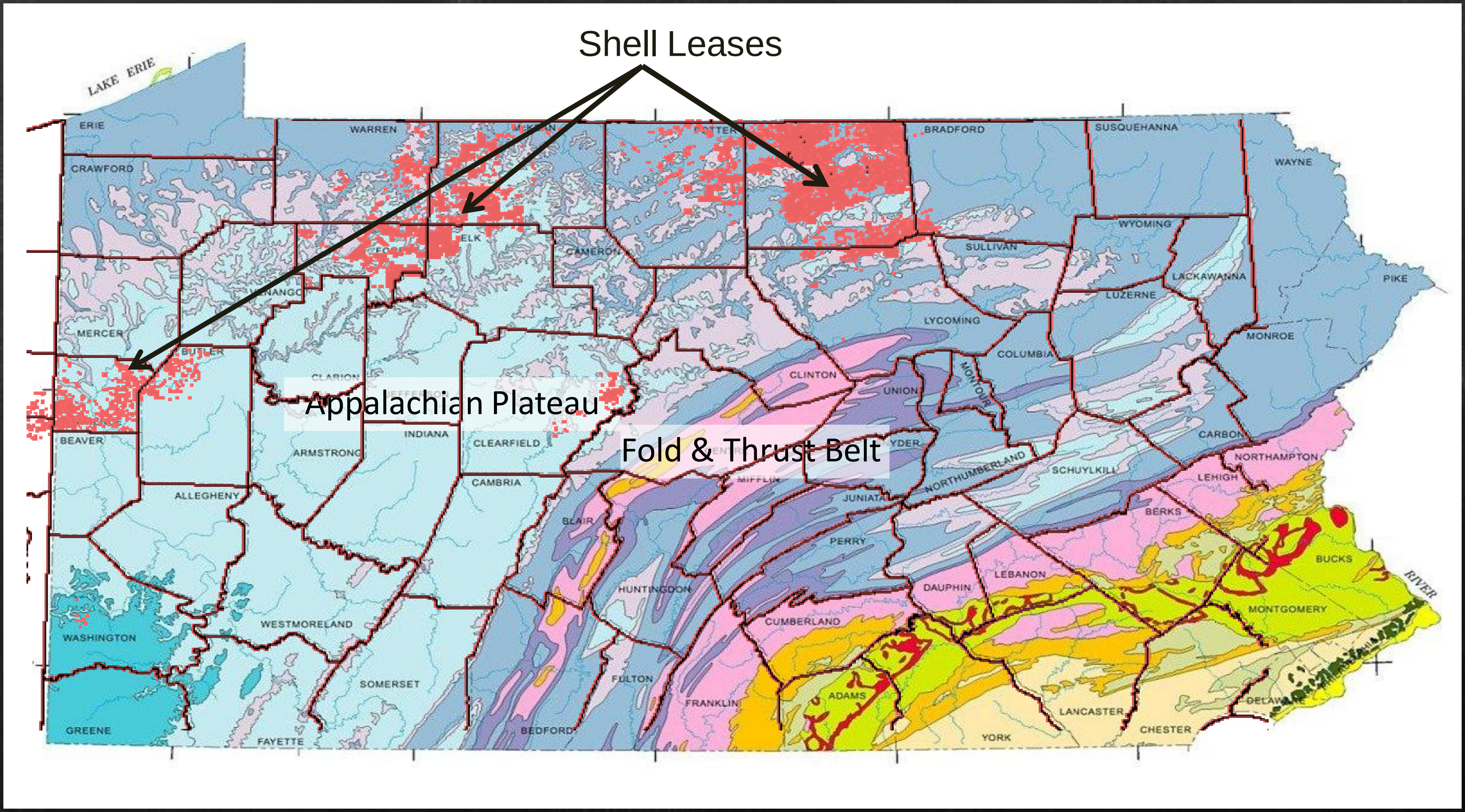
Pennsylvania Surface Geology

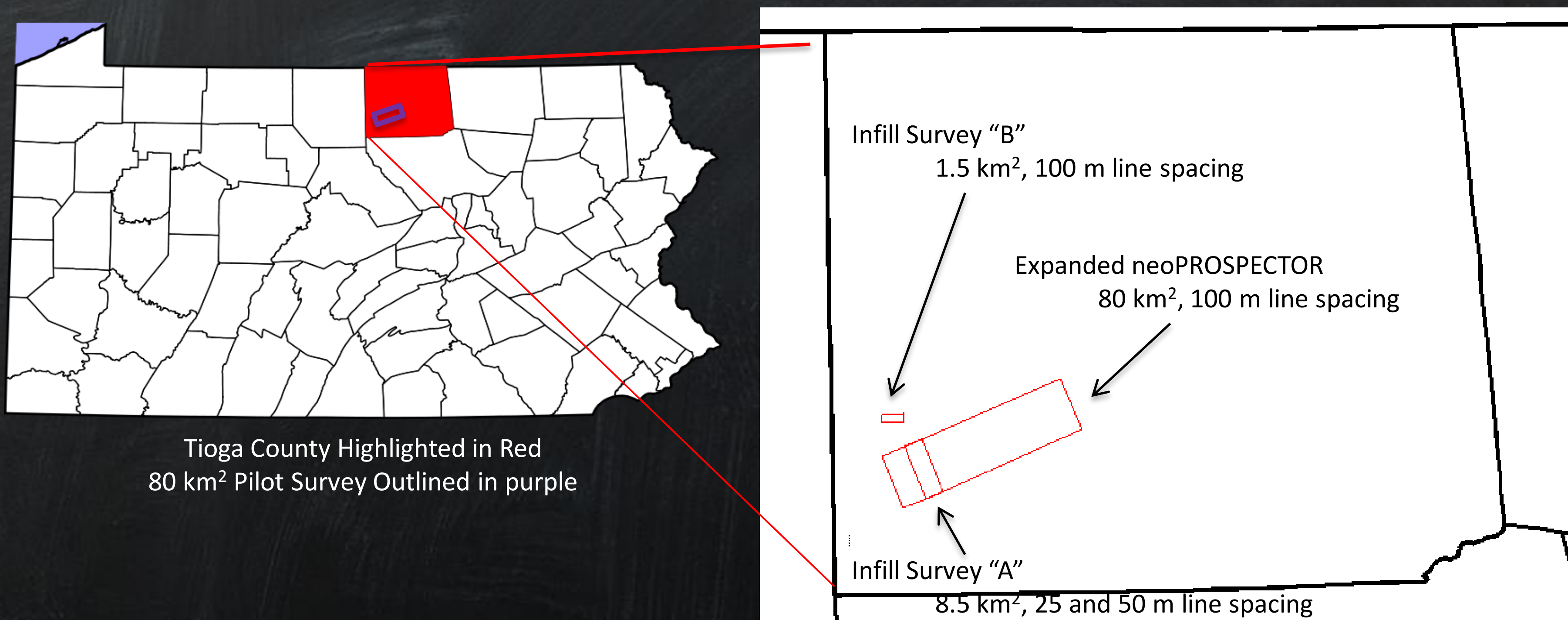


Shell-NEOS neoPROSPECTOR Project Location:

Tioga County, Pennsylvania

Pennsylvania

Tioga County, PA

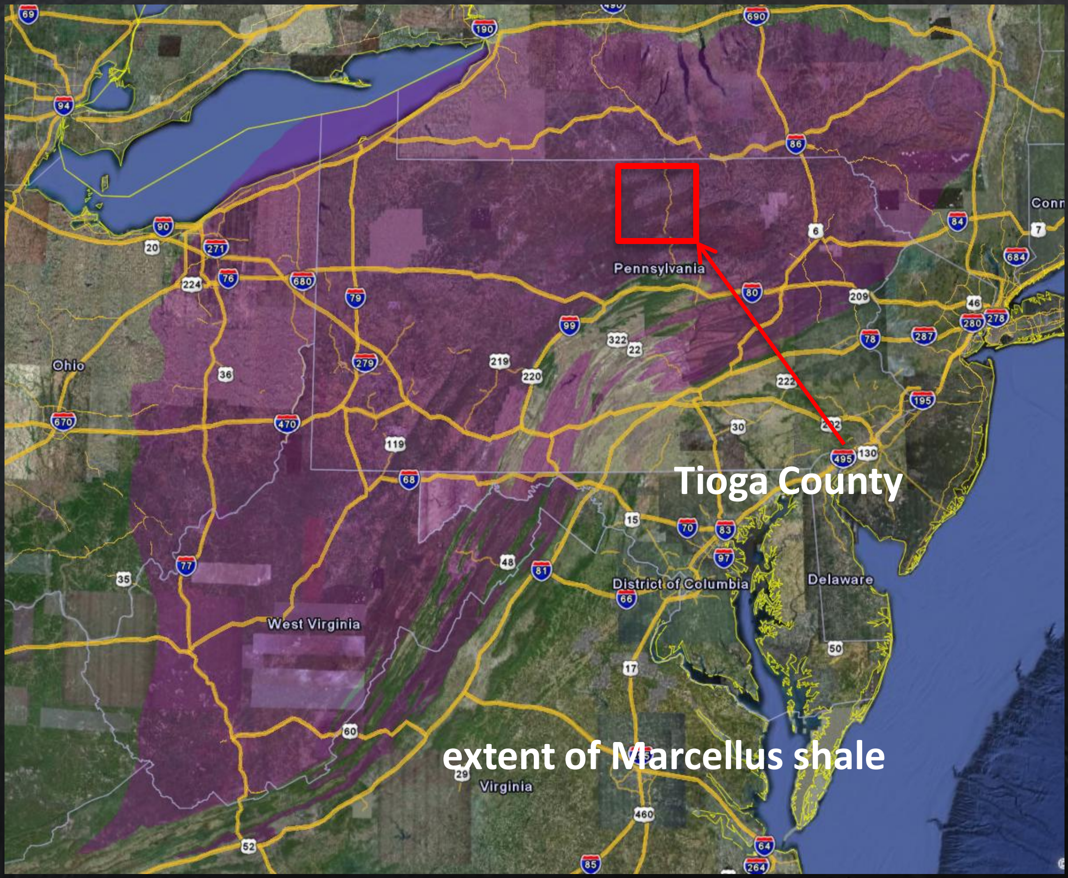


Tioga County Highlighted in Red
80 km^2 Pilot Survey Outlined in purple

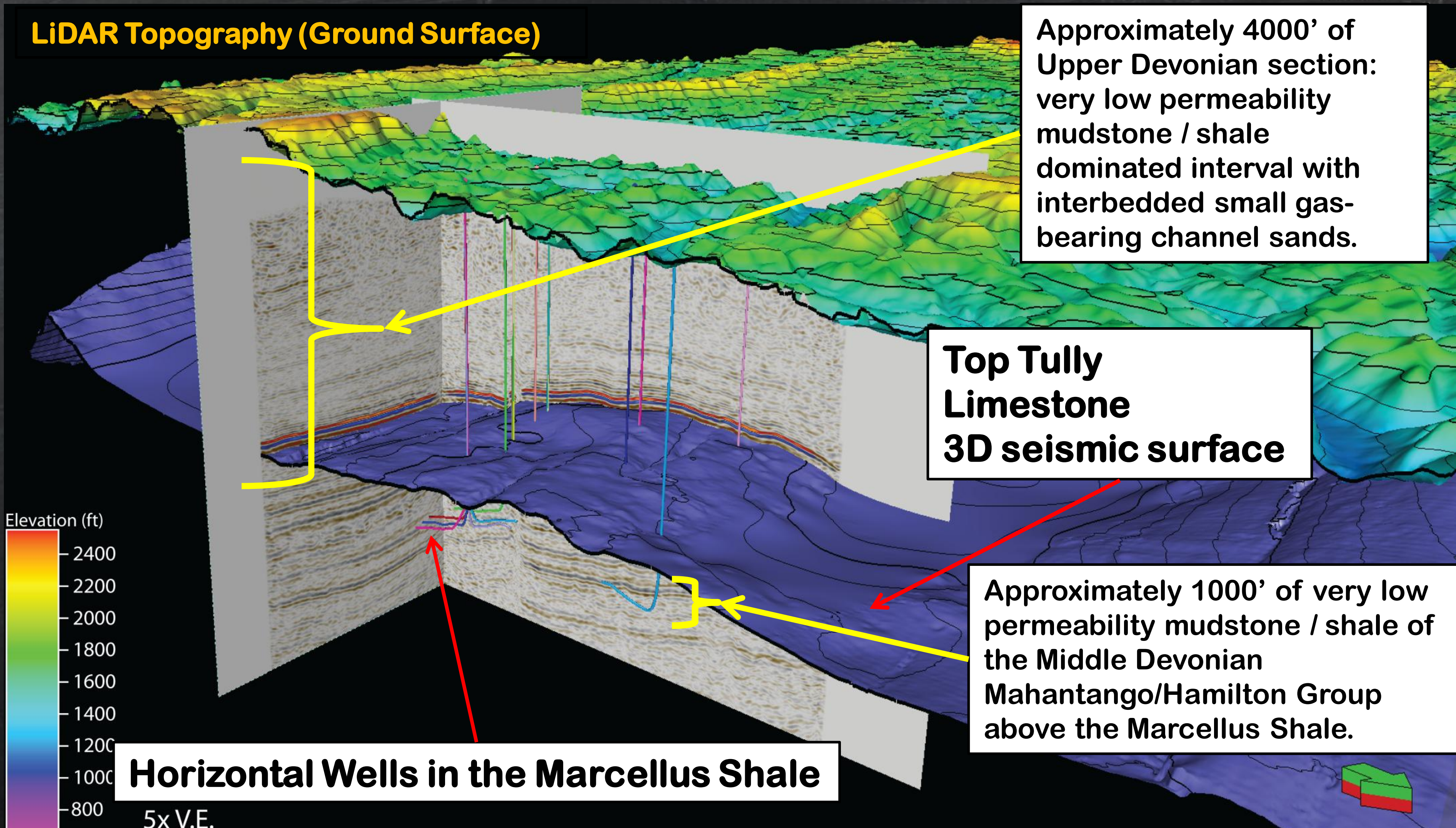
Shell-NEOS neoPROSPECTOR Project Objectives

Shell neoPROSPECTOR

- Well detection
  - **Detection of old abandoned wells.**
- Surface Lineaments & Hydrocarbon Seep Detection
  - **Surface structural features which control aquifer distribution and occurrence of hydrocarbon seeps.**
- Shallow Gas Sand Detection
  - **Shallow gas sands in the Upper Devonian Bradford Group above 3,000’ depth**



Tioga County, PA - Geologic Overview



Juxtaposition of Fresh Groundwater Aquifers and Shallow Upper Devonian Gas Sands (Conventional Gas Reservoirs) in North-Central and Northeast Pennsylvania

- Much of Tioga, Bradford, Lycoming, Susquehanna, and other counties in this part of the state are situated on **gas-bearing strata of the Upper Devonian Bradford Group**.

-Shallow gas sands in the Bradford Group (Lock Haven and Catskills formations) occur near the surface at very shallow depths, and in some cases outcrop at the surface. In glacially incised areas, these can be overlain by a veneer (1-100' thick). of Quaternary glacial alluvium.

- **Tioga County - AQUIFER TYPE 1 – Glacial Alluvium**
  Usually produce freshwater from unconsolidated sediments at depths <100' below surface

- These near-surface Upper Devonian rocks, when fractured are recharged on local topographic highs by rain and snow-melt, and are important freshwater aquifers used as the primary drinking water supply over much of Tioga County.

- **Tioga County - AQUIFER TYPE 2 – Fractured Upper Devonian Bedrock**
  Usually produce freshwater from the Lock Haven Fm. from depths <250' below surface

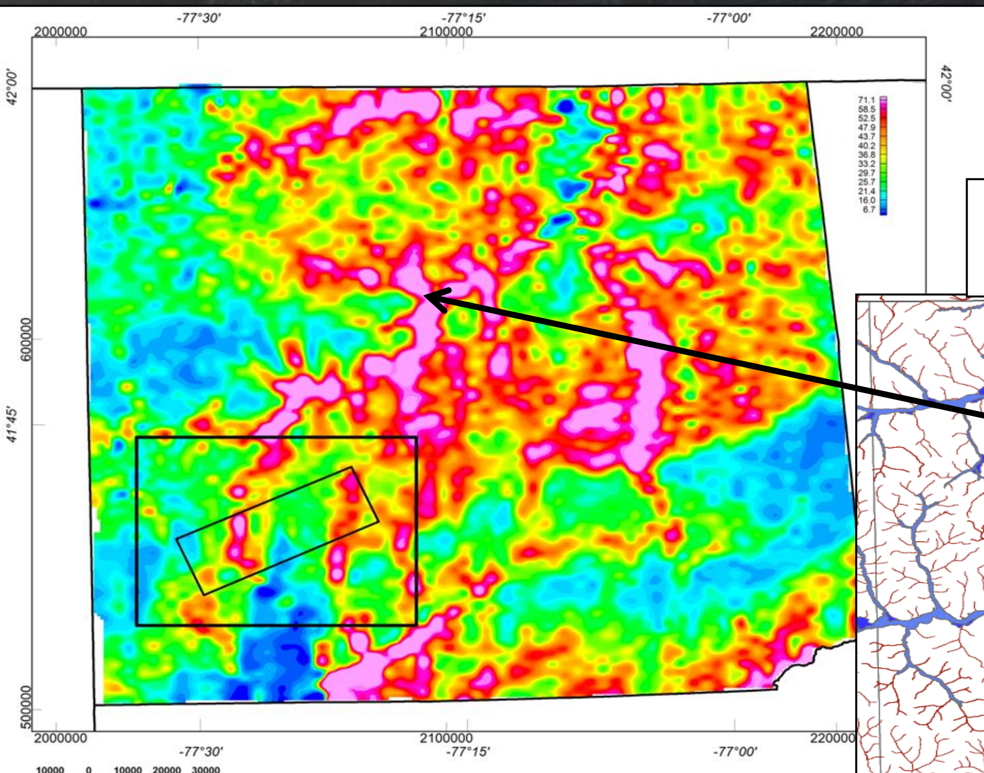
- Important to properly identify the freshwater aquifer zones (of either type) that often occur in close proximity above gas sands in the Upper Devonian Catskills and Lock Haven formations, to ensure zonal isolation and groundwater protection of these aquifers.

Example of glacial outwash aquifer from quarry in Tioga County, PA
(Note darker water-saturated sediments)

Example of fractured Upper Devonian bedrock aquifer from roadcut in Tioga County, PA
(Lock Haven Formation - Note dark water-saturated rock around vertical fractures)

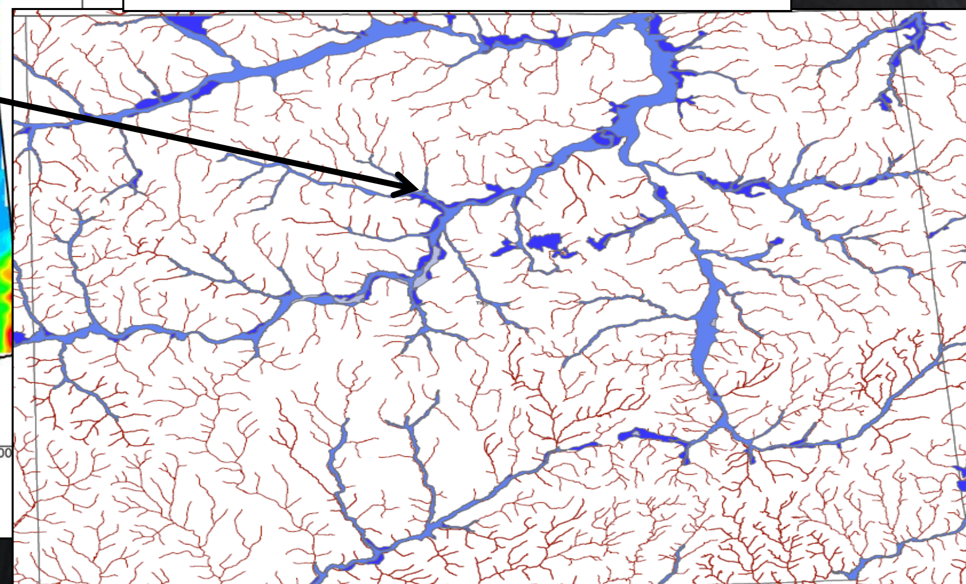
Shell-NEOS neoPROSPECTOR Aquifer Delineation

Total Count Radiometric Data Showing Glacial Valley-Fill with Elevated Natural Gamma Ray (U-K-Th) Emitting Sediments (Feldspar-Rich Granitic Canadian Shield Provenance)



Radiometric Total Count Map of Tioga County, PA

MAP OF GLACIATED VALLEYS IN TIOGA COUNTY, PA.
(Digitized from PA Geol. Surv. Water Resource Rept. 68, J. Williams, L. Taylor, D. Low, 1998)



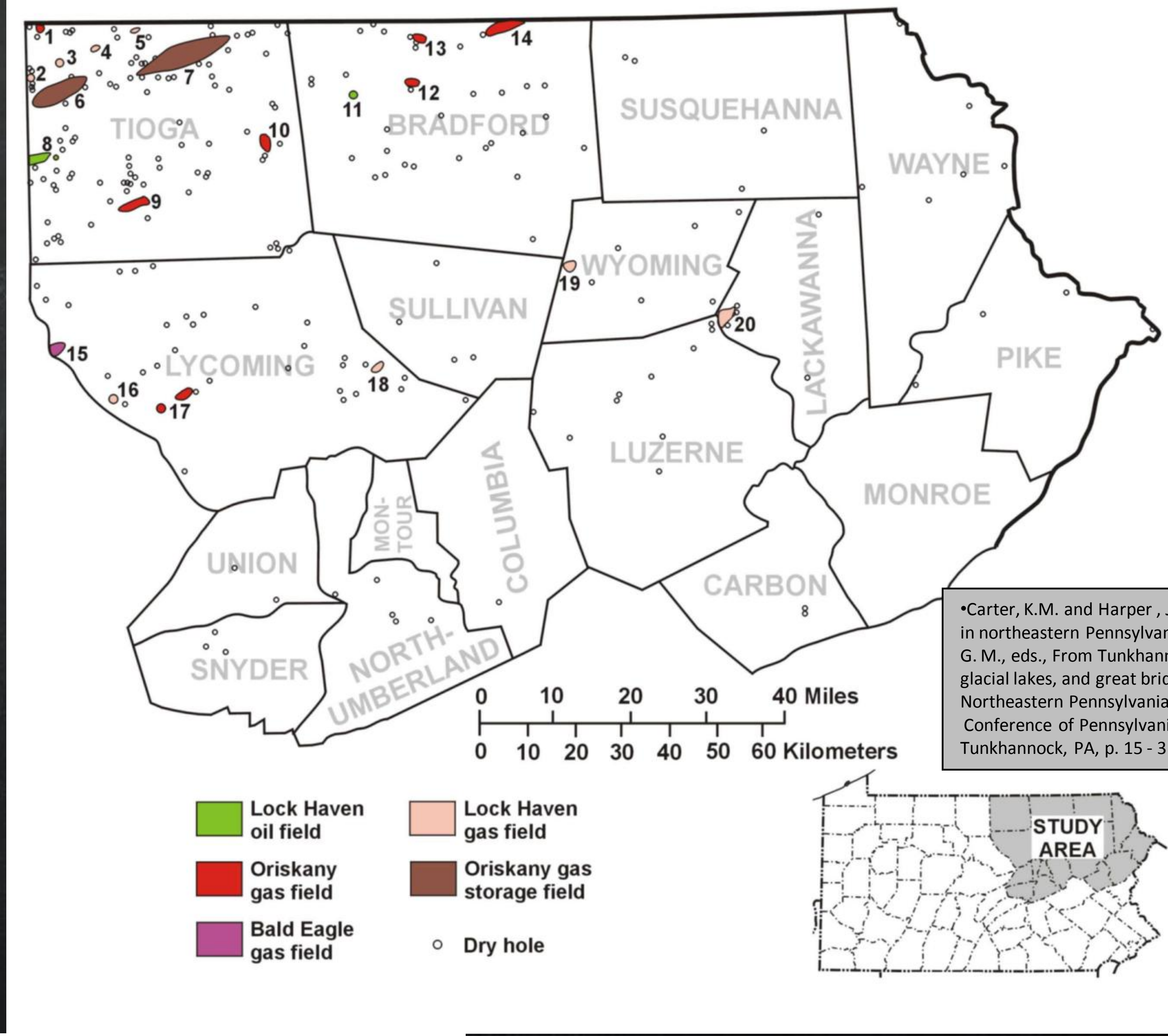
Shell-NEOS neoPROSPECTOR Methodology Overview

- **Well Detection**
  - Measurement: MAG (via helicopter and fixed-wing)
  - Analysis: Identify potential abandoned buried wells with high-resolution helicopter magnetic data. Overlay hyperspectral and multispectral datasets on known wells and interpreted faults to look for vegetative anomalies (from leaking gas) around old wellheads
- **Surface Fault / Lineament Mapping & Hydrocarbon Leak / Seep Detection**
  - Measurement: ASD spectral (via helicopter and ground measurements)
  - Measurement: FTIR spectral (via helicopter and ground measurements)
  - Measurement: HYPERSPECTRAL (via fixed-wing and ground measurements)
  - Measurement: MULTISPECTRAL (via ASTER satellite)
  - Analysis: Overlay hyperspectral and multispectral datasets on known wells and interpreted faults to look for vegetative anomalies (from leaking gas) around shallow faults / surface lineaments and old wellheads. Interpret fault/fracture patterns from high-resolution helicopter data and overlay results on EM and spectral data to interpret gas migration along shallow faults.
- **Shallow / Near-Surface Gas Sand Detection**
  - Measurement: EM (via helicopter and fixed-wing)
  - Analysis: Interpret shallow resistivity variations using high-resolution helicopter data and overlay results on spectral data maps to interpret the presence of shallow / near-surface gas sands.

Well Detection

- Looking for previously unidentified old abandoned "orphan" wells not appearing in DEP or industry well databases.

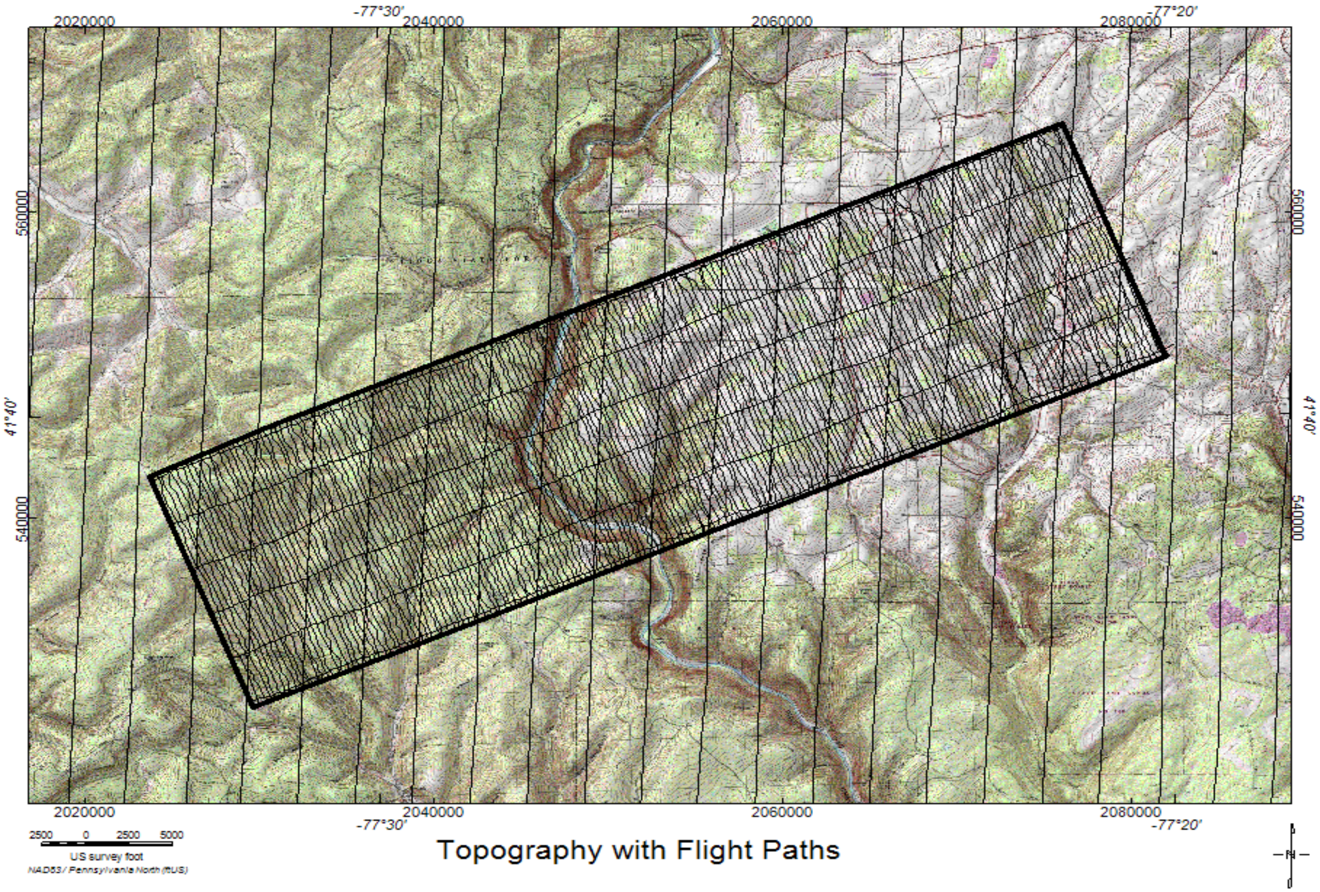
- Looking for unrecorded water wells not appearing in DEP database for avoidance, baseline sampling, and protection during operations.



•Carter, K.M. and Harper , J.A., 2002, Oil and gas prospects in northeastern Pennsylvania, *in* Inners, J. D., and Fleeger, G. M., eds., From Tunkhannock to Starrucca: bluestone, glacial lakes, and great bridges in the "Endless Mountains" of Northeastern Pennsylvania: Guidebook, 67th Annual Field Conference of Pennsylvania Geologists, Tunkhannock, PA, p. 15 - 31.

Map of northeastern Pennsylvania showing locations of producing oil and gas fields and old abandoned "legacy" wells.

Tioga County Project Area with Flight Paths



Topography with Flight Paths

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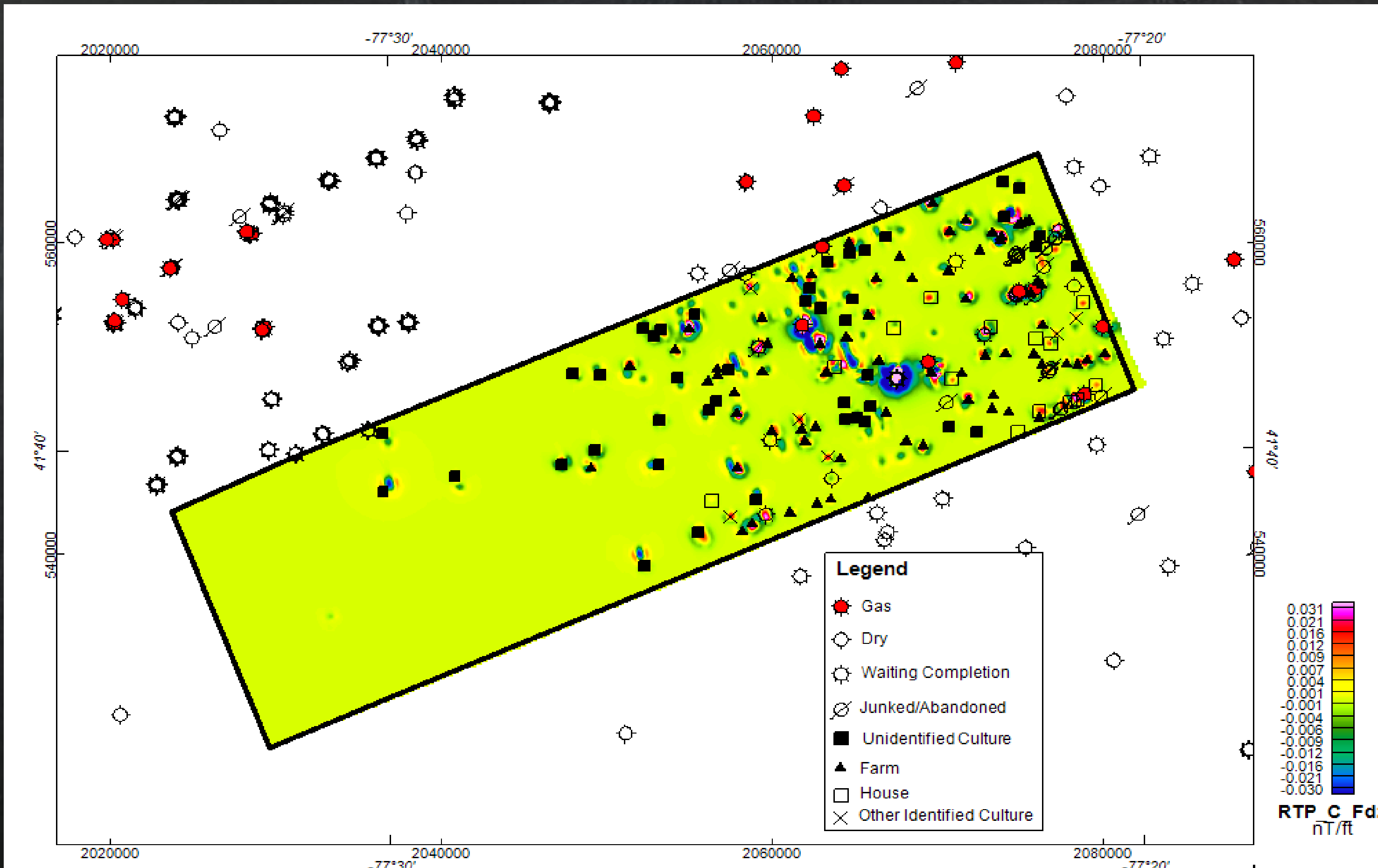
Known Wellheads and Infrastructure Seen on Aero-Magnetic Survey



RTP_Culture_Fdz Magnetic Image with Culture

Surface Faulting / Lineament & Gas Seep Detection

- Looking for surface lineaments / vertical fracture corridors (bedrock aquifers) for avoidance during selection of well surface locations.

- Identification of surface lineaments / vertical fracture corridors that may be acting as natural methane surface seeps.

Stray Gas Occurrence at the Surface in Ground Water:

- Stray gas contamination of freshwater aquifers in Tioga County can occur through:

- naturally occurring near-surface fault conduits, fracture systems, and deeper fault framework (surface drainage patterns seen on topographic maps often corresponds to fault framework in subsurface).

- water wells drilled slightly too deep (establishing communication with shallow gas sands),

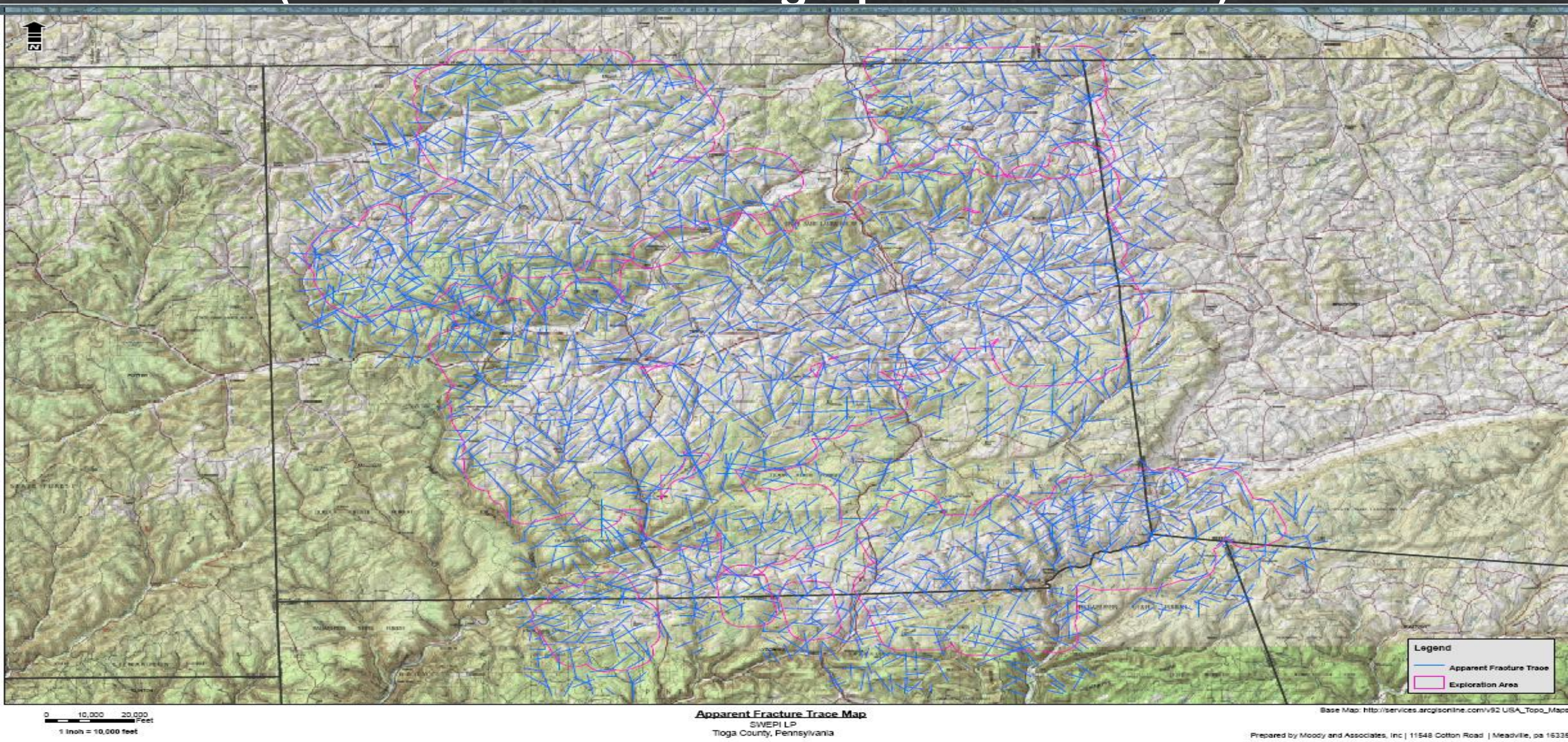
- gas migration through improperly abandoned old derelict gas wells,

- oil or gas wells with sub-optimal cement zonal isolation

- The occurrence of pre-existing methane gas that has either migrated naturally through faults and fractures into the groundwater or has migrated into groundwater from older drilling and mining operations is documented in historical records dating back to the early 1900’s.

- Important to be able to differentiate between pre-existing gas contamination of groundwater, and gas contamination caused by or exacerbated by drilling operations (incomplete zonal isolation of aquifer by cement and casing):

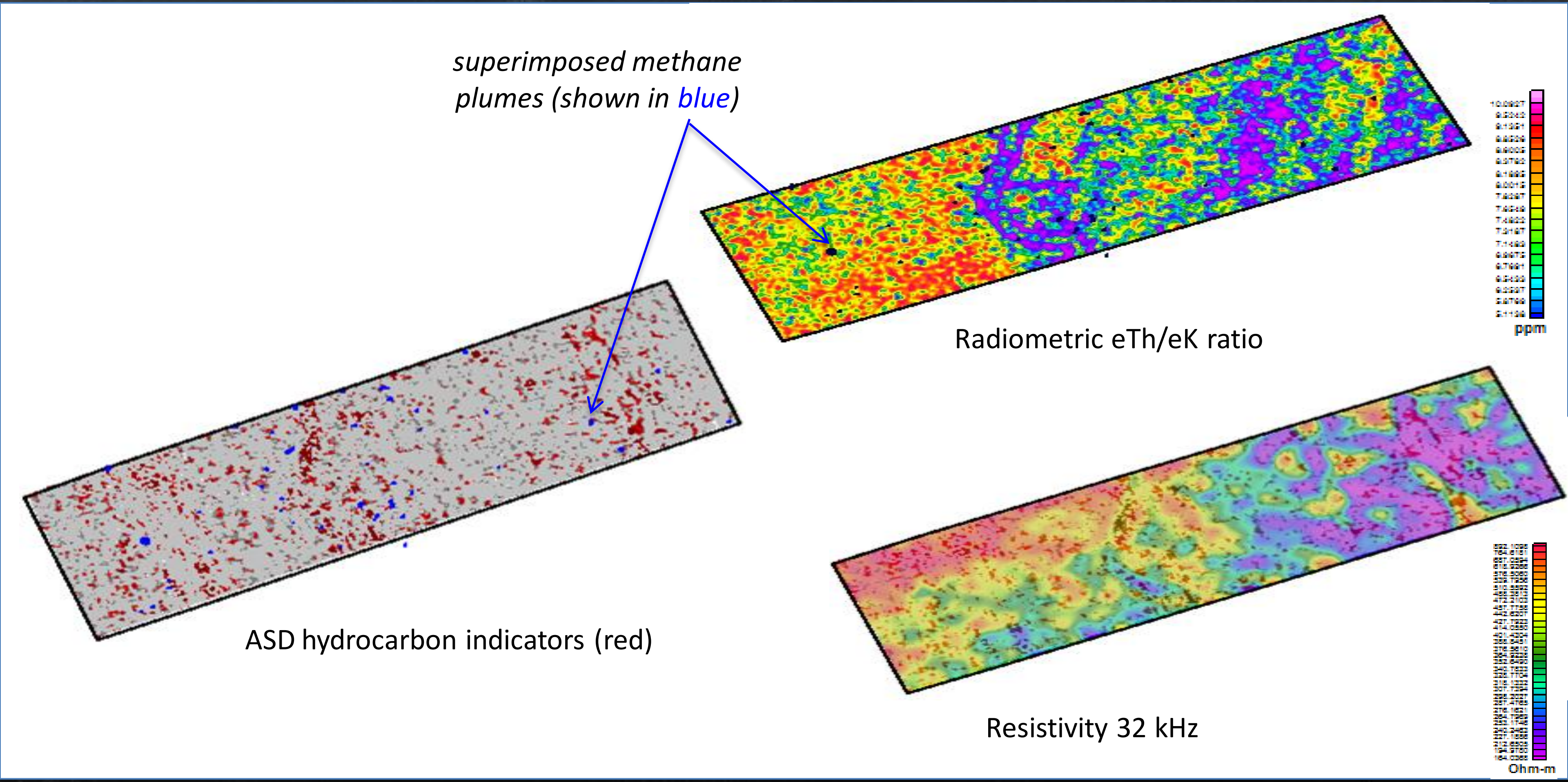
Surface Lineaments Identified During Pre-Drill Site Selection (Seen on Aerial Photograph Stereo-Pairs)



NATURAL SPRINGS & METHANE SEEPS

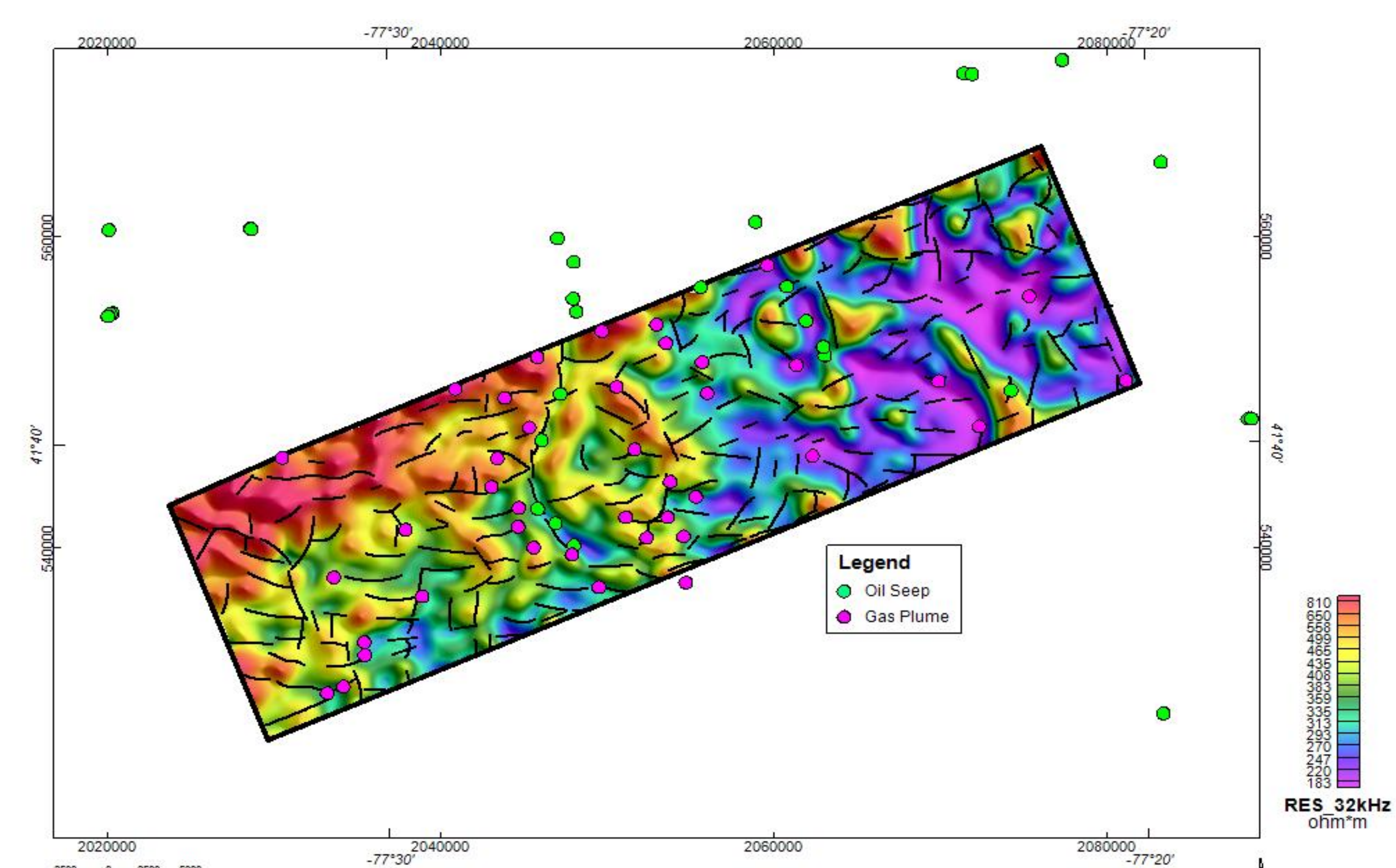
As early as 1795, Pennsylvania landowners described water that would "bubble and catch fire like black powder".

Hydrocarbon Seep Detection



Mapping Trace Hydrocarbons to Faults/Resistivity

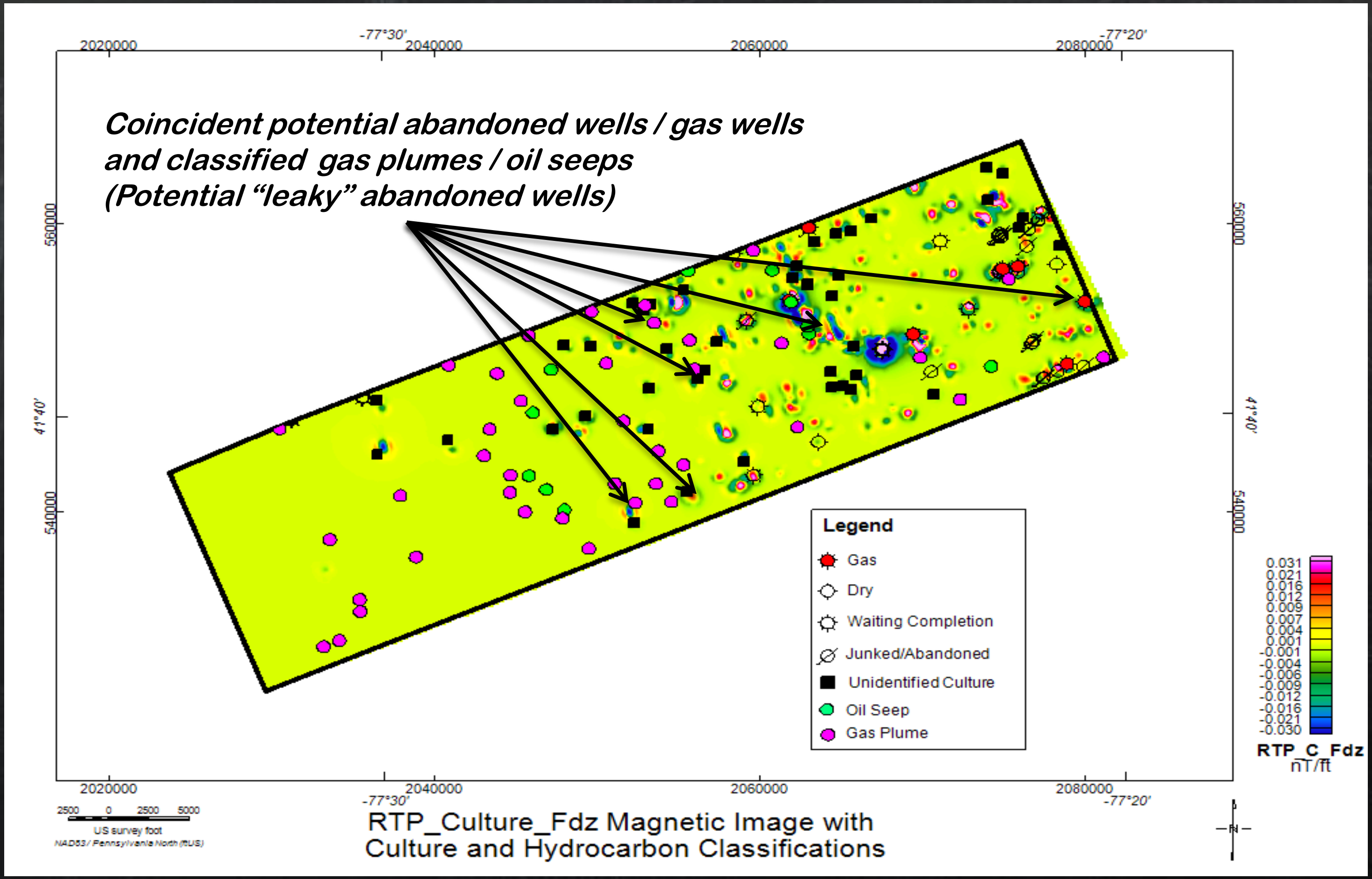
Several Areas Suggest Natural Methane Seepage



Resistivity (32kHz) Image with Hydrocarbon Classifications and Faults

Mapping Trace Hydrocarbons to Infrastructure

Location of Filtered Cultural Magnetic Responses in Project Area



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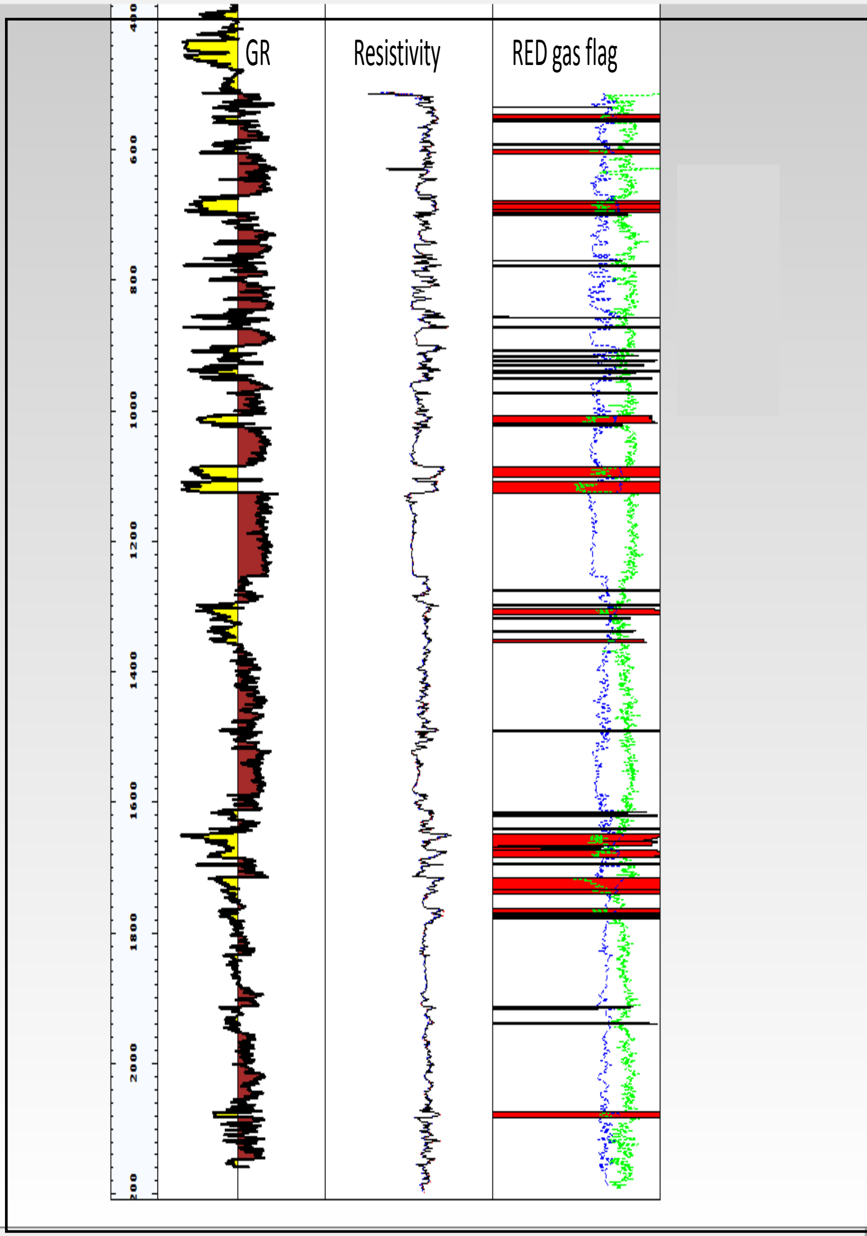
Field Verification of the Airborne Measurements

Ground Truthing that Indicated Trace Hydrocarbon Locations

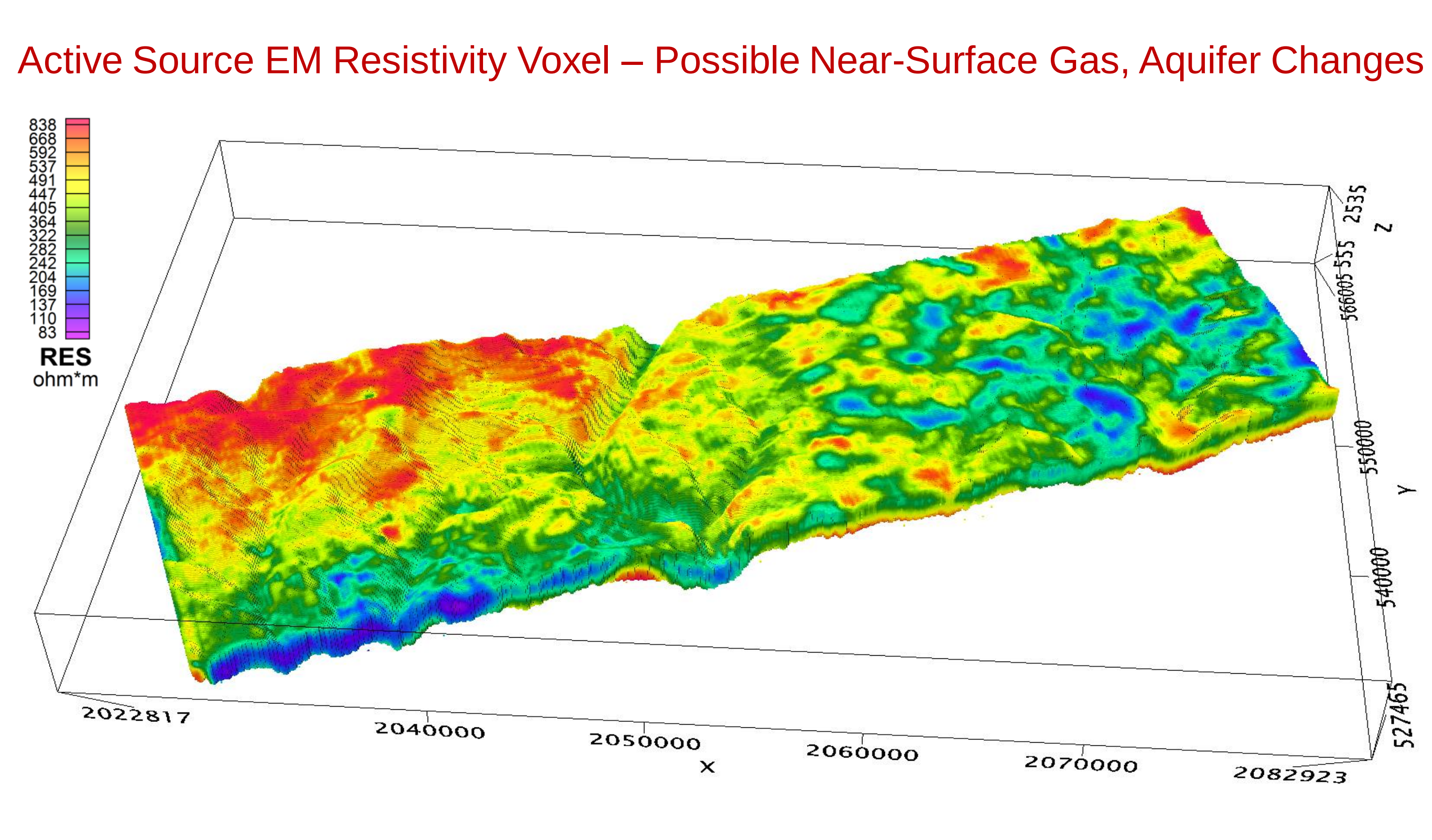
Shallow / Near-Surface Gas Sand Detection

Looking for resistivity variations in the shallow subsurface using high-resolution magnetic and EM surveys (via helicopter & fixed-wing platforms) that could indicate the presence of shallow gas sands.

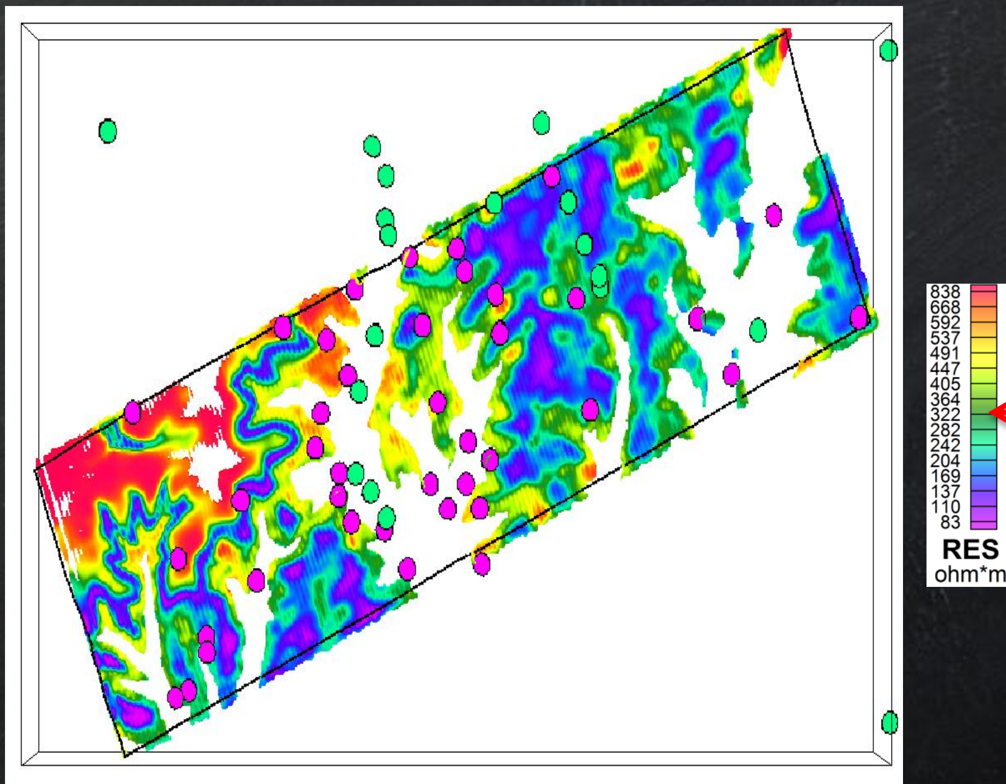


Example of shallow gas sands identified in initial study of 45 wells drilled in Tioga County (Brent Williams)

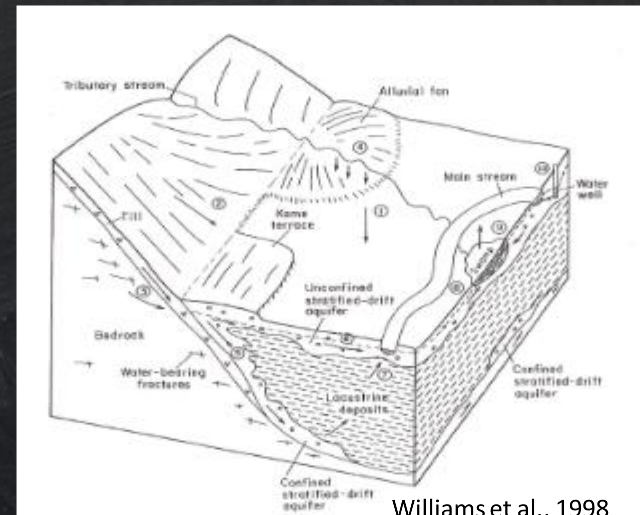
Additional Shallow Subsurface Analysis



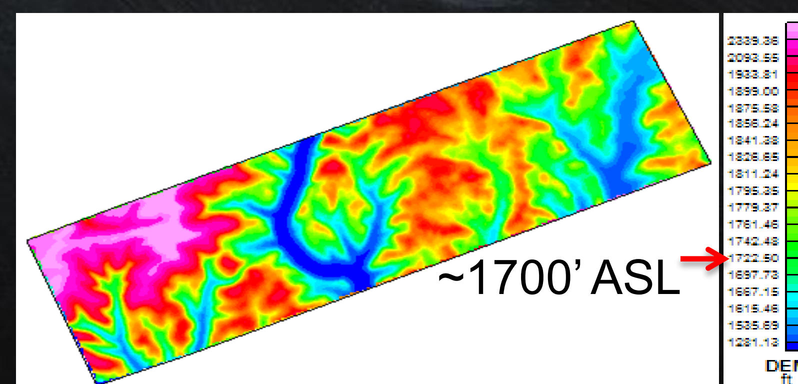
Active Source EM Resistivity Voxels
Highest Elevation Slice: 1700' ASL



- Classified Oil Seeps
- Classified Gas Plumes



Williams et al., 1998



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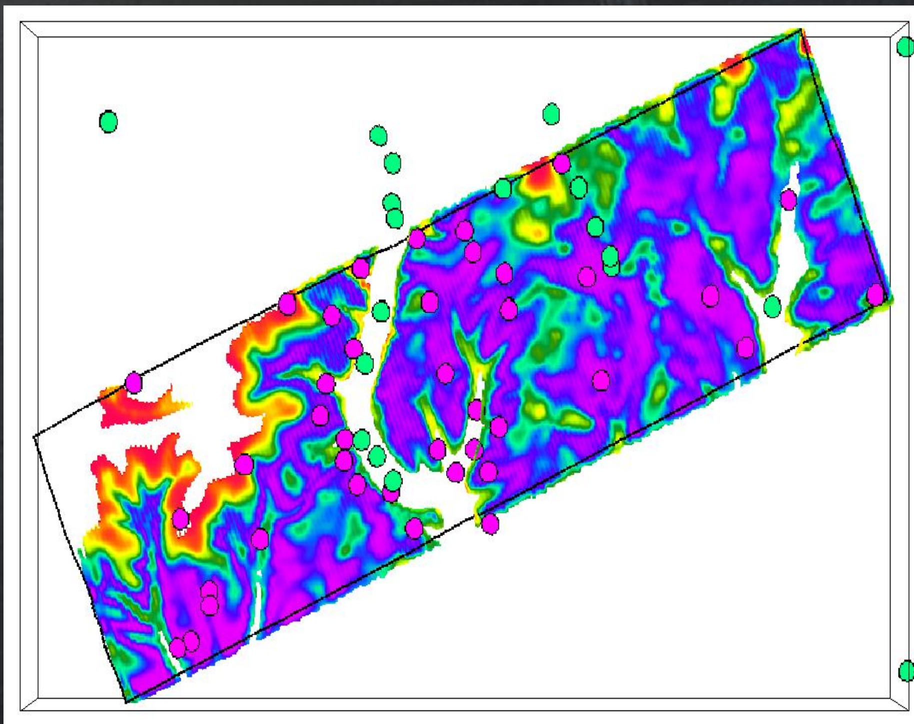
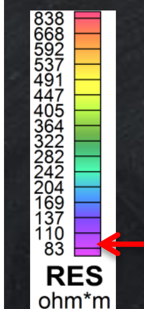
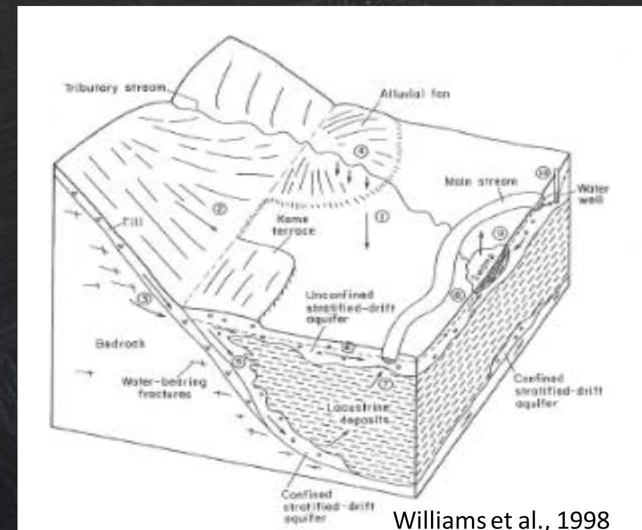
Active Source EM Resistivity Voxel
Deeper Elevation Slice: 1500' ASL

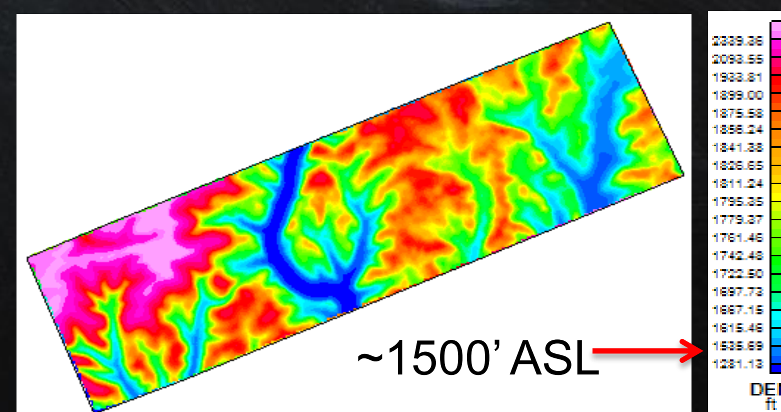




- Classified Oil Seeps
- Classified Gas Plumes

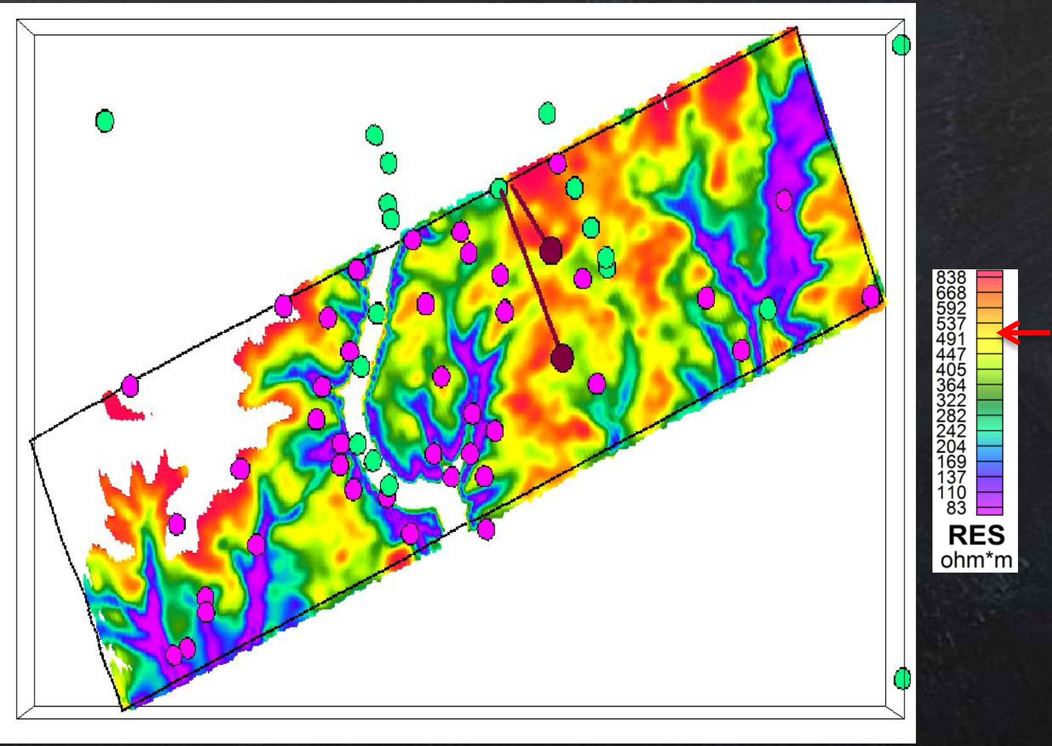


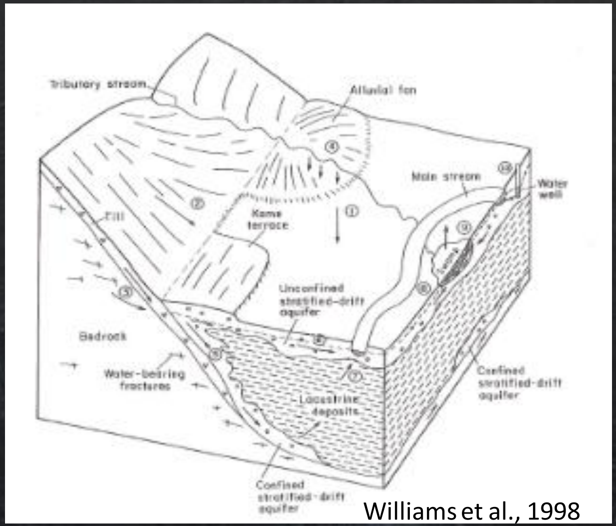
Williams et al., 1998



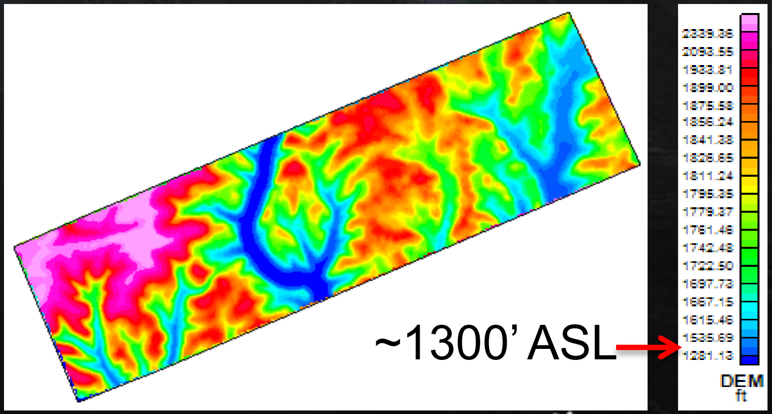
Active Source EM Resistivity Voxel

Deepest Elevation Slice: 1300' ASL





Williams et al., 1998



- Classified Oil Seeps
- Classified Gas Plumes
- Well Log Showing Shallow Gas

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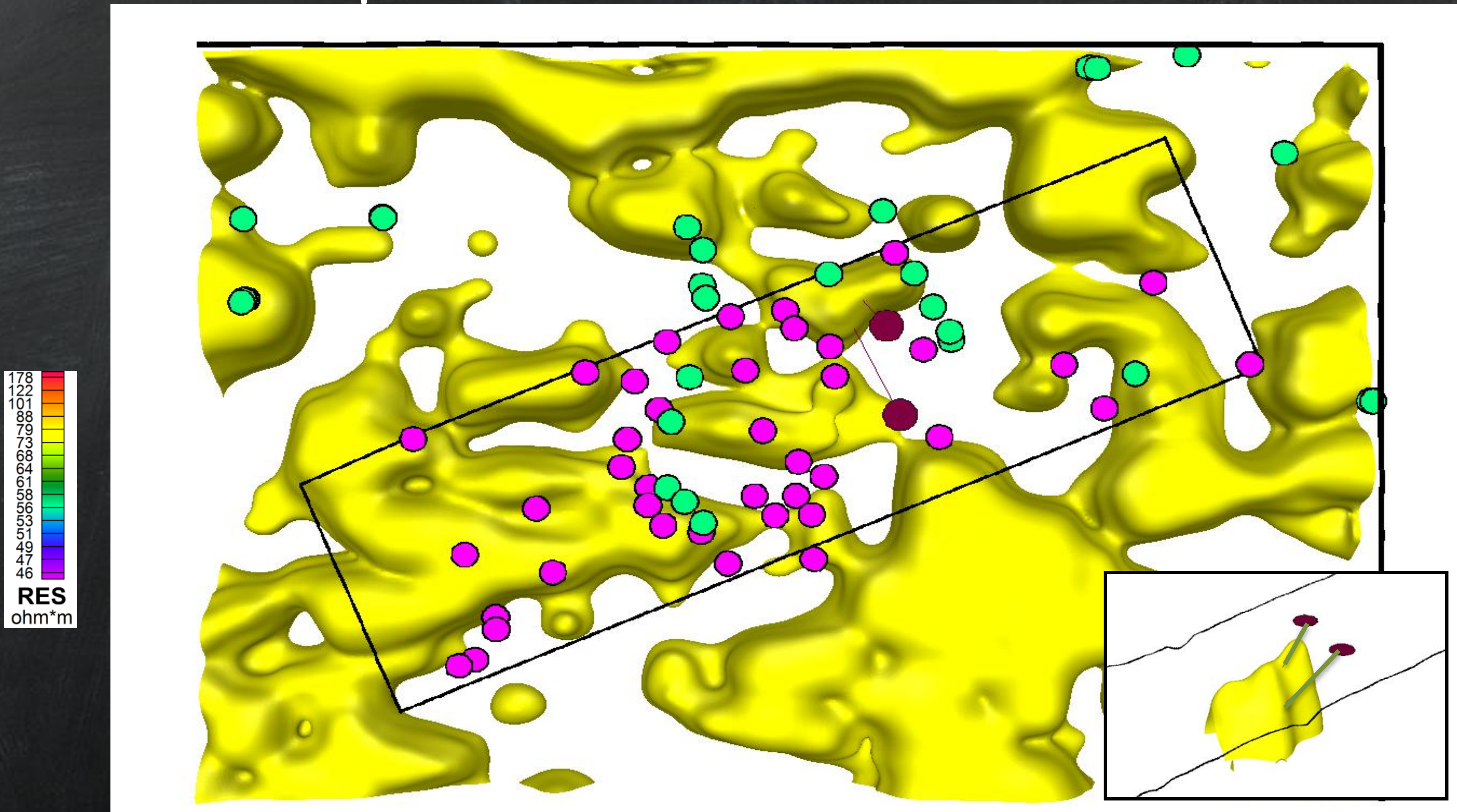
Passive EM Resistivity Voxel

Top Down View of 75 ohm*m Isosurface



- Classified Oil Seeps
- Classified Gas Plumes
- Shell Well with Shallow Gas

Summary of Findings

- **Well Detection** – This remote sensing project has been able to identify 67% of documented wells in the test area and has identified 43 additional "potential" abandoned buried well heads.

- **Surface Lineament Mapping & Hydrocarbon Seep Detection-** The project has been able to interpret faults/fractures at or near the surface These interpreted surface and near-surface structural features have been integrated with hydrocarbon indicator analyses to identify locations of surface hydrocarbon seeps. The project has identified potential surface hydrocarbon seeps based on Hyperspectral, ASD, FTIR and resistivity data.

- **Near-Surface Shallow Gas Sand Detection**– The project has been able to interpret shallow gas occurrence at a range of depths (using depth-matched filtering) with magnetic and EM resistivity data.

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