Geobotanical and Lineament Analysis of Landsat Satellite Imagery for Hydrocarbon Microseeps[1]

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Abstract

Both geobotanical and structural interpretations of remotely sensed data tend to be plagued by random associations. However, a combination of these methods has the potential to provide a methodology for excluding many false associations. To test this approach, a test site in West Virginia has been studied using remotely sensed and field data. The historic Volcano Oil Field, in Wood, Pleasants and Ritchie Counties was known as an area of hydrocarbon seeps in the last century. Although pressures in the reservoir are much reduced today, hydrocarbons remain in the reservoir. An examination of a multi-seasonal Landsat Thematic Mapper imagery has shown little difference between the forests overlying the hydrocarbon reservoirs compared to the background areas, with the exception of an image in the very early fall. This image has been enhanced using an nPDF spectral transformation that maximizes the contrast between the anomalous and background areas. A field survey of soil gas chemistry showed that hydrocarbon concentration is generally higher over the anomalous region. In addition, soil gas hydrocarbon concentration increases with proximity to linear features that cross the strike of the overall structure of the reservoir. Linear features that parallel the strike, however, do not have any discernible influence on gas concentration. Field spectral measurements were made periodically through the summer and early fall to investigate the origin of the spectral reflectance anomaly. Measurements were made with a full-range spectro-radiometer (400 nm to 2500 nm) on a number of different species, both on an off the spectral anomaly. The results lend support to the finding that in the early fall spectral reflectance increases in the near infrared and mid infrared in the spectrally anomalous regions.

Introduction

Remote sensing data and imagery collected by satellite-borne sensors are powerful methods of exploration for energy and mineral exploration. Unfortunately, a closed canopy forest such as that found over much of West Virginia limits the usefulness of remotely sensed data because the vegetation obscures the ground surface. Some studies have shown, however, that the obscuring

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vegetation is sometimes subtly influenced by the underlying geology, and especially the presence of anomalous concentrations of oil, gas or economic minerals. If the subtle influence can be detected, the vegetation then becomes the key to exploration strategies. For example, in a study of a test site at Lost River, WV (Lang *et al.*, 1985), it was found that areas of locally anomalous maple concentrations were associated with hydrogen-sulfide-rich springs over the Lost River gas field. The inferred association of maples and buried hydrocarbons is supported by independent studies, which have shown that of the trees found at Lost River, maples are the most tolerant of methane.

Another more indirect method of exploration is to identify linear features on satellite imagery, which are often called lineaments. Lineaments are commonly interpreted as surface expressions of rock fractures which may provide pathways for seepage of oil and gas from subsurface reservoirs.

Objectives

The primary objective of this study was to investigate structural and geobotanical features associated with surface expressions of enhanced porosity and permeability in oil and gas reservoirs using advanced remote sensing techniques. The aim was to integrate the mapping of lineaments with geobotanical methods that identify anomalous vegetation communities. This integration improves techniques utilizing remotely sensed data for hydrocarbon exploration and mapping in forested regions such as West Virginia, and provides a broad-scale, objective method of determining the significance of lineaments. Field-based methods were used to supplement the study, and to provide independent validation of the results.

Approach

A major problem with both lineament and geobotanical exploration is that they are associated with a great deal of uncertainty. Geological influences on vegetation communities are usually much less significant than other edaphic, biologic and climatic factors, making geobotanical approaches very complex. Thus for, example, although maples have been associated with hydrocarbon microseeps (Lang, *et al.,* 1985), not every stand of maples in West Virginia is likely to be associated with subsurface hydrocarbons. Lineament identification is often questioned due to the difficulty in showing the structural significance of either individual lineaments, or the observed pattern (Huntington and Raiche, 1978). Clearly, a methodological approach that incorporates additional supporting evidence is required, such as the ecological approach used in geobotanical analyses which integrate remotely-sensed edaphic and micro-climate information (Warner *et al.*, 1991.) An integrated approach reduces ambiguity by focusing on areas where the multiple methods all point to anomalous areas.

The integration of lineament mapping techniques with geobotanical exploration methods for this study provides a more reliable way to identify remotely-sensed indications of microseeps, and reduce the uncertainty inherent in both techniques. In previously known reservoirs, an approach based on such an integration has the potential to identify lineaments which are also zones of increased permeability, and thus locations where maximum reservoir production might be expected. In new areas, microseeps provide a surface indication of potential targets for further analysis or drilling.

The present satellite-borne sensors have a limited spectral resolution which limit the identification of subtle spectral effects related to vegetation stress. Previous studies (most recently Bammel and Birnie, 1994) have shown, for example, that the position of the chlorophyll red absorption feature (0.67 μm) shifts to shorter wavelengths in sagebrush stressed due to the accumulation of hydrocarbons at the surface or in the shallow subsurface. Although no currently-available satellite sensor can measure such small spectral shifts, aircraft-borne sensors such as the Airborne Visible/Infrared Imaging Spectro-radiometer (AVIRIS) have the potential to do so. Ground based measurements can provide further validation. In addition, multi-temporal analyses provide an alternative source of information, as some spectral anomalies may only be evident at certain times of the year.

Project Description

The approach used in this study was an empirical analysis of a known area of historical seeps of hydrocarbons, which was assumed to have the potential for current microseep activity. The study site is the historic Volcano Oil field, on the crest of the North-South trending Burning Springs Anticline. The oil field was discovered about 1864, and has produced over 2 million barrels of oil since that time. Production was from four sandstone horizons within the Connoquenessing Sandstone, the Pottsville, the Greenbrier, and the Pocono Big Injun Sands. Despite the extensive production, hydrocarbons are still present in parts of the structure, although a waterflood effort in the mid-1960's was a failure. The Burning Springs Anticline has nearly 500 meters of structural relief. The crest is almost flat for nearly a mile, and the flanks are characterized by very steep dips. Repeated strata were found in the Sandhill deep well, and this led to the recognition of thrust faulting in the lower and middle Devonian.

A Landsat image of April 19, 1987 was selected for lineament analysis. This image was acquired prior to forest leaf-out, and consequently there are few distracting variations in forest cover. However, pasture was green at this time, and this does provide some contrast with the forested areas. In order to improve the detection of lineaments, a 3 by 3 high pass filter was passed over the data. The high pass information was multiplied by 0.2 and combined with the original image data multiplied by 0.8. This combination of high pass and original data preserves the tonal features of the image and also enhances sharp discontinuities. A standard false color composite was chosen (green displayed as blue, red as green and infrared as red) for display and analysis at a scale of 1:100,000. Two interpreters independently mapped lineaments on the images, and the results were overlayed. Only lineaments identified by both observers were recorded on the final lineament overlay.

Imagery from spring, summer, early fall and fall was co-registered to a common UTM projection. An examination of this multi-seasonal Landsat Thematic Mapper imagery, and geological overlays has shown little difference between the forests overlying the hydrocarbon reservoir compared to the background areas. The one season that is an exception is an image acquired September 20 1985, in the very early fall. A spectral transformation for this image was developed using the nPDF suite of programs of Cetin (1991) and Cetin and others (1993). Training samples were selected from the anomalous areas, as well as nearby areas that did not exhibit increased infra-red reflectance. These areas were supplied to an algorithm that suppresses differences in illumination, and finds a "corner" in the data space that provides a perspective of the entire data set that gives the greatest difference between the two classes (Foote *et al.,* 1994).

This resulted in a transformation of (1110001), which is a projection from the maximum value in the visible bands (bands 1, 2, and 3) and the thermal band (band 6), and the origin in the near and mid-infrared bands (bands 4, 5, and 7).

A soil gas geochemical survey was carried out in May of 1996. A total of 32 samples were collected Although this is a rather small sample collection, their distribution provides an excellent overview of the soil gas geochemistry of the test site. The soil gas samples were collected with a 4 foot soil gas probe, which was inserted into a hole made with a slide hammer plunger bar. The sample bottle was evacuated to a pressure of 25 psi, and then allowed to draw vapor from the gas probe. After filling the sample bottle, the septum was sealed with silicon caulk. The samples were analyzed for light hydrocarbons by a contracting company. The sample locations were digitized and overlaid on a satellite image.

The multi-temporal field spectral reflectance measurements began with a series of reconnaissance measurements in October of 1995, which coincided with a Landsat overpass. From analysis of the Landsat image data base, it was clear that the spectral anomaly associated with the Volcano region was most clearly developed in the early fall (September). Consequently, it was decided to make repetitive spectral measurements in the field, covering the late summer and the fall of 1996. Spectra were measured in areas there were identified as anomalous in the September 1985 image, and compared to background areas. At each site leaf reflectance spectra were measured over the range from 400 to 2500 nm for at least 5 different tree species. Although an attempt was made to collect spectra of the same trees at all the sites, this was not always possible. The species for which spectra were collected include:

- Tulip poplar — *Liriodendron tulipifera* L.
- White oak — *Quercus alba* L.
- Chestnut oak — *Quercus prinus* L.
- Black oak — *Quercus velutina* Lam.
- Red oak — *Quercus rubra* L.
- Red maple — *Acer rubrum* L.
- Sugar maple — *Acer saccherum* Marsh.
- Shagbark hickory — *Carya ovata* (Mill.) K. Koch
- American beech — *Fagus grandifolia* Ehrh.

Spectra were measured from 400 to 2500 nm with a full range GER Mk. IV spectrometer. Although this is a relatively slow and cumbersome instrument, it has a particular advantage in that it continuously ratios between a reflectance standard and the target of interest. This proved to be more important than anticipated, due to the poor and highly variable illumination conditions common on the East Coast during the late summer. Although the continual ratioing of the instrument can normalize for most of the changes in illumination, the high humidity limits the optical depth, thus reducing the amount of illumination on the sample. This in turn causes a rather low signal to noise.

The initial field plan was to acquire spectra on a two week repeat cycle from mid-August through mid October. Very poor weather conditions caused some deviation from the schedule. Between 20 and 40 spectra were collected on each day. The final dates of coverage for 1996 were:

- 8/6/96
- 8/21/96

- 9/9/96
- 9/23/96
- 9/30/96

Results

An analysis of the geobotanical transformation shows that the early fall (September) image provided the best discrimination of spectral anomalies. In the spring image, a lack of vegetation limits spectral potential to evergreen species. The summer imagery shows little spectral variation. The late fall image shows a great deal of variation, but is dominated by fall colors. Contrary to expectation, these fall colors do not seem to be of great significance for predicting hydrocarbon microseep location.

The early fall image was obtained just prior to fall color development. It is hypothesized that in the microseep areas the additional stress from the seeps is causing early senescence, but it may be pre-visual. The ground spectra provide some verification of this, as can be seen in Figure 1, which compares the spectra of tulip poplar, both on and off the anomalies. Notice the higher spectral reflectance of the anomaly site, particularly in the near infrared.

The early fall nPDF spectral anomaly image has a concentration of high values of the transformation dominantly associated with the Volcano structure, and also to a certain extent with higher soil gas concentrations. However, as was expected, the geobotanical transformation is highly noisy. The combination of geobotanical transformation and lineaments seems to be a very effective solution to this problem.

A comparison of the soil hydrocarbon gas concentrations and the structural map shows that concentrations are highest over the Burning Springs Anticline. However, the pattern is fairly complex, and some higher values can be found away from the structure. This is not unexpected, as hydrocarbon reservoirs are also found off the Volcano structure, albeit generally at a greater depth. Particularly interesting is a comparison between gas concentrations and lineaments that were previously mapped on the Landsat imagery by two independent observers. In Figure 2, it can be seen that concentrations of ethane are correlated with distance from the nearest Landsat lineament. However, when gas concentration is plotted against distance from lineaments that cut across the strike of the Burning Springs structure (Figure 3), the pattern becomes a much clearer. By comparison, when gas concentration is plotted against distance from lineaments sub-parallel to strike, the association is very weak, or even inverse (see Figure 4). Thus cross-strike lineaments are much more likely to be indicators of zones of increased permeability for oil migration, compared to lineaments that are sub-parallel to strike. This suggests that for the Burning Springs structure, lineaments sub-parallel to strike represent fractures that have been sealed, or that they are represent stratigraphic or other non-structural features. Field observations lend support to this latter argument, especially for the lineaments that bound the Burning Springs anticline.

In summary, the following conclusions can be made: A geobotanical spectral anomaly is found over the Burning Springs Anticline. The spectral anomaly is best seen in the early fall, and with spectral observations in the near, middle, and thermal infrared wavelengths. The geobotanical anomaly corresponds to elevated soil gas levels over the Burning Springs anticline. Cross-strike lineaments appear to be of greater significance for zones of hydrocarbon microseeps than lineaments that are sub-parallel to strike.

Figure 1. Spectral reflectance of tulip poplar leaves from anomalous and background areas

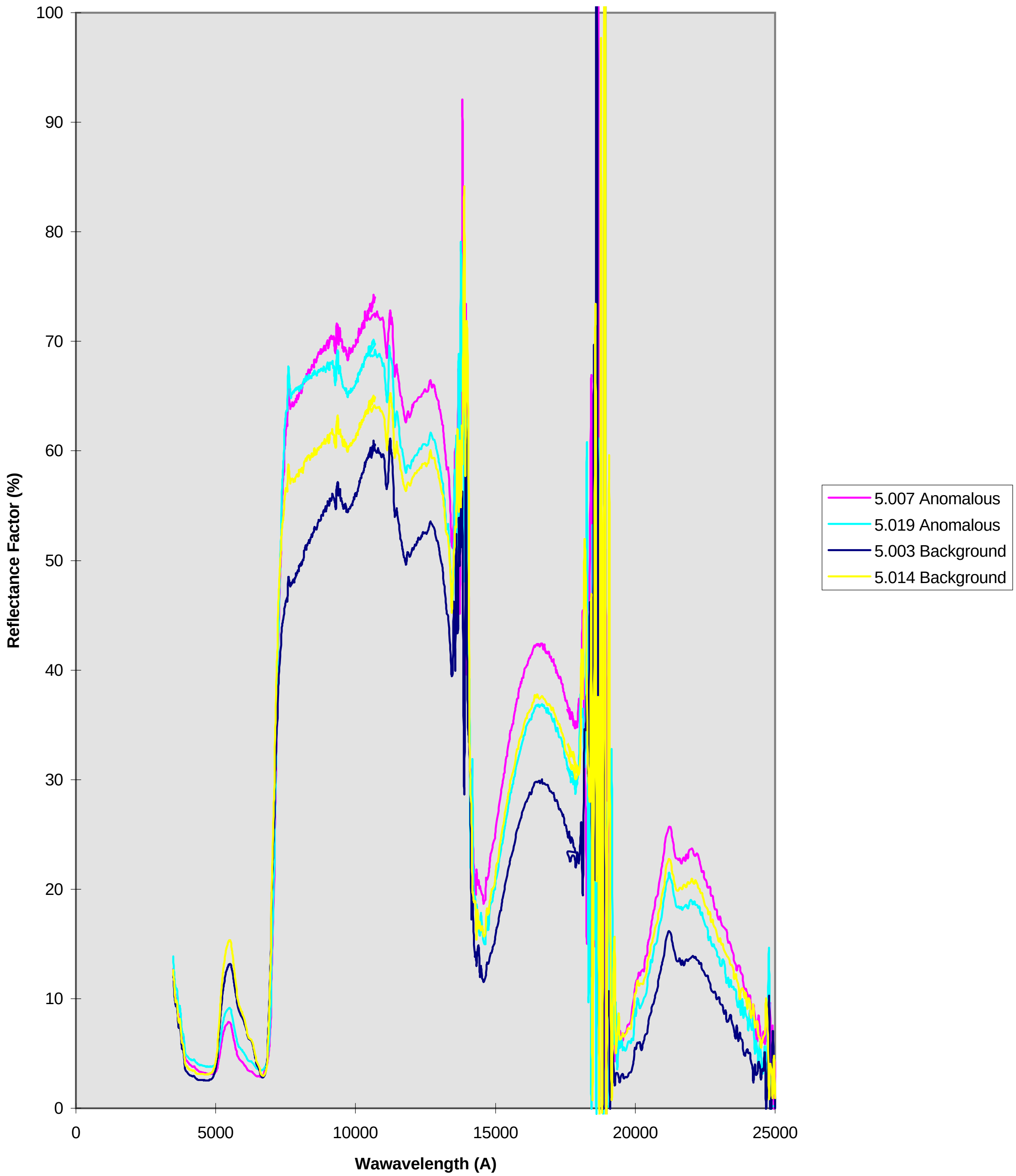


Figure 2. Soil gas concentration vs distance to all lineaments

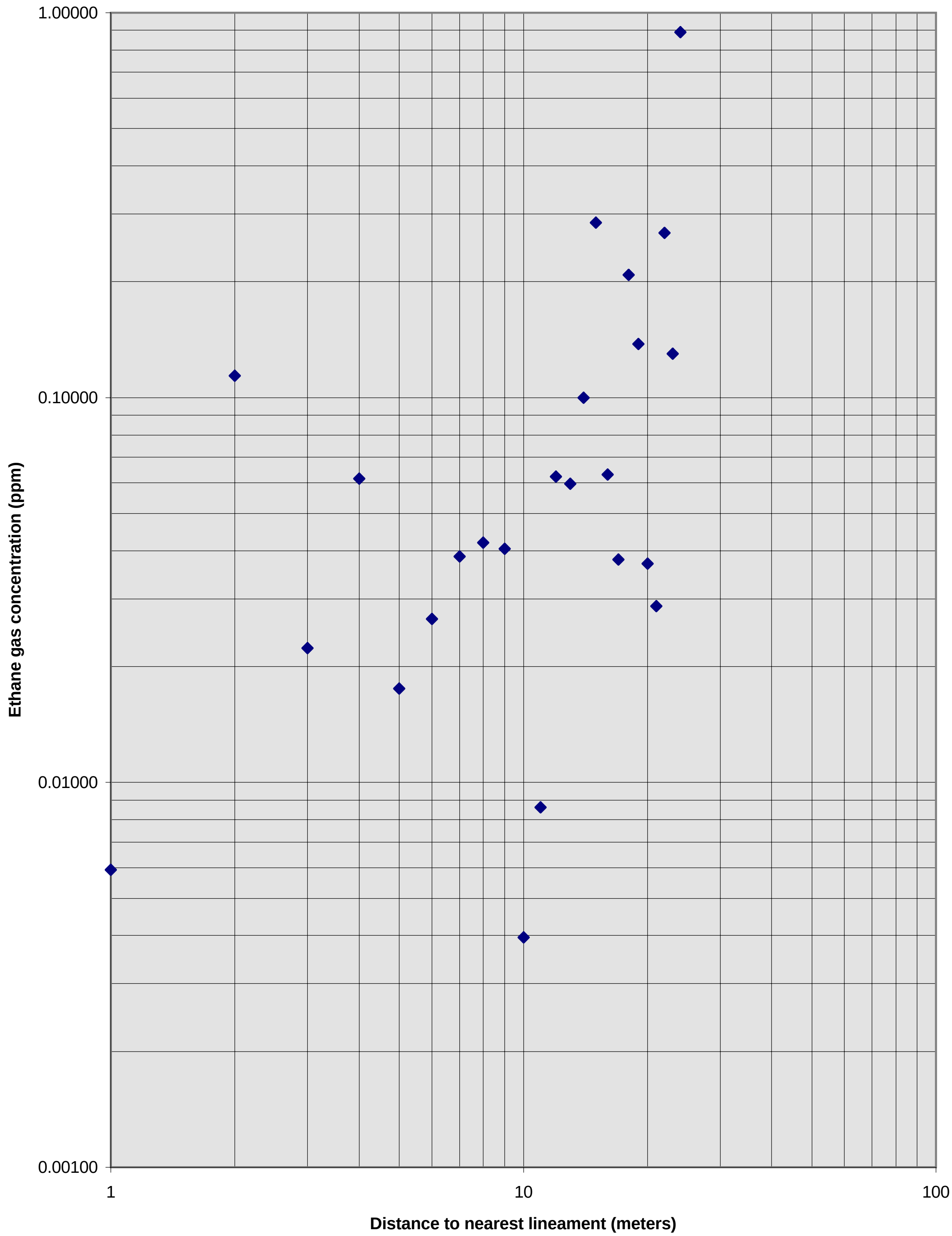


Figure 3. Soil gas concentration vs distance to cross-strike lineaments

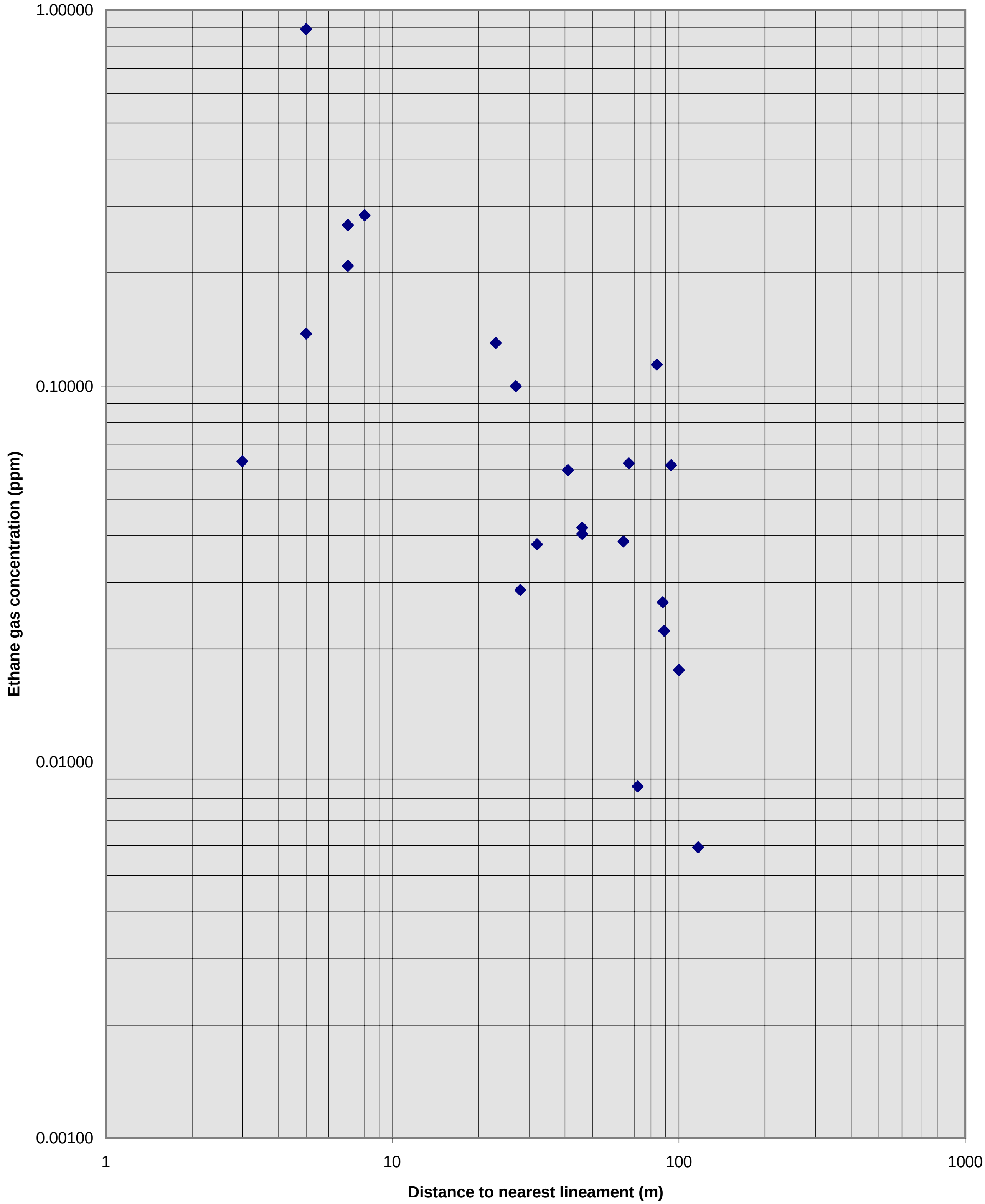
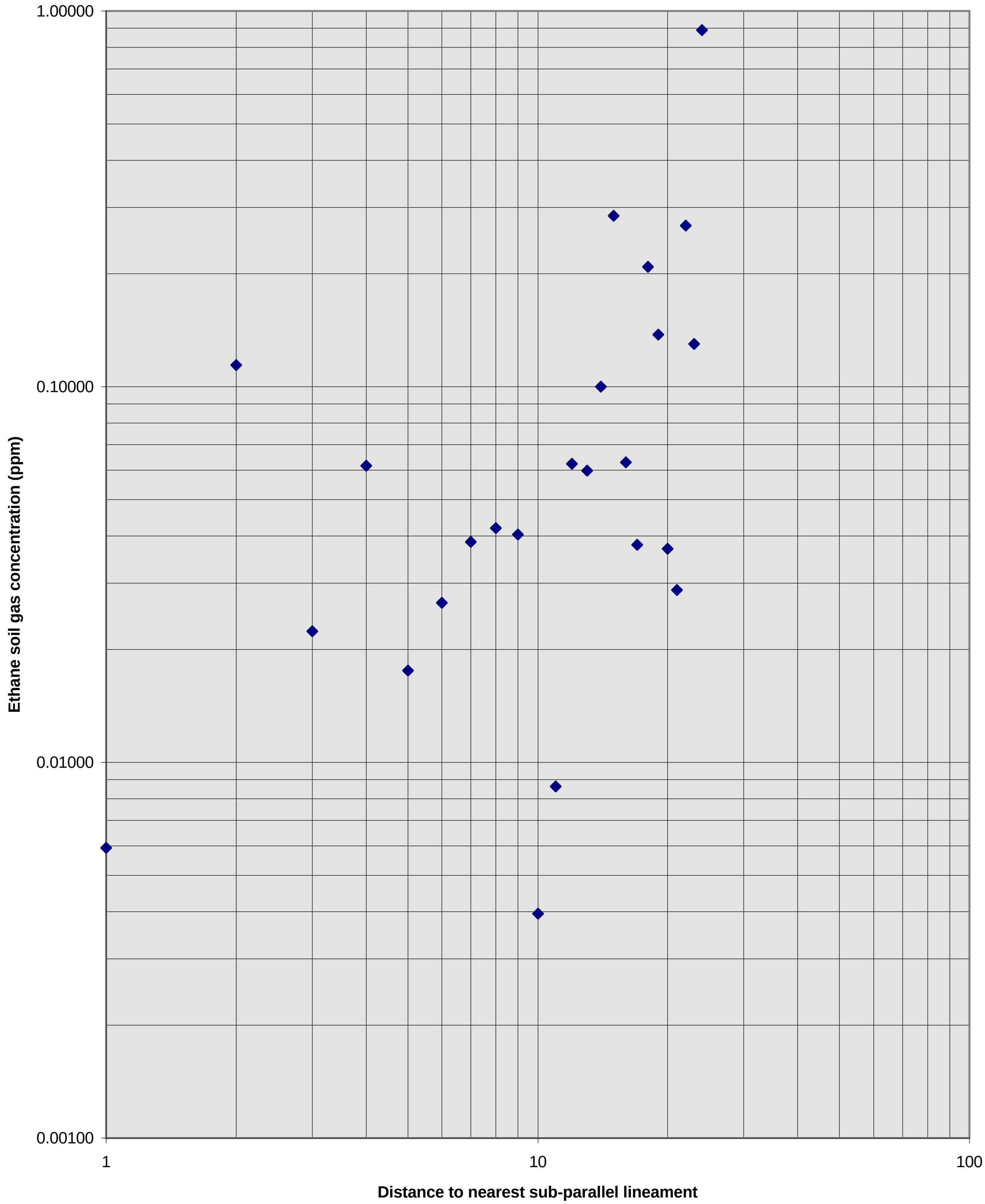


Figure 4. Soil gas concentration vs distance to sub-parallel lineaments



Applications

Hydrocarbon exploration in West Virginia has a long history, and most easily identified traps have been investigated. Finding new fields, and identifying high permeability zones where enhanced recovery can be obtained from mature fields, could add significant life to the Appalachian fields, and therefore have a major impact on the local economy. Thus although this project focuses on a specific test-site, the procedure has more general applicability as a prototype for exploration in other areas.

Integrating geobotanical exploration methods with lineament analysis provides an excellent method for reducing the uncertainty in both methods. With such an approach, remote sensing has great potential in forested regions, despite the presence of a closed canopy forest.

Future Activities

Future activities planned include further analysis of the field spectra, to identify particular narrow spectral regions with the most potential for discriminating vegetation with anomalous features associated with hydrocarbon microseeps. In addition, it is hoped to do a follow-up soil gas survey over anomalous regions outside the initial study area.

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