REMOTE SENSING AND SURFACE HYDROCARBON LEAKAGE *

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ABSTRACT

The Geosat oil and gas test site program stimulated interest in the interaction between surface hydrocarbon concentrations and interpretation of remote sensing data. The test case results suggested that lineaments correspond to avenues of preferential hydrocarbon seepage and that this seepage affects vegetation health and populations at Patrick Draw field in Wyoming and potentially at Lost River field, West Virginia. These two areas were selected for additional surface hydrocarbon surveys in order to test these hypotheses.

The Patrick Draw study shows that a zone of stressed vegetation, visible on thematic mapper data, definitely coincides with an area of marked leakage of hydrocarbons and that the composition of these gases would predict an intermediate type oil and gas reservoir such as exists in the area. The study further indicates that the leakage is in large part controlled by the presence of fractures/faults recognized as lineaments on the remote sensing images.

The Lost River study specifically investigated the possible existence of hydrocarbon leakage causing anomalous populations of maple trees in a climax oak forest. These maples were first recognized by study of thematic mapper simulator data. The soil gas hydrocarbon concentrations are above average in several of the maple anomalies over the field. This supports the inference that the maples are present because they are more tolerant of soil conditions where hydrocarbon seepage is active. The crest of the field has low soil gas magnitudes, but high values occur to the updip eastern edge of the field along a fault/fracture that was detected in the seismic data.

The conclusion that preferential pathways of hydrocarbon leakage are recognized in spectral and textural analysis of remote sensing data is supported by other studies and integrated into a suggested exploration/hydrocarbon migration model.

INTRODUCTION

The Geosat oil and gas test site program stimulated interest in the potential interaction between surface hydrocarbon seep concentrations and the interpretation of remote sensing data. The Geosat test case results suggested that lineaments correspond to avenues of preferential hydrocarbon seepage and that this seepage affects vegetation health and populations at Patrick Draw field in Wyoming and potentially at Lost River field, West Virginia. These two areas were selected in 1983 for additional extensive surface hydrocarbon surveys in order to test these hypotheses.

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The previous Patrick Draw study showed that a zone of stressed vegetation, visible on thematic mapper data, definitely coincided with an area of marked leakage of hydrocarbons and that the composition of these gases would predict an intermediate type oil and gas reservoir such as exists in the area. The study further indicated that the leakage is in large part controlled by the presence of fractures/faults recognized as lineaments on the remote sensing images (Richers, et al. 1982).

The Lost River study specifically investigated the possible existence of hydrocarbon leakage causing anomalous populations of maple trees in a climax oak forest. The existence of these stands of maples was first recognized by study of thematic mapper simulator data. The Geosat interpretation proposed that the maples were present because they are more tolerant of soil conditions where hydrocarbon seepage is active. The Lost River field was also found to be coincident with areas of increased lineament density. At Lost River the Geosat surface hydrocarbon program was based on microbiological techniques and was inconclusive.

Several near-surface hydrocarbon prospecting techniques using free, adsorbed, and acid-extracted gases were tested over both fields and will be the subject of a future publication. The most important technique for this investigation is the shallow 4-ft probe data which were used over both fields in order to determine the free gas associated with the stressed or otherwise unique vegetation reported over the Patrick Draw, Wyoming and Lost River, West Virginia fields by the previous Geosat Oil and Gas test site investigations.

EXPERIMENTAL

The 1983 survey consists of soil gases measured in soil gas samples collected in 125 cc septum cap bottles from 4-ft deep probe holes. The sampling hole is made by manually pounding a solid 1/2-in. steel bar probe into the ground to a depth of 4 ft. After the bar is removed, a soil gas probe is inserted into the hole. The septum bottles are evacuated to approximately 100 microns vacuum before each use, and are filled to a positive pressure of 7 psi using a hand pump attached to the top of the soil gas probe. Hydrocarbons are measured on a flame ionization gas chromatograph as described by Jones and Drozd (1983).

SURFACE GEOCHEMICAL MODEL

Experience in basins worldwide, including over 21,000 soil gas measurements, has been summarized by Jones and Drozd (1983). The most compelling evidence that the near-surface soil gases are related to reservoirs/sources at depth is the regularity of the compositional data. This is best demonstrated by Fig. 1 which shows histograms of the (C_3/C_1) 1000 compositional values in the Sacramento dry gas, Alberta Foothills gas condensate, and Permian Basin oil provinces. Surface hydrocarbon measurements that are dominated by biogenic activity can generally be recognized by their lack of heavier gases and discounted. Similarly, contamination has a unique signature and can be eliminated (Pirkle and Drozd, 1984).

The relationship of surface hydrocarbon seeps to subsurface reservoirs has been summarized by W. K. Link (1952). Although Link's paper deals only with macroseeps, the associations observed also apply to microseeps as well. The primary connection to the subsurface reservoirs is through the fault and fracture systems governed by the tectonics of the area. This has been clearly demonstrated for microseeps in examples published by Jones and Drozd (1983). Each case is unique and requires integration with the local geology in order to model the relationship. Although the composition of the near-surface hydrocarbons is controlled by the composition at depth, the interaction of two factors are important in controlling the magnitude of near surface hydrocarbon seeps: 1) the concentration/volume at depth, and 2) the permeability of the pathway from the accumulation to the surface. Thus, a large volume of free hydrocarbons concentrated in a reservoir would statistically be expected to yield large magnitude near-surface hydrocarbon values in comparison to disseminated subsurface hydrocarbons such as those associated with source rocks or a region of water wet sands, other factors being equal. However, a permeable pathway, such as a fault or outcropping sandstone, will yield higher surface hydrocarbon concentrations and can easily overshadow any effects related to the size of the subsurface reservoirs.

From a remote sensing viewpoint, it is critical to understand the expected spatial characteristics associated with potential seepage pathways of near-surface hydrocarbons, in addition to the problem of relating these seeps to the secondary or tertiary effects of the seepage that are manifested at the surface and that may be spectrally detectable. Examination of macroseeps reveals that hydrocarbon seepage is often spatially limited (Link, 1952). Indeed, if soil gas profiles such as shown in Fig. 2 are examined, they often appear noisy. This is because of the relationship between soil gas magnitudes and preferential pathways such as faults. If samples are taken within a fault zone, then hydrocarbon seep magnitudes are expected to be higher than those observed outside the fault zone proper, provided there are hydrocarbon reservoirs located in the subsurface in close proximity to the fault zone.

This observation, however, is only true statistically as shown in a conceptual model of a fault zone (Fig. 3). Samples taken outside the fault zone are expected to be representative of typical background seepage in the area. The fault zone, however, consists of at least two broad subtypes: 1) the fault/fracture/joint discontinuity itself, which is a swarm of narrow fractures whose density decreases outwards from the center of the zone into the unfractured area; and 2) the largely unfractured blocks between the narrow fractures. As shown in Fig. 3, if a measurement is made in a fracture, the value will be high, depending on the continuity of the fracture, its width, etc. If, however, the measurement is made in an unfractured block, the value observed may look very similar to that obtained outside the fault zone. However, it typically will be slightly higher on the average than outside the fault zone because of increased micropermeability within the fault blocks and diffusion from the nearby fractures.

LOST RIVER

The Lost River gas field is located in Hardy County, West Virginia, within the Eastern Overthrust Belt. The field was discovered by seismic techniques in 1960 and produces methane-rich gas from fractured Lower Devonian Oriskany Sands in the Whip Cove anticline from a depth of about 6000 ft. The Oriskany outcrops on the flanks of breached anticlines on both the east and west sides of the field. The region is extensively vegetated with Eastern hardwoods, largely dominated by oaks. The magnitude of free propane in the near-surface obtained with 4-ft probes is shown in Fig. 4. Also plotted on Fig. 4 is a simplified geologic map, producing wells, and lineaments interpreted from Landsat images by Reynolds (1979). As shown, the highest magnitude sites occur just to the east side of the field along the crest of the structure, and along the eastern end of the study near the outcrop of the Oriskany and overlying Marcellus Shales. These anomalies appear to be associated with a mapped fault.

A simplified structure map is shown in Fig. 5. The relative positions of the faults and Oriskany outcrops with respect to the propane anomalies are clearly outlined by the geochemical profile. Seeps occur predominantly at the outcrop of the Oriskany and over the fractured eastern flank of the Lost River structure.

The relationship of the gas magnitudes to lineaments mapped by Reynolds (inferred fractures) is less obvious, as would be expected from the previous discussion of Fig. 3. Generally speaking, however, the linears over the field have gas values as high or higher than the rest of the field, while the linears off the field have values similar to the rest of the off-field background values. Based on the lineament information and the geologic map, the near-surface soil gas program suggests the following geologic model. Oriskany Sands and adjacent facies are expected to be the principal reservoir target in the area based on the high values present at its outcrop. The compositional information suggests the reservoir to be gas-prone. The structure in the area is an anticlinal trap crossed by fractures which act as preferential migration pathways for the seeps and, in addition, may even represent zones of higher expected production due to the associated fractures.

The existence of the field and its production history coupled with the observation of contemporary leakage at the updip outcrop of the Oriskany to the east of the structure suggests that the source of the gas in the Oriskany is still active today.

The Geosat-NASA test case program mapped unusual occurrences of maple trees which were verified by botanical observations. It was further established that the anomalous maples were old enough that they should have been replaced by the oaks. The investigators proposed that their continued presence was due to their tolerance of hydrocarbon seepage. This premise was unsubstantiated, but inferred, based on the work of Flowers, Gilman and Leona (1981).

Detailed sampling within these maple tree areas is shown in Fig. 6 along with the location of the remote sensing "maple anomaly" boundaries. Keeping in mind the general model of near-surface hydrocarbon patterns, these areas appear to be enriched in hydrocarbons relative to the majority of the area over the field. The high values within these "maple anomalies" supports the model and suggests that their occurrence could be related to hydrocarbon leakage.

PATRICK DRAW

The Patrick Draw survey area contains oil, gas, and oil-gas mixed reservoirs in the Cretaceous Almond Sands. The reservoirs are for the most part stratigraphic in nature, however the Table Rock Field is anticlinal. These reservoirs are situated on the eastern flank of the Rock Springs uplift which has evidence of some late Cretaceous-early Tertiary (Laramid) deformation. The reservoirs are sealed by the Lewis Shale, and are underlain by the Erickson Sand. The Lewis is most probably the source of the hydrocarbons in these reservoirs.

The propane concentrations measured at 4 foot depths in this study are shown in Figure 7. The outcrop of the Oriskany sand, structure axies, lineaments, and field outlines are shown for reference. Note the obvious relationship between the northwestern fields and the high propane magnitudes.

In 1980 the University of Wyoming and the Geosat committee studied the foliage of the Patrick Draw area. In that study, an area with stunted sage and high overall albeito was detected on the landsat, landsat-D simulator, and high altitude photos. Subsequent study showed that the stress was recorded in the vegetation for over 75 years. This suggests that cultural effects were at best minimal prior to field development.

The blight zone appears to be an area of high concentration of near-surface free hydrocarbon gases. The reason for this concentration ($> 30,000$ ppm C_1) is undoubtedly due to the presence of fractures as revealed by the lineament study and verified in part by seismic discontinuities. The blight zone is also located preferentially over the gas cap of the reservoir. Although this field is under a pressure maintenance program by gas reinjection, the pressures have not exceeded the original formation pressure. Any leakage enhanced by artificial means should be restricted to the original leakage routes.

CONCLUSIONS

Although direct detection of hydrocarbon leakage is not currently possible from orbiting platforms, remote sensing spectral data appear, under appropriate conditions, to be able to highgrade potential zones of seepage. Near-surface hydrocarbon gases migrate preferentially along certain lineaments and are generally highest in magnitude in a lineament over a field. All lineaments do not, however, have associated high values of near-surface hydrocarbon concentrations, either off or over a field. The use of lineaments, however, to suggest geochemical sampling stations can reduce the search area and result in a more cost-effective geochemical survey. In addition, there appears to be a second or higher order interaction with near-surface hydrocarbons and vegetation. The resulting effect on the vegetation was detected spectrally and later verified as being related to high concentrations of near-surface hydrocarbons. Obviously, not all vegetation stress will be related to hydrocarbon seepage. However, the proper use of spectral data in conjunction with soil gas can result in a more efficient survey. Thus, anomalous vegetative patterns coupled with lineament studies appear to offer the most promise for predicting the potential locations of near-surface hydrocarbon anomalies. There are undoubtedly, however, many false signals in both the lineament and vegetative reflectance that are unrelated to hydrocarbon seepage. Other potential causes of vegetative stress include pH of soils, insects, drought, culture, etc. The relationship of near-surface hydrocarbon seeps and their associated near-surface alteration halos is only the first step in the use of unconventional exploration technology. Prospect definition using these methods is a separate matter entirely. Geochemical methods of prospecting for petroleum should be used only in conjunction with all available geological and geophysical data. Geochemical prospecting can only verify the existence of petroleum hydrocarbons, which may be present either in a concentrated or dispersed form. None of the geochemical methods can predict whether an oil or gas anomaly is of economic proportions.

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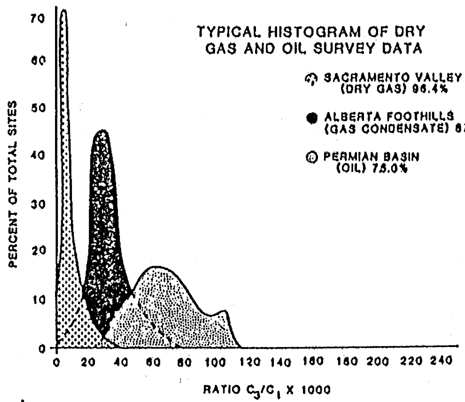
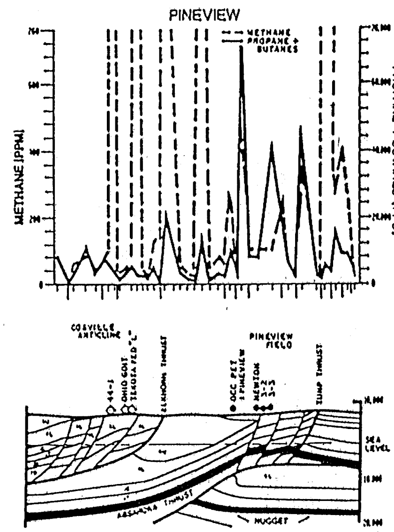
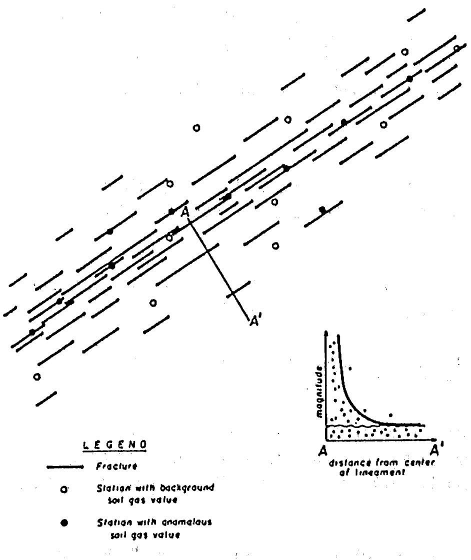


Fig. I



GEOCHEMICAL PROFILE

Fig. 2 Idaho - Utah - Wyoming thrust belt area



HIPOTHETICAL FRACTURE ZONE MODEL

Fig. 3

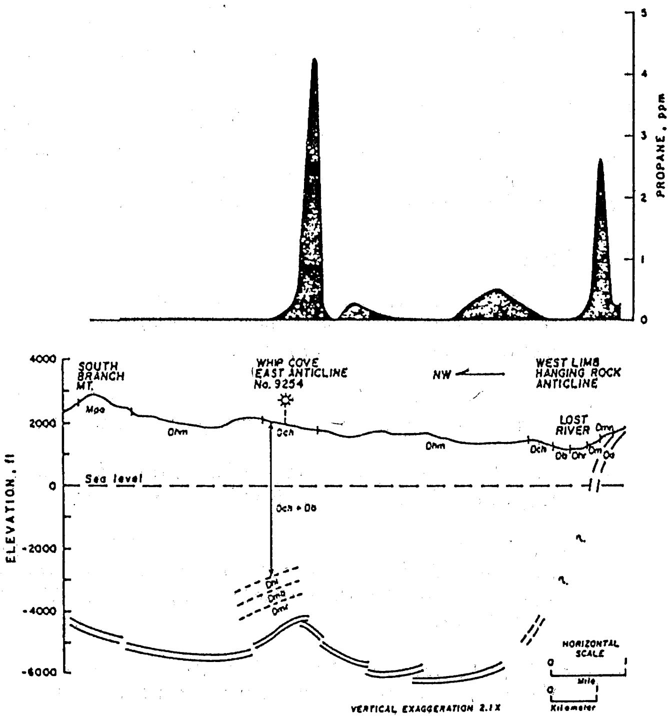


Fig. 5

STRUCTURAL CROSS-SECTION ON ORISKANY SANDSTONE

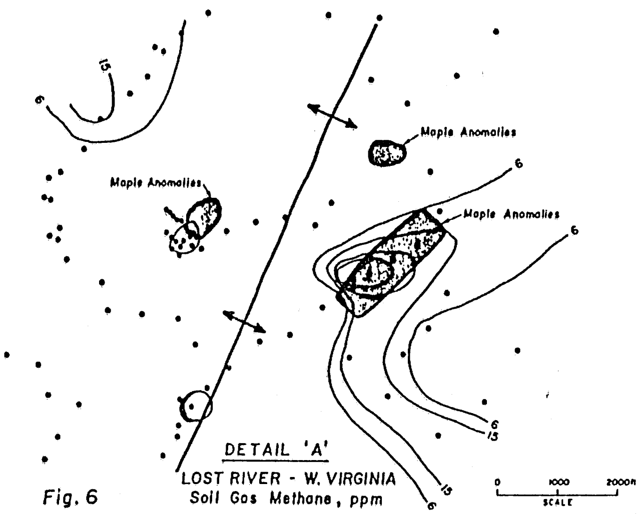
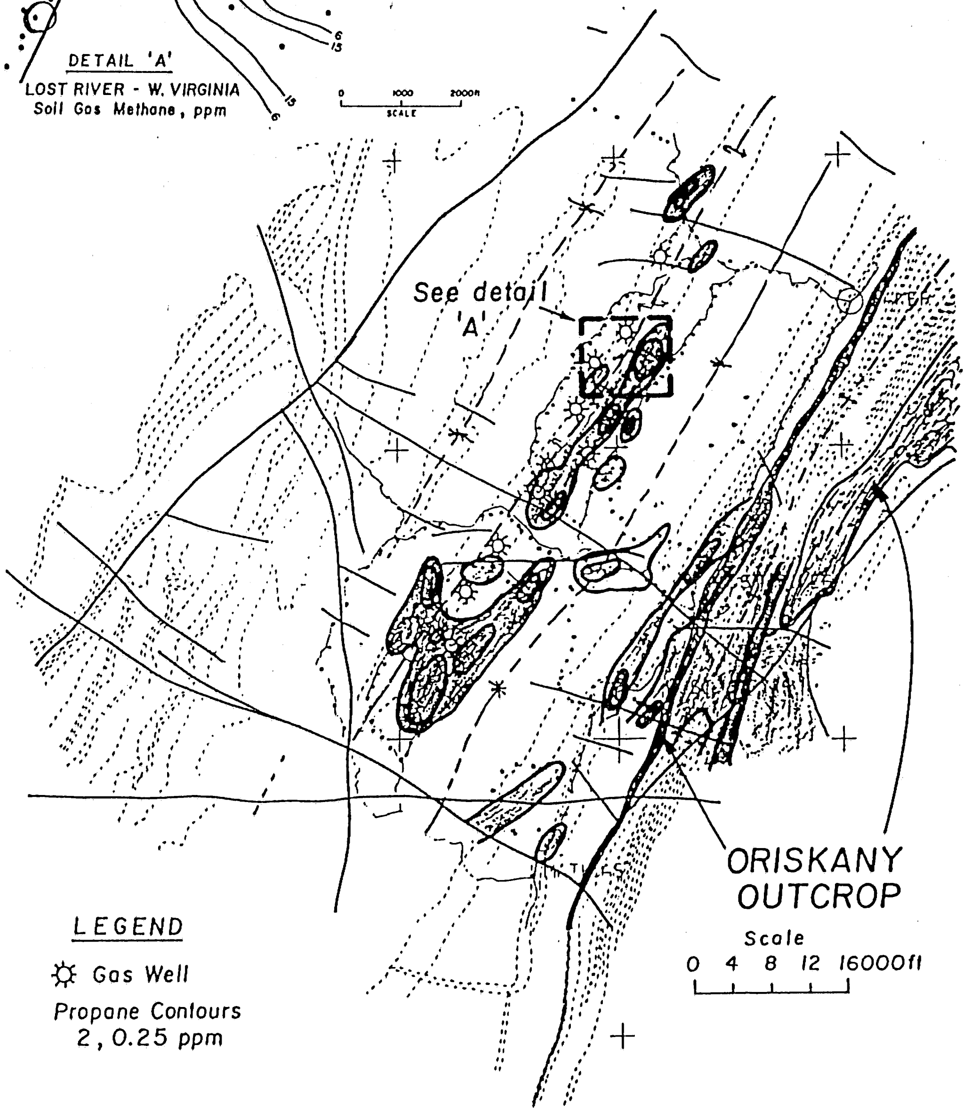
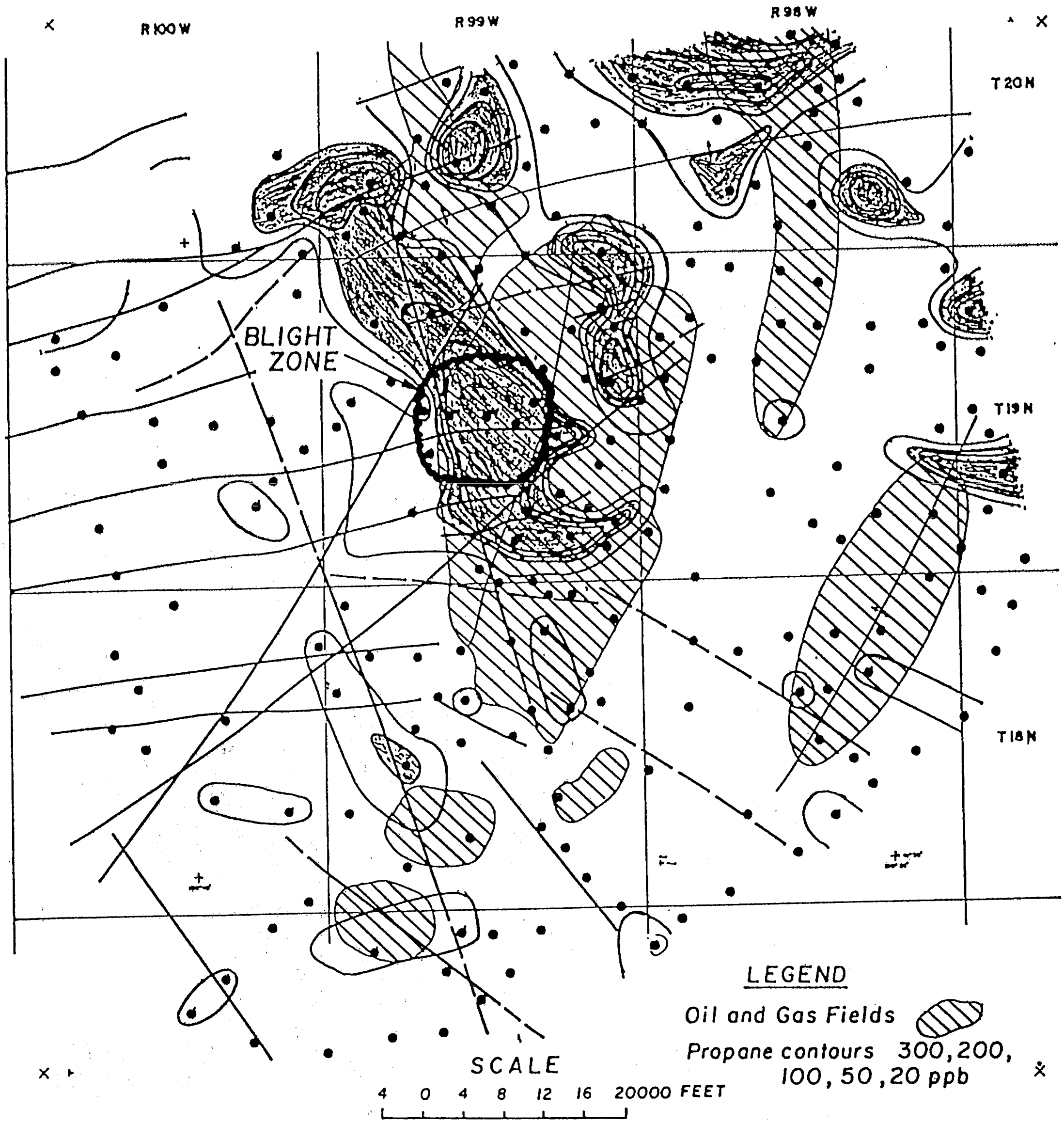


Fig. 6 LOST RIVER - W. VIRGINIA
Soil Gas Methane, ppm



LOST RIVER - W. VIRGINIA

Fig.4 Soil Gas Propane, 4 ft probes



PATRICK DRAW - WYOMING
Soil Gas Propane 4 ft probes

Fig. 7