GEOCHEMICAL APPLICATIONS AND REMOTE SENSING ANALYSIS APPLIED TO FRONTIER AREAS

by

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ABSTRACT

Remote sensing and surface geochemical prospecting are excellent tools for providing the initial evaluation of any frontier basin. Examples will be shown that demonstrate the natural utility of surface geochemistry to distinguish between potentially productive and non-productive basins and as a method of predicting the oil versus gas potential of productive reservoirs. Remote sensing techniques greatly increase the cost effectiveness of geochemical prospecting by highlighting areas most likely to have enhanced fracture permeability to aid regional geochemical survey design. The proper application of these two tools applied in concert provides a very cost-effective method for a preliminary evaluation of the hydrocarbon potential of any frontier basin.

Remote sensing techniques reveal linear, curvilinear, and tonal anomalies, which when correlated with major geological features, provide useful exploration information. However, it is important to note, that all basins have a complex mixture of these remote sensing anomalies. For example, lineament types: those that are traces of faults, and others that result from propagation of basement fractures. These basement fractures often have no systematic relationship to oil bearing structures, such as domes and anticlines. Therefore, during periods of uplift and erosion all the basement sets of lineaments can become active simultaneously with respect to fluid and gas transmission. In many cases mapped lineaments are a distracting element in interpreting the geochemistry because of their general lack of systematic relationships to petroleum reservoirs.

Applications covered in this paper will attempt to demonstrate the usefulness of remote sensing and surface geochemical relationships in both productive and non-productive basins. The importance of a subtle regional lineament will be demonstrated in Railroad Valley, Nevada, along with the need for detail studies using aerial photography and close-spaced geochemical sampling (1000' centers). These detailed data are needed for proper exploration evaluation to confirm and supplement regional results before any attempt is made to generate drillable prospects.

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INTRODUCTION:

Remote sensing and surface geochemical prospecting are excellent tools for exploration applications in frontier basins. In the proper combination they are complementary to one another, and offer definite advantages over more costly, traditional exploration techniques. Individually they are often misused and misinterpretated because of the tendency to consider preliminary regional results as prospects without the proper integration with other geologic and geophysical data. Remote sensing and surface geochemistry are often able to highlight prospective regions and fairways. Despite the tendency for each new technological advance to be hailed as a panacea by many of its advocates, there is no direct method for finding economic accumulations of petroleum short of the drill bit. If used intelligently, these techniques can be valuable additions in any frontier exploration program and are capable of increasing the cost effectiveness of geologic and geophysical efforts. An exploration approach for frontier basins is offered in this paper with several examples of applications in U.S. basins.

As an inexpensive first step Landsat is an excellent reconnaissance tool for preliminary basin evaluation. Landsat also provides a regional structural "framework" on which other exploration data, including seismic information, gravity, magnetics, lithology, and geochemistry, can be superimposed, as the complexities of a basin are unravelled.

Numerous studies by Short (1974, 1974a) and others have indicated that many of the linear features can be identified as faults or fracture zones upon field examination. The curvilinear patterns often represent such structures as ring dikes, caulderas, intrusive plutons and stocks, salt domes, and astroblemes. Saunders et al. (1973) and Saunders and Hicks, 1979) pointed out many cases in which the relationship of the linears have major geologic structural significance, and suggested that many of the regional lineaments which range in length from hundreds to even thousands of miles represent near-vertical basement faults. Comparison of the locations of mineral deposits and petroleum accumulations with these lineaments and curvilinears have often suggested genetic relationships that have been useful for directing exploration efforts into new prospecting areas (NASA, 1973; Short, 1974; 1974a; Short et al. 1976; Fischer and Lathram, 1973; Saunders et al., 1973; Saunders and Hicks, 1979; Collins et al., 1974).

Detailed geologic evaluation of a frontier basin by remote sensing and geochemical exploration techniques provides a logical continuation of preliminary Landsat analysis. The use of low altitude photography, coupled with surface geologic mapping, can extend and extrapolate limited outcrop data over wide regions. Preliminary wide spaced geochemical grids on one to three mile centers can suggest fairways of active hydrocarbon seepage and predict the compositional potential of the subsurface reservoirs (Jones & Drozd 1983). The placement of additional geochemical samples selectively along lineaments and lineament intersections highgrades the regional geochemical data because of the increased permeability of lineaments which controls microseepage magnitudes (Hodgson, 1982). Comparisons of source rock maturity studies with surface geochemical data aids in effective mapping of fairways and trends which have potential for petroleum generation and accumulation.

As economic petroleum reservoirs are discovered in a frontier basin, remote sensing and geochemical data take on a new role in the development of the basin by characterizing the signature of producing fields and fairways. Information from producing reservoirs can improve remote sensing and geochemical models and increase the likelihood of discovering new fields.

CASE STUDIES

A series of examples from the Appalachian basin, the Snake River downwarp and the Great Basin of Nevada are used to illustrate the usefulness of remote sensing and surface geochemical prospecting. Due to limited space only five examples are covered.

Tonal Anomalies,

Geological Significance

Everett and Petzel (1974), investigated the use of Landsat tonal anomalies for petroleum exploration and reported that 59 out of 76 geomorphic tonal and "hazy" anomalies in the Anadarko Basin correlated with producing oil and gas fields, while 11 correlated with known but nonproducing structures; the remaining six were not correlated with known features. Of these 35 "hazy" anomalies, 33 were reported to correlate with producing structures. Examples presented by Everett and Petzel (1974) on a color composite image were lighter in tone than their immediate surroundings, and on black and white Landsat mosaics, these "hazy" anomalies are light tonal anomalies on both MSS bands 5 and 7. Donovan et al. (1974) described calcitization and bleaching of sandstones and other surface formations attributed to seeping hydrocarbon gases over the Cement and Davenport oil fields and suggested models to explain the observed effects. Geologic features which exhibit the best tonal anomalies include volcanic calderas, intrusives, domes, anticlines, synclines, and playas.

Tonal Anomalies

Related to Vegetation,

Patrick Draw and Lost River

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 possibly at Lost River field, West Virginia.

The Patrick Draw study showed that a zone of stressed vegetation visible on thematic mapper data as a tonal anomaly definitely coincided with an area of marked leakage of hydrocarbons and that the composition of these gases was compatible with the known oil and gas reservoirs which exist in the area, Richers et al. (1986). 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 clearly demonstrated that hydrocarbon leakage occurred in direct association with anomalous populations of maple trees in a climax oak forest, Matthews et al. (1984), Rock et al. (1985). 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 reported to be coincident with areas of increased lineament densities (Abrams et al. 1985).

Linear Elements and Lineaments:

Geological Significance

As noted earlier, by several investigators, lineaments are often considered to be faults or fracture zones. This relationship is obvious in the example provided by the Athens Township gas field on the Tyrone Mount Union lineament. Geochemical anomalies often occur on such features because of the strong tectonic dependence as regards permeable migration pathways. The tectonic features demonstrated by Link (1952) to provide this fault association with macroseeps are also important for controlling microseeps. They are fractures, joints, fault planes, unconformities, bedding planes and diffusion through porous beds. Of these, fracture zones are perhaps the most common channels for vertical migration of hydrocarbon gases providing microseeps at the surface. A realistic concept of the relationship of geochemical anomalies to fracture zones is shown in Figure 1. As noted, fracture zones are not single cracks in the rocks, but are actually complex sets of en-echelon fractures parallel to the direction of the zone of most closely spaced joints. As shown in Figure 1, the background, nonfractured areas are quiet and have few anomalies, whereas the fractured zones have both background (in unfractured blocks within the fracture zone) and large anomalies when sampled in the fractured zone. This is only true when the fracture zone is in contact with a source at depth. Classic macroseeps observed over such zones are shown in Figure 2.

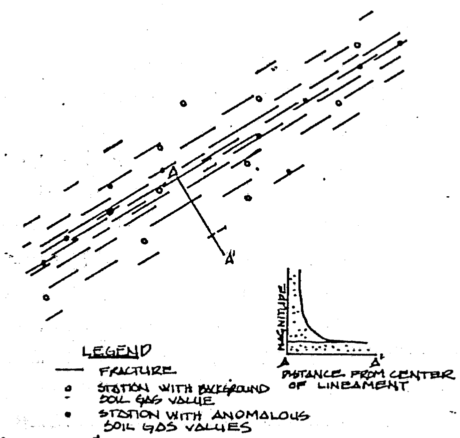
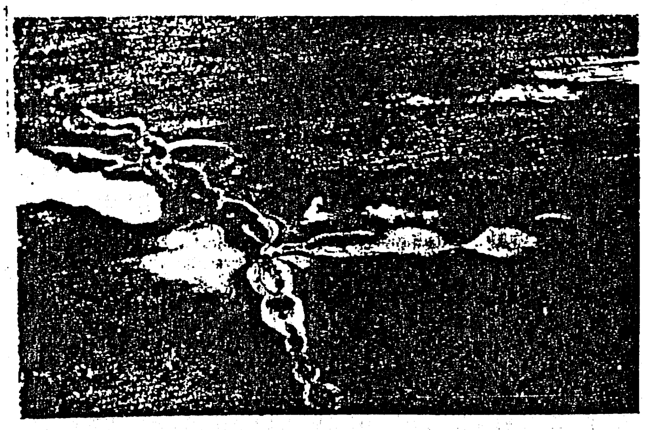


Figure 1
HYPOTHETICAL FRACTURE ZONE MODEL
From: MATTHEWS, JONES and RICHERS 1984



GAS VENTS IN THE CIMARRON RIVER DEPOSITS
From: Preston, 1980 FIGURE 2

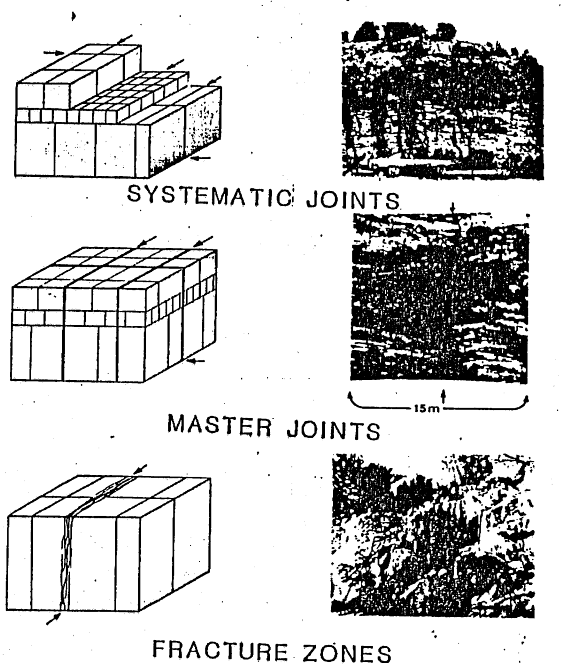
Lineaments and Fracture Zones

For many years, geologists have interpreted lineaments to represent the surface expression of buried faults or fracture zones. In mountainous terrains, field studies have shown that many of the lineaments appearing on air photographs and Landsat images contain traces of faults that can be mapped on the ground. Hodgson (1976) reviewed the early history of the development of lineament tectonics, and noted that, although lineaments are some sort of fracture phenomenon; it is obvious that most lineaments are not faults; in flat-lying sediments no offset of beds has been observed for a large percentage of the lineaments field checked. Such lineaments, which are not the result of faults, are ubiquitous. They are similar to joints, and generally represent extensional fractures which affect all rocks which have been uplifted.

The largest elements of the Earth's fracture networks are the lineaments so well-displayed on Landsat images (Hodgson, 1976). They differ significantly from the smaller elements of the networks in their great size and structure complexity but are similar in their systematic areal disposition. Lineaments are composite structures made up of many local fractural elements, when combined, form a rectilinear structure of great length and depth and, in some cases, considerable width. Lineaments further appear to be the primary control of the areal character and areal pattern of lower orders of fracturing such as faults, flexures, fracture zones, and joints.

Because of the nature of the greater than background structural activity along and adjacent to lineaments through time, there is a general increase in fracture density within and adjacent to lineaments. These are displayed as fracture zones which occur at intervals within the joint network as zones of very closely spaced joints which occur periodically parallel to joints of a given set and, in many examples, parallel to normal faults and the steep flanks of assymetric anticlines.

Fracture zones (Figure 3) are most important to geochemical surveying in that they comprise zones of greatly increased fracture porosity which are similar to faults (although they lack vertical or lateral displacement) in that they can extend great distances laterally and to depth cutting across otherwise impermeable lithologic units and so transmit gas and fluids from depth to the surface where they can be sampled and analyzed by modern geochemical methods.



From: Hodgson, 1976 Figure 3

Because the areal pattern of fracture zones and joints reflect in detail the structural frame work of a region, joints and fractures are preferred sites for geochemical sampling. In addition, a knowledge of the incidence of joint zones aids greatly in the interpretation of geochemical anomalies derived from gridded surveys. By integrating the elements of the regional fracture system with geochemical sampling programs and interpretations, one can outline the significant structural elements with respect to the sought after prospect and indicate the probable areal position of the prospect as well as the likely composition of its contents.

The last example is given by the regional Currant lineament located in Railroad Valley, Nevada. The Currant lineament is obvious on regional Landsat images and appears to be significant to the interpretation of potential oil deposits. However, this regional lineament is not defined by smaller order local photolineaments within the vallley. These photolineaments show no particular increase in density parallel to the lineament, but rather follow regional joint trends. In this particular example, only the geochemical composition reveals the presence of this important lineament across Railroad Valley.

LINEAMENT ANOMALY EXAMPLES

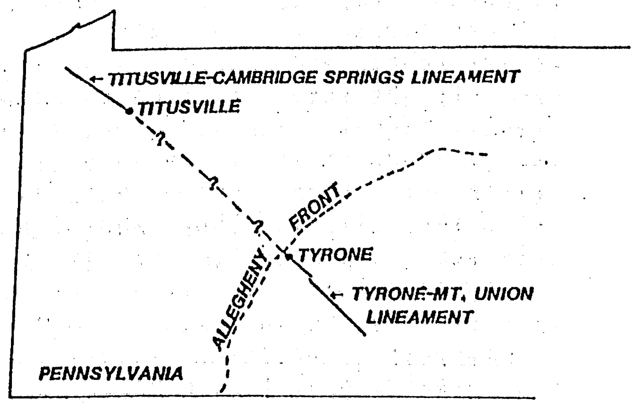
Tyrone-Mt. Union

Cross-Strike Lineament

The first example (in Figure 4) was selected to provide a classic example of a basement structure propagated up through the sediments on the Plateau province. This excellent study was conducted by Rogers and Anderson (1984), supported by Gulf Research & Development Company in Pittsburgh, PA. Of additional historical interest is the fact that the Titusville oil seep, which helped to start the petroleum exploration industry in the United States, is located directly on this lineament. This lineament is also a cross-strike structural discontinuity that extends across the Valley and Ridge province of Pennsylvania, transverse to the orientation of the structural axis of this province (Kowalik and Gold, 1974). This lineament is geomorphically defined by a series of fold terminations, water gaps, and aligned drainage patterns. It is well expressed from the Great Valley of Pennsylvania to the Allegheny structural front.

The Athens Township gas field (Figure 5), which produces from the Silurian Medina Sandstone, lies on this linea-

TYRONE - MT. UNION LINEMENT



LOCATION OF THE TYRONE-MT. UNION LINEAMENT

Figure 4

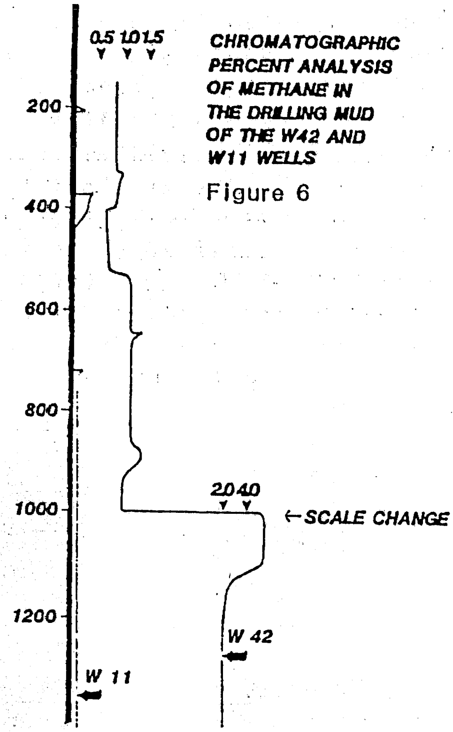


Figure 6

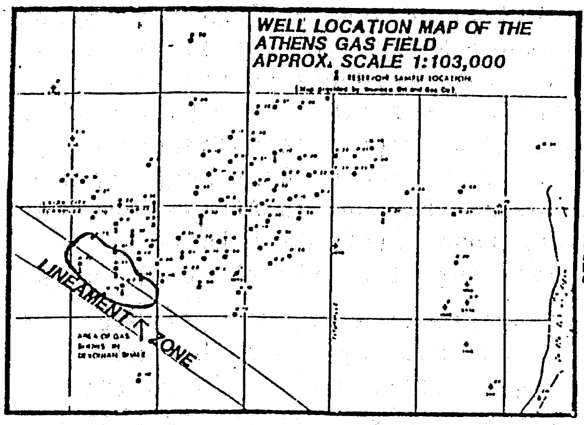


Figure 5

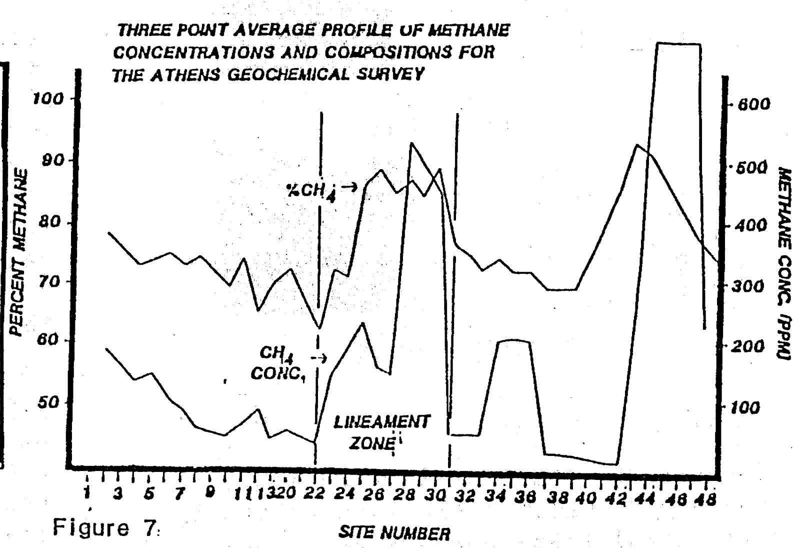


Figure 7

MEAN He, H_2 and CH_4 PERCENTAGES OBTAINED FROM RESERVOIR ANALYSES

	Three Wells Inside Lineament	Two Wells Within One Mile of Lineament	Four Wells Away From Lineament
Mean H2	.017 vol %	.045 vol %	.450 vol %
Std. Dev.	.012 vol %	.021 vol %	.272 vol %
Mean He	.180 vol %	.165 vol %	.123 vol %
Std. Dev.	.01 vol %	.007 vol %	.013 vol %
Mean % CH4	92.87%	94.23%	95.01%
Std. Dev.	1.070%	.538%	.418%

Figure 8

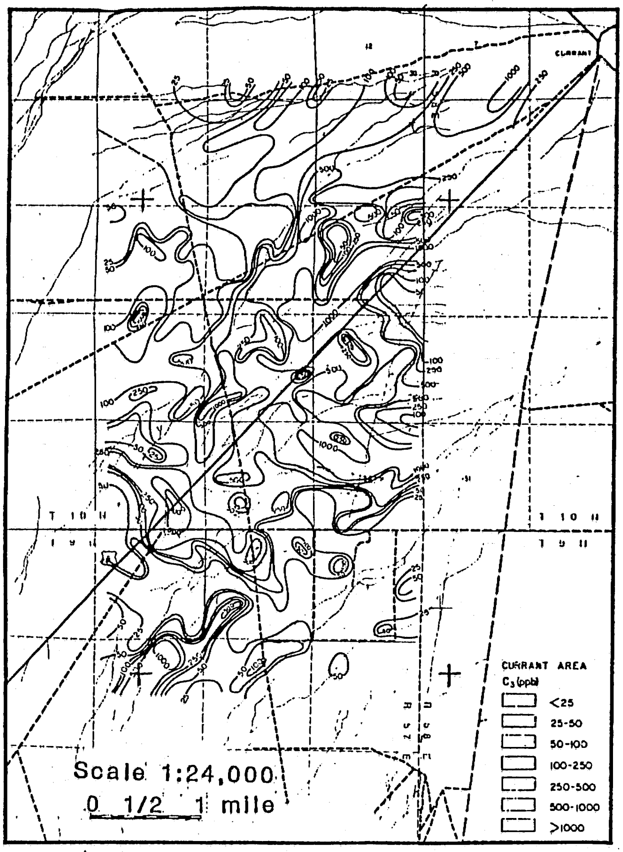


Figure 23

Compositional data from the Currant grid area adds great insight into the effect a regional lineament can have on the sources of migrating gases, even though the lineament is not directly mappable on a small scale. Regional data from the 1984 Railroad Valley program indicated a compositional shift accross the lineament zone. A methane-ethane crossplot of the 1985 Currant detailed grid data shows two distinct populations, which are separated aerially by the Currant lineament (Figure 26) Pixler ratio plots of anomalous sites support this subdivision and actually show three distinct populations, with the vast majority of the gassier sites plotting to the northwest of the lineament (Figure 25).

These two populations were assigned to different symbols in order to represent the different Pixler ratios. As shown in Figure 25, a striking compositional change is noted across this invisible lineament boundary. These three compositional groups are shown on Pixler

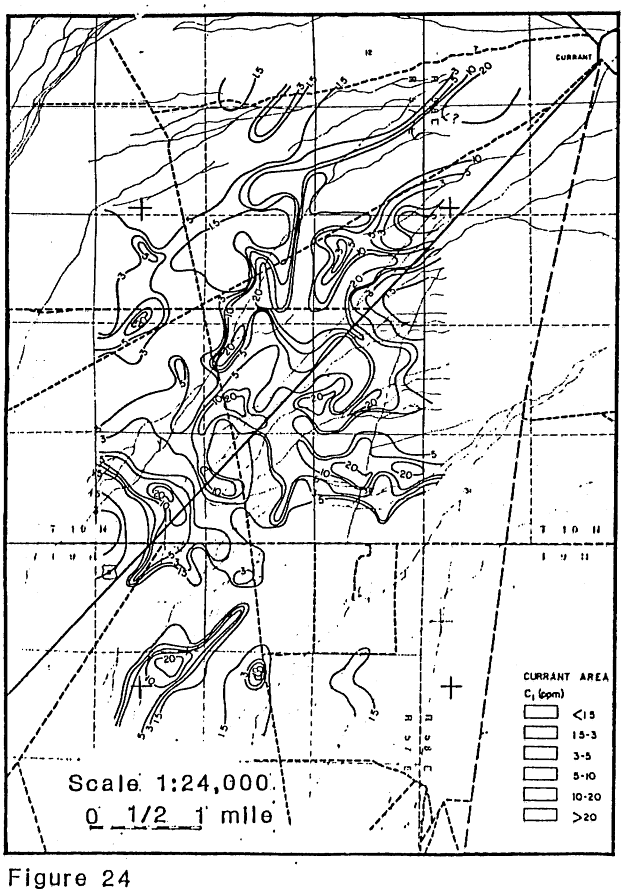


Figure 24

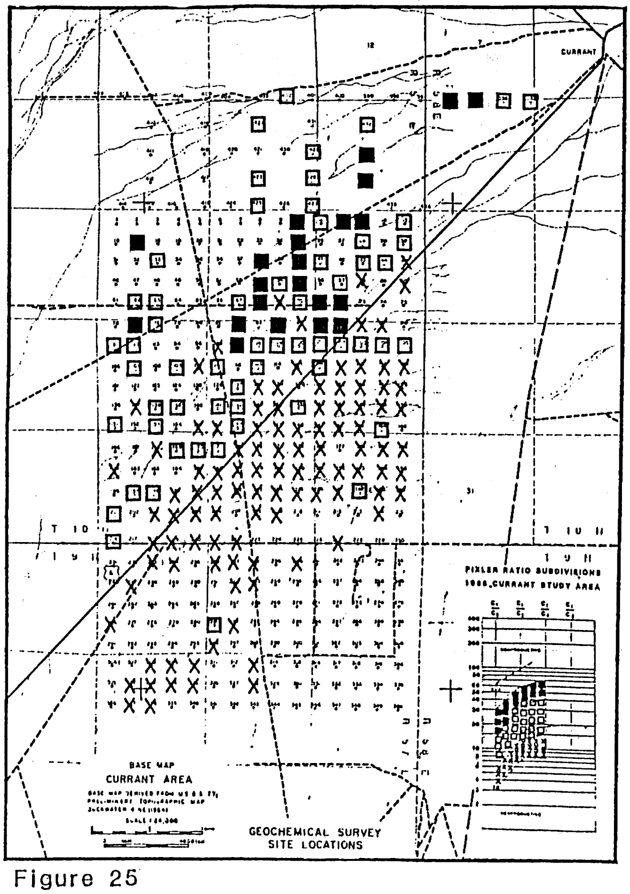
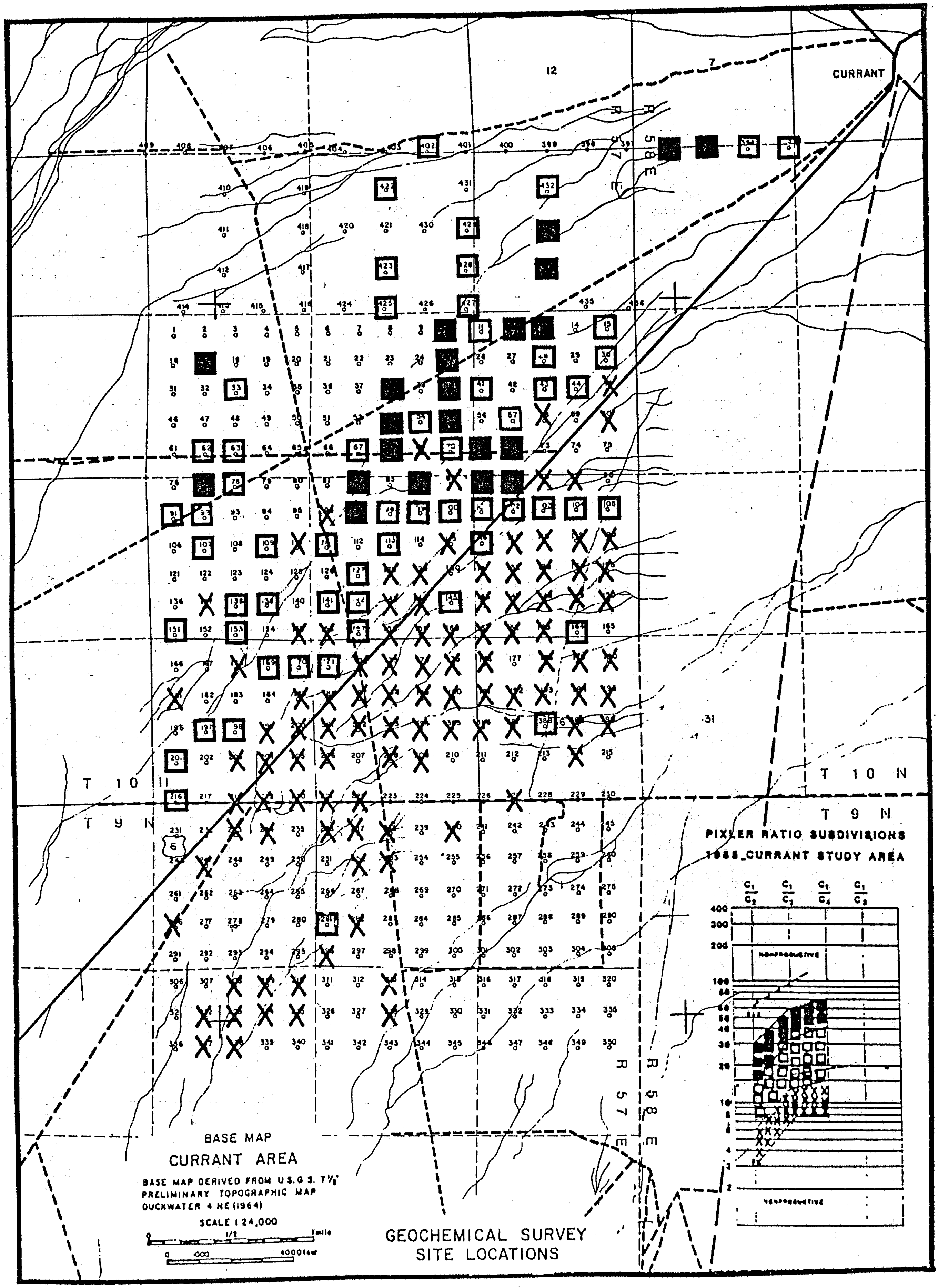


Figure 25


CURRANT
T 10 N
T 9 N
R 57 E
R 58 E
PIXLER RATIO SUBDIVISIONS
1985 CURRANT STUDY AREA
NONPRODUCTIVE
NONPRODUCTIVE
BASE MAP
CURRANT AREA
BASE MAP DERIVED FROM U.S.G.S. 7½' PRELIMINARY TOPOGRAPHIC MAP DUCKWATER 4 NE (1964)
SCALE 1:24,000
GEOCHEMICAL SURVEY
SITE LOCATIONS

ment. Anomalous fracturing was observed at the surface and in the reservoirs where this lineament intersects the southwestern corner of this field. Mud logs (Figure 6) from wells in this field indicate that a fractured Devonian shale 300 m (1,000 ft) below the surface yields as much as 1,000 times more methane into the drilling mud than does the same shale in wells outside the lineament. Borehole surveys in the lineament wells also indicate the presence of both temperature and sibilation anomalies in this shale interval. In addition, background concentrations of methane are at least 10 times larger for wells in the lineament than wells located outside. This was true from the glacial outwash-bedrock contact at 30 m (100 ft) below the surface to those organic-rich shale zones at 300 m (1,000 ft).

A near-surface hydrocarbon profile (Figure 7) was run across the lineament which extended approximately 8 km (5 mi) on either side. A three-point average profile clearly shows both concentration and compositional anomalies over the lineament. This anomaly begins at the southern edge of the lineament and extends out of the lineament valley approximately 1 km (0.5 mi) to the north. A second anomaly between sites 42 and 47 is coincident with a smaller tonal lineament observed on Landsat images. The mean concentration of methane in samples collected inside the lineament is 255 ppm as opposed to an average of 60 ppm methane for samples collected 8 km (5 mi) on either side. The mean methane percentage composition also varies across the lineament; percent methane in the lineament is 82.5% and 70.82% outside. This regional oily composition of 70.82% appears to be related to shallow oil producing formations, as is evidenced by the nearby Church Run oil field. The mean percent methane composition of gases inside the lineament (82.5%) reflects a gas-condensate source very similar in composition to the gas shows from the Devonian brown shales (79.5%) and the anomalous gas in the drilling mud at very shallow depths (80.77% at 30 m or 100 ft).

Figure 8 lists the concentrations of hydrogen and helium for wells located inside and outside the lineament. As shown, the percentages of hydrogen in reservoir gas samples collected inside the lineament is approximately 25 times less than the mean percentage in samples collected outside the lineament (Figure 5), whereas the average helium values in the lineament samples is 1.5 times larger than the mean concentration of nonlineament samples. This higher helium concentrations observed in the lineament could be related to basement sources, or perhaps to the fractured Devonian shales.

Snake River Downwarp

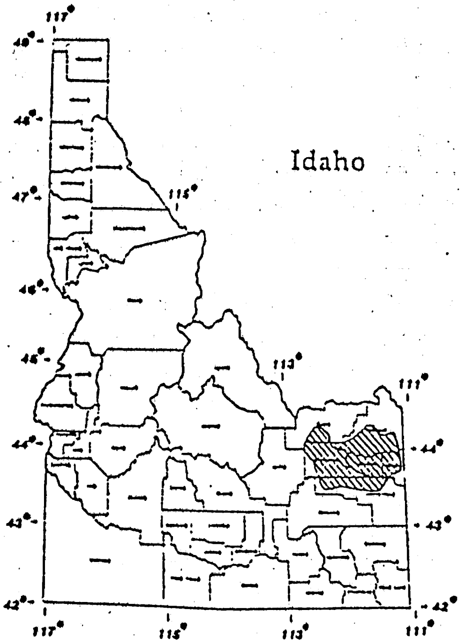
As a true example of a regional frontier, a study was conducted in the Snake River downwarp (Figure 9) in 1979 as an attempt to outline possible microseeps associated with subthrust structures associated with the Utah-Wyoming overthrust belt where they project into the downwarp. As shown (Figure 10), allochthons on both margins are terminated by the ESRP Cenozoic volcanotectonic depression.

As suggested by the idealized cross section in Figure 11 these allochthons may be displaced and rotated by younger Tertiary to Holocene basin and range faults which have overprinted a north-northwest trending structural grain on these thrust sheets.

Open fissures are often found on lava edifices. Accounts from the 1959 earthquakes suggest gas flames errupted from such rifts.

Some of the principal northwest trending faults shown in Figure 12 include the Warm Creek fault, Swan Valley, Warm Springs, Blue Dome, the Heise fault, the Snake River fault and the Thousand Springs lineament. As shown, many overlapping calderas are located at intersections of major northwest trending and inferred northeast-trending faults.

An important hydrological barrier, referred to here as Camas, exists east



INDEX MAP SHOWING AREA OF INVESTIGATION FOR GEOCHEMICAL SURVEY (WELL WATERS AND SPRING WATERS) EASTERN SNAKE RIVER DOWNWARP, IDAHO, 1979

Figure 9

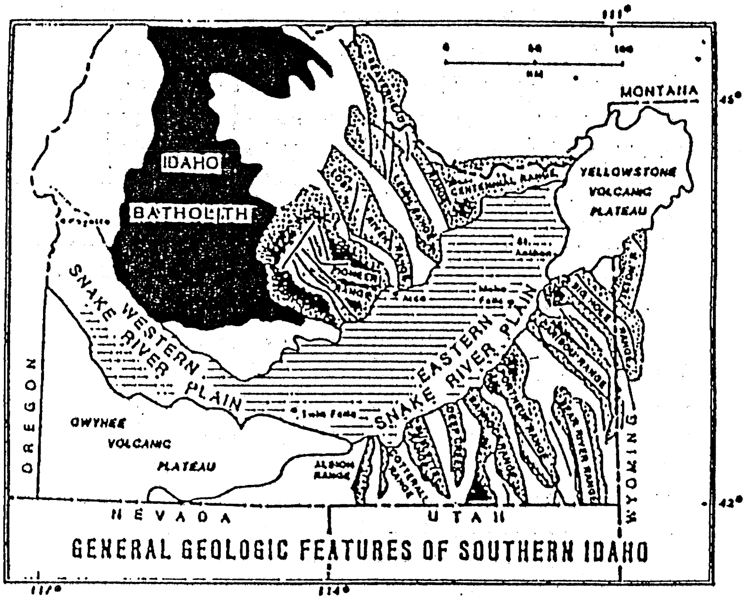
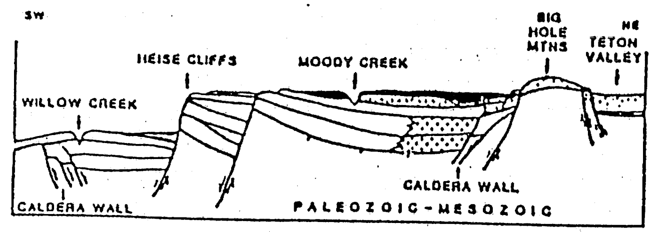
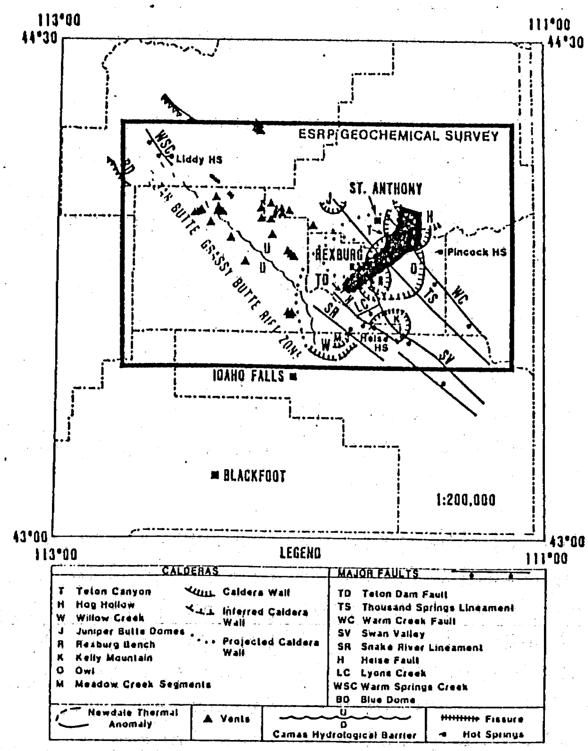


Figure 10



HIGHLY IDEALIZED CROSS-SECTION SHOWING THE GENERAL STRUCTURAL AND STRATIGRAPHIC RELATIONS ACROSS THE BEST PORTION OF THE REXBURG CALDERA COMPLEX

Figure 11



MAJOR STRUCTURAL FEATURES OF REXBURG-MUDLAKE GEOCHEMICAL WATER WELL SURVEY, EASTERN SNAKE RIVER DOWNWARP, IDAHO

Figure 12

of Birch Creek and extends southeastward through Mud Lake to the Lewisville Knolls Figure 12. Regional groundwater flow is from northeast to the southwest. At this barrier, the water table drops approximately 90-180 ft (Idaho Department of Water Resources, 1978). According to Hasket and Hampton (1979), this barrier consisted of sediment zones on the downstream side of old centers of volcanic activity which are now covered with younger basalts. This hydrological boundary is probably influenced by a rift zone traced by fissures and vents, referred to here as the Cedar Butte-Grassy Butte rift zone.

A total of 619 water well samples were collected and analyzed for dissolved

SNAKE RIVER DOWNWARP

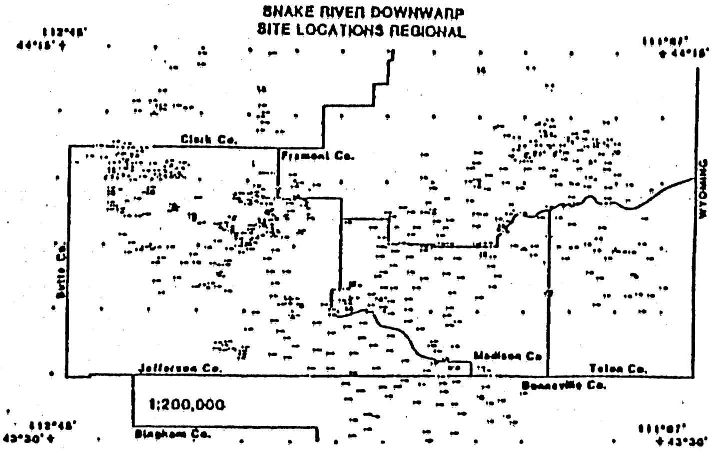


Figure 13

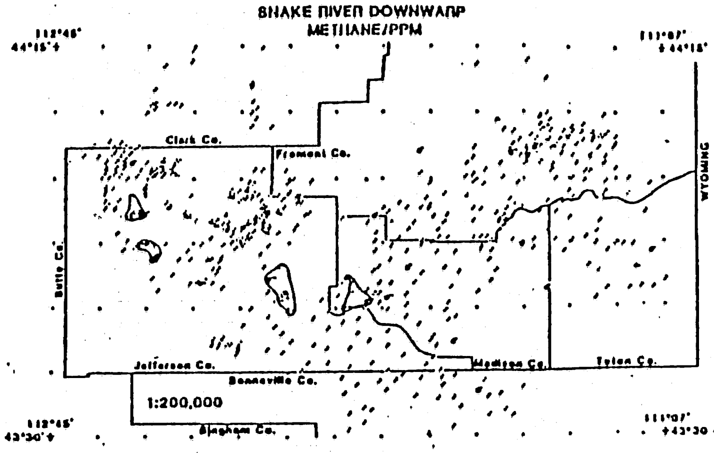


Figure 14

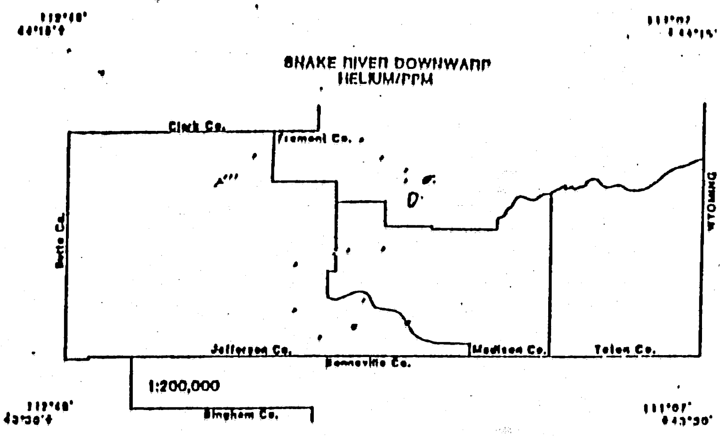


Figure 15

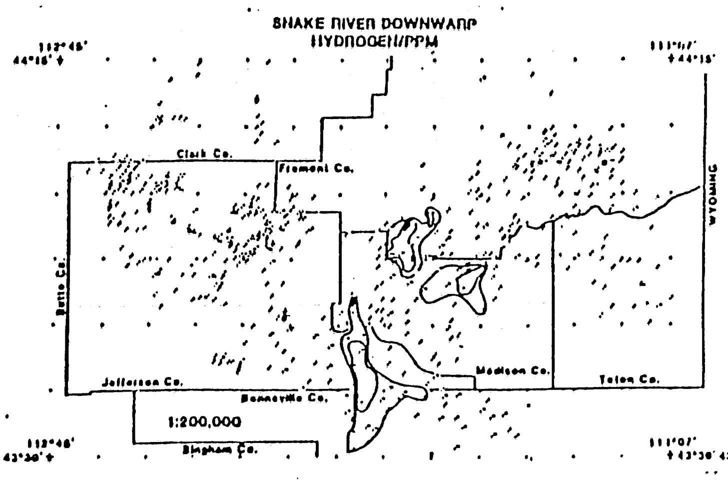


Figure 16

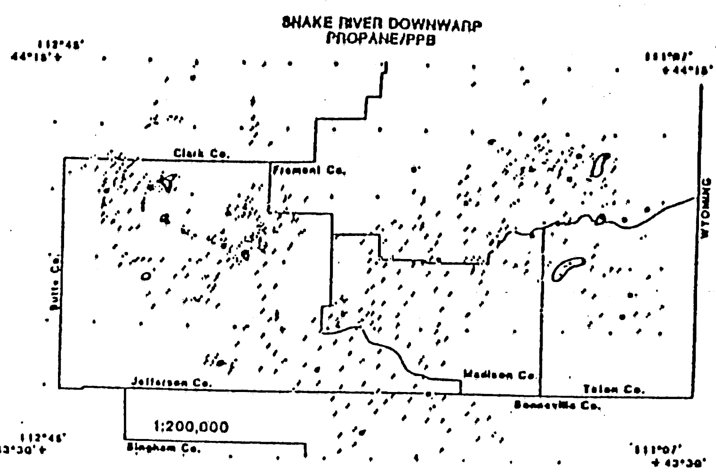


Figure 17

helium, hydrogen, and light C1-C4 hydrocarbons in Freemont, Jefferson, Madison, Clark, Teton, and Bonneville counties, Idaho as shown in Figure 13.

As shown in Figure 14, only four areas of anomalous methane areas are contoured. Two of these methane clusters are located northwest of Tenna near Mud Lake. The two other methane anomalies are at Tenna and Menan Buttes. Both of these latter two anomalies lie at the Camas hydrological barrier, and are also on strike with the projected Heise fault. No significant propane anomalies (Figure 15) are noted. Observed magnitudes are near the detection limit and show no correlation with methane anomalies. This suggests that any potential sedimentary hydrocarbon sources may have been assimilated in the ESRP.

Large continuous hydrogen anomalies ranging from 40 to 150 ppm hydrogen appear in the southern and central parts of the geochemical survey (Figure 16). One pervasive hydrogen anomaly is located over the intersection of the Heise and Snake River faults at the inferred southwest wall of the Willow Creek caldera. At Menan Buttes hydrogen anomalies correlate with a methane anomaly. Two additional hydrogen anomalies lie along the strike of the Thousand Springs linear.

Hydrogen is often genetically related to petroleum hydrocarbons (Neclayeva, 1968, Jones and Drozd, 1983). However, no marked correlation with the light hydrocarbons analyzed is observed on this survey. The hydrogen is probably most directly related to thermal centers present within the Rexburg caldera. The possibility of selective hydrogen liberation from steel casings exposed to geothermal fluids (McAdam et al., 1981) is discounted because the vast majority of wells throughout the survey area are cased at the surface string (Idaho Water Resources, 1981).

Localized helium anomalies (Figure 17) of 60 ppm and 177 ppm occur along the Thousand Springs lineament suggesting that structures associated with this lineament may be more active than some of the others tested. A subsequent earthquake supported this hypothesis. Another localized anomaly of 25 ppm is observed at the Heise fault.

Helium analyzed at these sites is attributed to discrete thermal manifestations. The helium data obtained are not sufficient to decipher whether thermal activity is solely from deep circulation through residual thermal zones or that a significant magmatic source is present in shallow reservoirs. High He3/He4 ratios would be a possible indicator of active magmatic reservoirs (Ellis and Mahon, 1977).

Significant light hydrocarbons were not detected in the calderas suggesting that any petroleum sourced blocks beneath the caldera floor have been assimilated, migration of hydrocarbon gases was inhibited, or water well sampling was inadequate. The first hypothesis is believed to be more likely for the following reasons. Geothermometer data for the Newdale anomaly indicate temperatures of 280 degrees F at depth (Idaho Department of Water Resources, 1980); nonhydrocarbon gases were observed to migrate into the shallow wells; and caldera formation would favor assimilation of all nearby country rock.

<u>Great Basin,</u>

<u>Railroad Valley, Nevada</u>

An integrated two year remote sensing and surface geochemical research project has been completed in Railroad Valley, Nye County, Nevada. These studies which consisted of a regional evaluation and close space detailed programs provide an excellent example of the exploration value of combined remote sensing and geochemical studies in frontier basins.

The first year study in Railroad Valley consisted of a regional lineament evaluation made from conventional

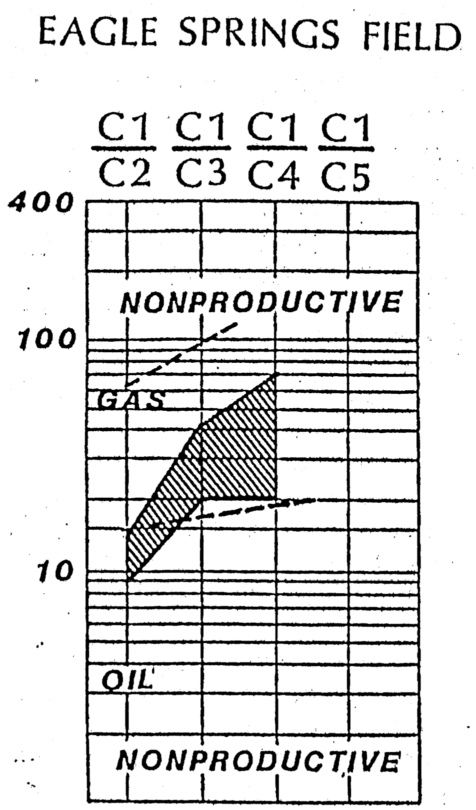
Landsat, Thematic Mapper (TM), and Synthetic Aperture Radar (SAR), coupled with regional soil gas probe sampling to identify areas of significant hydrocarbon seepage. As shown by the remote sensing data, Railroad Valley was chosen for this research study because of the excellent surface expression of structural features, including both lineaments and circular geomorphic anomalies. Circular geomorphic anomalies have been used by Dolly (1979) and Foster (1979) to locate drainage anomalies which reflect differential subsidence of subsurface structural blocks. All three producing fields in Railroad Valley: Eagle Springs, Trap Spring, and Grant Canyon occur in circular features as mapped by Dolly and Foster (1979).

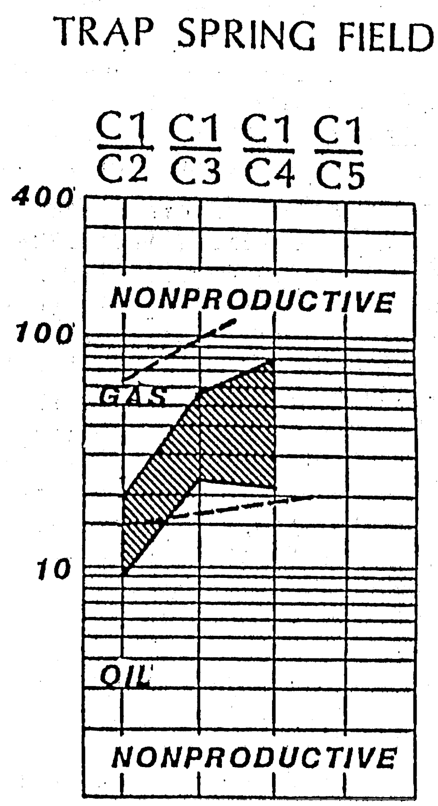
Two distinct soil gas hydrocarbon seep compositions have been identified in Railroad Valley which appear to differentiate productive or potentially productive reservoirs from non-productive heavy oil accumulations at depth (Figures 18 and 19). These two compositional types are closely related aerially, suggesting that the compositional changes occur across geologic boundaries which control both the hydrocarbon reservoirs and their associated surface seepage. As shown in Figure 18, large dots represent sites having magnitudes greater than 250 ppb iso-butane and small dots represent sites above 75 ppb. These dot clusters provide an alternate approach to contour maps (Figures 20 and 21) and provide an evaluation of each site in the study area. Anomalous (dot) sites always contain the best quality source information, whereas background sites which have no significant petrogenic sourcing are not plotted since they contain no significant compositional information.

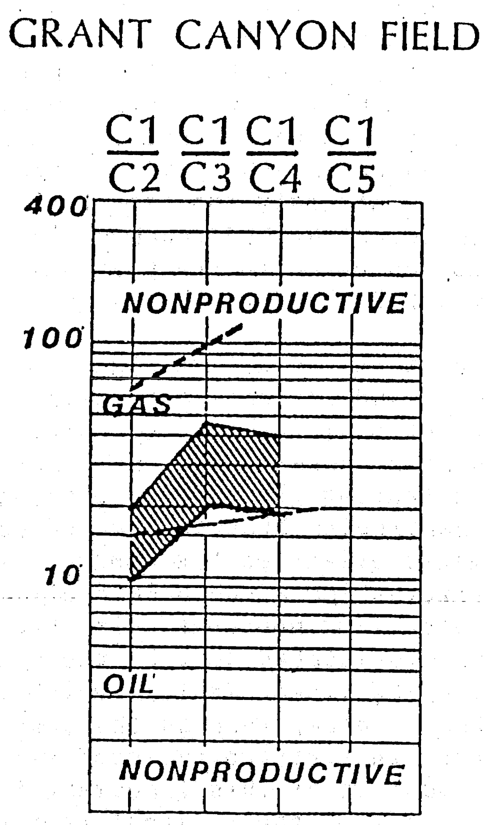
The composition of these anomalous sites is represented in Figure 19 by ratios of C1/C2, C1/C3, and C1/C4 plotted on a three-cycle log plot first published by Pixler (1969). These plots were developed for determining oil versus gas potential from hydrocarbon shows measured during mud logging operations. By plotting the high magnitude soil gas anomalies associated with each of the three producing fields and the non-economic, heavy oil Currant # 1 well, demonstrates that it was possible to differentiate between hydrocarbon type from each site's relative position on these Pixler plots. Eagle Springs, Trap Springs, and Grant Canyon fields have well controlled intermediate compositions while the Currant well area showed much lower, oilier ratios. The division between these potentially productive and non-productive compositions appear in many cases to be controlled by linear features which may be faults, fractures, or other structural zones.

It is apparent from Figures 20 and 21 that a large number of high magnitude seeps occur near to, or on lineaments and lineament intersections in Railroad Valley. This classic relationship again reflects one of the most valuable usages of remote sensing lineament studies in frontier basins. Preferential location of geochemical samples in the vicinity of active structural zones and their intersections will usually locate a large number of the hydrocarbon seeps in any basin. In addition, regions of intense fracturing which do not exhibit hydrocarbon seepage, strongly suggests that there is no source of hydrocarbons in such areas, as noted in the previous example from the Snake River Downwarp.

Although this final combined remote sensing and surface geochemical study contains many features of interest, this brief presentation will focus on demonstrating the surface expression of one particular lineament which has a dramatic effect on the commercial possibilities for a subsurface oil deposit. The non-commercial Currant # 1 well is located just to the southeast of a NE-SW linear feature which crosses Railroad Valley through the town of Currant in northern Railroad Valley. The location of this lineament is obvious on all of the regional remote sensing products, from conventional


EAGLE SPRINGS FIELD
C1/C2 C1/C3 C1/C4 C1/C5
400
100
10
NONPRODUCTIVE
GAS
OIL
NONPRODUCTIVE


TRAP SPRING FIELD
C1/C2 C1/C3 C1/C4 C1/C5
400
100
10
NONPRODUCTIVE
GAS
OIL
NONPRODUCTIVE


GRANT CANYON FIELD
C1/C2 C1/C3 C1/C4 C1/C5
400
100
10
NONPRODUCTIVE
GAS
OIL
NONPRODUCTIVE

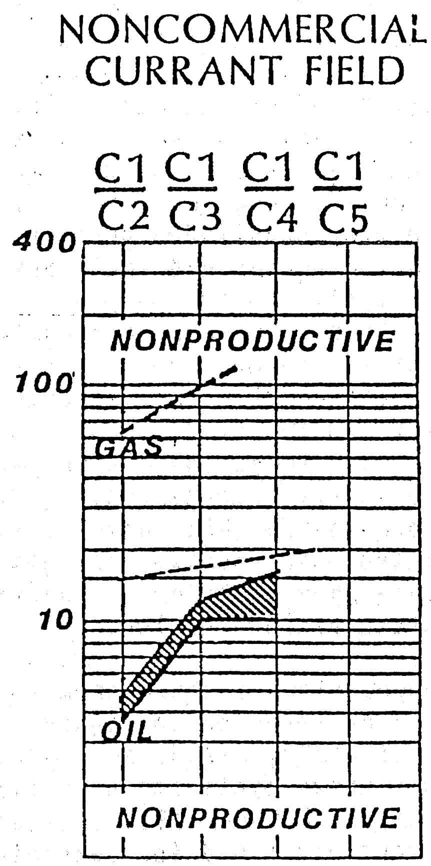

NONCOMMERCIAL
CURRANT FIELD
C1/C2 C1/C3 C1/C4 C1/C5
400
100
10
NONPRODUCTIVE
GAS
OIL
NONPRODUCTIVE

Figure 19

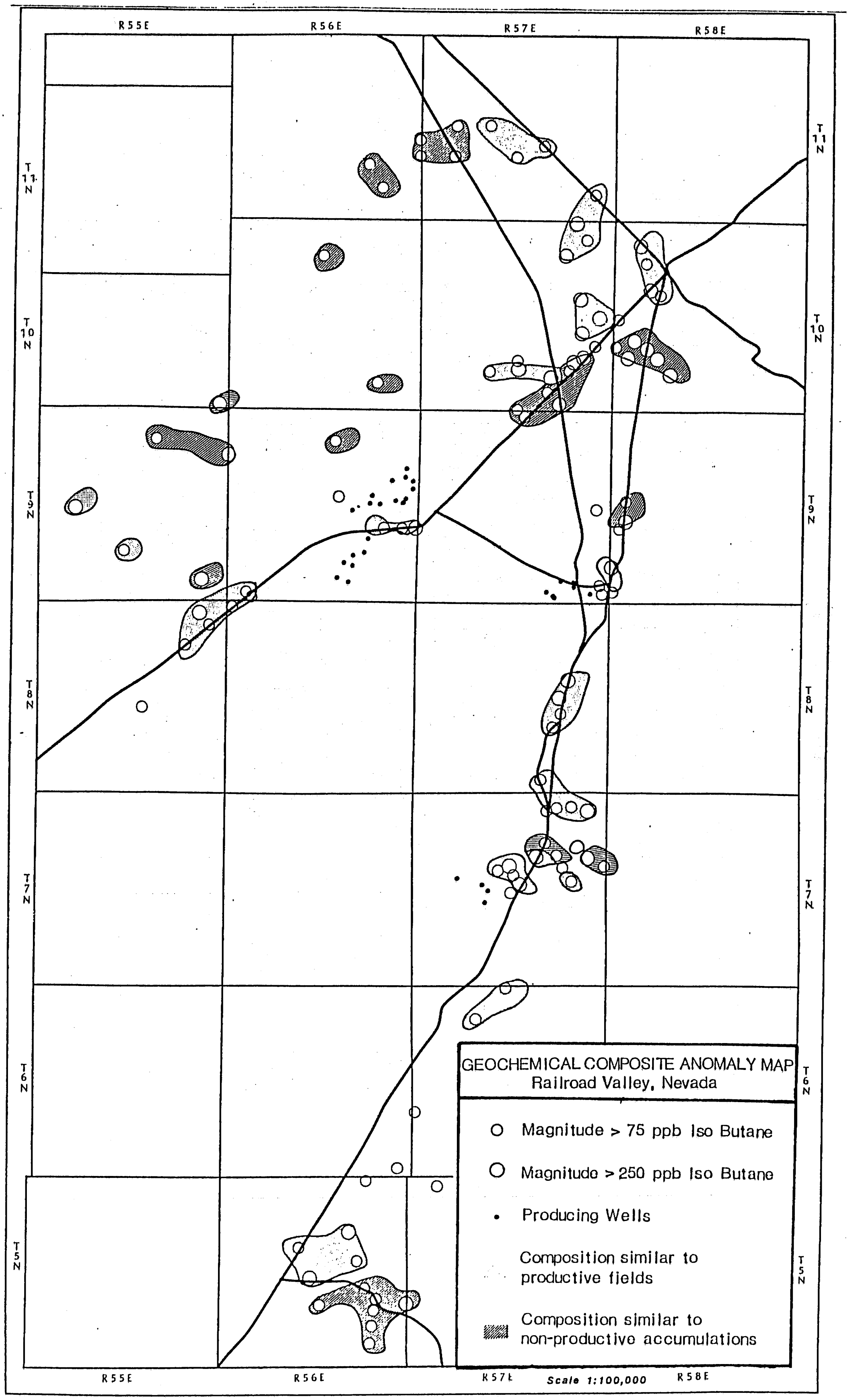

R55E
R56E
R57E
R58E
T 11 N
T 10 N
T 9 N
T 8 N
T 7 N
T 6 N
T 5 N
GEOCHEMICAL COMPOSITE ANOMALY MAP
Railroad Valley, Nevada
Magnitude > 75 ppb Iso Butane
Magnitude > 250 ppb Iso Butane
Producing Wells
Composition similar to productive fields
Composition similar to non-productive accumulations
Scale 1:100,000

Figure 18

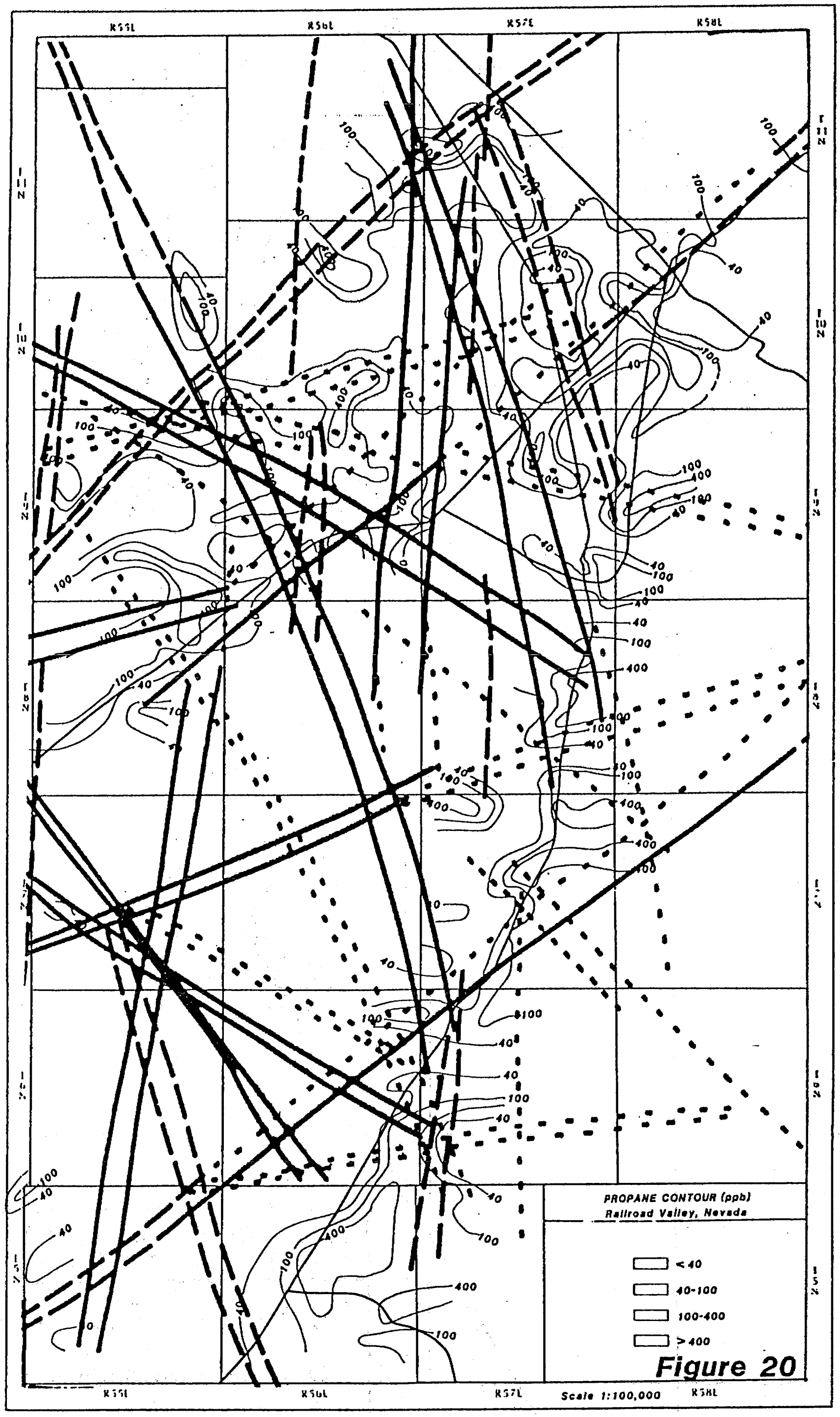
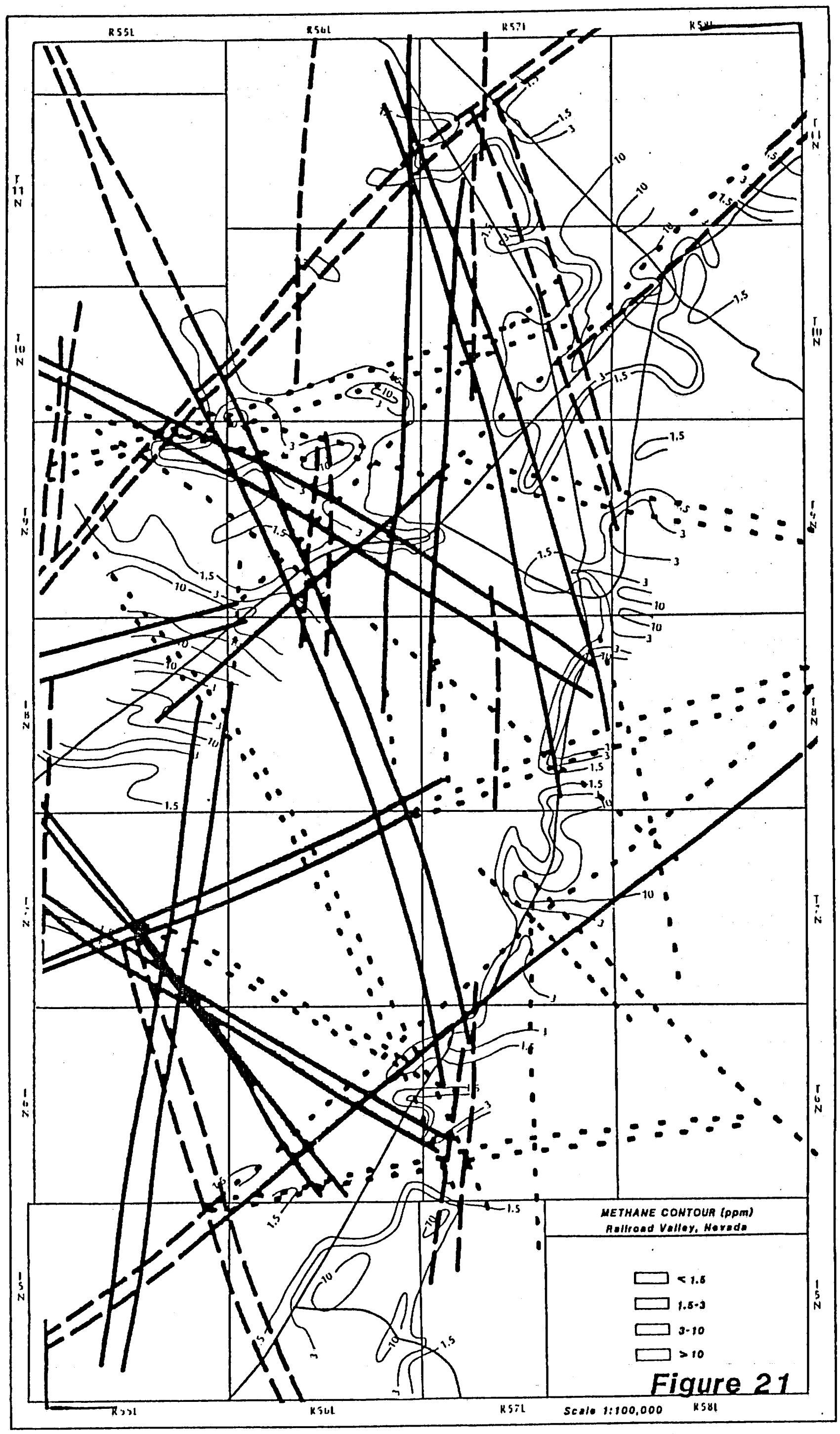

PROPANE CONTOUR (ppb)
Railroad Valley, Nevada
< 40
40-100
100-400
> 400
Scale 1:100,000

Figure 20


METHANE CONTOUR (ppm)
Railroad Valley, Nevada
< 1.5
1.5-3
3-10
> 10
Scale 1:100,000
R55E
R56E
R57E
R58E
Figure 21

Landsat, Thematic Mapper (TM), and enhanced TM CRT data. Although the lineament is dramatically expressed both northeast and southwest of Currant, it is not as obvious in the center of the study area. Even more detailed aerial photography yields only a series of fairly short photolineaments, most of which are drainage segments. Photolineaments do appear to map the approximate boundaries of close spaced geochemical anomalies, however, few of these photolineaments appear to be directly related to the more regional Current lineament.

As shown by the compositional dot map in Figure 18, hydrocarbon seeps to the northwest of the Currant lineament have compositions, as defined by Pixler ratio plots that are quite similar to the productive fields in Railroad Valley (Figure 19). Sites southeast of the lineament have a much oilier signature, suggesting a relative depletion of volatiles from the sources of measured soil gases.

A 400 site detailed grid geochemical survey on 1,000 foot centers was collected over a section of the Currant lineament and supplemented by aerial photographic studies in an attempt to characterize the local expression of this lineament. High and low altitude aerial photographic studies reveal that although the regional feature is well expressed from TM data, it does not dominate the length, azimuth, or density of small scale linear features. The lineament appears only as a minor group of parallel and subparallel lineaments which are easily lost in the clusters of more local fracture zones (Figure 22). The Currant lineament is, however, expressed in gravity data as a trough, suggesting that it is in fact a deep sourced feature of regional significance, which may influence subsurface fluid and gas migration along its strike.

Light hydrocarbon soil gas data from the Currant grid area show slight orientations of anomalous values along the strike of the lineament, however, it is apparent that the lineament does not control hydrocarbon magnitudes in this area (Figures 23 and 24). Hydrocarbon magnitudes appear to be controlled to a greater degree by NS and EW small scale linear features, which probably reflect, to some degree, the location of subsurface structural faults and fault related fracture systems. This relationship is quite important because structures identified by lineament zones are generally not the only controlling factor for light hydrocarbon seepage, but simply provide enhanced pathways of migration for gases and fluids. The local geologic framework and source potential are the most important factors for interpreting both hydrocarbon seeps and lineaments. This point is reflected by the Athens Township gas field, which was not formed because of the presence of the Tyrone Mt. Union lineament, however, productive capacity in wells drilled into the lineament are greatly enhanced by fracturing related to the lineament.

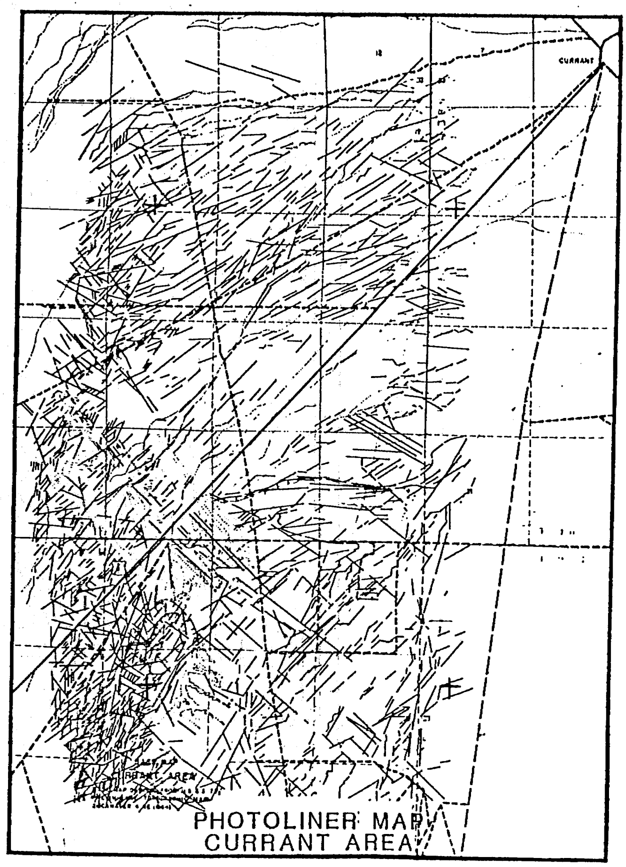


Figure 22

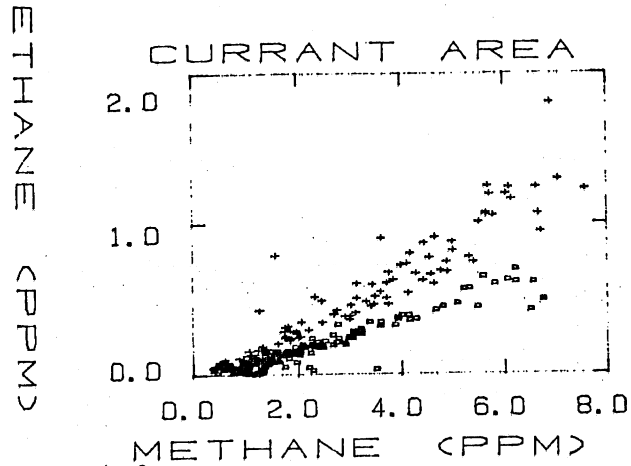


Figure 26

plots in Figure 19. Of additional interest, is the fact that placing the close detail fracture overlay on the Currant dot map shows that the major transgressions of oilier compositional sites across to the west side of the lineament occur preferentially on cross-strike lineaments which may be fracture systems.

The distinct compositional change associated with the lineament suggests that subsurface hydrodynamic processes related to the lineament may control the light hydrocarbon source accumulations at depth. The lineament may form a barrier to subsurface water flow and divert fluid flow to the east of the lineament. Oil accumulations east of the lineament could therefore be water-washed, resulting in the non-commercial heavy oil observed in the Currant # 1 well. Potential petroleum reservoirs west of the lineament may be protected from water-washing, retaining their volatile constituents, and providing a gassier soil gas signature at the surface. If this interpretation is correct, it proves the local significance of this regional lineament system, even though the feature is not immediately obvious from small scale remote sensing data alone. It is also important to note that the regional study would not have been sufficient to support this interpretation, and that close detailed data is needed to properly interpret the relationships between lineaments and hydrocarbon seepage in this case.

It is very important to realize that a regional geochemical survey on one mile (or even three mile) grids represents a low resolution approximation to the actual size or shape of any actual geochemical anomaly. As shown in Figures 23 and 24, the C1 and C3 detail on 1000 foot centers is very different from the 1984 regional contoured maps. The sharp geochemical boundaries observed in the 1985 detail study cannot be mapped from the regional remote sensing data. Clearly fracture orientations from the aerial photography overlay define and control the sharp boundaries of the geochemical anomalies. The Currant lineament cuts right through the center of this major seep anomaly. The bounding fractures are not obviously a part of this regional lineament.

A comparison of the original regional lineaments with the close detailed composite interpretation from the aerial photography shows that the azimuth of the Currant lineament is expressed only in the short photolineaments. However the regional lineament is not obvious from only the short photolineaments within the valley. Based on just the aerial photography we might suggest that this lineament is not real - the geochemical data, however, clearly shows otherwise.

Several important conclusions regarding lineaments and surface geochemistry follow.

CONCLUSIONS:

The term "lineament" is a generic classification which includes all linear alignments which can be mapped from Landsat imagery or aerial photography. This interpretation of the term makes no differentiation between faults, fractures or other geomorphologic features which may appear as a lineament. Therefore great care must be taken to insure that each lineament or group of lineaments are investigated by proper ground truth studies before a final evaluation of origin is concluded. When the object of an exploration effort is to find conventional oil bearing structures using Landsat images or aerial photos, lineaments can be a distracting element because of their prominence and general lack of systematic relationships to compressive type structures.

Basement fractures are extension features active during periods of uplift and erosion, they typically have no systematic relationship to oil bearing structures formed during regional compression, such as domes and anticlines. During uplift all sets of lineaments are transmitted simultaneously in the sediments, even though some of the lineaments have very different ages in the basement.

Most areas have a mixture of these two types of lineaments--those that are traces of faults, and lineaments resulting from the upward transmission of "master joints". Lineaments associated with these two types of structures are formed at different geologic times under different tectonic regimes. Geological-geophysical field work can usually determine not only which lineaments are faults, but also the type of faulting, i.e. normal, wrench, or thrust. Such a classification of lineaments greatly aids the structural interpretation and tectonic synthesis of an area.

Surface geochemical measurements depend on fractures as permeability pathways for migration from depth. Hydrocarbon seeps therefore often correspond to Landsat lineaments and intersections of lineaments and not necessarily with the specific locations of hydrocarbon accumulations.

Areas with a high density of lineaments, however, will tend to have a higher fracture permeability and are more likely to be visible from surface geochemical prospecting.

In the zone under a typical lineament there is, typically, no fracture that extends from the basement to the surface. Seeps associated with regional lineaments are vertical because of the lineament control.

Communication of fluids between beds is enhanced by lineaments but very soft sediments that do not fracture, such as salt and soft clay, act as aquacludes. Thus hydrocarbons in a reservoir rock are unlikely to leak along a lineament zone all the way to the surface if there are several aquacludes in the stratigraphic section. Hydrocarbons may tend to accumulate in lineament zones under aquacludes or to lesser extent under unconformities. If no aquacludes are present, then the lineament zones may form preferential migration pathways throughout the section. Migrating hydrocarbons therefore follow a tortuous path to the surface which often shifts the surface seep laterally from its source.

Despite enhanced permeability along lineaments, hydrocarbons are not present at the surface if an active source is not present at depth.

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