Gallagher Research and Development Company

Characterization of Shallow Hydrocarbon Reservoirs Using Surface Geochemical Methods

Teapot Dome Field, Natrona County, Wyoming

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Table of Contents

List of Figures

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Abstract

Multiple shallow reservoirs have been characterized using surface geochemical techniques over the Teapot Dome Field in Natrona County, Wyoming. The study is located in Sections 14 and 15, T 38 N-R 78 W, where the Upper Cretaceous reservoirs can be easily identified and separated. Reservoir fluid characteristics can be estimated though compositional analysis of surface hydrocarbon measurements while some structural aspects, such as faults and fractures, can be determined using indirect surface exploration methods. Geochemical techniques used in the study include surface hydrocarbons, Eh, pH, soil electrical conductivity, iodine, and bacteria.

The raw hydrocarbon data exhibits a positive anomaly over the anticlinall axis at the southern end of the Teapot Dome structure. The Shannon sandstone, the Steele and Niobrara shales, and the 2nd Wall Creek sandstone, all of which produce in the study area, are easily differentiated by surface hydrocarbon ratios. Average values for GOR and API, using surface hydrocarbon measurements, were calculated to be 673 cu. Ft./bbl, with a range of 184 to 2030 cu. Ft/bbl, and 36.6 degrees, with a range of 17 to 54 degrees, respectively. Actual values for the Steele Niobrara shales are 1000 cu. Ft/bbl and 35 to 42 degrees API. Actual GOR values for the Shannon and 2nd Wall Creek are variable. Actual oil gravity for the Shannon and 2nd Wall Creek ranges from 29 to 38 degrees. The reservoir lithology determined through surface hydrocarbon measurements is primarily sandstone.

The indirect geochemical methods indicate the primary strike of the faults in the study area is NE / SW which is consistent with the available geologic data. Several trends normal to the NE / SW orientation were also detected which may be fault related or due to the stratigraphic relationships of the overlapping reservoirs.

Introduction

Gallagher Research and Development Company (GRDC)- in cooperation with the Rocky Mountain Oilfield Testing Center, have undertaken a study of the characterization of shallow reservoirs using surface geochemical methods. The survey was conducted in November 1996 and confined to sections 14 and 15, T38N, R78W on the southern end of the Naval Petroleum Reserve No. 3.

In the study area a total of 134 wells have been drilled with 82 still listed as producing or intermittent producers from four reservoirs. The shallowest reservoir is the Shannon sandstone at approximately 300-400 feet which has produced 854, 380 BO from 69 wells. The Steele Shale reservoir at 800 - 2000 feet has produced 388,273 BO from 19 wells. The Niobrara Shale reservoir at 2000 - 2200 feet has produced 182,376 BO from 18 wells. The Second Wall Creek reservoir at 2800 feet has produced 691,286 BO from 14 wells. A total of 2,116,315 BO have been produced in the study area.

Naval Petroleum Reserve No. 3 Field History

Naval Petroleum Reserve No. 3 (NPR-3), Teapot Dome Field, was established by executive order of President Wilson in 1915. In December of 1927, production cam form 12 Steele/Niobrara Shale and 39 Second Wall Creek well out of a total of 84 wells drilled. At that time, control of the Reserve was transferred by to the U. S. Navy and the field was shut in for several years. Drilling and production activities resumed in 1958 to mitigate loss of production due to activity on the periphery of the Reserve. Full production began in 1976 when the Naval Petroleum Reserves Production Act (Public Law 94-258) was passed. The Reserve consists of 9,481 acres with 10 reservoirs that have produced in excess of 25 million barrels of oil or about 10% Original Oil in Place. Approximately 1362 wells have been drilled on the Reserve with 580 wells currently fisted as producing and intermittent producers.

The Reserve in operated by the U. S. Department of Energy through its contractors. Previous contractors for the DOE have included: Fennix and Scisson, Inc. (1976-1981); Lawrence-Allison & Associates West, Inc. (1981-1992). Fluor Daniels (NPOSR), Inc., a subsidiary of Fluor Daniels, Inc. became the operating contractor in October of 1992.

General Geologic Setting

Structurally, Teapot Dome is a elongate north - south trending domal structure. The north end of NPR-3 is part of the Salt Creek anticline that plunges to the southeast. North central NPR-3 is part of a structural saddle between the southern extension of the Salt Creek anticline and the doubly plunging Teapot Dome anticlinal structure in sections 3 and 10, T38N, R78W. The axis of the Salt Creek anticline trends S35E into the saddle to the right lateral strike-slip fault in sections 34, T39N, R78W. South of the strike-slip fault in section 34, the anticline axis trends nearly north-south in sections 3 and 10, T38N, R78W and then turns gradually to S20'E in the GRDC study area.

An east - west structural cross-section reveals the asymmetrical nature of the Teapot Dome showing steeply dipping limbs on the western flank of the anticline structure. The Teapot Dome is a drape fold created by Laramide Age westward thrusting of Paleozoic age sediments forming the western margin of the Powder River Basin. Reverse fault displacement below the Teapot Dome, caused by basement faulting, disappears below the Upper Cretaceous Age sediments.

NPR-3 Stratigraphy

The 74-CMX-10 well (SEA, NE/4 Section 10, T38N-R78W) was spuded on December 21, 1951 and drilled 6849 feet to basement in order to test all the formations in the Teapot Dome Field. Formations penetrated include Precambrian granite, Cambrian quartzites, Paleozoic carbonates through Upper Cretaceous marine shales. Productive formations range in age from Permian to Upper Cretaceous.

GRDC Study Area Reservoir Summaries

Shannon Sandstone

The Shannon sandstone is a member of the Upper Cretaceous, Steele Formation. Locally, the Shannon consists of two 30 to 70 foot thick stacked, heterogeneous, coarsening upward sandstone units separated by a 30-50 foot shaly nonproductive siltstone. The Upper and Lower Shannon sandstones were deposited as linear, north-south trending sand ridges approximately 200 miles offshore on a shallow marine shelf of the Cretaceous Age Western Interior Seaway. These sands were transported and accumulated by storm and southerly flowing longshore currents. Shannon sands outcrop in the Salt Creek field north of NPR-3. The average depth of the Shannon at NPR-3 is 300 to 400 feet.

The Shannon reservoir has an aerial extent of about 3500 acres in NPR-3, with an addtional 1600 acres of this reservoir present in the adjacent East Teapot Field. The reservoir is asymmetrical and produces from depths of 200 feet on the crest of the Teapot Dome, 1500 on the east flank and 700 feet on the west side of the structure.

Structurally, the Shannon reservoir is truncated by northeast trending Laramide Age horsts and grabbens which are perpendicular to the Teapot Dome hingeline. The Teapot Dome axis trends northwest to southeast with easterly offsets due to normal faulting with right lateral movement. A high degree of natural fracturing is associated with this faulting pattern. Normal faults trend N 65' E in 600 to 1000 foot intervals. Vertical displacement across the faults range 5-75 feet. Fracturing directions and density have not been quantified, but models suggest any fractures could be both parallel and perpendicular to the dome axis with an orientation of 120' to 130' from the dome axis.

Using wireline logs, core, and outcrops Obernyer developed a Shannon sandstone geologic model for NPR-3. He identified four lithofacies at NPR-3: Bar Margin, Interbar, Bioturbated Shelf Sandstone, and Bioturbated Shelf Sandstone. Central Bar facies indentified in the Salt Creek outcrops are missing on at NPR-3. The Upper Shannon sands at NPR-3 are primarily sandbar margin, interbar, and bioturbated shelf sands. The Lower Shannon sand are interbar and bioturbated shelf sands.

Minerology of the Shannon sands include 70-90% quartz, 10-20% feldspars, 13-21% clays and minor calcite. Clay minerology -consists of 0-75% kaolinite and chlorite, trace to 7% of montmorillonite or a mixed layer of illite and montmorillonite.

Steele Shale

The Steele Shale is a 2500 foot thick Upper Cretaceous, near - shore silty marine shale which occurs between the Mesaverde and Niobrara formations. It consists of upper and lower units separated by the Sussex and Shannon sands. The Upper Steele Shale outcrops at the surface at NPR-3 and Salt Creek Field. It is a soft, bluish, marine shale with layers of hard concretions and numerous bentonite beds. The Lower Steele Shale fies below the Shannon sand and consists of approximately 2000 feet of gray, moderately fissile, silty, micaceous, slightly to noncalcareous marine shales interbedded with numerous bentonite beds. These are used to subdivide the Steele Shale into mappable stratagraphic units. The bentonite also acts as a seal that prevents oil and gas migration between the bentonite intervals.

The Telegraph Creek and Brittle members are nearly identical and are described as gray, arenaceous, silty, moderately firm, slightly calcareous marine shales. Below these members the Fishtooth, the most productive member of the Steele reservoir, is a very silty to sandy shale with fossils. The Fishtooth member also occurs as a sandstone in the northern part of the Salt Creek Field. The Grey Dust member is below the Fishtooth and has an increased organic content as its only distinguishing feature. The lowest member of the Steele Shale is the Ardmore member. It is very calcareous, fissile to blocky gray marine shale with micronodules of chalk. The calcareous nature of the this interval makes the shale more firm.

Minerology of the Fishtooth is approximately 50% quartz, 10% feldspar, 10% dolomite, 10% illite-smectite, 10% illite and minor amounts of calcite, pyrite, chlorite and kaolinite/smectite clays. The Ardmore and underlying Niobrara are mineralogically indistinguishable and consists of 30% quartz, 4% feldspar, 22% calcite, 4% dolomite, 14% illite, 13% illite-smectite, and 2% chlorite, kaolinite and smectite clays.

Niobrara Shale

The Niobrara Shale is a 450 foot thick, Upper Cretaceous, off-shore marine shale and silty shale which occurs between the Steele Shale and Carlile Shale formations. The Niobrara is described as a gray, calcareous, fissile, marine shale with layers of chalk nodules and several bentonite beds.

Minerologically, the White Specks member is similar to the overlying Ardmore member of the Steele Shale. The White Specks member consists of 30% quartz, 4% feldspar, 22% calcite, 4% dolomite, 14% illite, 13% illite-smectite, and 2% chlorite, kaolinite, and smectite clays.

Second Wall Creek

The Second Wall Creek sandstone at NPR-3 is member of the Upper Cretaceous Frontier Formation. It lies conformably on a thick bentonite bed (Clay Spur Bentonite) on to the Lower Cretaceous Age Mowry Shale. The Frontier formation in Wyoming is a stratigraphically complex sandstone unit that consists of numerous stacked reservoirs reflecting changes in eustatic sea-level, sediment supply, subsidence rates and tectonism. In western Wyoming, Frontier Formation reservoirs are fluvial deltaic sandstones. In central Wyoming, Frontier Formation reservoirs are nearshore and offshore marine sandstones (Doelger, et al. 1993). Locally, the Frontier Formation is divided into the First, Second, and Third Wall Creek sands.

In the Kaycee-Tisdale Mountain area, just to the north of NPR-3, outcrops and core of the Frontier formation have been subdivided into two members, the Wall Creek and the Belle Fouche. These two members are separated by a regional unconformity. The First Wall Creek at NPR-3 and the underlying 70-80 of shale are equivalent to the regional Wall Creek member. The Second Wall Creek sandstone at NPR-3 is overlain by the Soap Creek bentonite. This bentonite is part of the regional Belle Fouche member which can be traced from the west to the east across the Powder River Basin.

In the subsurface, the Frontier Formation of the Salt Creek field is equivalent to the First and Second Wall Creek sands at NPR-3 (Haun, 1996). The Second Wall Creek is an offshore barrier bar, more than 60 miles long, 10 miles wide, and 100 feet thick.

Structurally, the Second Wall Creek offshore marine sands at NPR-3 are truncated by a series of N30' - 40'E and N80' - 90'E trending tensional faults with some strike-slip movement. Numerous surface tensional faults were formed when the Teapot Dome and Salt Creek Structures were formed, many which penetrate o the Second Wall Creek. Additionally, a few of these faults may be reactivated basement faults. Their structural throws range from a few feet to 130 feet. Faulting and related flexure, resulted in extensive fracturing throughout the Second Wall Creek reservoirs. A grabben in Section 34, T39N, R78W separates the Second Wall Creek sands into two reservoirs, the Northern Second Wall Creek (NSWC) and the Southern Second Wall Creek (SSWC).

A geologic model using core and wireline log data has been developed for NPR-3. Second Wall Creek sands are an offshore barrier bar sand that appears to have migrated from northwest to southeast. The thickest portion of the bar occurs over the Teapot Dome structure, and along with reservoir quality, diminishes down flank in all directions. These sands have be divided into three facies based on wireline logs, cores, and previous geologic studies and are the Middle Shoreface, Upper Shoreface, and Foreshore form bottom to top capped by a calcite cemented conglomerate.

The Second Wall Creek is classified as lithic arkose to feldspathic litharenite. Quartz as monocrystalline or lithic grains, is the most abundant constituent (50-75%) followed by feldspars (10-30%) and minor calcite. Clay minerology consists of varying quantities (3-20%) kaolinite, chlorite, illite smectite, and mixed layer illite and smectite.

Geochemical Methods

Direct and indirect geochemical methods were used in the study which allowed the ability to discern which parameters were potentially useful in reservoir characterization. The direct method uses soil gas measurement of low molecular weight hydrocarbons. The indirect methods include the bulk measurements of pH Eh, and soil electrical conductivity, as well as microbial, iodine analysis, and loss on ignition. Results for very near surface and deep samples are given for the indirect methods.

Soil samples are taken at 36 to 42 inch depths and canned in the field. Sample preparation consists of agitation and heating to help dislogde loosely held low molecular weight hydrocarbons from the soil matrix. Escaping hydrocarbons are then trapped in the sample "headspace" for analysis. The analysis consists of saturated, unsaturated, and iso-alkane hydrocarbon measurements up to pentane. Soil samples taken in Section 15 overlie the the structurally highest portion of the reservoir. Soil samples taken in Section 14 are approximately 300 feet downdip on the flank of the Teapot Dome structure.

Eh and pH are measured by standard electrodes by specific ion analyzer. Soil electrical conductivity is measured using a standard conductivity meter.

Measurement of non-specific aerobic bacteria constitute the microbial analysis. The method is based on a color change which indicates the amount of aerobic bacteria that are present. Darker colors indicate more bacteria while light colors indicate less bacteria. The degree of the color change is measured through image analysis of 256 channels of gray. Samples from the GRDC Study Area were incubated for 72 hours prior to the image analysis.

Iodine measurements are based on a titrimetric analysis on the sieved fraction of near surface soils.

Loss on Ignition is a simple change in weight analysis. LOI data is generated by determining the difference in weight of a sample after exposure to extreme heat from the weight of a sample prior to heating.

Results from the Standard Analysis

The mapped data are presented for the basic analyses provided by GRDC. When samples were taken at the surface and at depth two maps are provided.

The hydrocarbon concentrations over the survey area are low to moderate. This is to be expected due to field depletion as well as the shallowness of the reservoirs. Experience has shown that shallow reservoirs yield very low hydrocarbon concentrations. The methane and propane homologs have mean values of 5.6 and 0.38 ppm respectively. Anomalous values, using twice background as a threshold, are 12 and 0.8 ppm respectively.

Hydrocarbon concentrations tend to be higher over the anticlinal axis (NE / 4 Section 15), where multiple reservoirs are present, relative to the single Shannon reservoir located on the eastern side (NE / 4 Section 14) of the study area. Multiple trends are also indicated which appear to be related more to reservoir configuration and structural relationships then to fault and fracture patterns. Comparisons with multiple fault and fracture studies are given for methane and propane. The LOI and pH parameters reveal the structural / geochemical relationship very well as demonstrated with the transparencies. Both parameters exhibit the same NW / SE structural trend found in Section 15 and well as the N / S structural trend found in Section 14. The thickest reservoir pay is also located in Section 15 on top of the Teapot Dome structure and disminishes down the flanks of the structure.

Based on the geological data prepared by RMOTC the overall trends in the area should be fault related and striking NE / SW. However, a noticeable NW / SE trend is evident in Section 15 for the hydrocarbon and Eh data. This is related to either the structural relationship and the productive Shannon and Wall Creek reservoirs or indicates the productive limits of the Shannon and Wall Creek reservoirs. This is demonstrated by the ratio maps of the hydrocarbon data collected in the study area.

Oxidation-Reduction potentials, or Eh, normally have a negative or Eh low over the reservoir. However, the Eh measurements of the deep samples exhibit a very weak signature over the top of the structure as would be anticipated. The Eh data is significantly more variable, or "anomalous", where faults and fractures become more numerous as demonstrated on the the deep Eh Residual Map. Anomalous values are represented by higher values which is opposite to the traditional Eh interpretation. These anomalous trends are due to fracture related hydrocarbon microseepage from the shallow Steele and Niobrara reservoirs in the study area.

Another good indicator of the fracture related seepage from the Steele / Niobrara reservoirs is the microbial data. Both the deep and surface data correspond very well with fracture trends associated with the Steele / Niobrara reservoirs.

More general anomalies occurr with the iodine and conductivity parameters. These parameters are confined to the more productive part of the study area or along the upper most part of the Teapot Dome structure. The strong NW / SE trend in Section 15 is evident for the conductivity data which probably defines the productive pinchout of the Shannon or Wall Creek reservoirs.

Reservoir Characterization

The primary focus of this study is to attempt to characterize multiple shallow reservoirs using surface geochemical methods. Methods for estimating fluid type, gravity, maturity, and gas to oil ratio have been developed and improved during the duration of this study.

Well Name	Formation	API Gravity @ 60 degrees F
24-SX-14	SHANNON	33.9
74-SX-14	SHANNON	33.9
52-SX-15	SHANNON	30.0
81-11-SX-15	SHANNON	33.7
26-STX-14	STEELE SHALE	39.0
47-ST'X-14	STEELE SHALE	37.7
84-ST'X-15	STEELE SHALE	35.5
61-1-STX-15	STEELE SHALE	35.8
27-SHX-14	NIOBRARA SHALE	37.2
57-SHX-14	NIOBRARA SHALE	38.3
64-SHX-15	NIOBRARA SHALE	35.7
71-SHX-15	NIOBRARA SHALE	37.7
13-AX-14	SECOND WAIL r.R_EEK	32.6
12-AX-14	SECOND WALL CREEK	34.3
73-AX-15	SECOND WALL CREEK	33.2
71-AX-15	SECOND WALL CREEK	37.7

Table of actual API Gravity from wells within the GRDC Study Area

Estimated API Gravity Interpretation

Calculation of the gravity of hydrocarbons is one potential interpretative tool available for reservoir characterization. API values were estimated, from the surface hydrocarbon data, for each sample location and mapped. Corresponding gravity values for the above wells are plotted in blue for comparison with the estimated values. Estimated values are usually within 2 to 3 degrees of the actual values. However, values can vary by as much as 10 degrees. The range of API values is 17 to 54 degrees with an average of 36.6 degrees. This value is closer to those of the Steele / Niobrara Shales though is also within range of the 2nd Wall Creek.

Estimated GOR Interpretation

Another estimated reservoir parameter is the gas to oil ratio. The range of the estimated values, determined from the surface hydrocarbon data, is 184 to 2030 cubic feet / barrel. The average estimated GOR is 673 cubic feet / barrel. In map view the greatest GOR variation occurs in Section 15 where all four reservoirs are present. Where the Shannon is deeper in Section 14 the estimated GOR values are generally non-variable.

Estimated Reservoir Rock Interpretation

The graph of hydrocarbon ration Al and A2 indicate a varying range of reservoir rock types within the GRDC Study Area. Reservoir descriptions generally support the range of rock types, though the level of carbonate present, relative to the estimated amount, is probably much less.

Hydrocarbon Ratio Interpretation

Hydrocarbon ratios are used to estimated potential reservoir characteristics. The Teapot Dome Survey provided the opportunity to study the differences within an area of stacked reservoirs. Comparisons of hydrocarbon production and hydrocarbon ratios are given assuming that the oil and gas production values are estimates to the reservoirs productive limits. As an example the Percent Methane ratio is compared to the oil and gas production figures.

The Shannon Ss comparisons exhibit a strong NW / SE trend in Section 15 and a N / S trend in Section 14 that corresponds to the pH Eh, and LOI anomalies. This trend, of mostly extreme low or extreme high ratio values, corresponds closely to the structural trends and is anticipated to be the southern most limit of the Shannon in Section 15. The Steele Sh production is located adjacent to the Shannon and 2nd Wall Creek reservoirs in Section 15. Note that this area is primarily intermediate ratio values. The Niobrara Sh production tends to overlay the adjacent three zones and is somewhat un-interpretable. The 2nd Wall Creek is restricted to the NE A of Section 15 and approximates the limits of the Shannon production.

An estimate of hydrocarbon maturity is summarized on the Maturity Estimated map. Immature hydrocarbons are present throughout the study area. Hydrocarbons in the single Shannon Ss reservoir in Section 14 appears to least mature of the representative reservoirs. This is followed by the Steele / Niobrara Sh reservoirs, and the combination Shannon Ss / 2nd Wall Creek reservoirs.

Pixler Ratios of the hydrocarbon data also indicated differences in the surface hydrocarbon data that is directly related to the reservoirs at depth. Ternary plots of theCI/C2, CI/C3, andCl/C4 ratios exhibit dramatic compositional differences in the hydrocarbons from the NE/4 of Section 15, the NE/4 of Section 14, and the S/2 of Section 14. The map of the Pixler Slope data indicates the presence of multiple reservoirs, their structural relationship, and orientation relative to the southern end of the Teapot Dome Structure.

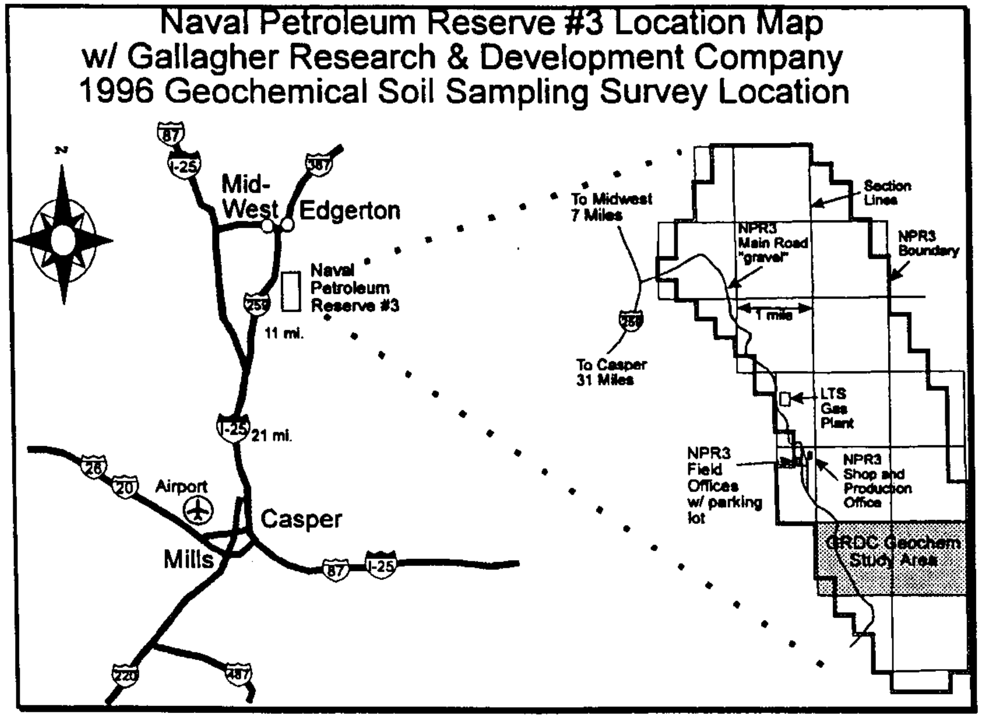
Summary

A simple reconnaissance surface geochemical survey was run to estimate reservoir characteristics in Sections 14 and 15, T 38 N - R 78 W of NPR3. Multiple geochemical techniques were used to determine the presence of particular reservoirs by comparing reservoir orientation, fault and fracture relationships, and compostional characteristics.

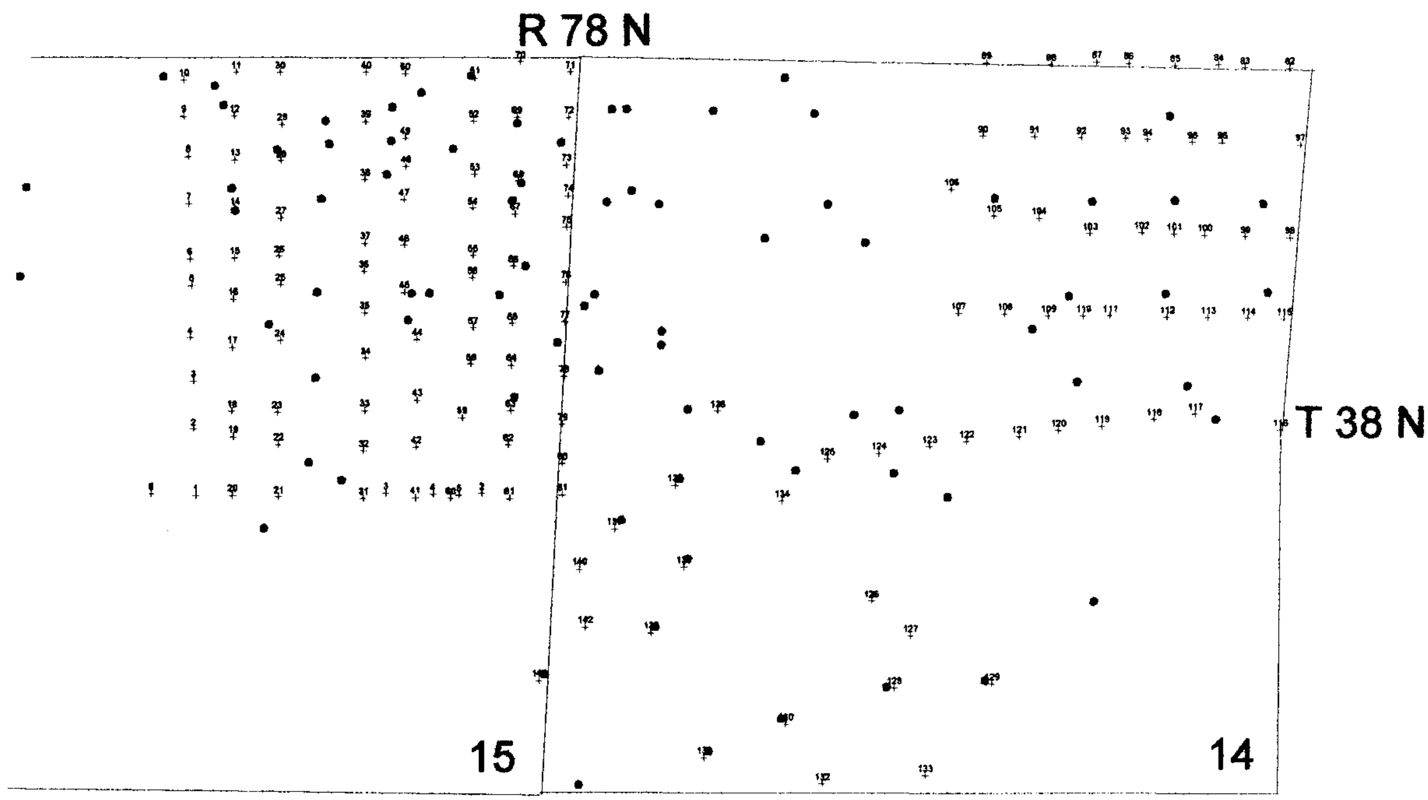
The final estimated characteristics identifies three separate reservoirs based on hydrocarbon composition and comparison with known parameters. Area I is located in the NE/4 of Section 15. This area is characterized by moderate estimated API gravity values, a variable GOR, and mature hydrocarbons. The area corresponds to the combined Shannon Ss and 2nd Wall Creek reservoir. The second area is in the E/2 of Section 14 which is the single Shannon Ss reservoir. This area is characterized by estimated API gravity values of 25 to 35 degrees, a less variable GOR, and low maturity values. The third area is located in the S2 NE/4 of Section 15 and corresponds to the Steele / Niobrara Sh resevior. The estimated characteristics are a moderate to high API gravity, variable GOR, and the presence of mature hydrocarbons.

Conclusion

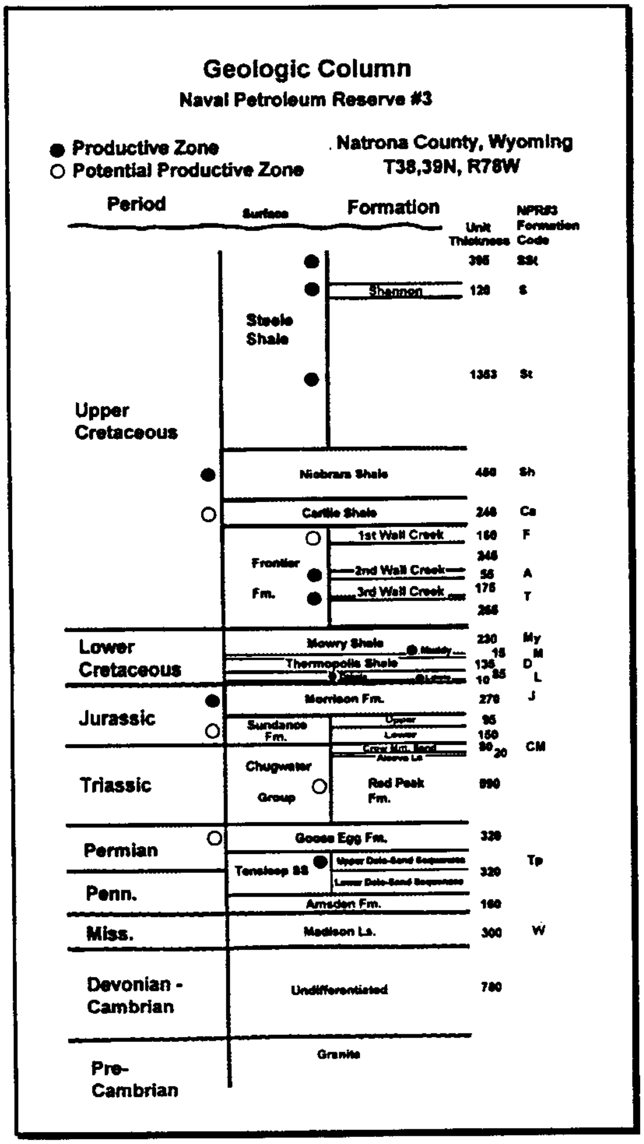
Surface geochemistry is traditionally used to isolate near surface anomalies which define active areas of hydrocarbon microseepage. This study supports the idea that surface geochemical methods can also be used to obtain information regarding reservoir characteristics. Microbial data was used to determine the orientation of the fracture related reservoirs, Eh helped map a potential reservoir pinchout, and the hydrocarbons were used to define compositional parameters in three areas of combined reservoirs. Refining these tools should help in estimating reservoir characteristics where abundant geologic data is not available.



Location of the GRDC Soil survey, Sections 14 and 15, T38N, R78W, November 1996.



TEAPOT DOME STUDY AREA
Sample and Well Base



Geologic Column
Naval Petroleum Reserve #3
Productive Zone
Potential Productive Zone
Natrona County, Wyoming
T38,39N, R78W
Period
Surface
Formation
Unit Thickness
NPR#3 Formation Code
Shannon
128
S
Steele Shale
1363
St
Upper Cretaceous
Niobrara Shale
Sh
Carlile Shale
Ca
1st Wall Creek
F
Frontier Fm.
2nd Wall Creek
A
3rd Wall Creek
T
Lower Cretaceous
Mowry Shale
230
My
Muddy
15
M
Thermopolis Shale
D
10
85
L
Jurassic
Morrison Fm.
J
Sundance Fm.
Upper
95
Lower
150
Crow Mt. Sand
20
CM
Alcova Ls.
Triassic
Chugwater Group
Red Peak Fm.
Permian
Goose Egg Fm.
Tensleep SS
Upper Dolo-Sand Sequence
Lower Dolo-Sand Sequence
320
Tp
Penn.
Amsden Fm.
Miss.
Madison Ls.
300
W
Devonian - Cambrian
Undifferentiated
780
Pre-Cambrian
Granite

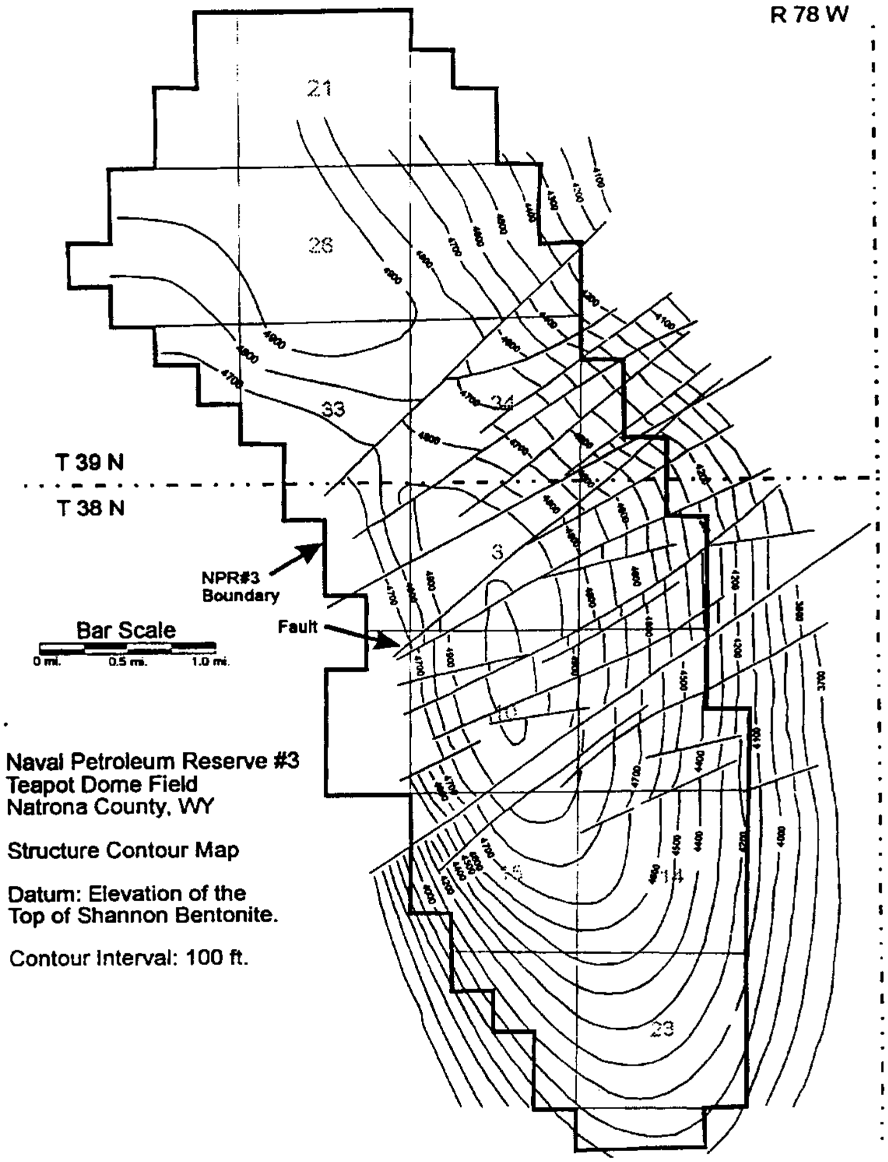
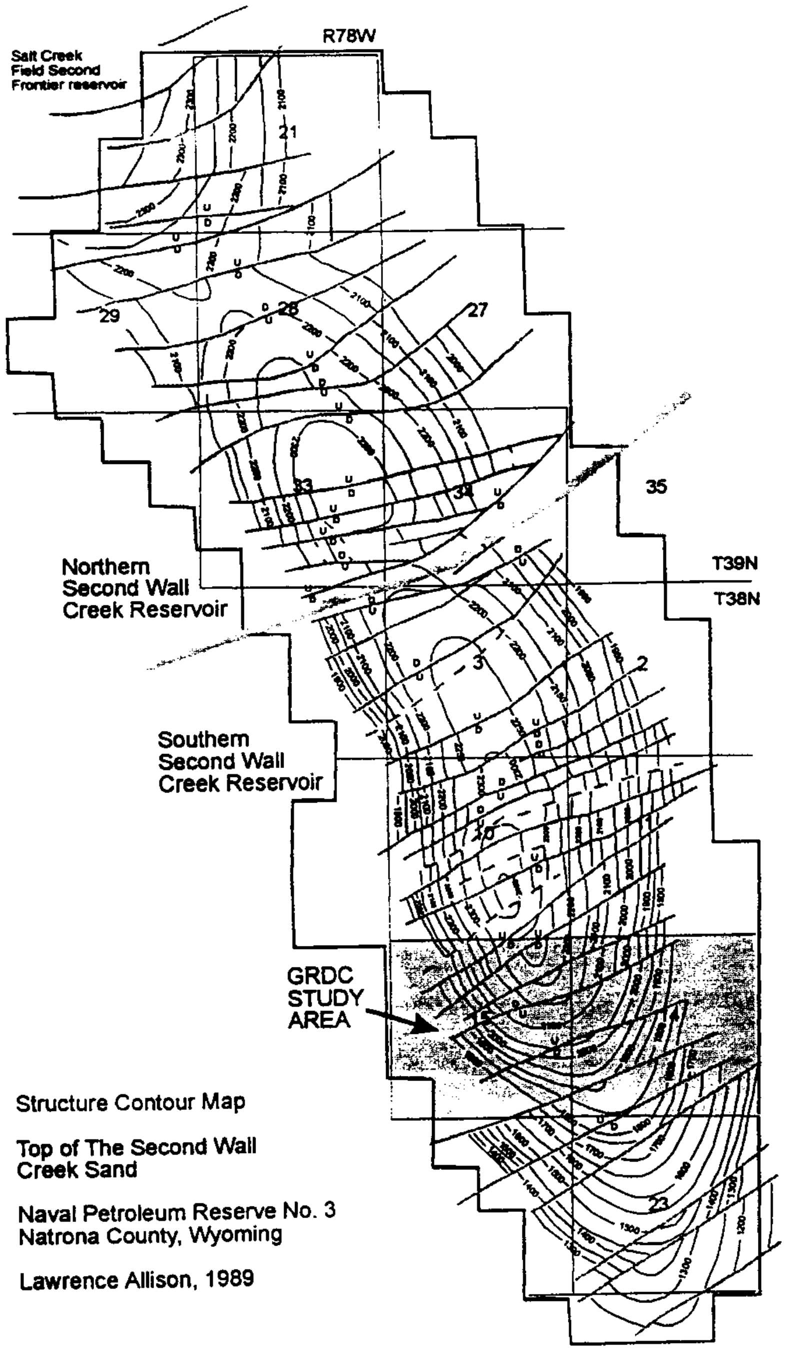
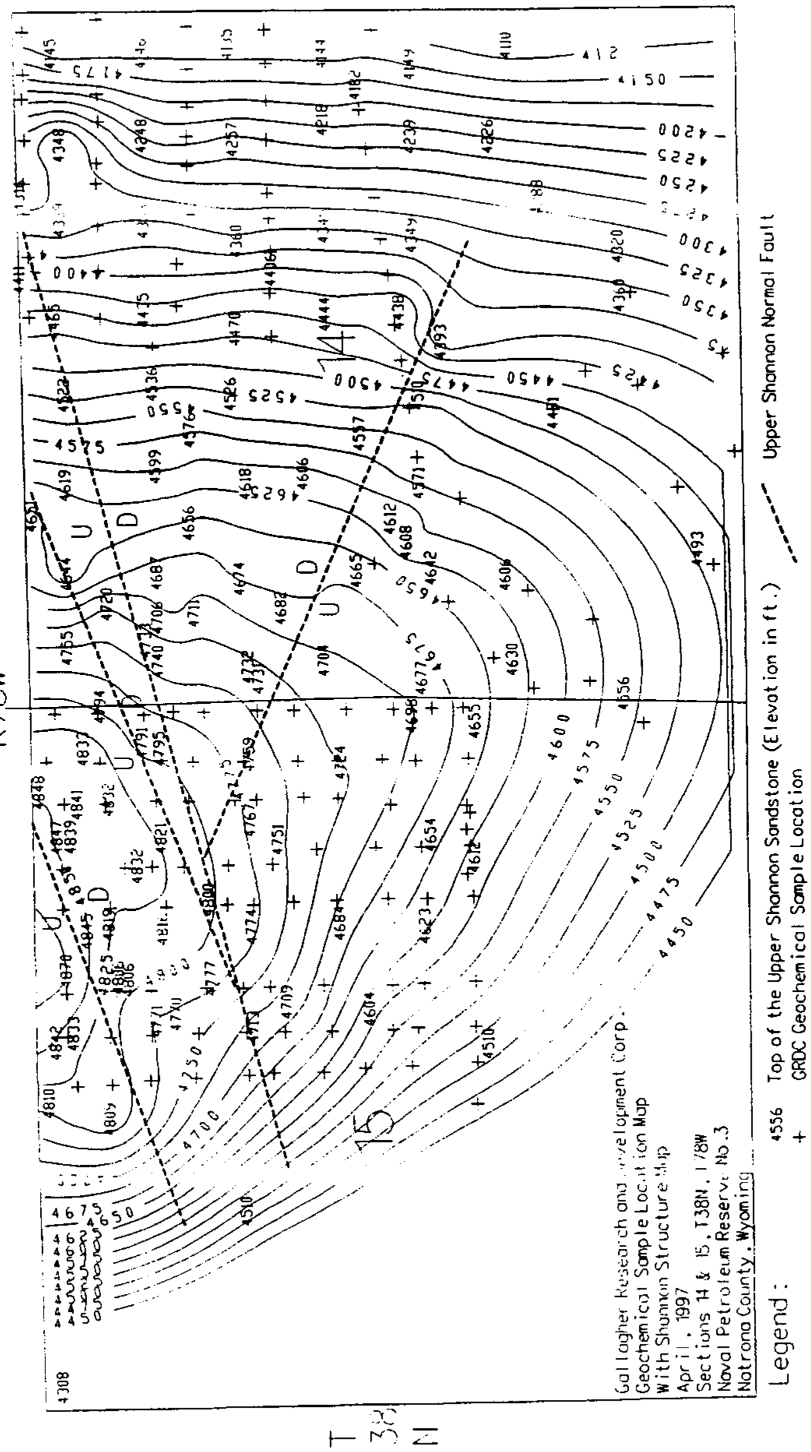


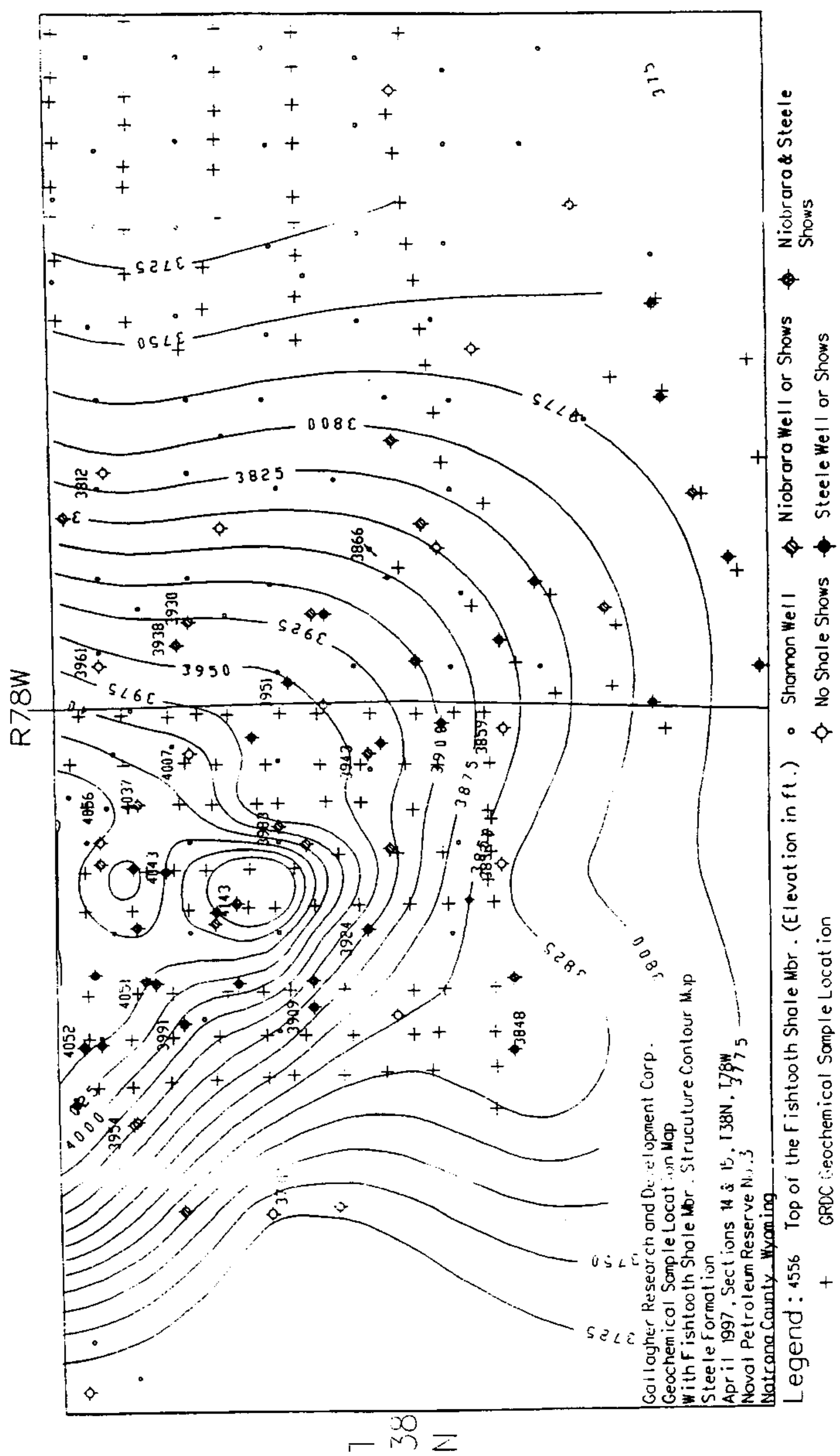
Figure 2: Structure contour map on top of the Shannon sands illustrating NPR-3 structural style.



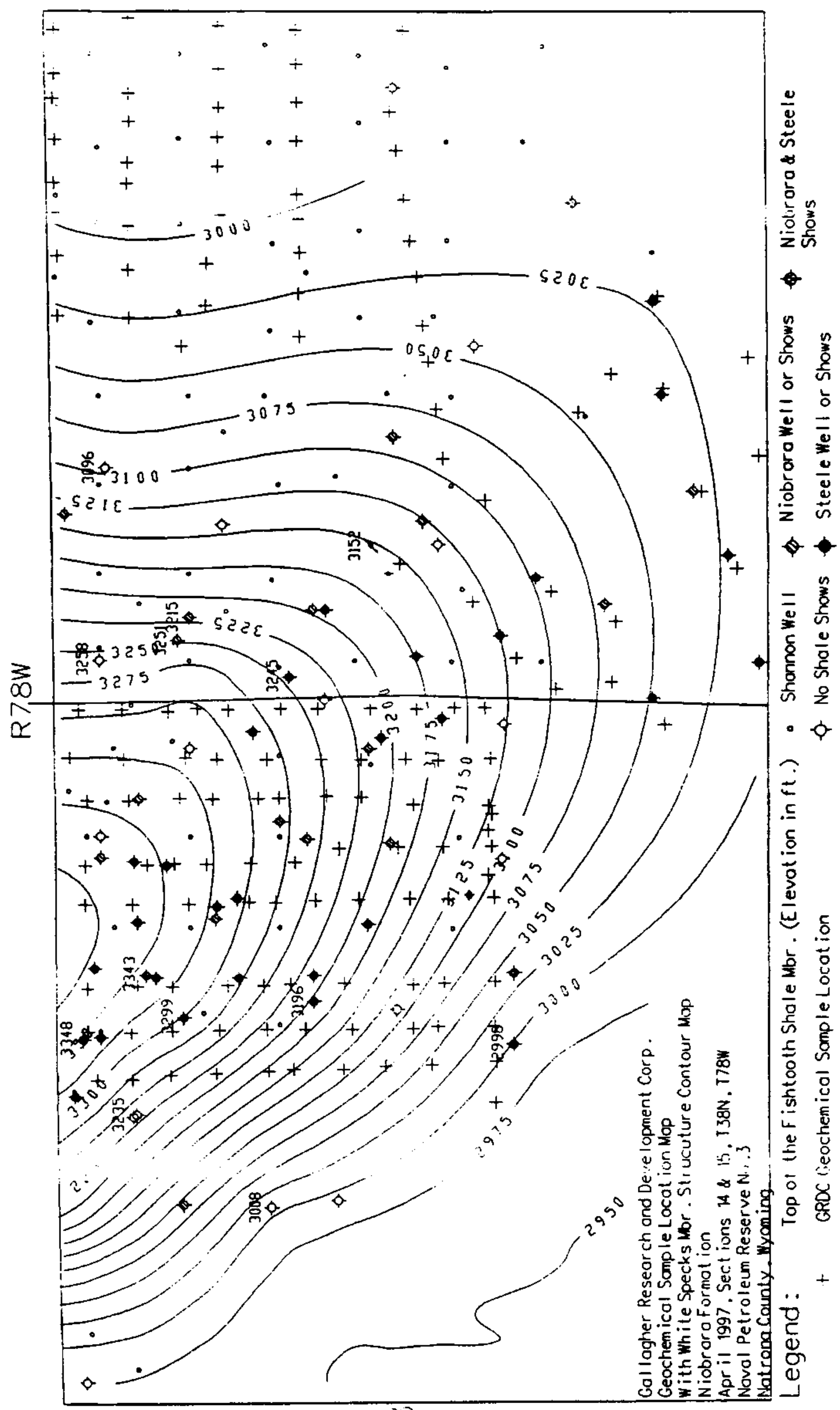
: Structure contour map on top of the Second Wall Creek sandstone.



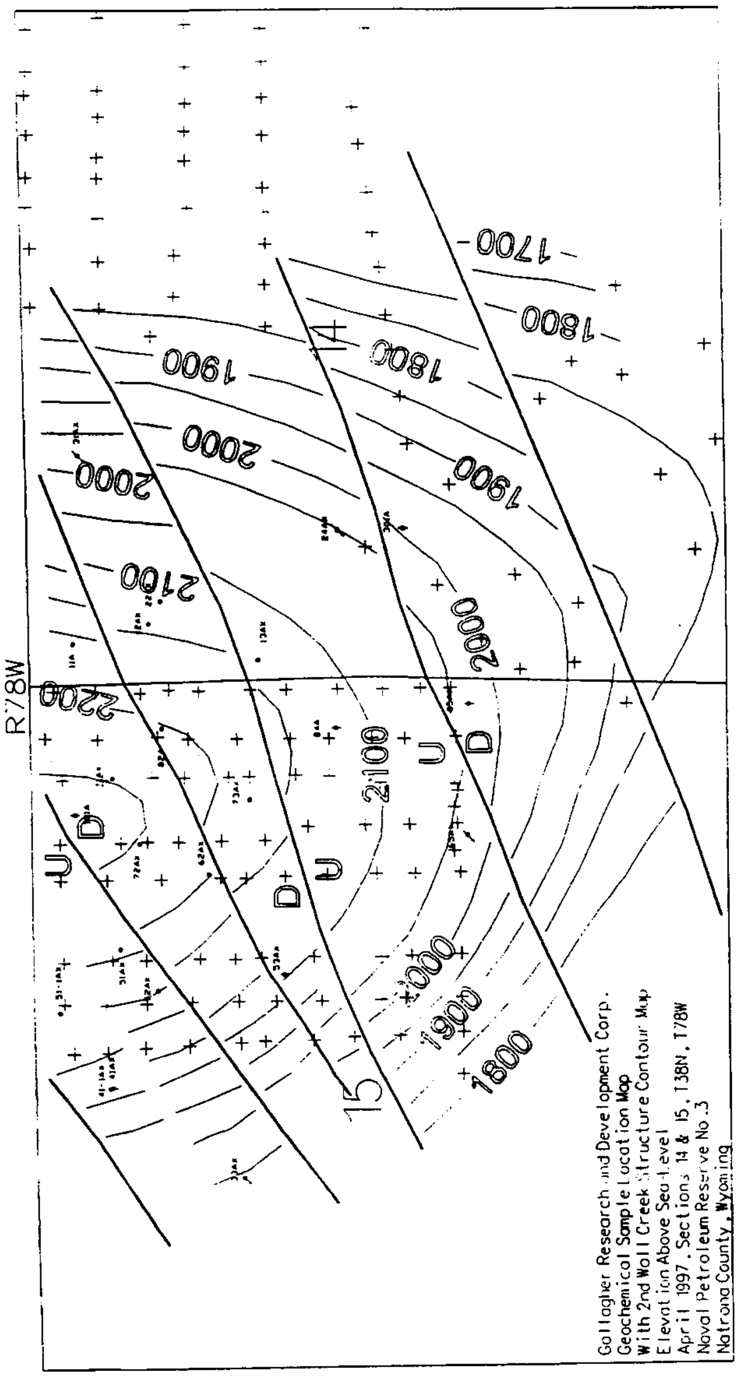
Upper Shannon Sandstone structure contour map.



Structure contour map of top of the Fishtooth member of the Steele Shale.

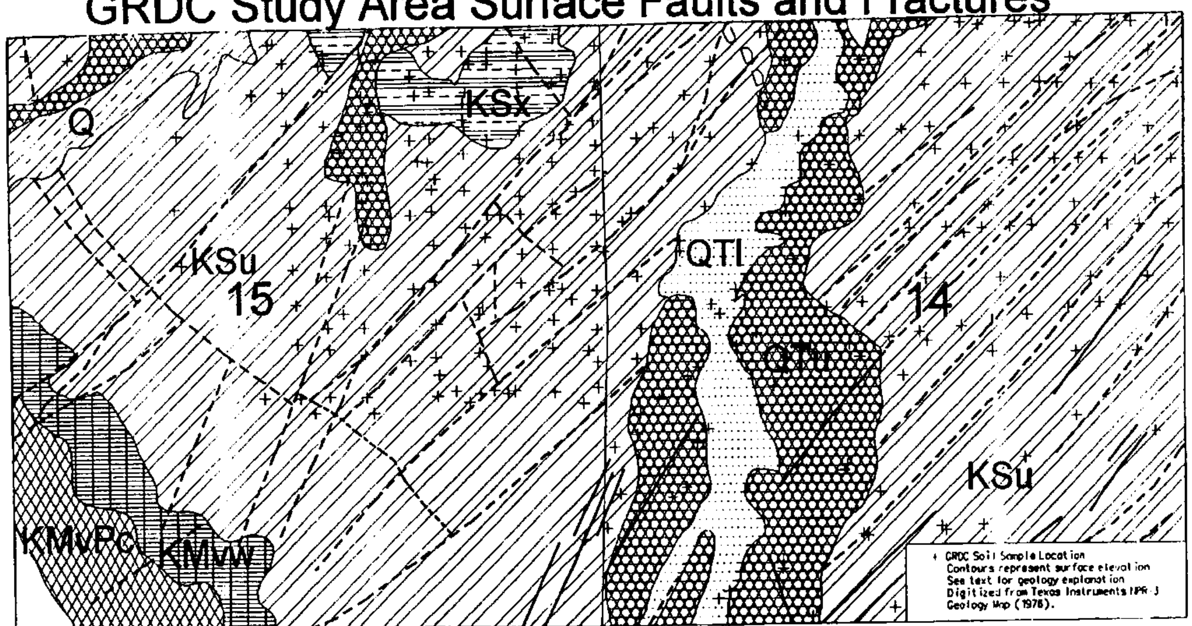


Structure contour map of the White Specks member of the Niobrara Shale.



. . . Second Wall Creek Structure Contour Map (Modified after Lawrence-Allison, 1987).

GRDC Study Area Surface Faults and Fractures

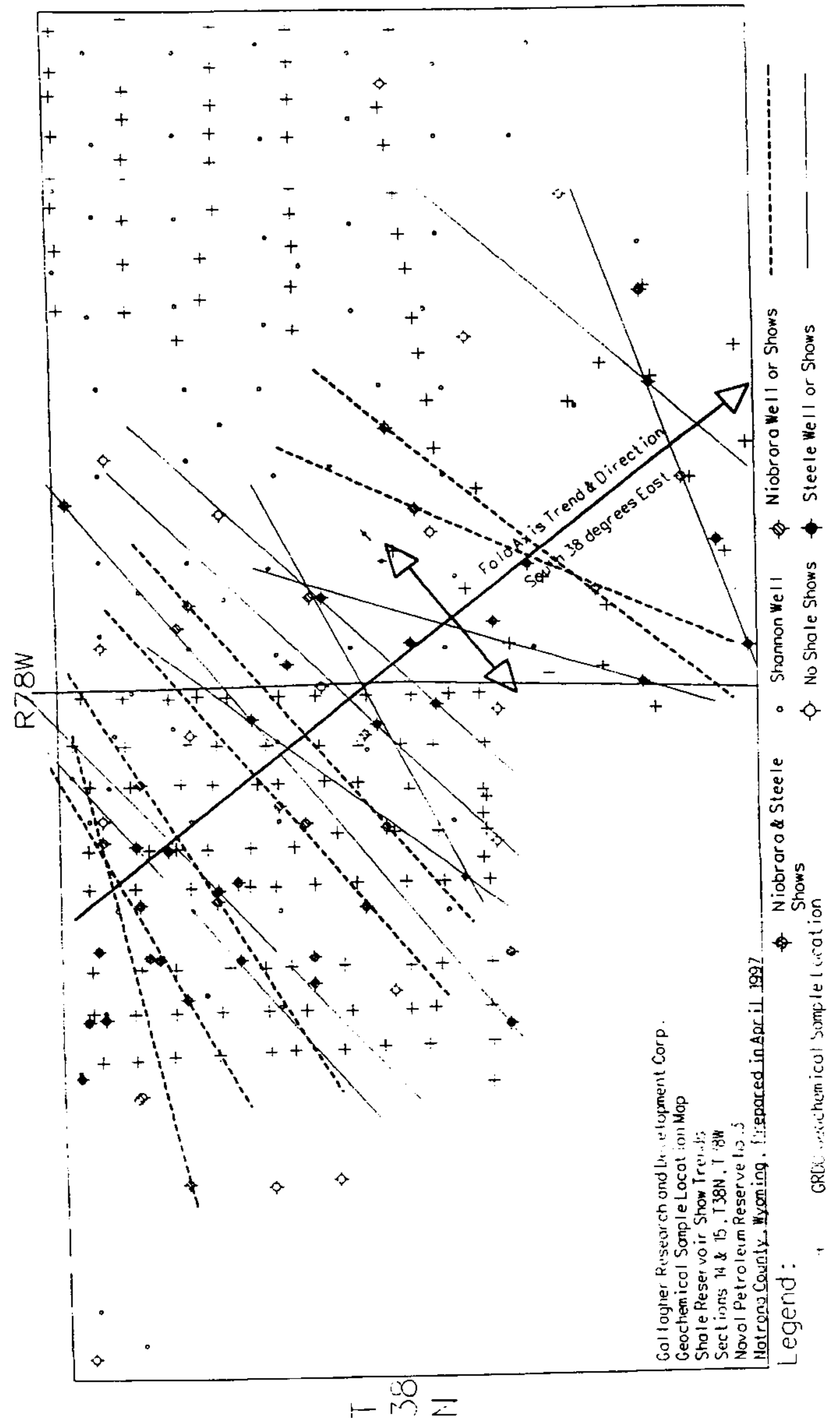


Legend:

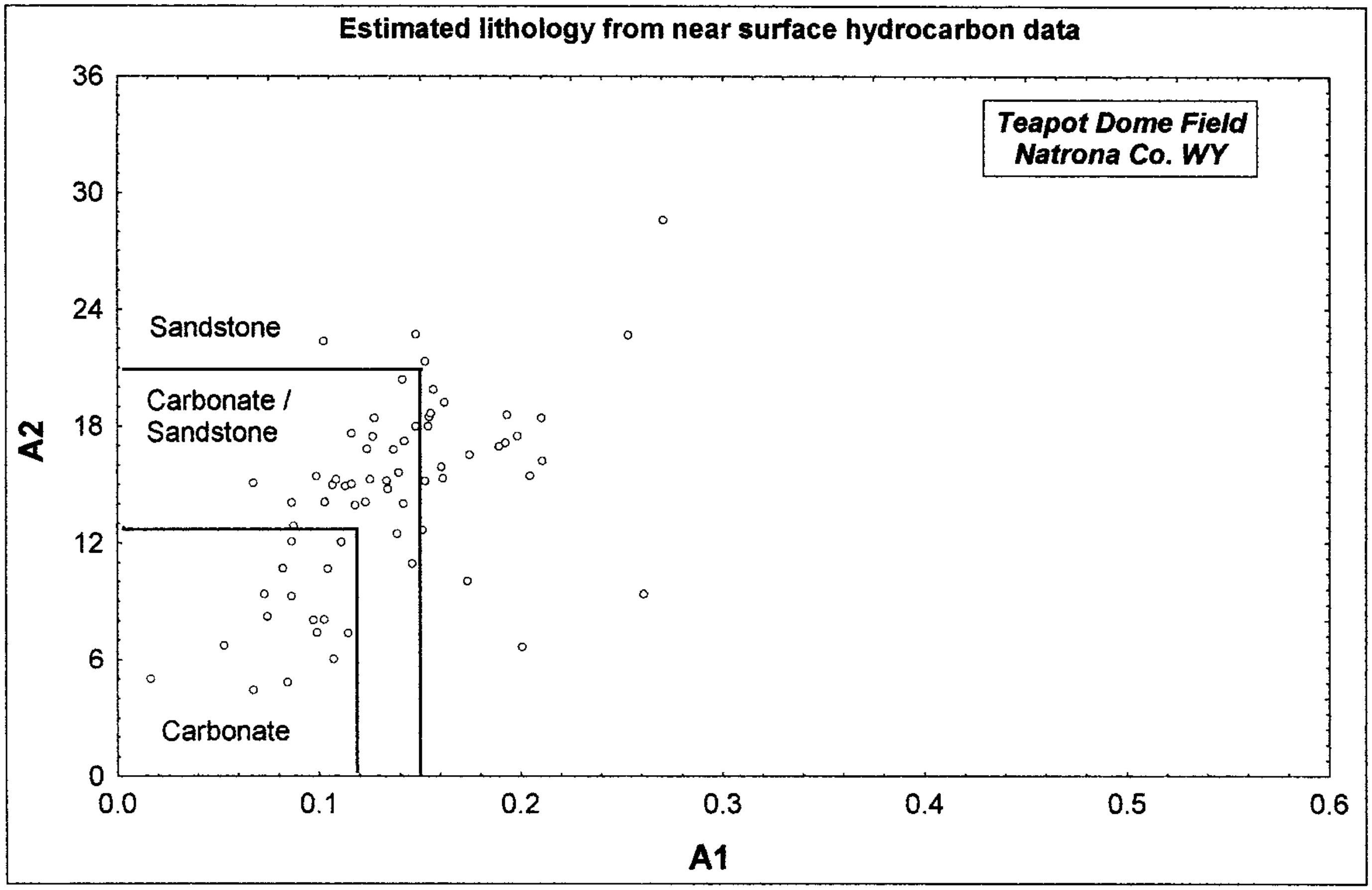
Q - Quaternary Undivided
QTl - Quaternary Lower Level Terrace
QTu - Quaternary Upper Level Terrace
KMvPc - Cretaceous Mesaverde Fm., Parkman S.S. member, Carbonaceous Unit
KMvw - Cretaceous Mesaverde Fm., Parkman S.S. member, Lower Unit
KSu - Cretaceous Steele Shale, Upper Unit
KSx - Cretaceous Steele Shale, Sussex S.S. member

——— Fracture Trace - - - - - - - Fault Trace

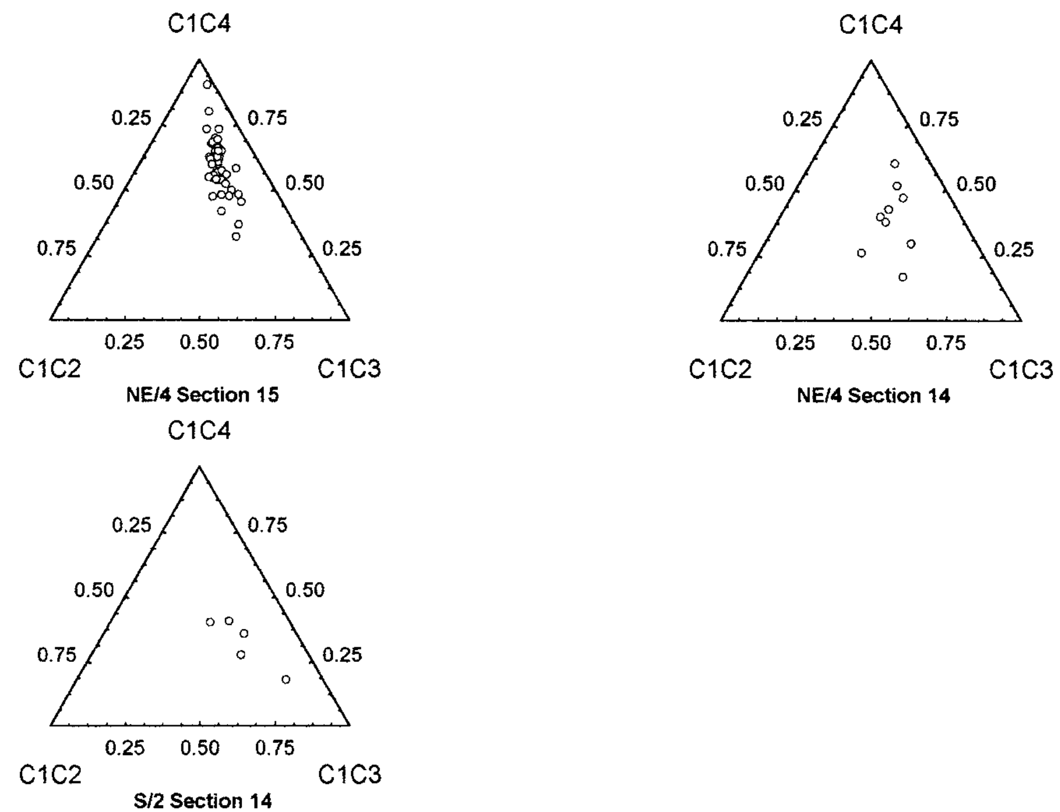
GRDC Study Area with surface geology and faults and fractures.

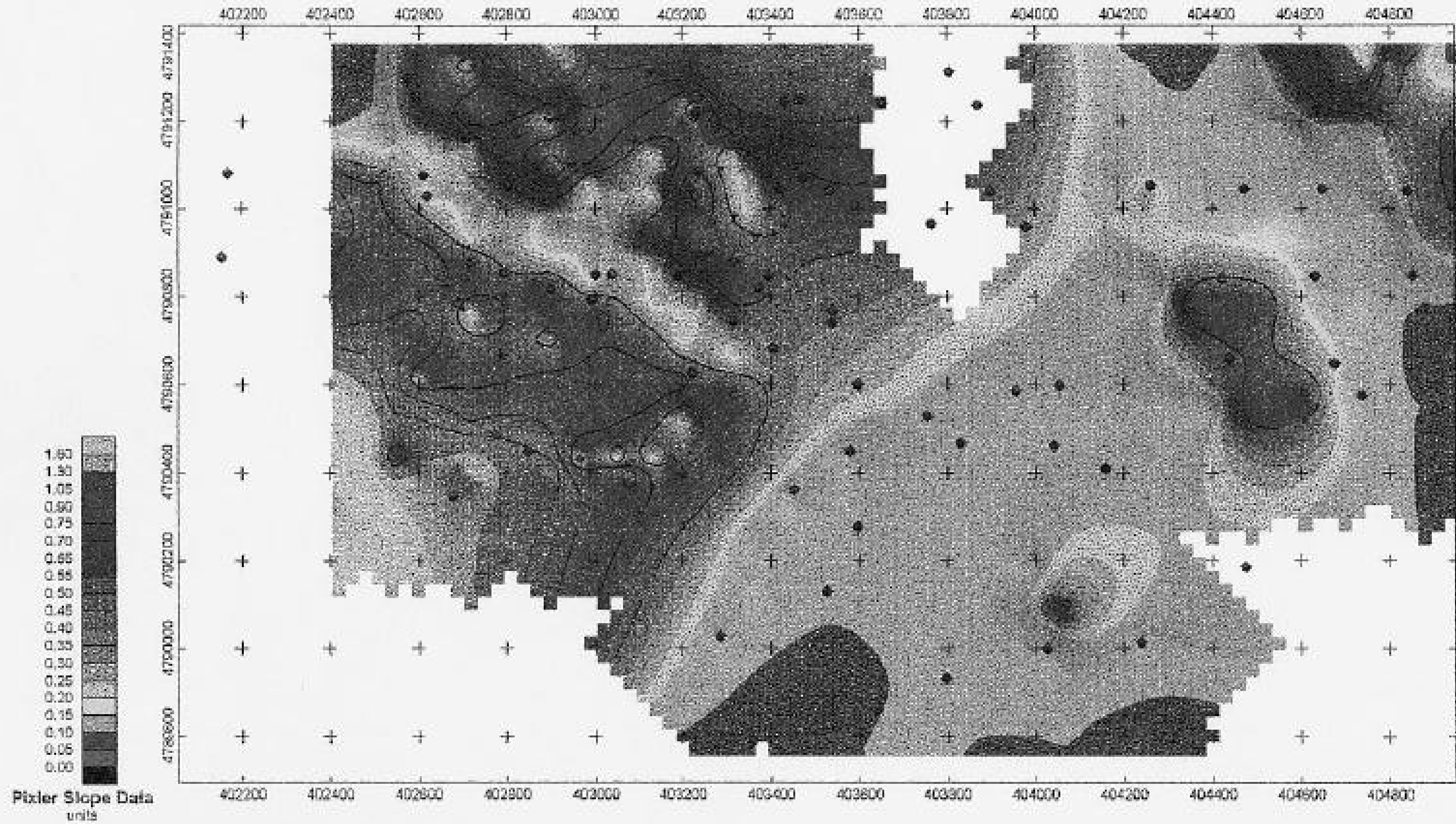


Steele and Niobrara reservoir show trends..


Estimated lithology from near surface hydrocarbon data
Teapot Dome Field
Natrona Co. WY
Sandstone
Carbonate /
Sandstone
Carbonate
A2
A1
0
6
12
18
24
30
36
0.0
0.1
0.2
0.3
0.4
0.5
0.6

Ternary Graph of Pixler Ratios



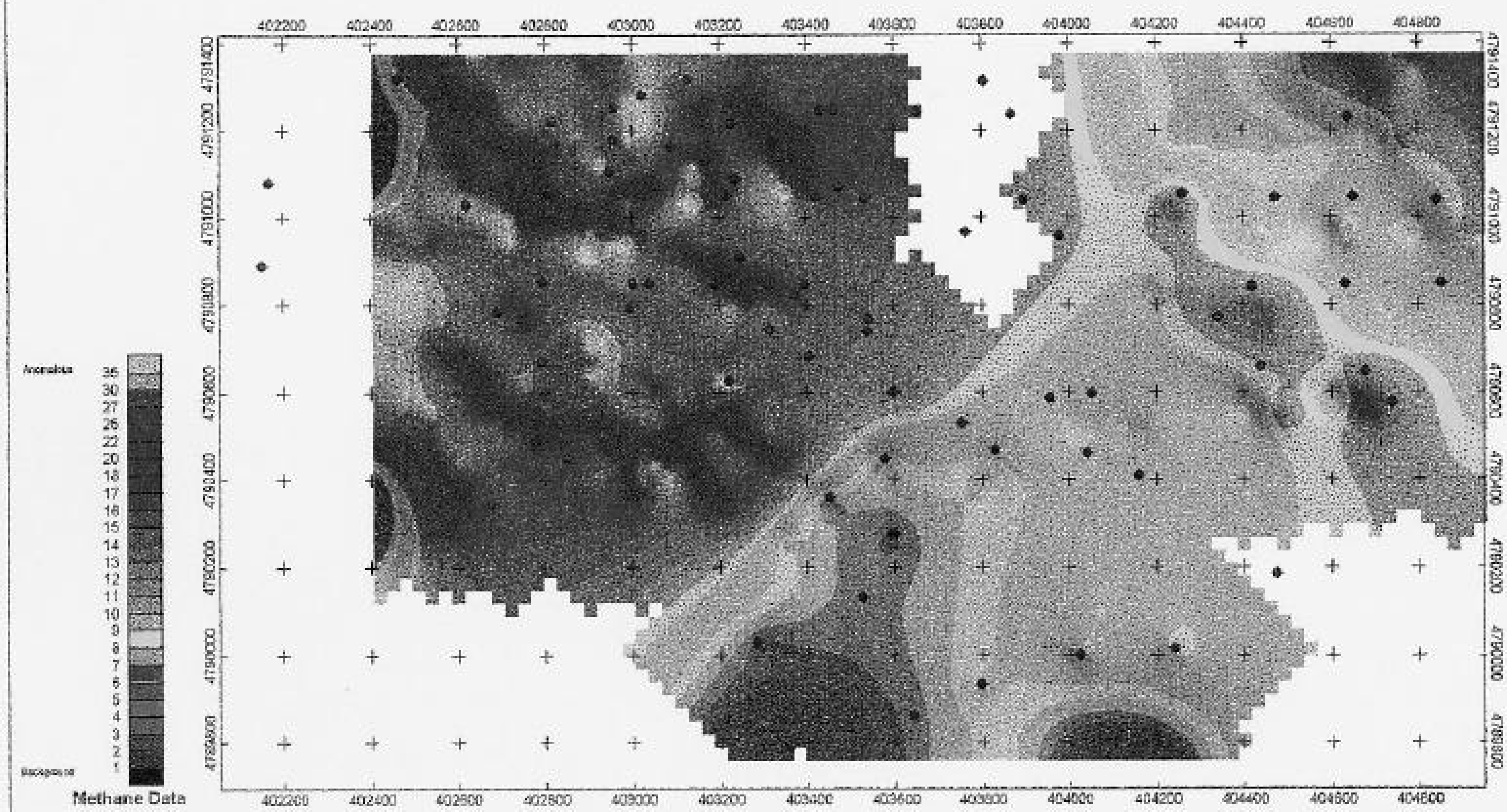


Contours indicate areas of greatest economic potential.

TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

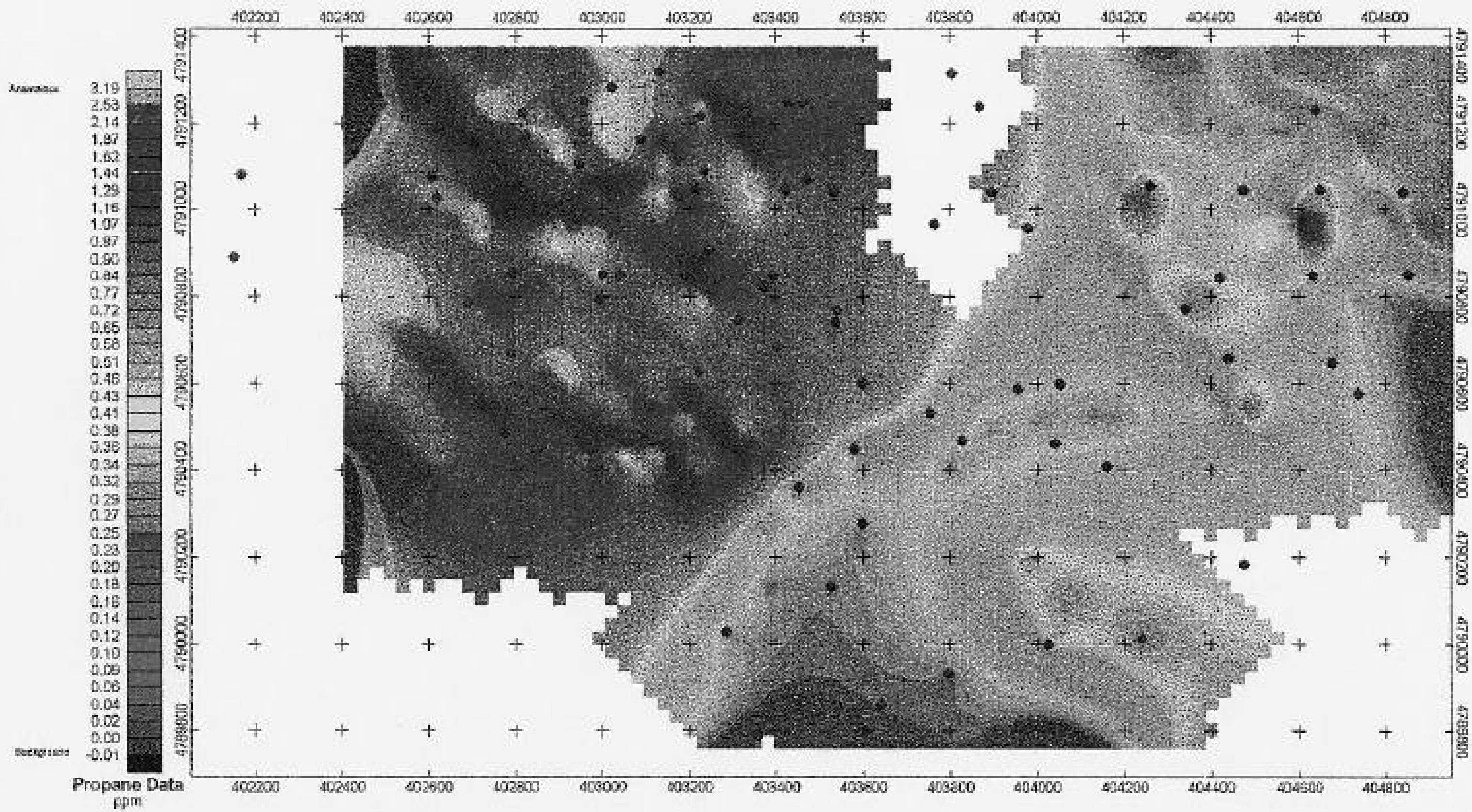
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

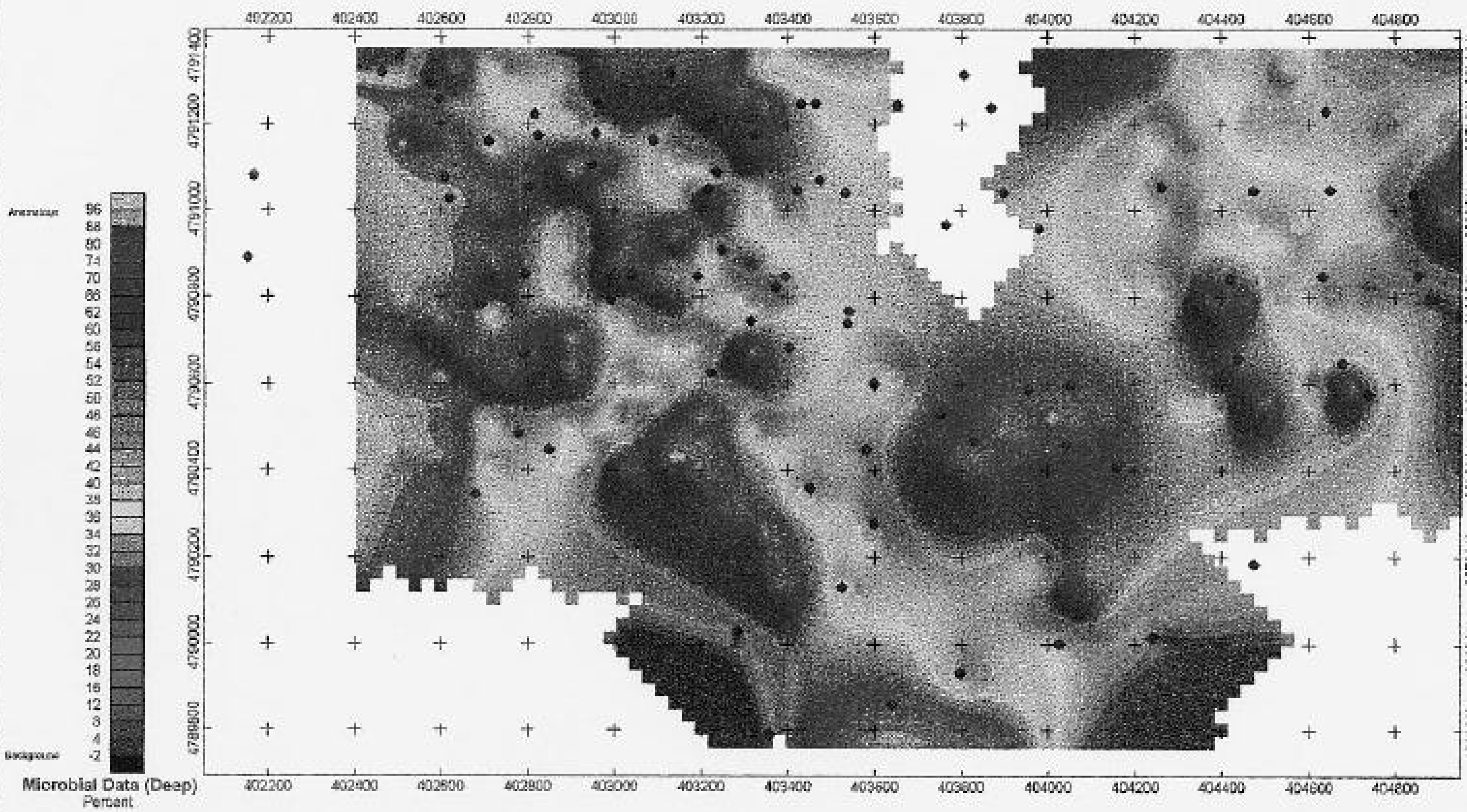
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

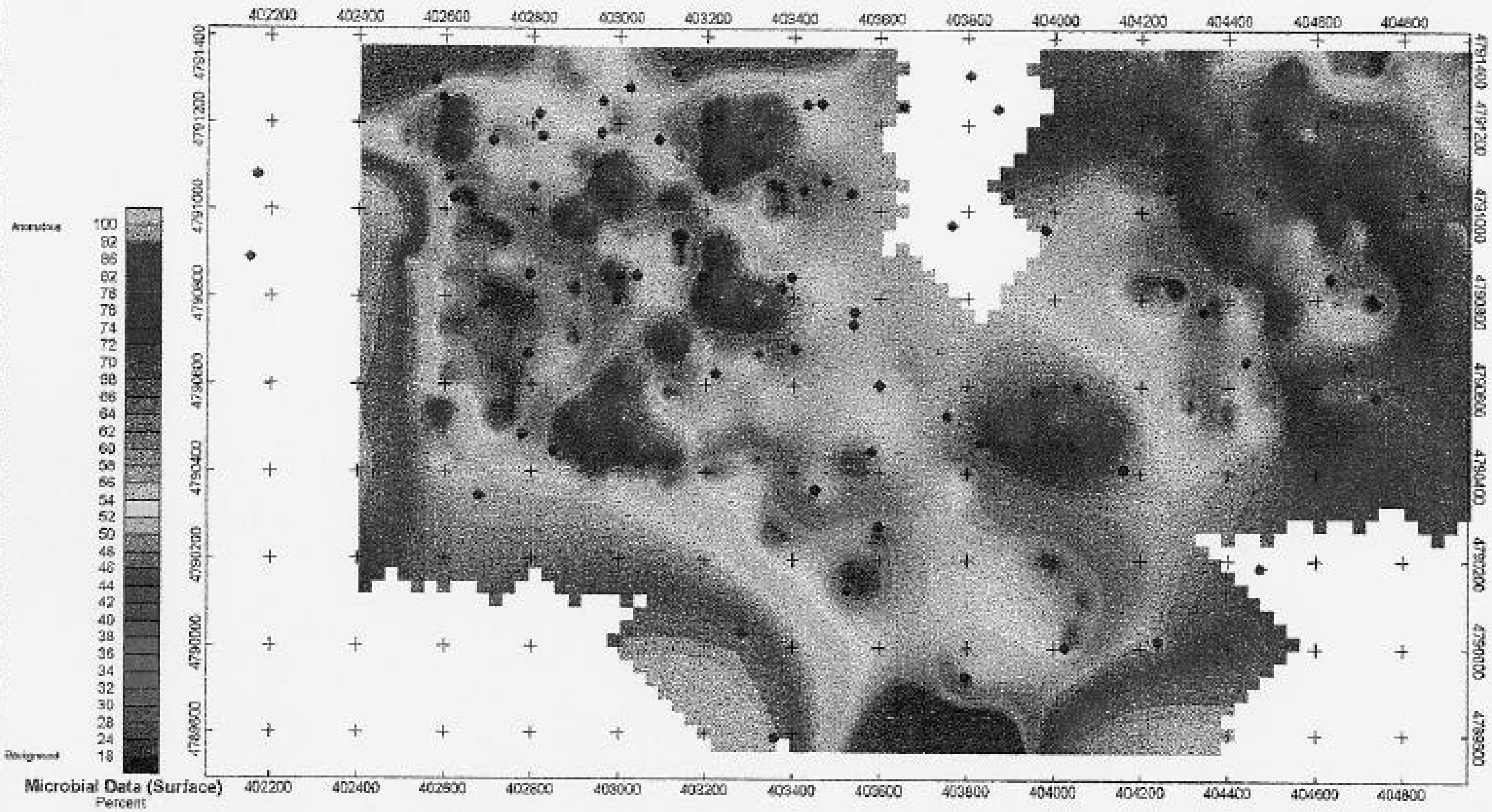
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

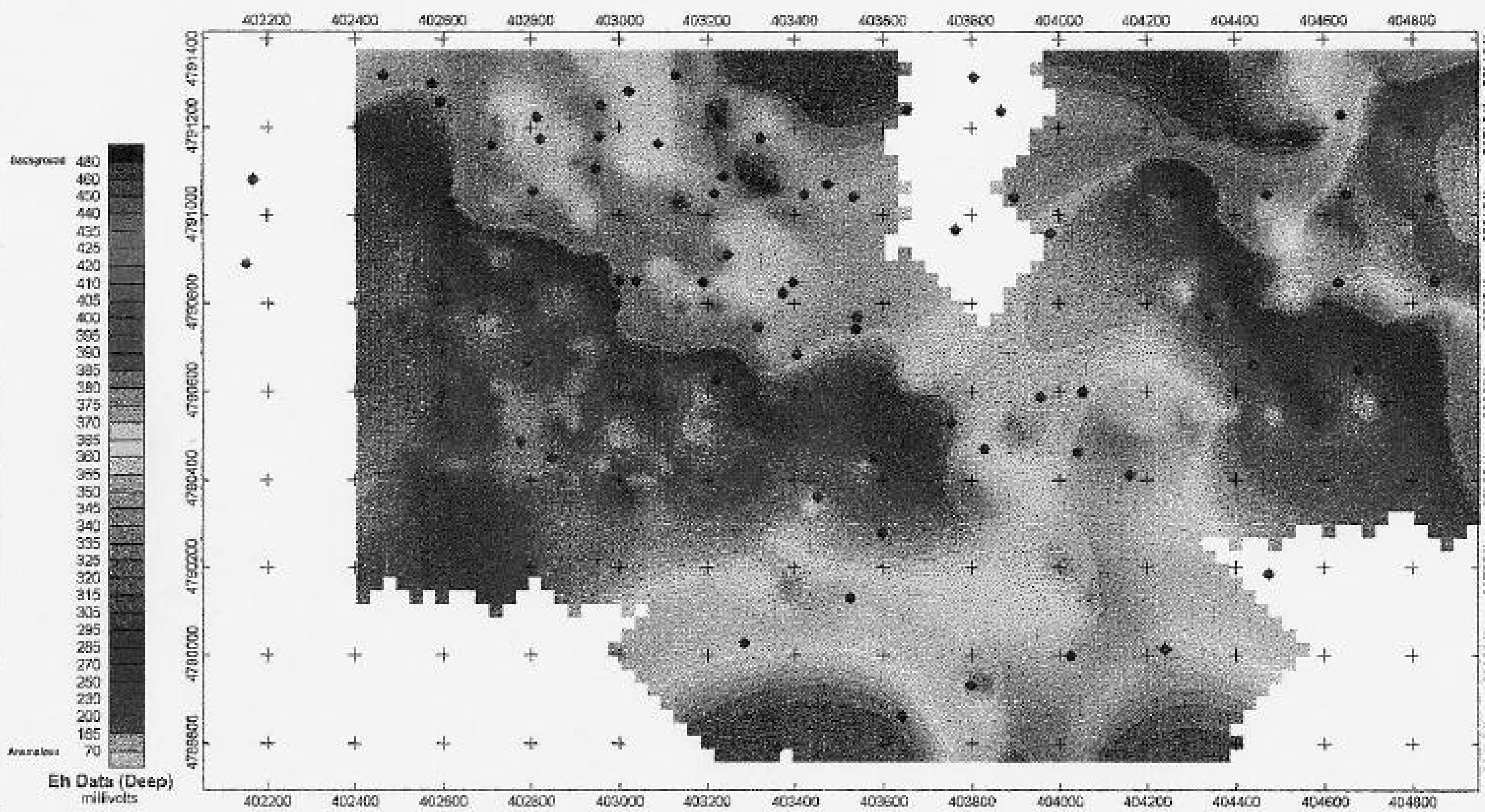
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

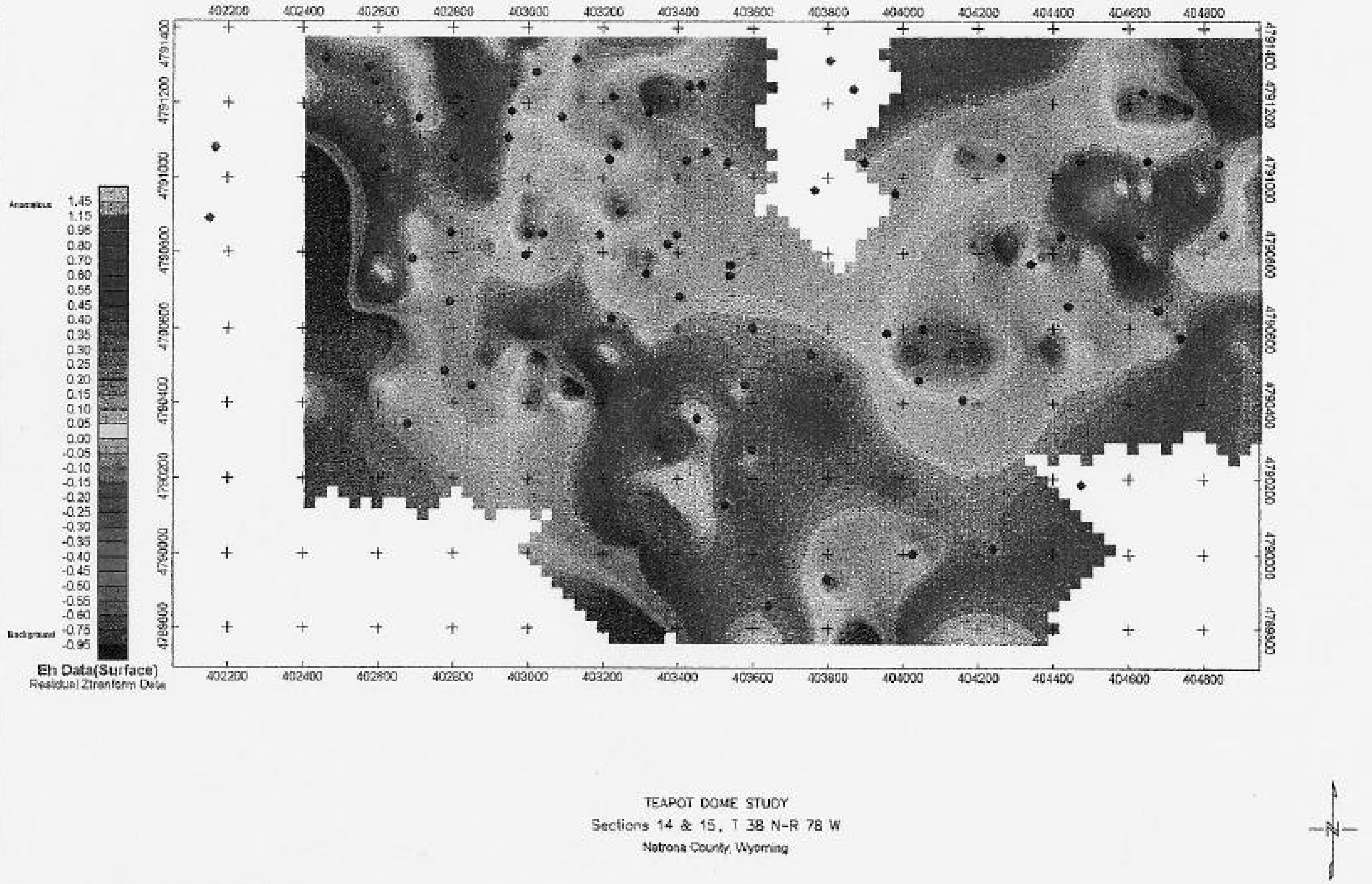
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

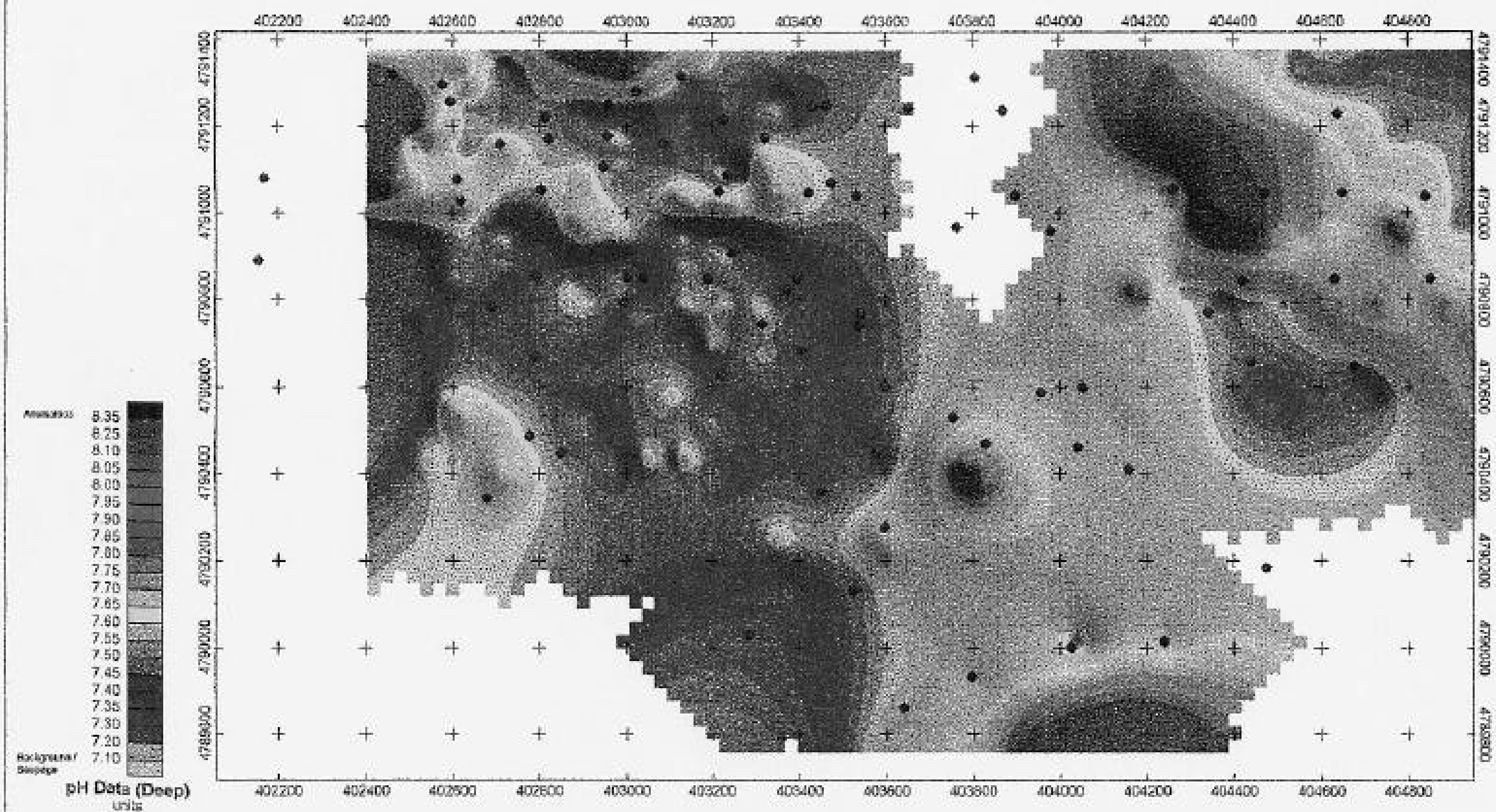
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

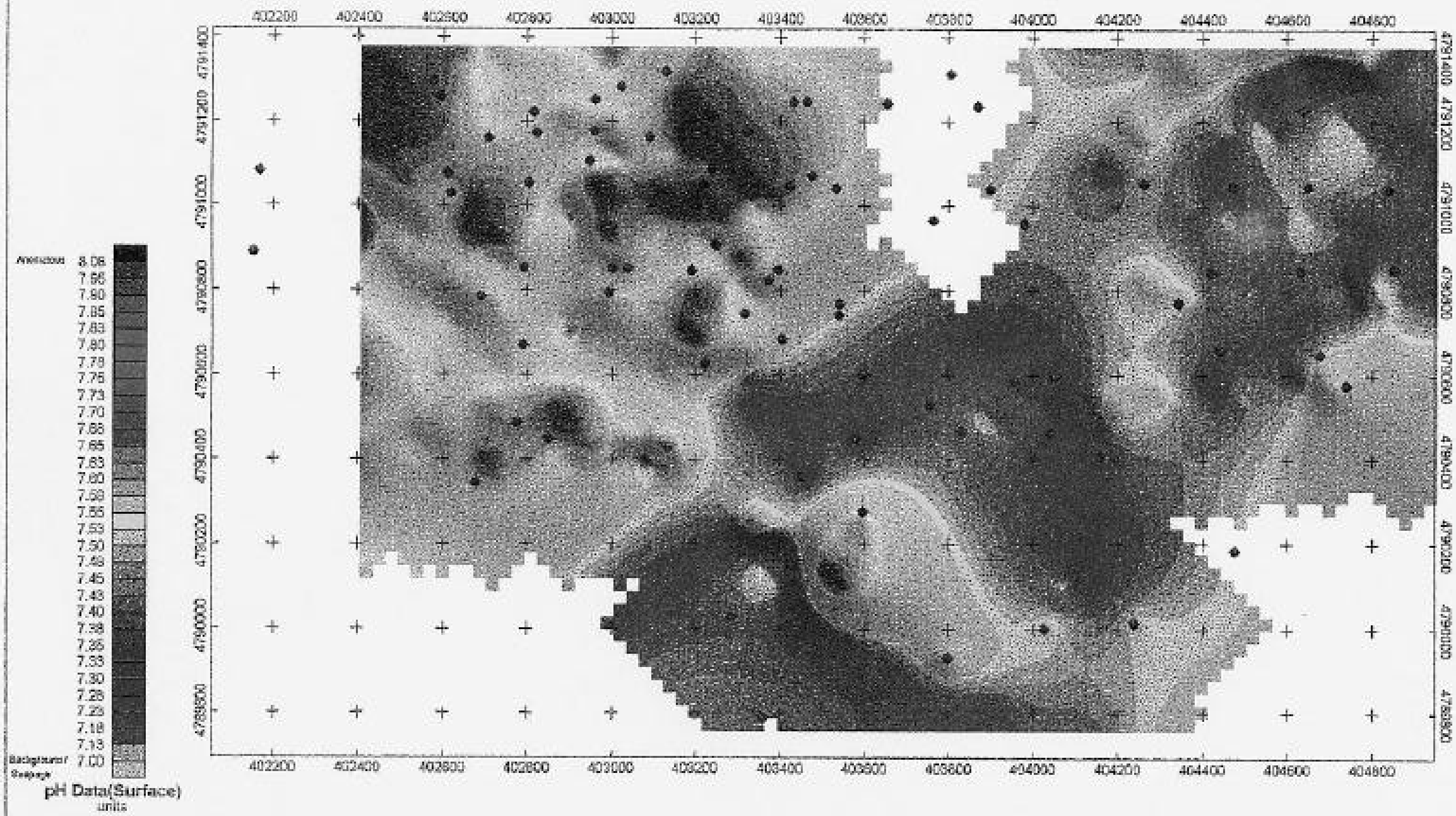
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

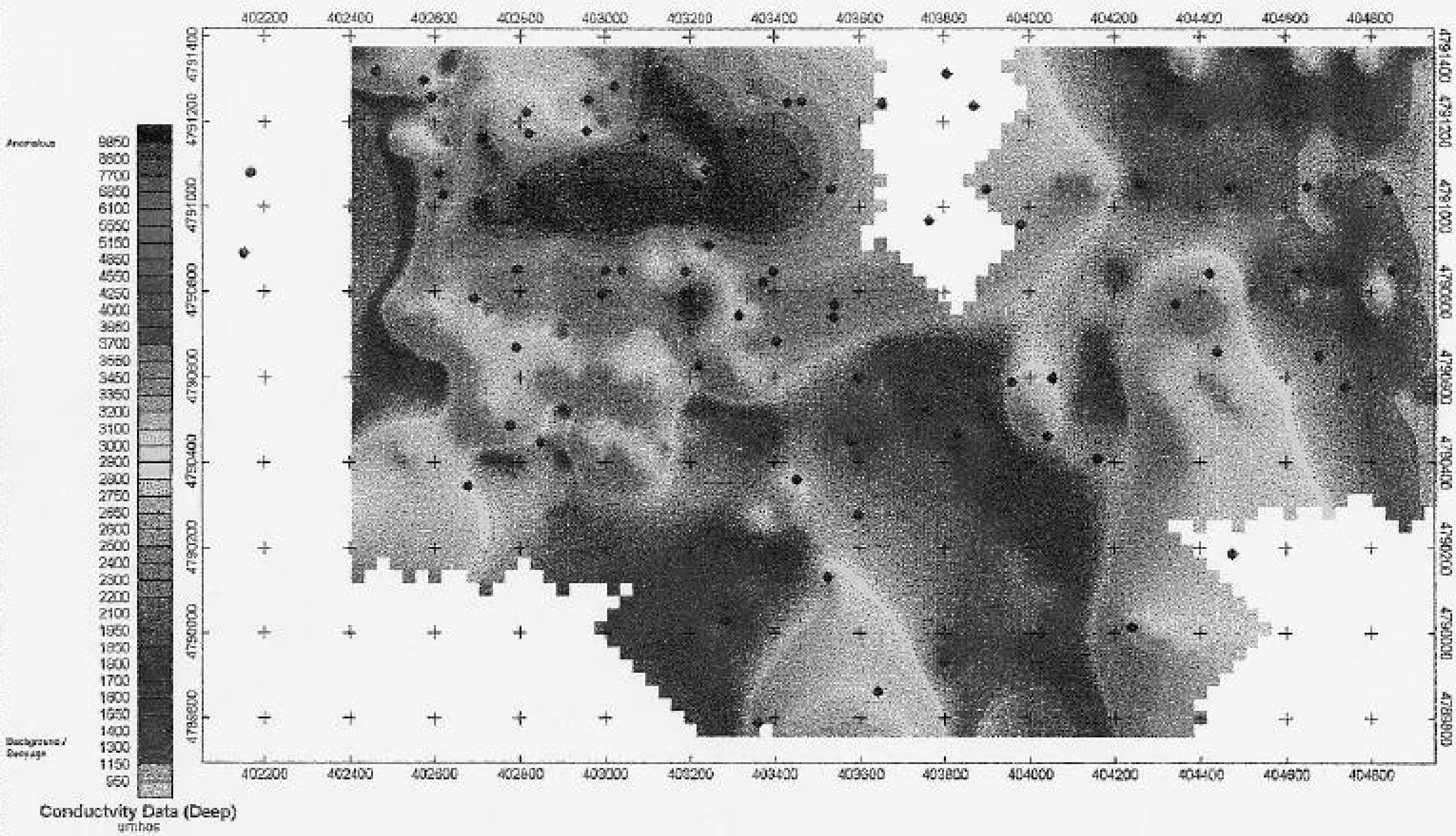
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 36 N-R 78 W

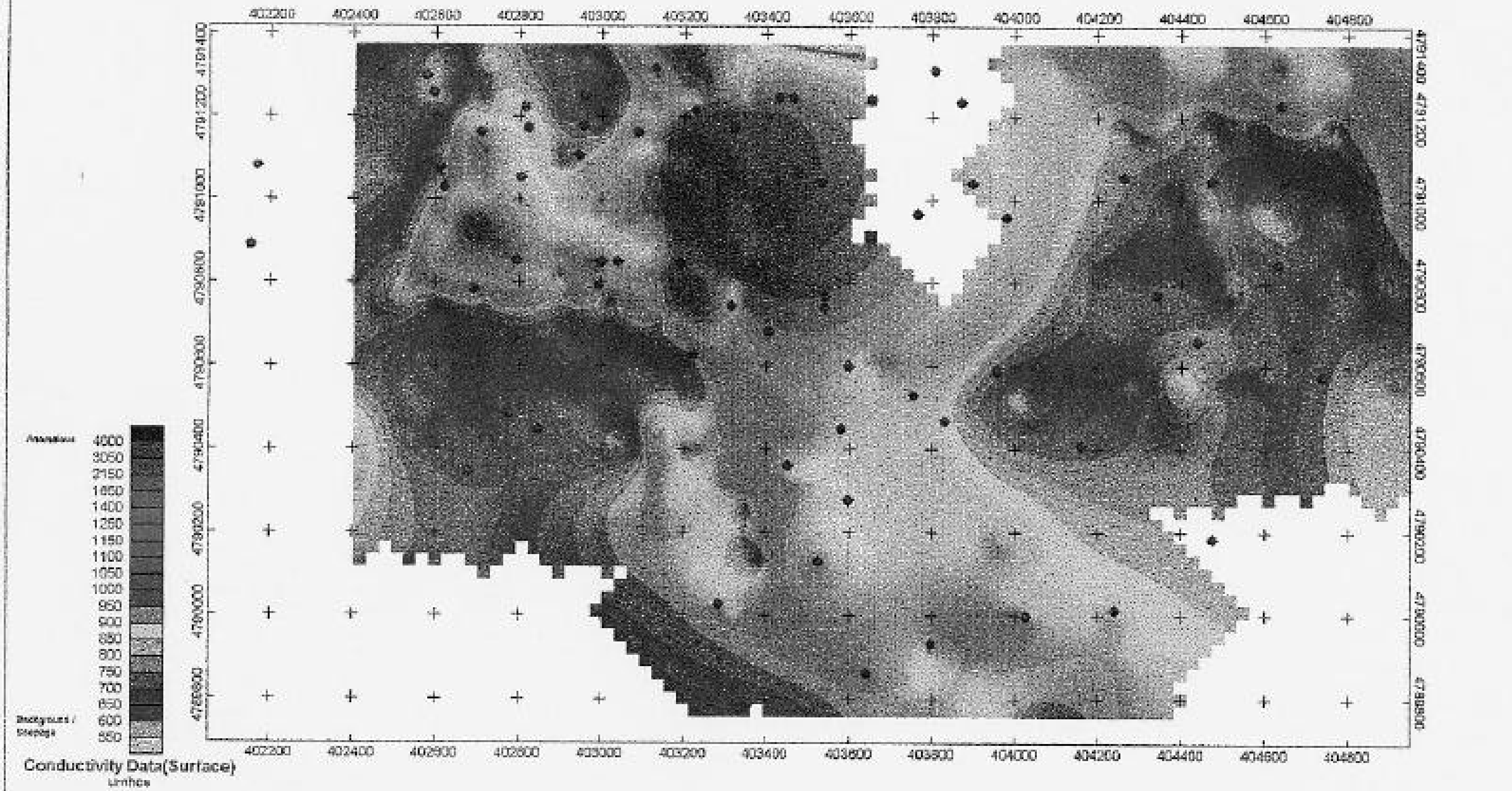
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

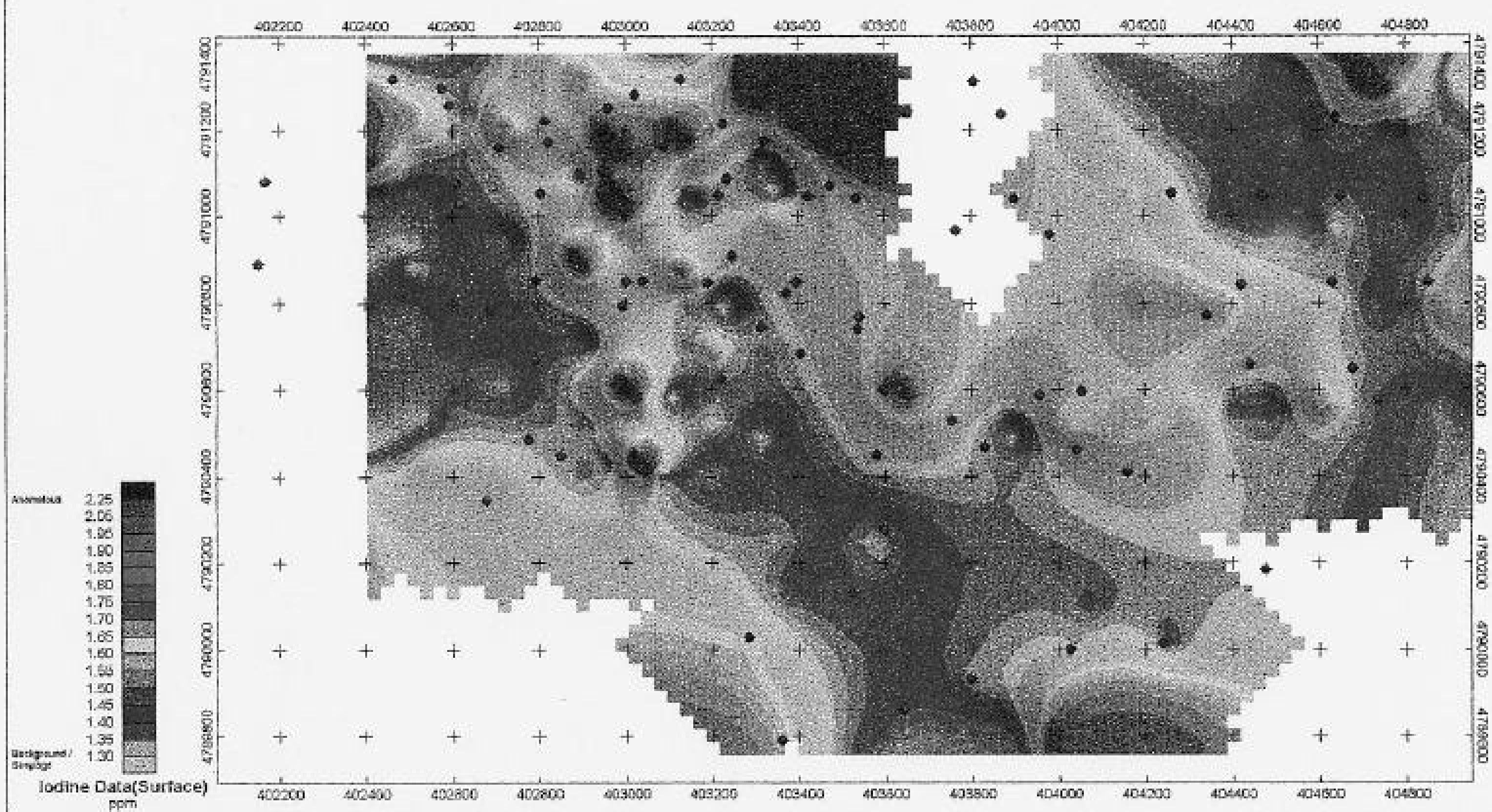
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

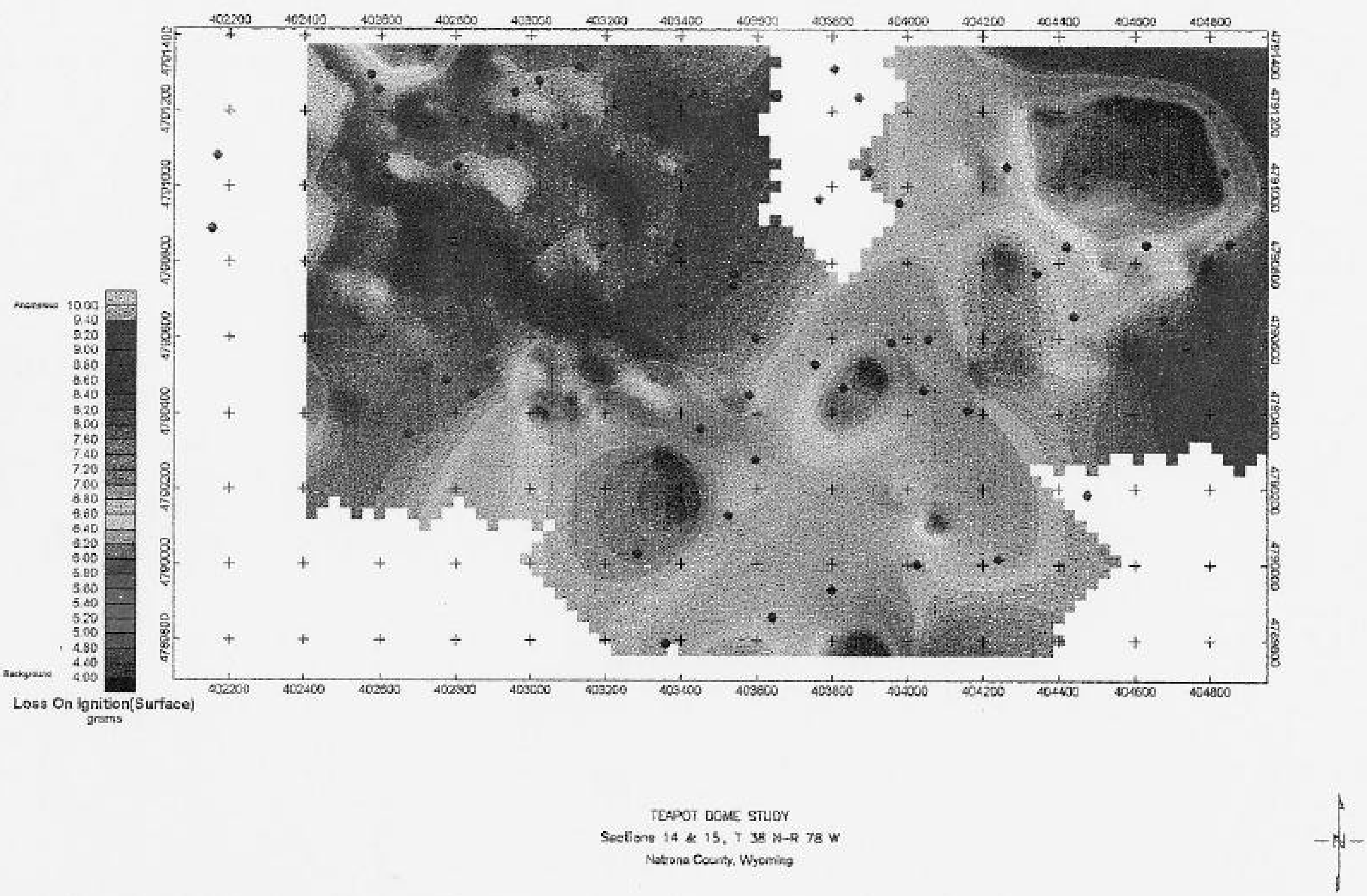
Natrona County, Wyoming



TEAPOT DOME STUDY

Sections 14 & 15, T 38 N-R 78 W

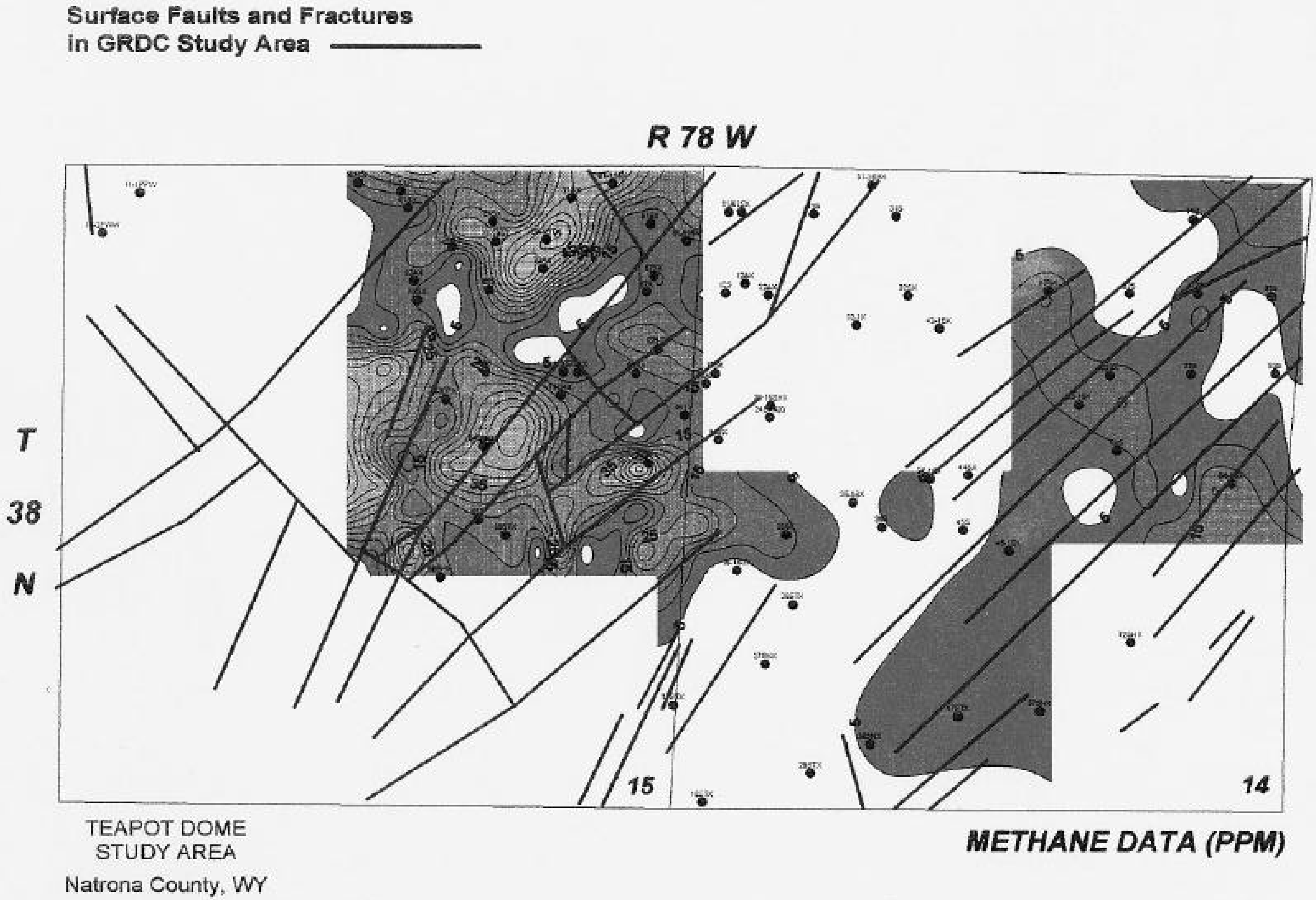
Natrona County, Wyoming

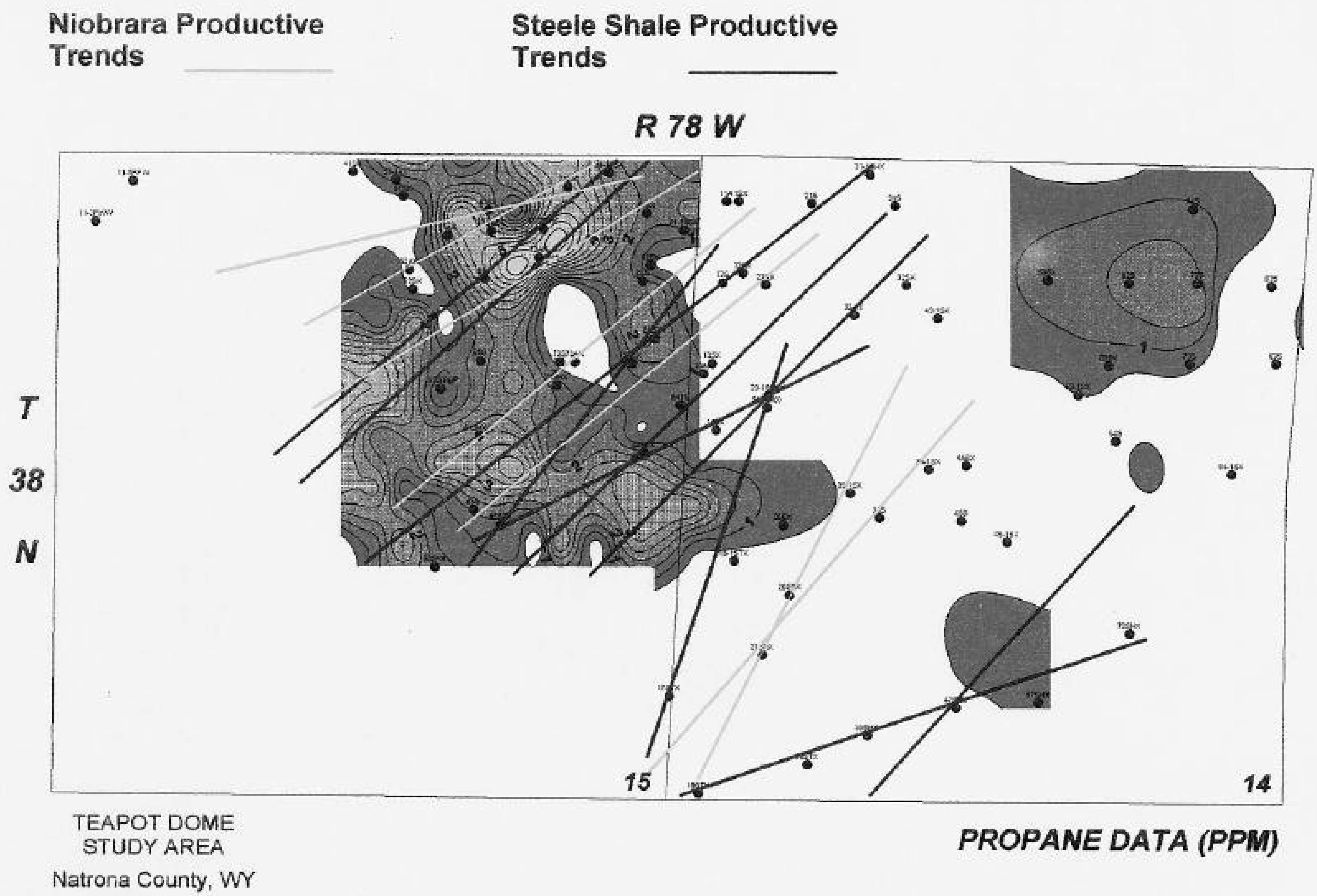


TEAPOT DOME STUDY

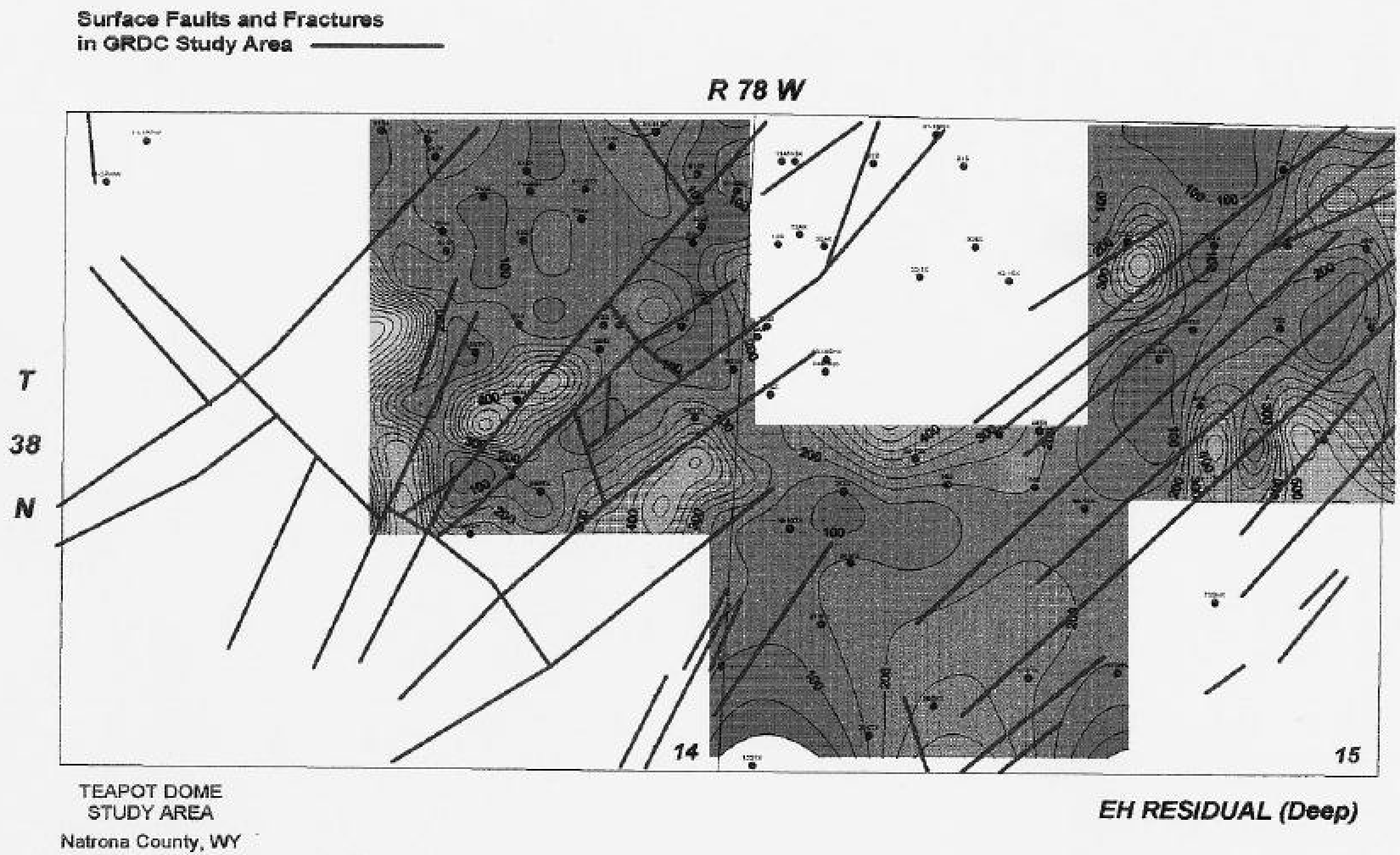
Sections 14 & 15, T 38 N-R 78 W

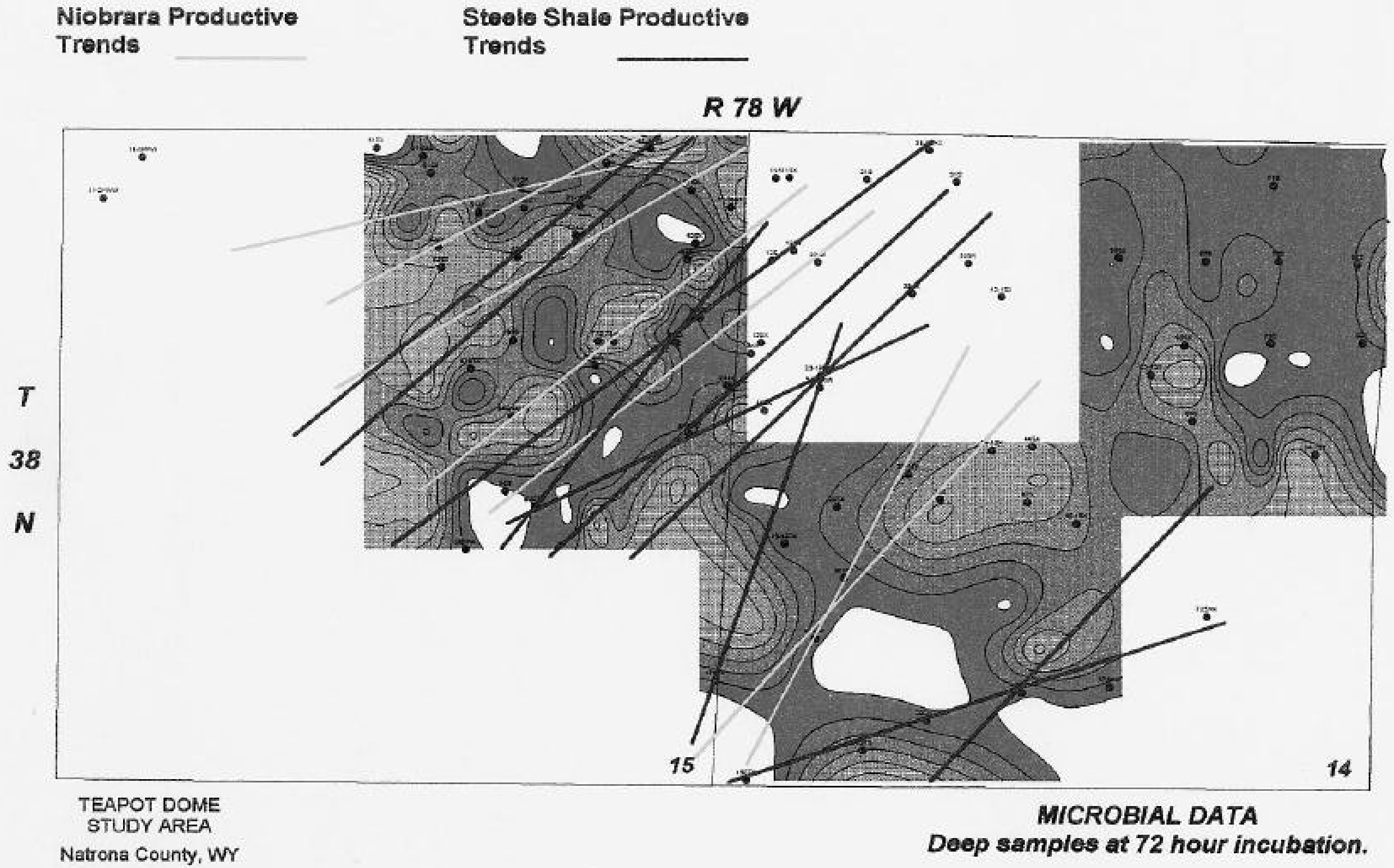
Natrona County, Wyoming


Surface Faults and Fractures
in GRDC Study Area
R 78 W
T
38
N
15
14
TEAPOT DOME
STUDY AREA
Natrona County, WY
METHANE DATA (PPM)

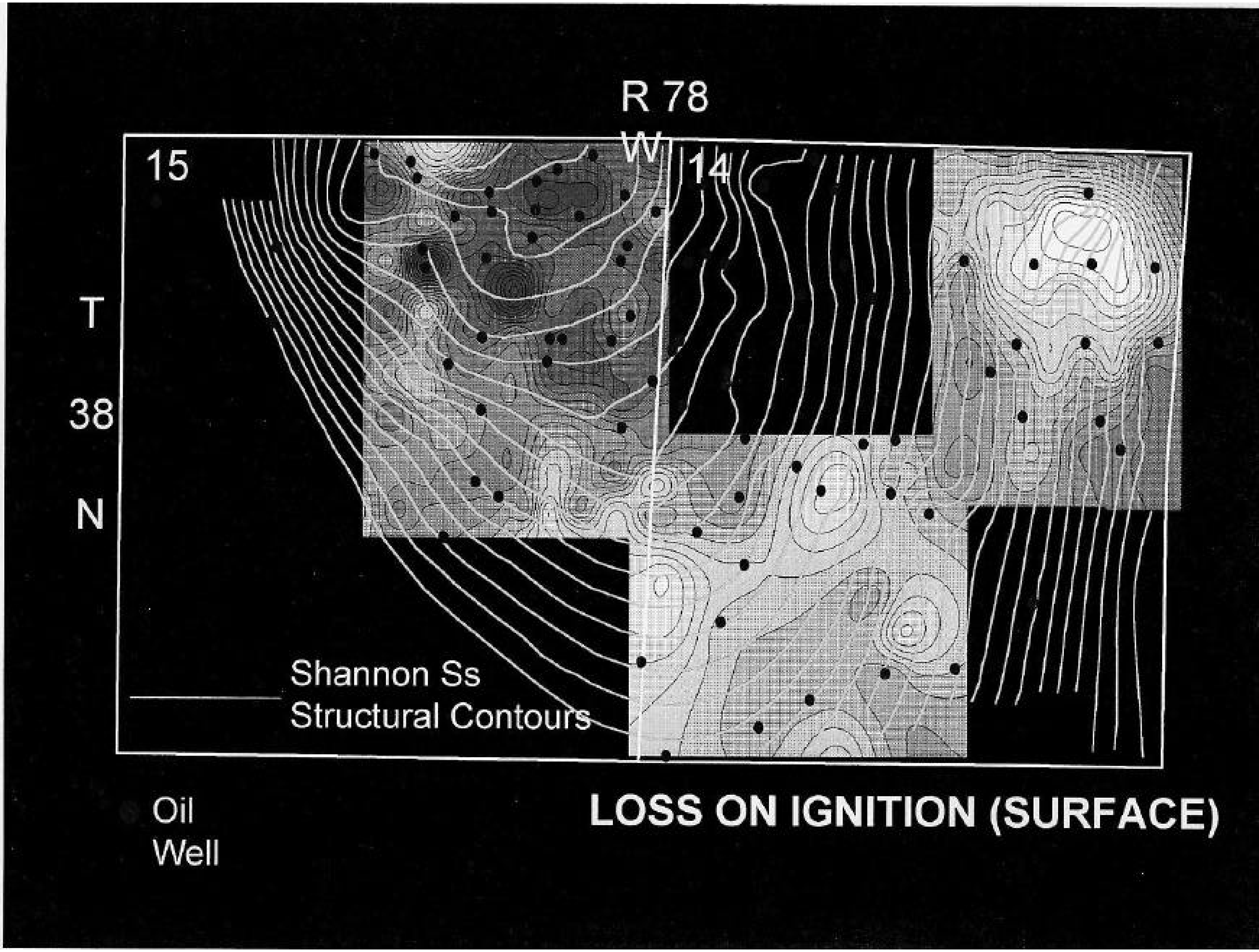


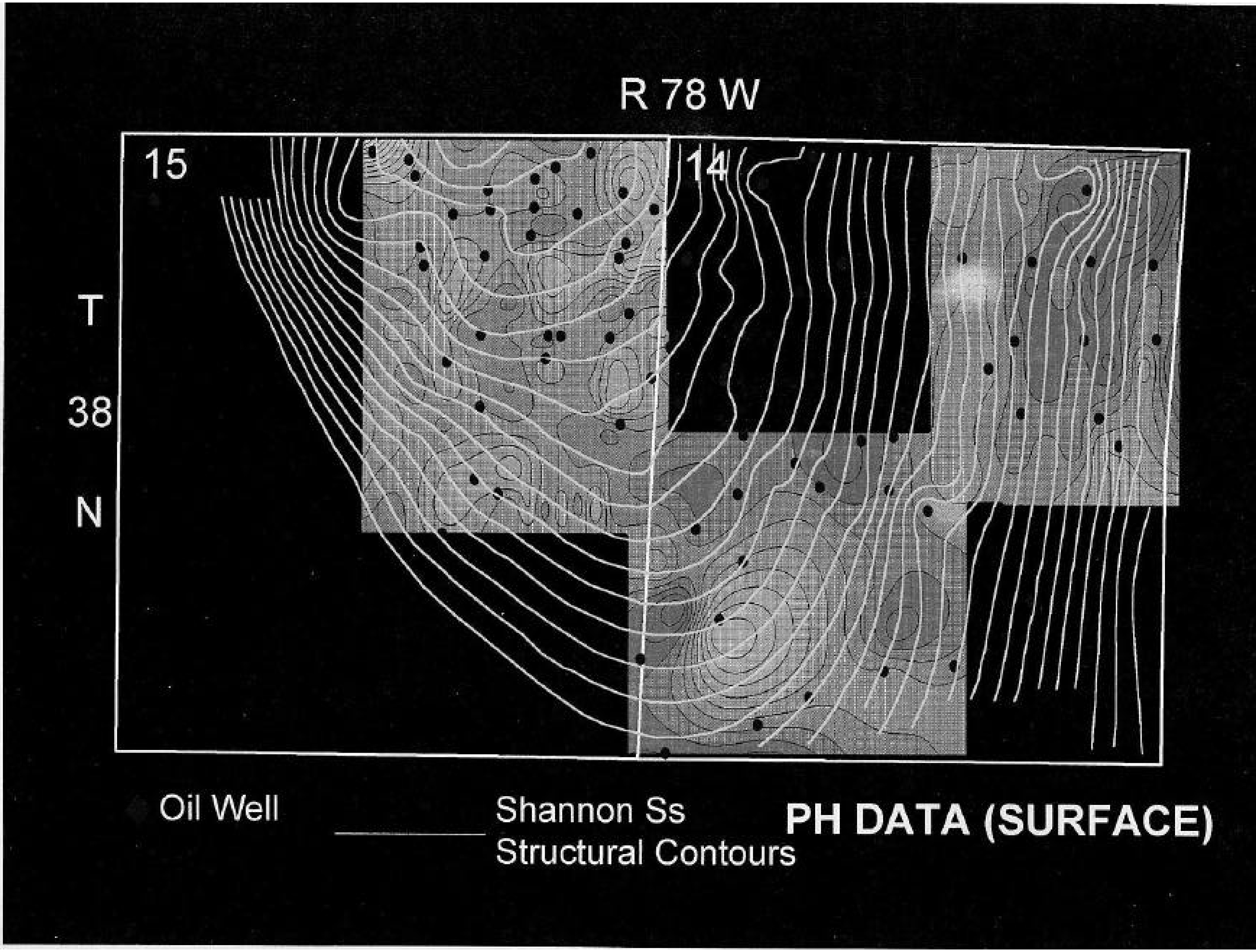
Niobrara Productive Trends
Steele Shale Productive Trends
R 78 W
T 38 N
15
14
TEAPOT DOME STUDY AREA
Natrona County, WY
PROPANE DATA (PPM)

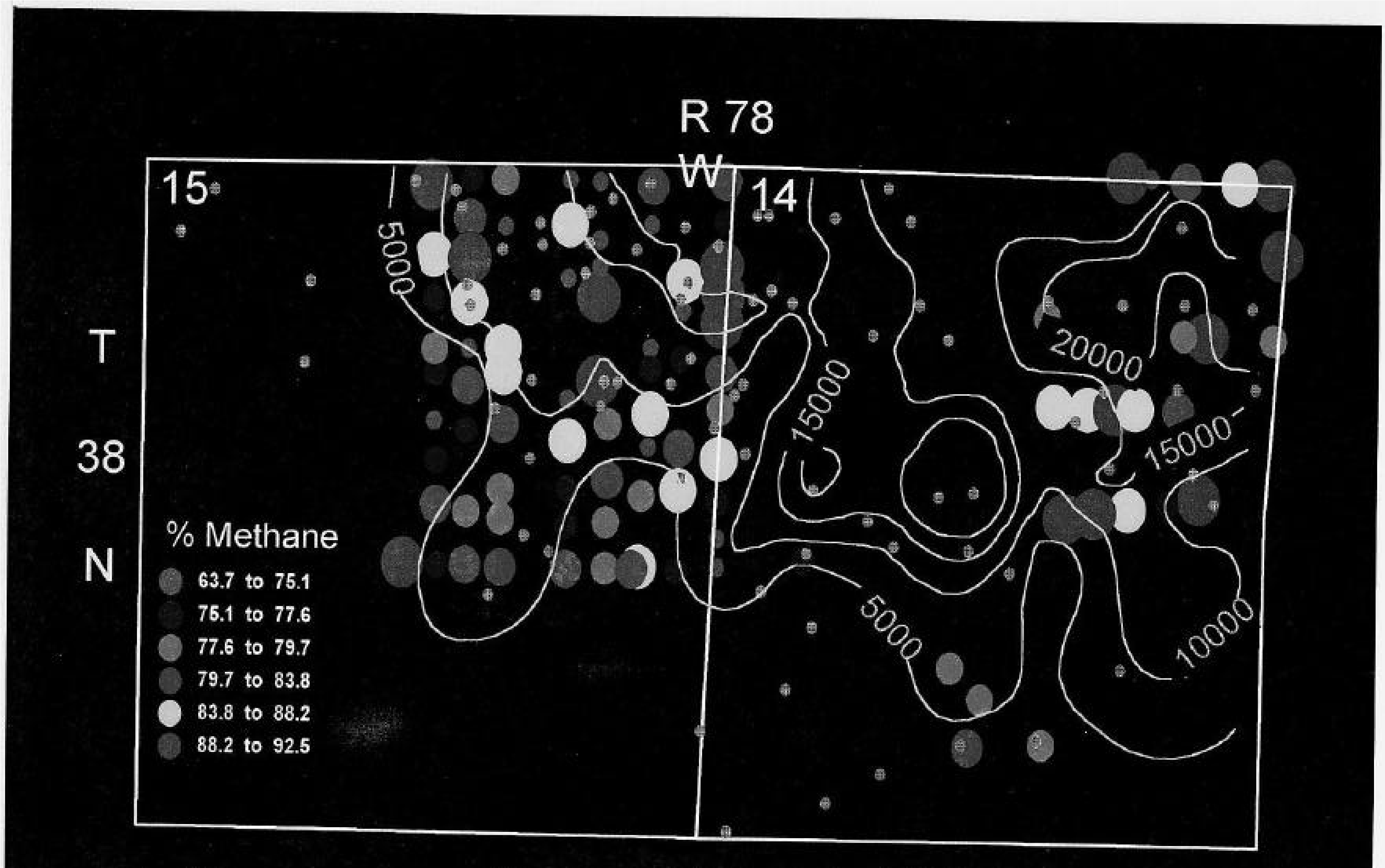

Surface Faults and Fractures
in GRDC Study Area
R 78 W
T
38
N
14
15
TEAPOT DOME
STUDY AREA
Natrona County, WY
EH RESIDUAL (Deep)



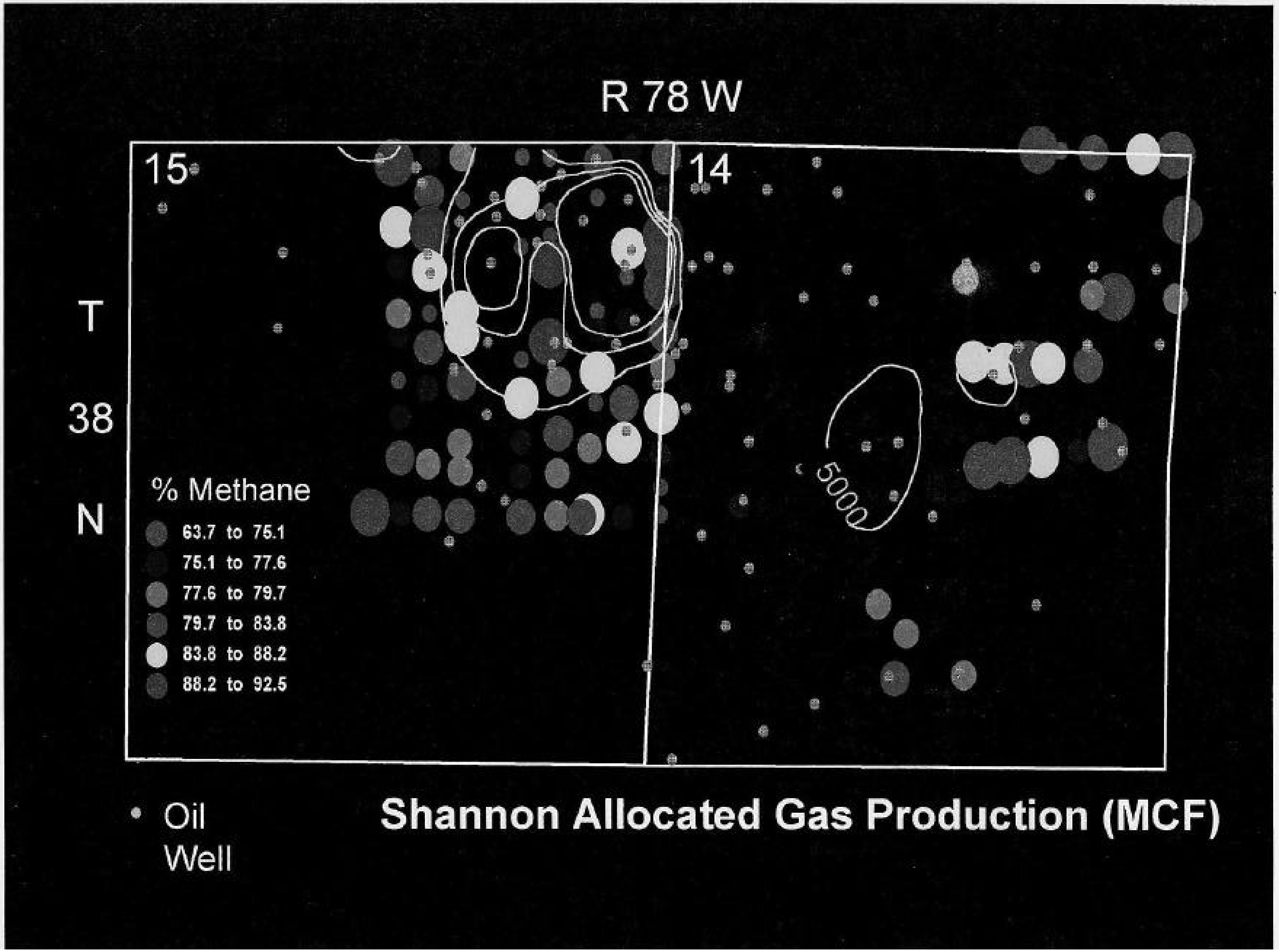
MICROBIAL DATA
Deep samples at 72 hour incubation.

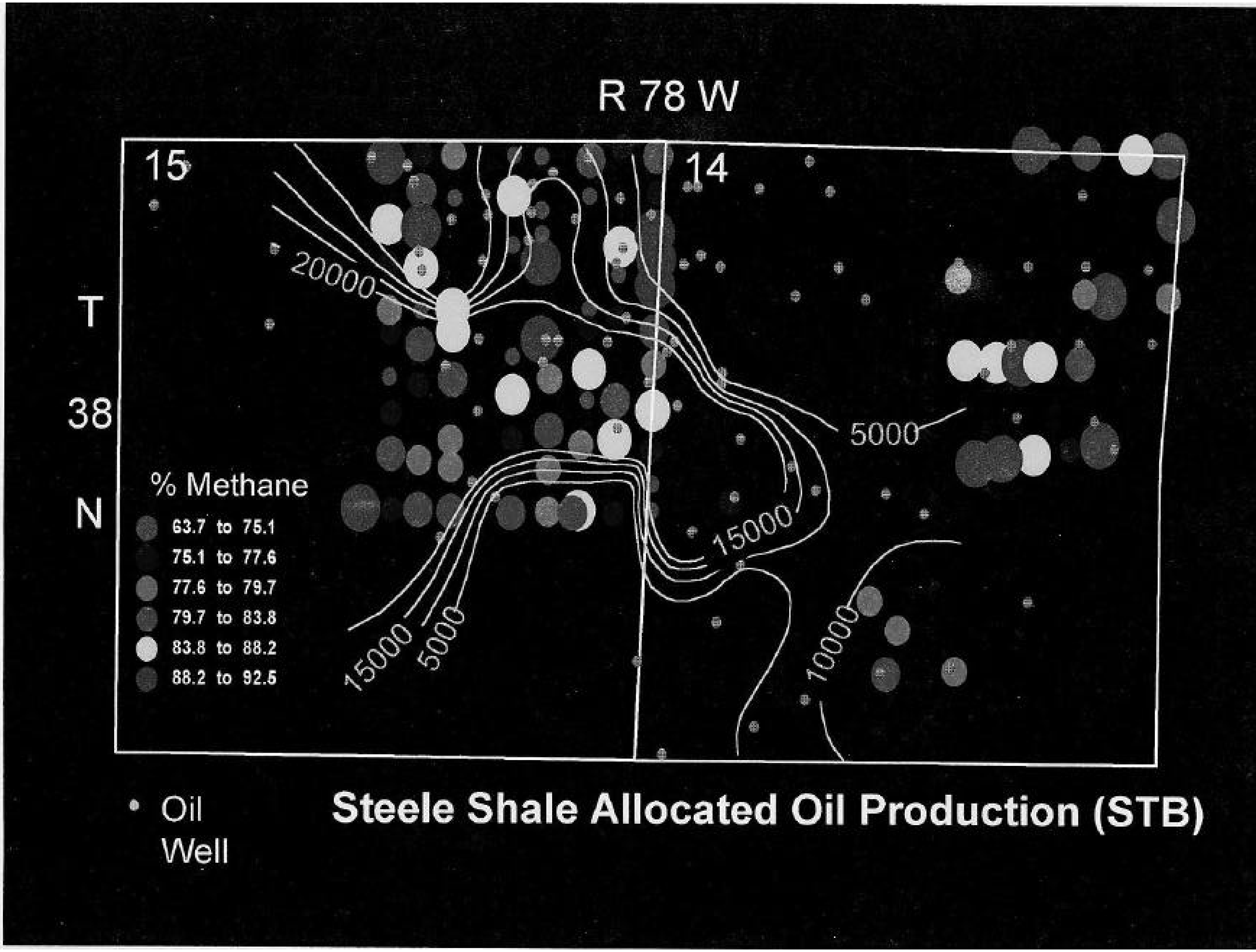

R 78
W
15
14
T
38
N
Shannon Ss
Structural Contours
Oil
Well
LOSS ON IGNITION (SURFACE)


R 78 W
15
14
T
38
N
Oil Well
Shannon Ss
Structural Contours
PH DATA (SURFACE)

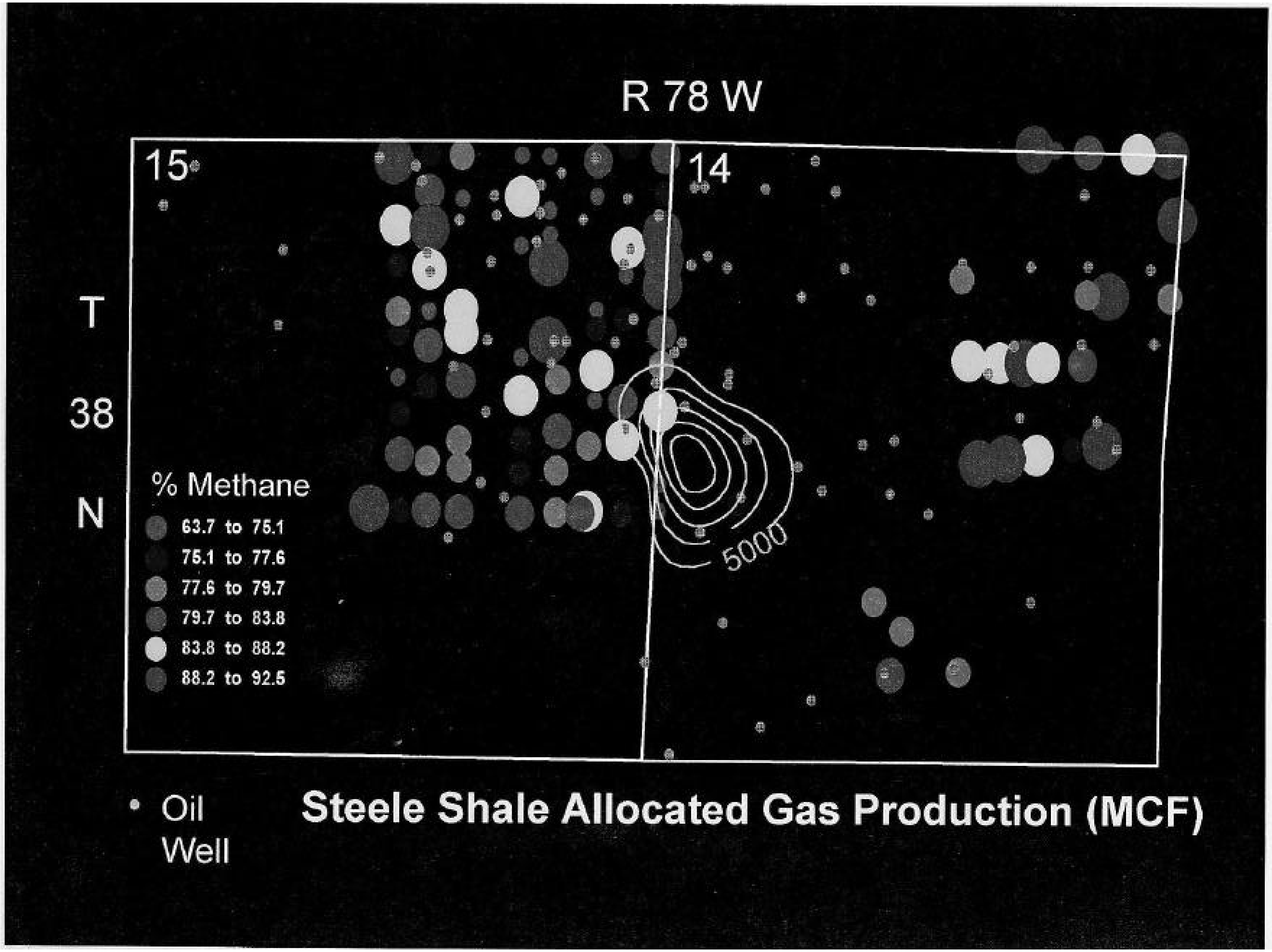


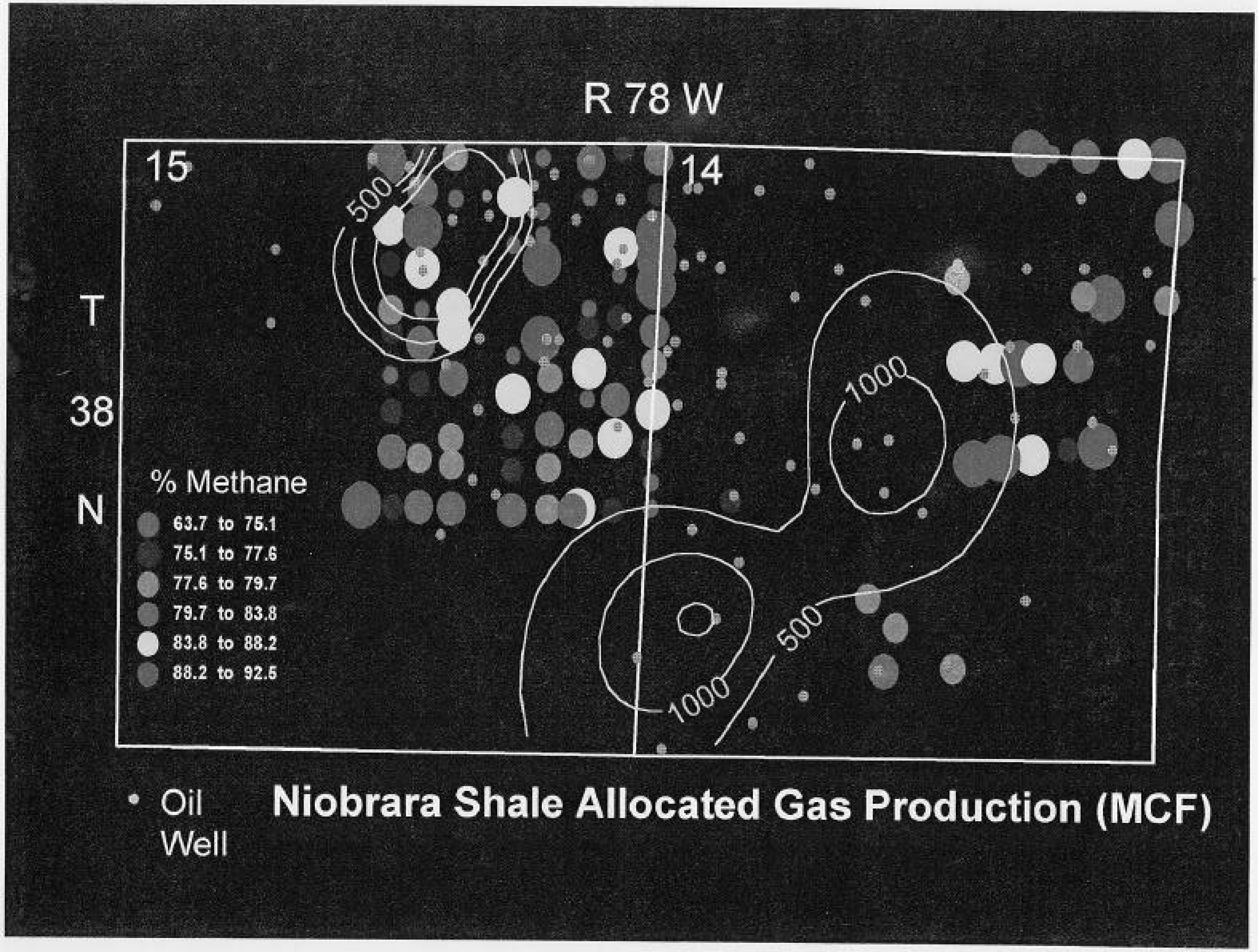
Shannon Allocated Oil Production (STB)


R 78 W
T
38
N
15
14
5000
% Methane
63.7 to 75.1
75.1 to 77.6
77.6 to 79.7
79.7 to 83.8
83.8 to 88.2
88.2 to 92.5
Oil
Well
Shannon Allocated Gas Production (MCF)

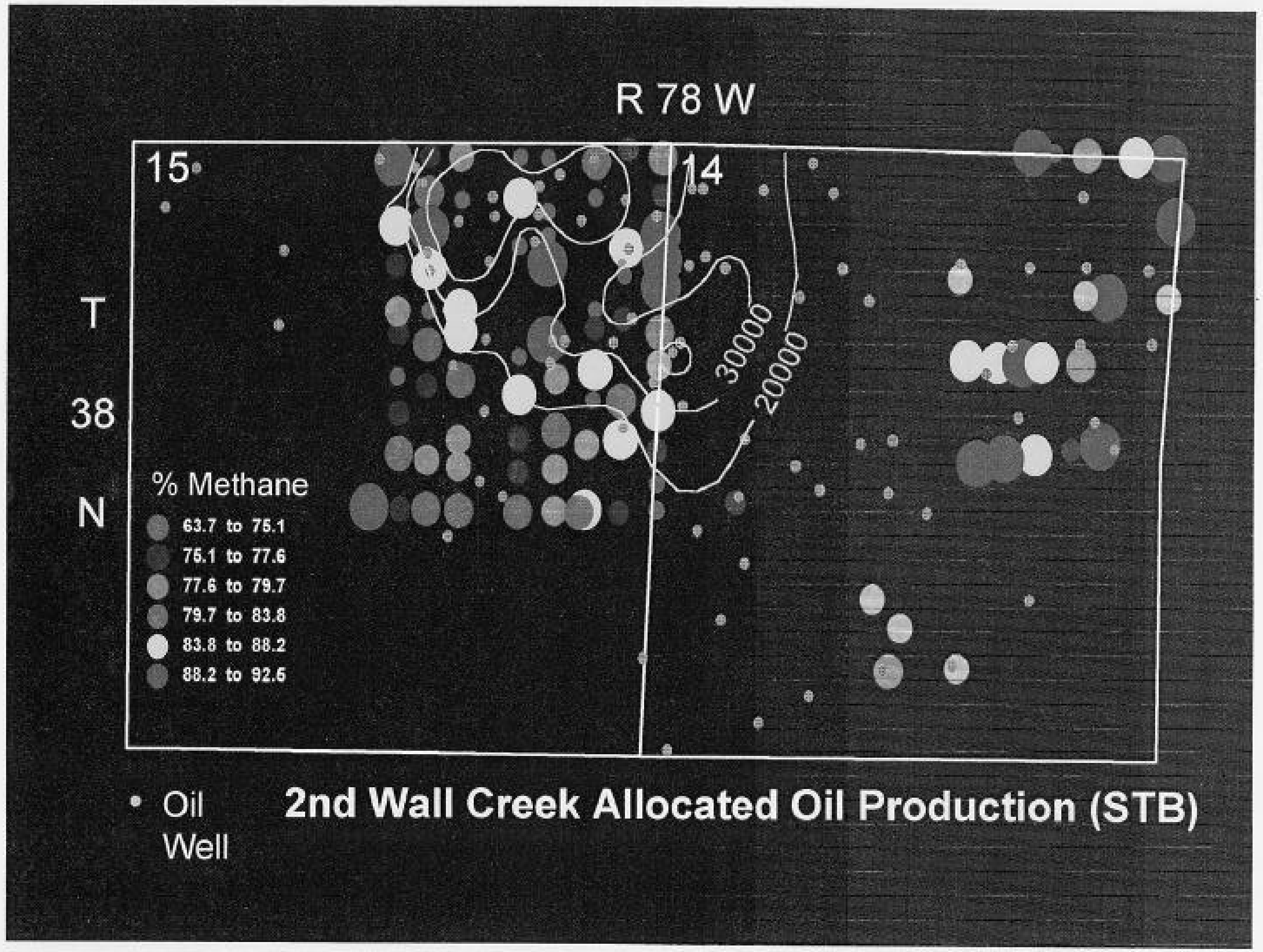


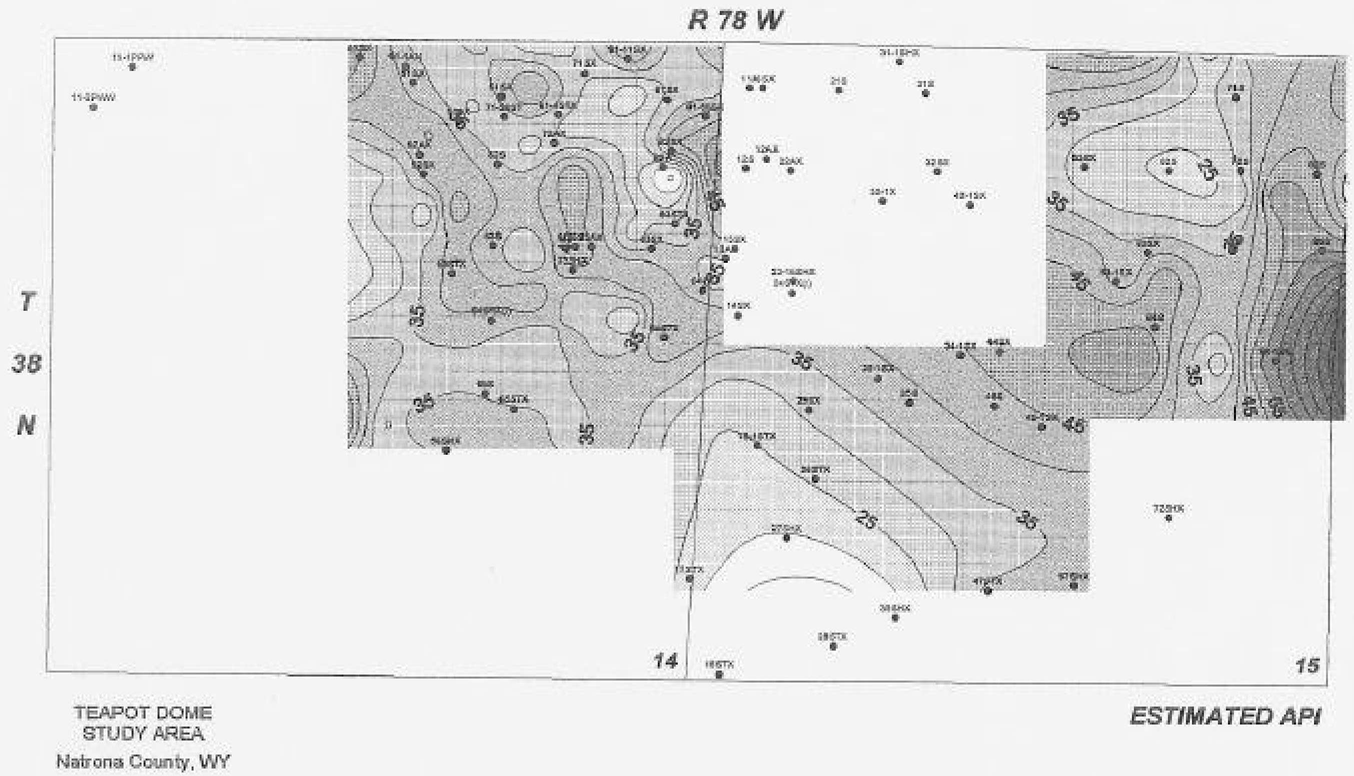
R 78 W
15
14
T
38
N
20000
5000
15000
10000
% Methane
63.7 to 75.1
75.1 to 77.6
77.6 to 79.7
79.7 to 83.8
83.8 to 88.2
88.2 to 92.5
Oil Well
Steele Shale Allocated Oil Production (STB)

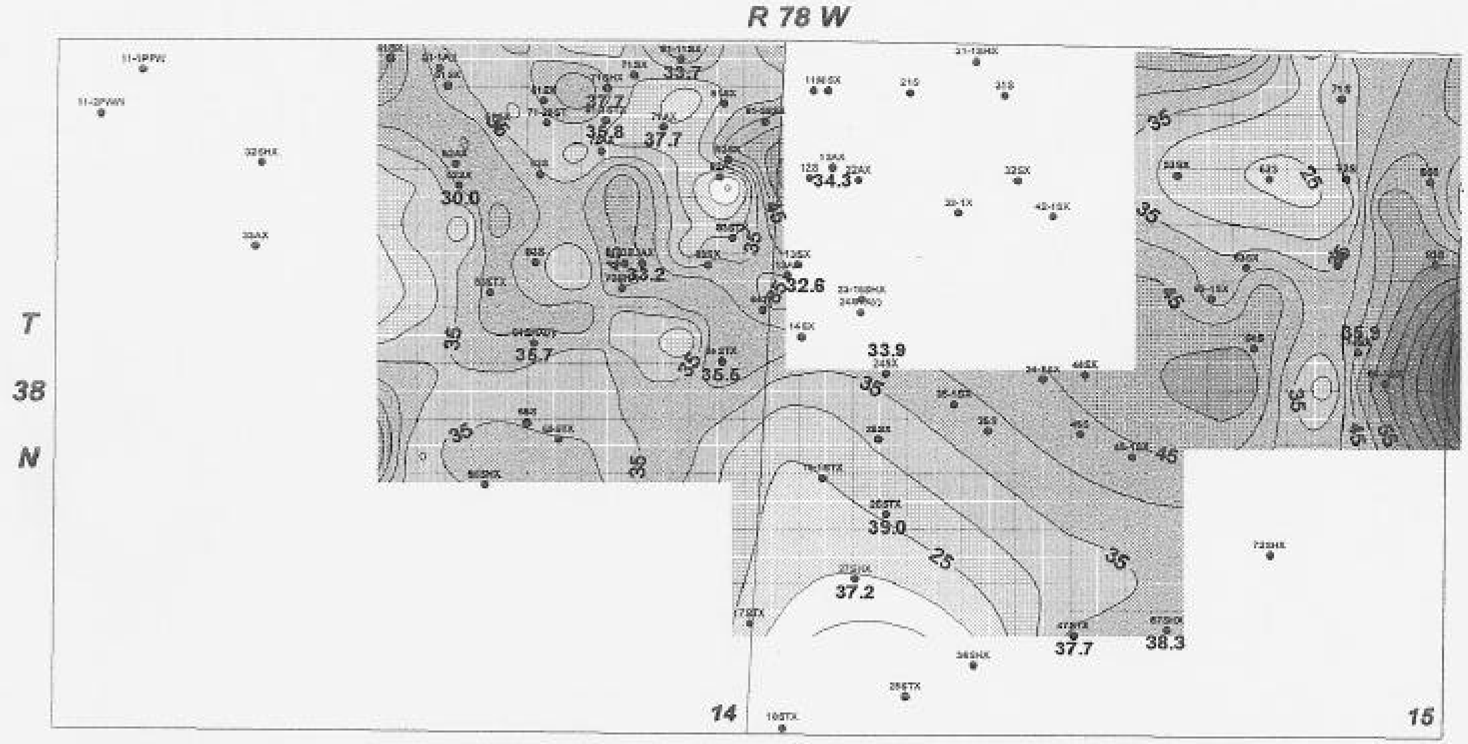

R 78 W
T
38
N
15
14
5000
% Methane
63.7 to 75.1
75.1 to 77.6
77.6 to 79.7
79.7 to 83.8
83.8 to 88.2
88.2 to 92.5
Oil
Well
Steele Shale Allocated Gas Production (MCF)



Niobrara Shale Allocated Gas Production (MCF)

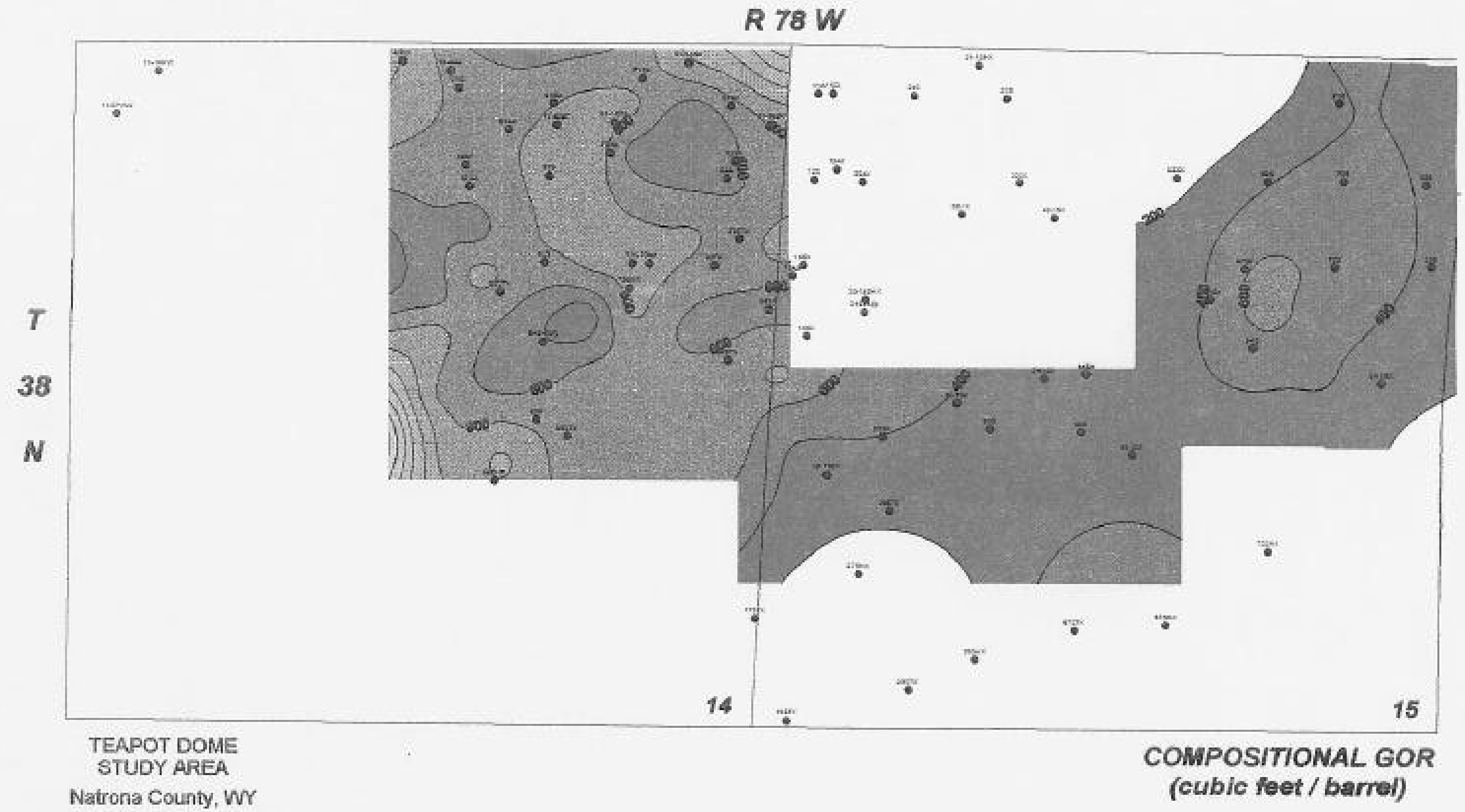

R 78 W
15
14
T
38
N
30000
20000
% Methane
63.7 to 75.1
75.1 to 77.6
77.6 to 79.7
79.7 to 83.8
83.8 to 88.2
88.2 to 92.5
Oil Well
2nd Wall Creek Allocated Oil Production (STB)

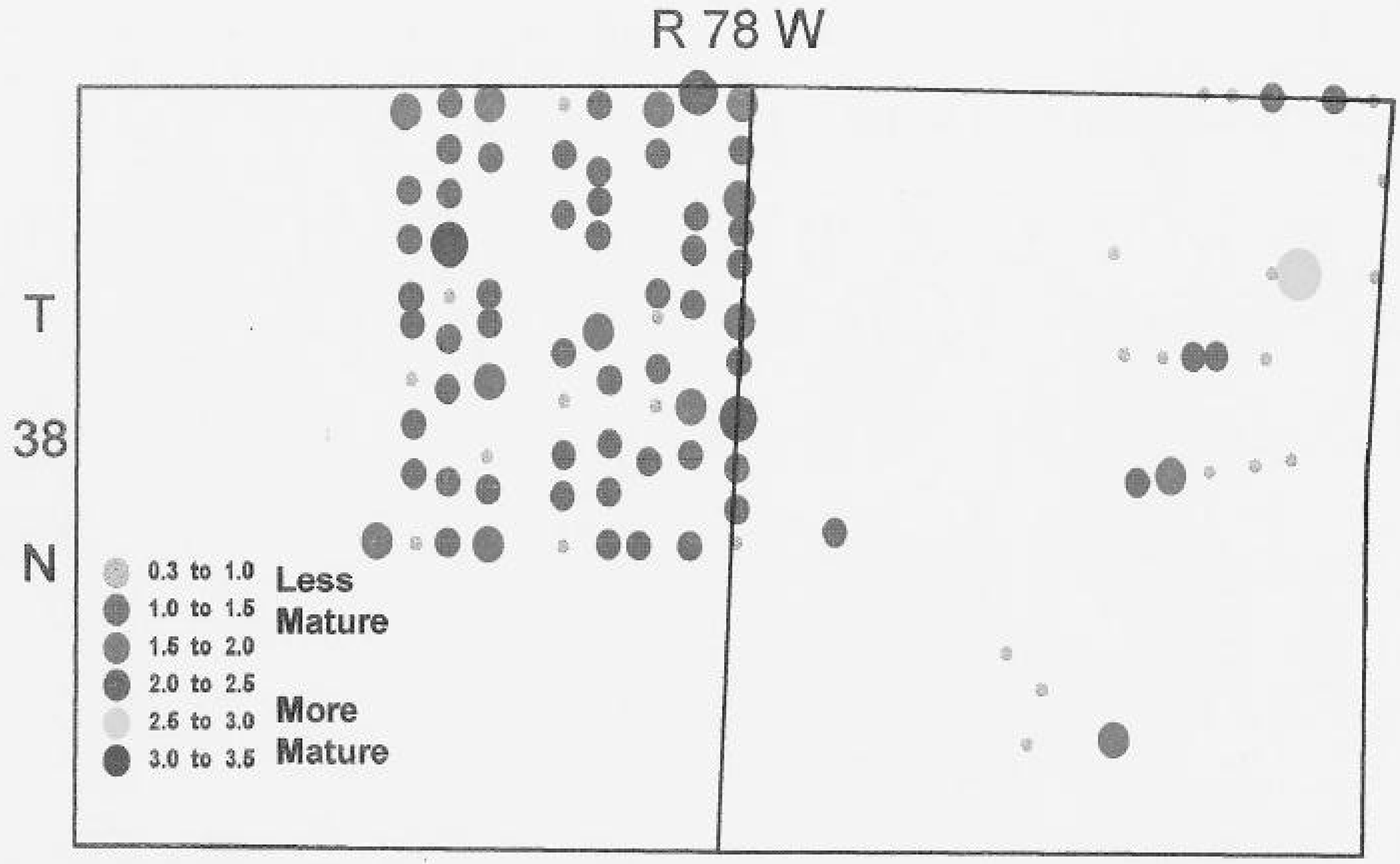

R 78 W
T
38
N
14
15
35
25
45
TEAPOT DOME
STUDY AREA
Natrona County, WY
ESTIMATED API



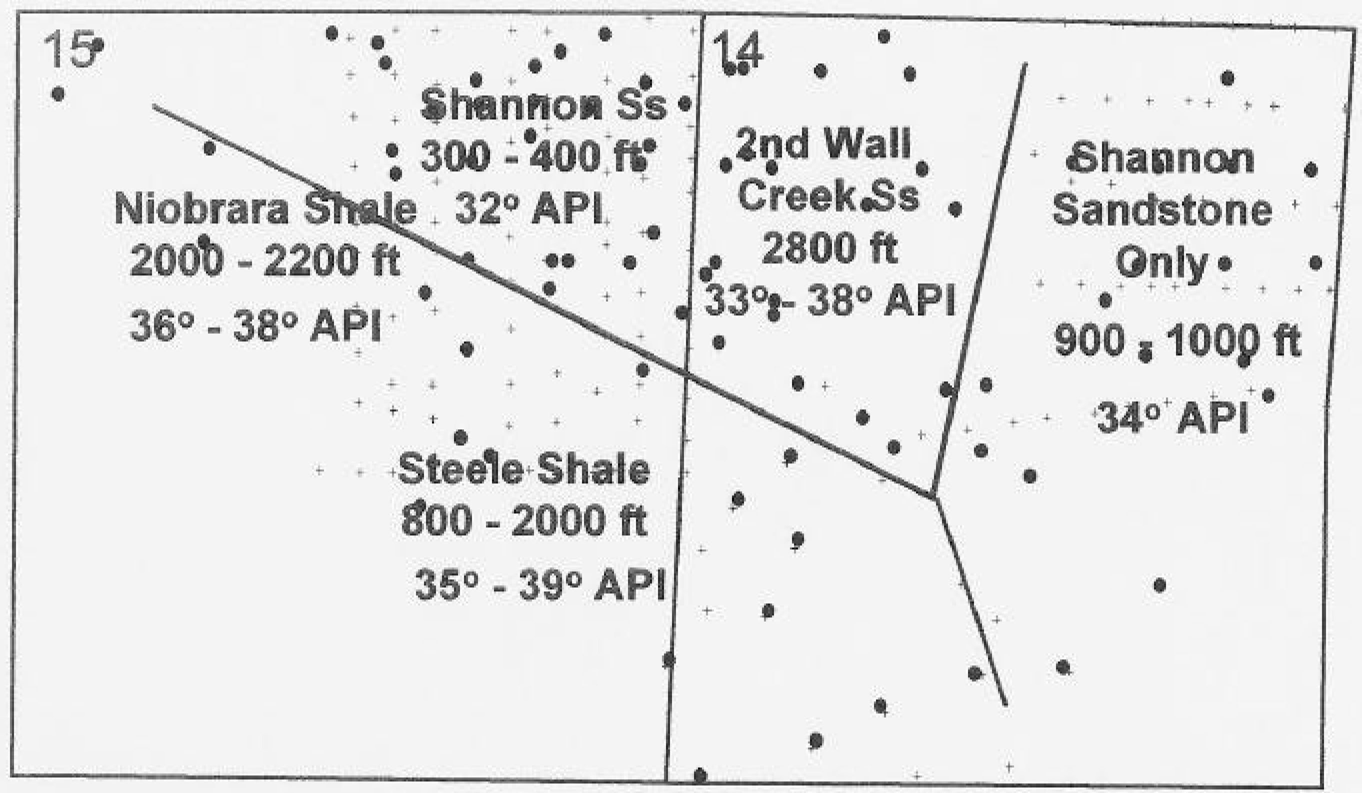
TEAPOT DOME
STUDY AREA
Natrona County, WY

ESTIMATED API
Comparison with known AP


R 78 W
T
38
N
400
600
200
14
15
TEAPOT DOME
STUDY AREA
Natrona County, WY
COMPOSITIONAL GOR
(cubic feet / barrel)

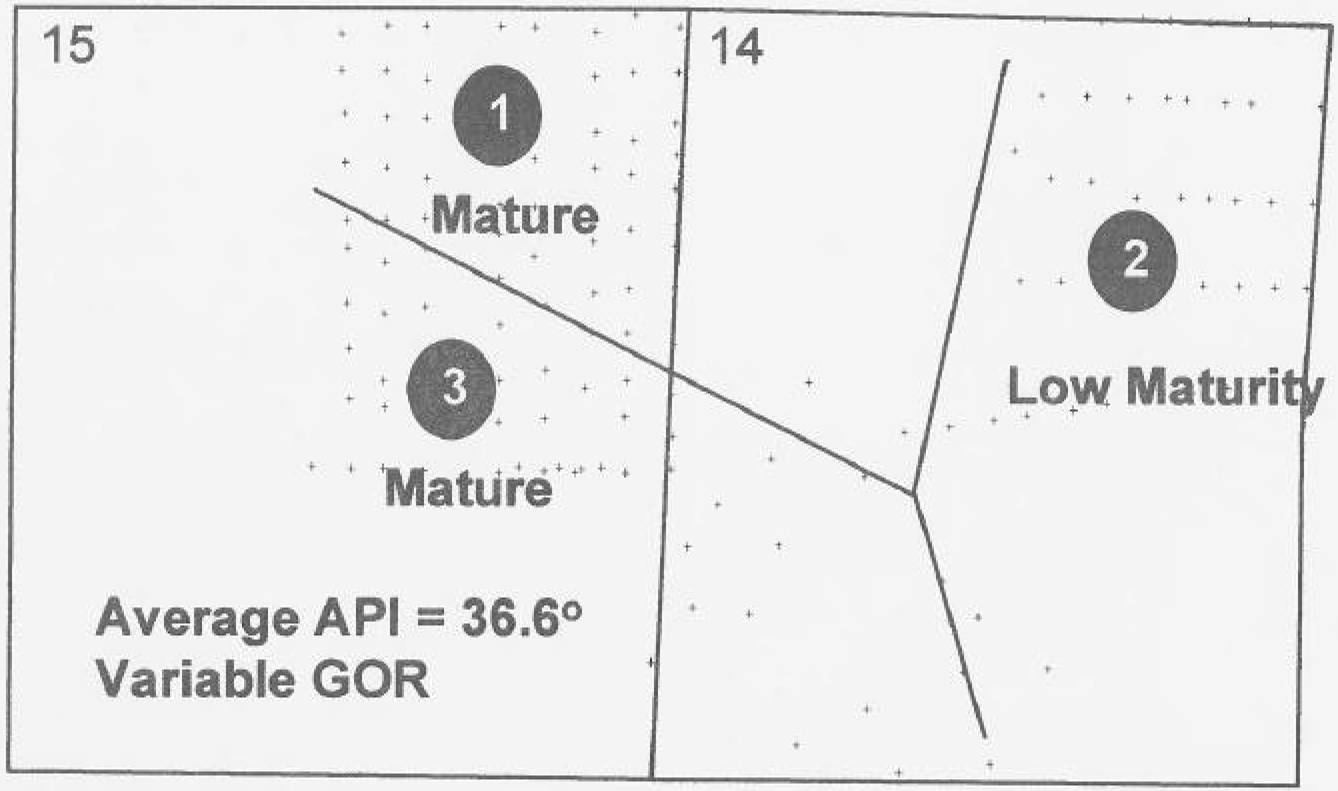

R 78 W
T
38
N
0.3 to 1.0
1.0 to 1.5
1.5 to 2.0
2.0 to 2.5
2.5 to 3.0
3.0 to 3.5
Less
Mature
More
Mature

Maturity



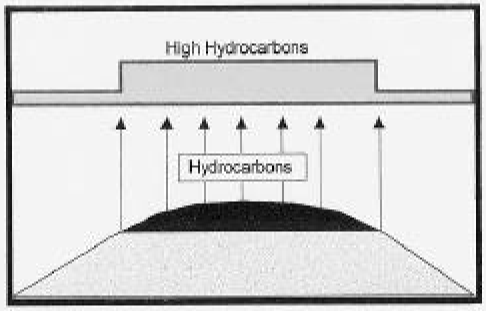
Locations of various reservoirs within the study area.

Actual Reservoir Character

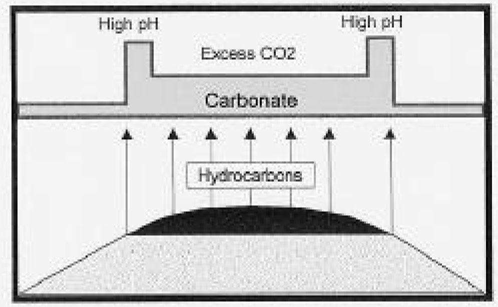


Estimated Reservoir Character

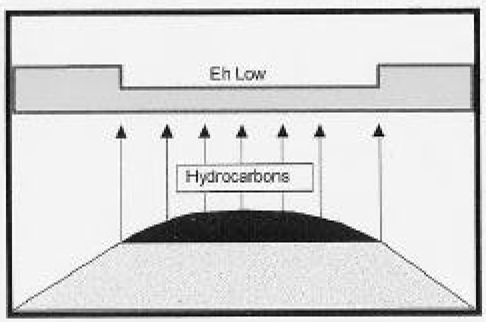
Anomaly Signatures



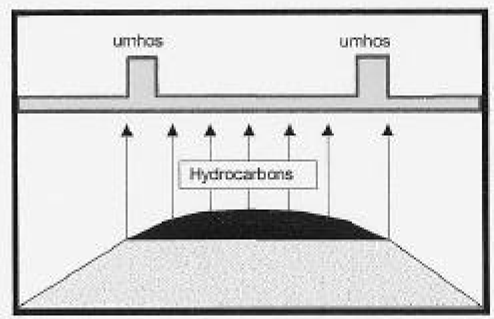
Apical hydrocarbon anomaly. The hydrocarbon highs are coincident with the reservoir at depth.



pH halo. The high pH values occur at the edge of the microseepage anomaly. The precipitation of the calcium carbonate causes a slight pH increase over the microseepage area.



Apical Eh or redox anomaly. Eh values decrease over hydrocarbon microseeps. This is often referred to as the "geochemical chimney". Low Eh values are often associated with moderate to high pH measurements.



Conductivity halo anomaly. Conductivity anomalies are associated with salts or ionic material in near surface soils. The salts accumulate in the higher pH regime at the edge of the microseepage anomalies.

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