KOGER

Remote Sensing Data, Processing, and Analysis

Including Landsat

10 May 2007

Mr. William H. Sydow, Director
Nebraska Oil and Gas Conservation Commission
Post Office Box 399
Sidney, Nebraska 69162

Re: Nebraska Oil and Gas Activity

Dear Mr. Sydow:

We have completed a preliminary photogeological study of the state of Nebraska. The scope of work included gathering imaging satellite data, computer/image processing, image creation and analysis, and photogeologic interpretation. We folded in ancillary data (e.g. geology maps, magnetics, gravity) that you provided.

We searched for the trapping mechanisms associated with the accumulation of hydrocarbons in economic proportions, for instance:

- linears, which include faults, fractures, jointing and the like;
- circular or ovoid features, which could be positive structures at depth, including anticlines, reefs, domes and such; and
- tonal anomalies, which could indicate the presence of hydrocarbon microseepages from reservoirs at depth.

3152 Waits, Fort Worth, Texas 76109-2330 U.S.A. • Voice (817) 921-6825 (RITS)
DKoger@aol.com. • www.davekoger.com

These interpretations are delivered in UTM WGS84 datum at 1:250,000 scale in three forms:

- as overlays over hardcopy images,
- printed onto USGS topographic maps at 1:250,000 scale, and
- in digital form on CD.

Also included is the report, detailing our findings, which follows.

The results of my analysis over your area of interest are presented here. It is anticipated that this work will foment exploration activity in Nebraska by identifying locations that are worthy of closer scrutiny with more expensive techniques, at more aggressive scales.

We appreciate your business.

Cordially,

David G. Koger

Regional Remote Sensing Geomorphic and Exploration Potential Analysis of Nebraska:

An Overview of the State based on Landsat Imagery

Final Project Report
February 2007

INTRODUCTION

This regional remote sensing-based geomorphic analysis was prepared for the Nebraska Oil and Gas Conservation Commission to provide an updated and independent interpretation of the state using spectrally enhanced satellite imagery. Twelve Landsat (Thematic Mapper) image sheets were spectrally enhanced and interpreted at 1:250,000 (1" ≈ 3.95 mi) scale. These, plus portions of the Omaha and Nebraska City sheets (in the extreme southeastern portion of the state) provided complete coverage of the state. A portion of NE Colorado (Sterling sheet) was also studied.

The objectives of the project were to examine the major geomorphic features of Nebraska, provide an overview perspective, and identify possible new exploration targets for further evaluation.

The geomorphic analyses are presented by individual sheets. These sheets are divided into eastern and western sections of the state from 100 degree west longitude. Both sections contain six 1:250,000 map sheets (again, the eastern section contains information from two additional partial sheets). The mapping was not intended to rigorously describe individual geomorphic features, but to provide an overview guide to the features observed in the imagery. This report presents an overview of the geomorphic features of the individual sheets, identifies primary exploration targets, and offers summary recommendations for furthering the evaluation of the targets we've identified.

These data and observations help identify and exploit new exploration leads in a generally well explored petroleum province, and should be used to supplement conventional exploration programs. The land surface is generally low relief and is covered by agricultural fields, sand seas, open ranch lands, alluvium and erosional remnants; none of which works in favor of the ability to use surface mapping to accurately depict geologic structure at depth.

OUR APPROACH

Map individual sheets and integrate results: Regional geomorphic clues and terrain features (Koger 1988; 1993) were used to "see through" the obscuring cover to recognize subsurface geologic structure and potential exploration targets.

In general, Nebraska is dominated by low relief terrain consisting of open range lands, ranches, agricultural fields, stabilized sand seas and dune fields, linear sand ridges and hills, loess deposits, and alluvium. Pleistocene glacial till covers the eastern portion of the state. Maps of existing oil and gas production in the Denver and Salina basins were used to identify unique surface characteristics. These were extended to unexplored areas of the state where similar surface characteristics were seen. These results should be evaluated in combination with conventional subsurface (seismic, well logs, company files) and field verification if possible.

Evaluate regional tectonic setting as a predictor of structural style, related structures, or potential migration fairways. Important geological information was obtained by examining fault and fracture patterns, often displayed for instance as aligned stream segments or linear ridges. These were used to infer the regional tectonic framework (e.g. compressional-extensional-strike slip/wrench settings) and to predict the types of potential traps often found associated with each (e.g. folds/thrusts, horst/graben, en echelon folds, pop up blocks).

"Stack" favorable exploration predictors: Exploration targets were selected on the basis of the coincidence—or "stacking"—of important exploration indicators. This approach is well known to oil and gas explorers and applied specifically to the Denver basin by W. Richard Moore, a Colorado independent geologist (Shirley, 2003). Moore's approach was found useful in this project because much of western Nebraska is underlain by the Denver basin, and available data sets were similar in both areas.

Exploration factors used by Moore in the Denver basin were supplemented by other surface indicators commonly used in the oil industry (Baker, 1998) to evaluate exploration targets by remote sensing methods:

1. **Basement lineaments**: are differentiated from surface lineaments by their subtle, broad, often disconnected but aligned and diffused linear pattern(s). They represent deep seated, throughgoing faults and fractures related to the regional tectonic framework. They have a major influence on structuring (trap formation) and the orientations of migration fairways. They are often indicators of important structural trends and stress field orientation. The locations and depths of these deep seated features can often be refined by comparing recent and historic earthquake activity records. In the Nebraska study, linear boundaries between distinct dune field patterns were interpreted as being related to basement features—possibly due to subtle land surface elevation variations (e.g. tilting or

local subsidence of basement blocks)—or to climate influences affecting the wind's ability to shift and redistribute the sand bodies.

Basement lineaments were also recognized in the regional 1:1,000,000 scale aeromagnetic and gravity surveys of Nebraska (Burchett, 1982 and 1985) by aligned, tightly spaced, or disrupted field gradient contours. Evidence of these features may persist at the surface due to periodic readjustment between basement blocks at depth or differential compaction around isolated basement highs (Donovan, 1974).

2. **Surface lineaments**: these are generally shorter in length, may consist of many short but aligned segments, and are texturally distinct and well defined. Often related to secondary or recent tectonic or epeirogenic movement (e.g. regional arching and crestal extension over the Chadron-Cambridge arch). Commonly displayed as linear stream segments, aligned karst (solution cavities), elongate lakes or topographic depressions; even a series of aligned or elongate tonal or textural anomalies. Regional sand streaks may be ephemeral geomorphic phenomena or they could be related to topographic lows and, therefore, represent valid structural trends. Areas where surface lineaments intersect or fracture density is high may indicate locally enhanced fracture porosity or migration pathways. An important technique is to extend the trends of existing oil and gas production (perhaps as contour maps of highest production rates) into unexplored but geologically similar terrain.

3. **Abrupt lineament bends**: in the Denver basin, Moore successfully used intersections or "corners" of the basement lineaments to predict subsurface structuring (structural noses) or fault offset traps at depth. Intersections or high concentrations of surface lineaments may indicate local deformation. Or, the individual lineaments could result from several episodes of unrelated tectonic events or ongoing tectonic activity.

4. **Drainage anomalies**: streams deflected from normal down-slope flow may reflect the influence of subtle topographic highs representing near surface geologic structure or an isolated erosional remnant.

5. **Tonal anomalies** are nothing new to photogeology (De Blieux, 1951). Often detected and enhanced by image processing techniques, these locations are possibly noticeable due to the presence of hydrocarbons seeping to the surface from buried oil or gas reservoirs. This can be a geochemical change in the soil (e.g. local reducing environment where oxidation normally occurs resulting in a stain or "bleached" zone, where secondary calcification and cementation occur), vegetation stress or enrichment caused by a reduction of water uptake by the plants (oil molecules form a barrier to the plant rootlets which stress the plant), and plant population density variation (Koger, 1988, 1993).

6. **Dark soils and barren areas** (where low reflectance is present in the visible and near IR spectra): Short and Blair (1986) reported that the "interdune" soils in central Nebraska are rich in organic matter and therefore have an increased potential for petroleum generation. Many of the producing oil fields in western Nebraska occur in these dark colored and barren areas, with well pads appearing as patterns of evenly-spaced bright spots. While some of these patterns are similar to oil fields elsewhere in the Midwest, local topographic maps show many wind mills on ranches, particularly in western Nebraska, which present a similar signature. These sites must be verified in the field or by higher resolution satellite data or aerial photography to identify their true purpose.

7. **Aeromagnetic data:** are an indicator of the presence and extent of sedimentary basins; generally shows the presence of high density (mafics, granite) basement rocks and volcanics; used to map general basin depth and configuration. A general indicator of the thickness of sedimentary fill within the basin and the presence of isolated structures and volcanic or plutonic bodies. The original 1:1,000,000 aeromagnetic survey map (Burchett, 1985) that you provided was enlarged to 1:250,000 to overlay the Landsat image sheets.

8. **Gravity data:** are a general indicator of basin size, shape, stratal thickness and depth to basement. The original 1:1,000,000 map (Burchett, 1982), also provided by you, was enlarged to 1:250,000 to overlay the Landsat image sheets.

9. **Topographic maps:** at 1:250,000 scale, provided a general reference and cross check to stream channel location, extent, local topography and place names of geographic boundaries and cultural features.

10. **Geothermal gradient:** these data were not available to this study, but was used by Moore in the Denver basin to locate high concentrations of basement faults (higher heat flow indicates greater fracturing in the basement and greater likelihood of structuring, enhanced fracture porosity and migration fairways). Recommended for future work.

<u>Prediction of Exploration Targets</u>: Much of Nebraska's underlying geology is obscured by the sand dune fields, open rangeland, and agricultural fields with no outcrop expression. In these areas, exploration potential predictions must be based on the subtle surface evidence of subsurface geologic structure (expressed as drainage deviations, tonal anomalies, subtle topographic highs), fault and fracture patterns, and evidence of possible oil seeps. The presence of "open" fractures (migration fairways) coincident with natural seeps and closed structures—especially when coincident with a geophysical (aeromagnetic or gravity) "low"—upgrades the target.

Factors 1-9 listed above (we had no heat flow data) were evaluated for each image sheet. Locations where a significant number of these factors coincided were selected as exploration targets for further evaluation. The level of significance for each of the individual factors varied by sheet. The individual data sets can also be ranked in order of significance (which may vary based on local knowledge of producing oil field characteristics).

RESULTS: GEOMORPHIC ANALYSES

Part (1) WESTERN NEBRASKA:

Denver and Kennedy (Salina) basins: *The southwestern portion of Nebraska is underlain by the Denver basin, a prolific oil producer consisting of an asymmetric Laramide-age structural downwarp whose axis parallels the Front Range. The Nebraskan portion of the Denver basin is bounded on the NE by the Chadron-Cambridge (CC) arch which acts as a structural barrier to the Kennedy (Salina) basin to the northeast. (Anon; USGS 1995).*

The primary producing plays in the province are the Dakota Group (D&J sandstones) and the J (Julesburg) sandstone deep gas play. Primary traps are stratigraphic (facies changes; updip pinchouts) which generally have no surface expression, and a combination of stratigraphic and minor structural traps. Most fields are small.

Much of Nebraska is underlain by westward dipping Tertiary and Cretaceous strata disrupted by the Chadron-Cambridge Arch (west central) and the Nemaha Ridge (eastern Nebraska).

Nebraska is old in the east and young in the west. Along it's eastern edge is sedimentary rock of Pennsylvanian and Permian age…. Pennsylvanian coals are almost absent here…Cretaceous rocks occur mainly in the east but are also exposed in the valleys of the Missouri and Niobrara rivers in the north, the White River in the extreme north west and the Republican river in the south. These are mainly marine rocks laid down in shallow seas.

The majority of the State is of Tertiary age and terrigenous in origin. A few slivers of Oligocene rocks crop out in the west, as do larger areas of Miocene and (mostly) Pliocene strata…. …The Oligocene and Miocene strata are freshwater lake beds ranging from limestone to sandstone, derived from the rising Rockies to the west. They include large volcanic ash beds from eruptions in Idaho and Nevada. The Pliocene rocks are sandy and limy; the sand hills in the west central part of the state derive from these…in eastern Nebraska marks the western limit of the Pleistocene glaciations…in these areas glacial till overlies the bedrock, blue clay, loose gravel and boulders with occasional buried soils…. (Taken from "Bedrock Geologic Map of Nebraska" (Alden, 2004.

<u>Sheet 1: Alliance 43102-A1</u>

Surface Geology: Cretaceous Pierre shale and Niobrara (north); Tertiary Hemingford-Arikaree, White River (north and west); Ogallala (central and southeast). Youngest (Tertiary Ogallala) to the east. Sheet 1 is underlain by the westward dipping northern flank of the Denver basin; this is bordered on the east by the Chadron-Cambridge (CC) arch. Surface lineaments suggest that this feature trends northwest in the subsurface between Rushville and Gordon. Some oil production (fewer than 10,000 bbl/yr) is reported in Sioux County (western third of the sheet). **All crude oil production figures from www.nogcc.ne.gov**

Geomorphic features: Low relief terrain, widespread sand dune fields to the east and southeast. Open range, ranchlands and agriculture; narrow but distinct belts of forest along the major rivers in the north. Widespread agriculture in the central and southwestern portions of the sheet.

Lineament analysis: NW trending lineaments between Rushville and Gordon may be extensional faults along the crest of the WNW trending CC arch. Lineaments are often obscured by sand seas and agriculture; major trends are defined by river channels and textural divides between sand seas.

Primary regional trends are NW, WNW, NE and NNW. Predicted migration pathways (open vs. sealing trends) are oriented NW and WNW based on regional lineaments related to extension and normal faulting over the broad structural axis of the CC arch. Closed (sealing) faults trend NE and NS (response to NE-SW compression axis).

Exploration Targets (numbered in reference to each sheet)**:**

1. Broad topographic high defined by drainage deflections. Short fault segments suggest increased fracturing at depth. Cut by major regional NW fault trends. Coincident with major gravity and aeromagnetic lows indicating thick sedimentary section and deep basin.

2. Subtle topographic high cut by numerous local faults and the regional NW lineament trend. Intersections of faults, abrupt changes in trend: the “elbows” described by Moore. The target occurs at the NE end of a gravity trough. This location is near existing production based on well pads evident in imagery (and windmills are not likely in this area).

3. Very subtle, elongate topographic high cut by numerous surface faults and regional WNW and NW trends. North of a regional gravity low, near the deepest part of the basin. Near existing production based on well pads evident in imagery.

4. Subtle topographic high cut by numerous local faults and the regional NW and NE lineament trends. North of a gravity flexure.

5. Large subtle topographic high defined by drainage. Some minor faulting. Coincident with major aeromagnetic low. Dark tonal anomaly at SE nose. Near existing production based on well pads evident in imagery.

Sheet 2: Scottsbluff 41102-A1

Surface Geology: Northwest quadrant consists primarily of Tertiary Hemingford-Arikaree, White River (north and west); Ogallala (central and southeast). The White River fm continues to the southeast. Cretaceous Fox Hills occurs in the extreme northwestern portion of the sheet. The entire map sheet is underlain by the Denver basin. Major oil production occurs in Kimball, Banner and Cheyenne Counties (extreme southwestern corner of the sheet). Significant production (greater than 10,000 bbl/yr) occurs in Scotts Bluff and Morrill Counties as well.
A major gravity low centers on Kimball, indicating a basinal trough deepening to the southwest.

Geomorphic features: Low relief terrain, extensive sand seas and dune fields to the northeast; ranchlands and agriculture. Three distinctive types of agriculture (center pivot irrigation, large continuous fields, smaller fields interspersed with open ranges) are seen. The entire sheet is dominated by agriculture except for the northeastern quadrant which contains sand seas and a cluster of lakes (filling depressions in the sand seas; possibly a basement depression). The major lake McConaughy is visible on the North Platte River in the southeastern portion of the map sheet. Plains, ranchlands and some agriculture to the west and north.

Lineament analysis: Primary zones trend WNW and NW. Shorter NS and occasional NE and NNE segments. Consistent with regional trends mapped throughout western and central Nebraska.

Exploration Targets (numbered in reference to each sheet)**:**

1. Subtle topographic high, elongate east-west, bounded by minor drainage deflections. The target is cut by the regional WNW lineament trend. Major shifts in fault trends (Moore’s “bends” or “elbows”) and high density local fracturing occur near the center of the feature. The target sits northeast of a major gravity low and is nearly coincident with a major magnetic low. Centered on “bright” signature; possible tonal anomaly, but likely surface sand or fallow field.

2. Subtle topographic high, elongate east-west. Highlighted by minor drainage deflection. Cut by major NW and minor NE regional lineament trends. Major shifts in fault trends and high density local fracturing. Occurs within ENE trending gravity trough; sits on minor magnetic ridge. Target 2a sits to the NE of

Target 2, within a local magnetic low. 2a is downgraded because it occurs in a thinner part of the basin.

3. This subtle target occurs on the east trending nose of a major topographic feature which deflects the course of Lodgepole Creek and on the flank of a regional gravity trough.
   The feature is cut by regional WNW and local ENE lineament trends, and east of major producing oil fields south of Kimball (spelled “Kimbol” on topographic map). Dark soils appear similar to those observed in other producing oil fields in the Denver basin.

4. Subtle topographic high, elongate east-west; highlighted by minor drainage deflection. Cut by major NW and minor NE regional lineament trends. West of gravity low; north of magnetic high (downgrading feature).

5. Subtle topographic high trending ENE. Cut by major NW and WNW regional lineament trends. Near minor local magnetic trough. Minor intersection of lineaments.

6. Subtle topographic high, elongate east-west, highlighted by minor drainage. Cut by major WNW and ENE regional lineament trends. Near deeper basin (gravity trough). Possible light tonal anomaly at crest of feature.

6. Composite southeast plunging subtle topographic highs; cut by WNW regional lineament trend and less distinct NE trend. Abrupt lineament bends. Occurs in major gravity low northeast of Kimball.

Sheet 3: Sterling (NE Colorado) 40102-A1

Surface Geology and setting: Major oil producing region. Entire sheet underlain by the Denver basin. Most production is from the Cretaceous D and J sandstones at 5000-5500 feet (Shirley, 2003). Fields are relatively small stratigraphic traps. Average field is ten wells; each well makes an average of 100,000 bbls of oil. In this area…“fracture zones control the location of stratigraphic and structural traps” (ibid). Strata dip gently to the southwest into the axis of the basin. The surface consists of Recent and Pleistocene Aeolian deposits and dunes fields, Tertiary Ogallala, Arikaree and some Cretaceous Pierre shale exposed in the gullies.

Geomorphic features: Located within the Colorado Piedmont and bordered by the High Plains escarpment (AAPG Highway map #2; 1990). Generally low relief; stabilized sand dune fields; agriculture and ranchlands; local areas of karst topography suggest vuggy carbonates and good reservoir potential. Rounded, featureless (stabilized dunes or erosional remnants) mounds. Areas marked “(oil fields)” are taken from the 1:250,000 topographic maps. Areas marked “oil wells” and “oil fields” (without parentheses) are features observed in the imagery.

Lineament analysis: Major regional trend NW and NNW. Lineaments are shorter and less continuous than in the sheets to the north. Minor NS segments. No apparent correlation between high density lineaments and mapped oil fields.

Exploration Targets (numbered in reference to each sheet; lettered when they are in the Colorado portion of the study…target numbers 3, 4 and 5 are also described in the Scotts Bluff sheet adjacent to the north)**:**

1. (A) Subtle topographic high, defined by minor drainage, elongate SSE. Located northwest of Fort Morgan and north of major producing fields. Cut by NNW trending lineaments. Abrupt lineament bends, high density local fracturing.

2. (B) Major NE trending, subtle topographic high; sandy, highly reflective surface; high density lineament intersections, others may be obscured by sand cover. Cut by major NNE lineament trend. Near existing oil production. Within area of dark (high organic soils?)

3. (C) Major NNE trending subtle topographic high; near existing production, possible tonal anomaly. Within area of dark (high organic soils?). Cut by major WNW lineament trend. Bordered on the northwest by a regional NE lineament trend, which controls the channel of the South Platte River.

4. (D) Subtle topographic high, defined by minor drainage, elongate NNW, cut by major NNW lineament trend and minor NS trends. High density lineament intersections. This target is in Nebraska. Located on the flank of a NE trending gravity trough and east of major magnetic trough (see accompanying McCook sheet gravity and aeromagnetics maps).

7. (E) Major, nearly circular subtle topographic high, defined by minor drainage deflections, cut by NW and NNW regional and EW lineament trends. Abrupt changes in trends, high density lineaments, numerous intersections. Possible minor tonal anomaly.

<u>Sheet 4: Valentine 42100-A1</u>

Surface Geology: Tertiary Ogallala covers the entire sheet; minor outcrops of Tertiary Hemingford-Arikaree occur along the Niobrara River channels in the north. The SW corner is underlain by the Denver basin; this structural downwarp is separated from the Kennedy (Salina) basin by the NW trending Chadron-Cambridge (CC) arch. No evidence of geologic structure (bedding, dipping strata, intrusives) or surface indicators of structures at depth.

Geomorphic features: Generally low relief; river incised erosional scarps; stabilized sand dune fields; agriculture and ranchlands; local areas of karst topography over soluble carbonates and rounded, featureless mounds and erosional remnants. Periodically spaced and isolated "bright" points have the appearance of well pads but are likely windmill sites. Concentrations of alkali lakes south of Valentine occupy a regional topographic depression (this depression coincides with a major gravity low, and occurs NW of a major aeromagnetic saddle, suggesting basinal subsidence and possibly a thicker sedimentary section in this area).

Lineament analysis: Primary trends NW in the western region, to NNW central, to WNW in the east. The disruption in regional trend may be due to the influence of the CC arch at depth. Shorter NS and occasional NE and NNE segments. Shorter NS segments occur primarily in the west central portion of the sheet near exploration target #2.

Exploration Targets (numbered in reference to each sheet)**:**

1. Subtle topographic high, defined by minor drainage, elongate EW. Cut by minor segments of WNW and NW regional lineament trends. Minor NE and EW fault segments. Possible minor tonal anomaly, fault bends, high density fault intersections. Target occurs east of major aeromagnetic low.

2. Major subtle topographic high defined by drainage deviations to north and south. Cut by regional NW and NE lineament trends. Central dark tonal anomaly; lineament bends and high density intersections in the northern portion. Coincident with major aeromagnetic low.

3. Subtle, compact topographic high, cut by regional NW and NE lineament trends. High density lineaments in center of the feature. Coincident with local aeromagnetic high (downgrading factor).

4. Composite NW trending topographic high bounded by NW lineaments. Drainage deviation defines the NW end of the feature.

5. Major NNW trending topographic high. Cut by NNW, NS and NW regional lineament trends. High lineament density in southern part of the feature. Subtle surface expression through stabilized dune field. Coincides with aeromagnetic low. Marked as target "5V" in North Platte sheet, below.

Sheet 5: North Platte 41100-A1

Surface Geology: Tertiary Ogallala covers the entire sheet; minor outcrops of Tertiary Hemingford-Arikaree occur along the North Platte River. The SW and western portions of the sheet are underlain by the Denver basin; the broad NW trending Chadron-

Cambridge arch is present in the east. The extreme western flank of the Salina basin may occur near the eastern edge of the sheet. No evidence of geologic structure (bedding, dipping strata, intrusives) or surface indicators of structures at depth.

Geomorphic features: Generally low relief; river incised erosional scarps; stabilized sand dune fields; agriculture and ranchlands; local areas of karst topography over soluble carbonates and rounded, featureless mounds and erosional remnants. Periodically spaced and isolated "bright" points occur in the central and eastern portions of the map sheet. These have the appearance of well pads but are likely windmill sites. A local concentration of lakes SW of Mullen may occupy a local topographic depression.

Lineament analysis: Major lineaments trend NW and WNW, similar to the regional trends described in adjacent map sheets. The major NW trend is well expressed in the vicinity of Tryon and may be related to extension and arching over the axis of the Chadron-Cambridge arch. Local NE lineaments occur NE of North Platte.

Exploration Targets (numbered in reference to each sheet…target marked "5V" on the overlay map is described in the Valentine sheet)**:**

1. Subtle NNE trending topographic high, defined by minor drainage in the south and cut by NW and NS regional lineament trends. Subtle tonal anomaly; high density lineaments and abrupt changes in lineament trends. The feature sits just south of an EW trending aeromagnetic low.

2. Very subtle NS trending topographic high, defined by drainage deviations to the west and north; cut by the regional NW lineament trend, shorter EW and NNE segments. High density of lineament intersections, fault bends and abrupt changes in trend. Near subtle NW trending aeromagnetic ridge and SW of major gravity low.

3. Subtle topographic high, poorly defined, drainage deviation defines western boundary; minimal lineaments evident. Coincident with major aeromagnetic low. On eastern flank (Salina basin side) of the CC arch.

4. Compact topographic high bounded by NW trending lineament sets. Some deflection of drainage to the north. On SW flank (Denver basin side) of the CC arch.

5. Small composite topographic high, bounded by WNW and EW faults. Minor NE trending faults. East of major gravity low, sits at the SE end of a NW trending magnetic ridge.

Sheet 6: McCook 40100-A1

Surface Geology: Surface cover obscures Tertiary Ogallala; Cretaceous Pierre shale (western) and Niobrara (eastern) formations which are infrequently exposed in major river channels. The western third of the sheet is underlain by the Denver basin. South central counties (those closest to the deeper Denver basin) have significant crude oil production (highest production in Hitchcock, Dundy and Red Willow Counties).

Geomorphic features: Generally low relief; river incised erosional scarps; stabilized sand dune fields; agriculture and ranchlands; local areas of karst topography over soluble carbonates and rounded, featureless mounds and erosional remnants. Periodically spaced and isolated "bright" points occur in the western and southern portions of the map sheet.

Lineament analysis: primary trends NW and NNW; minor NE trends occur in the central sheet, NE of Imperial. Similar to regional trends described in adjacent map sheets.

Exploration Targets (numbered in reference to each sheet**…**target "D" is described in the Sterling sheet)**:**

1. Subtle SSE trending topographic anomaly; bounded on the west by drainage deflections; cut by NW and NNW lineament trends. Lies between two major regional NW lineaments. Subtle tonal anomaly at northern end.

2. NW trending topographic high, completely encompassed by drainage deflections. Cut by NW and WNW regional lineament trends. East of major aeromagnetic low; high density lineament intersections.

3. Subtle dark tonal anomaly; near existing production; cut by NW and NNW regional trends. Lies between two major regional NW lineaments. North of major aeromagnetic low; in deeper Denver basin as shown by gravity map.

4. Subtle, near circular topographic high; bright tonal anomaly; cut by NW trending regional lineaments. High density lineament intersections in the northern part of the feature. SE of gravity low.

5. Composite topographic highs separated by NNW and NW trending lineaments. Few lineament intersections. NW of aeromagnetic high (downgrading feature).

6. Subtle, nearly circular topographic highs near current production and in the relatively deepest part of the Denver basin (in the McCook sheet). Just north of a major aeromagnetic low. NW regional trend and local NE trend. Few intersections, minor tonal anomaly.

Part (2) EASTERN NEBRASKA:

The eastern map sheets, numbered 7-12, cover portions of the Salina (including the Kennedy) and Forest City Basins. They make up a large portion of the Western Interior basin. The NW-SE trending Salina Basin is similar to the Forest City basin of northeastern Kansas and contains Paleozoic strata in—based on thermal maturity models—the early stages of oil generation (Newell & Hatch, 2000). In southeastern Nebraska, the Mid Continent Rift and Nemaha Ridge influence the surface geomorphology and the distribution of exploration targets. Tedesco, (2003) describes the potential for coal bed methane resources in the Forest City (Western Interior basin) and the fault and fracture patterns mapped in southeastern Nebraska could support exploration for this resource.

Rocks become progressively older to the east. While the surface is largely obscured, the underlying lithologies range from widespread Tertiary Ogallala to the Cretaceous Niobrara and finally through the Jurassic, Permian and upper Carboniferous sections to the east. The extreme eastern part of the State is covered by Pleistocene glacial till and unconsolidated Recent and Pleistocene sediments. The surface is rolling to flat and featureless. In many cases, stream channels have been “canalized,” their courses artificially “straightened;” altered so that they provide only a general indicator of the regional drainage regime.

Sheet 7: O’Neill 42098-A1

Surface Geology: Surface lithologies are poorly exposed and consist of the Tertiary Ogallala, with some Hemingford-Arikaree and Pierre shale exposed in the Niobrara and Missouri river channels. Strata are nearly flat lying with regional gentle undulations (dip reversals).

Geomorphic features: The majority of the surface is covered by agriculture, open rangeland, and a remnant of the pervasive sand seas more common to the west. Irregular lakes and some karst topography occupy geomorphic depressions. Occasionally, these are aligned and indicate the trace of a regional lineament trend. River and stream channels appear to be structurally controlled by similar regional lineament trends. Topographic anomalies are likely not related to subsurface structure; those associated with active faults may be structural and evident due to reactivation along the bounding faults.

Lineament analysis: Primary trends are WNW to NW with secondary trends NNW, NS and NE, with a major ENE deflection in the Niobrara River. Fracture density appears to be highest in the central and south central portion of the image. Similar trends may be more pervasive but are obscured by the agriculture in the east and the sand seas in the west.

Exploration Targets (numbered in reference to each sheet)**:**

1. Subtle topographic high trending NE. Defined by drainage deviations, cut by short NE and NNW lineament segments.

2. Composite small ovoid topographic anomalies cut by NNW and NE lineament segments. The feature continues to the SE but is more subtly exposed.

3. EW trending composite and near circular topographic anomaly cut by NE and NNW lineament segments. Multiple fracture intersections, abrupt changes in lineament trends and a possible tonal anomaly at the crest of the main feature. Several topographic highs continue to the SE. Appears to be on regional WNW lineament trend. Major magnetic low occurs to the east.

4. NNE trending subtle ovoid topographic anomaly cut by NW lineaments, short NS and NNE segments. Associated with major magnetic low.

5. Compact, NNW trending topographic anomaly, cut by NW and NNW lineament trends. Eastern boundary defined by drainage. A similar feature occurs to the SSE, but it has few lineaments associated with it.

6. NS trending circular to ovoid topographic high, cut by NNW regional lineament trend; shorter WNW, NW and EW trends. Major fracture intersections, abrupt changes in lineament trends.

Sheet 8: Broken Bow 41098-A1:

Surface Geology: Surface covered by Tertiary Ogallala. Geology obscured by sand hills, range land and agriculture.

Geomorphic features: Sand hills to north and west; agriculture elsewhere. Major rivers deviate around subtle structural highs (i.e. North and Middle Loup Rivers). Subtle topographic highs not related to major drainage deviations are likely erosional remnants and are not indicative of subsurface structures.

Lineament analysis: Major NW and NNW trends continue from adjacent map sheets. In the central image (near Burwell and south) regional lineament trends shift abruptly from WNW to NW. This shift is reflected in the 1:250,000 aeromagnetic survey where (SE of Ord and Loup City) local aeromagnetic highs and relatively steep field gradients are evident. This transition may mark a basinal boundary or basement structural high.

Exploration Targets (numbered in reference to each sheet)**:**

1. NNW trending subtle topographic high; cut by short lineament sections of varying orientations: NW, NNW, NNE and NS. Abrupt changes in lineament orientation; possible high fracture density. Feature is defined by drainage deviations and minor tonal anomaly.

2. NNW trending subtle topographic high; few lineaments, north of possible left lateral fault segment. This region has a series of left stepping strike slip faults offsetting the course of the South Loup River SW of Broken Bow. No evidence of wrenching in geophysical data.

3. Large NW trending topographic high, semi-circular to ovoid, cut by the major NW regional lineament trend. This feature coincides with a large aeromagnetic low.

4. Minor topographic high trending NNW; cut by regional NW and ENE trends. Possible tonal anomaly at center of feature.

Sheet 9: Grand Island 40098-A1:

Surface Geology: Tertiary Ogallala covers the western two thirds of the region. Strata become older to the SE: Cretaceous Pierre, and Niobrara reportedly occur in the river channels and SE of the rivers; however, the surface is nearly completely obscured by agriculture. The NE two thirds of the sheet is underlain by the Salina basin.

Geomorphic features: Remnant sand hills to the extreme NW; the entire sheet is covered by agriculture, major river channels and isolated lakes. Subtle topographic highs not related to major drainage deviations are likely erosional remnants and are not indicative of subsurface structures.

Lineament analysis: Major trends are NW and NNW. ENE and EW trends occur generally east of Hastings. A major drainage reversal occurs in the Platte River (trend shifts from WNW to ENE), and this is likely related to basement structuring—regional lineaments or a basement high. Similarly, a major arcuate deviation in the Republican River west of Harlan County Lake may also be basement controlled. The available aeromagnetic and gravity maps did not support this.

Exploration Targets (numbered in reference to each sheet)**:**

1. Subtle EW trending topographic high, defined on the NW by an elongate lake; cut by minor NW lineament trend. Lineaments poorly defined. No other remarkable features.

2. Subtle composite NNW trending topographic high; bounded by NW lineament trends. Possible tonal anomaly, high density fracturing; sharp lineament bends. East of aeromagnetic low.

3. Nearly NS trending topographic anomaly, ovoid, cut by NW lineament trend, minor NE trends. No other remarkable features.

4. Composite subtle topographic anomaly cut by NNW and NS lineament trends. Northern half defined by stream channel deviation. Minor NE trends.

Sheet 10: Sioux City 42096-A1:

Surface Geology: The SW third of the sheet is underlain by the Salina basin. Tertiary Ogallala covers the western half of the sheet; strata become older to the east: Cretaceous Pierre, Niobrara and Carlile and some Dakota near the Missouri River. Pierre shale has been reported in the river channels but could not be specifically identified in the Landsat imagery.

Geomorphic features: The surface is nearly completely obscured by agriculture, making the identification of subsurface features tenuous. Major river channels display unusual changes in course, which suggests basement control. Darker tones near the Missouri River could be the reported outcropping of Pierre shale; this must be verified in the field. Subtle topographic highs not related to major drainage deviations are likely erosional remnants and are not indicative of subsurface structures.

Lineament analysis: Major trends are NW and NNW. NE trends occur in easternmost Nebraska. NNE trends and NE become more common and significant east of the Missouri River in Iowa, suggesting a basement discontinuity defined by the channel of the Missouri River.

Exploration Targets (numbered in reference to each sheet …targets 1 and 2 from the O'Neill Sheet are shown circled in the western portion of the Sioux City sheet)**:**

1. NNE trending subtle topographic high; WSW of Tilden, cut by WNW and NW, NNE to NS regional lineament trends. NE of aeromagnetic low trough. Some minor changes in lineament trend. No other remarkable features.

2. Very subtle, large topographic high, trends NE, cut by numerous NE and NW trending lineaments. High concentration of lineament intersections, abrupt changes in trends. This feature coincides with a minor aeromagnetic low trough of similar NE trend.

3. NW trending subtle topographic high, cut by NW and minor NE trends. No other remarkable features.

Sheet 11: Fremont 41096-A1

Surface Geology: The western two thirds of the sheet is underlain by the Salina Basin. The southeastern region is underlain by the Midcontinent rift, which appears to be reflected in the short but pervasive NNE to NS lineaments found in this area. Eastern Tertiary Ogallala covers the extreme NW portion of the sheet; strata become older to the east: Cretaceous Pierre, Niobrara and Carlile with Dakota through Permian and Pennsylvanian strata found in the central to eastern regions. Pennsylvanian strata are reportedly exposed near the Missouri River. Some Pierre shale occurs in the river channels to the extreme west. The NE trending Midcontinent rift is clearly displayed in the geophysical data—an elongate aeromagnetic high and a less continuous gravity high likely results from high density basaltic flows that filled the rift post extension (Kansas Geol. Survey, Info Circ 3, 1989).

Geomorphic features: The entire sheet is covered by agriculture, loess deposits, Pleistocene glacial till and major river channels. Abrupt and major changes in these river channels indicate structural control at depth. Darker tones near the Missouri River could be the near surface occurrence of Pennsylvanian strata; this must be verified in the field. The right lateral sense of movement along the Platte River fault described in the literature (Tedesco, 2003) could not be confirmed in the imagery, although, should wrenching be proven, additional oil and gas trapping possibilities could occur in this region. Subtle topographic highs not related to major drainage deviations are likely erosional remnants and are not indicative of subsurface structures.

Lineament analysis: Major lineament trends occur in two regimes: NW and WNW trends dominate in the west; NE, NNE and NS trends dominate east of Wahoo. NE trends occur in easternmost Nebraska, likely related to the Midcontinent rift, and made visible by reactivation along rift margin normal faults. The NE and NNE trends are significant east of the Missouri River in Iowa, also related to the rift. Major course changes in the Missouri River suggest the additional influence of basement structuring.

Exploration Targets (numbered in reference to each sheet)**:**

1. Subtle NNW trending topographic anomaly, ovoid, cut by NW and WNW trending lineaments. Acts as drainage divide. Near local aeromagnetic low. No other remarkable features.

2. Extremely subtle NW trending topographic anomaly; ovoid, cut by NNE and NW lineament trends. Possible subtle tonal anomaly.

3. Near circular topographic high, subtle, cut by minor NW trending lineaments. The feature occurs NW of local aeromagnetic and minor gravity lows.

4. Topographic high, ovoid, possibly an erosional feature. Sandy surface, cut by NE and minor NW trending lineaments.

Sheet 12: Lincoln 40096-A1:

Surface Geology: The western half of the sheet is underlain by the Salina basin. The southeastern region is underlain by the Midcontinent rift and the northern extension of the Nemaha Ridge, which may be reflected in the short but pervasive NE, NNE to NS lineaments found in this area. Tertiary Ogallala is absent; sedimentary section became older to the east: Cretaceous Niobrara and Carlile; Greenhorn-Graneros with Dakota through Permian and Pennsylvanian strata found in the central to eastern sheet. Pennsylvanian and Permian strata are reportedly exposed near the Missouri River. The surface is nearly completely obscured by agriculture, loess and glacial till.

Geomorphic features: The entire sheet is covered by agriculture and major river channels. Abrupt and major changes in the river channels indicate structural control at depth. Darker tones near the Missouri River could be the near exposure of Permian and Pennsylvanian strata; this must be verified in the field. Subtle topographic highs not related to major drainage deviations are likely erosional remnants (not indicative of subsurface structures).

Lineament analysis: Major trends are NW and WNW in the west; NE, NNE and NS east of Lincoln. NE trends occur in easternmost Nebraska, and these and NNE trends become more evident and significant east of the Missouri River in Iowa (north) and Missouri (south) suggesting a basement discontinuity defined by the Missouri River.

Exploration Targets (numbered in reference to each sheet …targets 1, 2, 3 and 5 align parallel to the major NE structural trend observed in the aeromagnetic and gravity data…south of a regional NE trending elongate gravity ridge)**:**

1. Subtle composite WNW and NS trending topographic anomalies, ovoid, fault bounded and cut by ENE and WNW trending lineaments. Abrupt changes in lineament trends.

2. Very subtle, NS trending topographic anomaly, cut by NS and NNW trending lineaments. No other remarkable features.

3. Very subtle, NE trending topographic anomaly; defined by drainage deflection on the western and southern sides. Occurs just south of an aeromagnetic high (downgrading factor).

4. Subtle, NNE trending topographic anomaly; defined by drainage deflections to west and north. Cut by minor NNE, NS and NW lineaments. High density lineament intersections.

5. Partial NNE trending topographic anomaly cut by major NNE and minor NW and NNW lineament trends. Occurs just south of the Midcontinent rift aeromagnetic high; near an aeromagnetic trough defining the southern border of this feature.

SUMMARY and CONCLUSIONS

1. The exploration targets identified in this project are based on the combination of topographic and textural clues interpreted to represent important geological information extended into the subsurface. Company private subsurface data could help define the structural nature of the "topographic" anomalies described—e.g. erosional remnants, local uplifted blocks, drape folds over horst blocks, en echelon anticlines associated with fault movement. Long linear stream segments are probably structurally controlled. Fault offsets which might suggest strike slip models would probably show up at higher resolution satellite imagery or aerial photos (~ 1-5 meters spatial resolution).

2. Exploration prospects should occur where the mapped topographic highs coincide with regional NW, NNE and NS lineament trends; also where lineament density is highest, and where the locally proven reservoir beds are thickest. Reactivated Precambrian trends and those related to the Nemaha Ridge and Midcontinent rift—generally NW, NE and NS—may produce open fractures as extensional faulting (in eastern Nebraska) and along the NNW trending Chadron-Cambridge regional arch (in western Nebraska). Unusual drainage deviations or "dips" already observed in the exploration blocks might provide useful guides to additional traps in adjacent regions. Some of these trends are artificially "canalized" such that they represent only a general indication of the natural regional drainage pattern.

3. Oil seeping from reservoirs along open fracture systems could generate geochemical spectral anomalies detected by image analysis of satellite data at more aggressive scales. "Open" vs. "closed" fracture trends can be predicted from an analysis of the regional stress field when supported by field work.

4. Circular to ovoid drainage anomalies which display a light (dry signature as opposed to dark or wet) tone could be uplifted horst blocks. Check local seismic as available to confirm.

5. Subsurface tops and isopach maps, seismic data and well production figures would be useful to constrain the interpretation. The occurrence of open NW, NE to NNE fracture trends could be checked with production data from nearby

producing fields, or production from Denver basin fields to the south and SW where total cumulative production figures should parallel these trends (i.e. higher production rate contours should elongate along similar trends).

6. Correlations between production and fracture trends should clarify which lineament trends are significant for further evaluation. Some of the subtle targets may be expressed at the surface by the reactivation of faults at depth (Donovan, 1974, example in the Anadarko basin of Oklahoma).

7. The project area has limited surface expression of structural features, and most structural conclusions required the extrapolation of information interpreted from the regional overview (1:250,000 scale) imagery.

8. Exploration targets should occur in areas where lineament trends parallel the dominant subsurface structure, multiple lineament sets occur in high density, local traps (inferred from regional tectonics), and spectral anomalies coincide. If wrench tectonics can be supported in the area (e.g. Platte River right lateral offset?) additional targets could occur as en echelon anticlines, local pop up blocks (restraining bends) and pull apart basins (local divergent wrenching).

RECOMMENDATIONS

1. Areas of known production or exploration potential should be evaluated, including a detailed structural interpretation, image processing for tonal anomaly detection, and compiling the multiple coincidence of favorable exploration indicators in a GIS format to guide exploration in the surrounding regions.

2. The same approach should be conducted over a known field to determine which surface indicators hold the most exploration promise for this area. Overlay geochemical results with Landsat -derived spectral anomalies, “open” extensional lineaments.

3. Contour maps of highest production rates should reveal linear trends useful for exploration.

4. Compare oil and gas production histories of the various producing fields to the distribution of major lineaments to determine which trends are “open” as migration pathways, or “closed” as seals (traps or barriers to migration; these features may compartmentalize the reservoirs). Contour maps of highest production should reveal linear trends useful for exploration.

5. Company seismic data should be compared to surface fault traces mapped in the imagery to confirm their presence.

6. Soil gas surveys should be conducted across key faults to determine hydrocarbon "leakage"; which fault trends are tight and which are open.

7. Geothermal gradient data—from well bores and regional—should be incorporated in the exploration potential evaluation. Areas of high heat flow will upgrade the potential of previously identified exploration targets.

8. Areas of high interest—potential exploration targets—should be evaluated using high resolution air photos or satellite imagery, combined with image processing and analysis to detect subtle indicators of seeping hydrocarbons.

9. Water well records, available from commercial sources (Purolator Company has these types of records) might describe customer or driller's comments re: an "oily" taste or sheen in the water; these occurrences might be plotted up and contoured to discover previously overlooked oil seeps and reservoirs.

10. The results of this work should be presented to the client in their offices to discuss the results of this project, implications for success, and compare to company data and review the exploration program.

We appreciate the opportunity to be of service to you and wish the best for you in your exploration activities.

Respectfully submitted,

David G. Koger
Ralph N. Baker
Fort Worth, Texas

REFERENCES

AAPG Highway Map #2; 1990, Southern Rocky Mountain Region, Tulsa, OK.

Alden, A., 2004; "Bedrock Geologic Map of Nebraska," About.com; (derived from King & Beikman's Geologic Map of the United States, 1974).

Anon; 1982, Bouguer Anomalies of the Gravity Map of the United States, Soc. Econ. Geol.

Baker, R.N., 1998; "Multifactor Analysis of the Oman Foreland for Exploration Target Ranking and Evaluation," AMOCO Production Company, Houston, TX (Tech Services Internal Report).

De Blieux, C. 1951; “Photogeologic Study in Kent County, Texas,” Oil & Gas Journal, July 12, pp 86-100.

Burchett, R.R., 1985; Aeromagnetic Map of Nebraska, 1:1,000,000. Nebraska Geological Survey, Lincoln, NE. Enlarged to 1:250,000 for this project.

Burchett, R.R., 1982; Bouguer Gravity Map of Nebraska, 1:1,000,000. Nebraska Geological Survey, Lincoln, NE. Enlarged to 1:250,000 for this project.

Corbley, K., “CEOCAP Project Targets Antrim Shale,” Earth Observation Magazine, December 1995.

Donovan, T.J., 1974; “Petroleum Microseepage at Cement field, OK,” Bull. Amer. Assoc. Petr. Geol; vol 58, pp 429-446.

Elam, J., 1992; “The Reality of the 3-D World,” Houston Geol. Soc. Bull. V.35 no.3 p 41.

Harding, T.P., 1984; “Graben Hydrocarbon Occurrences and Structural Style,” AAPG vol. 68, p 333.

Koger, D.G., 1984; “Image Creation for Geologic Analysis and Photo-interpretation,” Proc. Southwest ASP-ACSM, San Antonio, pp 526-530.

Koger, D.G., 1988; “A Close Look at Photogeology, Remote Sensing, and Image Analysis,” Oil & Gas Journal, (cover story, Dec. 5) pp 54-57.

Koger, D.G., 1993; “Landsat 6 Images to Provide More Remote Sensing Muscle,” Oil & Gas Journal, (cover story, Feb. 1) pp 51-55.

Newell, K. and Hatch, J., 2000; “A Petroleum System for the Salina Basin based on Organic Geochem and Geologic Analog,” Kansas Geological Survey, Lawrence, KS.

Paleontologic Research Institute, (Cornell) Ithaca NY; www.priweb.org.

Prost, G., 1994; *Remote Sensing for Geologists*, Gordon and Breach Science Publishers, Lausanne, Switzerland.

Shirley, K., “Inexpensive Legwork Goes Far in Denver Basin,” AAPG Explorer, April 2003, www.aapg.org.

Short N. and R.W. Blair, 1986; “Geomorphology from Space,” NASA SP 486, Washington D.C.

Tedesco, S., 2003; "Coalbed Methane Potential and Activity of the Western Interior Basin." Search and Discovery Article # 10059 (2004) AAPG Ann. Mtg. Salt Lake City, Utah, May 2003.

USGS 1995: National Assessment of United States Oil and Gas Resources DDS-30; release 2.

Zietz, I., 1982; Composite Magnetic Anomaly Map of the United States, USGS Invest. Map GP-984-A, 1:2,500,000

ENCLOSURES

Image Map Sheets 1-12: Surface Geomorphic Interpretation at 1:250,000 based on Landsat TM mosaic, accompanied by Landsat images, aeromagnetic, gravity and topographic maps at same scale.

APPENDICES

1. Geophysical Survey Data: Aeromagnetic and Gravity Surveys

Our interpretations were compared with the gravity and aeromagnetic survey maps. These maps are made up of gradient contours and compressed contour edges. Typically, these types of geophysical surveys are presented as three dimensional surfaces where "highs" indicate higher field intensities and the "lows" are weaker field intensities.

The linear zones where the intensities of the gravity and magnetic fields change rapidly (i.e. where the contours are "tight") create an "edge" in what normally appears as a closely spaced contour. In some cases, the magnetic edges indicated local areas of high magnetic intensity: a magnetic high, possibly a near surface mafic (volcanic?) or granitic body. Second derivative processing can be used to enhance the edges:

Because of the locations and density of geophysical data points, the displacements may appear in the surveys as gently sloping variations over distances of a half mile. To assist in locating possible basement faults, second derivative functions were applied to the survey data. Second derivative functions highlight maximum gradient changes in the magnetic and gravity data. Those areas where gradient changes are sharpest may occur at the edge of basement faults. When these results were mapped, contour lines denoted severe gradient changes and indicated the possible presence of a fault. (Corbley, 1995).

Disruptions in the contours indicate fault offset at depth and confirms the presence of basement faults. Comparing these magnetic highs to the known basement geology finds some correlation with the distribution of buried volcanics and associated subsurface intrusive bodies.

2. Lineament Analysis

In general: the exact location of a linear feature mapped in an image is the average of the irregularities (many short fault segments and splays are combined into an overall regional trend).

These irregularities may be caused by refraction of the trend through different lithologies, local syn- or post- faulting movement, and tectonic readjustment. The surface trace of the fault can also be modified or obscured by erosion or later deposition (alluvial fill, sand sheets, dune fields, rangeland, cultural interference such as agriculture, roads, etc.). The interpreted location of the lineament marks the most likely position ("surface trace") of a regional fault that extends beyond the locality where the feature is well displayed on the land's surface. In some cases, aligned karst lakes or disrupted dune field patterns mark the exact surface trace of the fault because the underlying fault served as the structural and, by extension, topographic control.

If the subsurface fault plane is anything other than vertical, the surface trace of the fault will be offset. Normal faults in this area represent extensional systems where the faulting is high angle but not vertical. So, the actual position of the fault plane in the subsurface will vary with depth, and the surface map represents the best "pick" at positioning the surface trace. Further, the fault plane may shallow out with depth, or the fault plane may have been reoriented by later tectonic events.

Influence on Migration Fairways: For exploration targeting purposes, it was felt that well documented regional fracture trends could provide migration pathways for mobile hydrocarbons. Further, the described orientations of major trends coincided with a stress strain model of ENE to N-E directed maximum compression (Sigma 1) with corresponding WNW to NW maximum extension (Sigma 3). Corresponding compressive and extensional forces can be used to predict the types and orientations of structural traps. This generalized analysis suggests that major compressive structures should be oriented NW-SE (e.g. the Chadron-Cambridge arch) and major extensional faults—maximum migration potential—NE-SW.

Stratigraphic Traps: Not directly observable from Landsat (except when expressed as areas of anomalous photo tone), these require geophysical or seismic data to prove up. Positive aeromagnetic anomalies may represent high density basement features and noses which could provide basement pinchout plays. The general basin geometry and individual fault boundaries as interpreted from the TM imagery could also indicate the presence of buried reef trends, platform/basin margin carbonate mounds; reef fringes around evaporitic masses, in areas of shallow tropical seas, which may be detected by drainage anomalies around topographic highs and differential compaction. Higher resolution gravity data could help define shallow basin margin environments. These regions should be examined for topographic or tonal anomalies in the Landsat imagery.