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How to Design an Exploration Surface Soil Gas Geochemical Survey: Illustrated by Application Examples from the Hugoton Embayment of SE Colorado and SW Kansas

EXTENDED ABSTRACT

Three regional surface geochemical soil gas surveys covering areas of 150, 53, and 209 square miles were conducted in the Hugoton Embayment of southeast Colorado and southwest Kansas (Figure 1). The three surveys exhibit different sampling densities and comprise both reconnaissance and detailed sampling grids. The surveys were conducted over the prolific Pennsylvanian Morrow Stateline Trend and the Permian Chase Carbonate Gas Trend of eastern Colorado and western Kansas.

The stratigraphic entrapment of oil and gas in these two plays, relatively shallow depth, and highly variable porosity and permeability of the reservoirs are factors which favor the application of surface soil gas surveys as an important exploration method to reduce risk in exploration, exploitation, or development efforts in these two plays. Examples of actual reconnaissance and detailed surface soil gas surveys in this petroleum province are discussed.

The surveys were conducted from 1987 to 1992 before there was the widespread development drilling as witnessed today. Both the advantages and limitations of soil gas surveys over the Stateline Trend from Frontera to Second Wind to Moore-Johnson fields and the area around Byerly gas field are discussed. The paper is a retrospective analysis of soil gas surveys conducted in this complex stratigraphic area in light of new geologic knowledge of the area that has been revealed in the past decade.

North Stateline Trend, Morrow Oil Trend

Reconnaissance soil gas surveys were conducted in the Stateline Trend area in 1987 shortly after the development of SW Stockholm field and before the development of Frontera, Arapahoe, and Harker Ranch fields to the north and Second Wind field to the south. This reconnaissance survey, which consists of a grid pattern of 11 sites per section over a 150-square mile area, accurately defined the general areal extent of the productive Morrow incised valley fairway in 1987, well before it was confirmed by three years of development drilling that culminated in 1990 (Figure 2). Although this sample density did define the overall trend, it was inadequate for selecting individual 80-acre or 40-acre drilling sites, and for mapping the narrowest portions of the incised valley (north part SW Stockholm and Second Wind fields) where there were just too few samples to define the smaller sized reservoirs within these areas. The soil gas survey also detected microseepage from Morrow gas fields and Mississippian oil fields in the area. A detailed discussion of the relationship of the regional soil gas data with respect to these complications provides a better understanding of the relationship of the soil gas data to the subsurface reservoirs and demonstrates the value that soil gas data could have played in the development of these fields.

South Stateline Trend, Morrow Oil Trend

Using the knowledge gained in the Stateline area, a regional soil gas survey was conducted in the south part of the Stateline Trend over a 53-square mile area with 16 sites per section in 1992 (Figure 1). This density was increased still further to 32 sites per section for development drilling in the Moore-Johnson Field (Figure 3). These higher-density soil gas surveys illustrate the benefits of surface geochemistry for reducing risk in such a complex area. The highest density soil gas survey conducted for development included 106 sites collected over a four square mile area. The integration of geochemistry with geological and geophysical data allowed a compatible, unified interpretation that indicated that the field could be extended to the north.

Only one company of the several developing this field utilized geochemistry. Using this higher-density geochemical data this company completed the first well (a 4700-foot stepout) extending the field and beginning the final development. This company then completed eight consecutive successful Morrow wells in the field before drilling a dry hole, giving them an overall 90% success rate. During final development a total of 34 wells were drilled by all of the oil companies working the Moore-Johnson field. The company utilizing soil gas geochemistry acquired 47% of the reserves produced to date by only drilling 29% of the total wells. Success rates for the remainder of the other field operators were 0%, 30%, 50% and 67%.

Byerly Field, Permian Chase Carbonate Gas Play

Another example of a detailed regional soil gas survey, covering an area of 209 square miles, was conducted around and over Byerly gas field in Greeley County, Kansas (Figure 1). This soil gas data exhibits magnitude differences that appear to depict complex porosity and permeability variations that exist within the Chase Carbonate. The variability of the cumulative gas production from individual wells in the northwest part of Byerly field was contoured and shows a pronounced northeast-southwest orientation of porosity and permeability development (Figure 4). As evidenced by the cumulative gas production contour map, there are three porosity/permeability fairways within the area of the survey at Byerly field. An ethane concentration contour map, constructed from soil gas magnitude data in the northwest portion of Byerly field shows very good correlation between areas of maximum cumulative gas production and anomalous ethane soil gas concentrations. The trends of microseep anomalies, indicated by the ethane contour map, exhibits the same northeast-southwest orientations as seen in the contour map of cumulative gas production. Since there are many more soil gas data points than development wells at Byerly field, the soil gas anomalies, indicated by the contour map, may be providing a more realistic depiction of the subsurface porosity/permeability trends in the Chase Carbonate at Byerly field than are the less dense wells. Untested soil gas anomalies are noted to occur beyond the current limits of the field, and even more exciting localized anomalies found within the existing field appear to suggest areas of bypassed production within the known Byerly and Bradshaw field areas.

Recommendations

It is apparent that the most recently developed fields in the southern part of the Stateline Trend (Jace, Sunflower, Sidney) have the lowest development success rates to date. As demonstrated at Moore-Johnson field, high-density soil gas surveys could probably improve drilling success in these areas. Employment of soil gas surveys could also have accelerated the development drilling schedule at Sorrento and SW Stockholm fields from the 10-year period that was required for full field development. An incorrect depositional model appears to be the main reason for the rather lengthy development time frame (1979 to 1984) required for these two fields.

Success rates for Morrow exploration wells were reported to have been 5% in the Sorrento-Mt. Pearl-Sianna area and 10% in the Stateline area. There still remain areas of untested Morrow exploration potential in the transitional and updip facies tracts where soil gas surveys could be employed to improve the exploratory success rates over those previously reported. Regional isopach maps of the upper Morrow section have been used to define other areas where Morrow V1, V3, and V7 incised valleys may exist. Examples presented in this paper indicate that regional soil gas surveys could be very useful in exploration ventures when used in conjunction with this method, especially in areas with sparse well control.

As shown in this paper, surface soil gas geochemistry has been successfully used in developing oil reserves in the Morrow V7 incised valley trend. This method would also be applicable in other Morrow incised valley trends of southeast Colorado and southwest Kansas such as the V1 and V3 Valley systems. These two incised valley systems are transparent on 2-D or 3-D seismic due to their close proximity to the base of Atoka/top of Morrow interface. Additionally, other Morrow incised valley fill systems have been discussed in the literature in Wallace County, Kansas and farther south in Kiowa, Brent, and Powers Counties, Colorado.

A high degree of compartmentalization has been observed in the Morrow V7 reservoirs in the downdip facies tract. Future soil gas surveys in this area, for development drilling purposes, should have a higher density of samples than the grid of 30 sites per section used in the 1992 survey at Moore-Johnson field. For regional exploration activities in the Morrow trend, a soil gas grid of 16 sites per section appears satisfactory only for delineating regional microseep anomalies.

Soil gas geochemistry would also be applicable in other younger Pennsylvanian incised valley systems that have been identified in central and southern Kansas and northern Oklahoma. Likewise, Cretaceous age incised valley-fill systems exist in Rocky Mountain areas such as the Denver, Powder River, and Williston basins.

The advantages of using each of the disciplines of geology, geophysics, and soil gas geochemistry in Morrow exploration and development are obvious, however the three disciplines are seldom used in tandem. A somewhat lesser discussed topic is that of the limitations of these three sciences.

The limitations of using soil gas surveys in the Morrow oil trend have been discussed, to some extent, in this paper. Bowen et al. (1993) discussed limitations of subsurface geology and 2-D seismic in locating reservoir quality sandstones in the Sorrento-Mt. Pearl-Sianna area. Germinario et al. (1995) likewise discussed the limitations of 2-D and 3-D seismic surveys in locating both the incised valleys and reservoir sandstones in the southern Stateline Trend.

The integrated, multi-disciplined approach of using geology, geophysics, and soil gas geochemistry (3-G Method) in Morrow exploration is a superior method whereby the advantages in one of the three disciplines complement and overcome the limitations or shortcomings of the other disciplines.

Summary

Examples of a reconnaissance soil gas survey conducted over the Stateline Trend in 1987 and a detailed soil gas survey in the Chase Carbonate Gas Trend in the vicinity of Byerly and Bradshaw fields illustrate the significant risk reduction in exploration and development drilling ventures, respectively, that can be achieved in these two stratigraphic plays.

Moore-Johnson field was initially discovered by a major oil company applying conventional geology/geophysics techniques. However, development efforts ceased in 1990 after drilling seven dry holes with only three producers. A second attempt to extend the field was conducted by six other companies, starting in 1992. One of these companies used an integrated approach of combining subsurface geology and seismic with a high-density geochemical soil gas survey. The remainder of the independent oil companies used industry-standard Morrow exploration techniques acquired from 1978 to 1990 during development of Morrow oil fields to the north.

A high-density soil gas survey, consisting of 106 sites, was conducted over a four square mile area of interest. Integration of geochemistry, geology, and geophysics resulted in a compatible, unified interpretation that the field could be extended to the north. The company utilizing the soil gas survey completed the first well to extend the field with a 4700-foot stepout. This company completed eight consecutive successful Morrow wells in the field before drilling a dry hole. After drilling 10 wells, the company had a 90% success rate.

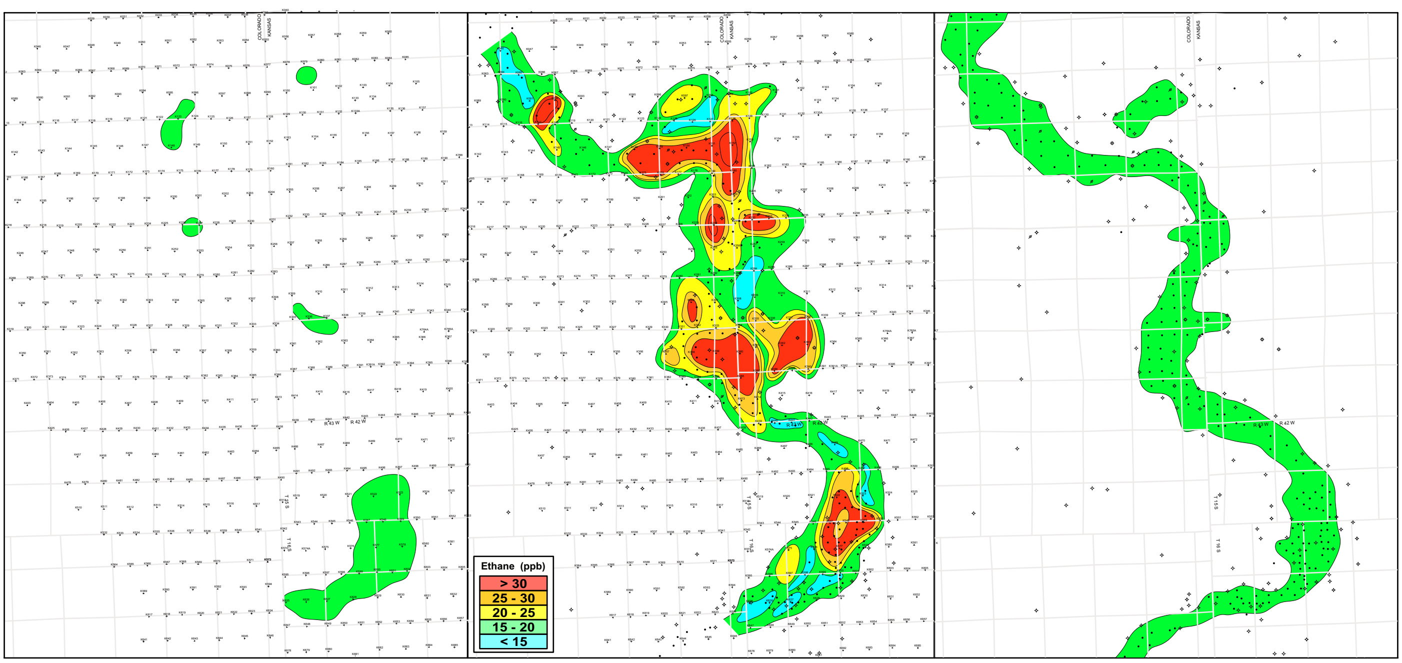
A total of 34 wells were drilled by all the oil companies to both define the limits of the field and develop the Morrow reserves. By drilling only 29% of the total wells, the company utilizing soil gas geochemistry acquired 47% of the reserves produced to date. Success rates for the remainder of the other field operators were 0%, 30%, 50% and 67%

There are still areas of untested potential in the Morrow oil trend. Fields discovered to date have produced 66.5 MMBO with ultimate recoverable reserves estimated at about 110 MMBO. Fields in the southern portion of the trend are in the downdip facies tract where Morrow sands in these wider incised valleys are of smaller areal extent, smaller in cross section, and more compartmentalized. Correspondingly, the average reserves per well are smaller than in the northern fields. Although reserves are lower in the downdip facies tract, employing soil gas geochemistry appears to have the best potential for improving the relatively low success rates now being encountered in this area. This could also vastly improve the rate of return on drilling capital.

This documentation of successful applications of detail soil gas surveys demonstrates how the method could be used to delineate other areas of Morrow incised valley-fill systems in areas of untested potential. Additionally, the method would also be applicable in incised valley-fill systems of other geologic ages in Mid-Continent and Rocky Mountain basins.

Soil gas geochemistry is not a panacea for Morrow sandstone and Chase carbonate exploration, exploitation, or development drilling, but should be integral part of a thorough exploration program. Applying the recently related concepts of Morrow sequence stratigraphy will undoubtedly be a tremendous advantage in future Morrow exploration and development drilling ventures, reservoir maintenance, and in secondary recovery operations. Using soil gas geochemistry in tandem with this concept could provide a very powerful synergistic effect to Morrow exploration and development projects.

Figure 1. Areas of three regional soil gas surveys, Southeast Colorado and Southwest Kansas.



A. Stateline Complex Development
January 1987

B. Soil Gas Survey Conducted - November 1987
Ethane Magnitude Contour Map

C. Stateline Complex Development
August 1990

Figure 2. Reconnaissance soil gas survey over Stateline Complex.

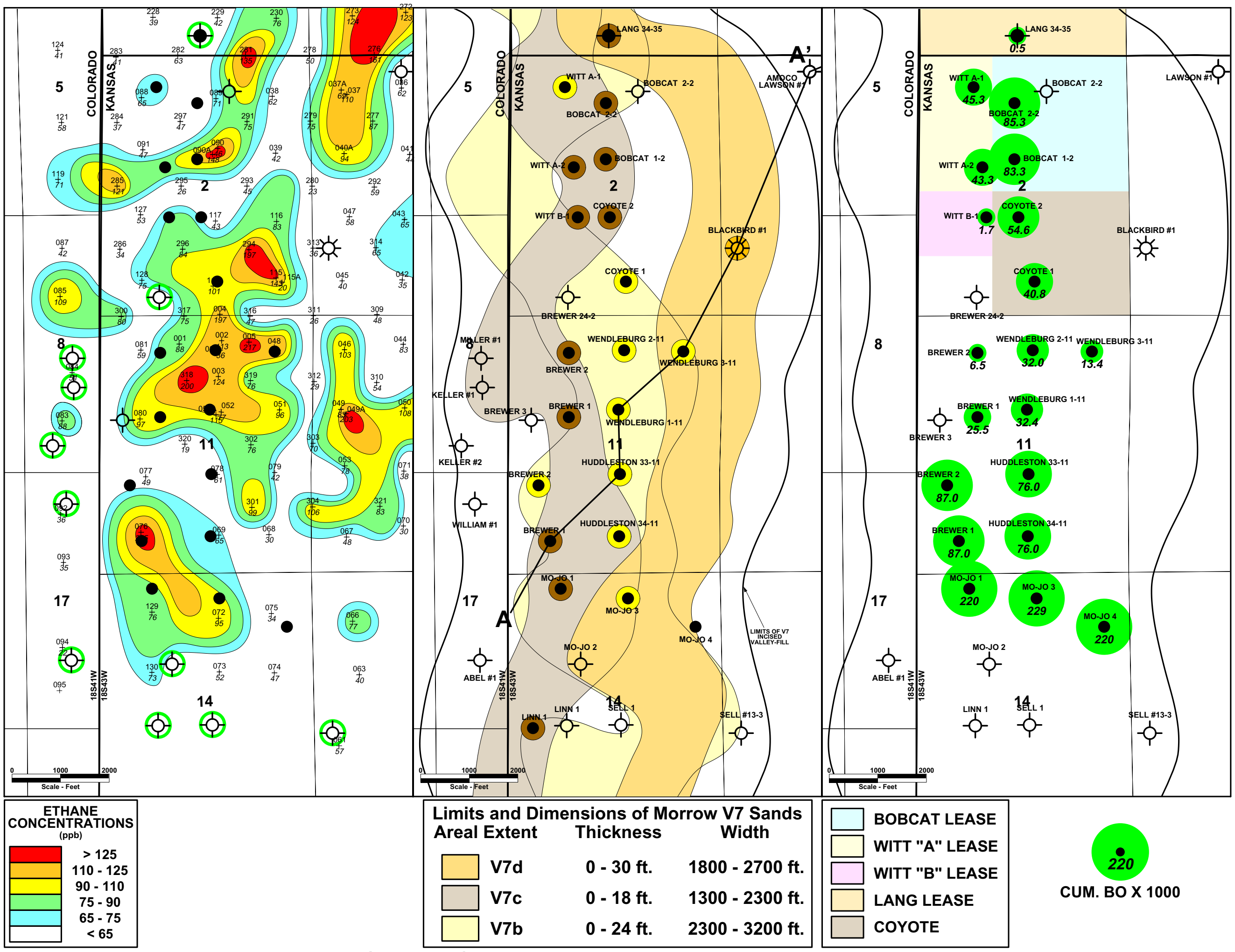


Figure 3. Moore-Johnson Field, Greeley County, Kansas

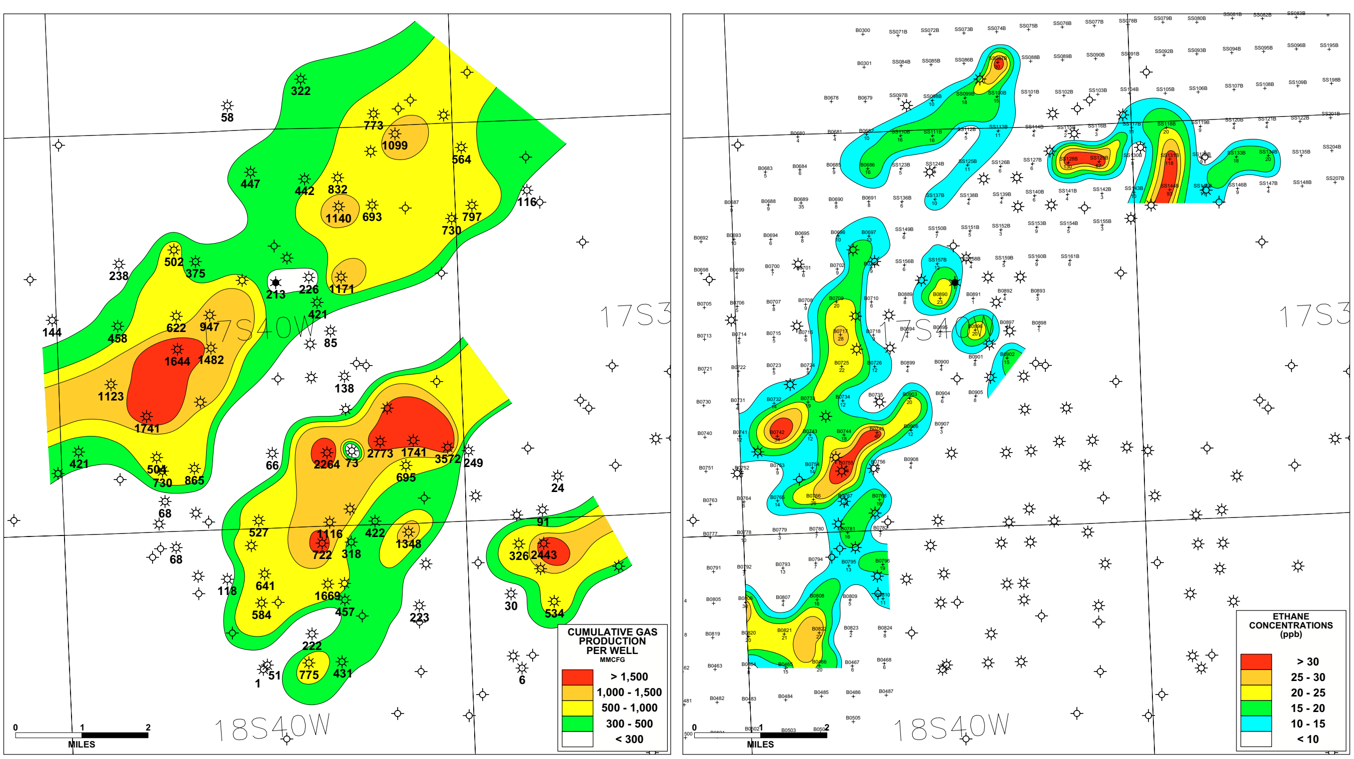


Figure 4. Byerly Field. 4a) Contour Map of cumulative gas production from wells of Byerly Field. 4b) Ethane magnitude contour map of Byerly Field