Moore-Johnson (Morrow) Oil Field, Greeley County, Kansas: A Successful Integration of Surface Soil Gas Geochemistry with Geology and Geophysics

Victor T. Jones, III and Rufus J. LeBlanc, Jr.,
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Revision 3.0

Aerial photograph of the Red Deer River in Alberta, Canada which is a modern day incised valley. The valley was originally incised by a river during the late Pleistocene that was much larger than the present-day river. Note smaller incised tributaries along the margins of the valley. Except for scale, this is an excellent analog for Frontera Field in the Morrow Stateline Trend.

Image: Posamentier, Henry W., Lowstand alluvial bypass systems: Incised vs. unincised, AAPG Bulletin, V. 85, No. 10 (October 2001), P. 1784, Figure 13.

AUTHORS NOTE

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Text and relational graphics are all contained on the same page for ease of editing and review.

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Moore-Johnson (Morrow) Field, Greeley County Kansas: A Successful Integration of Surface Soil Gas Geochemistry With Subsurface Geology and Geophysics.

Victor T. Jones III and Rufus J. LeBlanc, Jr.

ABSTRACT

Moore-Johnson Field in Greeley County, Kansas produces oil from a stratigraphic/structural trap involving sandstones of the Morrow V7 incised valley-fill system. This field is one of a complex of Morrow oil fields known as the Stateline Trend. These fields in the incised valley trends of southeast Colorado and southwest Kansas will have ultimate recoverable reserves of about 110 MMBO.

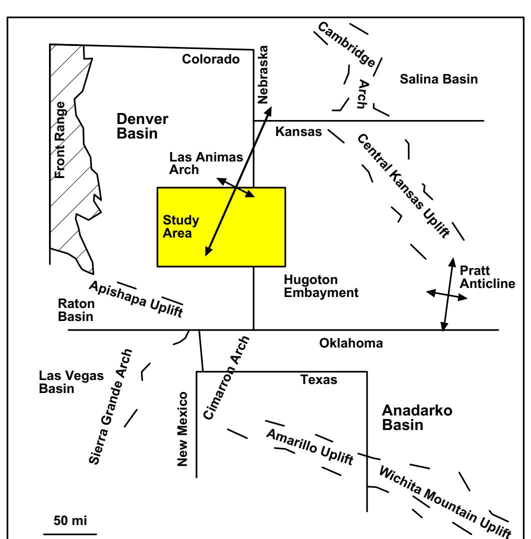
A high-density soil gas survey was conducted over a four square mile area in the vicinity of Moore-Johnson Field in 1992. The survey was conducted after the discovery of the field and initial development attempts, all by the same operator, which resulted in a total of 10 wells. All the wells were drilled by the end of 1990 resulting in three Morrow completions and seven dry holes. A second attempt to extend the field, starting in 1992, was conducted by six companies. One of the companies used an integrated approach of combining subsurface geology and seismic with a detailed geochemical soil gas survey. The remainder of the companies used industry-standard Morrow exploration techniques.

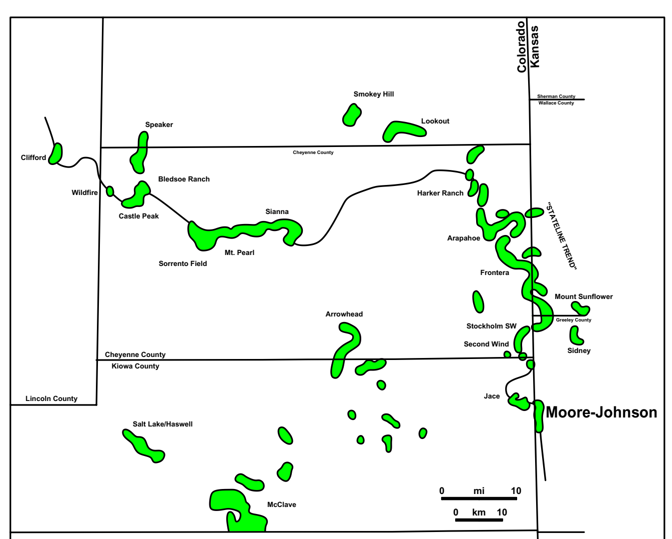
A soil gas calibration survey was first conducted over the area of the three producing wells and the dry holes on a uniform sample grid of 40-acre spacing. Analyses of the samples indicated areas of anomalous and background microseeps that corresponded to the oil wells and dry holes, respectively. A high-density soil gas survey, consisting of 106 sites, was next conducted over a four square mile area of interest. Integration of geochemistry, geology, and geophysics resulted in a compatible, unified interpretation.

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 to both define the limits of the field and develop the Morrow reserves. Of the total 34 wells drilled, 19 wells were completed in the Morrow as oil completions. By only drilling 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%. The latter two rates are within the range of industry success rates for development of Morrow fields.

This documentation of a successful application of a detail soil gas survey 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 Midcontinent and Rocky Mountain basins.





INTRODUCTION

In December 1941, the AAPG published the 902-page symposium – Stratigraphic Type Oil Fields which was edited by A.I. Levorsen. A foreword to the symposium was written by Levorsen. In the first two sentences he stated – "The backbone of the literature of petroleum geology is a description of an oil field – its history, its geology, its production, and its economics. New principles for future oil discovery depend to a large extent on an understanding of past experience, and the recording of these data should continue until all known producing areas have been described."

After 62 years, the authors strongly feel that this message is still very important and pertinent and is the chief reason for documenting this case history of the development of a stratigraphic trap using surface soil gas geochemistry, subsurface geology, and geophysics.

Moore-Johnson Field in Greeley County, Kansas produces oil from a stratigraphic/structural trap involving sandstones of the Morrow V7 incised valley-fill system. The field has a cumulative production of 1,729,000 BO with ultimate recovery of about 2,000,000 BO. This field is one of a complex of Morrow oil fields known as the Stateline Trend. These fields in the incised valley trends of southeast Colorado and southwest Kansas will have ultimate recoverable reserves of about 110 MMBO.

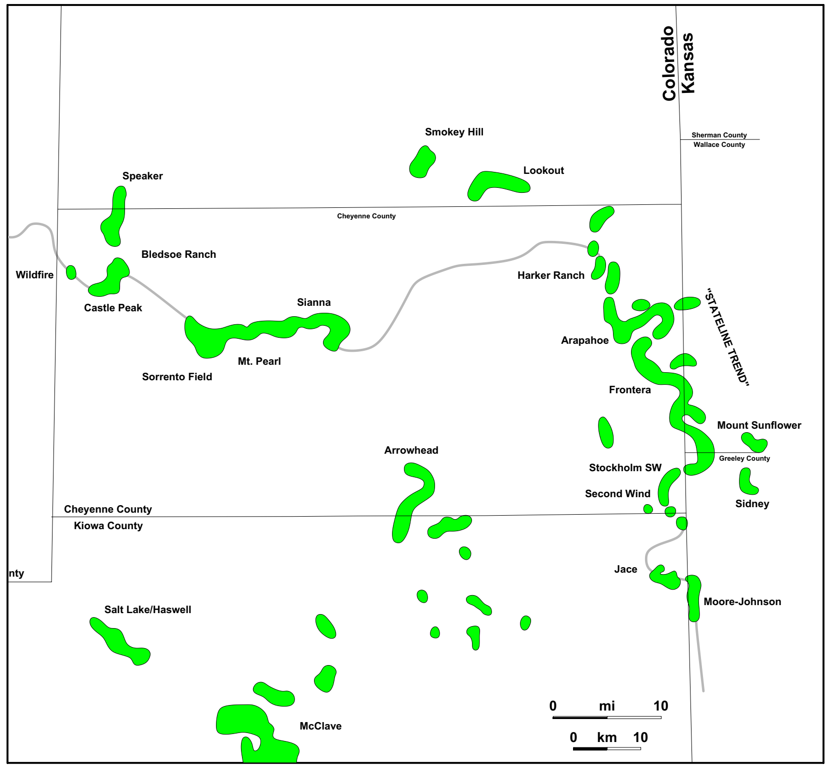
A discussion of the regional stratigraphy, sedimentation, structure and petroleum geology of the Morrow Formation is beyond the scope of this paper. The reader is referred to Sonnenberg and others (1990) for a thorough discussion of these important topics. An excellent, concise summary of this reference has been presented by Weimer (1992, p. 977-980). Likewise, the theory, methodology, and application of exploration soil gas geochemistry are too lengthy to discuss and the interested reader may pursue Jones and Drozd (1983), or, more recently Jones and others (2000).

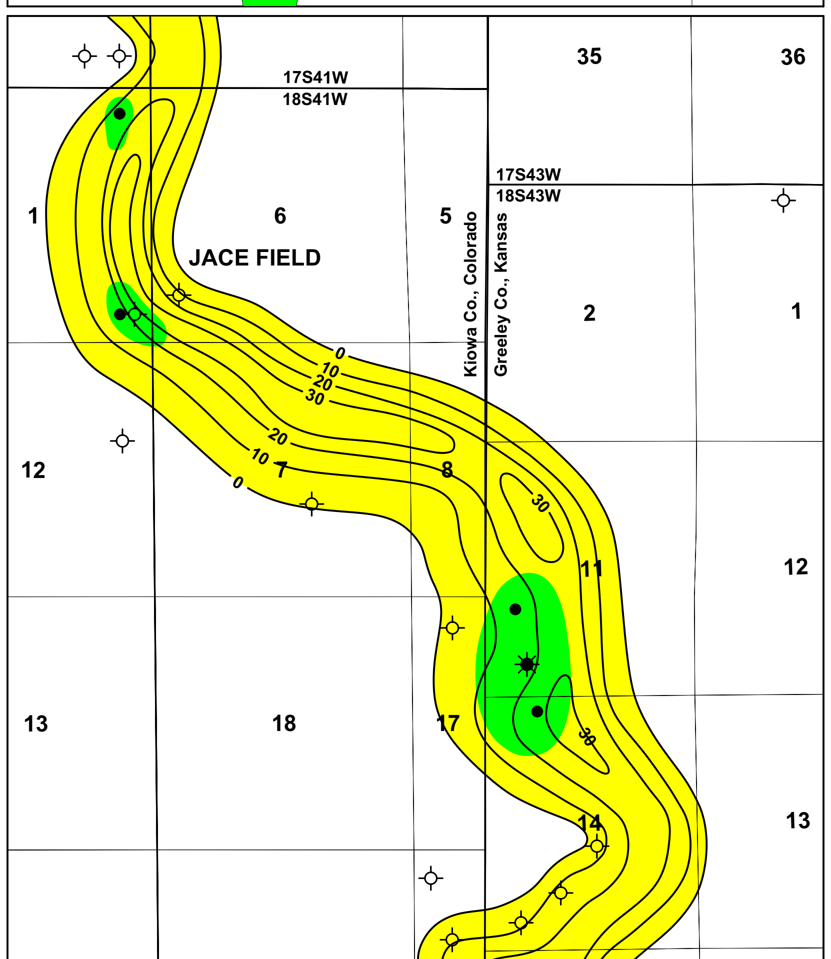
The event which provided the opportunity to create this case history was the release of the proprietary soil gas survey data by the owner. This release of the data fortunately occurred around the same time as the publication of the comprehensive account detailing the sequence stratigraphy of Morrow incised valley sandstones and the relational aspects to reservoir geology and production performance by Bowen and Weimer (2003). Moore-Johnson field was also detailed in this paper.

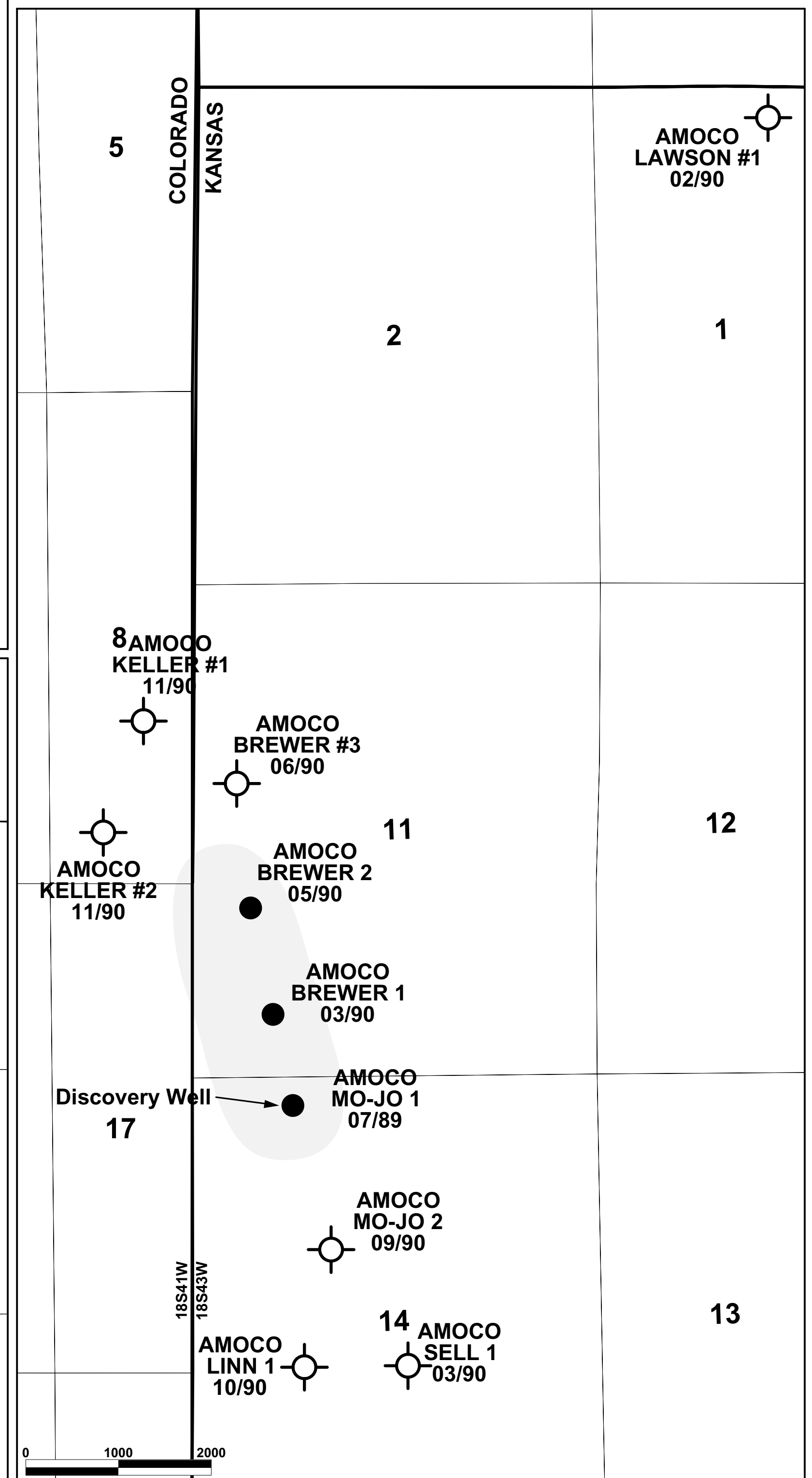
There are only two published accounts of soil gas geochemistry being used for exploration and development purposes in the Morrow Stateline Trend. Moriarty (1990) published an account of using single line soil gas profiles to extend Morrow production at NW Stockholm Field. Dickinson and others (1994) published an account of a 798-site exploration reconnaissance soil gas survey conducted in 1987 on a grid pattern over a 150 square mile area over the north part of the Stateline Trend. A more detailed account of this survey may be found in LeBlanc and Jones (2004).

The significance of this account is that it relates a rare occurrence of a high-density, detailed soil gas survey being conducted and used for exploitation/development purposes in the Morrow Trend with very successful results. The authors are very aware of the "serendipity factor" that has been a part of the Morrow oil play and that some serendipity may have been involved in this single case history. However, the most important point is that a documentation process has been started that will hopefully create an awareness in the geologic community on the advantages of using soil gas geochemistry in Morrow exploration and development ventures.

The purposes of this paper are to (1) Document the application of a high-density soil gas survey conducted for development purposes at Moore-Johnson Field. (2) Relate how the geochemical data was integrated with the subsurface geology and geophysics. (3) Discuss the results of the soil gas survey. (4) Discuss the advantages and limitations of using surface soil gas geochemistry in the Morrow Stateline Trend. (5) Recommend how soil gas surveys can be further applied in the Morrow Stateline Trend to provide risk reduction and a higher rate of return. (6) Recommend other areas to apply this exploration and development method.







Discovery of Moore-Johnson Field and Early Development Drilling in 1990

Moore-Johnson Field in Greeley Co., Kansas was discovered by Amoco in October 1989 (Adams, 1990). At the time of the discovery, the Stateline Trend had been developed to the extent shown in the map on the far left. The Amoco Moore-Johnson #1 was the discovery well for the field and was completed for 522 BOPD. The well was completed in the sands of the V-7 valley fill sequence of the Morrow Formation. This equivalent interval in the Morrow Formation was initially named the Stockholm Sand during development of SW Stockholm Field to the north. The sequence stratigraphy of the Morrow in relation to reservoir geology in the vicinity of Moore-Johnson Field has been more recently discussed by Bowen and Weimer (1997, 2003).

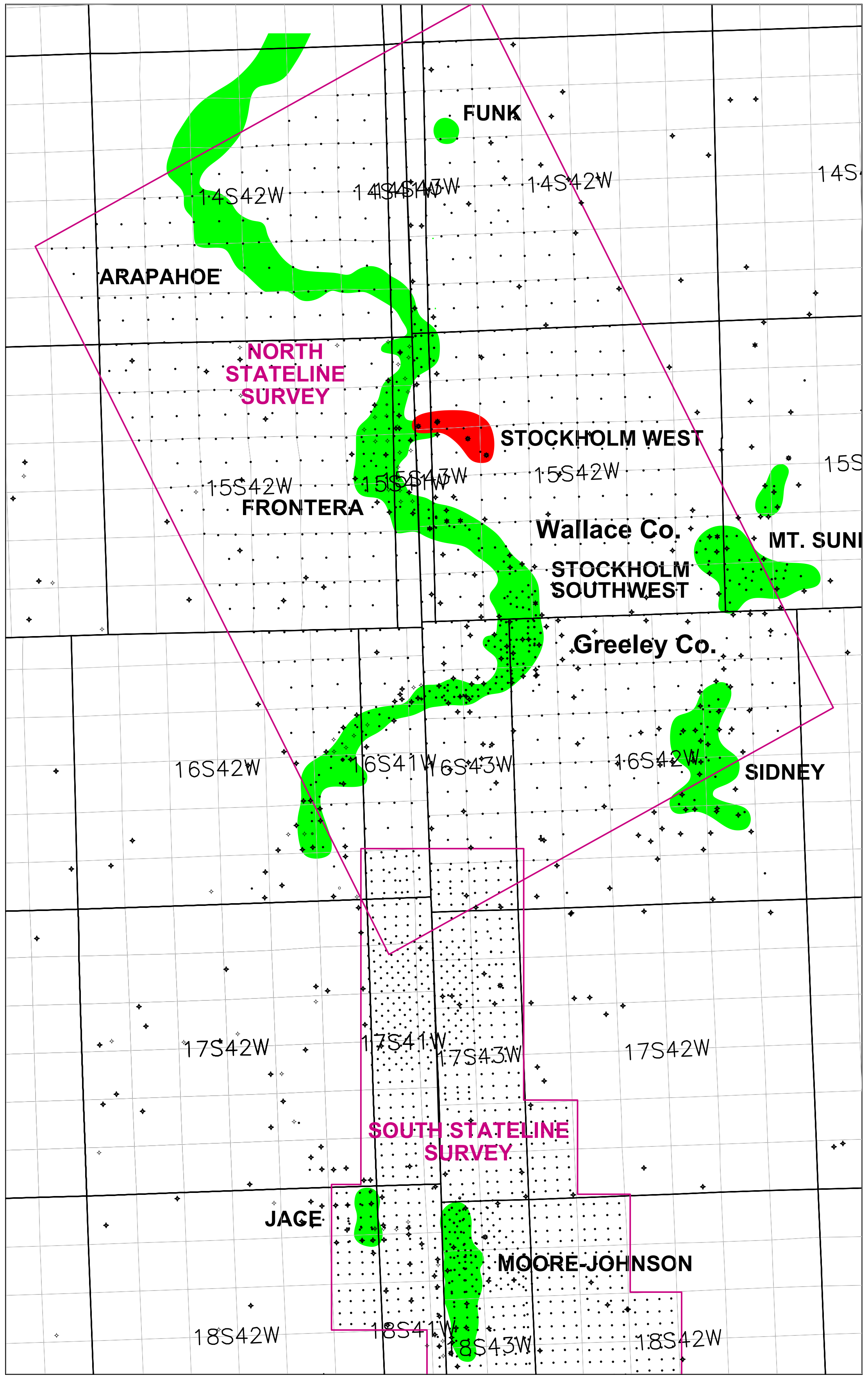
The Amoco combined geological and seismic conceptual model was that of a northwest-southeast oriented Morrow sand body. The location for the discovery well was determined by identification of the basal upper Morrow fluvial incised valley on 2-D seismic lines supplemented by data from available well control (Adams, 1990). By May 1990, Amoco had extended the field to include three wells. The Brewer #1 and Brewer #2 flowed at rates of 670 and 350 BOPD, respectively. In the first four months, the Moore-Johnson #1 produced 30,000 BO.

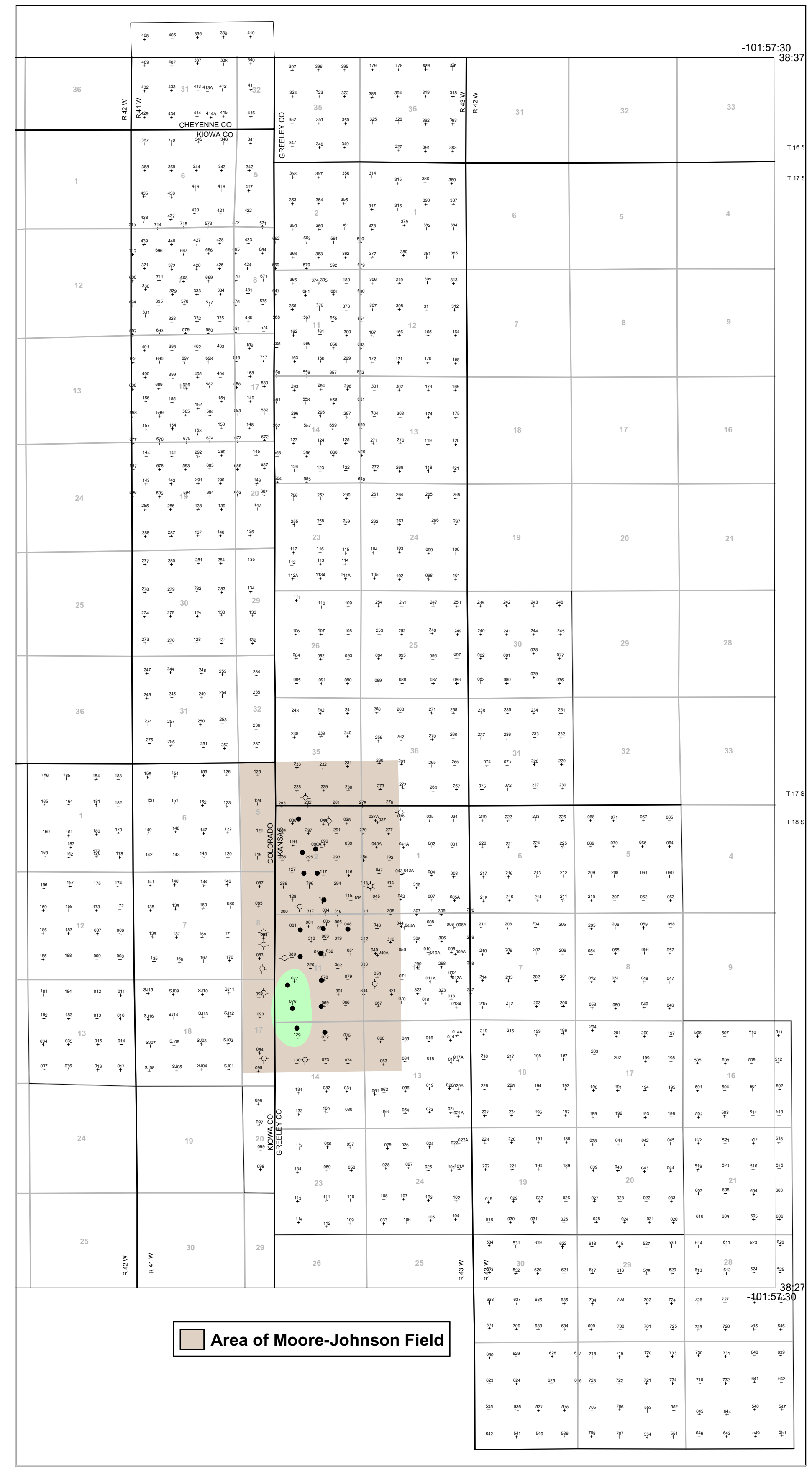
This was a very significant Morrow discovery in that it extended Morrow production for a distance of 10 miles to the south from Second Wind Field of the Stateline Trend. Amoco attempts at further development drilling was another story, however.

As shown in the figure on the left, attempts to extend the field to the south by Amoco in 1990 resulted in three dry holes (Moore-Johnson #2, Linn #1, Sell #1). Two successful Morrow development wells were completed by Amoco to the northwest of the discovery well in March and May of 1990 (Brewer #1, Brewer #2). Attempts by Amoco to extend the field farther to the northwest resulted in three more dry holes (Keller #1, Keller #2, Brewer #3). Amoco also drilled another dry hole to the northeast in February 1990 with the Lawson #1.

The overall success rate, at the end of 1990, for development drilling in the Moore-Johnson Field area was a disappointing 33%. This was considerably below previous industry standards in the Morrow Trend. Success rates for development of Frontera, SW Stokholm and Second Wind Fields of the Stateline Trent were 73%, 68%, and 56%, respectively. There was no further drilling in the field area during all of 1991.

As will be shown later in the paper, had Amoco used soil gas geochemistry, in conjunction to seismic and subsurface geology, the six dry holes could have been avoided.





Surface Soil Gas Geochemistry

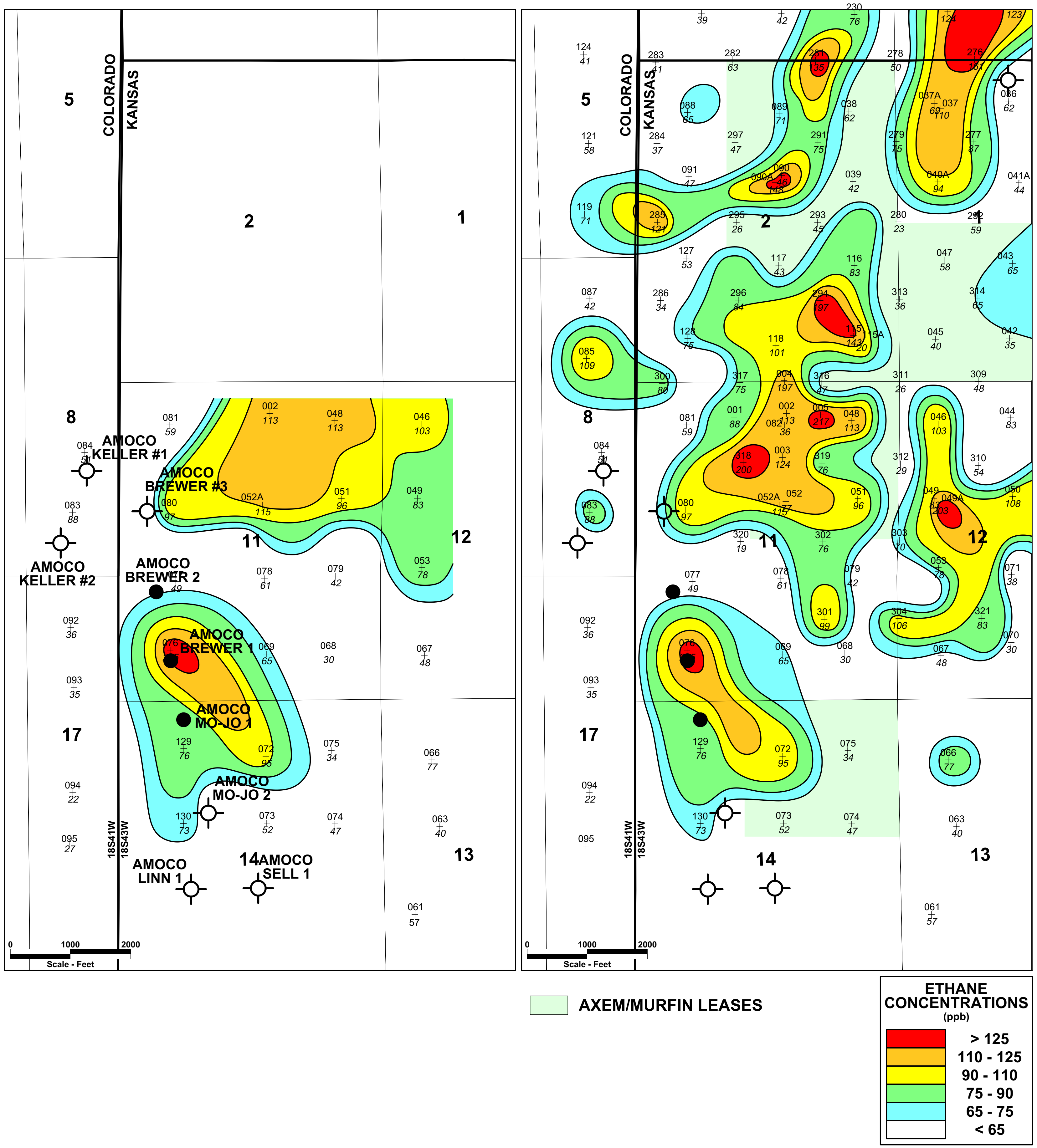
A Denver-based independent oil company decided to explore for Morrow oil in the Stateline Trend on a regional level and attempt to increase the drilling success rate by using surface soil gas geochemistry. The company first purchased a reconnaissance soil gas data set in the north part of the trend and later conducted a new detailed soil gas survey in the south area as shown in the figure on the far left. At the time of the new survey (April 1992), the development drilling had been completed at Second Wind Field and there were only three development wells at Moore-Johnson (MoJo) Field in the south. The two combined soil gas surveys provided soil gas microseep data consisting of 1817 samples covering a total area in the Morrow Trend of 203 square miles.

The detailed soil gas survey in the south part of the trend, consisting of 1034 sites, was conducted over a very large area (53 square miles) from just southeast of Second Wind Field in Cheyenne County, Colorado to two miles south and five miles southeast of Moore-Johnson Field in Greeley County, Kansas.

Realizing the limitations of the northern reconnaissance survey spacing (11 sites per section), this company increased the basic sample density in the southern survey to 16 sites per section (40-acre spacing). In addition as shown in the figure on the left, the company already had several prospects in the survey area and elected to increase the sample density in these areas over the standard spacing of 16 sites per section.

The high-density soil gas survey in the vicinity of Moore-Johnson field consisted of 106 sample sites over a four square mile area (24-acre spacing). It is this area which will be the focus of this paper.

The purpose of the more detailed soil gas survey was threefold: (1) calibration of the soil gas survey to the production at Moore-Johnson field, (2) to aid in further exploitation and development drilling at Moore-Johnson field, and (3) to determine other areas along trend that exhibited similar anomalous soil gas microseepage and therefore would have Morrow exploration potential.



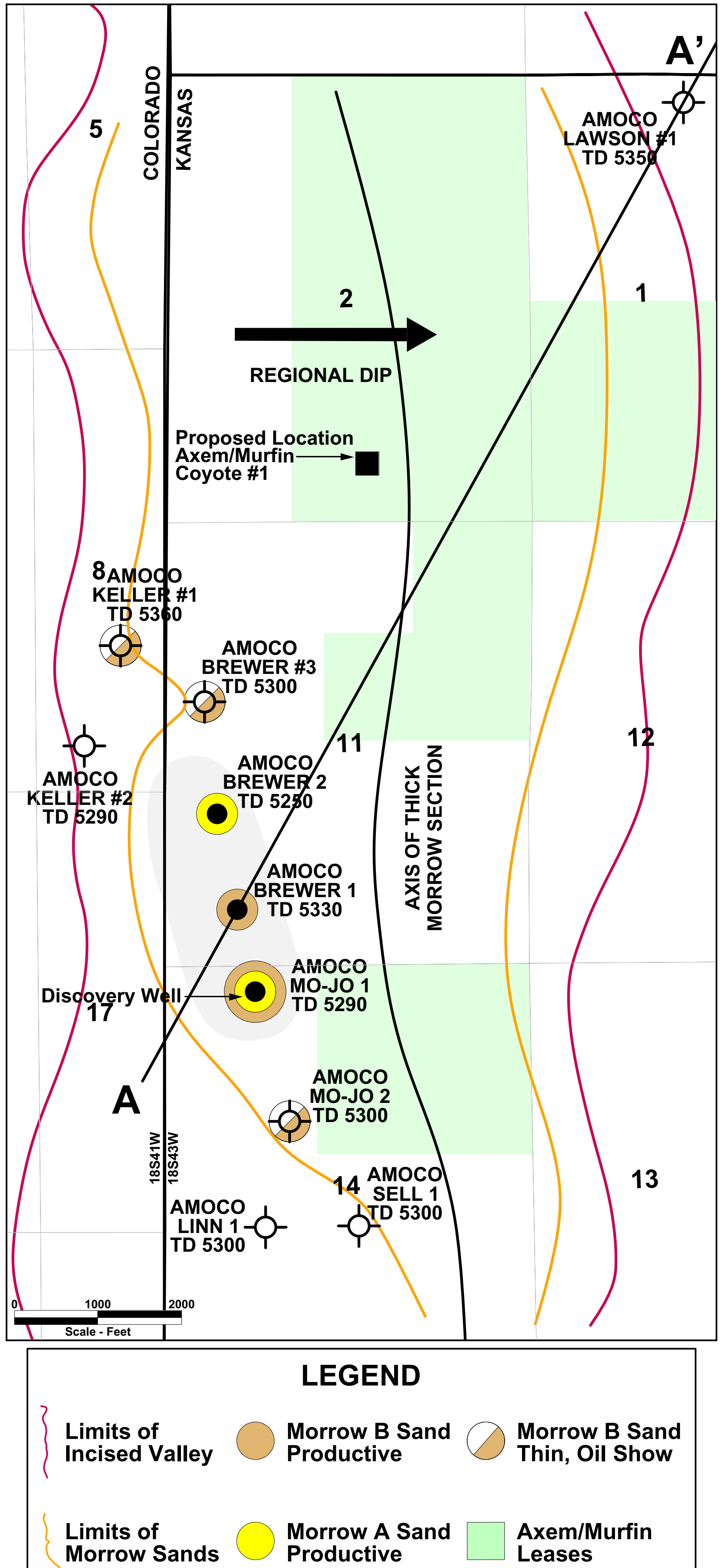
Soil Gas Calibration Survey and Detailed Survey in Moore-Johnson Field Area

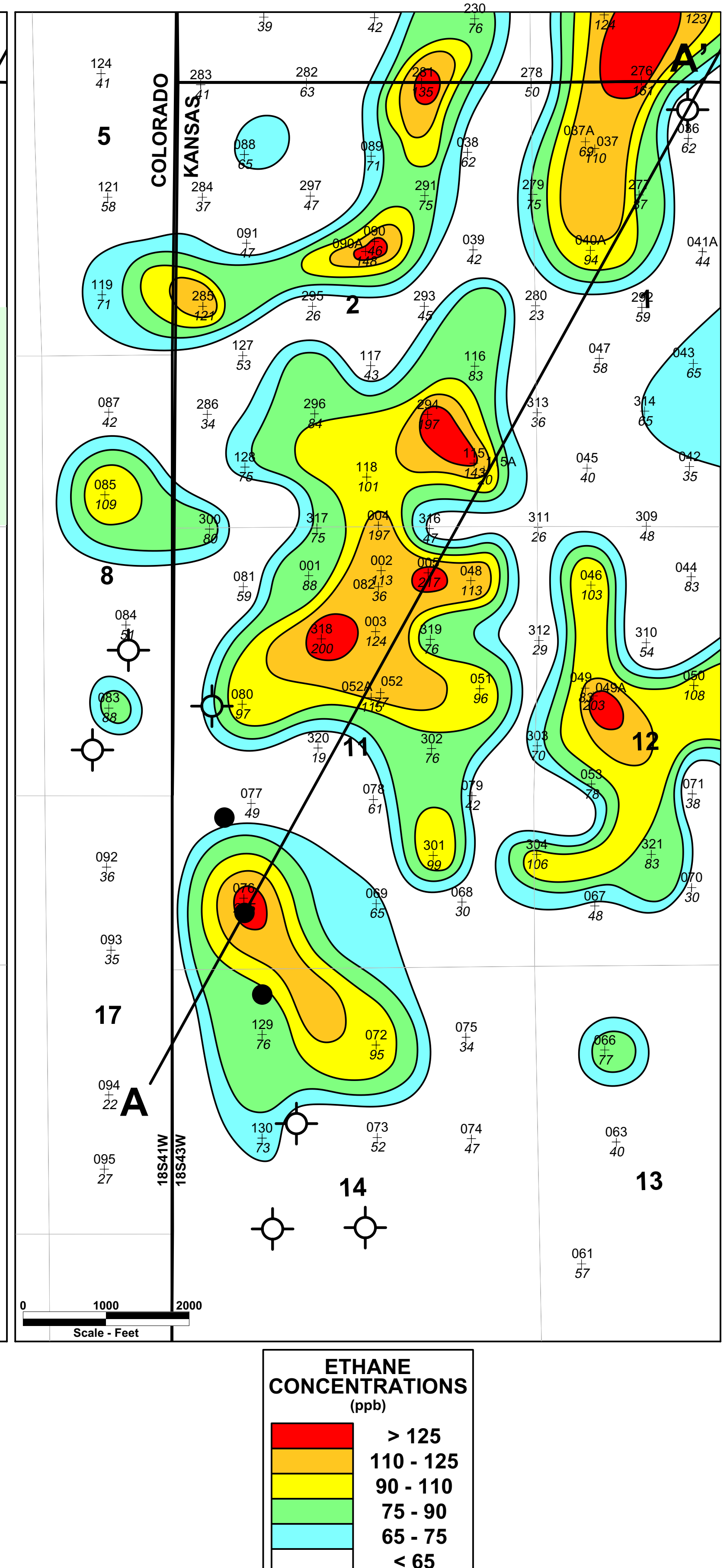
A soil gas calibration survey was first conducted over the 3-well field and in the area of the 6 dry holes in April 1992. Because the field was being developed in 40-acre units, a sample density of 16 sites per section was selected. An ethane magnitude contour map of the soil gas data in the calibration area is shown in the figure on the far left. As shown on the ethane magnitude contour map, low ethane magnitudes were observed in areas where the dry holes were drilled and the anomalous ethane values corresponded to the area of the 3 Morrow oil wells. There was no problem with reservoir pressure depletion at the time of the survey because of the limited production at that time.

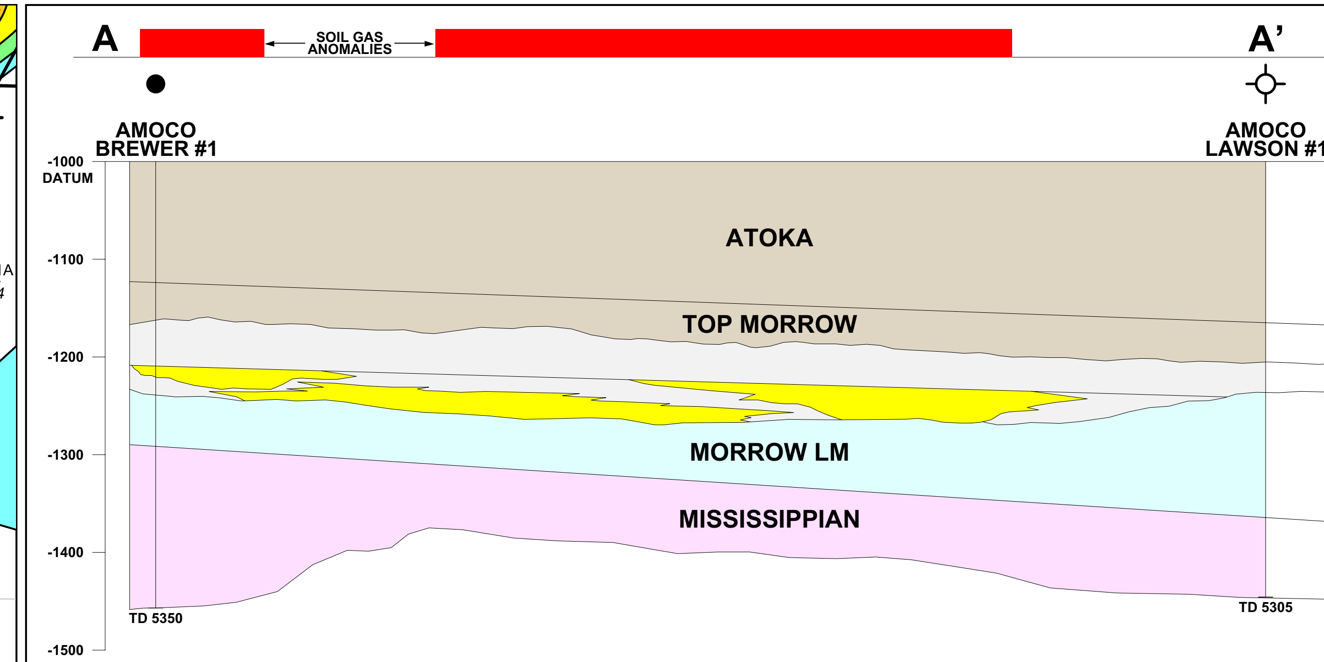
The soil gas contour map for the calibration survey also indicated other areas of anomalous microseepage to the east and northeast of the three productive wells. The more detailed soil gas survey was extended into those areas to aid in further development drilling at Moore-Johnson Field.

The initial sample grid of 16 sample sites per section was increased with infill soil gas sites as shown on the figure of the left. A total of 106 soil gas sites were sampled within the map area. The infill sample data significantly increased the detail of the microseepage anomaly pattern from that of the original calibration survey, as evidenced by comparing the two contour maps on the left. Ethane magnitudes ranged from 22 ppb to 205 ppb within this area. The ethane magnitude contour map indicated anomalous microseepage over the Axem/Murfin lease block in sections 2, 11, and 14.

The surface soil gas geochemical data was next integrated with the combined subsurface geology and seismic interpretations.







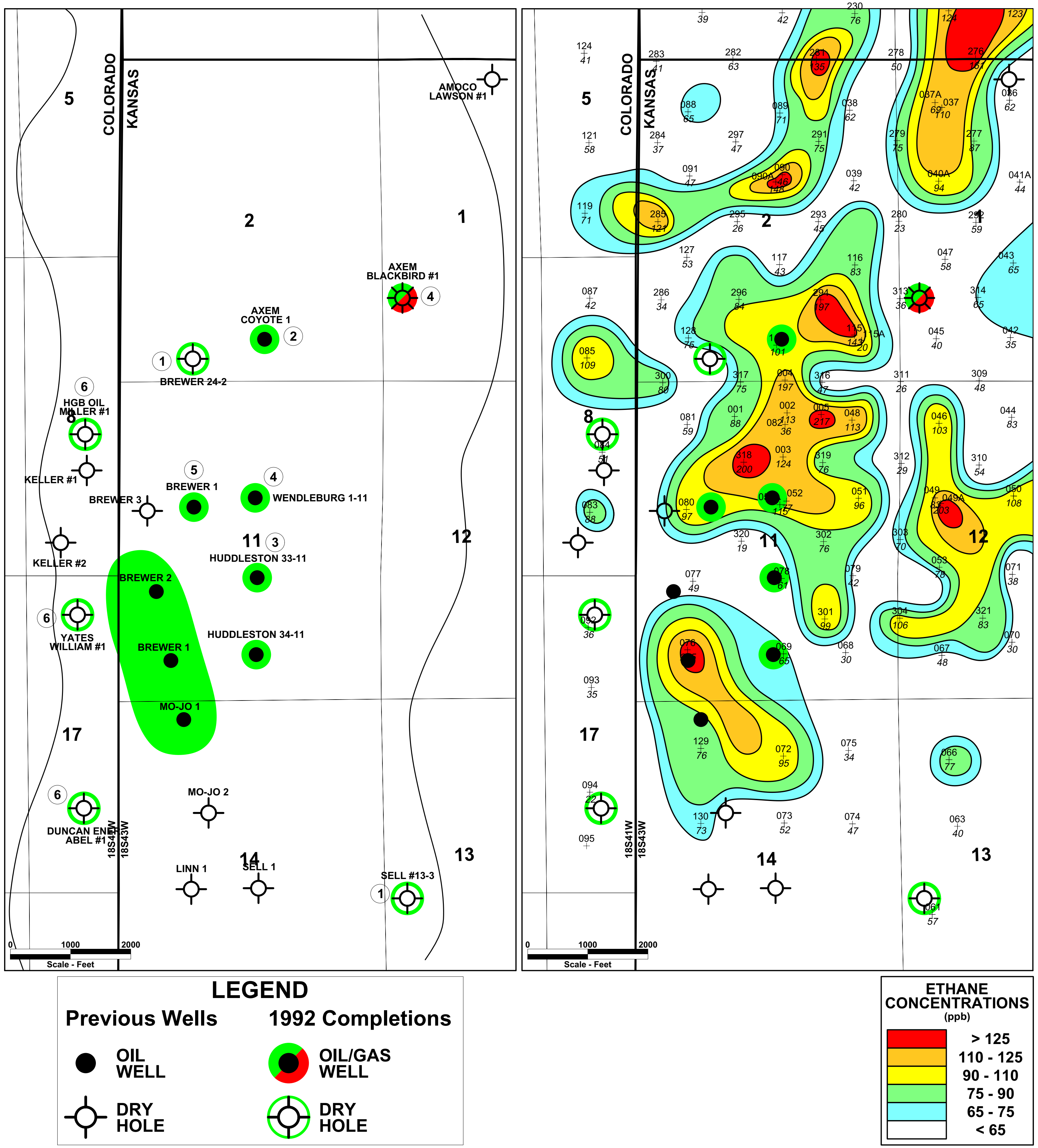
Integration of Subsurface Geology, Seismic, and Surface Soil Gas Geochemistry

During the first half of 1992, Axem/Murfin integrated the combined subsurface geology and seismic interpretation with the surface soil gas data. The conceptual model for the Morrow trend, derived from the all the development of the northern Stateline Trend fields, was that the Morrow section (base of Atoka to top Morrow Limestone) was observed to thicken in the areas of maximum Morrow sand development and productive wells. In contrast, the Morrow section was much thinner, with non-deposition of Morrow sands, on the east and west flanks of the Morrow fields. This was the Axem/Murfin conceptual model at the Moore-Johnson area interpreted from the available well control and seismic data. The map on the far left shows the well control available at that time.

Subsurface data from the 10 Amoco wells in the area and seismic interpretation provided the Axem/Murfin concept of the Morrow incised valley boundaries, regional dip, and general axis of the depocenter of the Morrow valley as indicated on the map and cross section. Amoco had established production from 2 different Morrow sands (named “A sand” and “B sand”) in their three wells. The Morrow completion zones in the three wells are as indicated on the map. Additionally, the Morrow “B sand” was encountered in three other Amoco wells (see map) with oil shows, however, the porosity/permeability and thickness of the sand precluded completion attempts in those wells. The Morrow sands were not present in the other four Amoco wells. The expected areal distribution of Morrow sands was interpreted as shown on the map. Axem/Murfin had interpreted the Morrow sands to be oriented north-south in the area as opposed to the previous Amoco concept of a northwest-southeast alignment. In the new interpretation, the Amoco productive wells were interpreted to be at the west, updip limits of a Morrow stratigraphic trap.

The interpretation of the soil gas survey data is shown on the left. The ethane magnitude contour map indicated that the maximum gas microseeps were observed in the central portion of the expected Morrow incised valley and within the expected Morrow sand fairway (see maps and cross section). The geochemical, geological, and geophysical data were all compatible with the conceptual model for a Morrow stratigraphic trap.

The Axem/Murfin acreage position was excellent. A location was staked (see map) for the Axem/Murfin Coyote #1 in section 2. The well was spudded July, 25, 1992.



1992 DRILLING - MOORE-JOHNSON FIELD

Eleven wells were drilled in 1992 by 5 oil companies. Only Axem Res. / Murfin Drl. used the integrated approach of soil gas geochemistry with geology and seismic to select well locations. The locations of the wells drilled in 1992 are shown on the map on the far left. An ethane magnitude contour map illustrates the basis of Axem/Murfin decisions in selecting well sites. The following is the order in which the 1992 wells were drilled:

1 In April and May 1992, MW Pet. drilled two Morrow dry holes with the Brewer #24-2 and Sell #13-31 wells. Both wells were 4000-foot step-outs. Both well locations are in areas of background soil gas concentrations. No further wells were drilled by this company in this area

2 In August 1992, Axem/Murfin drilled their first well and completed the Coyote # 1 as a Morrow oil well. This was a very significant well in that it was a 4700-foot step-out extension for Moore-Johnson Field. The well location was supported by a strong soil gas anomaly. The well confirmed the conceptual model established by integrating geochemistry with geology and geophysics.

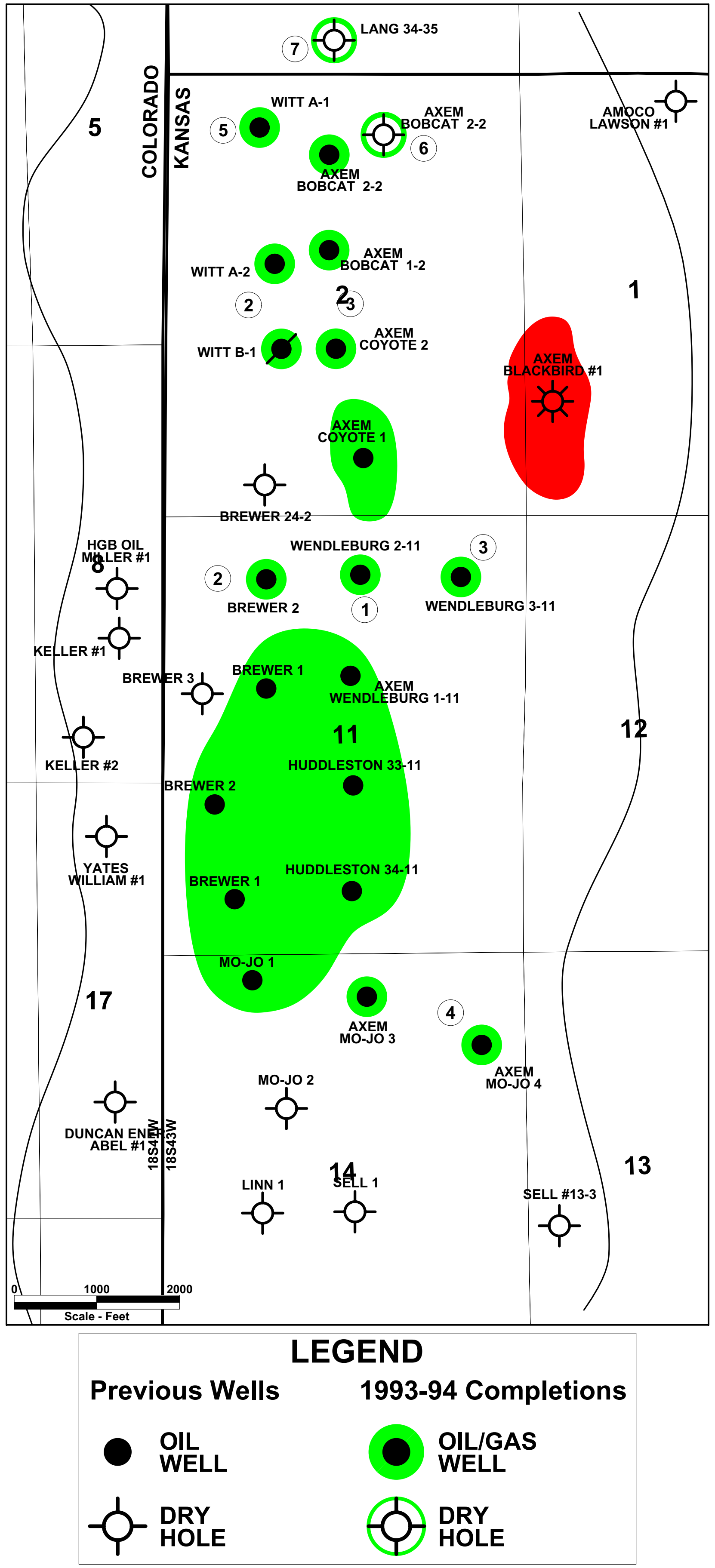
3 Duncan Ener. completed two direct offsets in October and November to the Amoco Brewer #1 and #2 producing Morrow wells. These 2 wells were only 1500-foot offset locations.

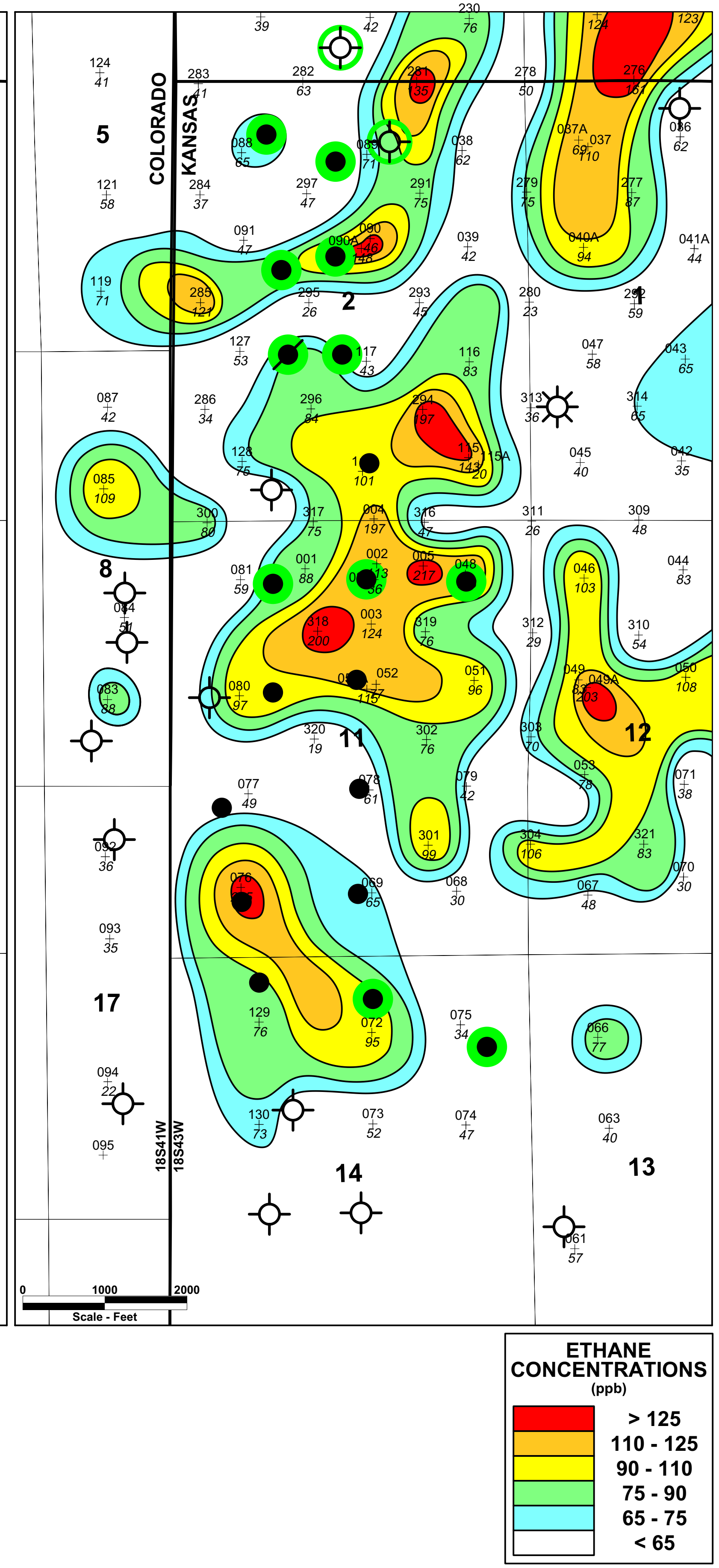
4 In November 1992, Axem/Murfin completed two Morrow wells with the Wendleburg #1-11 and Blackbird #1 wells. The Wendleburg #1-11 location was supported by a strong soil gas anomaly.

5 In December 1992, HGB Oil completed the Brewer #1 as a Morrow oil well. This location had been proven by the preceding surrounding wells to the west, east, and south.

6 HGB Oil, Yates, and Duncan Ener. each drilled a Morrow dry hole in Colorado attempting to extend field production updip and to the west. There were now 5 dry holes in Colorado to the west of the field. All 5 well locations are in areas of low magnitude soil gas data.

By the end of 1992, Moore-Johnson field had produced 512,714 BO.





1993 and 1994 DRILLING
MOORE-JOHNSON FIELD

The locations of all the wells previously drilled through 1992 are shown on the map on the far left. An ethane magnitude contour map illustrates the basis of Axem/Murfin decisions in selecting well sites. The following are the 1993 wells that were drilled:

1 Marathon completed the Wendleburg #2-11 as a Morrow oil well in February 1993. This well was a direct offset to the Axem/Murfin Wendleburg #1-11 drilled 3 months previously in November 1992. This was the only lease Marathon held in the field area.

2 HGB Oil drilled 3 Morrow oil completions from March through July 1993 (Witt #A2, Witt #B1, Brewer #2). The wells were on the updip, west side of the field. The Witt #B1 only produced 1745 BO and is considered to be a dry hole.

3 Axem/Murfin drilled 3 Morrow oil wells in the north area with the Bobcat #1-2, Coyote #2, and Wendleburg #3-11. The Bobcat and Wendleburg well locations were in areas of anomalous microseeps.

4 Axem/Murfin drilled 2 Morrow oil wells in the south area with the MoJo #3 and MoJo #4 wells. The MoJo #3 well was completed in August 1993 and was located in an area of anomalous ethane concentrations.

By the end of 1993, Moore-Johnson Field contained 17 Morrow oil wells and extended for 11,000 feet in a north-south direction and 3000 feet in width. Axem/Murfin had completed 7 successful Morrow wells without a dry hole. At the end of 1993, cumulative production at the field was 780,549 BO.

In 1994, 4 wells were drilled by three oil companies in the north area of the field. The following are the 1994 wells that were drilled:

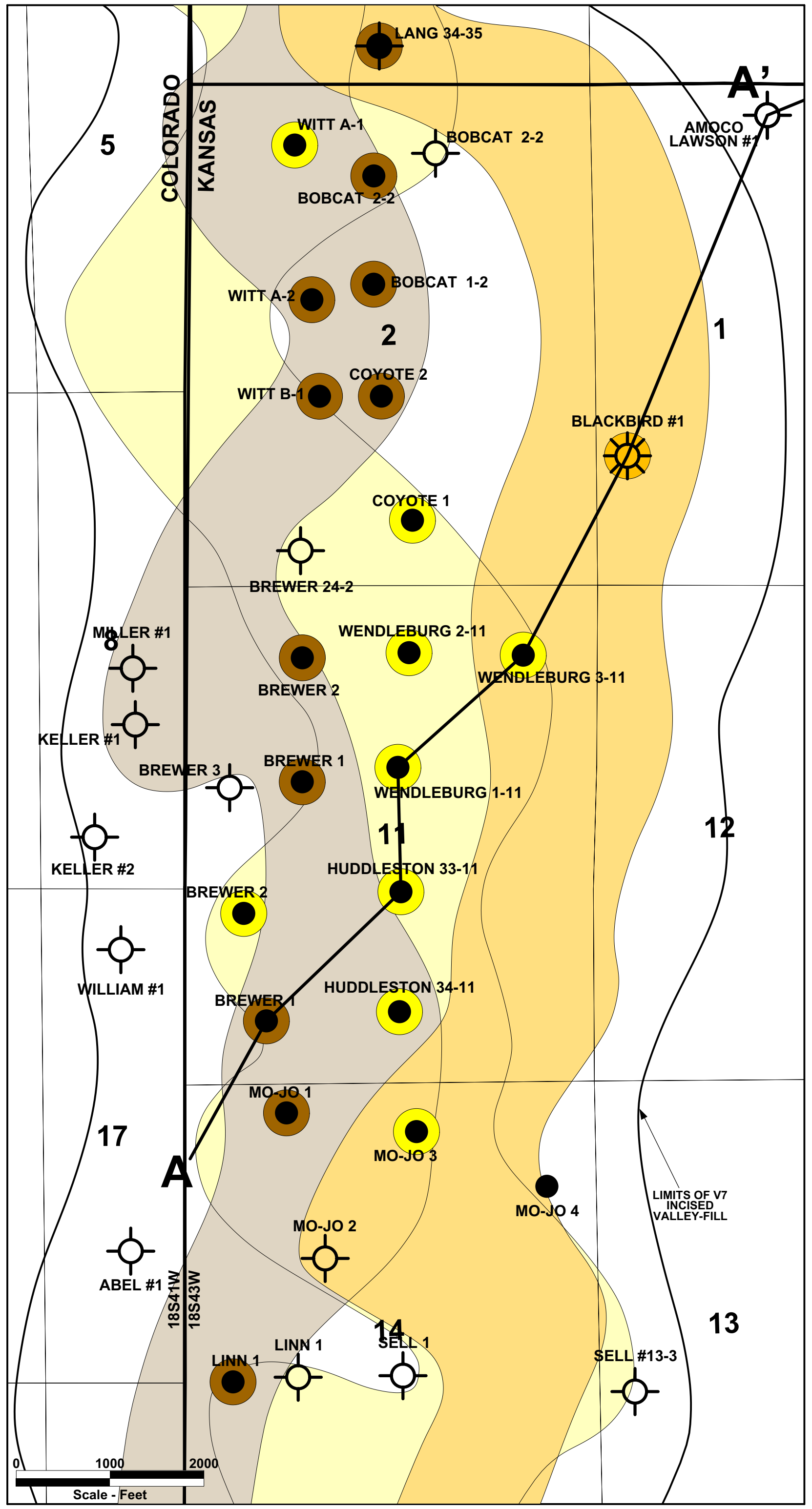
5 HGB Oil drilled the Witt #A1 as a Morrow oil well in January 1994. The well location was on trend and 1500 feet from their Witt #A2 completion 6 months earlier.

6 Axem/Murfin drilled their first dry hole in the Bobcat #2-2 in January 1994. A 700-foot offset to the southwest, however, resulted in a Morrow oil completion. The Bobcat lease, to date, has produced a total cumulative of 170,646 BO from 2 wells.

7 Duncan Energy completed a marginal Morrow well with the Lang #34-35 in March 1994. After only producing 477 BO, the well was converted to an injection well.

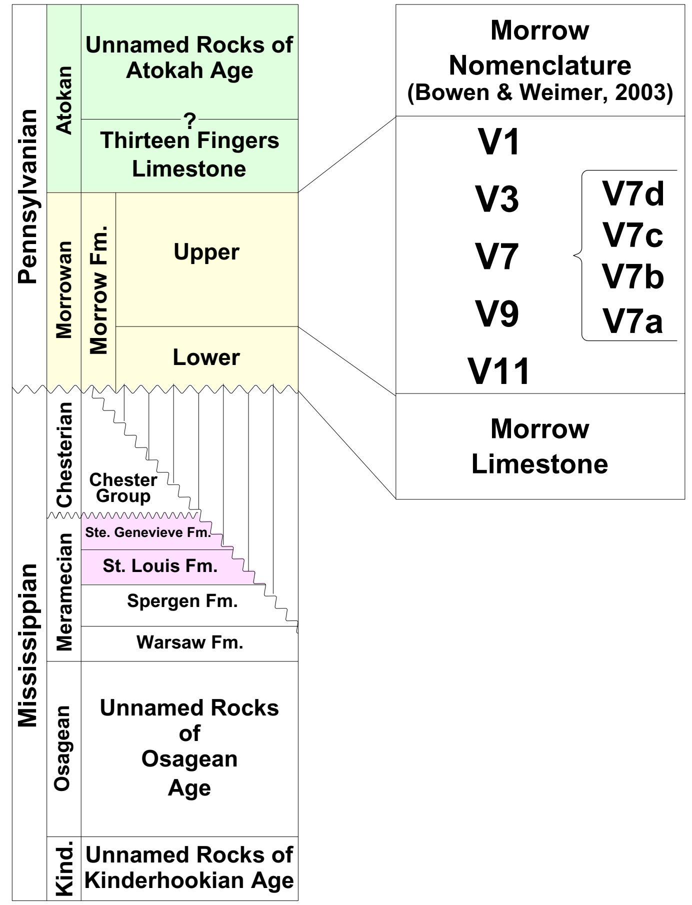
Moore-Johnson field was fully defined by 34 wells. The major extension of the field only took 24 months. This is one of the shortest development periods for a comparative size field in the whole Morrow trend.

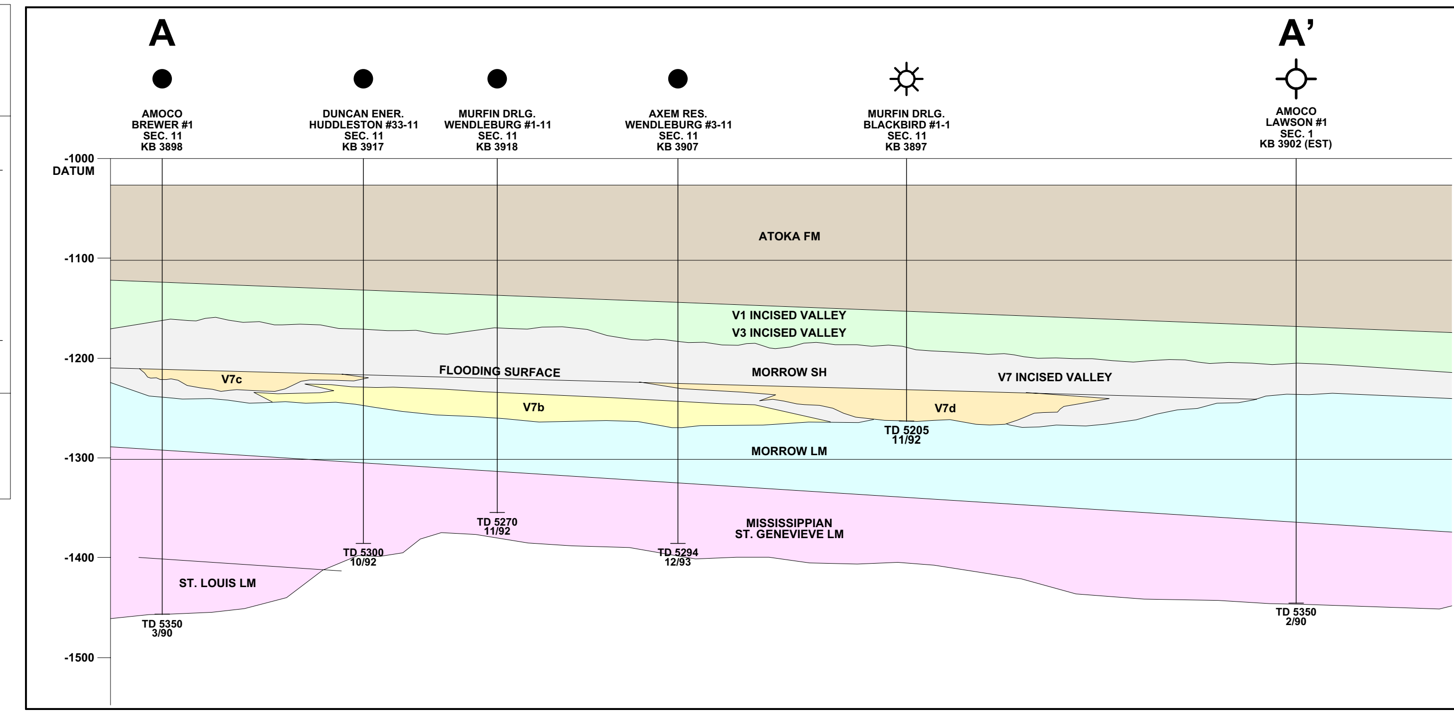
By the end of 1994, the cumulative production from the 19 Morrow wells in Moore-Johnson Field was 980,152 BO.



Limits and Dimensions of Morrow V7 Sands		
Areal Extent	Thickness	Width
V7d	0 - 30 ft.	1800 - 2700 ft.
V7c	0 - 18 ft.	1300 - 2300 ft.
V7b	0 - 24 ft.	2300 - 3200 ft.

Morrow Well Completion Zones
V7d
V7c
V7b





Moore-Johnson Field Parameters

(Revised after Adams, 1990)

Reservoir:	Morrow V7
Lithology:	Sandstone
Type Trap:	Stratigraphic/ structural
Discovery:	Oct. 1989
Depth:	5100-5200 ft.
Spacing:	40 ac.
Field Size:	1290 ac.
Avg. Net Pay:	16 ft.
Porosity:	14 to 28%
Permeability:	22 to 9,990 md
Water Sat.:	13 to 47%
Pressure:	1040 psi
Reserv. Drive:	Gas cap expansion/ solution gas drive
GOR:	107:1 cu ft / bbl
Cum. Prod:	1,729,000 BO
Ultimate Prod.:	2,000,000 BO

Subsurface Geology and Reservoir Performance

Moore-Johnson field has been discussed by Adams (1990) and more recently by Bowen and Weimer (1997, 2003). These last two papers document the Morrow sequence stratigraphic framework throughout the trend and relate it to the subsurface geology, reservoir geometry, and reservoir performance at Moore-Johnson Field.

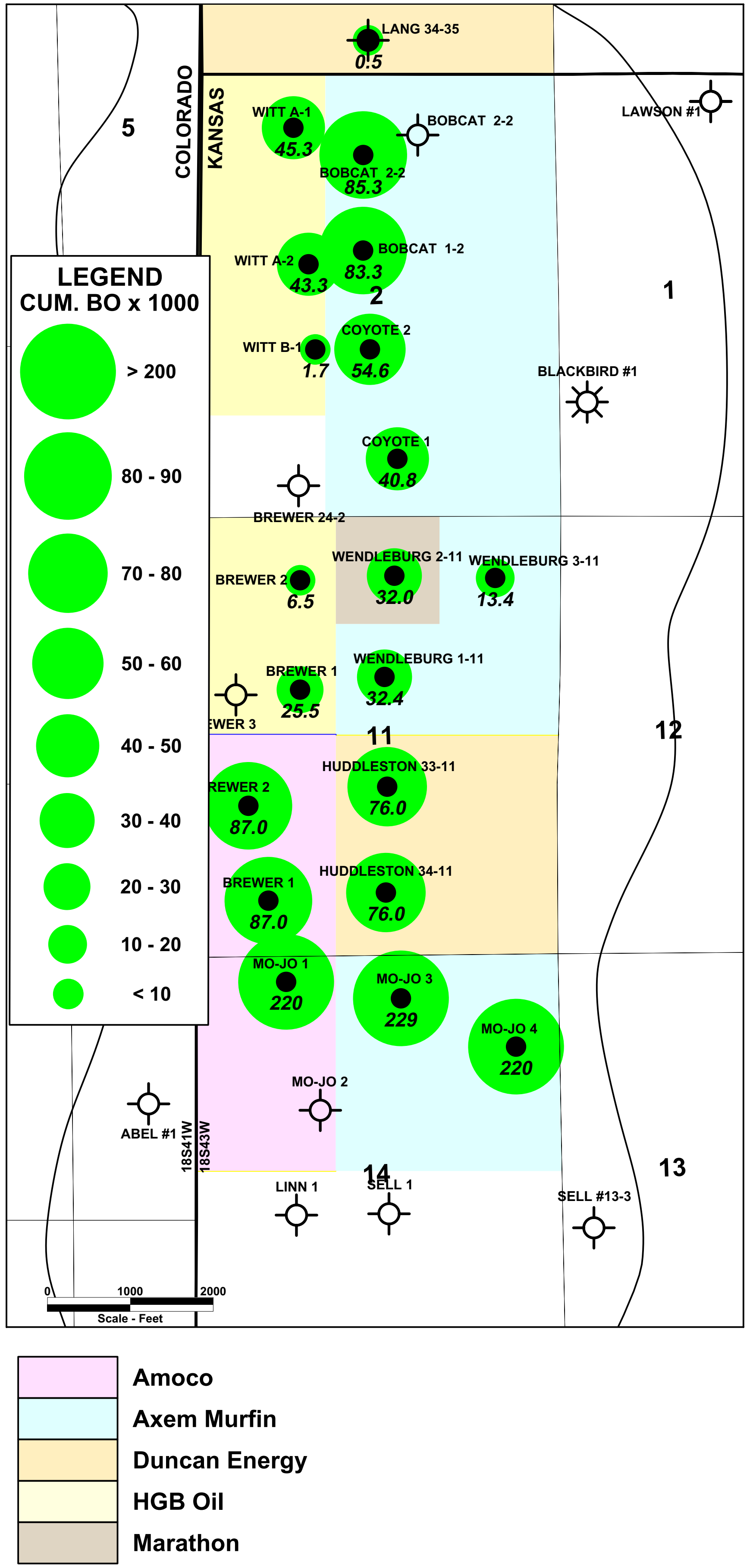
The reservoir sands at Moore-Johnson Field were deposited as fluvial valley-fill deposits in a valley incised into the Morrow Limestone (see cross section). These Morrow sands have been correlated regionally to the Morrow V7 valley sequence (see stratigraphic nomenclature).The areal distribution of the three reservoir sands deposited within the incised valley is shown by the figure on the left. From oldest to youngest, the order of deposition was V7b, V7c, V7d valley fill-sequences.

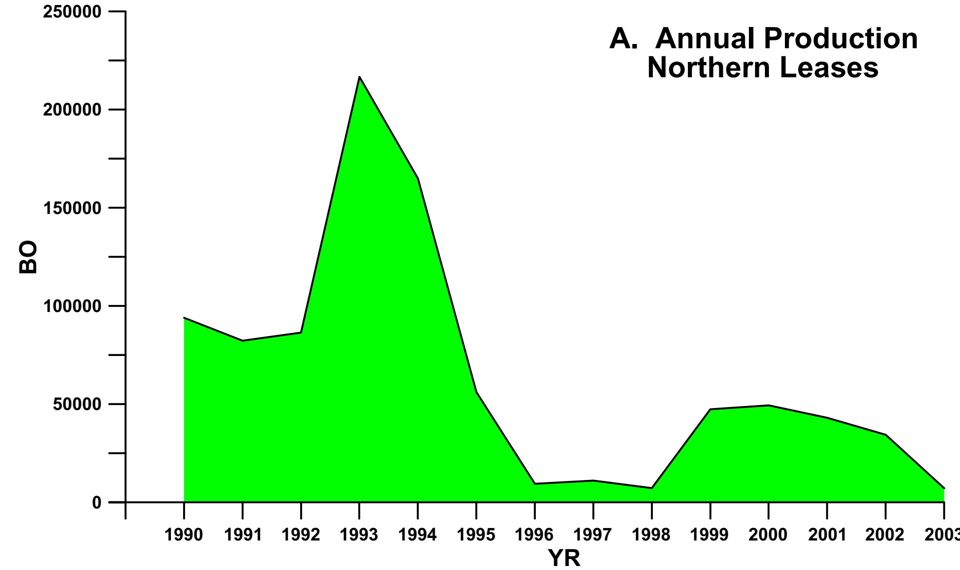
Structural cross section A-A' depicts the positions of the three valley-fill sequences with respect to depth. Regional dip is to the east-southeast. The various Morrow reservoirs were encountered at depths ranging from 5100 to 5150 feet. Initial reservoir pressure was 1040 psi. Other reservoir parameters are shown in the table.

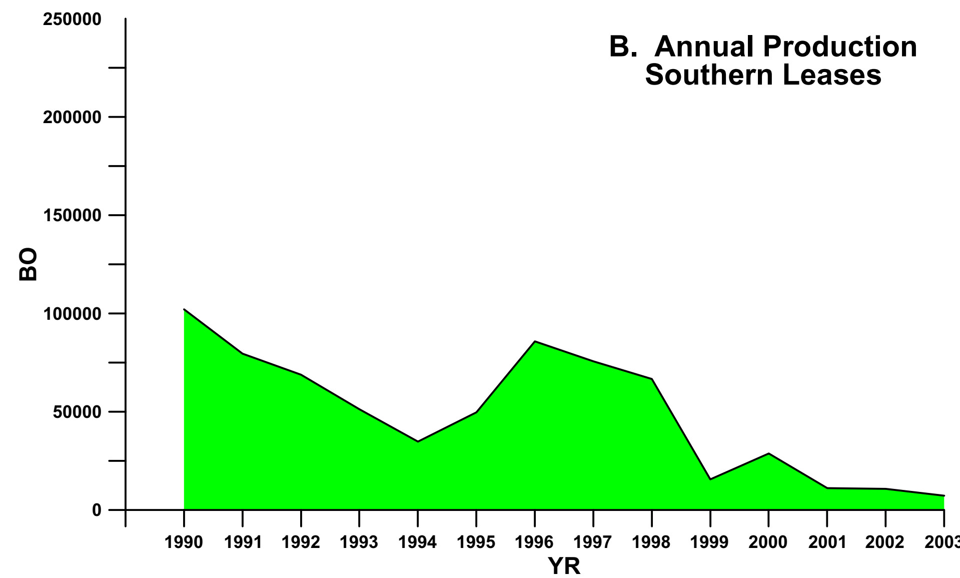
The three reservoir sand bodies are predominantly lateral to each other and are rarely incised into one another as is the case in the northern fields. Generally, the three sand bodies are completely encased in estuarine shales. Porosities range from 14% to 28 % with permeabilities from 22 to 9,990 md (Adams, 1990). The GOR was 107: 1 (cu ft/bbl)

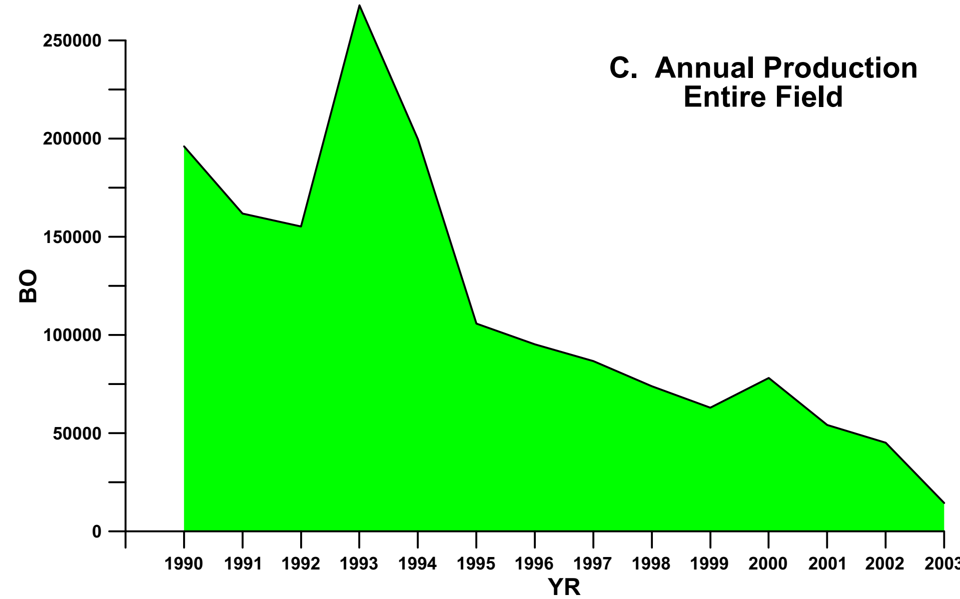
Compared to the V7 valley fill reservoirs in northern fields, the reservoirs at Moore-Johnson are narrower in cross section (see map legend) and of smaller extent and more compartmentalized due to the dominant shale facies. Because of these conditions, oil columns are thinner and production values are somewhat lower, however, drainage efficiency is high (Bowen and Weimer, 2003). Recovery factors are variable due to, in some cases, problems with pressure maintenance.

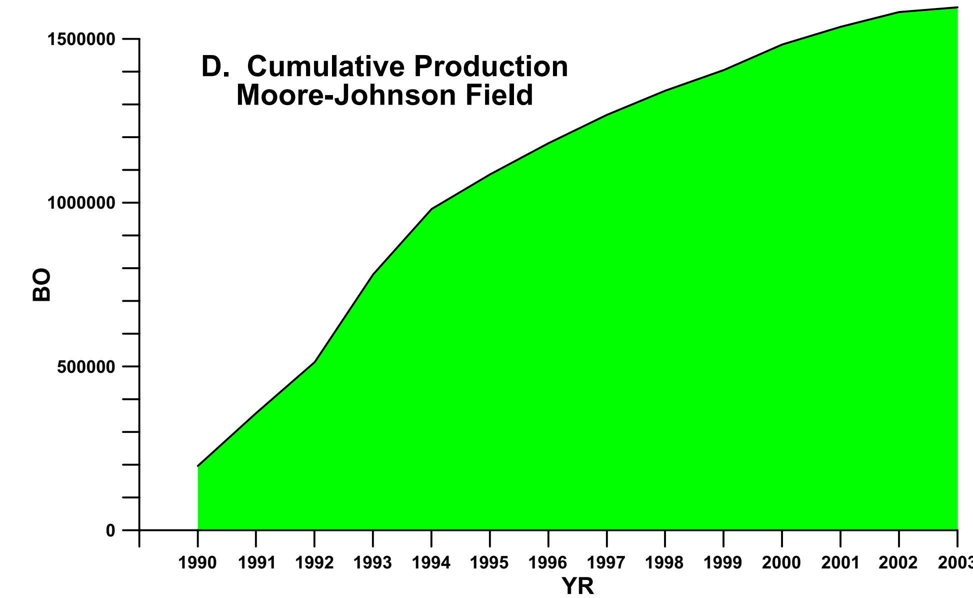
Oil volumes produced to date from individual wells range from 32,000 BO to over 230,000 BO. The field-wide average, to date, for the 19 wells is 91,000 BO per well. These per well averages are better than the average values at Castle Peak, Harker Ranch, SW Stockholm, and Jace Fields reported by Bowen and Weimer (2003).











Oil Production at Moore-Johnson Field

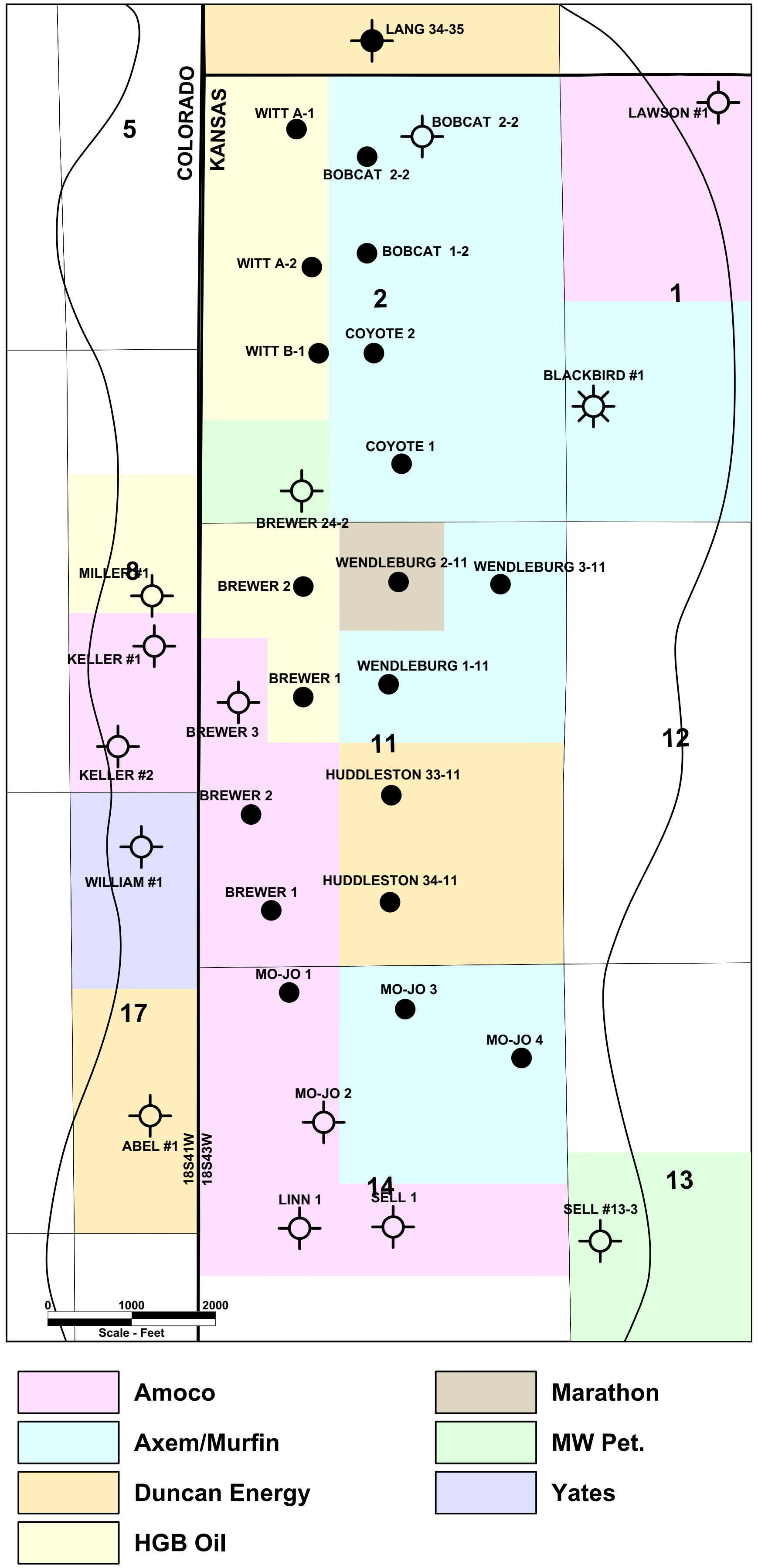
Production for Moore-Johnson Field is reported by the Kansas Geological Survey (KGS). Cumulative production is reported by lease and not individual wells. To attempt to show variation in production in the individual wells, the lease production totals were divided by the appropriate number of wells in each lease. The figure on the left illustrates the variation in production among all the wells. Note the differences in cumulative production between the Witt "A" and Bobcat leases in the north part of the field.

Annual production for the northern leases (Witt, Bobcat, Coyote, Brewer, Wendleburg and Huddleston) is shown in Graph A. The peak in production from 1992 to 1995 reflects the addition of the new development wells. Annual production volumes for the Moore-Johnson lease are shown on Graph B. The peak in production from 1994 to 1998 reflects the addition of the Axem/Murfin Moore-Johnson #3 and #4 wells. Annual production volumes for the entire field are shown in Graph C. Total production for the field in 2002 was 45,000 BO. Since 1997, annual production volumes have been declining at a rate of about 15% per year.

The field was unitized in 1995 for pressure maintenance by gas and water re-injection. Effects of secondary recovery operations in the north leases can be seen, beginning in 1998, in Graph A and for the south lease in 1999 on Graph B.

Cumulative production for the field is shown on Graph D. The year to date total production for the field is 1,729,000 BO. Average per well production for the 19 wells in the field is 91,000 BO. Average per well production for the eight Axem/Murfin wells is 93,750 BO.

The KGS reported 7 wells still producing in 2003. Ultimate recoverable reserves for the field will be about 2,000,000 BO.



SUCCESS RATIOS

COMPANY	TOTAL WELLS	OIL COMP.	D&A	SUCCESS RATIO
MW Pet.	2	0	2	0 %
Amoco	10	3	7	30 %
Duncan Energy	4	2	2	50 %
HGB Oil	6	4	2	67 %
Axem/Murfin	10	9	1	90 %

SUCCESS RATIOS

COMPANY	TOTAL WELLS	OIL WELLS	D&A	SUCCESS RATIO
Amoco	10	3	7	30 %
MW Pet.	2	0	2	
Duncan Energy	4	2	2	
HGB Oil	6	4	2	
Total for 3 Companies	12	6	6	50 %
Axem/Murfin	10	9	1	90 %

Moore-Johnson Field: In Retrospect

The major advantage of using detailed soil gas surveys for exploitation/development drilling is to increase the success rate (risk reduction). A total of 34 wells were drilled both to define the limits of the field and to develop the Morrow reserves in Moore-Johnson Field culminating with 19 producing wells and 15 dry holes. An initially completed well at the north end of the field (Lang #34-35) was a marginal well (447 BO) which was converted to an injection well and later into a salt water disposal well and is considered as a dry hole. This represents an overall success rate of 56%, which at the end of 1994, was on the low side of the industry average in the Morrow Trend.

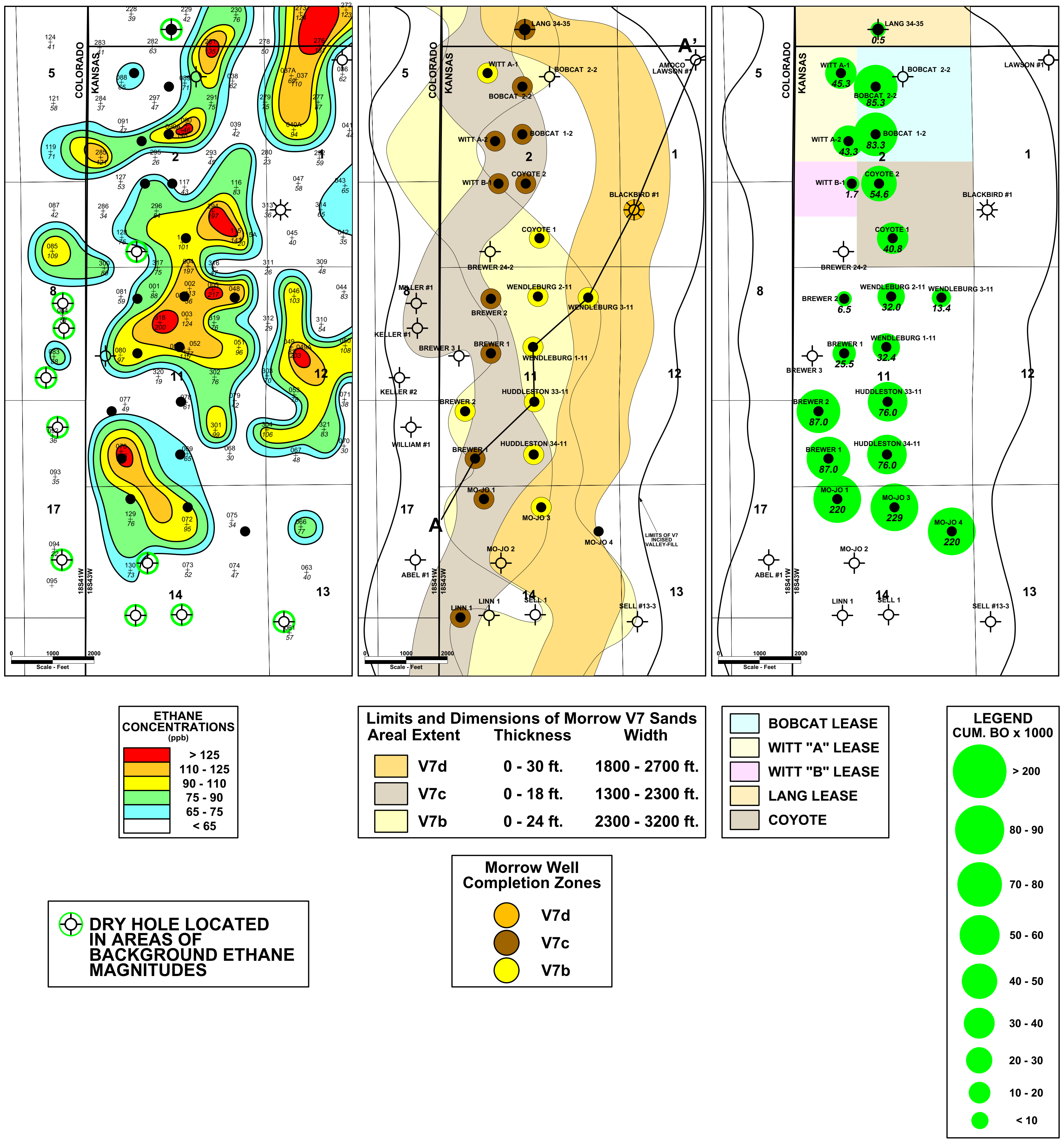
To characterize the success rate at this field in this way is somewhat misleading. The drilling statistics are severely hampered by the dismal Amoco success rate of 30% and, on the other hand, strengthened by the exceptional Axem Res. and Murfin Drl. success rate of 90%. A better way of characterizing the success rate at Moore-Johnson Field is to look at the individual drilling statistics of five companies. The major lease blocks held by the operators in the field, along with the completed wells, is shown on the map on the far left. Marathon and Yates each drilled only one Morrow oil well and one dry hole, respectively, in the field area and are not dicussed further.

As shown in the Table 1 on the left, the success rates for the six companies, that drilled at least 2 wells, ranged from 0% (MW Pet.) to 50% (Duncan Engin.) to 90% for Axem Res. and Murfin Drl.. The chief reason for the high success rate of Axem Res. and Murfin Drl. was that they used an integrated approach of surface geochemistry, subsurface geology and geophysics.

This analysis, however, uses widely varying populations of drilled wells. If the Duncan Ener., MW Pet., and HGB Oil wells are grouped together, then an even comparison can be made to Axem/Murfin and Amoco with the groups each having drilled 10 or 12 wells. As Table 2 indicates, Amoco and the Duncan – HGB Oil – MW Pet. group had a success rates of 30% and 50%, respectively, (without using geochemistry) and the Axem/Murfin group had a 90% success rate.

Axem/Murfin drilled 9 successful Morrow wells which accounted for 47% of the total Morrow oil wells in the field. HGB Oil and Duncan Ener. both gained valuable subsurface control from these Axem/Murfin wells which ultimately helped increase their success rate. The Axem/Murfin Coyote #1 and Wendleburg #1-11 were very early Morrow completions which greatly aided HGB Oil in evaluating their southern leases.

Besides discussing success rates, the benefits of using surface soil gas geochemistry can also be illustrated by considering discovered oil reserves. Cumulatives for the 3 companies are listed on Table 3. By drilling 10 wells Duncan Energy and HGB Oil had a cumulative production (to 2003) of 418,429 BO. By drilling the same number of wells, Axem/Murfin wells had produced 749,800 BO. This is almost twice as much production. By drilling only 29% of the total wells (34), Axem/Murfin wells, to date, have produced 47% of the produced reserves. The ultimate recoverable reserves for Moore-Johnson Field are estimated at 2,000,000 BO.



Advantages and Limitations of Soil Gas Surveys

As previously discussed, the major advantage of soil gas surveys in the Morrow oil trend is that of risk reduction, or, improving the success ratio. As shown on the figure on the far left, had the survey been available to all companies, then obviously, 11 of the dry holes on the west side and the north and south end of the field would not have been drilled. This alone would have increased the overall success rate for the field from 56% to 82%. Had the data been available to Amoco in 1990, at least five of the dry holes could have been avoided increasing Amoco's success rate from 30% to 60%.

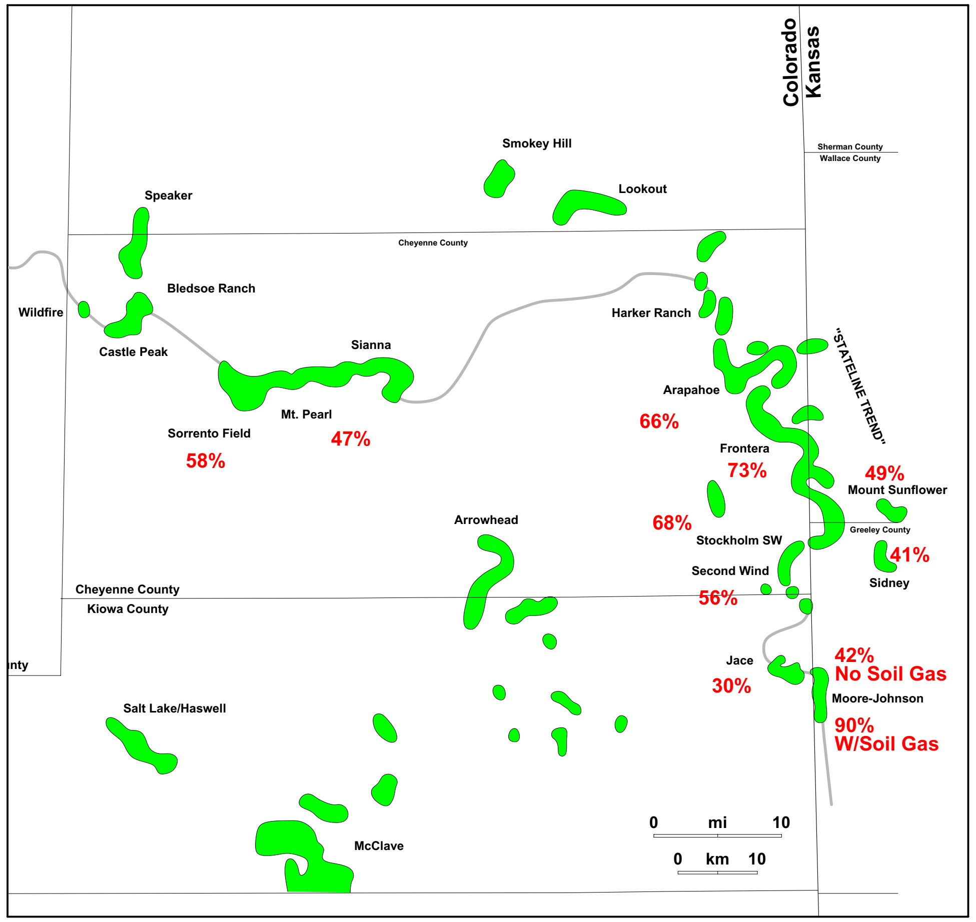
Another major advantage of soil gas surveys is the relatively low cost. Considering sample collection, laboratory analyses, and interpretation and reporting costs, the present day cost of the 106 site soil gas survey conducted at Moore-Johnson Field would be about $14,000. This is only about 15% of the dry hole cost of a single Morrow well.

In this portion of the Morrow trend, the sample density of 16 sites per section is only adequate for defining a lead or prospect area and possibly acquiring acreage. This sample density is not adequate for exploitation or development drilling. A sample density of at least 30 sites per section is needed as was shown at Moore-Johnson Field (LeBlanc and Jones, 2004).

Surface soil gas geochemistry will not eliminate all dry holes being drilled within a field. The example previously discussed of the Bobcat #2-2 wells is a good example to illustrate this point. As pointed out by Bowen and Weimer (2003), the V7 sands in this part of the Morrow trend are of smaller areal extent, smaller in cross section, and more compartmentalized than in the Morrow fields to the north. At the sample density of this survey, microseep anomaly patterns could not distinguish the individual trends of the V7b, V7c, and V7d reservoirs. This is because the widths only range from 1800 to 3000 feet (see map legend). Perhaps a denser soil gas grid may have provided the necessary resolution.

Soil gas anomaly data can not distinguish between oil reservoirs of different geologic ages. In this part of the Morrow trend, in most wells the Mississippian has been a secondary (or primary) objective. Although not productive at Moore-Johnson Field, anomalous microseeps in the surrounding area could indicate Mississippian potential in addition to Morrow. Additionally, shows were reported in some wells in the Pennsylvanian Lansing-Kansas City interval.

There is no direct relationship between the magnitudes of microseeps and either the rate or total volume of hydrocarbons a well will produce except in a very general sense. As can be seen comparing the ethane contour map to the production map on the near left, the Bobcat lease (170,646 BO) has been more productive than the Witt "A" lease (90,575 BO) and the Lang lease (477 BO). Similarly, the Coyote lease (95,362 BO) has been more productive than the Witt "B" lease (1745 BO). The ethane magnitudes suggest differences that may be related to these production volumes. This suggests that the amount of reserves on a prospect could likely be improved by a company getting a competitive edge in early lease acquisitions based on soil gas data. One of the reasons that Axem/Murfin had such sizeable reserves at Moore-Johnson Field was their excellent lease position.



Factors Affecting the Rate of Return in the Morrow Trend

FACIES TRACT	FIELD	RESER-VOIRS	SUCCESS RATIO	YRS. TO DEVELOP	AVG. PER WELL RESERVES BO
UPDIP	Sorrento	V7	58%	10 YRS. 1979-1988	358,333
	Mt. Pearl-Sianna	V7	47%	6 YRS. 1984-1990	321,429
TRANSITIONAL	Arapahoe	V3 V7	66%	3 YRS. 1988-1990	154,419
	Frontera	V7	73%	3 YRS. 1988-1990	106,429
	SW Stockholm	V7	68%	9 YRS. 1979-1988	69,892
	Second Wind	V3 V7	54%	4 YRS. 1988-1991	139,474
	Sunflower	V1 V3 V7	49%	4 YRS. 1993-1998	83,500
	Sidney-Kriss	V1 V3 V7	41%	9 YRS. 1990-1999	42,950
DOWNDIP	Jace	V1 V7	31%	5 YRS. 1989-1993	63,846
	Moore-Johnson	V7	42% W/O SOILGAS SURVEY 90% W/ SOIL GAS SURVEY	2 YRS. 1992-1994	91,000

Recommendations

The table and map list success rates for development drilling in representative fields in the Morrow oil trend and other factors (yrs. to dev., per well reserv.) affecting the rate of return in the Morrow trend. The fields are grouped according to the facies tracts as defined by Bowen and Weimer (2003). It is apparent that the newer fields most recently developed (Jace, Sunflower, Sidney) have the lowest success rates. As shown at Moore-Johnson field, high-density soil gas surveys could 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. As discussed by Bowen and others (1993) initially (1979 to 1984), an incorrect depositional model was the main reason for the rather lengthy development time frame at these two fields.

Success rates for Morrow exploration wells were reported by Bowen and others (1993) to have been 5% in the Sorrento-Mt. Pearl-Sianna area and reported by Moriarty (1990) to have been 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 and 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 might exist (Bowen and Weimer, 2003, Figure 10). 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 (LeBlanc and Jones, 2004a).

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. As reported by Bowen and Weimer (1997, 2003) 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 were outlined by Wheeler and others (1990) in Wallace County, Kansas and farther south in Kiowa, Brent, and Powers Counties, Colorado.

A high degree of compartmentalization has been observed in the 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 (KGS, 2003). Likewise, Cretaceous age incised valley-fill systems exist in Rocky Mountain areas such as the Denver, Powder River, and Williston basins. The generalized paleodrainage network for the Muddy Formation was illustrated by Weimer (1992, Fig. 3) over the north Colorado, Wyoming, and eastern Montana areas. A more detailed picture of paleovalleys in the Denver basin which were filled with Muddy valley-fill sandstones was also presented.

The advantages of using each of the disciplines of geology, geophysics, and soil gas geochemistry in Morrow exploration and development are well known, however the three disciplines have seldom been 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 and others (1993) discussed limitations of subsurface geology and 2-D seismic in locating reservoir quality sandstones in the Sorrento-Mt. Pearl-Sianna area. Germinario and others (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, multidisciplined approach of using geology, geophysics, and soil gas geochemistry in Morrow exploration (LeBlanc and Jones, 2004b) is a superior method whereby the advantages in one of the three disciplines complement and overcome the limitations or shortcomings of another.

Summary

A high-density soil gas survey was conducted in the vicinity of Moore-Johnson Field in 1992. The survey was conducted after the discovery of the field and initial development attempts, all by the same major oil company, which resulted in a total of 10 wells (3 oil wells, 7 D&A). A second attempt to extend the field, starting in 1992, was conducted by six independent oil companies. One of the companies used an integrated approach of combining subsurface geology and seismic with a detailed geochemical soil gas survey. The remainder of the 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 to both define the limits of the field and develop the Morrow reserves. By only drilling 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 as characterized by Bowen and Weimer (2003). The 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 the northern fields. Although reserves are lower in the downdip facies, employing soil gas geochemistry can improve the relatively low success rates now being encountered in this area. This could vastly improve the rate of return.

This documentation of a successful application of a detail soil gas survey 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 Midcontinent and Rocky Mountain basins.

Soil gas geochemistry is not a panacea for Morrow exploration, exploitation, or development drilling, but is an 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 would provide a very powerful synergistic effect to Morrow exploration and development projects.

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FIGURE CAPTIONS AND CITATIONS

Figure 1. Location maps of Morrow oil trend, eastern Colorado and western Kansas. (A) Hugoton Embayment, Denver basin, and bounding tectonic features. (B) Location of Moore-Johnson field with respect to other fields in Morrow oil trend. From Bowen and Weimer (2003).

Figure 2. Discovery and early development of Moore-Johnson field 1989-1990. (A) Location of Moore-Johnson field with respect to other fields in Stateline Trend. (B) Amoco concept of distribution of Morrow sandstone reservoirs as of May 1990. (C) Chronology of early field extension attempts. Modified from Bowen and Weimer (2003) and Adams (1990).

Figure 3. Location maps of regional soil gas survey grids. (A) Location of north and south regional soil gas surveys in Morrow oil trend with respect to oil fields in the Stateline Trend. (B) Detail of south Stateline Trend soil gas survey showing locations of soil gas sample sites. Area of High-density soil gas survey in Moore-Johnson field area.

Figure 4. Ethane magnitude soil gas contour maps in the Moore-Johnson field area. (A) Ethane magnitude contour map of soil gas data from calibration survey. (B) Ethane magnitude contour map of soil gas data from high-density grid.

Figure 5. Integration of subsurface geology, geophysics, and soil gas geochemistry. (A) Combined geological and seismic interpretation of location of Morrow incised valley and sandstone fairway. (B) Anomalous ethane microseepage pattern detected at the surface from vertical migration from the underlying oil reservoirs. (C) Structural cross section A-A' illustrating stratigraphic and structural relationships of Morrow formation derived from 2-D seismic and well data. Extent of ethane microseeps also indicated. See Figures 5A and 5B for locations of cross section.

Figure 6. Chronology of development drilling during 1992. (A) Locations of previously completed wells in Moore-Johnson field area and wells drilled in 1992. Circled reference numbers refer to corresponding sections in text. (B) Contour map of ethane magnitudes showing geochemical basis for selection of development well locations. Well locations modified from Bowen and Weimer (2003) and Kansas Geological Survey (2003).

Figure 7. Chronology of development drilling during 1993 and 1994. (A) Locations of previously completed wells in Moore-Johnson field area and wells drilled in 1993 and 1994. Circled reference numbers refer to corresponding sections in text. (B) Contour map of ethane magnitudes showing geochemical basis for selection of development well locations. Well locations modified from Bowen and Weimer (2003) and Kansas Geological Survey (2003).

Figure 8. Subsurface geology and reservoir parameters of Moore-Johnson field. (A) Areal distribution of Morrow V7 reservoir sandstones within incised valley. Note sequence of deposition, ranges in thickness, and width of Morrow V7b, V7c, and V7d valley sequences. (B) Stratigraphic nomenclature of Morrow formation in eastern Colorado and western Kansas. Overlying and underlying formations also indicated. (C) Structural cross section A-A' depicting both stratigraphic and structural elements contributing to entrapment of hydrocarbons at Moore-Johnson field. Location of cross section indicated in 8A. Modified from Bowen and Weimer (2003).

Table 1. Moore-Johnson field parameters. Data from multiple sources but chiefly from Adams (1990).

Figure 9. Oil production from Moore-Johnson field. (A) Variation in cumulative production from individual leases and wells. Dot size is proportional to cumulative oil volumes. (B) Annual oil production from 1990 to 2003 for north leases. (C) Annual oil production from 1990 to 2003 for Moore-Johnson leases. (D) Annual oil production from 1990 to 2003 for entire field. (E) Cumulative production for field from 1990 to 2003. Annual oil production data ffor field and leases from Kansas Geological Survey (2003).

Figure 10. Well status and lease blocks for oil companies involved in development of Moore-Johnson field from 1989 to 1994. Thirty-four wells were drilled to define and develop the field.

Table 2. Success ratios for oil companies involved in development of Moore-Johnson field. (A) Success ratios for all oil companies. (B) Success ratios for groups drilling ten or more wells.

Figure 11. Summary of results of multi-disciplined approach for development of Moore-Johnson field. (A) Ethane magnitude contour map. Note locations of dry holes in areas of ethane background concentrations. (B) Areal extent of Morrow V7 sandstone reservoirs at Moore-Johnson field. (C) Cumulative production from wells in Moore-Johnson field.

Figure 12. Fields in Morrow oil trend. Development drilling success ratios are listed for representative fields. Additional information pertaining to factors which affect the rate of return is listed in Table 3. Map of oil fields modified from Bowen and Weimer (2003).

Table 3. Factors affecting the rate of return in the Morrow oil trend. Data from columns 1, 2, 3, and 6 from Bowen and Weimer (2003). Data in columns 4, and 5 compiled from other sources.