Open File Report 498

Geologic trends of oil and gas production in the Secretary of the Interior's Potash Area, Southeastern New Mexico

Final Report to the Bureau of Land Management

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Executive summary

The Bureau of Land Management (BLM) is charged with managing leases for resource development in the Secretary of the Interior's Potash Area (SPA), Southeastern New Mexico. Because oil and gas wells must pass through potash layers to reach their targets, wells in the Secretary of the Interior's Potash Area (SPA) are allowed only by special permit and must be more than ¼-mile from existing mine workings. Potash mining companies allow ¼ mile berth around existing oil wells. The resulting conflict between oil and gas operators and potash mining companies over resource development initiated work by the BLM to assess the future potential of these resources.

The BLM needs accurate and complete databases for each industry, as well as geologic interpretations to guide future development. Prior to this study, the New Mexico Oil Conservation Division (NMOCD) provided the only digital oil and gas well database publicly available. The NMOCD well database primarily contained header and recent production data with little geologic information, and the quality, completeness, and accuracy were inconsistent.

The results of this study are intended to assist the BLM by providing a comprehensive oil and gas database and by identifying geologic trends that are favorable for oil and natural gas production. The New Mexico Bureau of Geology and Mineral Resources (NMBGMR) database provides complete geologic coverage for oil and gas wells within the SPA, and provides some additional information in a six-mile-wide area outside the SPA. The project added more than 100 fields to the available NMOCD data, including the following: depths to stratigraphic units, perforations and initial production, producing formations, core interpretations, and drill stem test results from well records, and new, internally consistent correlations for as many as 16 stratigraphic units and measured net sand thickness for several key formations.

Geologic analysis using the new database, along with existing published geologic interpretations, helped to define oil and gas production trends within the SPA. Geologic analyses were focused on two of the major reservoir zones, the Brushy Canyon and the Morrow Formations, which together produce almost 80 percent of the oil and gas within the SPA. Geologic summaries of several other productive stratigraphic units provide general information and relative potential of those units. Even considering only the Brushy Canyon and Morrow Formations, a large part of the SPA has significant future oil and gas potential along presently producing trends.

Introduction

The relative position of deep (~2000 to >14000 ft) oil and gas resources to shallow (<2000 ft) potash resources in southeastern New Mexico has caused conflict between the two industries due to mining safety concerns. Oil and gas wells in the Secretary of the Interior's Potash Area (SPA) are allowed only by special permit and must be more than ¼-mile from existing mine workings, and potash mining companies allow ¼ mile berth around existing oil wells (Herrell 2006). The Bureau of Land Management (BLM) has to manage potash and oil leases and activity within the SPA. Prior to this study, the New Mexico Oil Conservation Division (NMOCD) provided the only publicly accessible digital well database available (New Mexico Oil Conservation Division 2005). The NMOCD well database primarily contained header and recent production data with little geologic information, and the quality and completeness of information for individual wells were sporadic. Locations in that database were apparently calculated using at least two different methods. For this project, New Mexico Bureau of Geology and Mineral Resources (NMBGMR) workers developed an extensive database which includes the NMOCD data, and we have added geologic data from well records and new stratigraphic correlations over the entire SPA. The Petroleum Research and Recovery Center (PRRC) calculated well locations in latitude and longitude format over the entire area using one consistent method. There have been many pool-scale geologic studies and some larger basin-scale studies that include the SPA, but no published regional studies describe the oil and gas geology of the SPA specifically. This study used the new database correlations and stratigraphic and structural analyses, along with published interpretations, to examine the geologic trends of oil and gas production so that the (BLM) can better manage the resources involved with this conflict.

The SPA in Southeastern New Mexico encompasses approximately 760 square miles in the northern portion of the Delaware Basin and southwest portion of the Northwest Shelf (Fig. 1). Operators have drilled more than 2600 oil and gas wells within the Potash Area boundaries. The enclosed database is intended to provide the Bureau of Land Management (BLM) with current, accurate information and should be updated quarterly or yearly to retain maximum value. Appendix A includes a complete description of the database and all of the tables and fields that it contains. Appendix B contains definitions for geologic terms that may be unfamiliar to the reader.

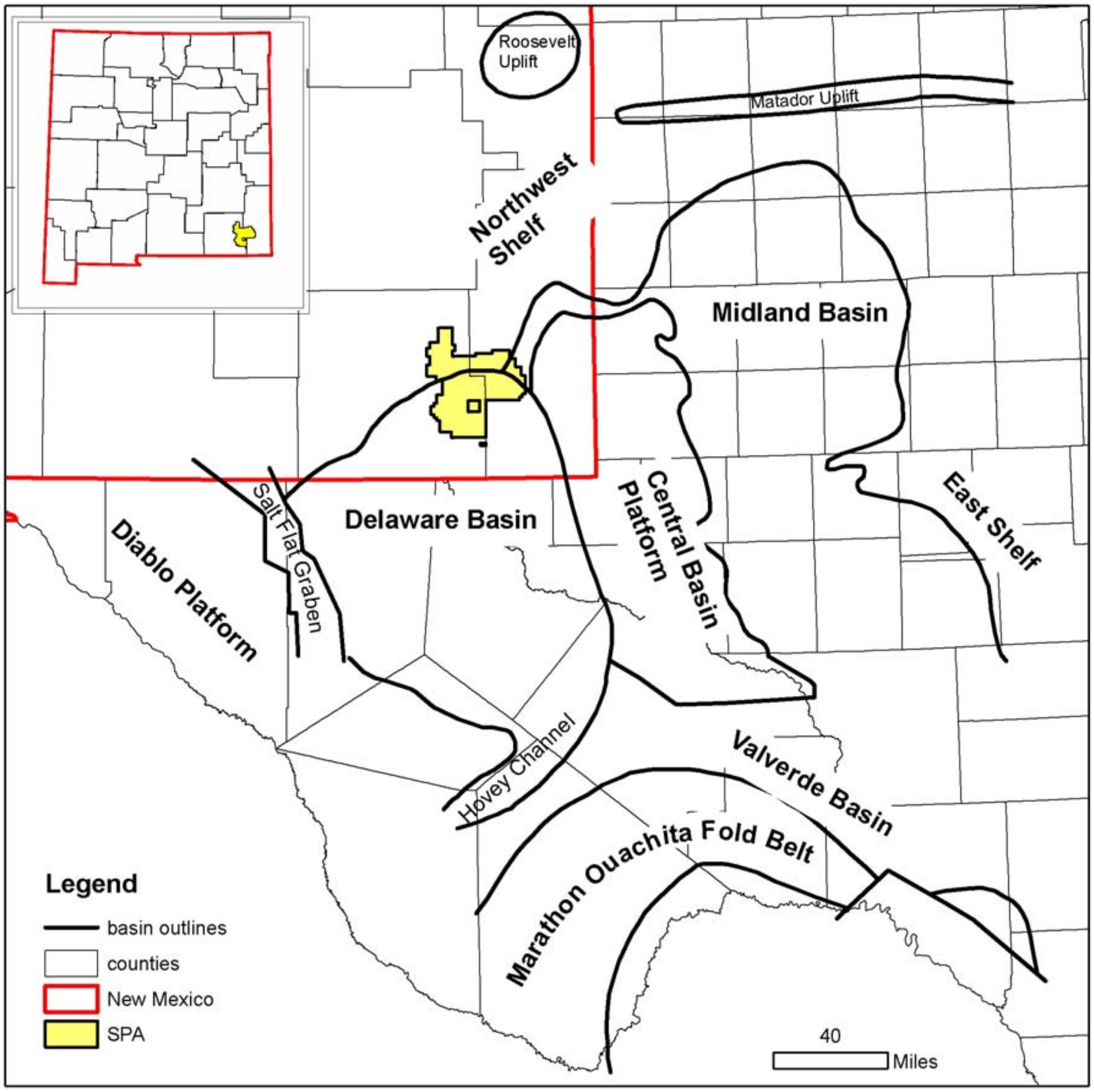


Figure 1. Geologic overview map with basin outlines, Secretary of the Interior's Potash Area (SPA) boundary, and New Mexico and Texas counties (Modified from (Hills 1984). Inset shows SPA location within New Mexico.

Geologic overview

Several published papers have provided summaries of the tectonic history of the study area, which will be summarized here (Hills 1984; Broadhead et al. 1998; Montgomery et al. 1999). The Delaware Basin is a structurally-defined, deep-marine portion of the Permian Basin. Renewed movement along Proterozoic faults during the Pennsylvanian differentiated the Delaware Basin from the Central Basin Platform and Midland Basin to the east. Starting in the Early Permian, several reef complexes created the constructional shelf margin between the Northwest Shelf and the Delaware Basin, and this margin is probably underlain by deep basement faults. Thick sequences of Pennsylvanian and

Permian strata provide the primary source and reservoir rocks within the area. Carbonate and clastic rocks provide reservoirs around the basin margins, while clastic rocks typically provide reservoirs in the deeper portions of the basin. Carbonate debris flows also provide reservoirs on the slope. The basin is a prolific producer with over 1.8 billion barrels (Bbbl) of oil in place at the time of discovery (Dutton et al. 2000). Overlying the >10,000 feet of oil and gas producing strata, shallow (<2000 ft.) Late Permian (Ochoan) evaporites provide potash resources within the area. This study describes the oil and gas producing units.

As many as nineteen vertically stacked pay zones produce in some areas of the Delaware basin, providing incentive to drill vertical wells, offsetting costs of deeper wells with possible shallow pay, and lowering risk (Worthington 1999). However some reservoirs may be better developed by horizontal wells to increase effective permeability. Strata providing commercially producible hydrocarbons within the Potash Area include the Morrow, Atoka, and Strawn Formations (Pennsylvanian); the Delaware Mountain Group, Bone Spring Formation, Wolfcamp Group, Queen, Grayburg, Seven Rivers and Yates Formations (Permian) (Fig 2). The Queen, Grayburg, Seven Rivers, and Yates Formation are the shelfal equivalents of the Bell Canyon and Cherry Canyon (Delaware Mountain Group) basinal rocks (Fig 2a). As of 2004, The Delaware Mountain Group provides primary oil production, and the Brushy Canyon Formation within the Delaware Mountain Group and the Morrow Formation provide primary natural gas production (Fig 2b, Table 1). The Brushy Canyon and Morrow Formations are the most significant producers and will hold the largest presently identifiable future potential. Maps and discussions also summarize production geology of other significant stratigraphic units, including the Atoka and Bone Spring Formations.

Table 1. 2004 annual production from reservoir systems in the SPA
(New Mexico Oil Conservation Division 2005)

	2004 gas production (MMcf)	2004 oil production (Mbbl)	2004 calculated barrels of oil equivalent (Mboe)
Delaware Mountain	10204	3817	5518
Bone Spring	1095	368	550
Wolfcamp	97	22	38
Strawn	1271	69	281
Atoka	2957	85	578
Morrow	10801	121	1922

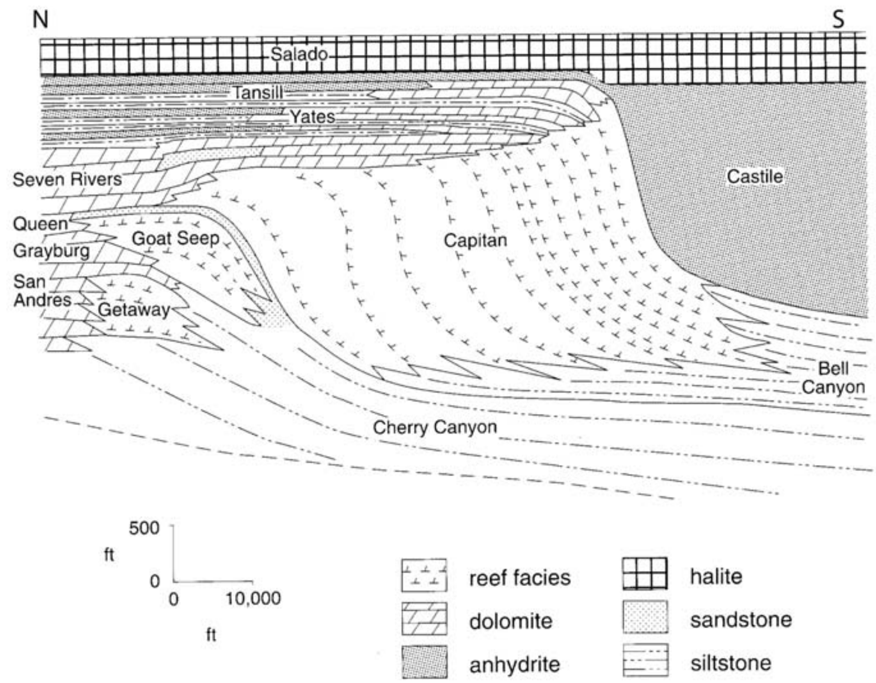
MMcf – million cubic feet of gas
Mbl – thousand barrels of oil
Mboe – thousand barrels of oil equivalent, assuming 6 Mcf/bbl

Well drilling and development history

NMBGMR well records indicate that the earliest wells drilled within the Secretarial Potash Area date back to the 1920’s, producing from sandstone and dolomite reservoirs in the Yates, Seven Rivers, Queen, and Grayburg Formations. According to NMOCD records some wells drilled in the 1930's are still actively producing from these formations. Operators have drilled more than 2,600 wells since then with some correlation between drilling activity and oil prices, especially in the last 5 years and previously during the oil crisis of the late 1970's with increasing prices leading to increased drilling (Fig. 3).

Prior to 1970, most wells targeted shallow oil zones (Yates, Seven Rivers, Queen, Grayburg, and Delaware), with fewer than 60 out of ~850 wells being drilled to depths reaching Strawn or deeper formations. From 1970 to 1985 approximately half of the wells drilled (202 of 417) targeted gas in the deeper formations. These drilling programs often targeted structures associated with basement deformation, although the traps tend to be stratigraphic or combination structural-stratigraphic. The increase in drilling beginning in the late 1980's and peaking at 155 wells drilled in 1993 had two causes: 1) recognition and initial development of Brushy Canyon reservoirs throughout the New Mexico portion of the Delaware Basin and 2) opening up of new areas in the Potash district to drilling (Ramey 1995). More than half of the wells (380 of 744) drilled between 1987 and 1995 produced from the Brushy Canyon. This trend has continued with approximately half of the wells drilled since 1987 producing from the Brushy Canyon Formation (701 of 1344). The Morrow Formation has remained an important target during that time, but the stratigraphic nature of these reservoirs has probably not been fully exploited, as industry tends to drill on known structures rather than along stratigraphic trends. In 2004, the total production within the SPA was 27.3 billion cubic feet of gas (Bcf) and 4.77 million barrels of oil (MMbbl). In 2004, the Morrow and Delaware Mountain Group together produce 80% of the oil and gas resources in the SPA.

a)



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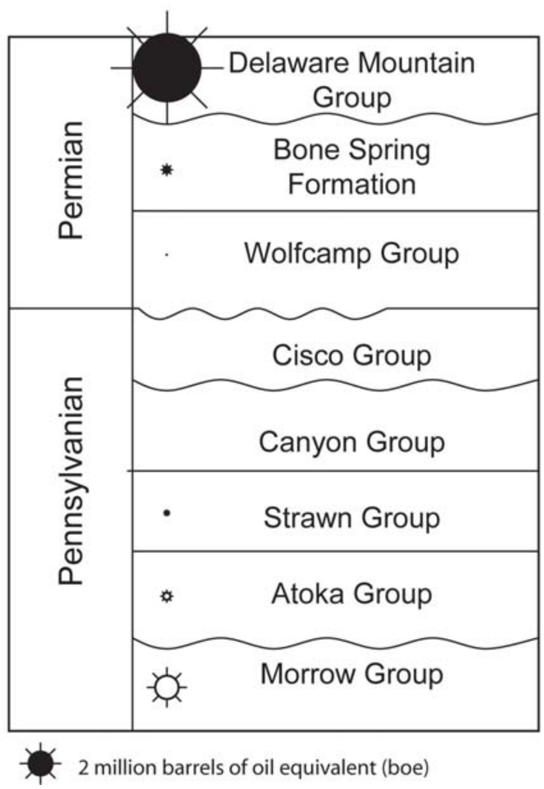

Figure 2. a) North-south cross section showing Capitan shelf margin barrier complexes and time relationship between Bell Canyon and Cherry Canyon (Delaware Mountain Group) basinal sediments with Yates, Seven Rivers, Queen and Grayburg Formations. After Garber et al. (1989, fig. 10). b) Partial Pennsylvanian and Permian stratigraphic column of oil and gas producing formations with symbols indicating relative quantities produced in 2004. Modified from Broadhead et al., 1998. Table 1 shows production data that were used to scale symbols.

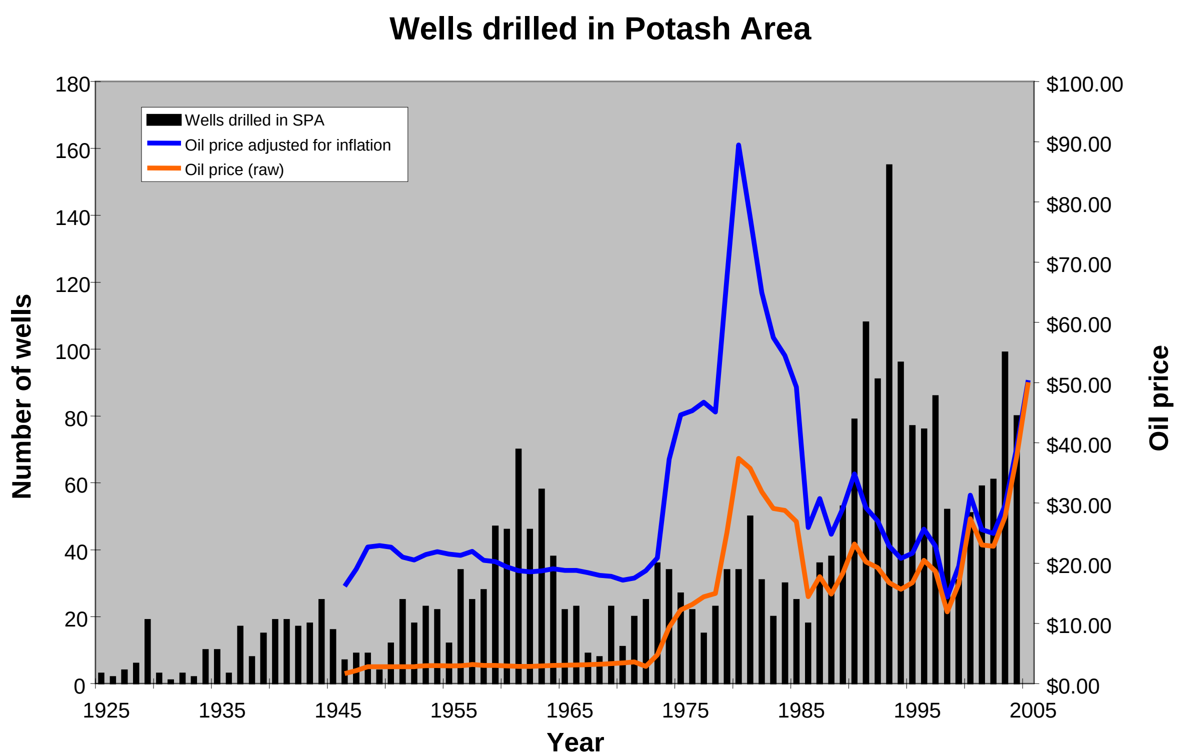

Figure 3. Well drilling activity within the BLM Secretarial Potash Area in Southeastern New Mexico compared with oil price. Oil price data from http://inflationdata.com/inflation/Inflation_Rate/Historical_Oil_Prices_Table.asp

Methodology of geologic interpretation

Well logs were correlated for the stratigraphic units shown in Figure 2 based on published cross sections and type logs. Correlating well logs involves comparing similar log features and interpreted lithologies to mark the boundaries between stratigraphic units, also known as "tops" or "picks". Individual companies and geologists may disagree on pick depths for stratigraphic units within a well or across an entire region. For this reason, a well log and one or more cross sections accompany the description of each formation. Appendix C contains brief descriptions and illustrations for each type of log used in this study. NMBGMR has an extensive collection of donated well logs, and these provided the foundation for correlations. Correlating at least one well per section where available ensured adequate coverage across the study area. Wells have not been drilled in many sections, and some wells do not have logs available. In some cases logs that are available online filled in the correlation gaps (New Mexico Oil Conservation Division 2005).

Structure maps from log correlations reveal whether trapping mechanisms tend to be structural or stratigraphic. For the lower Brushy Canyon and Morrow Formations, net sand thickness were measured based on gamma ray logs using a cutoff of 50 API (Fig. 4), which was selected to map trends of clean reservoir quality sandstones. The resulting thickness maps should not be used to estimate reservoir volume because units in this area tend to have interbedded hydrocarbon-saturated and wet sands, especially in the Brushy Canyon Formation (Montgomery et al. 1999). A combination of structure maps, stratigraphic trend maps based on interpretation of the thickness maps, and maps of existing production delineated areas with future oil and gas production potential for each stratigraphic unit.

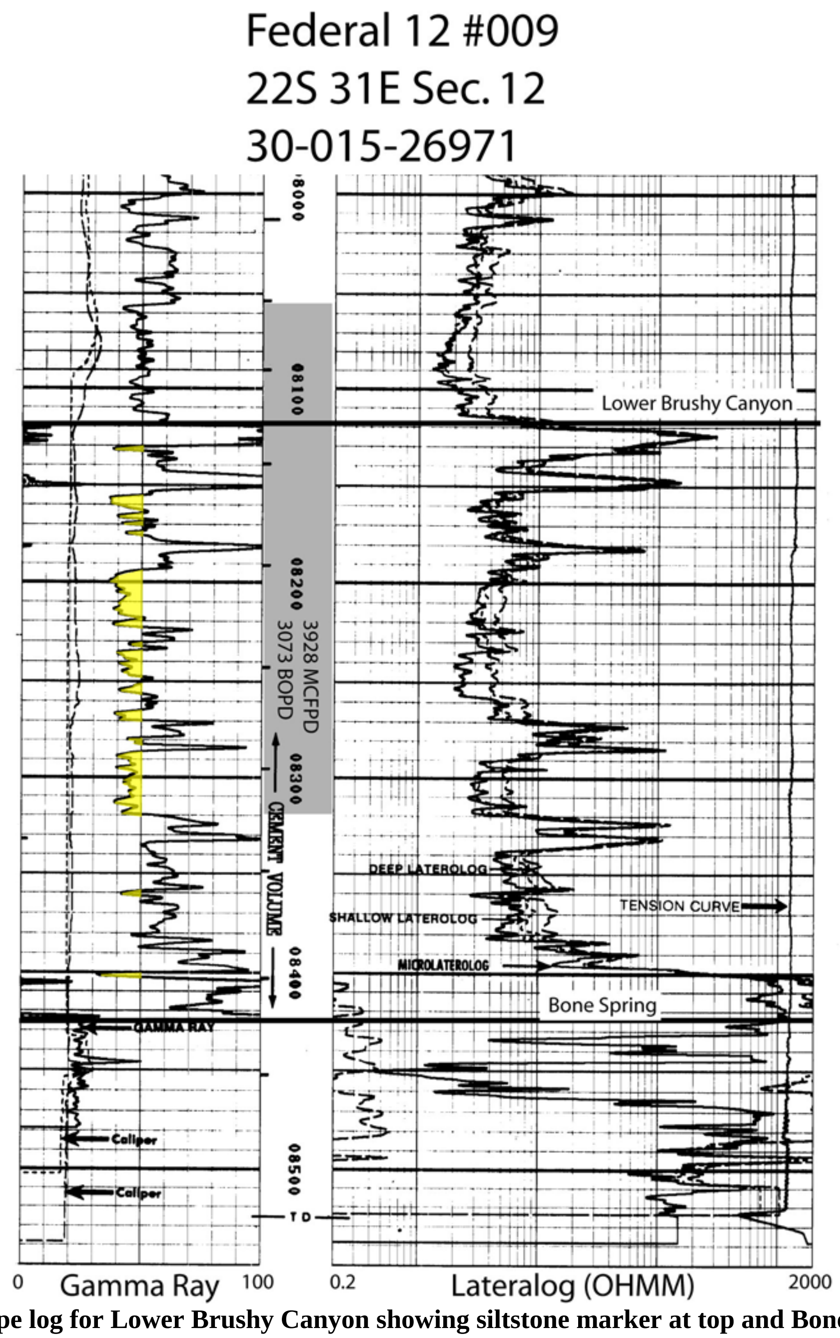

Figure 4. Type log for Lower Brushy Canyon showing siltstone marker at top and Bone Spring limestone at base. Yellow highlight demonstrates net sand thickness based on 50 API cutoff. Gray box shows reported perforations and initial production.

Geology of producing formations

Each of the producing formations will be considering individually, starting with the most significant producers. These descriptions will include summaries of published interpretations, type logs, cross sections, structure maps, net sand maps, trend maps, and oil- and gas-potential maps.

Delaware Mountain Group

Depositionally, the Delaware Mountain Group is the best understood due to surface exposure in the Guadalupe and Delaware Mountains, high industry interest as a target and as an analog, and a large number of penetrating wells (DeMis and Cole 1996; Beaubouef et al. 1999; Montgomery et al. 1999). The following summary is condensed from these sources. The Delaware Mountain Group is divided into three formations from youngest to oldest: Bell Canyon, Cherry Canyon, and Brushy Canyon. All three formations consist of interbedded sandstones, siltstones, and shales. The boundaries between the formations are difficult to correlate because of long distances from type sections and similar rock types and depositional environments that make up each formation. Researchers have proposed two primary depositional models for the sandstones, including turbidity currents and saline density currents (Harms and Williamson 1988; Gardner and Sonnenfeld 1996). Both models require submarine channels to deposit the sands. Several models have also been proposed to explain the deposition of siltstones that drape over channel sands and supply stratigraphic traps, including distal fans, fallout from density currents, and eolian fallout directly into the marine basin.

Previous studies have demonstrated that Brushy Canyon reservoirs tend to be elongate perpendicular to the basin margins, which means that reservoir-quality sandstone trends are roughly perpendicular to Bone Spring structure (Broadhead and Luo 1996; May 1996), (Fig. 5). The basin was tilted eastward somewhat due to Laramide (Late Cretaceous to Early Tertiary) deformation, so that some of the trends roughly parallel current Bone Spring structure near the current Bone Spring low (Figs. 5 and 6).

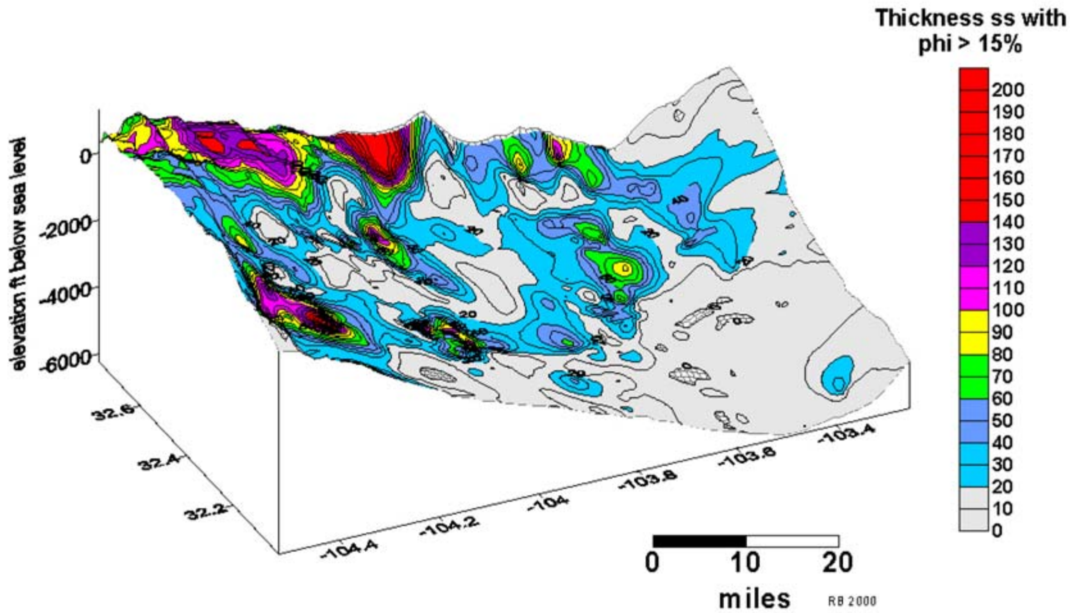

Figure 5. 3-D image showing lower Brushy Canyon sandstone thickness with porosity >15%, draped over Bone Spring structure (from(Broadhead and Justman 2000).

In 2004, the Brushy Canyon Formation produced oil and gas in approximately 75% of the wells producing from the Delaware Mountain Group and from approximately half of all wells drilled since 1987 within the SPA. Operators started developing Brushy Canyon Pools primarily in the late 1980's and made several discoveries in the 1990's. Prior to that, industry considered the formation to have limited potential and typically ignored it on the way to deeper reservoirs. The Brushy Canyon Formation overlies or cuts into a widespread limestone bed marking the top of the Bone Spring Formation. The formation was deposited when sea level was at a low point, and channels cut through the carbonate shelf margin, supplying arkosic to subarkosic sands to the basin (Beaubouef et al. 1999; Montgomery et al. 1999). The Formation is informally divided into upper, middle and lower units. For this study the Brushy Canyon top, the lower Brushy Canyon top, and the Bone Spring Formation top were correlated in 561 wells. The depth to these stratigraphic markers is included in the enclosed database. The small number of structural closures shown on a structure map of the Bone Spring top indicates that most Brushy Canyon pools are stratigraphic or combination structural-stratigraphic (Fig. 6), as indicated by previous studies (e.g. (Brown 1995; DeMis and Cole 1996; Montgomery et al. 1999).

Most of the recent Brushy Canyon drilling has targeted the lower Brushy Canyon. This activity and high future potential of the lower Brushy Canyon justified closer inspection. Approximately 300 feet above the Bone Spring Formation, a pervasive organic-rich siltstone with a characteristic induction log signature marks the top of the lower Brushy Canyon. Net sand thicknesses were measured within the lower Brushy Canyon in 416 wells to map channel-fan system trends in this part of the formation (Figs. 4 and 7). The Lower Brushy Canyon trends provide production in several pools in the southeast portion of the study area. However the thickness trends do not explain all of the production, especially in Nash Draw, where thin (1 to 6 feet) stacked sands provide marginal, compartmentalized reservoirs (Murphy et al. 1996; Martin et al. 1999). Researchers and companies have successfully used 3-D seismic data to characterize these reservoirs and guide drilling. This study did not have access to seismic data for, and industry has not collected 3-D seismic data across most of the SPA. Brushy Canyon discoveries have typically been tests based on Brushy Canyon shows in deeper wells, with little new exploration specifically targeting this interval.

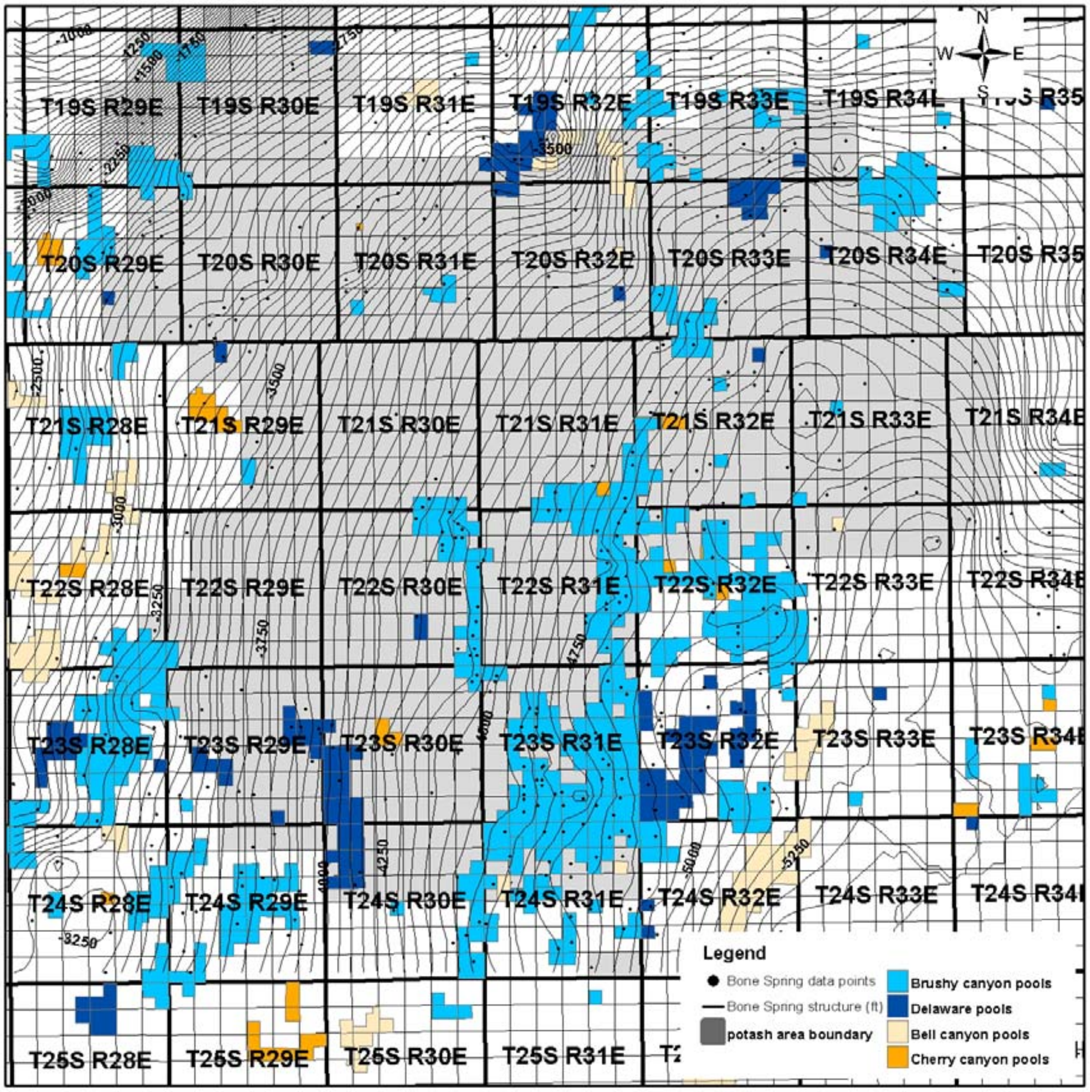

Figure 6. Bone Spring structure map and Delaware Mountain Group pools in the vicinity of the Potash Area. Some pools designated as Delaware produce from the Brushy Canyon, most notably the Nash Draw field in T23S R29E and R30E and T23S R30E.

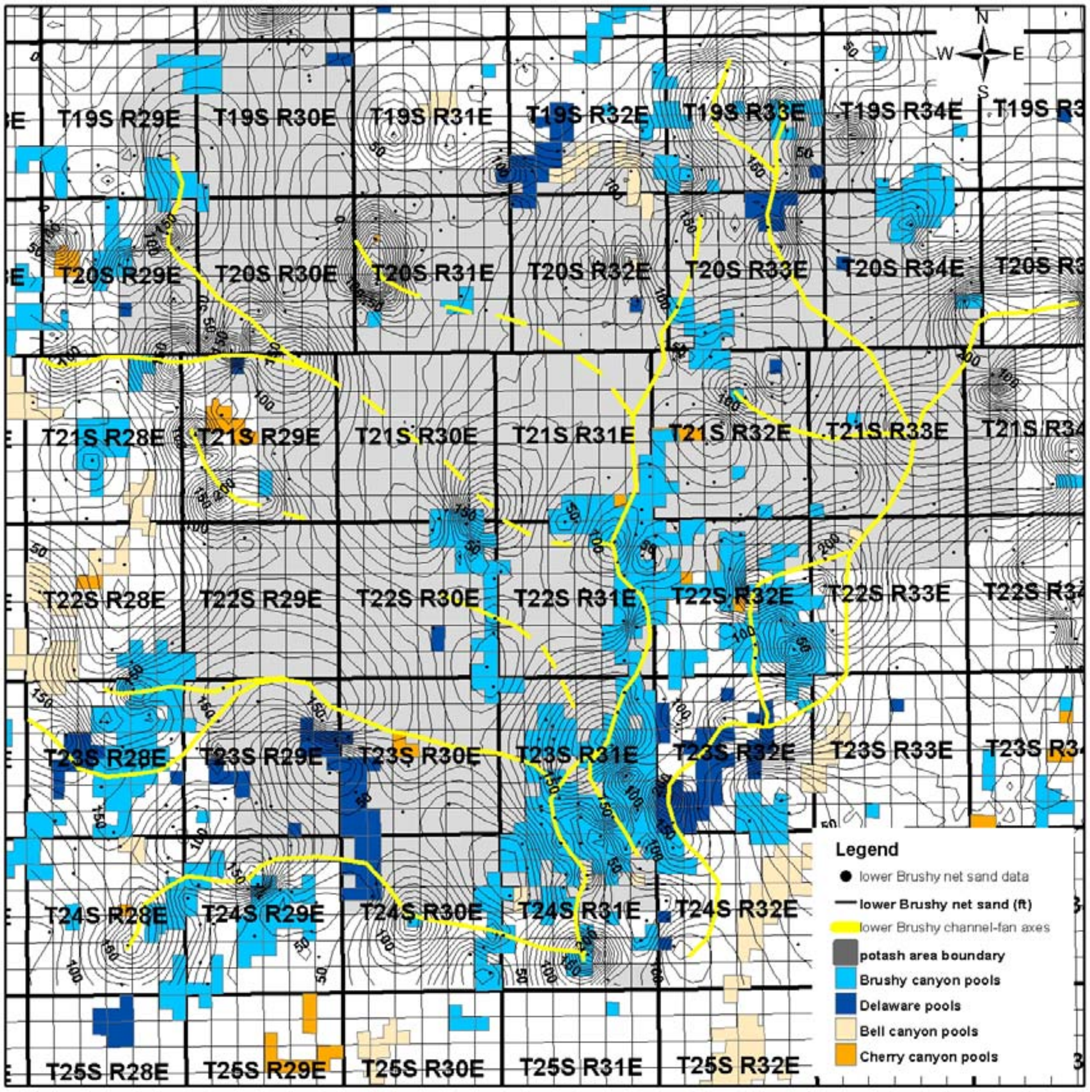

Figure 7. Lower Brushy Canyon net sand thickness map with interpreted channel/fan systems.

Bone Spring Formation

Depths to Bone Spring Formation reservoirs range from approximately 7,000 to 11,000 feet below ground surface within the study area. This formation produces oil and associated gas from carbonate debris flows and turbidite reservoirs throughout the ~2500-foot section. The formation is divided into three alternating carbonate intervals (first, second and third carbonates), which are separated by three sandstone intervals (first, second and third sands) (Fig. 8) (Gawloski 1987). In addition, the Avalon sandstone was discovered within the first carbonate during the early-1990’s (Montgomery 1997). Traps tend to be stratigraphic or structural-stratigraphic. The Bone Spring Formation is time-equivalent to thick shelf and shelf-margin carbonates of the Yeso and Abo formations on the Northwest shelf (Fig 8).

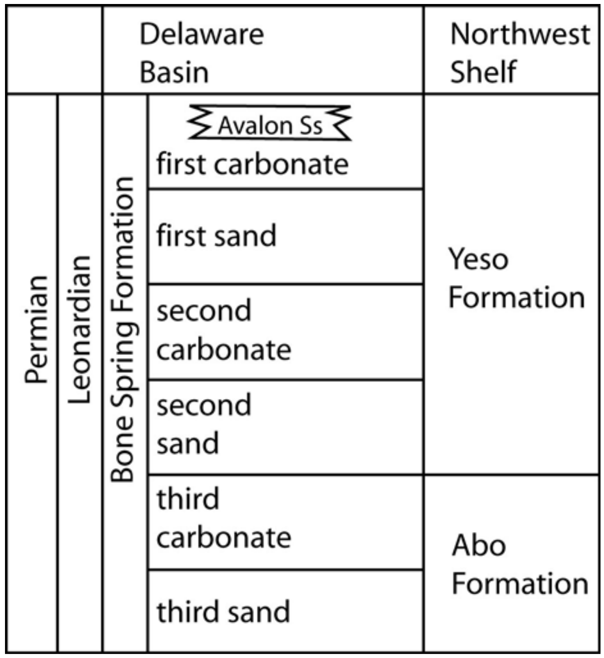

Figure 8. Bone Spring stratigraphy (Gawloski 1987)

Wave erosion and collapse of the Abo and Yeso carbonate shelf buildups provided material for the allochthonous carbonate intervals during periods of high sea level. (Gawloski 1987; Montgomery 1997). Mudstones within the carbonate intervals supply source rocks. Secondary porosity in dolomitized carbonate debris flows of the second and third carbonate intervals supply the primary reservoirs. Complicated stacking patterns within each carbonate interval make correlation and mapping of producing units difficult. This problem combined with reduced porosity due to diagenesis make future production predictions difficult for the Bone Spring carbonates.

Submarine canyons and fan systems deposited fine- to very fine-grained sands during relative lows in sea level (Gawloski 1987; Montgomery 1997). The sand intervals are regionally extensive, with elongate trends of porous units that are roughly perpendicular to the shelf edge. Historically, the dolomite and authigenic clays that cement the sandstones have indicated high water saturations in well logs and have resulted in low initial fluid production. The combination of apparently high water saturation with low initial production caused industry to overlook these reservoirs. Operators have used hydraulic fracturing to increase effective permeability in these reservoirs.

The Bone Spring Formation has a relatively high potential for oil and gas production within the SPA. Horizontal wells targeting specific intervals may produce from currently overlooked reservoirs, and hydraulic fracturing in horizontal wells may allow production in low-permeability limestones that are currently non-productive. Horizontal wells may be drilled based on either 3D seismic data or shows in existing vertical wells. A separate study focusing on this interval within the Potash Area would delineate exploration targets and should have at least some component of seismic data interpretation.

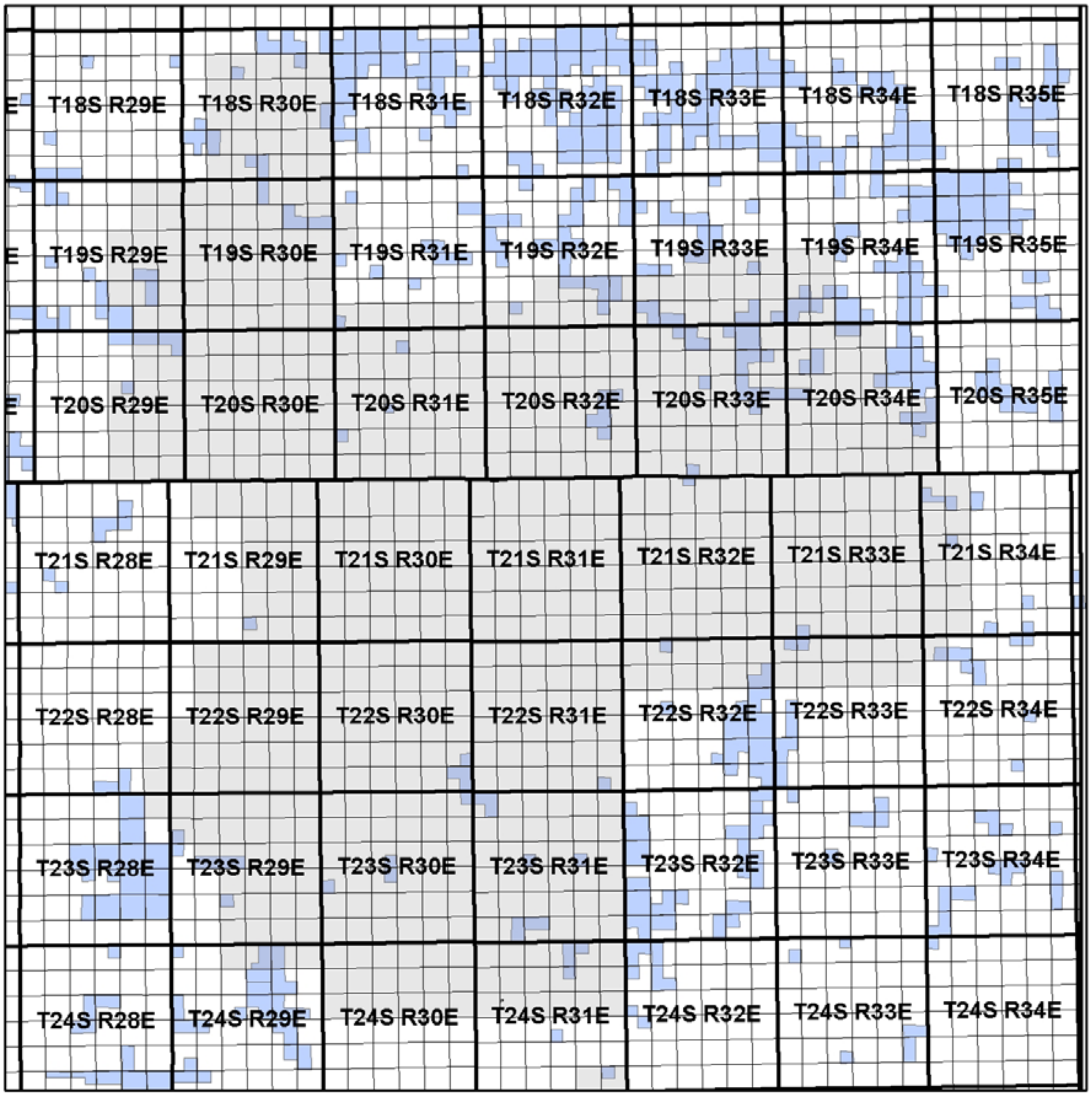

Figure 9. Map showing producing pools in the Bone Spring Formation.

Atoka Group

Atokan rocks overlie the Morrow Formation throughout the study area. Reservoirs include fluvial-deltaic, shore-zone, and, in the south, carbonate mounds (Speer 1993). Structural-stratigraphic and stratigraphic traps are typical of the Atoka reservoirs. An Atoka structure map shows that most of the major Atoka fields are on structural highs (Fig. 10). The Atoka tends to be a secondary target, completed when the primary objective, the Morrow, is not productive or when well logs indicate potentially better producing characteristics within the Atoka. That trend will most likely continue with future Atoka discoveries being keyed to Morrow drilling.

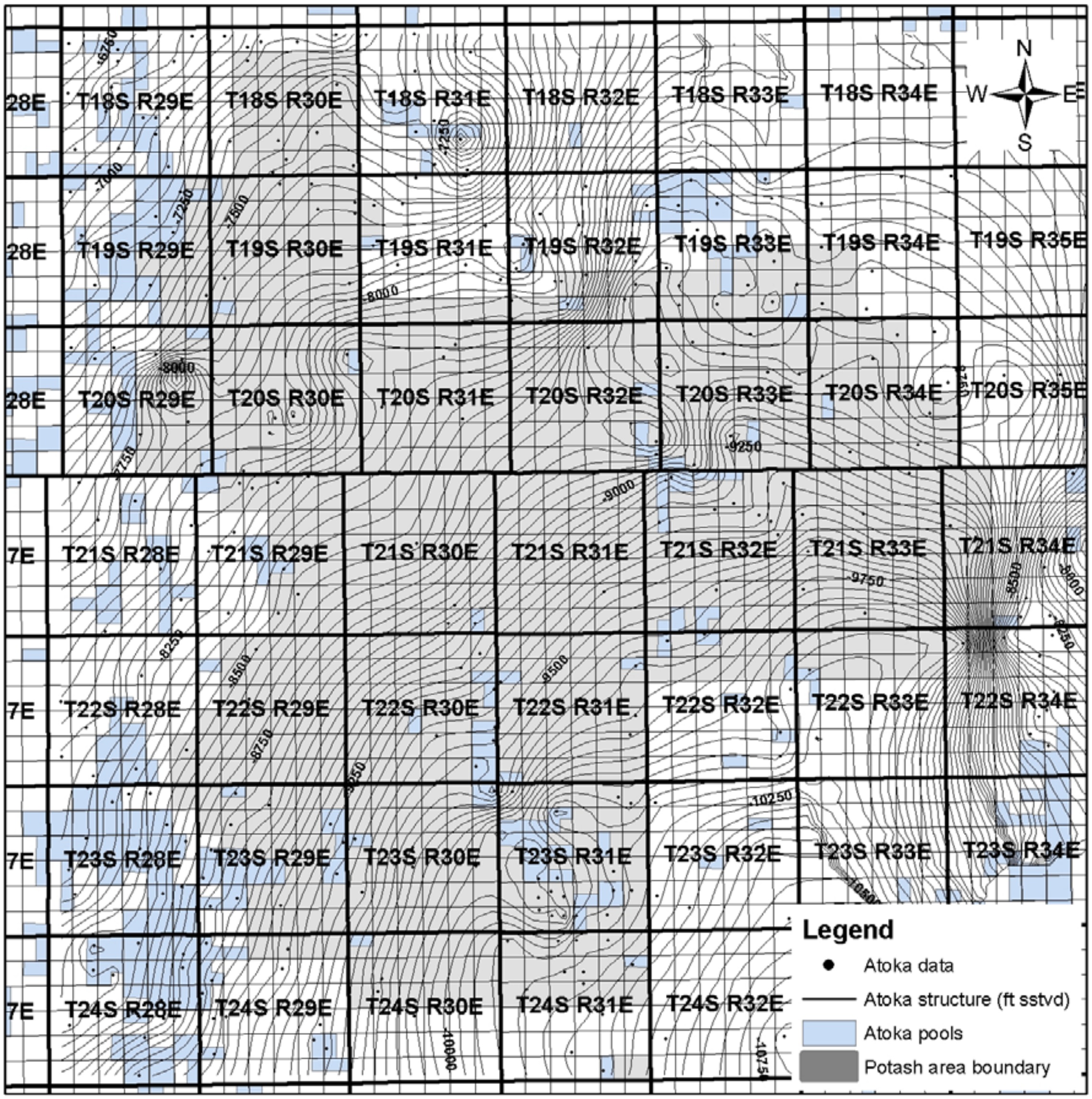

Figure 10. Atoka structure map (ft below sea level), showing the typical structural highs associated with Atoka production within the Potash Area.

Morrow Formation

The Morrow Formation is the lowermost Pennsylvanian unit, with top depths between 10,500 and 14,700 feet below ground level. The formation is typically divided into two units, the Morrow lime, which starts at the upper Morrow contact, and the Morrow clastic, which comprises the bottom of the Morrow interval (Fig. 11). The Morrow lime consists of interbedded limestones and marine shales with some local marine sandstones. The uppermost limestones may be Atokan in age, but no good log marker differentiates the Atoka and Morrow. There is some question concerning the differentiation of these two units, even using biostratigraphy (Dunn 1976; Sutherland and Manger 1983). Morrow picks throughout the study area are based on the Morrow top interpreted by (Broadhead et al. 1998; Worthington 1999). The Morrow lime thickens basinward, from approximately 400 feet near the basin margin to nearly 700 feet in the southeastern part of the study area (Plate 1). The Morrow is absent on basin margins.

The Morrow clastic section consists of interbedded sandstones and shales of fluvial-deltaic origin, including delta plain and delta front environments (Speer, 1993). Sandstones in the Morrow clastic provide most of the current Morrow production, typically from stratigraphic or combination structural-stratigraphic traps (Worthington and Brown 1999). Despite this fact, much of the Morrow drilling has targeted structural highs rather than stratigraphic plays (Fig. 12). Off-structure drilling will most likely provide significant future reserves (Worthington 1999). Basement faults that were active during Late Mississippian to Early Pennsylvanian form the structural highs in the Morrow and probably influenced sand deposition (Casavant 1999). Thicker sands may provide better reservoirs on the downthrown sides of faults.

This study divided the Morrow clastic interval into 3 units based on log character and shale markers that could be correlated throughout the study area (Plate 1). The lower and middle Morrow units are commonly identified in published literature (Speer 1993; Worthington 1999). The middle Morrow was divided into "A" and "B" units to highlight differences in sand distribution and therefore depositional environments. In the White City Penn Gas Pool to the west of the study area, (Casavant and Mallon 1999) divided the Morrow clastic into 8 parasequences, 3 in the lower Morrow, 3 in our middle "B" and 2 in our middle "A". This project required fewer subdivisions due to time constraints and difficulties associated with correlating individual parasequences on a large scale.

The top of the lower Morrow is marked by a shale with a distinctive decreasing-upward gamma ray profile (Plate 1). Stacked sands in the lower Morrow tend to show coarsening upward profiles with sharp contacts indicating fluvial dominated deltaic deposition. A lower Morrow net sand map shows three linear northwest-southeast thickness trends with apparent splays near the east end of each system, providing support for a deltaic complex interpretation (Fig. 13).

The middle "B" Morrow unit tends to be predominantly shale with two or three sequences of sands with sharp upper and lower contacts, indicating channel deposition or possibly crevasse splays (Plate 1). A middle "B" Morrow net sand map shows several nearly north-south oriented thickness trends, indicating possible fluvial or shallow marine channel systems (Fig. 14).

The middle "A" Morrow unit tends to have one or two sequences of coarsening-upward, more massive stacked sands with sharp boundaries and interbedded shales, indicating possible distributary mouth bar or wave reworked delta environment (Plate 1). A middle "A" net sand map shows relatively linear southwest-northeast thickness trends that are nearly perpendicular to the middle "B" Morrow trends, indicating a possible reworked delta system with some shallow marine channels in the southwest part of the study area (Fig. 15).

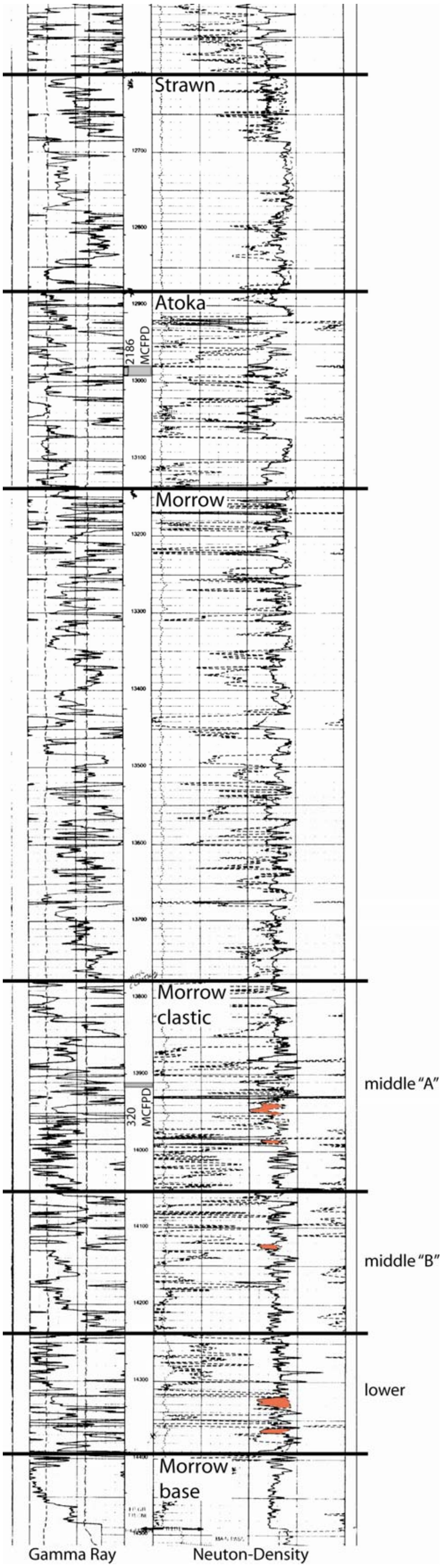

Figure 11. Partial Pennsylvanian type log showing Strawn, Atoka, Morrow, Morrow clastic and Morrow Base picks. Apache 25 Fed #1 well in Sec. 25 T22S R30E; API 30-015-27410. Morrow Clastic subdivisions used in this study are indicated outside the right margin. Formation correlations are based on Broadhead et al., 1998. Gray boxes show producing perforations. Red area highlight possible hydrocarbon saturated zones in the Morrow Clastic interval that have not been perforated as identified by cross over on the neutron porosity and density porosity logs.

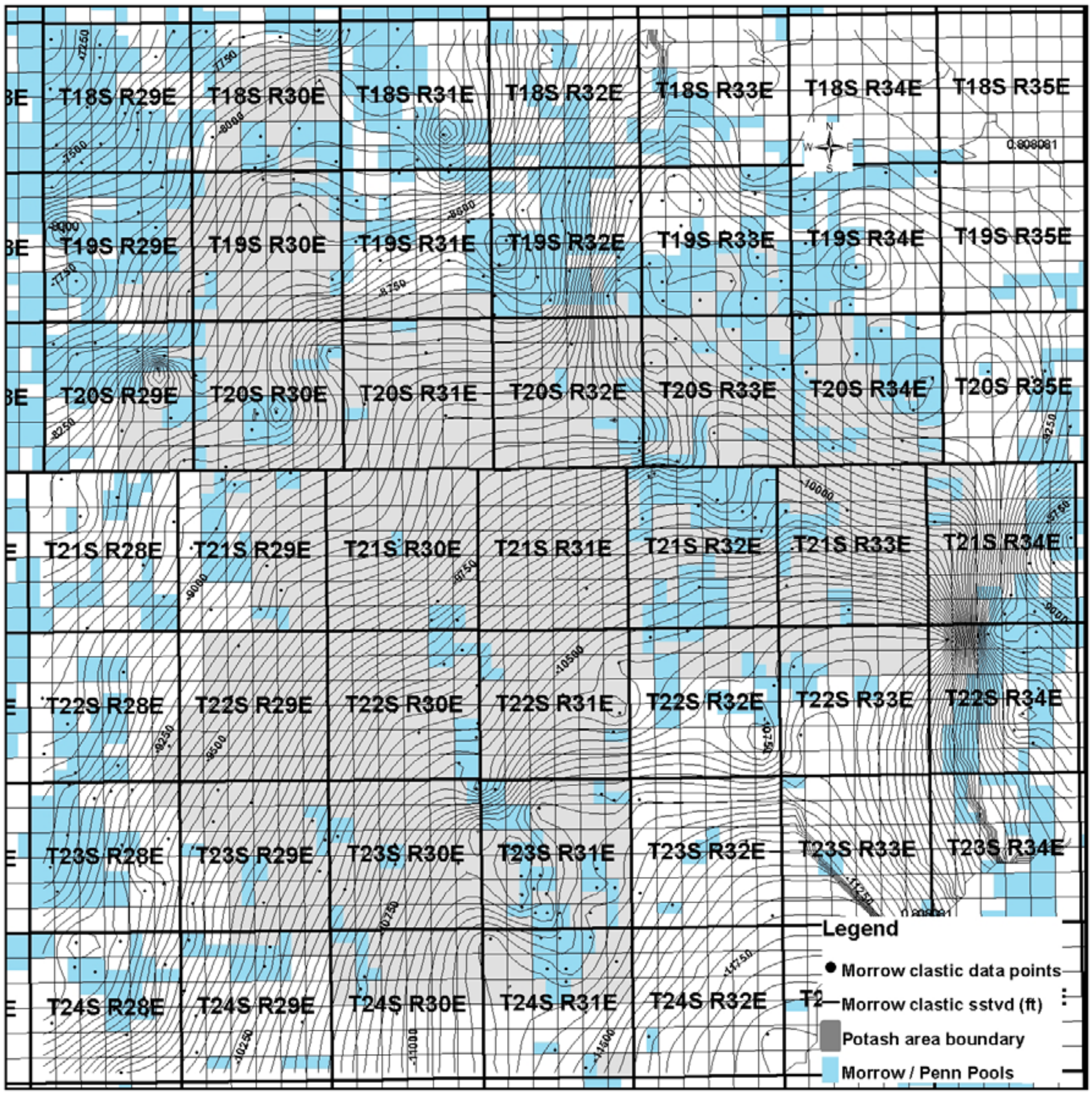

Figure 12. Map showing Morrow structure and Morrow pools.

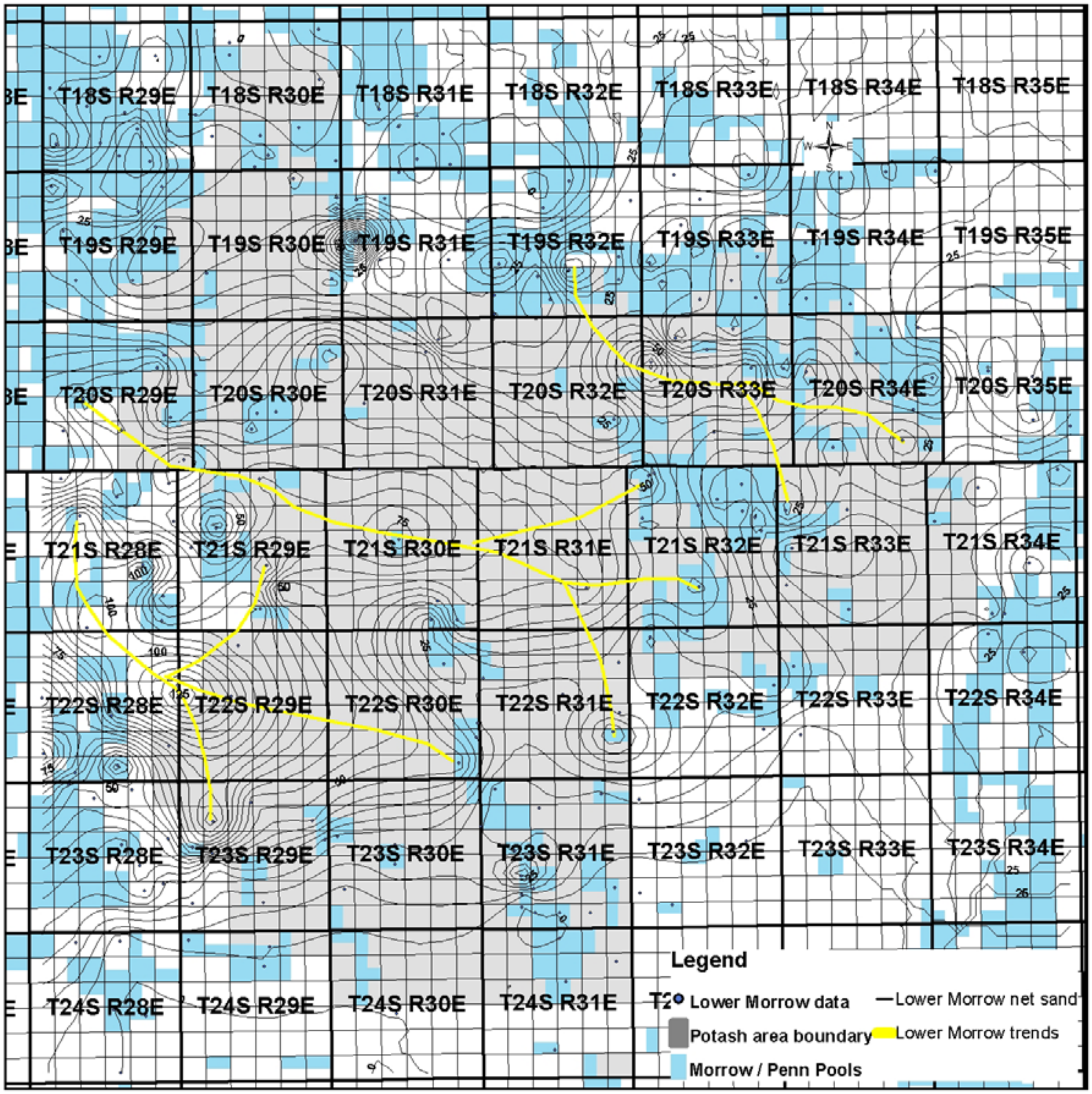

Figure 13. Map showing lower Morrow net sand map thickness (ft) and interpreted depositional trends.

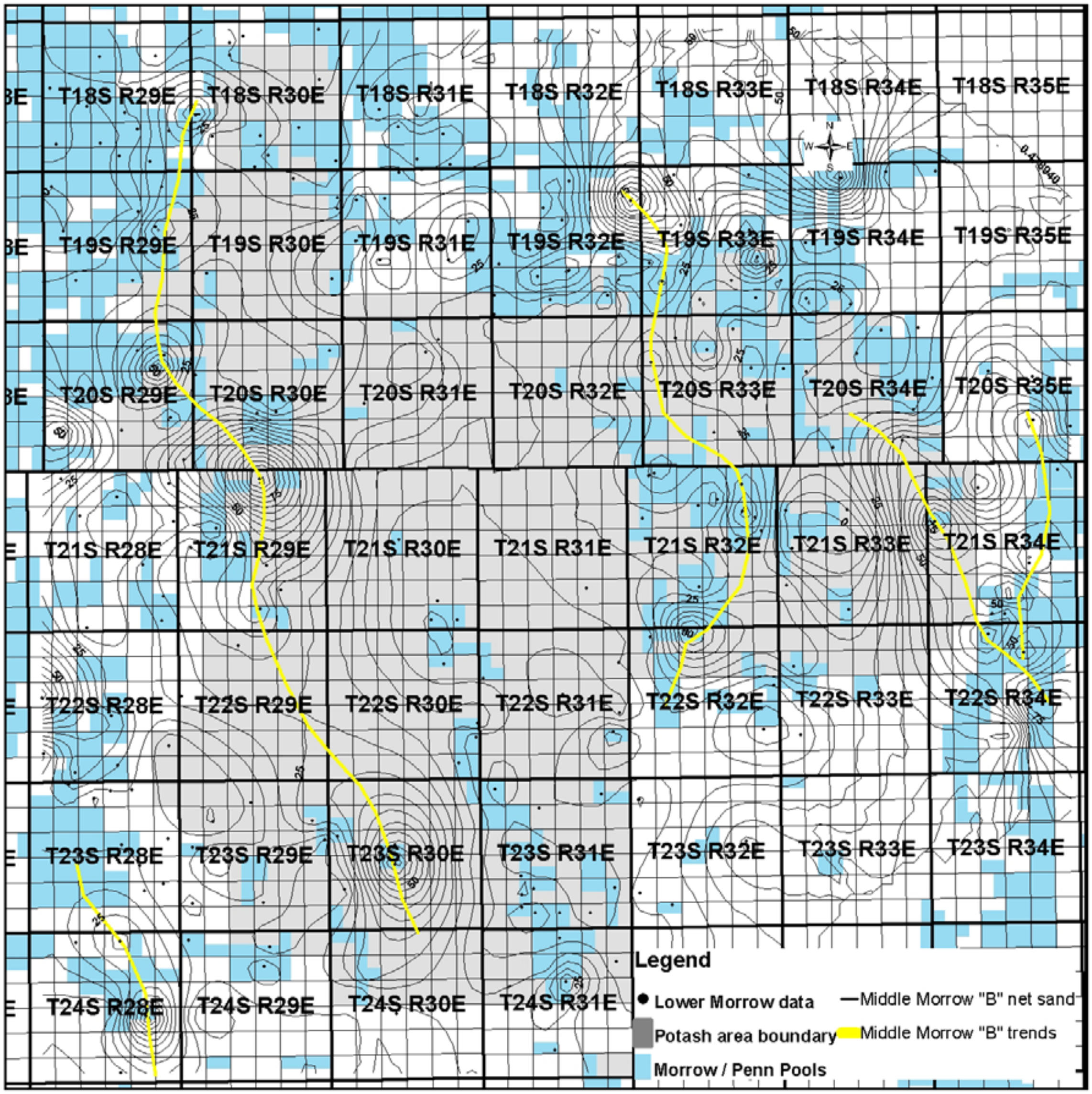

Figure 14. Map showing middle "B" Morrow net sand thickness (ft) and interpreted depositional trends.

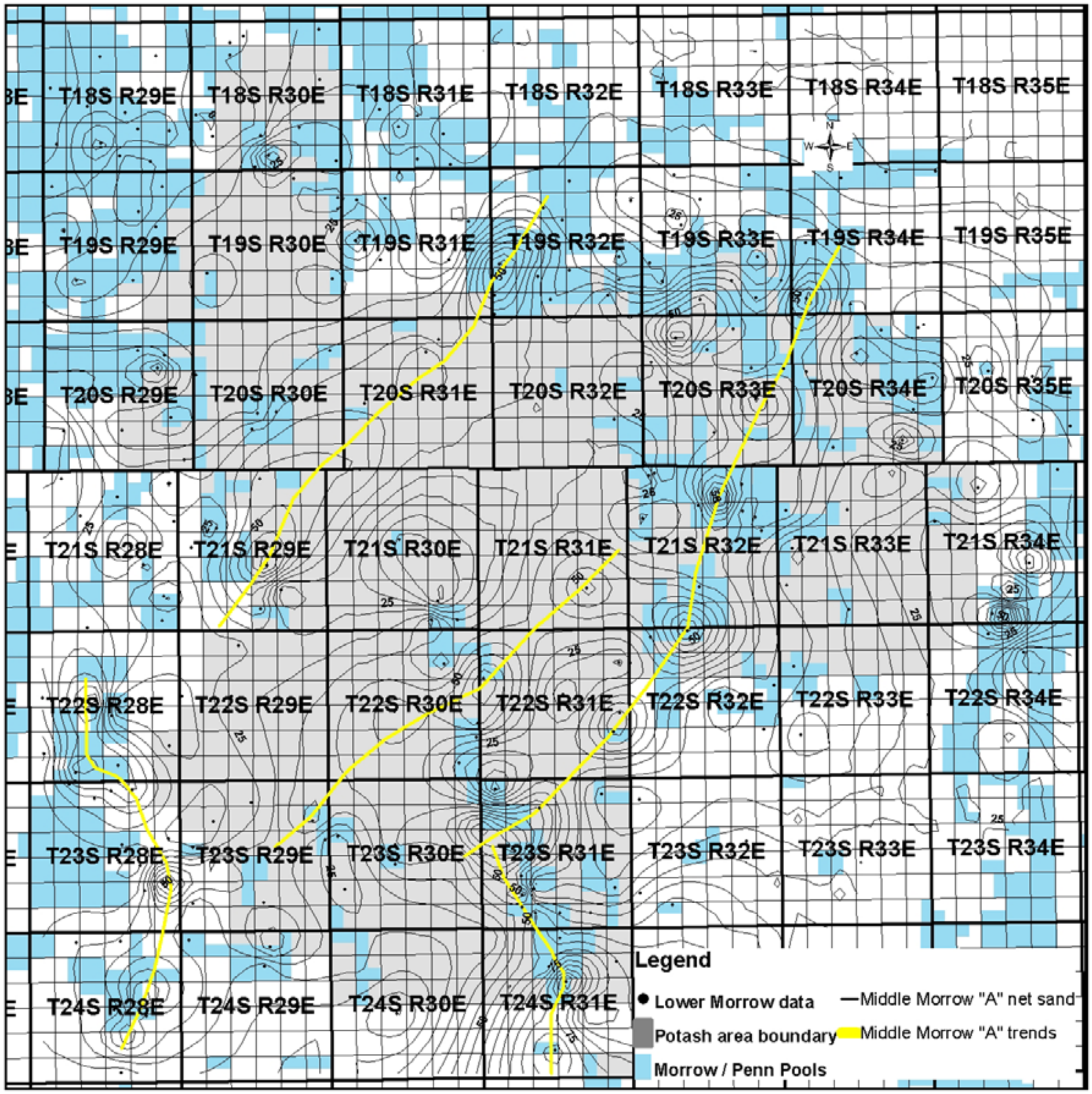

Figure 15. Map showing middle "A" Morrow net sand thickness (ft) and interpreted depositional trends.

Areas with future potential

A combination of existing production trends and geologic trends described in the previous section helped to create maps showing areas with anticipated future oil and gas production potential (Figs 16-20, Plates 2-6). In all of the potential maps, yellow shading highlights areas with existing production, and brown shading delineates areas of potential interest based on geologic trends for each formation. Regions outside of the areas of potential interest are not necessarily low interest. In many cases, lack of data precludes highlighting those areas. The wells show existing production and are color-coded by spud date to demonstrate areas of recently active drilling for each formation. The enclosed CD contains shapefiles for all of the potential maps.

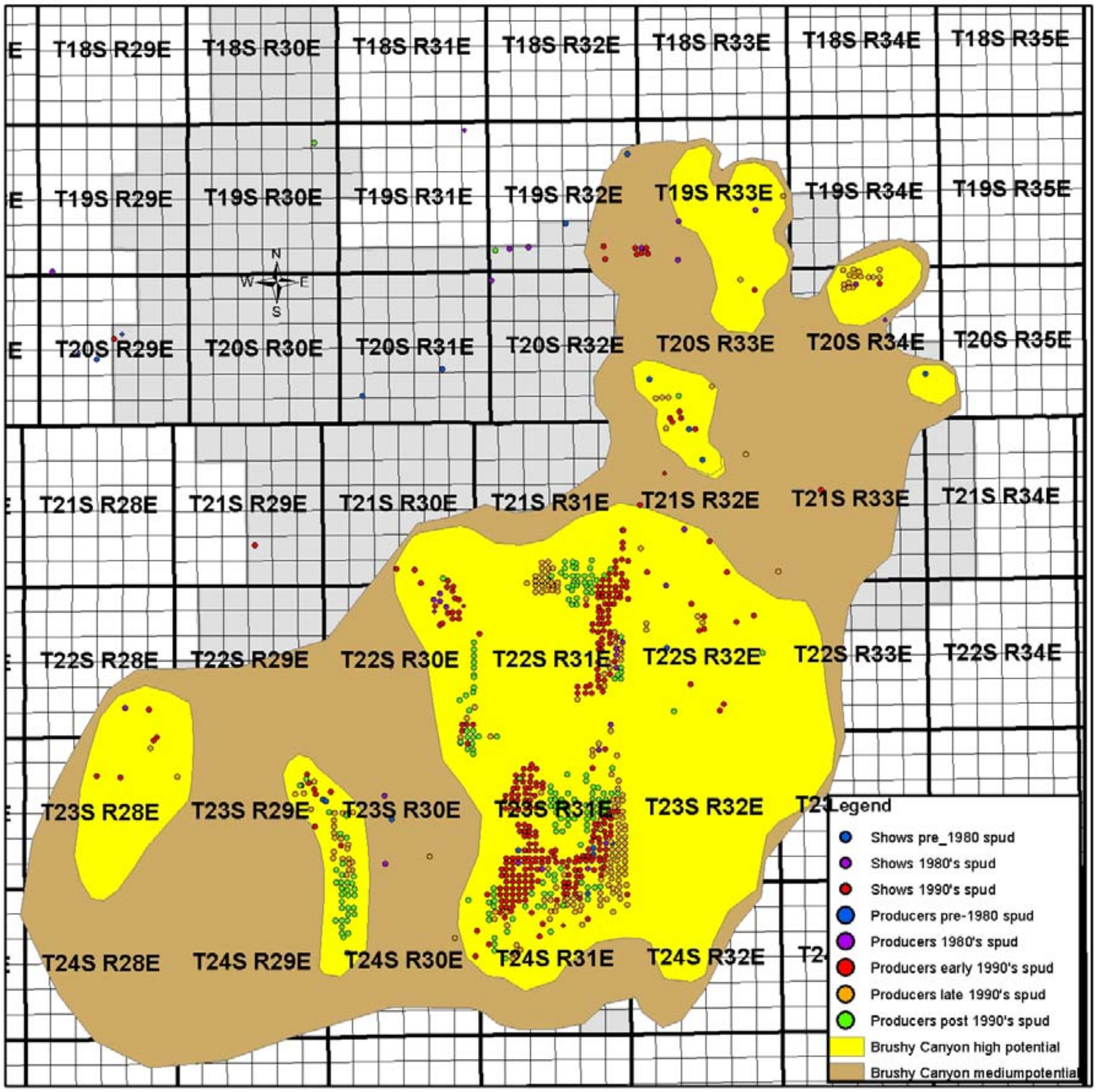

Figure 16. Map showing areas with anticipated future oil and gas production from lower Brushy Canyon.

The Brushy Canyon Formation has good potential over much of the Potash Area (Fig. 16). Future development may include more horizontal drilling as operators wish to develop this formation near potash mines and as they use seismic data to define targets (Martin et al. 1999). Horizontal wells may provide superior production characteristics. For example, the Nash Unit #36 and Nash Unit #33 wells (both horizontal) were by far the biggest Nash Draw producers in 2004 (Table 2).

Table 2. 2004 five highest annual producing wells in the Nash Draw Pool by barrels oil equivalent.

API	WELL_NAME	GAS PROD (MCF)	OIL PROD (bbls)	BOE (1 mcf = 6 boe)
30-015-30176	NASH UNIT #036	127739	23529	44819
30-015-32476	NASH UNIT #033	75341	31825	44382
30-015-32882	POKER LAKE UNIT #200	51487	25178	33759
30-015-31689	POKER LAKE UNIT #157	100996	8327	25160
30-015-31696	POKER LAKE UNIT #167	66441	9860	20934

The Bone Spring Formation has good potential, especially as an unconventional play. Long horizontal wells may produce from low permeability limestones that are currently not considered reservoirs. This play is likely to become more important as some of the older Morrow fields reach maturity. Operators may re-enter these deep wells in hopes of producing from the Bone Spring Formation.

The Atoka is of interest along roughly north-south apparent channel trends (Fig. 17), but it will most likely continue to be a secondary play until more regional work is done or until Morrow reservoirs are mostly played out. In the future, Atoka sands should be divided into depositional units and mapped independently to show producing trends within those intervals.

The Morrow clastic interval has good future potential over much of the Potash Area. The lower Morrow is of interest along three delta complex trends (Fig. 18). The middle "B" Morrow interval is of interest along two main channel trends (Fig. 19). The middle "A" Morrow interval is of interest along several apparent beach bars or reworked delta intervals and along some apparent channel trends (Fig. 20). All three of these trends currently produce natural gas within the SPA. Unperforated zones that may be hydrocarbon saturated, based on cross over of neutron porosity and density porosity logs, are common in Morrow wells (Fig. 11), indicating additional future potential within existing wells.

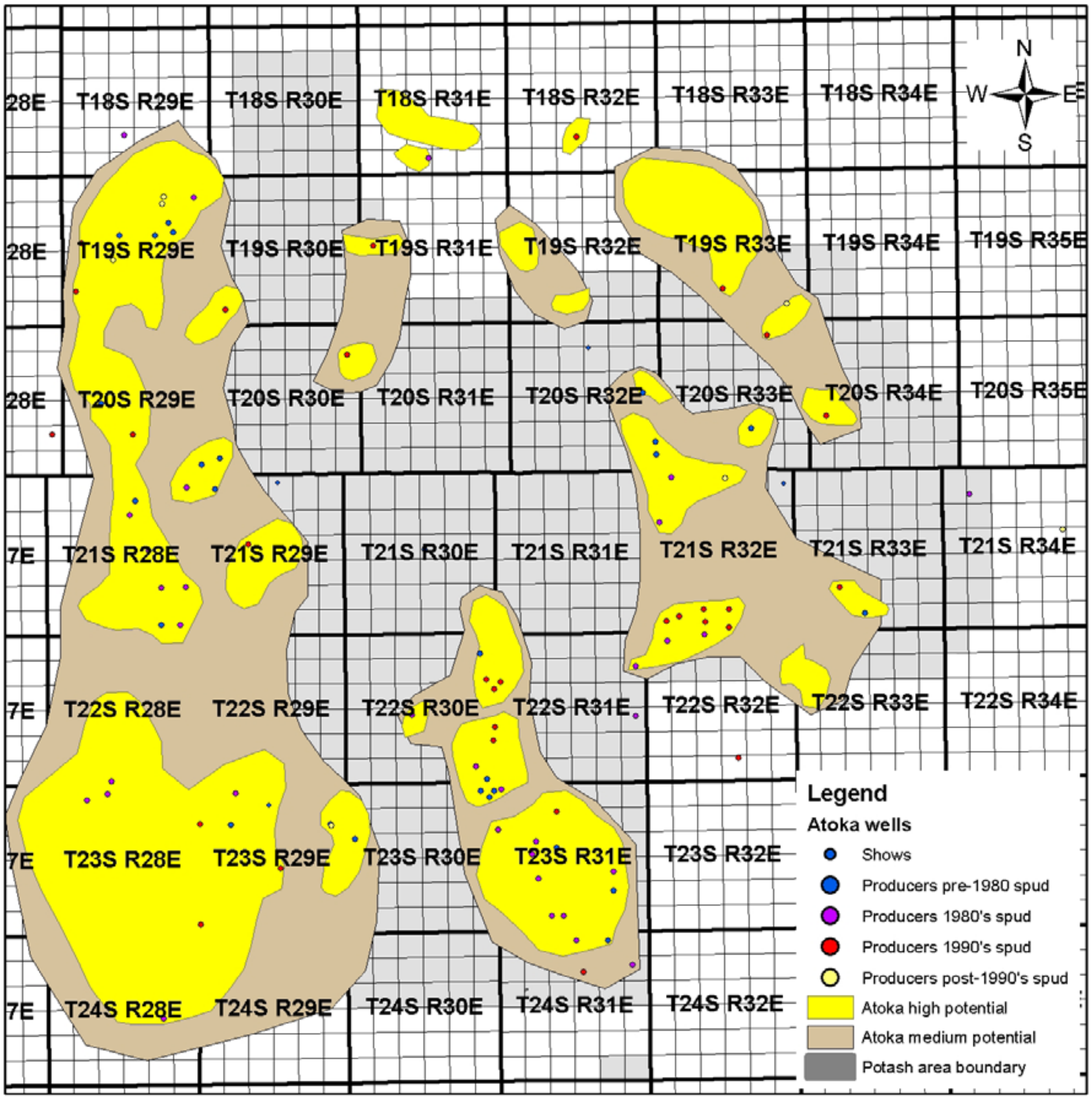

Figure 17. Map showing areas with anticipated future oil and gas production from Atoka Formation.

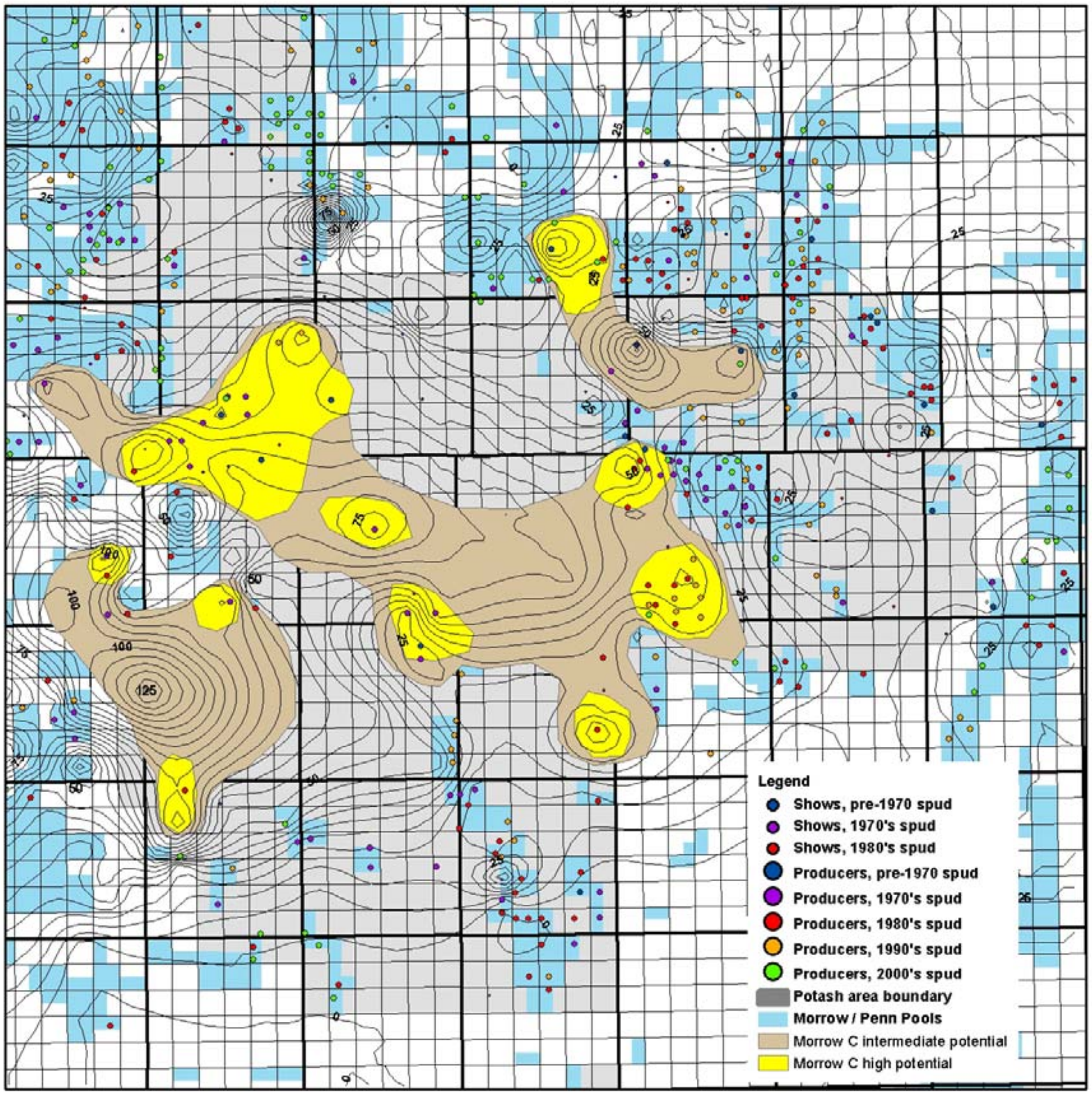

Figure 18. Map showing areas with anticipated future oil and gas production from lower Morrow Formation. Wells shown may produce from lower, middle "B", or middle "A" intervals.

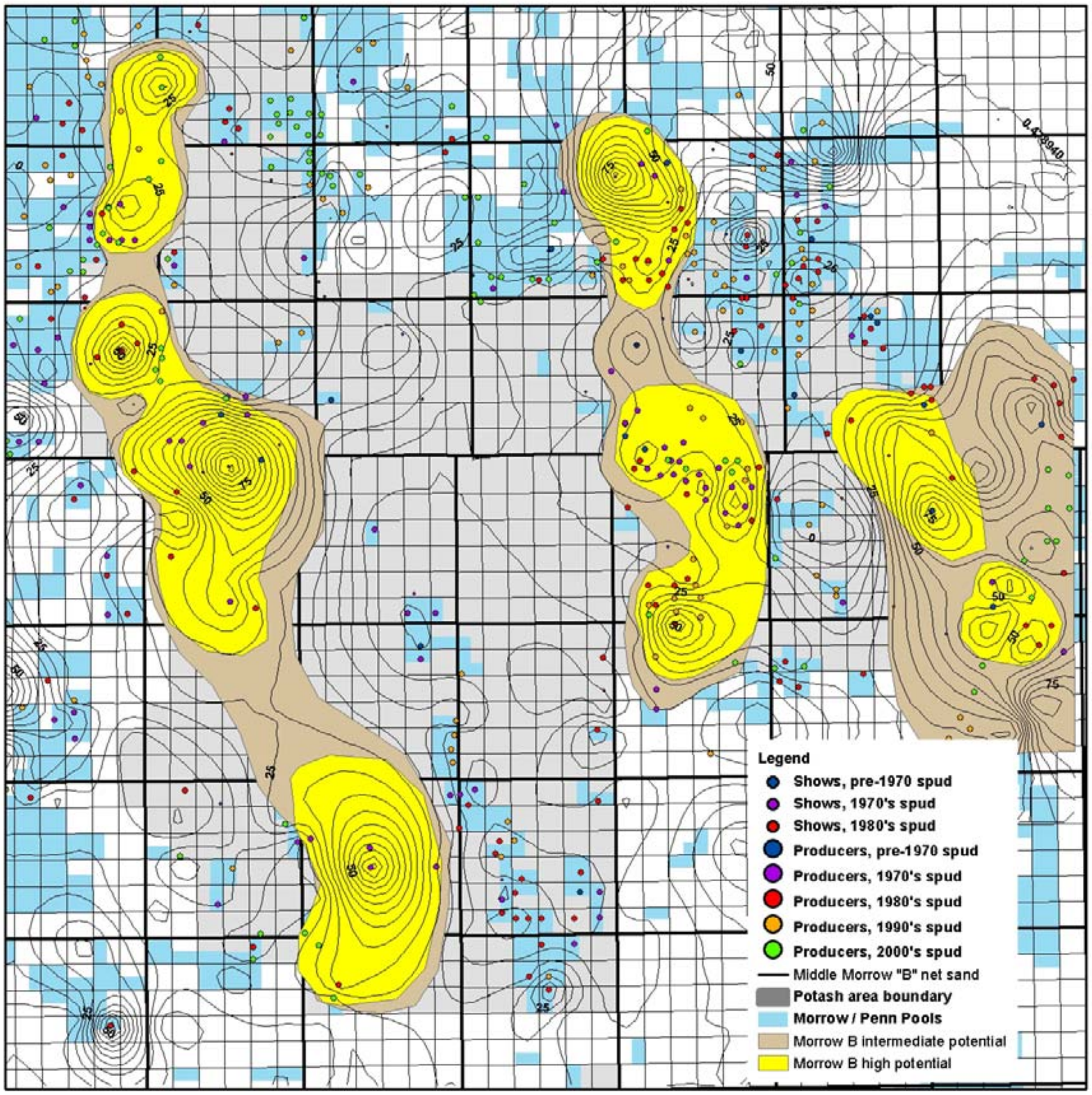

Figure 19. Map showing areas with anticipated future oil and gas production from middle Morrow "B". Wells shown may produce from lower, middle "B", or middle "A" intervals.

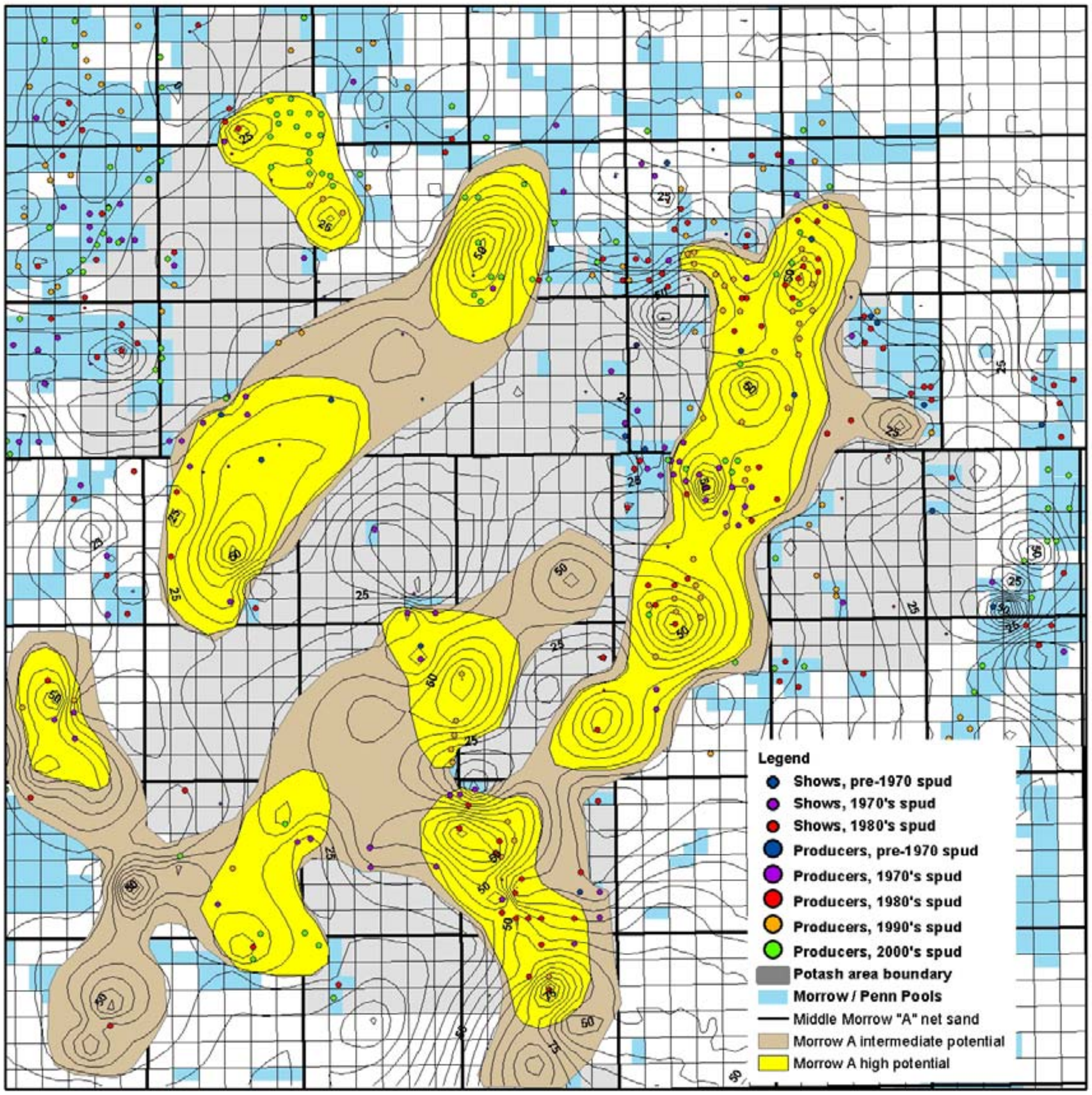

Figure 20. Map showing areas with anticipated future oil and gas production from middle Morrow "A". Wells shown may produce from lower, middle "B", or middle "A" intervals.

Conclusions

The Secretary of the Interior's Potash Area is a prolific oil and gas producing region with significant future reserves. If one considers only the Delaware Mountain Group and Morrow Formation, almost the entire SPA is of interest for future development, based on geologic production trends. These formations will most likely continue to be the largest producers for the foreseeable future, primarily because they consist of extensive sandstones that have demonstrated production characteristics. Conventional drilling of vertical wells will most likely not be permitted in many areas due to the presence of potash mines and potash reserves. Horizontal wells have been demonstrated to work with good production, and drilling islands in areas with existing wells are one method of permitting sub-potash development in the future. One argument in favor of vertical drilling has been the large number of pay zones throughout the section and the resulting risk reduction associated with drilling vertical wells. The lower Brushy Canyon has the best potential for initial development by horizontal drilling because it is relatively shallow compared to Bone Spring, Atoka, and Morrow Formations so that this argument is less effective. It may also be possible to drill directionally to undercut the potash resources and guide the well to a more vertical orientation within the Delaware Mountain Group when drilling for deeper targets. Some low-permeability sections of the Bone Spring Formation may exhibit enhanced production when drilled with horizontal wells due to the formation's overall low permeability characteristics. Plate 7 shows plugged wells that may be considered for drilling islands.

Acknowledgements

I would like to thank the Bureau of Land Management for their funding of this project and their excellent comments during presentations. Nilay Engin, a New Mexico Tech student, was instrumental in assembling the database and measuring net sand values. I would also like to thank Ron Broadhead for his feedback during the project and his review of this manuscript. Anthonius Irianto Sulaiman, working for the Petroleum Research and Recovery Center, calculated well locations in latitude/longitude format. Lewis Gillard provided computer and GIS assistance.

Appendix A – Database

Downloaded well data from the New Mexico Oil Conservation Division (NMOCD) form the core of the NMBGMR database (New Mexico Oil Conservation Division 2005). NMOCD data is in both Microsoft Excel and Microsoft Access formats. The NMBGMR database is in Microsoft Access due to the significant quantity of value-added data. A logical database structure is intended to be intuitive and is based on the types of data available (Fig. A-1). Every table is tied to the header table by API number. Table A-1 provides detailed information concerning the source for each field within every table.

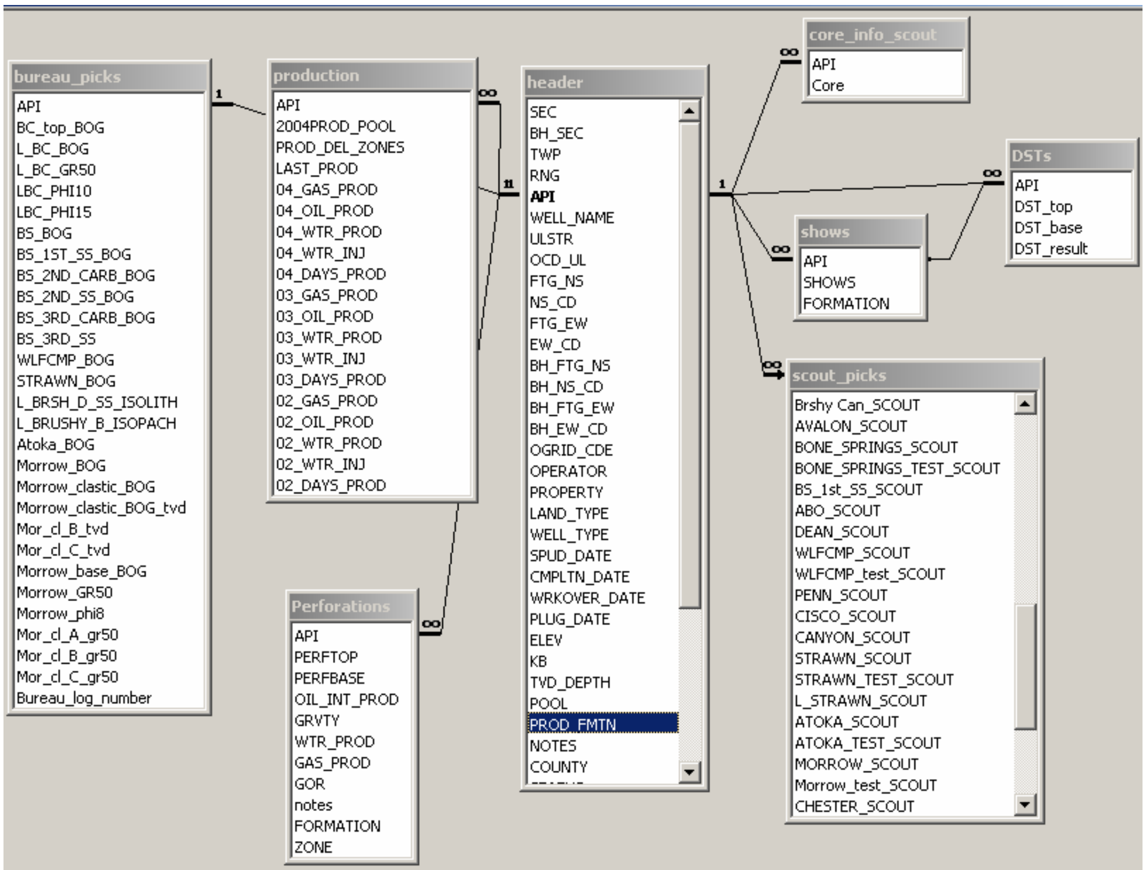

Figure C-1. Table relationships in NMBGMR access oil and natural gas wells database for the SOA area.

Table A-1. Field descriptions for each database table.

TABLE	Field Name	Description
core_info_scout		
	API	NMOCD API number
	Core	Core descriptions entered from scout cards
Bureau Picks		
	API	NMOCD API number. New Mexico Bureau of Geology emplyees or students made all correlations and thickness measurments in this table.
	BC_top_BOG	Brushy Canyon top
	L_BC_BOG	Lower Brushy Canyon top
	L_BC_GR50	Lower Brushy Canyon net sand thickness based on Gamma Ray log values less than 50 API units
	LBC_PHI10	Lower Brushy Canyon net sand thickness based on porosity log >10%
	LBC_PHI15	Lower Brushy Canyon net sand thickness based on porosity log >15%
	BS_BOG	Bone Spring Formation top
	BS_1ST_SS_BOG	Bone Spring Formation first sandstone top
	BS_2ND_CARB_BOG	Bone Spring Formation second carbonate top
	BS_2ND_SS_BOG	Bone Spring Formation second sandstone top
	BS_3RD_CARB_BOG	Bone Spring Formation third carbonate top
	BS_3RD_SS	Bone Spring Formation thrid sandstone top
	WLFCMP_BOG	Wolfcamp Formation top
	STRAWN_BOG	Strawn Formation top
	L_BRSH_D_SS_ISOLITH	
	L_BRUSHY_B_ISOPACH	
	Atoka_BOG	Atoka Formation top
	Morrow_BOG	Morrow Formation top
	Morrow_clastic_BOG_tvd	Morrow Clastic unit top
	Mor_cl_B_tvd	Morrow Clastic informal unit "B" top
	Mor_cl_C_tvd	Morrow Clastic informal unit "C" top. This is typically referred to as the Lower Morrow top
	Morrow_base_BOG	Base of Morrow Formation
	Morrow_GR50	Morrow Clastic net sand. This net sand thickness is based on gamma ray values less than 50 API. The Morrow_phi8 field may be better measured.
	Morrow_phi8	Morrow Clastic net sand. This net sand thickness is based on gamma ray values less than 50 API and density porosity log greater than 8%.
	Mor_cl_A_gr50	Morrow Clastic informal unit "A" net sand thickness based on gamma ray values less than 50 API
	Mor_cl_B_gr50	Morrow Clastic informal unit "B" net sand thickness based on gamma ray values less than 50 API
	Mor_cl_C_gr50	Morrow Clastic informal unit "C" net sand thickness based on gamma ray values less than 50 API
	Bureau_log_number	New Mexico Bureau of Geology well log number. These numbers can be used to find paper well logs in the Bureau's petroleum archive.
DSTs		

TABLE	Field Name	Description
	API	NMOCD API number
	DST_top	Dril stem test interval top. Entered from scout cards.
	DST_base	Dril stem test interval base. Entered from scout cards.
	DST_result	Drill stem test results. Entered from scout cards.
header		
	SEC	Section of well surface location. These were typically downloaded from the New Mexico Oil Conservation Division (NMOCD) website but some were hand-entered or hand-corrected.
	BH_SEC	Section of well bottom hole location (if different from surface). These records may not be complete but we have entered the field when we came across deviated wells during our study.
	TWP	Township of well surface location. These were typically downloaded from the New Mexico Oil Conservation Division (NMOCD) website but some were hand-entered or hand-corrected.
	RNG	Range of well surface location. These were typically downloaded from the New Mexico Oil Conservation Division (NMOCD) website but some were hand-entered or hand-corrected.
	API	Most wells are in the form xx-xxx-xxxxx and these represent NMOCD API numbers. We have found records for some wells that do not appear to have NMOCD records and we entered these as township range section well name (e.g.18S30E21MCCLAY002)
	WELL_NAME	Some of these are as downloaded from NMOCD website. Others have been entered from scout cards
	ULSTR	All from NMOCD download
	OCD_UL	All from NMOCD download
	FTG_NS	Well surface location distance from north or south section line. Some of these are as downloaded from NMOCD website. Others have been entered from scout cards.
	NS_CD	North or south section line associated with FTG_NS field. Some of these are as downloaded from NMOCD website. Others have been entered from scout cards.
	FTG_EW	Well surface location distance from east or west section line. Some of these are as downloaded from NMOCD website. Others have been entered from scout cards.
	EW_CD	East or west section line associated with FTG_EW field. Some of these are as downloaded from NMOCD website. Others have been entered from scout cards.
	BH_FTG_NS	Well bottom hole location distance from north or south section line. All of these have been entered from scout cards. These records may not be complete but we have entered the field when we came across deviated wells during our study.
	BH_NS_CD	North or south section line associated with BH_FTG_NS field. All of these have been entered from scout cards.

TABLE	Field Name	Description
	BH_FTG_EW	Well bottom hole location distance from east or west section line. All of these have been entered from scout cards. These records may not be complete but we have entered the field when we came across deviated wells during our study.
	BH_EW_CD	East or west section line associated with BH_FTG_EW field. All of these have been entered from scout cards.
	OGRID_CDE	
	OPERATOR	Some of these are as downloaded from NMOCD website. Others have been entered from scout cards
	PROPERTY	Downloaded from NMOCD
	LAND_TYPE	Downloaded from NMOCD
	WELL_TYPE	Downloaded from NMOCD
	SPUD_DATE	Some of these are as downloaded from NMOCD website. Others have been entered from scout cards
	CMPLTN_DATE	Completion Date. Entered from scout cards
	WRKOVER_DATE	Workover date. Entered from scout cards
	PLUG_DATE	Plug date. Some of these are as downloaded from NMOCD website. Others have been entered from scout cards
	ELEV	Well elevation in feet above sea level. Some of these are as downloaded from NMOCD website. Others have been entered from scout cards
	KB	Kelly Bushing elevation. Entered from scout cards or well logs.
	TVD_DEPTH	Total vertical well depth. Some of these are as downloaded from NMOCD website. Others have been entered from scout cards or well logs.
	POOL	Downloaded from NMOCD
	PROD_FMTN	Entered data based on scout cards and 2004PROD_POOL field in production table
	NOTES	This field represents notes concerning intended reservoirs producing reservoirs and operators.Some of these are as downloaded from NMOCD website. Others have been entered from scout cards.
	COUNTY	Downloaded from NMOCD
	STATUS	Downloaded from NMOCD. This field should be updated at least annually.
	NMOCD_LAT	Latitude as downloaded from NMOCD website. These should be taken with caution because they appear to have at least two different sources and are variable in accuracy.
	NMOCD_LONG	Longitude as downloaded from NMOCD website. These should be taken with caution because they appear to have at least two different sources and are variable in accuracy.
	LAT_CALC	Latitude. Calculated by New Mexico Tech Petroleum Research and Recovery Center (PRRC) from FTG_NS NS_CD FTG_EW and EW_CD fields. These appear to be in NAD27 projection.

TABLE	Field Name	Description
	LONG_CALC	Longitude. Calculated by New Mexico Tech Petroleum Research and Recovery Center (PRRC) from FTG_NS NS_CD FTG_EW and EW_CD fields. These appear to be in NAD27 projection.
	UTM13X	Calculated x coordinates in UTM13 NAD27. We calculated these based on the LAT_CALC and LONG_CALC fields using corpscon software.
	UTM13Y	Calculated y coordinates in UTM13 NAD27. We calculated these based on the LAT_CALC and LONG_CALC fields using corpscon software.
	ACRES	Downloaded from NMOCD
	NBR_COMPLS	Downloaded from NMOCD
	DISTRICT	Downloaded from NMOCD
Perforations		
	API	NMOCD API number
	PERFTOP	Perforation interval top. Entered from scout cards.
	PERFBASE	Perforation interval base. Entered from scout cards.
	OIL_INT_PROD	Oil initial production in barrels of oil per day (BOPD). Entered from scout cards.
	GRVTY	Oil gravity. Entered from scout cards.
	WTR_PROD	Water initial production in barrels of water per day (BWPD). Entered from scout cards.
	GAS_PROD	Gas initial production in million cubic feet per day (MCFPD). Entered from scout cards.
	GOR	Gas oil ration. Entered from scout cards.
	notes	Entered from scout cards.
	FORMATION	Formation(s) perforated. Entered from scout cards or based on bureau or scout card tops.
	ZONE	Informal production zones. Entered based on bureau tops.
Production		
	API	NMOCD API number
	2004PROD_POOL	2004 producing pool. Downloaded from NMOCD website.
	PROD_DEL_ZONES	Producing Delware zones. Entered based on New Mexico Bureau of Geology informal delaware zones.
	LAST_PROD	Last year of production. Downloaded from NMOCD website.
	04_GAS_PROD	Downloaded from NMOCD website.
	04_OIL_PROD	Downloaded from NMOCD website.
	04_WTR_PROD	Downloaded from NMOCD website.
	04_WTR_INJ	Downloaded from NMOCD website.
	04_DAYS_PROD	Downloaded from NMOCD website.
	03_GAS_PROD	Downloaded from NMOCD website.
	03_OIL_PROD	Downloaded from NMOCD website.
	03_WTR_PROD	Downloaded from NMOCD website.
	03_WTR_INJ	Downloaded from NMOCD website.
	03_DAYS_PROD	Downloaded from NMOCD website.
	02_GAS_PROD	Downloaded from NMOCD website.
	02_OIL_PROD	Downloaded from NMOCD website.
	02_WTR_PROD	Downloaded from NMOCD website.

TABLE	Field Name	Description
	02_WTR_INJ	Downloaded from NMOCD website.
	02_DAYS_PROD	Downloaded from NMOCD website.
scout_picks		
	API	NMOCD API number.
	Rustler_SCOUT	All fields in the scout_picks table were entered from scout card data.
	Rustler_TEST_SCOUT	
	OCHOAN_SCOUT	
	Salt_SCOUT	
	CASTILLE_SCOUT	
	Base Salt_SCOUT	
	Tansill_SCOUT	
	YATES_SCOUT	
	YATES TEST_SCOUT	
	7Rivers_SCOUT	
	7Rivers_TEST_SCOUT	
	CAPITAN_RF_SCOUT	
	BOWERS_SCOUT	
	QUEEN_SCOUT	
	QUEEN TEST_SCOUT	
	PENROSE_SCOUT	
	GRBG_SCOUT	
	GRBG_TEST_SCOUT	
	LOCO HILLS_SCOUT	
	LOCO HILLS test_SCOUT	
	PREMIER_SCOUT	
	SA_SCOUT	
	B_RUST_SCOUT	
	DELA_SCOUT	
	DELA TEST_SCOUT	
	LAMAR_SCOUT	
	RAMSEY_SCOUT	
	Bell Can_SCOUT	
	Cherry Can_SCOUT	
	Brshy Can_SCOUT	
	AVALON_SCOUT	
	BONE_SPRINGS_SCOUT	
	BONE_SPRINGS_TEST_SCOUT	
	BS_1st_SS_SCOUT	
	ABO_SCOUT	
	DEAN_SCOUT	
	WLFCMP_SCOUT	
	WLFCMP_test_SCOUT	
	PENN_SCOUT	
	CISCO_SCOUT	
	CANYON_SCOUT	
	STRAWN_SCOUT	

TABLE	Field Name	Description
	STRAWN_TEST_SCOUT	
	L_STRAWN_SCOUT	
	ATOKA_SCOUT	
	ATOKA_TEST_SCOUT	
	MORROW_SCOUT	
	Morrow_test_SCOUT	
	CHESTER_SCOUT	
	AUSTIN_SCOUT	
	Barnett_SCOUT	
	MISS_SCOUT	
	DEV_SCOUT	
	WDFD_SCOUT	
	FUSS_SCOUT	
	SIMP_SCOUT	
	ELLEN_SCOUT	
	ELLEN_TEST_SCOUT	
	GRANITE_SCOUT	
shows		
	API	NMOCD API number
	SHOWS	Oil and gas shows are based on scout card information including but not limited to drill stem tests and core descriptions
	FORMATION	Formation of show based on bureau picks or scout picks

Appendix B – Definitions

Allochthonous – refers to rocks found somewhere other than where they were deposited, in this case carbonates formed on the shelf and were transported down the slope

Arkosic sandstone – sandstone with a relatively high percentage of feldspar

carbonate rocks – limestone or dolomite, refers to the presence of CO_3^{2-} in the chemical make-up of the sedimentary rock

clastic rocks – rocks composed of transported fragments of pre-existing rocks

diagenesis – low temperature and pressure alteration of sedimentary rocks that change the rock's mineralogy and texture.

Distal – refers to a relatively large distance that rocks were deposited from their source into the basin

Evaporites- sedimentary rocks deposited as material left behind following the evaporation of water, includes potash

Eolian – wind-blown

Potash – "…common industrial term for potassium in various chemical combinations with sodium, magnesium, chloride, and sulfate…" (Barker and Austin 1999)

reservoir rocks – permeable rocks containing movable hydrocarbons

shelf – shallow-dipping area between shoreline and the shelf break, where the dip increases to start the continental slope

source rocks – rocks with high organic content that have produced oil or gas due to exposure to temperature and pressure

stratigraphic trap – lateral permeability change, lithologic pinchout, or unconformity that causes oil or gas to be trapped

structural trap – fold or fault that causes oil or gas to be trapped

subarkosic sandstone – sandstone with composition between arkose and quartz sand

Appendix C - Well log explanation

Well logs measure rock and fluid properties surrounding boreholes. We used five primary well logs for correlations and net sand calculations (Fig. C-1).

Gamma ray (GR) logs measure naturally emitted radioactivity and are typically used to distinguish shale from other rock types. Modern GR logs are measured in American Petroleum Institute (API) units, which are supposed to be universally keyed to the same calibration but may show variability in different wells. Fine clastic rocks such as shale tend to contain much higher quantities of radioactive minerals than sandstones or limestones. The logs can also be used for assistance in determining depositional environment by the character of their profile. For example, a sharp basal contact indicates an abrupt change in rock type, while a gradual change may indicate a gradation between rock types. In some cases, thin sandstones interbedded with shale give high gamma ray readings even though they may provide reservoirs. Also, feldspar, which is contained in arkosic sandstones, emits gamma rays and can result in good quality sandstones having apparently high gamma ray readings.

Laterologs or lateral focus logs measure formation resistivity in a lateral direction, allowing relatively thin (1 ft) beds to be distinguished. The units of measure are ohm-meters (ohm-m). These logs can be used to distinguish between water- and oil-filled sandstones because oil is much more resistive to electrical currents than water. Regionally extensive shales also tend to have relatively consistent resistivity signatures, which can help in regional correlations.

Induction logs use an electromagnetic technique to measure formation conductivity, but the logs are typically presented as resistivity, which is the inverse of conductivity. The resistivity is presented using the same units as lateral focused logs (ohm-m), and the logs can be correlated to laterologs.

Density logs indicate bulk density in grams per cubic centimeter (g/cc). The logging tool emits gamma rays and measures back-scattering. For known lithologies, the bulk density can be calibrated to porosity. For porous formations containing water, the measured density porosity is similar to neutron porosity.

Neutron logs measure the presence of hydrogen in a formation. The logging tool emits neutrons, which are bounced back by most nuclei. However, because hydrogen nuclei are nearly the same size as the emitted neutrons, hydrogen absorbs energy from the neutron bombardment. The logging tool measures the rate of energy loss, and because formations are typically water filled, the quantification of hydrogen content can be directly linked to porosity. If a formation contains gas or light oil, the hydrogen content is reduced, and the apparent porosity is lower. The difference in apparent porosity in hydrocarbon-saturated zones results in what is typically referred to as Neutron-Density crossover (Fig. C-1).

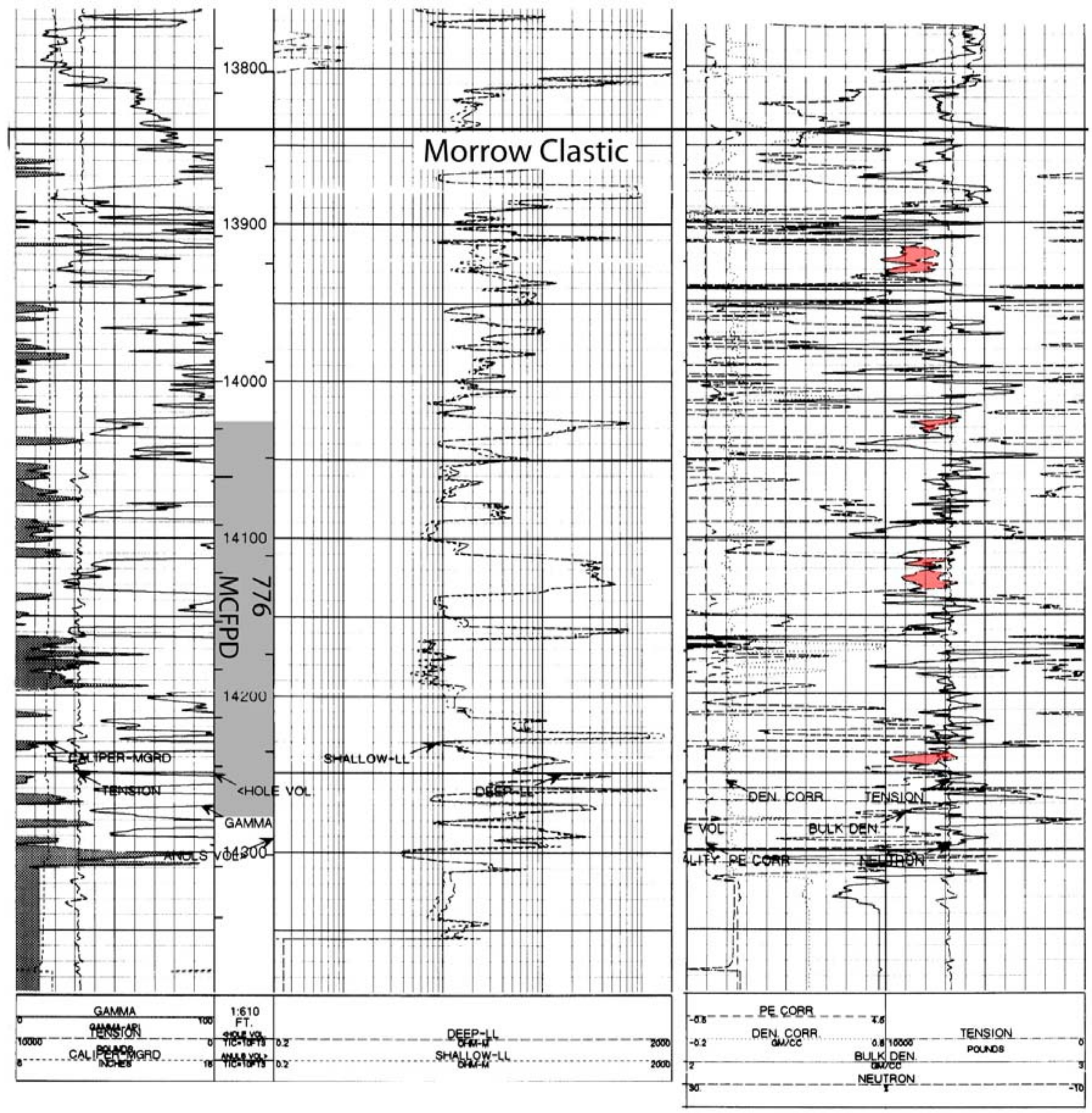

Figure C-1. Demonstration of gamma ray, laterolog, density, and neutron logs over Morrow clastic interval in Minis 2 Federal Com #002 well, API 30-025-36059. Neutron-density cross over indicating possible hydrocarbon saturation in red; gray box shows perforations.

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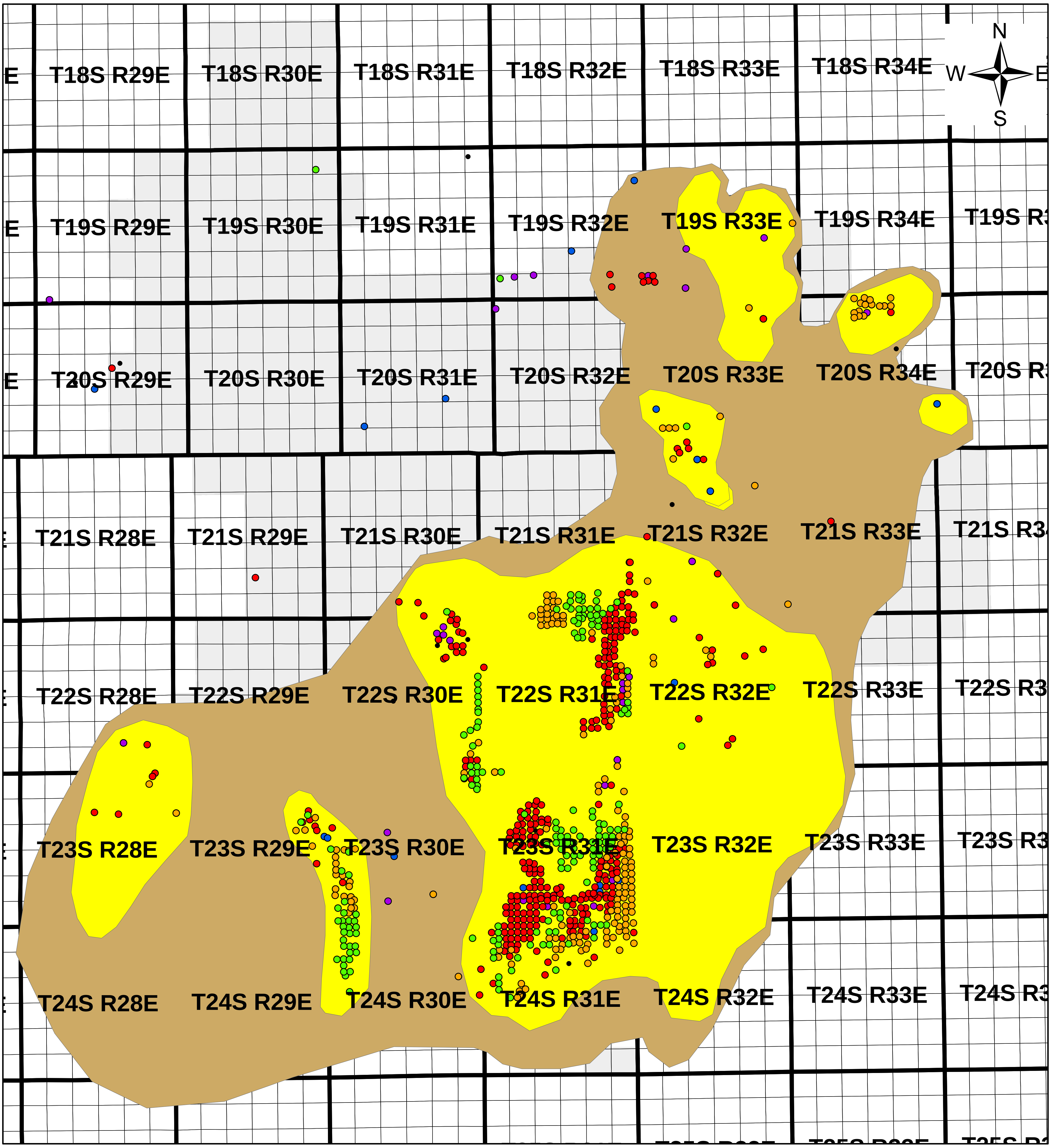
Plate 1. Northwest-southeast cross-section through Secretary's Potash Area showing Pennsylvanian producing intervals and informal Morrow clastic units used in this study.



Legend

- potash_boundary
- Brushy Canyon high potential
- Brushy Canyon mediumpotential

Wells

- Brushy Canyon shows
- Brushy Canyon producers pre-1980 spud dates
- Brushy Canyon producers 1980's spud dates
- Brushy Canyon producers early 1990's spud dates
- Brushy Canyon producers late 1990's spud dates
- Brushy Canyon producers post 1990's spud dates

1:250,000

0 — 56,000 Feet

Plate 2. Lower Brushy Canyon areas with anticipated future oil and gas production

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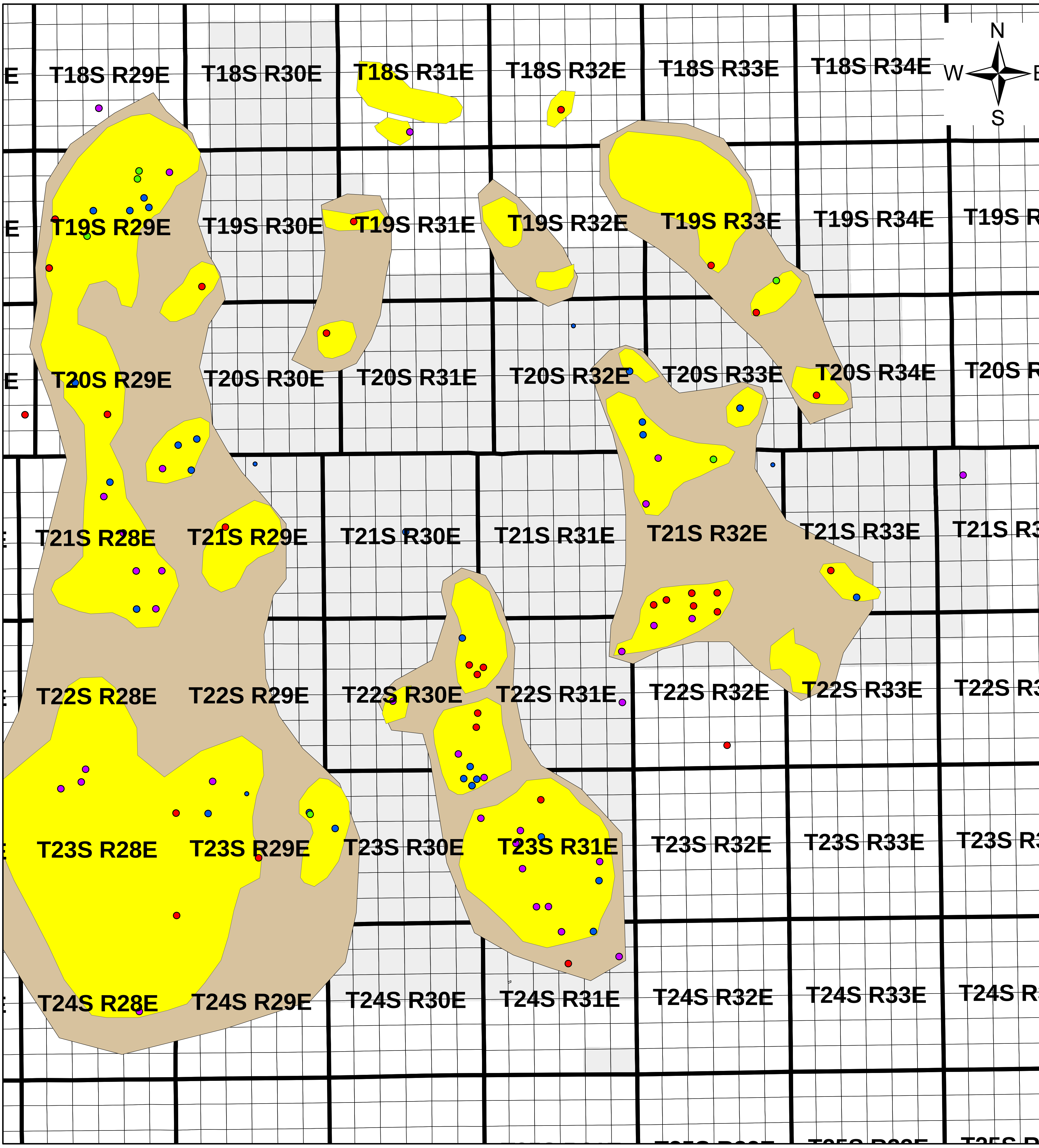


Legend

atoka

Wells

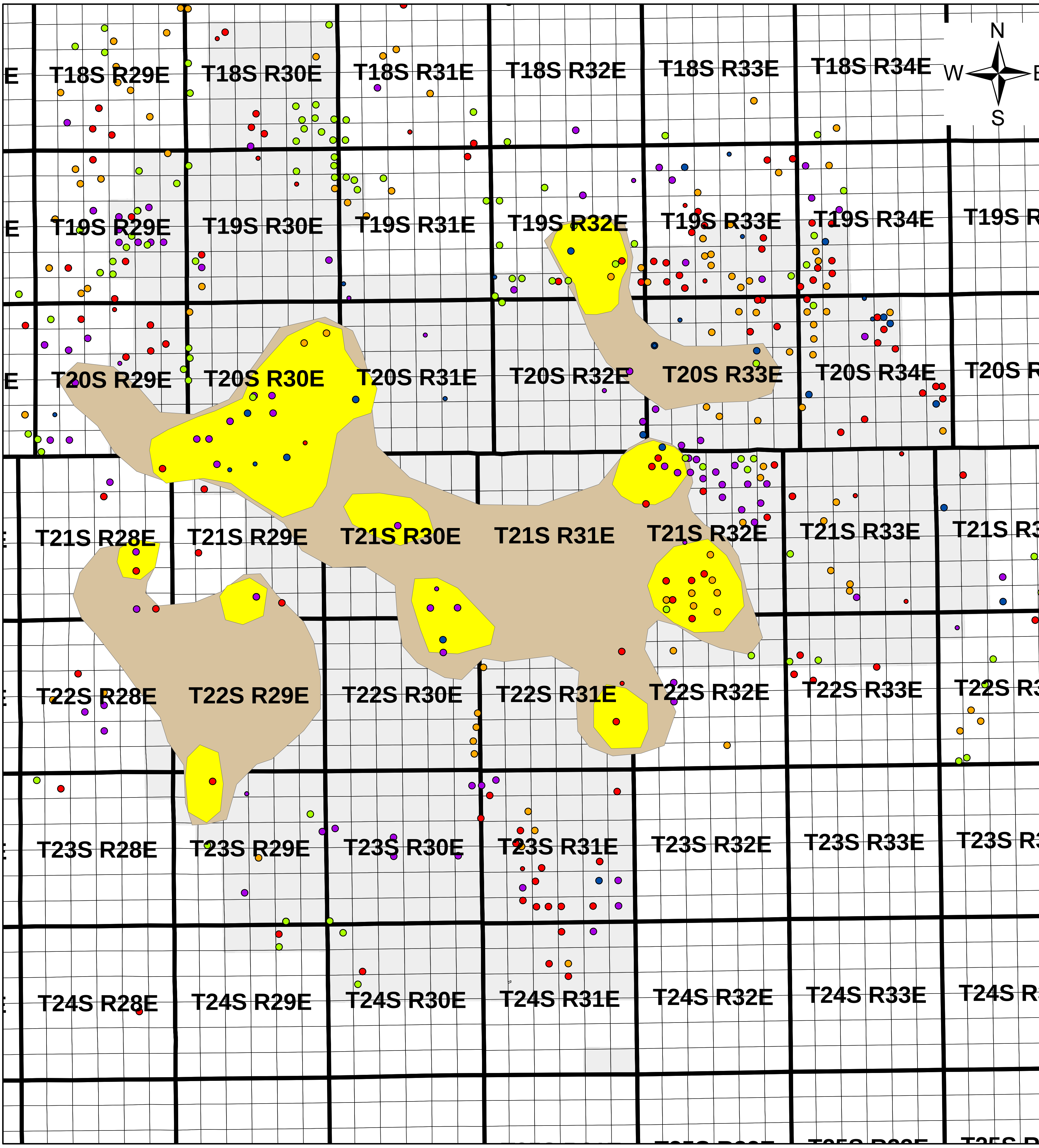
- Atoka shows
- Producers pre-1980 spud
- Producers 1980's spud
- Producers 1990's spud
- Producers post-1990's spud
- Atoka high potential
- Atoka medium potential
- **potash_boundary**

1:250,000

0 50,000 Feet

Plate 3. Atoka areas with anticipated future oil and gas production

Geologic trends of oil and gas production in the Secretary of the Interior's Potash Area, Southeastern New Mexico



Legend

morrow wells

Morrow wells

- Shows, pre-1970 spud
- Shows, 1970's spud
- Shows, 1980's spud
- Producers, pre-1970 spud
- Producers, 1970's spud
- Producers, 1980's spud
- Producers, 1990's spud
- Producers, 2000's spud
- Lower Morrow high potential
- Lower Morrow intermediate potential
- **potash_boundary**

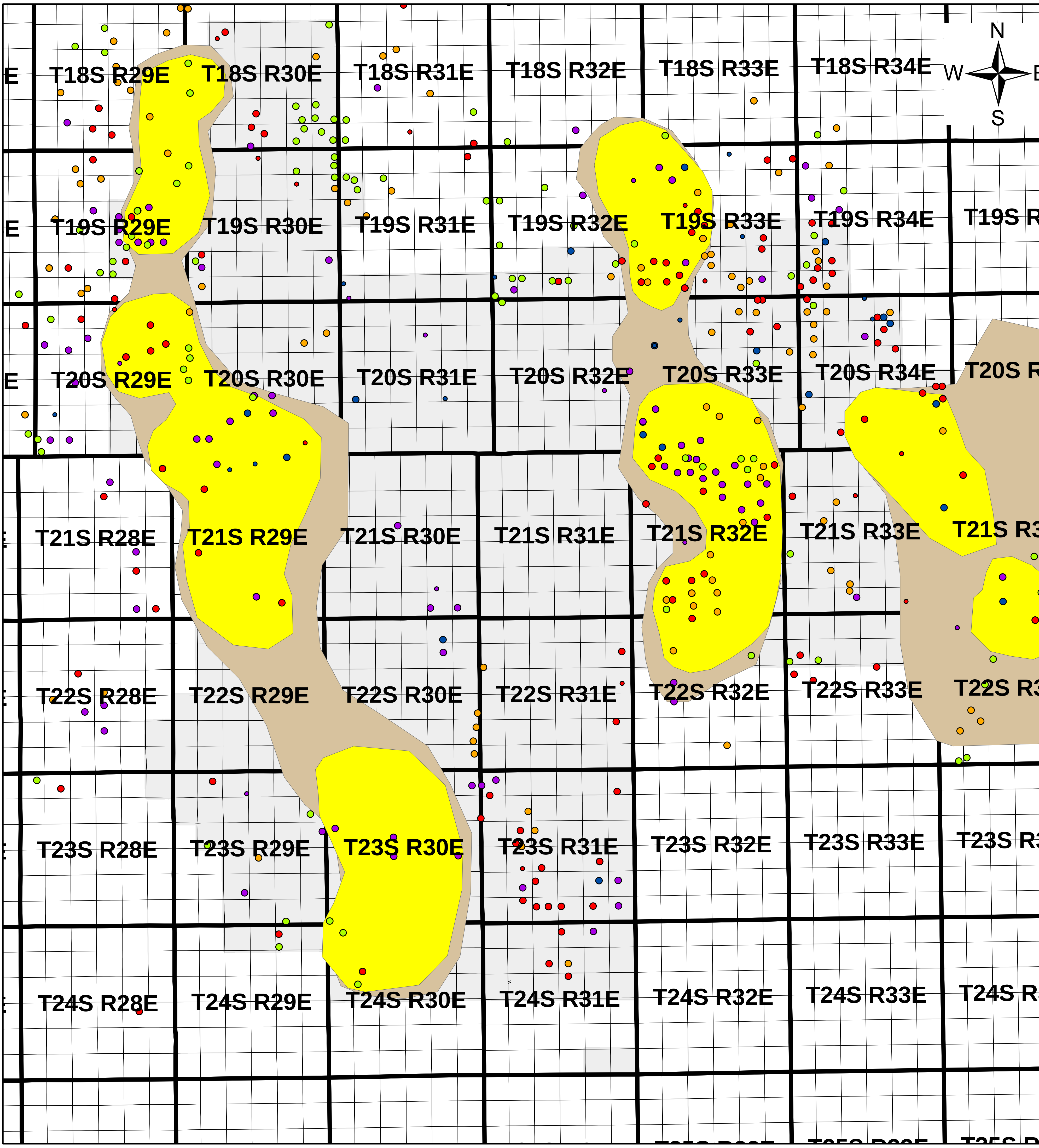
1:250,000

0 50,000 Feet

Plate 4. Lower Morrow areas with anticipated future oil and gas production

New Mexico Bureau of Geology and Mineral Resources
New Mexico Tech
Earth Science for the 21st Century

Geologic trends of oil and gas production in the Secretary of the Interior's Potash Area, Southeastern New Mexico



Legend

morrow wells

Morrow wells

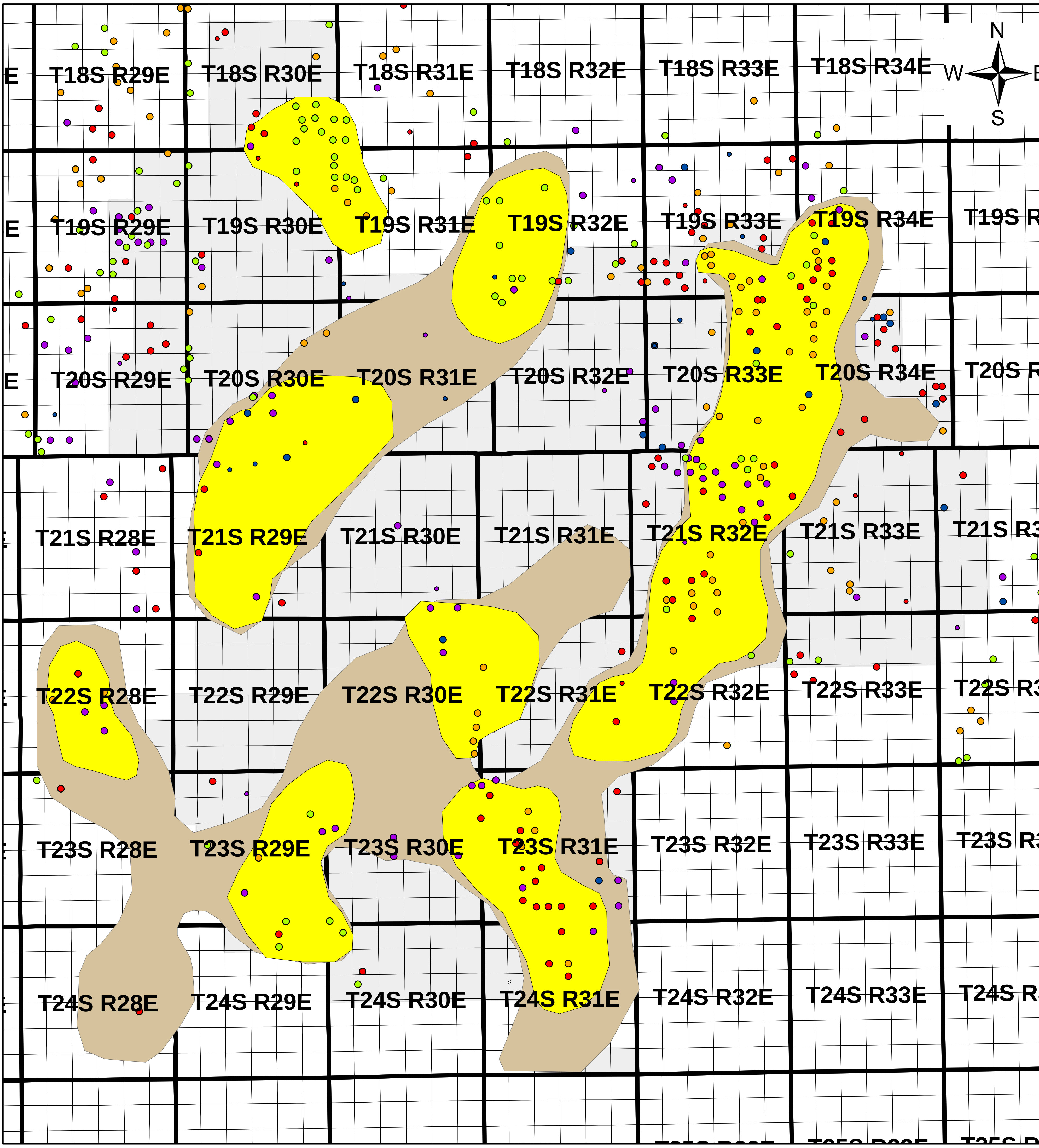
- Shows, pre-1970 spud
- Shows, 1970's spud
- Shows, 1980's spud
- Producers, pre-1970 spud
- Producers, 1970's spud
- Producers, 1980's spud
- Producers, 1990's spud
- Producers, 2000's spud
- Morrow B high potential
- Morrow B intermediate potential
- **potash_boundary**

1:250,000

0 50,000 Feet

Plate 5. Middle "B" Morrow areas with anticipated future oil and gas production

Geologic trends of oil and gas production in the Secretary of the Interior's Potash Area, Southeastern New Mexico



Legend

morrow wells

Morrow wells

- Shows, pre-1970 spud
- Shows, 1970's spud
- Shows, 1980's spud
- Producers, pre-1970 spud
- Producers, 1970's spud
- Producers, 1980's spud
- Producers, 1990's spud
- Producers, 2000's spud
- Morrow A high potential
- Morrow A intermediate potential
- **potash_boundary**

1:250,000

0 50,000

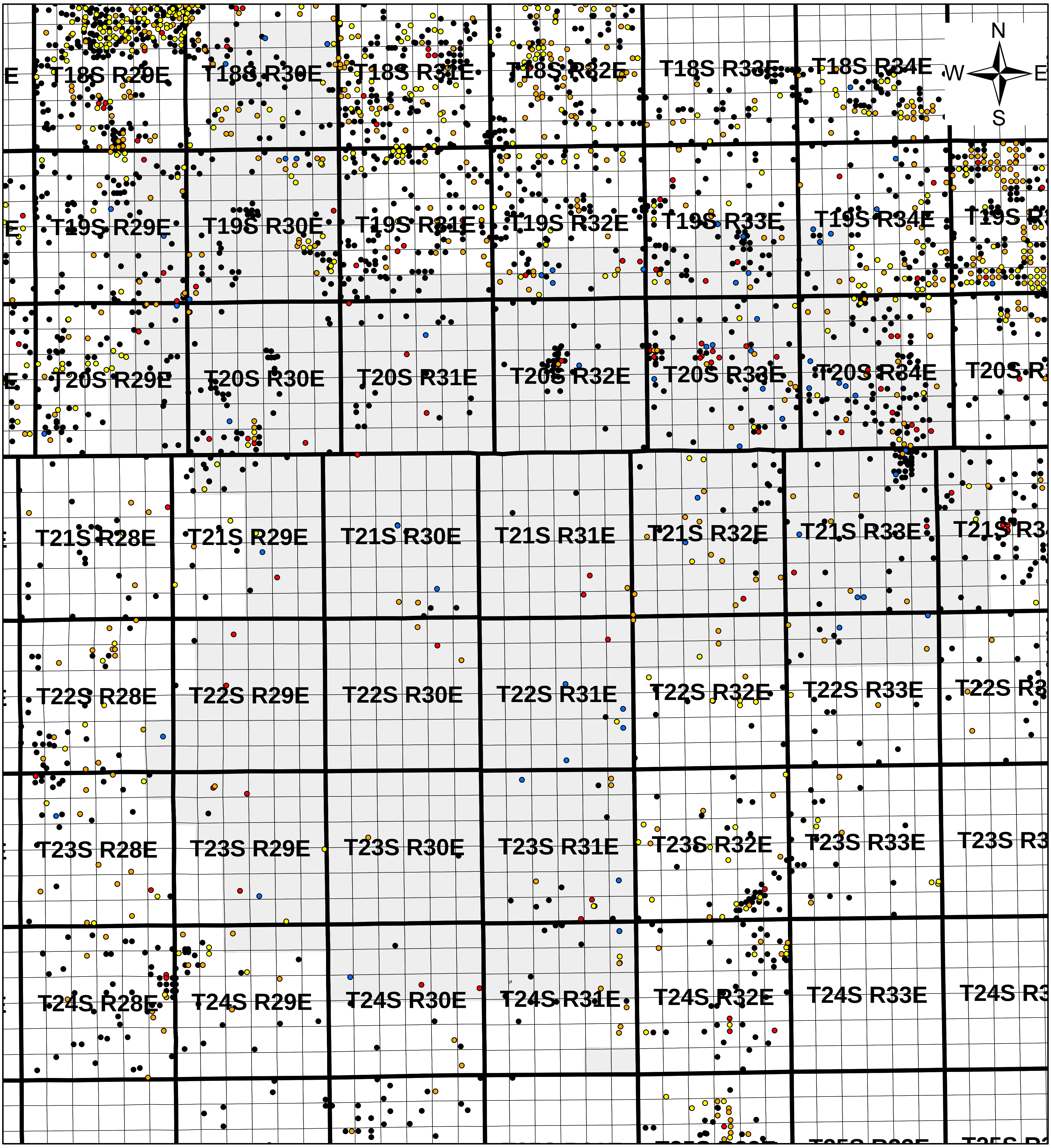
Feet

Plate 6. Middle "A" Morrow areas with anticipated future oil and gas production

New Mexico Bureau of Geology and Mineral Resources

New Mexico Tech

Earth Science for the 21st Century



1:250,000

0 52,000 Feet

Legend

potash_boundary

Plugged wells

plug date

- unknown
- pre-1970
- 1970's
- 1980's
- 1990's
- 2000's

Plate 7. Plugged wells (NMOCD, 2005)

Geologic trends of oil and gas production in the Secretary of the Interior's Potash Area, Southeastern New Mexico