Cost-effective integration of geologic and petrophysical characterization with material balance and decline curve analysis to develop a 3D reservoir model for PC-based reservoir simulation to design a waterflood in a mature Mississippian carbonate field with limited log data

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Purpose

To develop and demonstrate the application of a number of low-cost modern tools and techniques that independent operators can inexpensively employ to characterize assets to evaluate secondary recovery applications.

Tasks involved in this study include:

1. Consolidation of available data into a digital database.
2. Reservoir characterization and development of 3D integrated geo-model.
3. Use of advanced decline curve analyses to fill in missing production data to reconstruct well production histories, and to determine if wells produced under constant bottom hole pressures.
4. Reservoir simulation studies to history match primary production.
5. Use of iterative history matching technique to estimate the initial fluid saturations in the reservoirs lacking sufficient resistivity logs.
6. Mapping residual reserves and evaluating the potential of incremental reserve recovery by such means as water injection.

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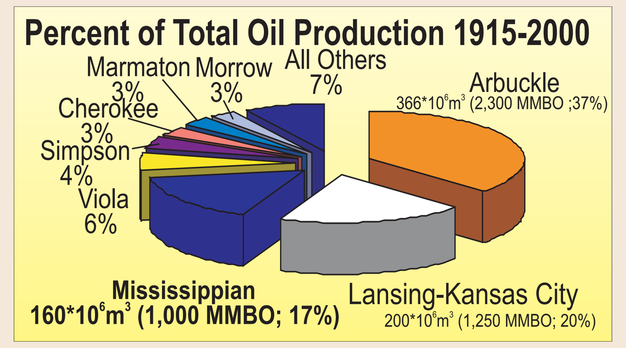
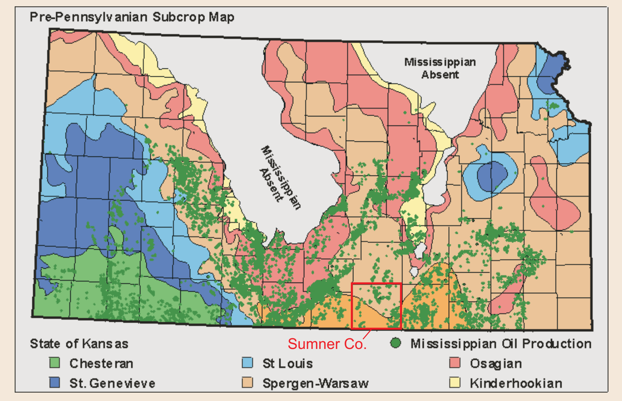
Importance of Mississippian Production in Kansas

Of the 6.3 billion barrels of oil produced in Kansas, Mississippian carbonate reservoirs have produced about 1 billion barrels (i.e., 17% as of 2000). With declining production from the Arbuckle and Lansing-Kansas City formations, the contribution of Mississippian reservoirs to the state's oil production has increased significantly over the past ten years and presently represents over 40% of the state's 35 million barrels annual production.

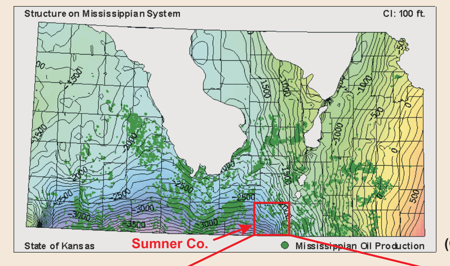
Mississippian oil production is focused in the Mississippian subcrop along the flanks of the Central Kansas Uplift (green dots). The study field is located in Sumner County on the southern flank.

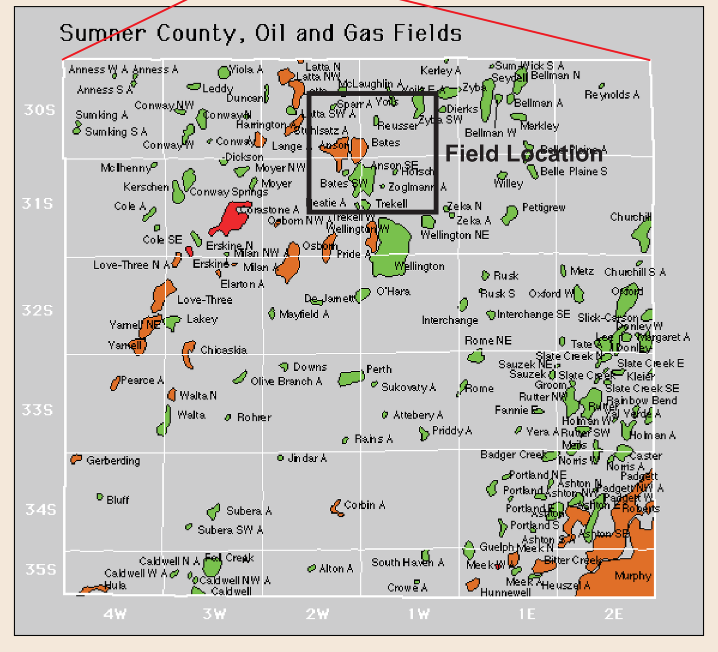




Location

Wellington West field is located in Sumner County, Kansas (Figure). The Mississippian-Warsaw age reservoir rock is dolomite-wackestone to packstone. The field produces from a structural-stratigraphic combination trap. The discovery well was Becker No. 1 (located in the SW-NW-SE, Sec30 T31S, R1W), drilled by Zenith Drilling in 1977.

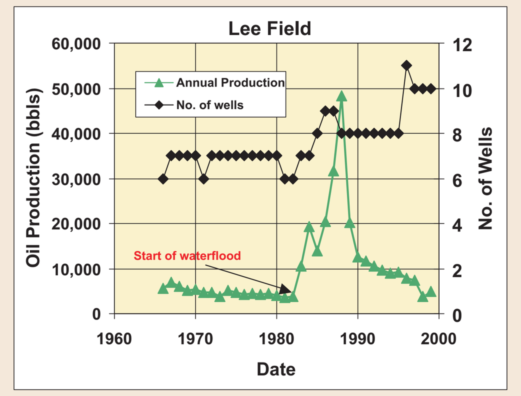


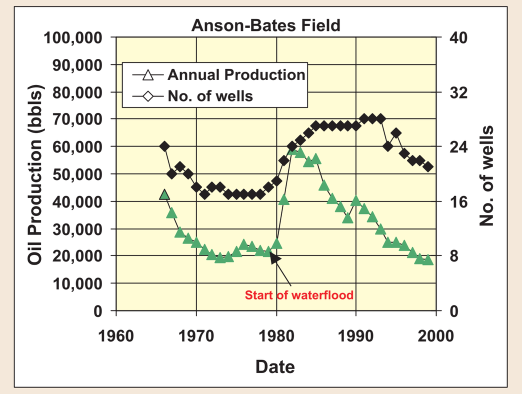


Results of Successful Waterfloods in Neighboring Fields

Data available from two Mississippian fields show remarkable incremental production during planned secondary recovery. The Lee field, Sumner County, Kansas, is similar in size and number of wells as the Wellington West field. Detailed studies were carried out on this field to design an effective waterflood. At the onset of the waterflood, the annual field production was close to 3,880 BO. Upon full implementation of the waterflood, peak production rose to 48,000 BO/year, and currently, 10 years after the onset of the flood, this field continues to produce at a higher rate (4,200 BO/year) higher than the pre-flood production (Figure). Cumulative production from the Lee field before the onset of the waterflood was 263.2 Mstb. Additional incremental oil from waterflooding is estimated to be 255.2 Mstb. The Lee field demonstrates the immense potential that properly designed and implemented waterfloods have in recovering the significant resources left behind after primary production in Mississippian carbonate fields.

The Anson field, Sumner County, Kansas, is another example of a successful waterflood in a Mississippian dolomitic reservoir. The operator of this field employed a consulting firm to characterize the reservoir and design an effective waterflood. The preflood annual field production was 24,500 bbls. After the implementation of the flood, the annual field production peaked close to 9,400m³ (59,000 bbls), and currently, after 17 years since the inception of the flood, the field produces at 18,000 bbls/year. The Anson field is slightly bigger in size than the Wellington West field with the number of operating wells during the waterflood varying between 21 and 28. The waterflood in the Anson field resulted in a cumulative production of 740 Mstb while the pre-flood production cumulative production was 1,450 Mstb.





Production History

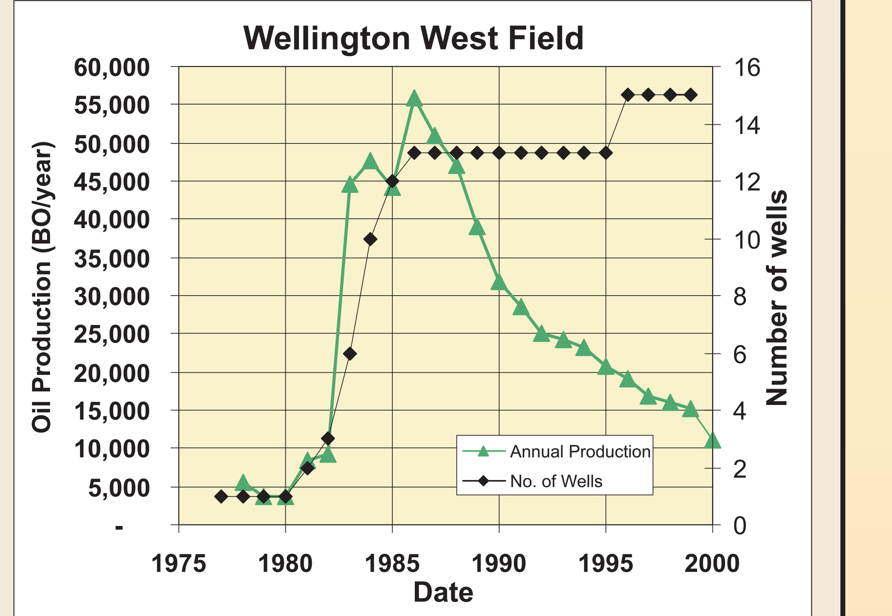
The initial production (IP) recorded at Becker No. 1 was 50 bopd. Most of the primary field development occurred between 1983 and 1986. By 1986, the total number of wells in the field was 13 and resulted in the annual oil production to peak at 55,962 bbls (Figure). The combination trap allows wells located low on the structure (subsea depth of 747 m; 2450 feet) and with average permeability to produce oil. Two infill wells, drilled in the later years, were unable to halt the production decline in the field.

The reservoir drive mechanism is attributed to a strong bottom-water drive. Shut-in pressures from drill stem tests (DSTs) recorded in the initial wells indicate the initial reservoir pressure to be close to 2,000 psi. IP rates for most of the wells have ranged between 15 to 30 bopd. However, field-wide differences between the final shut-in pressures (FSIPs) and the final flow pressures (FFPs), from DST records, indicate permeability heterogeneity within the pay zone.

From its discovery to the present, the field has been under primary production without any artificial pressure support. Over the field history of 24 years, reservoir pressure has declined from 2,000 psi to 1,700 psi. The initial recoverable reserves in Wellington West field have been estimated at 6.1 MMstb. Total cumulative recovery, as of 2000, has been 600 Mstb, resulting in a primary recovery efficiency of about 10%.

The American Energies Corporation (AEC) currently operates the Wellington West field. With primary production having reached economic limits, AEC must design and implement an effective secondary recovery strategy to continue operating the field. Recoveries from infill vertical wells have been marginal due to low reservoir pressure and reservoir heterogeneity.

Low primary recovery factors have resulted in significant volumes of residual reserves, estimated at 5.5 MMstb, in the Wellington West field. To implement a development plan capable of recovering some of these reserves this study was conducted.



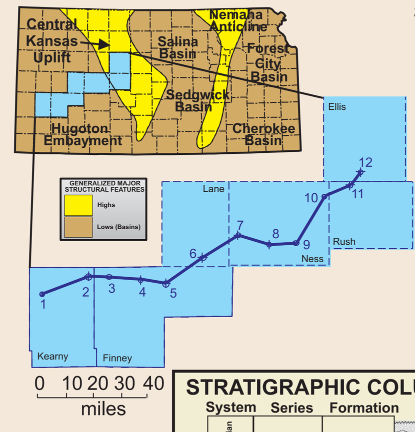
Abstract

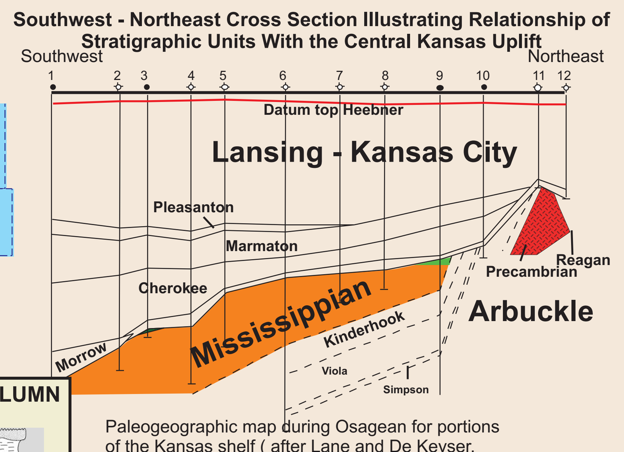
Kansas Mississippian shallow shelf carbonates reservoirs, operated by small independent operators, have produced over 1 billion barrels of oil and presently represent over 40% of Kansas annual oil production. Despite prolific production recovery efficiencies are low (12-18%) due to reservoir heterogeneity and variable drive support, limited geologic and engineering data, and lack of application of integrated reservoir evaluation tools. The goal of this DOE-funded project is to develop and demonstrate the application of a number of low-cost modern tools and techniques that independent operators can inexpensively employ to characterize assets to evaluate secondary recovery applications. Major aspects of the study have involved tasks directed at obtaining a representative reservoir model to study responses to various waterflood designs at the American Energies Wellington West Field.

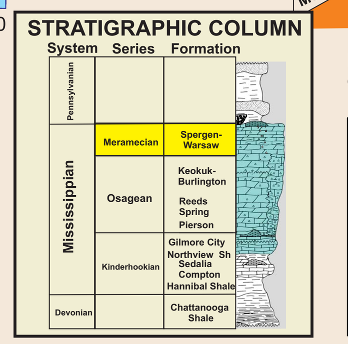
Tasks involved include: consolidation of available data into a digital database; geologic and wireline log reservoir characterization, core petrophysical characterization, and engineering characterization to understand the reservoir system. These data have been used to develop an integrated geomodel of the reservoir; which has been used as the basis for reservoir simulation studies to history match primary production and to design an effective strategy to recover incremental reserves. Wireline log signatures, capillary pressure data, and OOIP volumes were integrated in a 3D reservoir model that described reservoir architecture, distribution of flow-units, and variability of reservoir properties. A PC-based reservoir simulator used this model to map areas with residual mobile oil saturation and predict performance of different waterflooding patterns.

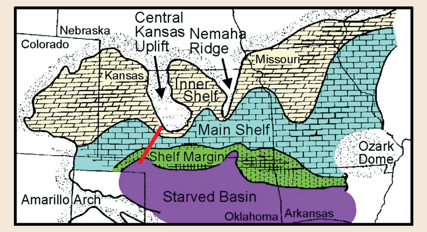
Geologic Setting

Mississippian fields are located on the upper shelf of the Hugoton Embayment of the Anadarko Basin. The fields are situated on the southern and southwest flank of the Central Kansas Uplift, a structural high during Mississippian time that was accentuated in post-Mississippian time. Mississippian units get progressively older as strata are traced onto the Central Kansas Uplift. Strata in the fields represent shelf carbonates deposited on a gentle south-southwest sloping ramp. A transition from shelf carbonates to basin facies in Osagean strata occurs along the southern flank. Post-depositional regional uplift, subaerial exposure and differential erosion of the ramp strata at the pre-Pennsylvanian unconformity resulted in paleotopographic highs (buried hills). These structural highs have been the targets of exploration and production efforts. The majority of Mississippian production in Kansas occurs at or near the top of the Mississippian section just below the sub-Pennsylvanian unconformity. Field locations can also be correlated in some areas with basement lineaments.









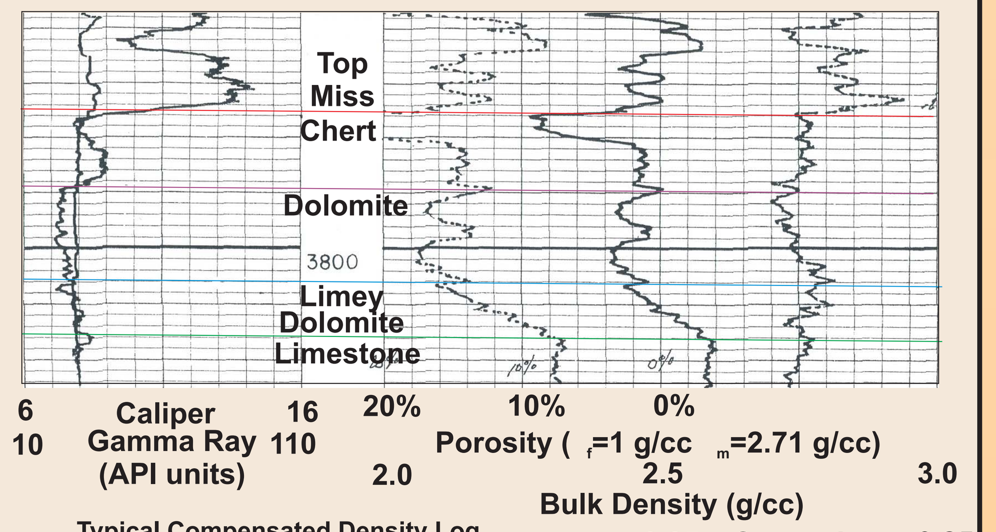
Paleogeographic map during Osagean for portions of the Kansas shelf (after Lane and De Keyser, 1980). Note location of cross-section shown above.

Wireline Log Interpretation

A major problem in these Mississippian fields is the difficulty in identifying the dolomitic interval on some wireline logs and identifying effective porosity within the dolomitic interval. To identify the dolomitic interval geologic sample logs were correlated with wireline logs to properly identify the productive dolomitic interval.

For most wells, the productive dolomite interval underlying the chert interval is between 10 and 50 ft in thickness. Analysis indicates that where the dolomitic interval is less than 15 feet in thickness porosity is less than 15% and permeabilities are near the lower limit or below values suitable for good reservoir rock.

Chert Interval - Overlying the Mississippian surface is a chert zone ranging in thickness from 8 to 20 ft. Though this zone has been reported to have oil shows, permeability in the chert interval is poor. Electric wireline log analysis and sample descriptions can be interpreted to indicate that this chert zone is unproductive. Though a cross-plot of vertical (k_v) and horizontal permeability (k_h) in Anson-Bates field indicates that the high k_v/k_h ratio might allow water injection during a waterflood operation to move into the chert zone, low permeability in the chert zone results in acceptable water loss.

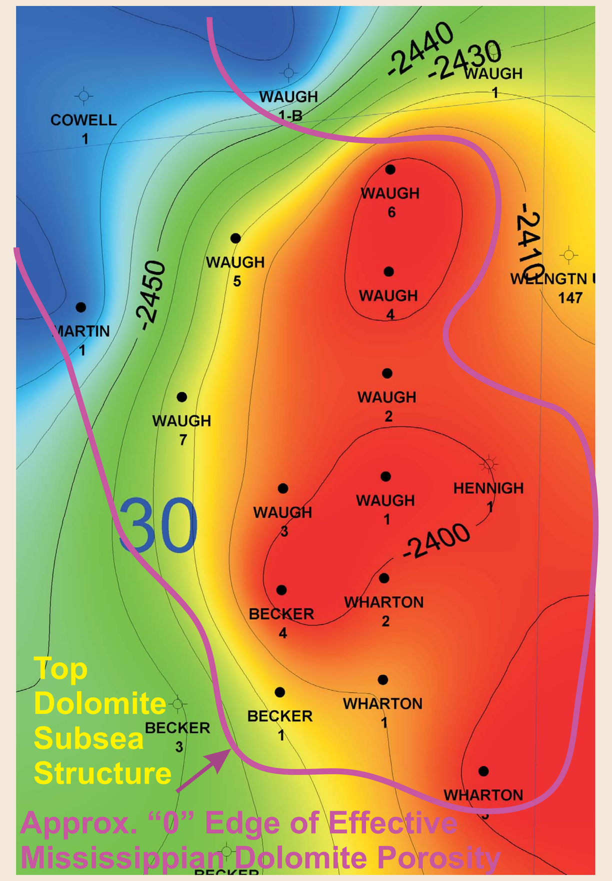


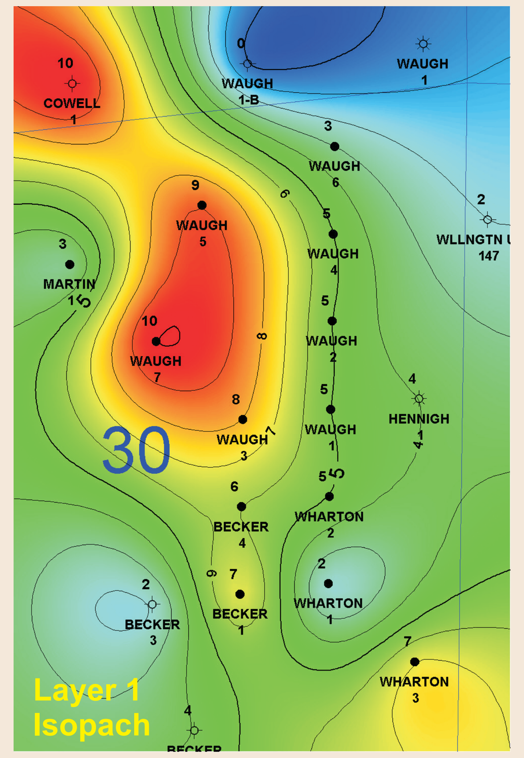
Typical Compensated Density Log
Zenith Drilling Becker #1
T31S R1W Sec 30 SE NW SE

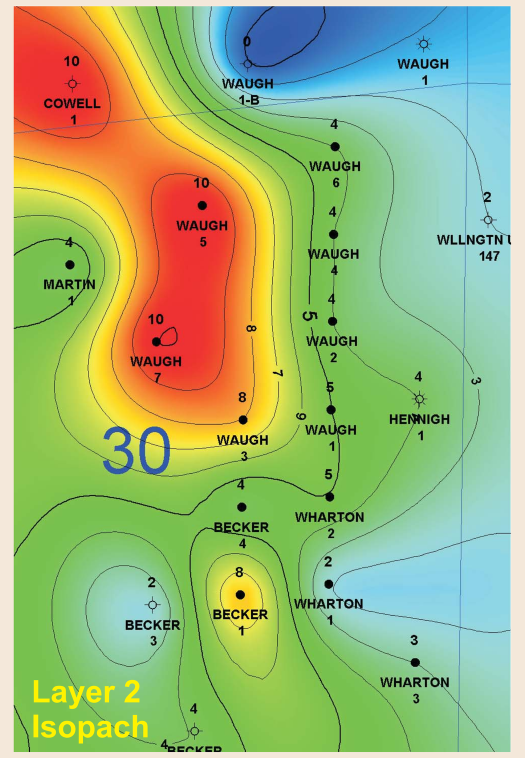
Basic Reservoir Geomodel

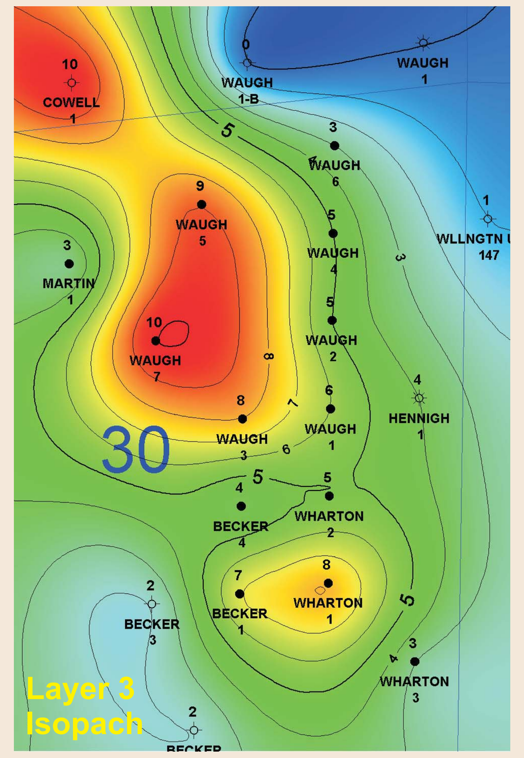
Since the thin dolomites do not contain good reservoir rock, an isopach map of the dolomite was utilized to delineate the reservoir boundaries in the north, east and the south side.

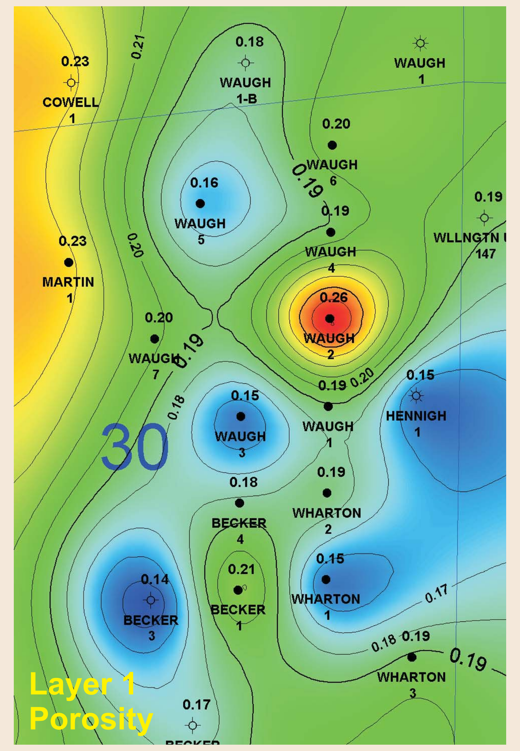
- Wireline logs were used in cross-sections of the field to correlate the top and thickness of the dolomitic and the chert zones. Figure below shows the top of the dolomite.
- Based on differences in properties the reservoir was divided into three intervals (Figures show isopach and porosity distribution).

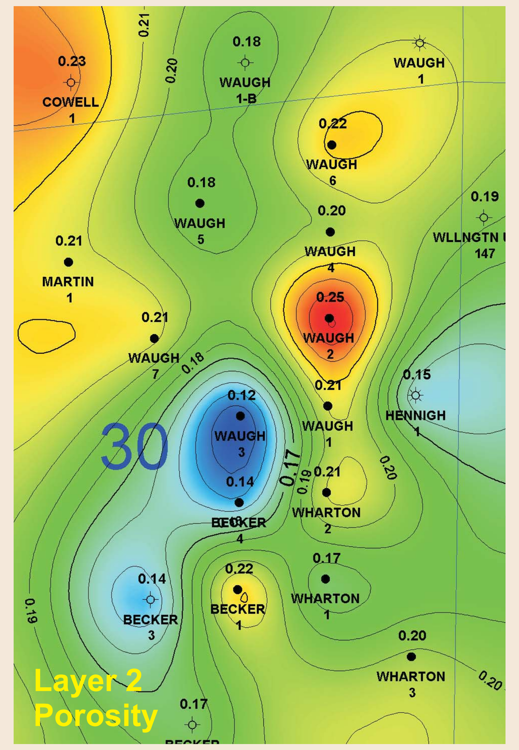


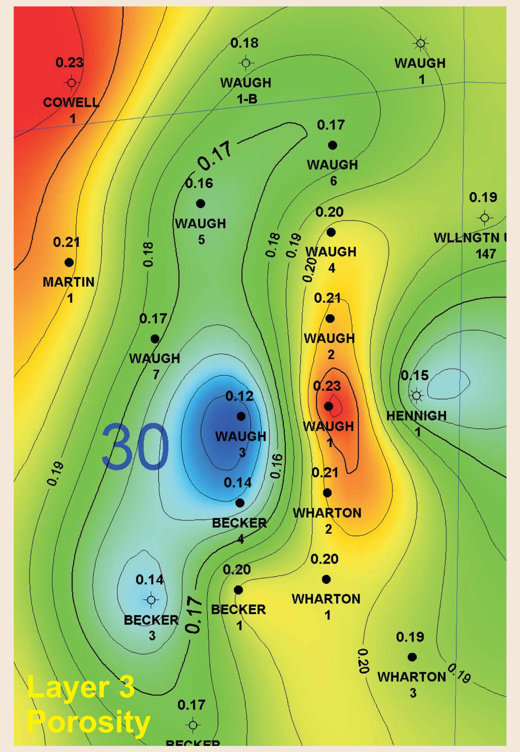












PfEFFER Analysis

- Wireline logs were analyzed using PfEFFER, an Excel program that provides Super-Pickett analysis for pattern recognition.
- Inputs - wireline log resistivity and porosity, water salinity, Archie parameters (m and n).
- Porosity, BVW, and permeability cut-offs were used to identify the net pay at each well.
- Log-calculated water saturations were found to compare well with capillary pressure-calculated saturations when rock permeability was accurately assigned.
- Note high water saturations due to much of interval being in the transition zone.