IMPROVED RESERVOIR CHARACTERIZATION OF THE ROSE RUN SANDSTONE IN THE EAST RANDOLPH FIELD, PORTAGE COUNTY, OHIO

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Acknowledgments

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Abstract

The East Randolph Rose Run Field is located in Randolph Township, Portage County, Ohio. The field was discovered in 1992 as a down-dip extension of the Randolph Gas Field discovered by Belden & Blake Corporation a year earlier. Since the East Randolph Field discovery, over 40 wells have been drilled that have produced an estimated 600,000 barrels of oil and 1.5 billion cubic feet of gas.

Characterization of the productive upper Rose Run sandstone members is underway to determine the technical and economic feasibility of water flooding, gas pressure maintenance, or infill drilling for improved oil recovery in the East Randolph Field. Core and log data of each sandstone member were analyzed and mapped to determine their relationship with estimated ultimate recovery of oil and gas.

The upper Rose Run sandstone can be subdivided into four distinct sandstone zones characterized by bedding, mineralogy, and log character. Each of the four sandstone zones usually represents a fining-upward sequence of sandstone, sandy dolomite, and dolomite. The uppermost zone (Zone 1) consists of tightly cemented sandstone with quartz overgrowths, low permeability, and low porosity; while the lowermost sandstone zone (Zone 3B) is usually the most porous and permeable. The variation in porosity and permeability is predominantly controlled by grain size, amount and type of intergranular cement, and extent of secondary dissolution porosity.

Most of the East Randolph Field's oil production can be attributed to the reservoir development of the Rose Run Zone 3A and Zone 3B. Gas production appears to be present in all zones, but seems to be best when good reservoir development is present in Zone 1 and Zone 2. Volumetric calculations using new geologic models increases estimates of the amount of original oil-in-place to more than 10 million stock tank barrels, more than double initial estimates. The new geologic model will be used as input for reservoir simulation to optimize future locations of infill wells, and determine waterflood and/or pressure maintenance feasibility.

Introduction

The Rose Run sandstone is a member of the Upper Cambrian Knox Supergroup. The Rose Run sandstone ranges in thickness from 110 to 150 feet and consists of stacked sheet sandstone deposits separated by and interbedded with thin, low permeability dolomites and carbonaceous shales. The Rose Run sandstone is overlain by the Beekmantown Dolomite, which is capped by the Knox unconformity, and underlain by the Trempaleau Dolomite. Hydrocarbon traps in the East Randolph Field are a combination of structural and stratigraphic features.

Since 1992, the East Randolph Field, located in Randolph Township, Portage County, Ohio (Figure 1), has produced an estimated 600,000 barrels of oil and 1.5 billion cubic feet of gas (BCF) from the Rose Run sandstone. Field development and infill drilling opportunities illustrate the need for improved reservoir characterization of the hydrocarbon productive zones. This reservoir study is conducted by Belden & Blake Corporation and BDM-Oklahoma under the U.S. Department of Energy's Reservoir Management Demonstration Program.

Early reservoir modeling characterized the Rose Run sandstone in Randolph Township as a homogeneous sandstone body. Subsequent studies have shown this to be oversimplified (Riley and others, 1993). Core studies on several wells in the East Randolph Field indicate the existence of three to four individual flow units of varying reservoir quality separated by nonreservoir layers, usually low permeability dolomite.

Well log and core analyses were conducted to determine the reservoir distribution, the heterogeneity of the hydrocarbon producing zones, and the effects of faulting and fracturing on well productivity. The Rose Run sandstone and interbedded dolomites were subdivided into three productive zones (Figure 2). Cross sections were constructed for correlation of individual zones and identification of localized faulting. The geologic data was input into GeoGraphix software for the construction and interpretation of structure, net pay, production, and gas- and water-oil ratio maps.

Rotary sidewall cores and core plugs from the McGuire #2 infill well were analyzed to determine porosity, relative permeability, fluid saturation, and capillary pressures. Detailed core descriptions provided information on lithologies, diagenesis, fracture density, and depositional environments. Core to log relationships were used to refine geologic mapping. Relationships between estimated oil and gas ultimate recoveries and reservoir parameters, such as structure, net sand thickness (using a 6% porosity cutoff), and porosity were investigated.

The influence of structure on the reservoirs and entrapment of hydrocarbons in the East Randolph Field is not fully understood. Several studies (Harper, 1989; Riley and others, 1993, and Moyer, 1995) discuss the complex structural history along the Akron-Suffield fault system and the influence on trapping mechanisms in the Rose Run sandstone. Further discussion on this topic is beyond the scope of this paper and warrants a separate study.

Rose Run Sandstone Reservoir Zones

Reservoir quality studies in the East Randolph Field indicate pronounced differences in porosity and permeability between the various Rose Run sandstone zones. Sandstone intervals having the best reservoir quality tend to be located near the basal portion of each zone, and fine upward, usually grading into a nonreservoir, low permeability dolomite or carbonaceous shale. The repeated fining-upward cycles of sandstone and dolomite suggest changing sea level conditions and fluctuating sediment supply. The following is a brief discussion of the four productive Rose Run sandstone zones present in the East Randolph Field.

Zone 1 has the poorest reservoir quality of all the sandstone zones. This zone varies laterally from a tightly cemented fine-grained quartz arenite to a sandy dolomite. Average porosity in this zone is less than 6%. Permeability is also low, usually less than 0.1 md. The dominant cement in this zone is quartz overgrowths, which are dense in localized areas. Bedding is usually horizontal, with beds ranging in thickness from 6 inches to 2 feet. Hydrocarbon production form this zone is limited to a few wells where porosity exceeds 6%. Based on gas detection, which usually does not exceed 100 units when drilling on air, this zone contributes only small volumes of gas to total Rose Run production. Because of the lack of significant production and poor reservoir quality of this zone, no maps were constructed showing its distribution.

Zone 2 sandstones are generally continuous across the area and range from 1 to 8 feet thick. Average net sand thickness using a 6% porosity cutoff is approximately 5 feet (Figure 3). The sandstone has a sharp lower contact with interbedded dolomite. Log analysis indicates a gradational upper contact into laminated sandy dolomites. Underlying dolomites are typically massive, burrowed, and contain dolomite clasts. Wavy shale laminations contain reddish oxidation, possible root traces, and bioturbation.

From core descriptions, Zone 2 sandstones are light gray to medium gray, fine-grained, well sorted, and parallel laminated to cross-laminated. The sandstone lithology is classified as arkosic (Folk, 1968). Alternating light and medium gray laminations are defined by grain size differences and shale content. The sandstone is burrowed in places with the burrows filled with finer-grained material than surrounding sediments. The presence of soft sediment deformation is due to compaction and dewatering with small microfractures filled with quartz cement.

Routine core analyses were performed on Rose Run sandstone core plugs from the McGuire #2 well in the East Randolph Field to determine porosity and permeability differences. Core porosity measurements for Zone 2 range from 1.7% to 6.2%; air permeability ranges from 0.01 to 0.42 md. Log porosity varies from 1 to 7%, with neutron-density crossover of 4 to 6% suggesting high gas saturation.

Zone 3A is continuous across the area and ranges from 2 to 12 feet in thickness. Average net sand thickness using a 6% porosity cutoff is approximately 7.5 feet (Figure 4). The sandstone has a sharp lower contact with thin shales separating the dolomites from the overlying sandstones. The sandstone is fine-grained at the base and becomes very fine-grained with lower porosity near the top. The upper contact is conformable and gradational with interbedded sandstones and dolomites.

From core description, Zone 3A is a light gray to medium gray, well sorted arkosic sandstone. The sandstone is parallel laminated to lenticular cross laminated. Ripple cross lamination and wavy laminations occur near the base of the interval. Laminations are defined by variations in grain size and accentuated by higher concentrations of shaley material. The sandstones are interbedded with wavy laminated and flaser-bedded shales and microcrystalline dolomites. The interbedded dolomites act as baffles to fluid flow and create fluid-flow compartments. The intercalated shaley flaser bedding results from the accumulation of shale in the ripple troughs. Bioturbation, soft sediment deformation due to compaction and dewatering, and styolites have distorted or destroyed the laminations in places. The varying lithologies and character of the laminations reflect changing current directions and variations in wave energy and sediment supply.

Routine and special core analyses were performed on core plugs to determine porosity, permeability, and saturation differences. Routine and special core analyses indicate porosity for Zone 3A ranges from 7.3% to 11.1%. Air permeability ranges from 1.02 md to 12.9 md; brine permeability ranges from 0.42 md to 1.92 md, approximately 10% of air permeability. Water saturation ranges from 32.5% to 51.4%.

Permeability measured in special core analyses was higher than that measured with routine core analyses. The differences were predominantly due to the differing core plug cleaning procedures. The longer period of cleaning used in special core analyses allowed the toluene to dissolve paraffin paraffin present in the micropores. The high paraffin content of the oil (8-10% by weight) was confirmed by fluid analyses prior to special core analyses. Additional work is being done to design improved treatment procedures that will help to alleviate paraffin problems in wellbores in the future.

Zone 3B typically consists of two separate sandstone deposits separated by a thin dolomite interbed. Individual sandstone deposits are continuous locally, but discontinuous regionally. Thickness ranges from 3 feet up to 12 feet. Average net sand thickness using a 6% porosity cutoff is approximately 8 feet (Figure 5). The upper contact is gradational with shale rip-ups present in the overlying mottled dolomite. The sandstone has a sharp, conformable basal contact on top of a mottled gray dolomite.

From core description, Zone 3B is a tightly cemented, light gray to medium gray, well sorted, arkosic sandstone. The sandstone is parallel laminated to ripple cross laminated and burrowed near the top. Individual laminations are defined by variations in grain size and varying amount of shaley material. The sandstone is interbedded with dolomite and thinly laminated to flaser bedded shale. The wavy laminated sandstones contain angular shale rip-up clasts and shale drapes.

Zone 3B porosity ranges from 7.9% to 10.6%. Air permeability ranges from 0.54 md to 2.13 md; brine permeability ranges from 0.14 md to 0.38 md, approximately 10% of air permeability. Water saturation ranges from 49.2% to 70.7% indicating a higher water saturation toward the base of the interval.

Petrographic analyses were performed on selected thin sections from the McGuire #2 cored infill well. The objectives of the analyses were to:

- Characterize the texture, mineralogy, and cementation of the productive zones
- Incorporate the results of special core analyses to evaluate the reservoir quality
- Integrate the core analyses with log analyses to refine the geologic model.

Petrographic analyses indicate that most of the Rose Run sandstones analyzed are silica or dolomite cemented, moderately well to very well sorted, fine-grained sandstones. The sandstones are typically parallel laminated to low angle cross laminated. Individual laminations are often defined by variations in grain size.

The dominant mineral constituents are monocrystalline quartz, K-feldspar, plagioclase feldspar, polycrystalline quartz, rock fragments (predominantly sedimentary), and iron oxides. Chert occurs in a few samples. Feldspar grains are generally partially to completely leached due to secondary dissolution. Glauconite is present in some samples near the contacts with dolostone interbeds.

Most primary intergranular porosity has been partially to completely occluded by cementation. Silica cement is the dominant cement in the sandstones (5-20% of the rock). Brownish dust rims define some of the quartz overgrowth contacts with the detrital quartz grains. Quartz overgrowths restrict pore throat openings between larger pores and completely fill smaller pores. Dolomite and calcite comprise a major proportion (up to 30%) of the cement where silica cement is minimal. Other cements that are present in minor amounts include feldspar overgrowths, ankerite, and pyrite. Minor amounts of authigenic clays (primarily illite) are present and coat framework grains and bridge pores inhibiting the precipitation of quartz overgrowths.

Primary intergranular porosity is the major porosity type present. Most of the intergranular pores are small and poorly interconnected. Porosity enhancement is due to secondary intergranular and grain-moldic pores created from partial and complete dissolution of unstable feldspar grains and rock fragments. In many samples, well connected intergranular porosity distribution is restricted to distinct laminations. Microporosity is typically associated with authigenic clays. Fracture porosity was rarely observed in the samples analyzed. Mechanical deformation due to compaction is evident in some samples with fractured grains and styolites being formed.

Conclusions

The reservoir quality of the Rose Run sandstone varies from good to poor. The reservoir quality is predominantly controlled by the amount of silica cement, the amount of secondary carbonate cement, and the extent of secondary dissolution porosity. The thicker sandstone intervals in Zone 3A and Zone 3B have much better developed effective intergranular porosity and higher permeability. Thinner intervals tend to be have higher amounts of silica and carbonate cement and less secondary dissolution accounting for the reduced porosity and permeability.

The interbedded dolomites may act as permeability barriers or baffles preventing effective communication between the sandstone flow units. This is most likely the case between Zone 2 and Zone 3A, less likely between Zone 3A and Zone 3B. Areas of faulting and fracturing may allow cross communication between each of the sandstone flow units. Interference and pulse pressure tests are required to confirm whether faulting further compartmentalizes the reservoir.

The net sand thickness of the Rose Run Zone 3A and Zone 3B correlates well with the estimated ultimate oil recovery (Figure 6). Cumulative production comparisons are biased due to the range in production times for the wells from only a few months to several years. Instead, estimated ultimate recovery maps for oil and gas were constructed to account for the range in well completion dates and production data over the last couple of years. The highest estimated ultimate oil recovery correspond to the thickest net sands in the central part of the field. These sands also have the highest porosity and permeability, and lower water saturation.

Estimated ultimate recovery of gas corresponds best with the net sand thickness and reservoir quality of Zone 2 (Figure 7). The high gas saturation of Zone 2 has been observed when drilling through the zone on air and from log analyses. Wells in the southern and eastern portion of the field have lower estimated ultimate oil and gas recovery due to slightly lower porosity, higher water saturation in Zone 3B, and possibly completion differences.

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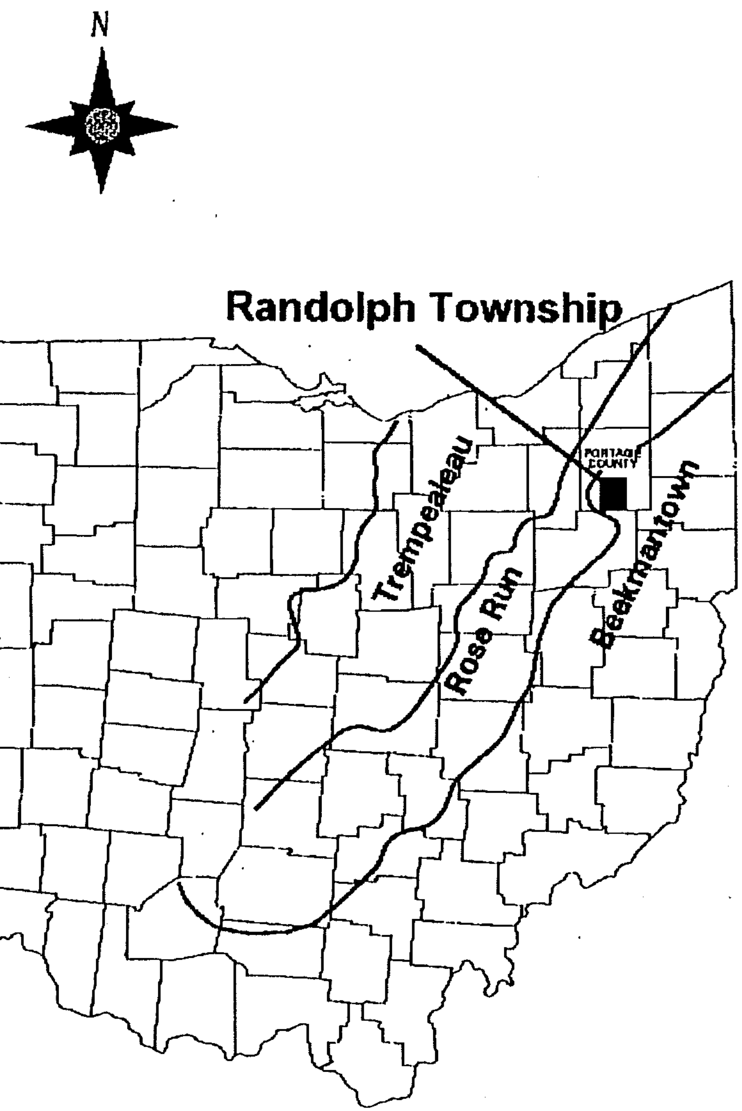
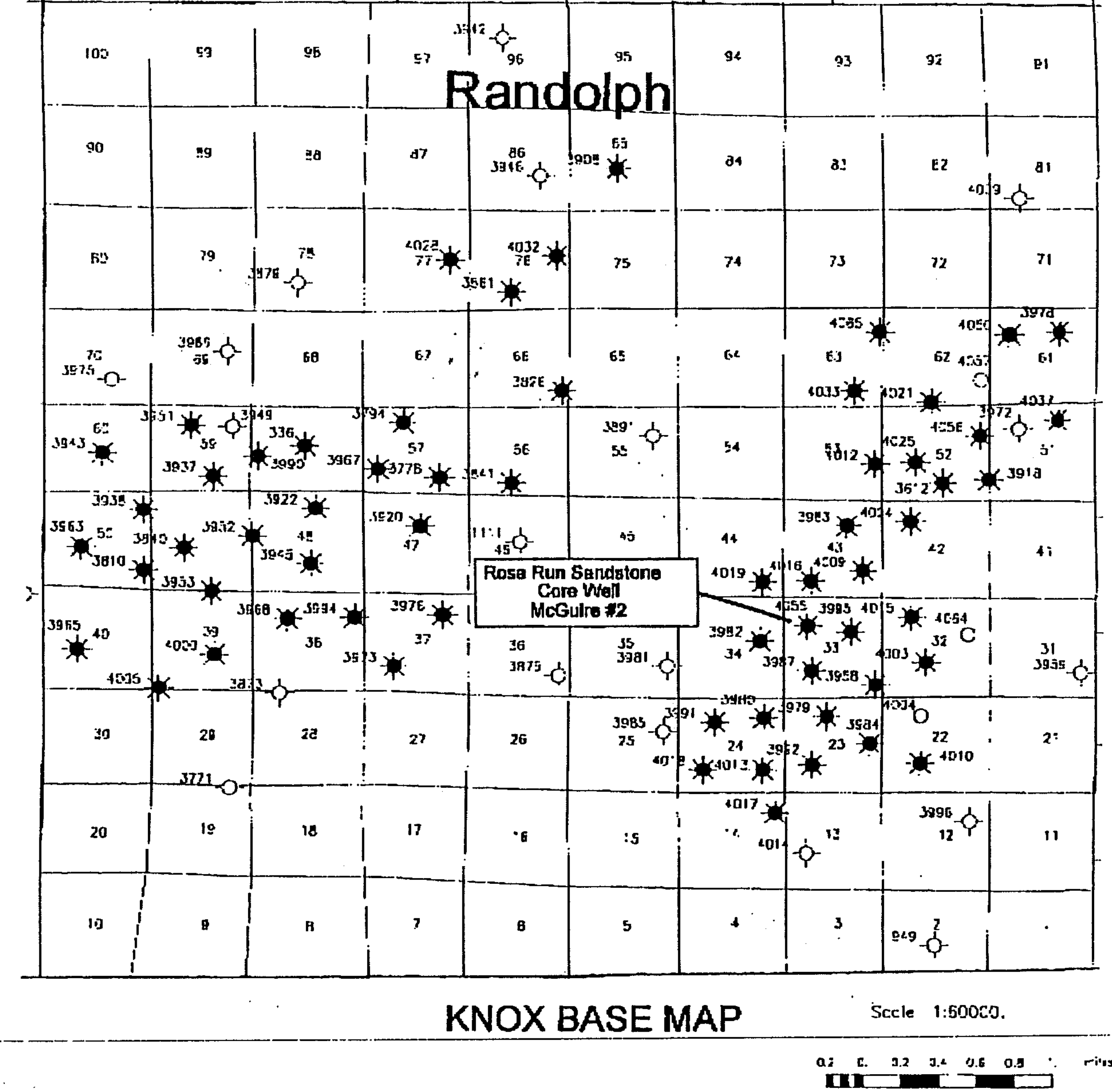


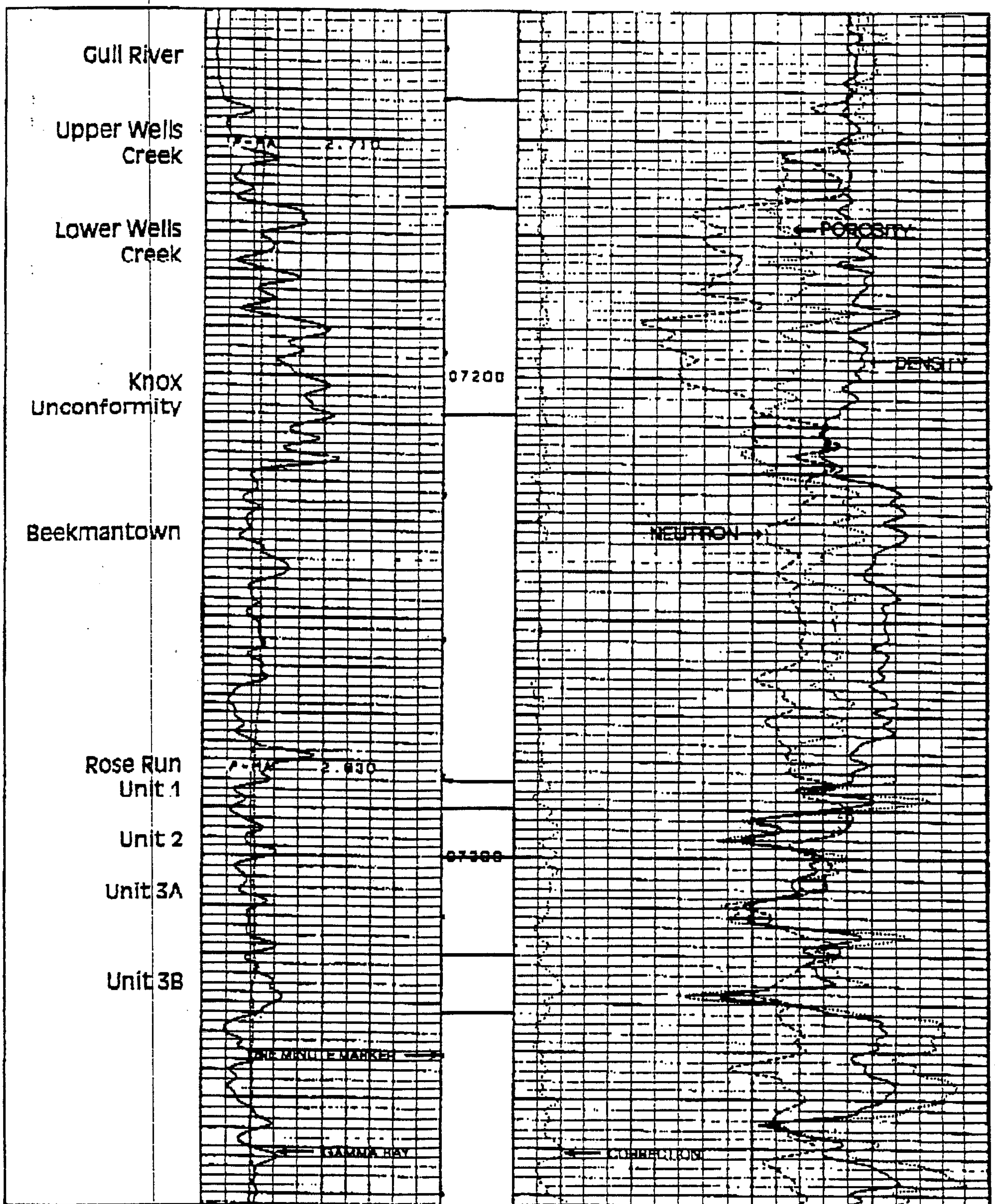
OHIO KNOX TRENDS



KNOX BASE MAP

Scale 1:60000.

FIGURE 1



TYPE LOG
EAST RANDOLPH FIELD PERMIT NO. 3983
SHOWING PRODUCTIVE ROSE RUN SAND ZONES

Cumulative Production from this well is
31,925 Barrels of Oil / 139 MMCF Gas in 27 months

FIGURE 2

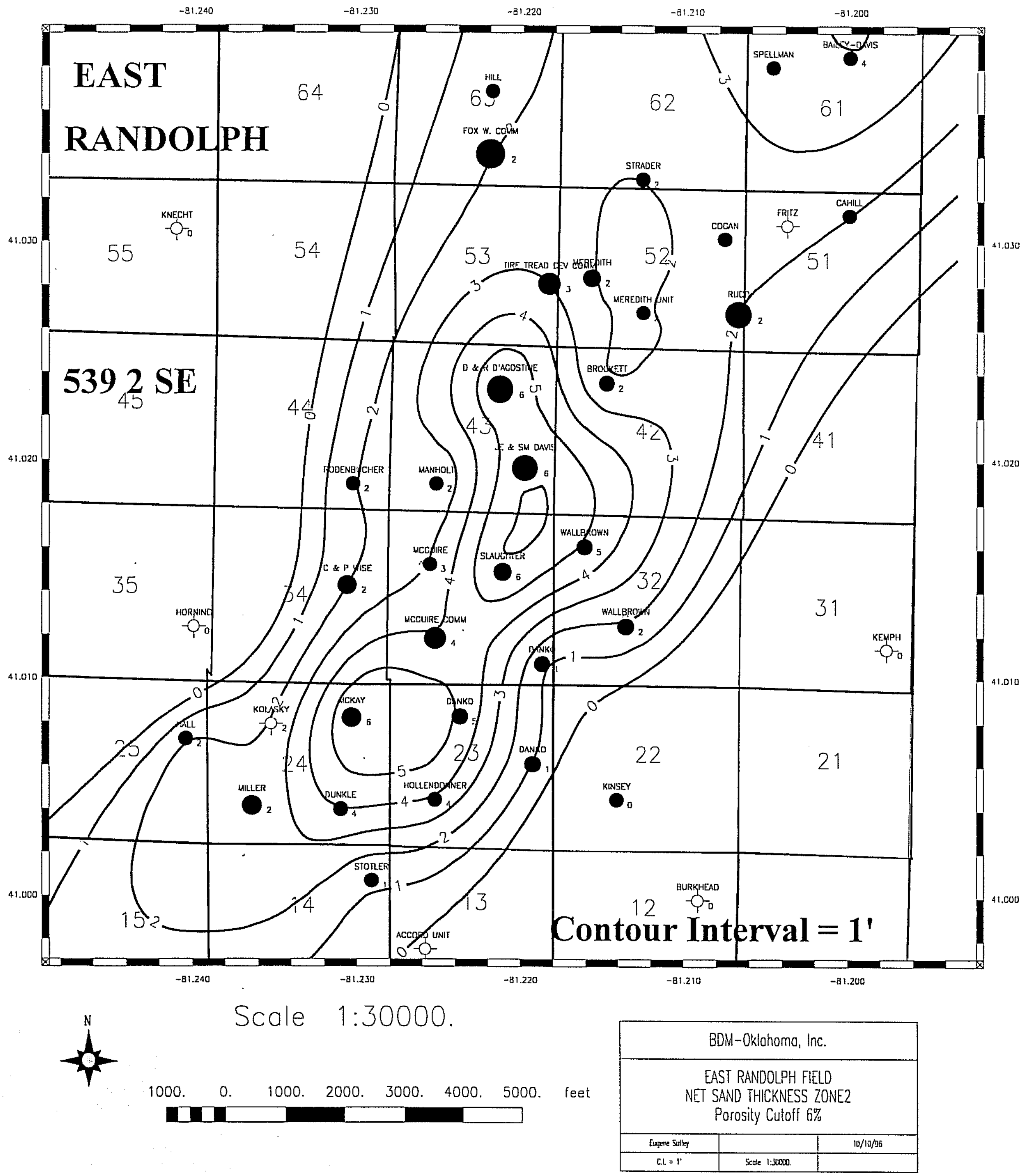
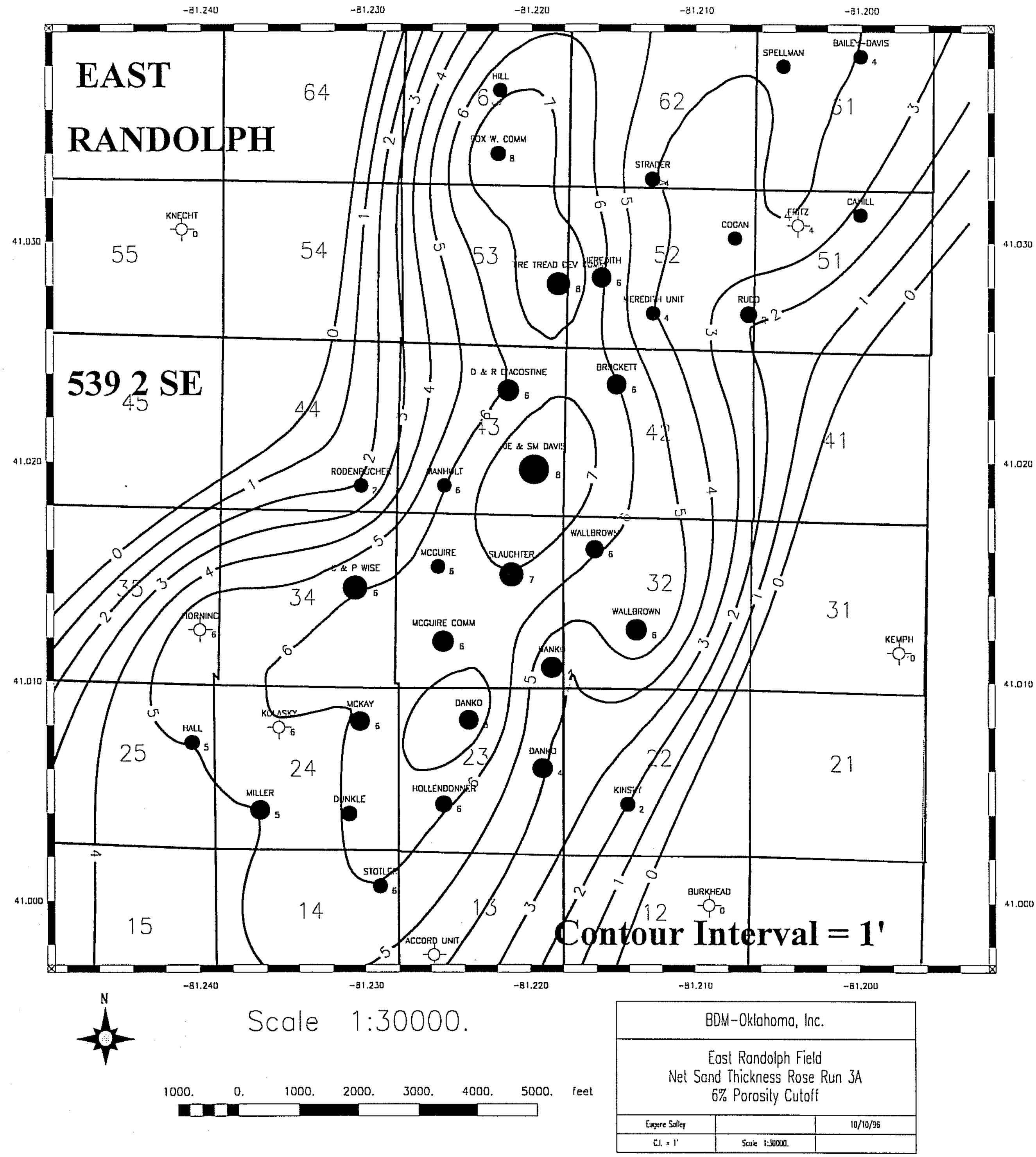

EAST RANDOLPH
539 2 SE
Contour Interval = 1'
Scale 1:30000.
1000. 0. 1000. 2000. 3000. 4000. 5000. feet
N
BDM-Oklahoma, Inc.
EAST RANDOLPH FIELD
NET SAND THICKNESS ZONE2
Porosity Cutoff 6%
Eugene Safley
10/10/96
C.I. = 1'
Scale 1:30000.

FIGURE 3


EAST
RANDOLPH
539 2 SE
Contour Interval = 1'
-81.240
-81.230
-81.220
-81.210
-81.200
41.030
41.020
41.010
41.000
64
63
62
61
55
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HILL
FOX W. COMM
SPELLMAN
BAILEY-DAVIS
STRADER
KNECHT
COGAN
FRITZ
CAHILL
TIRE TREAD DEV COMM
MEREDITH
MEREDITH UNIT
RUDD
D & R DACOSTINE
BRACKETT
JOE & SM DAVIS
RODENBUCHER
RANHOLT
MCGUIRE
SLAUGHTER
WALLBROWN
C & P WISE
HORNING
MCGUIRE COMM
DANKO
KEMPH
KOLASKY
MCKAY
HALL
MILLER
DUNKLE
HOLLENDONNER
KINSEY
STOTLER
BURKHEAD
ACCORD UNIT
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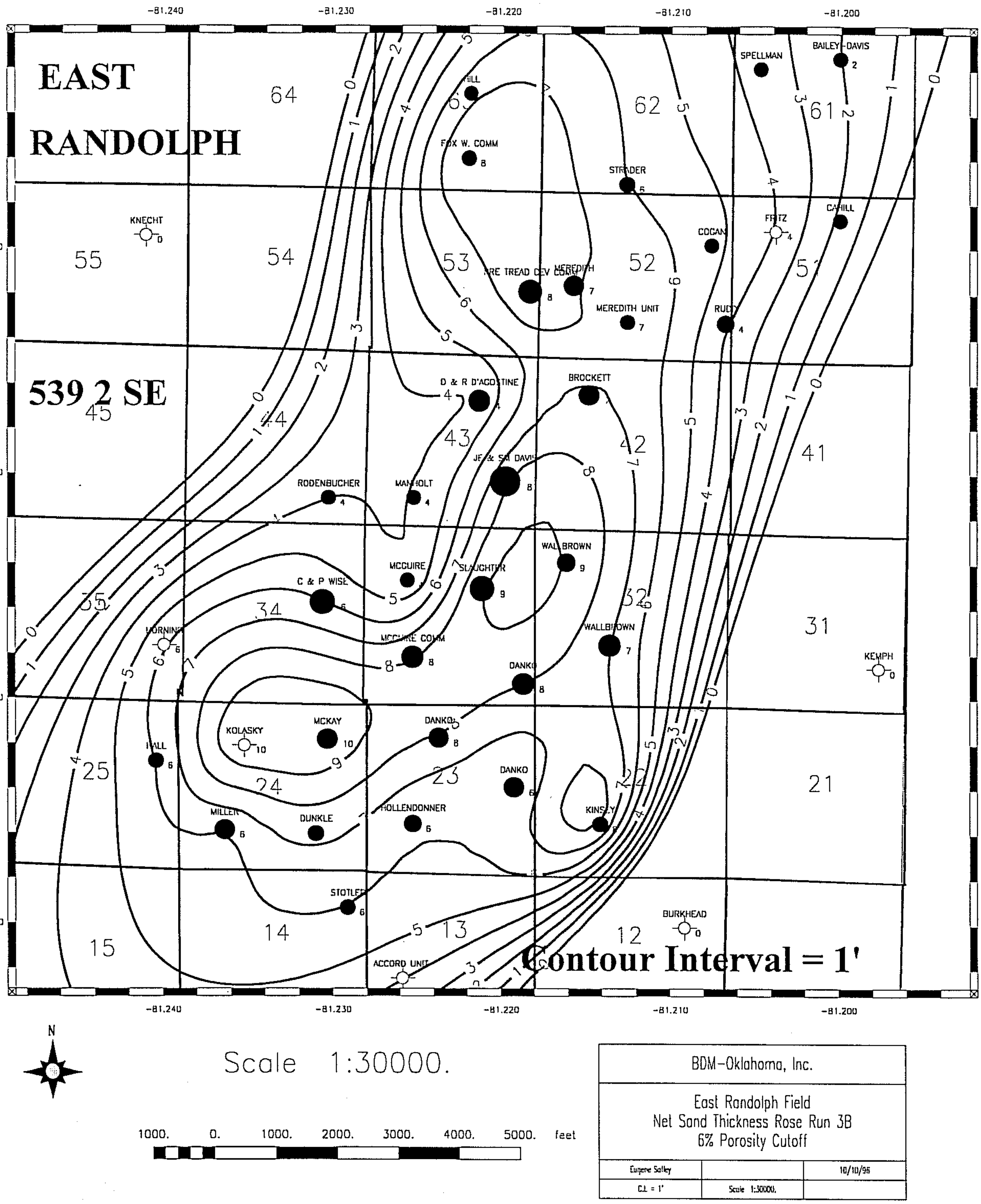
Scale 1:30000.
1000. 0. 1000. 2000. 3000. 4000. 5000. feet
BDM-Oklahoma, Inc.
East Randolph Field
Net Sand Thickness Rose Run 3A
6% Porosity Cutoff
Eugene Safley
10/10/96
C.I. = 1'
Scale 1:30000.

FIGURE 4



EAST
RANDOLPH
539 2 SE
Contour Interval = 1'
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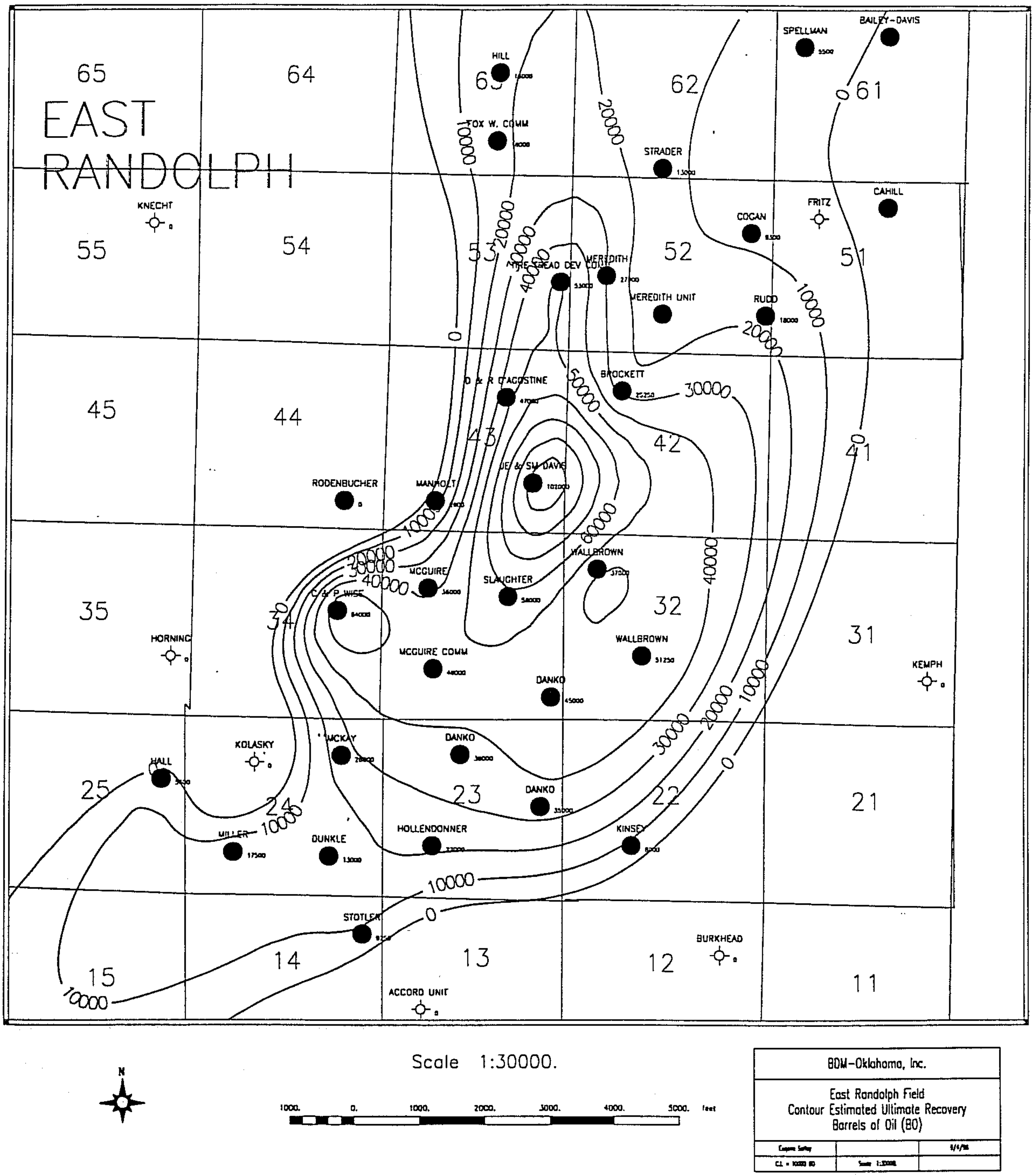
-81.230
-81.220
-81.210
-81.200
41.030
41.020
41.010
41.000
SPELLMAN
BAILEY-DAVIS
HILL
FOX W. COMM
STRADER
KNECHT
COGAN
FRITZ
CAHILL
MEREDITH
MEREDITH UNIT
RUDY
D & R D'AGOSTINE
BROCKETT
RODENBUCHER
MANHOLT
MCGUIRE
SLAUGHTER
WALLBROWN
C & P WISE
MCGUIRE COMM
HORNING
DANKO
KEMPH
KOLASKY
MCKAY
HALL
KINSLY
MILLER
DUNKLE
HOLLENDONNER
STOTLER
BURKHEAD
ACCORD UNIT
N
Scale 1:30000.
1000. 0. 1000. 2000. 3000. 4000. 5000. feet
BDM-Oklahoma, Inc.
East Randolph Field
Net Sand Thickness Rose Run 3B
6% Porosity Cutoff
Eugene Safley
10/10/96
C.I. = 1'
Scale 1:30000.

FIGURE 5


EAST RANDOLPH
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FOX W. COMM
STRADER
SPELLMAN
BAILEY-DAVIS
KNECHT
COGAN
FRITZ
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MEREDITH
MEREDITH UNIT
RUDD
D & R D'AGOSTINE
BROCKETT
RODENBUCHER
JE & SM DAVIS
MCGUIRE
SLAUGHTER
WALLBROWN
C & P WISE
HORNING
MCGUIRE COMM
DANKO
KEMPH
KOLASKY
HALL
MCKAY
MILLER
DUNKLE
HOLLENDONNER
KINSEY
STOTLER
BURKHEAD
ACCORD UNIT
0
10000
20000
30000
40000
50000
60000
Scale 1:30000.
N
1000.
0.
1000.
2000.
3000.
4000.
5000.
feet
BDM-Oklahoma, Inc.
East Randolph Field
Contour Estimated Ultimate Recovery
Barrels of Oil (80)

FIGURE 6

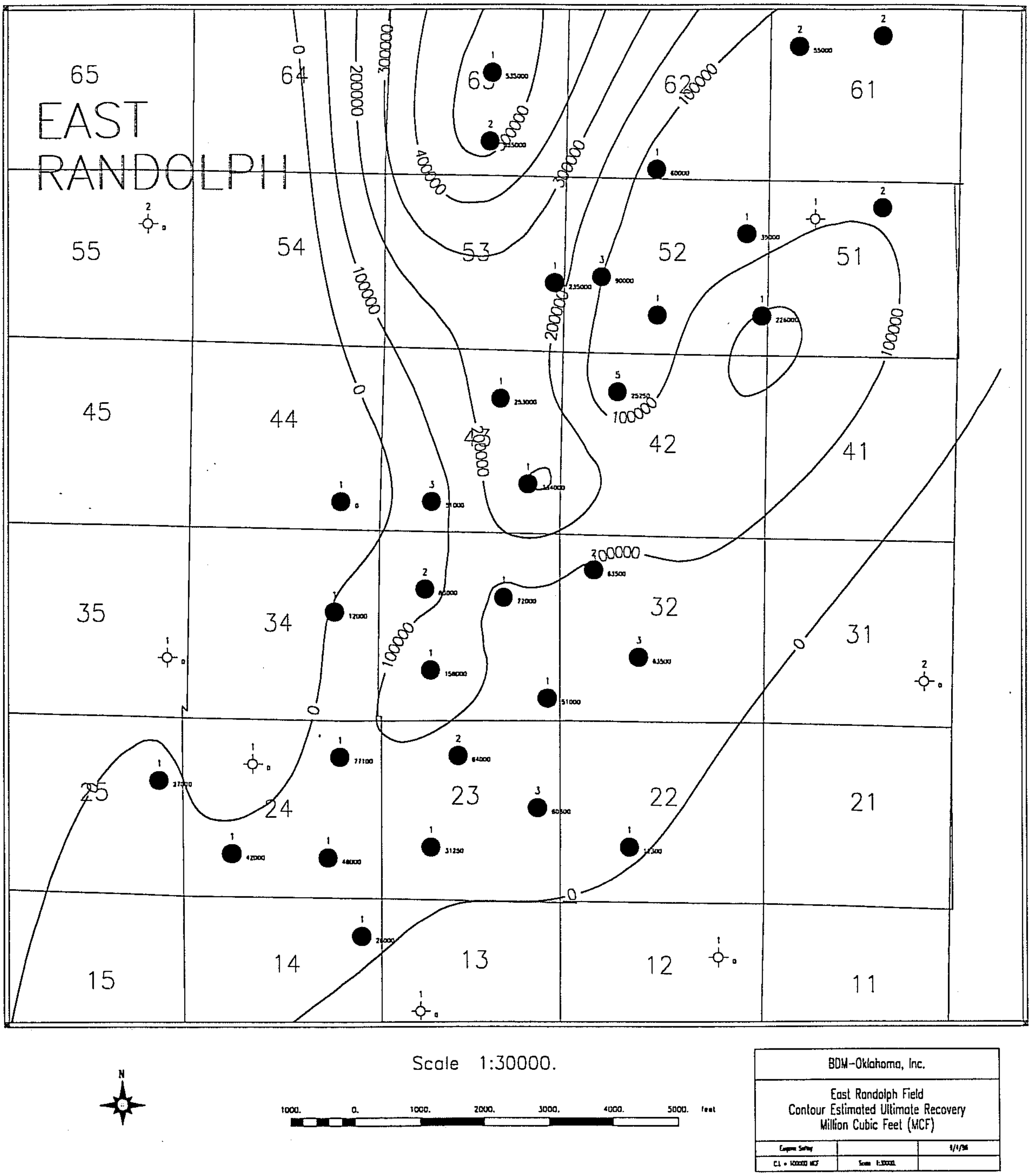
EAST RANDOLPH
Scale 1:30000.
N
BDM-Oklahoma, Inc.
East Randolph Field
Contour Estimated Ultimate Recovery
Million Cubic Feet (MCF)

FIGURE 7